NSW GOVERNMENT
Department of
Primary Industries

Southern NSW research results 2017

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

www.dpi.nsw.gov.au

NSW Department of Primary Industries

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Southern NSW research results 2017

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

an initiative of Southern Cropping Systems

Editors: Deb Slinger, Director Southern Cropping, NSW DPI, Wagga Wagga; Tania Moore, NSW DPI, Griffith and Carey Martin, NSW DPI, Orange.

Reviewers: Don McCaffery, Technical Specialist Pulses & Oilseeds, NSW DPI, Orange and Dr Peter Martin, Howqua Consulting.

Cover images: Main image–La Trobe$^{\phi}$ barley in *Managing soil acidity* experiment (p 119), Guangdi Li, NSW DPI, Wagga Wagga; inset left–stubble cruncher, Warwick Holding, Tootool experiment cooperator (p 17); inset centre–cotton in *Herbicide resistance in cotton* (p 169), Eric Koetz, NSW DPI Wagga Wagga; inset right–canola shade shelter in *Critical growth periods in canola* (p 56), Rohan Brill, NSW DPI, Wagga Wagga.

© State of New South Wales through Department of Industry, 2017

ISBN 978-1-76058-066-7 (web)

jn 14288

Published by NSW Department of Primary Industries,
a part of NSW Department of Industry

You may copy, distribute, display, download and otherwise freely deal with this publication for any purpose, provided that you attribute the Department of Industry as the owner. However, you must obtain permission if you wish to:

- charge others for access to the publication (other than at cost)
- include the publication in advertising or a product for sale
- modify the publication
- republish the publication on a website.

You may freely link to the publication on a departmental website.

Disclaimer

The information contained in this publication is based on knowledge and understanding at the time of writing (June 2017) and may not be accurate, current or complete. The State of New South Wales (including the NSW Department of Industry), the author and the publisher take no responsibility, and will accept no liability, for the accuracy, currency, reliability or correctness of any information included in the document (including material provided by third parties). Readers should make their own inquiries and rely on their own advice when making decisions related to material contained in this publication.

The product trade names in this publication are supplied on the understanding that no preference between equivalent products is intended and that the inclusion of a product name does not imply endorsement by the department over any equivalent product from another manufacturer.

Always read the label

Users of agricultural or veterinary chemical products must always read the label and any permit, before using the product, and strictly comply with the directions on the label and the conditions of any permit. Users are not absolved from compliance with the directions on the label or the conditions of the permit by reason of any statement made or not made in this publication.

Australian Government
Cotton Research and Development Corporation

CRC PLANT biosecurity

Australian Government
Rural Industries Research and Development Corporation

Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW Research Results 2017. 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 Grains Research & 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 support 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 clients you work with.

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

The Research and Development Teams
NSW Department of Primary Industries

Contents

Agronomy – cereals

Agronomy – canola

Agronomy – pulses

Nutrition & soils

Crop protection

Irrigation & climate

Other research

Seasonal conditions 2016

Dr Peter Martin (Howqua Consulting)

Temperature

Condobolin Agricultural Research and Advisory Station

Average minimum temperatures were above the long-term average (LTA) from May to September (Figure 1). Average maximum temperatures were near average from May to August and 2.6 °C and 2.8 °C below average for September and October respectively. The lower average maximum temperatures meant that there was lower than normal heat stress in the grain-filling period.

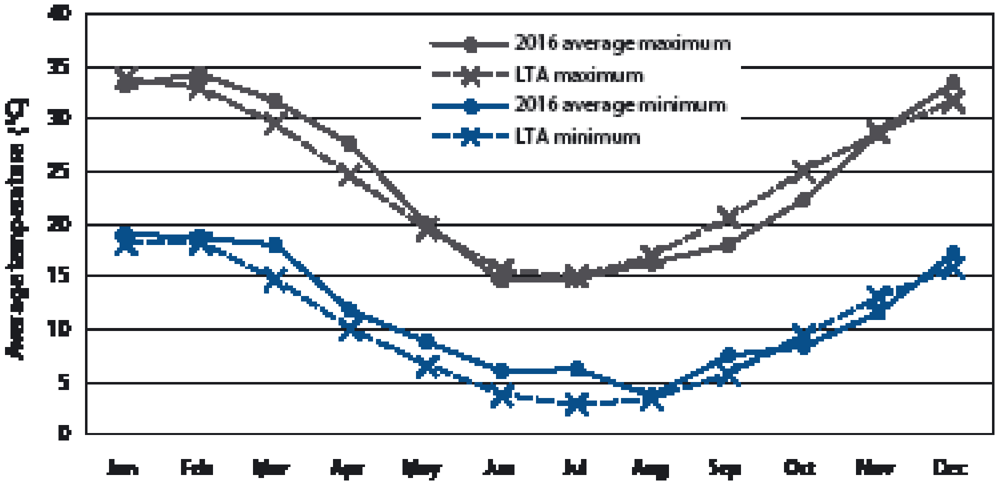


Figure 1. Monthly temperatures at Condobolin Agricultural Research and Advisory Station in 2016.

Wagga Wagga Agricultural Institute

Average maximum temperatures were 0.3 °C above the long-term average for May to November. Average minimum temperatures were 0.7 °C above the long-term average for May to November (Figure 2).

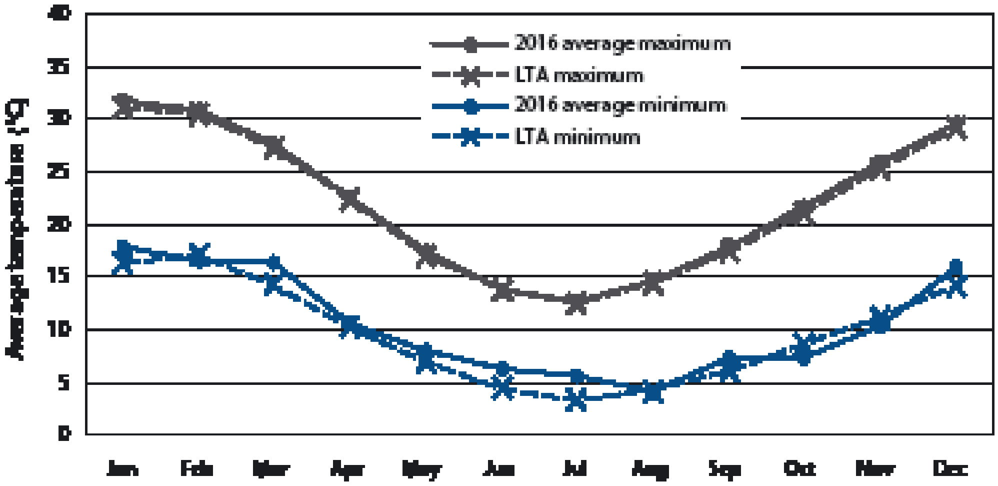


Figure 2. Monthly temperatures at Wagga Wagga Agricultural Institute in 2016.

Yanco Agricultural Institute

Average maximum temperatures were 1.3 °C below the long-term average for May to November. Average maximum temperature in September and October were 3 °C and 3.4 °C below the long-term average. Average minimum temperatures were 2.4 °C above the long-term average for May to November (Figure 3).

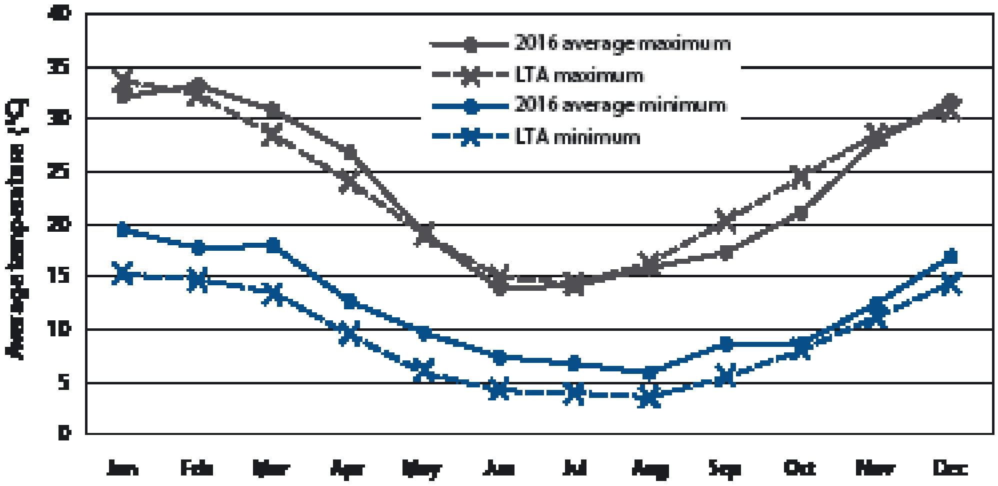


Figure 3. Monthly temperatures at Yanco Agricultural Institute in 2016.

Rainfall

Rainfall in crop (May to October) was above average across most of southern NSW. June and September rainfall was the highest on record in many locations. Flooding was widespread. Waterlogging and wet conditions resulted in decreased establishment and reduced early growth in many crops and experiments. The record September rainfall meant that waterlogging and flooding in southern NSW continued during the grain filling period.

Condobolin Agricultural Research and Advisory Station

Rainfall during January and May was above average. Record rainfall in June and September meant that waterlogging and flooding was common (Figure 4). Waterlogging and wet conditions resulted in decreased establishment and reduced early growth in many crops and experiments.

Wagga Wagga Agricultural Institute

Rainfall from May to October was above average. May and June had approximately double the average monthly rainfall. September rainfall was the highest on record (Figure 5).

Yanco Agricultural Institute

Rainfall was above average for May to October (Figure 6). Rainfall in June and September was the highest on record.

Disease

The wet conditions over winter and spring were ideal for disease development, in particular:

- Blackleg and sclerotinia stem rot were widespread in canola.
- Black spot was widespread in field peas.
- Sclerotinia was severe in some chickpea crops.
- Sclerotinia was observed in a number of isolated lupin crops.
- Chocolate spot of faba beans was widespread and severe.
- Sudden death, caused by *Phytopthera* spp., was widespread in lupins.
- Stem and leaf rust did not develop to damaging levels in wheat.
- Stripe rust was detected early in wheat but did not cause large losses, possibly because of fungicide control and cool temperatures in spring.
- Septoria tritici blotch (STB) and yellow leaf spot (YLS) thrived in wheat.
- Scald and the spot form of net blotch (SFNB) were widespread and at high levels. There were crops where scald caused 100% of leaf loss.
- Barley leaf rust was not a substantial problem.
- Take-all of wheat was widespread.
- Crown rot was widespread (detected in surveys) with symptoms less evident due to the cool wet spring.

Extensive use of foliar fungicides in cereals was generally effective given the wet conditions however significant yield losses occurred in some crops. The re-emergence of STB as a major disease was a feature of the 2016 season. Some crops were sprayed with fungicide to control STB.

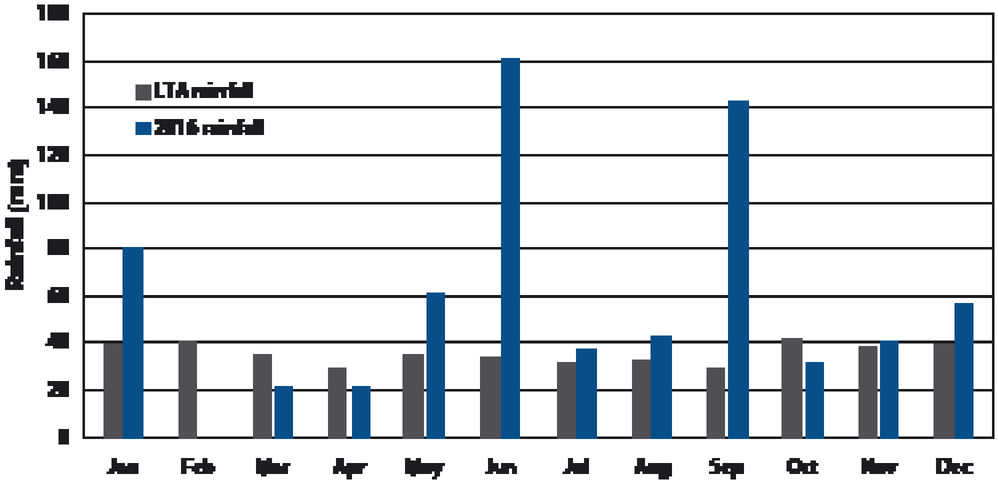


Figure 4. Monthly rainfall at Condobolin Agricultural Research and Advisory Station in 2016.

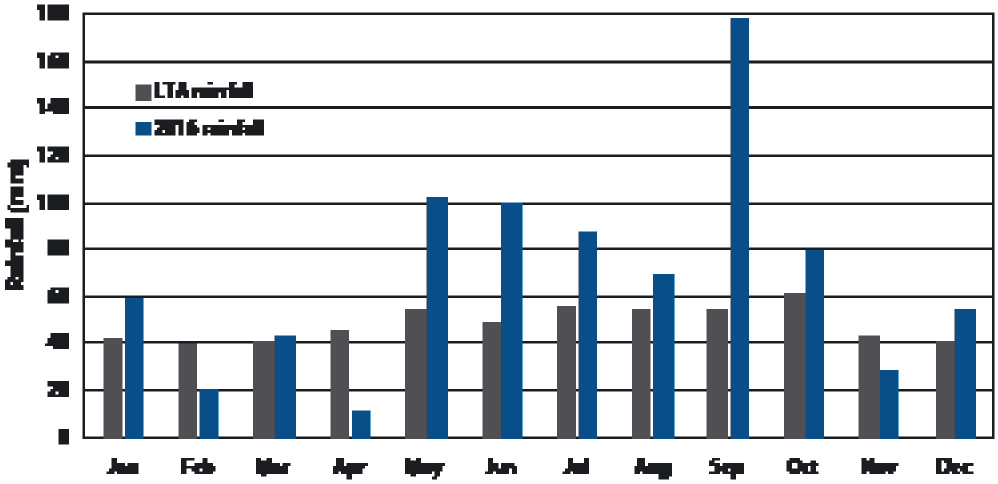


Figure 5. Monthly rainfall at Wagga Wagga Agricultural Institute in 2016.

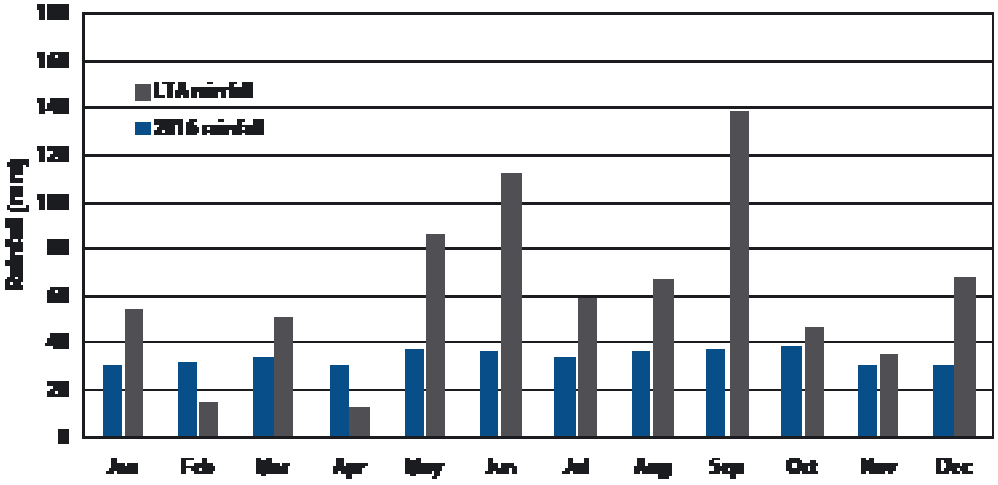
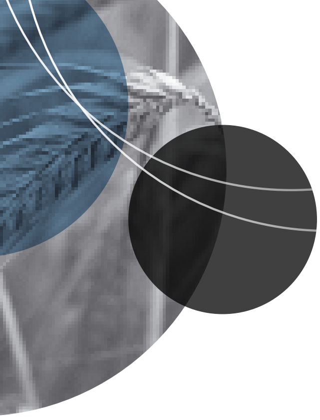


Figure 6. Monthly rainfall at Yanco Agricultural Institute in 2016.

Acknowledgements

Thanks to Dr Kurt Lindbeck, Dr Andrew Milgate and Ian Menz for considerable support in compiling this information and data.



Agronomy – cereals

Effect of sowing date on phenology and grain yield of thirty-six wheat varieties – Wagga Wagga 2016

Dr Felicity Harris, Eric Koetz, Hugh Kanaley and Greg McMahon (NSW DPI, Wagga Wagga)

Key findings

- It is critical to match sowing time with varietal phenology to optimise yield potential.
- Longer-season varieties were high yielding in 2016 due to the extended grain filling period due to adequate soil moisture and mild spring temperatures.
- There is a range of newer varieties with varied phenology with high yield potential.

Introduction

There is a range of varieties suited for sowing in southern NSW, these vary in phenology from slow-developing winter to fast-developing spring varieties. To achieve maximum grain yield potential, it is important to ensure varieties are sown according to their relative maturities so that flowering occurs at an optimum time. This experiment reports the effect of sowing time on the phenology, grain yield and quality of 36 wheat varieties.

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.
Fertiliser	100 kg/ha mono-ammonium phosphate (MAP) (sowing) 50 kg N/ha UAN (31 May)
Soil pH_{Ca}	5.1 (0–10 cm)
Mineral nitrogen at sowing (1.5 m depth)	142 kg N/ha
Weed control	Knockdown: glyphosate (450 g/L) 1.2 L/ha Pre-emergent: Sakura® 118 g/ha + Logran® at 35 g/ha
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser (400 mL/ha) In-crop: Prosaro® 300 mL/ha at GS30 and GS37 to prevent and/or suppress rust infections
In-crop rainfall (April–October)	592 mm (long-term average is 355 mm)
Irrigation	9 mm applied 21 April to establish first sowing time only

Treatments

Thirty-six wheat varieties varying in maturity were sown on three sowing dates: 15 April, 3 May and 20 May 2016 (Table 1).

Table 1. Putative phenology types of the experimental varieties.

Phenology type	Varieties
Winter (W)	EGA Wedgetail⏀, LongReach Kittyhawk⏀
Very slow (VS)	EGA Eaglehawk⏀, LPB12-0648, Sunlamb⏀
Slow (S)	Bolac⏀, Cutlass⏀, Kiora⏀, LongReach Lancer⏀, Mitch⏀
Mid (M)	Coolah⏀, DS Darwin⏀, DS Pascal⏀, EGA Gregory⏀, Janz, LongReach Flanker⏀, LongReach Trojan⏀, Sunvale⏀, UQ01512, UQ01553
Mid-fast (MF)	Beckom⏀, Suntop⏀, LongReach Spitfire⏀
Fast (F)	Corack⏀, Emu Rock⏀, Livingston⏀, LongReach Reliant⏀ Mace⏀, Scepter⏀
Very fast (VF)	Condo⏀, LongReach Dart⏀, Hatchet CL Plus⏀, HTWYT_012, LPB12-0391, LPB12-0494, Sunmate⏀

Results

Phenology response to sowing time

The warmer winter temperatures in 2016 resulted in flowering starting 10–14 days earlier than in 2015 (Slinger et al. 2016), while the cooler spring temperatures extended the flowering period into early November (tables 2, 3 and 4). Detailed phenology measurements were recorded in 2016 to determine variation in phase duration among maturity groups in response to sowing date.

There were significant differences between varieties in the phasic duration from sowing to start of stem elongation (GS31), ear emergence (GS59) and flowering (GS65). The warmer temperatures early in the season resulted in many faster-developing spring varieties starting stem elongation quicker from the first sowing (15 April) compared with the later two sowing dates. In contrast, the slowest-developing spring variety (Sunlamb⏀) and winter varieties (EGA Wedgetail⏀ and LongReach Kittyhawk⏀), which have increasing responsiveness to vernalisation, had prolonged vegetative phases (Table 4).

Delayed sowing reduced the length of the growing season and the reproductive phase (GS31–GS59) was most affected. This corresponds to the period in which potential grain number is largely determined.

Differences in the phenology of varieties are largely controlled by response to vernalisation and photoperiod. Winter varieties are responsive to vernalisation and can be sown early, remaining vegetative until their vernalisation requirement is satisfied. Should a spring variety with minimal response to vernalisation be sown early (when temperatures are warmer and days longer), development progresses quickly, flowering occurs earlier than is optimal and grain yield potential is lower. For example, LongReach Dart⏀, sown on 15 April 2016 at Wagga Wagga, started stem elongation on 8 June and flowered on 30 August (Table 2). However, EGA Wedgetail⏀, sown on the same day, was slower to reach GS31 (20 July) and flowered on 8 October (Table 4).

Varieties differ in their response to photoperiod. In photoperiod-sensitive varieties, development is accelerated in response to longer days. However, there is variation in photoperiod response amongst Australian wheats with many insensitive to photoperiod. The slow maturity of Sunlamb⏀ is controlled largely through response to vernalisation coupled with photoperiod sensitivity. This is different from the winter types EGA Wedgetail⏀ and LongReach Kittyhawk⏀, which are relatively insensitive to photoperiod. This is observed through the shortened vegetative phase and extended reproductive phase of Sunlamb⏀ compared with the winter types (Table 4).

The accelerated development of fast spring varieties such as Hatchet CL Plus⏀ and LongReach Dart⏀ meant that when sown early, they were exposed to two frost events (26–27 August) at early ear emergence and had significantly lower yield (Table 5). These fast developing varieties produced high numbers of later tillers which resulted in varied maturity within plots, delayed harvest and varied grain quality (Table 5).

Table 2. Phase duration of very fast- to fast- (VF–F) maturing varieties at Wagga Wagga, 2016. Dates of key development stages: Sowing (S), start of stem elongation (GS31), ear emergence (GS59) and flowering (GS65). Sowing dates: 15 April (1), 3 May (2) and 20 May (3).

Variety	Sowing date	Date development stage reached			Duration of phase		
		GS31	GS59	GS65	S-GS31 (days)	GS31–59 (days)	GS59–65 (days)
Hatchet CL Plus	1	8 Jun	5 Aug	6 Sep	48	58	32
	2	4 Jul	27 Aug	13 Sep	63	53	17
	3	22 Jul	19 Sep	6 Oct	64	58	18
LongReach Dart	1	8 Jun	7 Aug	30 Aug	48	60	23
	2	30 Jun	29 Aug	14 Sep	58	60	16
	3	22 Jul	17 Sep	26 Sep	64	56	10
Sunmate	1	8 Jun	23 Aug	11 Sep	48	76	19
	2	11 Jul	13 Sep	25 Sep	69	64	13
	3	1 Aug	2 Oct	8 Oct	73	62	7
HTWYT_012	1	14 Jun	25 Aug	6 Sep	54	72	12
	2	7 Jul	14 Sep	23 Sep	65	69	9
	3	29 Jul	27 Sep	3 Oct	70	60	7
LPB12-0391	1	8 Jun	19 Aug	4 Sep	48	72	16
	2	4 Jul	7 Sep	20 Sep	62	65	14
	3	26 Jul	26 Sep	5 Oct	67	62	10
LPB12-0494	1	16 Jun	19 Aug	5 Sep	56	64	17
	2	11 Jul	10 Sep	23 Sep	69	61	13
	3	26 Jul	27 Sep	2 Oct	67	63	6
Condo	1	8 Jun	19 Aug	1 Sep	48	72	13
	2	11 Jul	7 Sep	16 Sep	69	58	9
	3	26 Jul	24 Sep	2 Oct	67	60	8
Corack	1	20 Jun	19 Aug	4 Sep	60	60	16
	2	11 Jul	7 Sep	19 Sep	69	58	12
	3	1 Aug	22 Sep	2 Oct	73	52	11
Emu Rock	1	8 Jun	5 Aug	3 Sep	48	58	29
	2	4 Jul	2 Sep	17 Sep	62	60	15
	3	26 Jul	26 Sep	4 Oct	67	62	8
Livingston	1	8 Jun	16 Aug	3 Sep	48	69	18
	2	4 Jul	4 Sep	22 Sep	62	62	18
	3	2 Aug	24 Sep	3 Oct	74	53	9
Mace	1	8 Jun	29 Aug	10 Sep	48	82	12
	2	12 Jul	12 Sep	22 Sep	70	62	10
	3	1 Aug	30 Sep	6 Oct	73	60	6
LongReach Reliant	1	27 Jun	30 Aug	11 Sep	67	64	12
	2	11 Jul	13 Sep	19 Sep	69	64	6
	3	1 Aug	27 Sep	6 Oct	73	57	9
Scepter	1	20 Jun	30 Aug	9 Sep	60	71	10
	2	11 Jul	11 Sep	25 Sep	69	62	15
	3	1 Aug	2 Oct	8 Oct	73	62	6
l.s.d. ($P<0.05$)					5.2	6.4	7.2

Table 3. Phase duration of mid-fast- to mid-slow- (MF–MS) maturing varieties at Wagga Wagga, 2016. Dates of key development stages: Sowing (S), start of stem elongation (GS31), ear emergence (GS59) and flowering (GS65). Sowing dates: 15 April (1), 3 May (2) and 20 May (3).

Variety	Sowing date	Date development stage reached			Duration of phase		
		GS31	GS59	GS65	S-GS31 (days)	GS31-59 (days)	GS59-65 (days)
LongReach Spitfire	1	14 Jun	18 Aug	6 Sep	54	65	19
	2	6 Jul	6 Sep	19 Sep	64	62	14
	3	26 Jul	26 Sep	6 Oct	67	62	10
Beckom	1	23 Jun	31 Aug	14 Sep	63	69	14
	2	11 Jul	14 Sep	23 Sep	69	65	10
	3	6 Aug	3 Oct	8 Oct	79	57	5
Suntop	1	8 Jun	30 Aug	15 Sep	48	83	16
	2	11 Jul	19 Sep	29 Sep	69	70	10
	3	5 Aug	4 Oct	9 Oct	77	60	6
Coolah	1	22 Jun	8 Sep	25 Sep	63	77	17
	2	15 Jul	13 Sep	25 Sep	73	60	12
	3	9 Aug	6 Oct	15 Oct	81	58	9
EGA Gregory	1	23 Jun	12 Sep	21 Sep	63	81	9
	2	15 Jul	21 Sep	30 Sep	74	67	9
	3	11 Aug	7 Oct	13 Oct	83	57	7
Janz	1	20 Jun	30 Aug	14 Sep	60	71	15
	2	13 Jul	16 Sep	28 Sep	71	65	13
	3	4 Aug	30 Sep	7 Oct	76	57	7
LongReach Flanker	1	27 Jun	5 Sep	19 Sep	67	70	14
	2	16 Jul	20 Sep	30 Sep	75	65	10
	3	9 Aug	4 Oct	11 Oct	81	56	7
Sunvale	1	27 Jun	5 Sep	17 Sep	67	70	12
	2	18 Jul	22 Sep	30 Sep	76	66	8
	3	11 Aug	7 Oct	15 Oct	83	57	8
LongReach Trojan	1	23 Jun	5 Sep	19 Sep	63	74	14
	2	13 Jul	18 Sep	30 Sep	71	67	12
	3	5 Aug	7 Oct	11 Oct	77	63	5
DS Darwin	1	20 Jun	28 Aug	9 Sep	60	69	12
	2	11 Jul	17 Sep	25 Sep	69	68	8
	3	4 Aug	3 Oct	6 Oct	76	60	3
DS Pascal	1	7 Jul	13 Sep	26 Sep	77	68	13
	2	22 Jul	25 Sep	6 Oct	81	64	11
	3	12 Aug	7 Oct	16 Oct	84	56	9
UQ01512	1	25 Jun	6 Sep	18 Sep	66	72	12
	2	18 Jul	20 Sep	27 Sep	76	64	8
	3	10 Aug	5 Oct	9 Oct	82	56	5
UQ01553	1	30 Jun	5 Sep	19 Sep	70	67	14
	2	18 Jul	18 Sep	29 Sep	76	62	11
	3	15 Aug	4 Oct	12 Oct	87	50	9
Mitch	1	20 Jun	9 Sep	18 Sep	60	81	9
	2	11 Jul	19 Sep	28 Sep	69	70	9
	3	8 Aug	4 Oct	17 Oct	80	57	13
l.s.d. ($P<0.05$)					5.4	6.4	7.2

Table 4. Phase duration of slow-winter (S–W) maturing varieties at Wagga Wagga, 2016. Dates of key development stages: Sowing (S), start of stem elongation (GS31), ear emergence (GS59) and flowering (GS65). Sowing dates: 15 April (1), 3 May (2) and 20 May (3).

Variety	**Sowing date**	**Date development stage reached**			**Duration of phase**		
		GS31	**GS59**	**GS65**	**S-GS31 (days)**	**GS31–59 (days)**	**GS59–65 (days)**
Bolac	1	30 Jun	5 Sep	22 Sep	70	67	17
	2	18 Jul	24 Sep	6 Oct	76	68	12
	3	10 Aug	7 Oct	16 Oct	82	58	10
Cutlass	1	23 Jun	14 Sep	23 Sep	63	83	9
	2	16 Jul	30 Sep	9 Oct	75	75	10
	3	11 Aug	7 Oct	18 Oct	83	57	12
Kiora	1	20 Jun	7 Sep	30 Sep	60	79	23
	2	11 Jul	20 Sep	4 Oct	69	71	14
	3	11 Aug	7 Oct	19 Oct	83	57	12
LongReach Lancer	1	23 Jun	9 Sep	20 Sep	63	78	11
	2	18 Jul	19 Sep	30 Sep	76	63	11
	3	9 Aug	9 Oct	18 Oct	82	61	10
EGA Eaglehawk	1	5 Jul	13 Oct	19 Oct	75	100	6
	2	18 Jul	19 Oct	25 Oct	76	93	6
	3	9 Aug	25 Oct	31 Oct	81	77	7
LPB12-0648	1	9 Jul	20 Sep	1 Oct	79	73	11
	2	26 Jul	23 Sep	2 Oct	84	59	9
	3	15 Aug	8 Oct	20 Oct	87	54	12
Sunlamb	1	11 Jul	17 Oct	21 Oct	81	98	4
	2	1 Aug	25 Oct	27 Oct	90	85	2
	3	18 Aug	28 Oct	31 Oct	90	71	4
LongReach Kittyhawk	1	16 Jul	3 Oct	5 Oct	86	81	2
	2	4 Aug	8 Oct	16 Oct	93	65	8
	3	22 Aug	18 Oct	23 Oct	94	57	6
EGA Wedgetail	1	20 Jul	2 Oct	8 Oct	90	74	6
	2	5 Aug	26 Sep	15 Oct	94	52	19
	3	18 Aug	16 Oct	22 Oct	90	59	6
l.s.d. ($P<0.05$)					5.2	6.4	7.2

Grain yield

The cooler spring temperatures favoured later-maturing varieties in 2016, which had reasonably stable yields across all three sowing dates due to the extended grain-filling period. The later sowing time (20 May) did not incur the grain yield penalties often associated with later heading dates (Figure 1). There was no significant difference in mean grain yield between the second and third sowing dates. The winter and longer-season varieties achieved similar grain yields across sowing dates (Table 5). Newly released winter wheat LongReach Kittyhawk$^{\phi}$ yielded similarly to EGA Wedgetail$^{\phi}$. It developed 3–4 days faster than EGA Wedgetail$^{\phi}$ from stem elongation through to flowering (Table 4).

As expected, fast-maturing varieties such as Hatchet CL Plus$^{\phi}$, LongReach Dart$^{\phi}$, Condo$^{\phi}$, Sunmate$^{\phi}$, Emu Rock$^{\phi}$, Corack$^{\phi}$ and LongReach Reliant$^{\phi}$ had a positive grain yield response with delayed sowing, achieving higher yields from the latest (20 May) sowing (Table 5). Some varieties such as Beckom$^{\phi}$, Coolah$^{\phi}$, Scepter$^{\phi}$, LongReach Trojan$^{\phi}$ and LongReach Lancer$^{\phi}$ have shown flexibility in sowing date across 2015 and 2016, achieving above site mean grain yields consistently across sowing times.

Note: whilst all seasons are unique, it is important to consider long-term data to determine suitability of varieties based on matching phenology and sowing time for the growing environment.

Table 5. Grain yield and quality of 36 varieties across three sowing dates at Wagga Wagga, 2016.

Variety	Sowing date											
	15 April				3 May				20 May			
	Grain yield (t/ha)	Yield rank	Protein (%)	Screenings (%)	Grain yield (t/ha)	Yield rank	Protein (%)	Screenings (%)	Grain yield (t/ha)	Yield rank	Protein (%)	Screenings (%)
Beckom	6.35	6	11.9	3.5	7.46	2	10.1	2.0	7.67	5	9.7	4.8
Bolac	6.70	3	12.0	4.1	7.32	4	11.2	7.1	6.52	29	10.6	4.8
Condo	5.22	21	13.3	0.2	6.78	17	12.2	1.0	7.64	6	11.2	1.5
Coolah	6.91	2	12.2	1.1	7.13	8	11.2	1.3	7.68	3	9.9	2.3
Corack	3.92	32	14.1	0.8	5.85	28	13.4	0.7	6.91	18	11.0	0.1
Cutlass	5.30	19	12.1	0.2	7.28	5	11.1	1.4	7.73	2	9.6	1.3
DS Darwin	5.30	20	13.5	1.0	6.59	22	11.9	1.1	7.13	12	10.7	1.1
DS Pascal	6.38	5	12.1	0.7	6.90	14	11.3	2.2	7.51	7	10.3	4.1
EGA Eaglehawk	5.93	12	10.6	3.4	4.90	35	10.1	3.7	6.48	33	9.4	5.4
EGA Gregory	6.05	11	12.5	1.3	6.76	19	12.8	1.2	6.74	22	10.9	2.4
EGA Wedgetail	6.21	9	10.3	1.7	6.94	13	10.9	1.2	7.10	14	10.8	3.4
Emu Rock	4.46	30	15.3	1.2	6.34	25	13.3	1.4	6.85	21	11.5	3.4
Hatchet CL Plus	2.04	36	19.4	0.8	2.87	36	16.3	0.5	6.49	31	11.1	0.9
HTWYT_012	4.72	25	14.2	3.7	6.25	27	13.7	2.8	6.57	27	11.0	7.1
Janz	5.46	18	12.6	2.2	6.77	18	11.3	3.8	6.66	23	10.7	2.3
Kiora	6.17	10	12.7	2.6	7.56	1	11.4	5.7	7.31	9	11.1	6.4
Livingston	2.39	35	16.2	2.9	5.26	34	14.0	1.2	6.46	34	12.5	2.5
LongReach Dart	2.79	34	16.5	0.7	5.59	31	14.3	1.5	6.48	32	12.1	3.3
LongReach Flanker	5.63	17	11.9	1.0	7.01	11	10.9	1.5	7.37	8	9.5	1.6
LongReach Kittyhawk	6.42	4	10.8	2.5	7.12	9	11.1	3.0	6.65	24	9.2	3.4
LongReach Lancer	5.63	16	13.3	0.9	7.07	10	12.1	1.6	6.65	25	11.4	2.4
LongReach Reliant	4.55	28	14.5	0.7	5.43	33	12.9	1.6	6.05	36	11.0	1.5
LongReach Spitfire	3.51	33	15.2	1.4	6.30	26	12.6	0.7	7.13	13	11.4	3.3
LongReach Trojan	6.29	7	11.8	2.5	7.41	3	10.8	1.7	7.68	4	9.9	2.2
LPB12-0391	4.97	23	14.0	1.2	6.72	20	12.7	1.9	6.57	28	9.2	4.7
LPB12-0494	4.51	29	14.1	2.4	6.63	21	12.5	1.1	7.24	11	11.3	5.0
LPB12-0648	5.90	14	13.4	2.5	6.86	15	11.0	3.9	7.10	15	10.0	3.6
Mace	4.60	27	14.9	1.2	5.84	29	13.5	1.2	6.90	19	10.7	1.5
Mitch	7.22	1	10.8	2.4	7.21	6	10.4	4.0	7.31	10	9.2	2.0
Scepter	6.25	8	12.7	0.9	7.14	7	11.9	0.6	7.89	1	11.4	1.1
Sunlamb	5.75	15	10.8	3.9	6.48	23	10.6	6.6	6.87	20	53.8	10.9
Sunmate	4.41	31	13.9	0.0	6.40	24	11.8	1.1	6.52	30	10.3	1.5
Suntop	5.91	13	12.2	4.3	7.00	12	11.4	4.3	6.94	16	11.5	8.2
Sunvale	4.95	24	13.7	2.4	6.81	16	11.3	1.3	6.60	26	10.7	2.9
UQ01512	5.20	22	12.2	1.9	5.79	30	12.3	0.7	6.45	35	10.7	2.0
UQ01553	4.63	26	13.4	0.4	5.44	32	13.6	0.6	6.93	17	11.0	2.3
Mean (sowing date)	5.24		13.2	1.8	6.48		12.1	2.1	6.97		11.8	3.3
l.s.d. grain yield (*P*<0.05)	0.83 t/ha											
l.s.d. protein (*P*<0.05)	6.2											
l.s.d. screenings (*P*<0.05)	2.2											

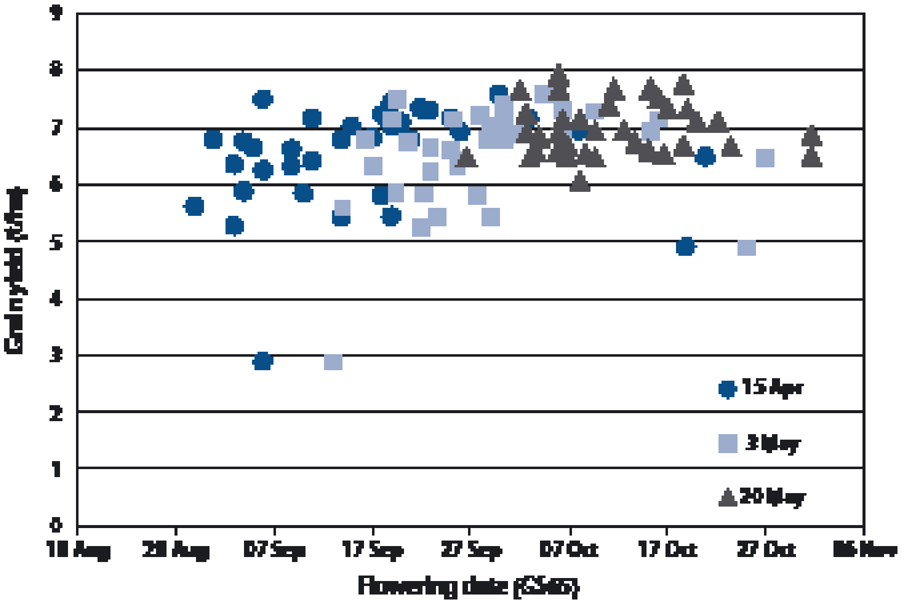


Figure 1. Flowering date and grain yield of 36 wheat varieties for three sowing dates at Wagga Wagga, 2016.

Summary

Varietal phenology is important when determining the effect of sowing time on grain yield potential. Longer-season varieties were high yielding with the extended grain-filling period in 2016. However, decisions should be based on results across a number of seasons. Winter wheats can be sown early (late February–April), with long-season spring wheats from mid April to early May, and main season spring wheats from late April onwards. Some of the newer varieties have been high-yielding and are worth consideration: LongReach Kittyhawk⁽ᴰ performed similarly to EGA Wedgetail⁽ᴰ and provides an alternative for earlier sowing; mid-maturing varieties Beckom⁽ᴰ, Coolah⁽ᴰ and LongReach Trojan⁽ᴰ have shown some flexibility across sowing times, achieved high yields and are suited to main-season sowing; while faster-maturing varieties such as Scepter⁽ᴰ, Condo⁽ᴰ and Cutlass⁽ᴰ achieved high yields from later sowing. Further research will be undertaken in 2017 to better understand the impact of phenology on grain yield formation.

References

Slinger, D, Madden, E, Podmore, C & Martin, C (eds) (2016). *Southern NSW research results 2015*. NSW Department of Primary Industries.

Acknowledgements

This experiment was part of the project 'Variety Specific Agronomy Packages for southern, central and northern New South Wales', DAN00167, 2012–17, with joint investment by GRDC and NSW DPI.

We also acknowledge the technical support of Danielle Malcolm, Warren Bartlett, Sharni Hands, Jessica Simpson and Hayden Petty.

The role of stubble management on frost severity and its effects on the grain yield of wheat – Tootool 2014 and 2015

Rohan Brill, Karl Moore, Paula Charnock, Greg McMahon, Warren Bartlett and Sharni Hands
(NSW DPI, Wagga Wagga)

Key findings

- Stubble retention increased the severity of frost events in experiments over two years.
- There was no difference in floret sterility due to stubble treatment, but grain yield was highest where stubble was removed by burning.
- Stubble retention reduced the amount of heat stored in the soil during spring. With less heat stored there is less capacity for energy release at night to buffer against frost damage.
- Consider management strategies that avoid frost (e.g. crop choice, sowing date, variety choice) where high stubble loads are retained at sowing.

Introduction

Stubble retention is an important component of no-till farming systems. The main benefits of stubble retention are increased water infiltration rates and reduced evaporation from the soil surface. There are challenges with stubble retention that are well recognised, including disease and weed management. Stubble retention has helped producers buffer against variable climatic conditions, especially by maintaining seedbed moisture and hence widening sowing windows. There has, however, been little research on the effect of stubble on the crop canopy climate. These experiments aimed to determine the effect of stubble management on crop canopy temperature (especially during frost events) and the associated effects on sterility and grain yield of wheat.

Site details

Location	Tootool, approximately 10 km west of The Rock
Soil type	Sodic red–brown chromosol
2013 crop	Canola (with retained wheat residue)
2014 variety	Bolac$^{\phi}$ wheat
2015 variety	Whistler wheat
Plot size	36 metres (comprising three passes of a 12 metre seeder) by 200 metres

Treatments

Stubble management

1. Removed – burnt just before sowing.
2. Reduced – mulched using a K-Line stubble cutter just before sowing.
3. Retained – sown directly into the previous crop residue using inter-row sowing.

Methodology

In early May 2014, each stubble treatment was imposed on the grower's existing controlled traffic operation before sowing. Plot size was 0.72 ha with three replicates of each treatment. The treatments were imposed on the same plots in late April 2015.

Weed, disease and nutrient management were at the discretion of the grower, but decisions were made so that yield potential was optimised.

Canopy temperature was measured using unshielded Tinytag Plus 2 data loggers with two loggers in each plot. The loggers were set around the height of the canopy and moved up through the season as the crop grew taller. Temperature was logged every 15 minutes.

Just before crop maturity, 30 heads were collected from three separate locations within each plot. Heads were frozen and later assessed for floret sterility.

Grain harvest was completed using the grower's existing machinery. Yield data came from the grower's yield maps and were assigned to specific plots using the software Ag Leader® SMS™ Basic.

Results

Stubble biomass

In 2014, stubble biomass was similar for the Reduced and Retained treatments (approximately 3.2 t/ha). Stubble biomass in the Removed treatment was nil.

In 2015, stubble biomass was greatest for the Retained treatment (6.1 t/ha), reducing to 5.7 t/ha for the Reduced treatment and nil for the Removed treatment.

Crop establishment

There was no difference in crop establishment between treatments in 2014. In 2015, there was a slightly higher established plant population from the Reduced treatment, however, the differences were small (less than 10 plants/m^2) and likely to be inconsequential.

Crop development

There were slight differences in plant development across the different treatments. The Removed treatment was generally the most advanced and the fastest to reach anthesis. The Retained treatment was on average 2–3 days slower to anthesis than the Removed treatment, and the Reduced treatment was intermediate between these.

Canopy temperature

2014

From September to early November, the Removed stubble canopy had less time below the thresholds of −2.0 °C, −3.0 °C and −4.0 °C than either the Reduced or Retained treatments (Figure 1). The Removed treatment had less time below −1.0 °C than the Reduced stubble treatment, and there was no treatment difference below the 0, −5.0 °C and −6.0 °C thresholds.

There were 31 separate frost events from early September to early November (events where temperature dropped below 0 °C in any treatment). There were treatment effects on canopy temperature in 18 of the 31 events. In 16 of the 18 instances, the Reduced and Retained treatments were colder than the Removed treatment.

For the events where there was a difference between Removed and Retained stubble, the temperature difference averaged 0.45 °C.

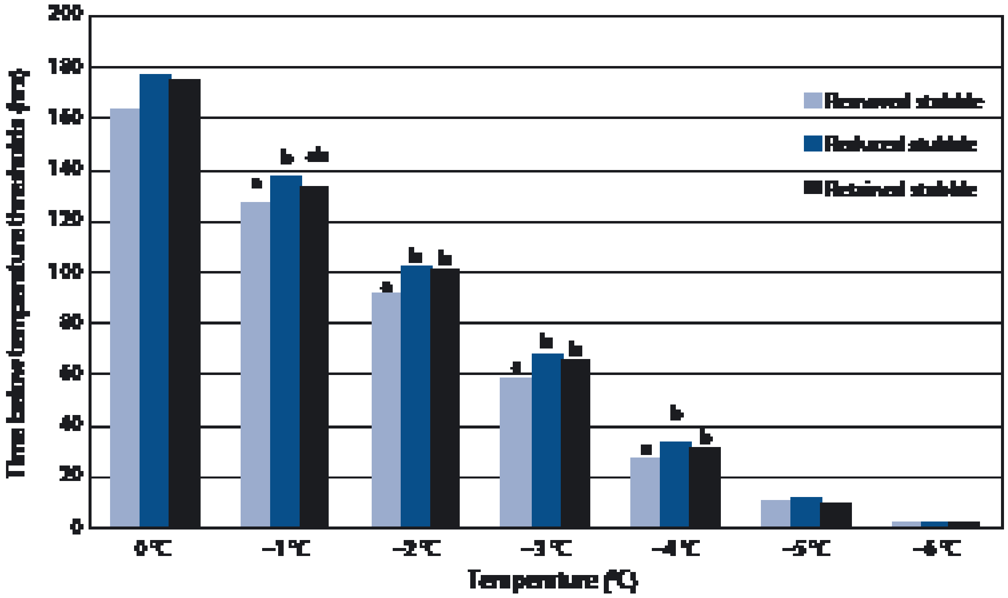


Figure 1. The number of hours below specific threshold canopy temperatures of three treatments from September to early November at Tootool, New South Wales in 2014. Significant difference is indicated by different letters ($P<0.05$).

2015

From late August to October, the Removed treatment had less time below each threshold from 0 °C to −6.0 °C than either the Reduced or Retained treatments (Figure 2). The Reduced treatment had less time below −2.0 °C or −3.0 °C than the Retained treatment, but these treatments were similar for all other temperatures.

There were 41 frost events (events where temperature dropped below 0 °C in any treatment) between 29 August and the last frost event on 2 October. In 35 (Retained) and 33 (Reduced) of 41 events, minimum temperature was less than the minimum temperature of the Removed treatment (data not shown).

For the events where there was a difference between Removed and Retained stubble, the temperature difference averaged 0.79 °C.

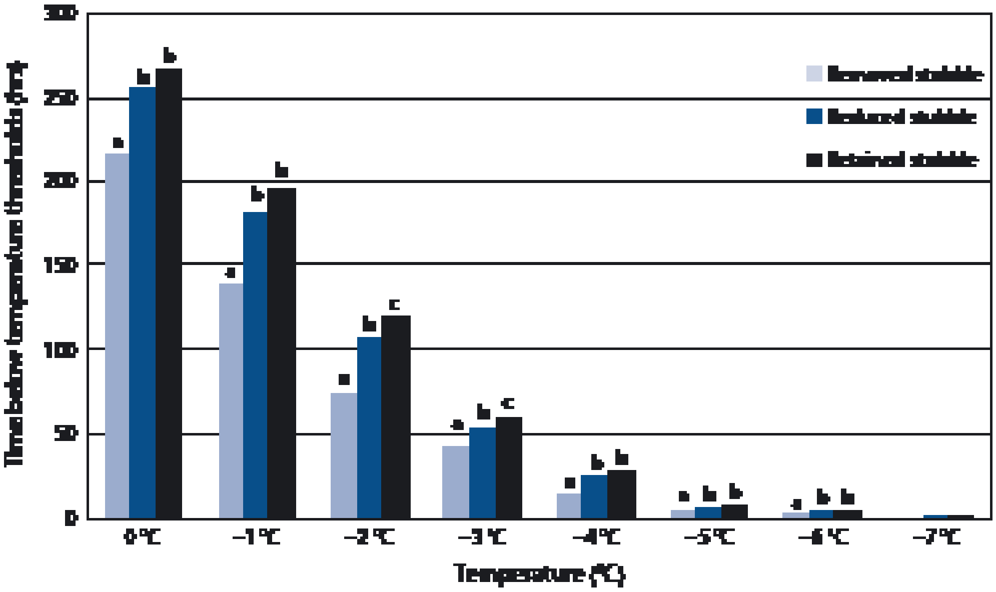


Figure 2. The number of hours below specific threshold canopy temperatures of three treatments from late August to October at Tootool, New South Wales in 2015. Significant difference is indicated by different letters ($P<0.05$).

Soil temperature

The effect of stubble management (Retained and Removed only) on soil temperature (at 5 cm depth) was measured in 2015. An analysis of the soil heat sum during the night (sum of the hourly mean soil temperature between 6 pm and 5 am) from 5 September to 9 November showed that the soil was warmer overall ($P = 0.028$) where stubble was Removed (12880 °C) compared with Retained (12605 °C).

Floret sterility

Floret sterility (FS) was not affected by the stubble treatments in 2014 and 2015. There was, however, large differences in FS between years with an average FS of 21.1% in 2014 compared with 6.0% in 2015.

Grain yield

In 2014, the Removed treatment (2.2 t/ha) was higher yielding than the Retained treatment (2.0 t/ha). The Reduced treatment (2.1 t/ha) was not statistically different from either the Removed or Retained treatment.

In 2015, the Removed (3.4 t/ha) and Reduced (3.3 t/ha) treatments were both higher yielding than the Retained treatment (3.0 t/ha).

Conclusion

Stubble retention consistently reduced canopy temperature during frost events when compared with stubble removal by burning. This did not affect the level of floret sterility at maturity, but did affect the final grain yield, with burnt stubble out-yielding retained standing stubble in both seasons of this experiment.

The colder minimum canopy temperatures from stubble retention are believed to be the result of two factors:

1. Stubble shades the soil during the day so it heats up less than bare soil.
2. When the air temperature drops at night, there is less heat available in the soil to radiate out and warm the canopy.

Stubble retention brings benefits to the farming system, especially for improved water infiltration and reduced evaporation. Growers need to consider management strategies that avoid frost where high levels of stubble are retained at sowing. This could include selecting a more frost-tolerant species (such as barley or oats) or delaying flowering slightly (using a combination of sowing date and variety choice).

Acknowledgements

This experiment was part of the project ‘Farming systems to improve crop tolerance to frost’, DAW00241, 2014–16, with joint investment by NSW DPI, DAFWA and GRDC.

Thanks to cooperators Warwick and Di Holding from Pontara Grain for their tireless efforts with these experiments.

Optimising grain yield of thirty-two wheat varieties across sowing dates – Condobolin 2016

Ian Menz, Nick Hill and Daryl Reardon (NSW DPI, Condobolin)

Key findings

- Scepter⦸ (6.17 t/ha) yielded the highest from the 20 April sowing date; Cutlass⦸ (4.38 t/ha) yielded the highest from the 19 May sowing date; and Viking⦸ (3.22 t/ha) yielded the highest from the 1 June sowing date.
- The 20 April sowing germinated and established well before the waterlogged conditions occurred during late May and early June causing reduced germination and poorer establishment for the 19 May and 1 June sowing dates (SD). This low establishment resulted in reduced yields between sowing dates of 0.78 t/ha from SD1 and SD2 and 1.01 t/ha from SD2 and SD3.
- Grain yields of varieties were highest when they were sown in their recommended sowing window.

Introduction

The experiment was designed to evaluate the response to sowing time of 32 current and new wheat varieties within the Central West region of NSW.

To optimise the yield potential of wheat varieties it is necessary to understand the variety response to varying sowing times. It is important to choose a current variety best suited to a given sowing time. Varieties have different phenology so it is important to select the variety with the correct phenology to optimise the yield potential.

This experiment was part of a series of experiments sown across NSW in a range of agronomical zones aimed at establishing variety response to sowing dates. The three sowing dates selected for this experiment represented a range suitable for the region.

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	Lucerne pasture (2012–15) Fallowed August 2015
Fertiliser	70 kg/ha mono-ammonium phosphate (MAP) + Jubilee (Flutriafol 500g/L) at 400 mL/ha (fungicide on fertiliser)
Soil available nitrogen	225 kg/ha (0–60 cm), soil test conducted in February 2016
Growing season rainfall (1 April–30 September)	467 mm
Harvest dates	SD1 and SD2: 28 November SD3: 2 December
Weed control	Once established, the experiment was well maintained and weed-free. Grass weeds were controlled with in-crop herbicide application of Axial® at 300 mL/ha + Adigor® at 500 mL/100 L of water. An application of Precept® at 1 L/ha + Hasten™ at 500 mL/100 L water for broadleaf control. Broadleaf weeds were further controlled with a late season application of L.V.E. Agritone® at 500 mL/ha + Ally® at 5 g/ha.

Season conditions

The growing season rainfall at the experiment site was above average with the Condobolin ARAS recording 466.8 mm. The long-term average (LTA) growing season rainfall is 192.1 mm. There was 80.9 mm of rain during January with no rain recorded in February and below-average rainfall during March and April. There was above-average rainfall during the May to September period with Condobolin ARAS receiving the highest June rainfall in recorded history (Table 1).

This above-average rainfall resulted in secondary growth on some varieties and harvest was delayed. The late season varieties EGA Wedgetail$^{\phi}$ and EGA Eaglehawk$^{\phi}$ had higher yields than expected on the later sowing times (Table 2).

There were two sub-zero frost events at Condobolin during the growing season. On 26 June and again on 27 August, the temperature was –0.6 °C.

Irrigation and sowing conditions

The site was irrigated with 25 mm of water applied on 18 April to allow the early sowing treatment to establish within the early sowing period for the Condobolin region. The irrigation provided adequate moisture and SD1 established quickly and evenly.

There was a scheduled two-week interval between each sowing time within this experiment. SD2 was delayed by an additional two weeks due to wet conditions in the latter part of May. SD3 was sown two weeks after SD2.

The high rainfall during late May and June caused waterlogging resulting in seed burst, rotting seed, soil sealing and poor early vigour.

Table 1. Monthly rainfall 2016 and long-term average (LTA) at Condobolin ARAS.

	Monthly rainfall (mm)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Growing season
2016	80.9	0	21.8	21.4	60.2	161.5	37.1	43.4	143.2	31.6	40.8	56.7	698.6	466.8
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

Treatments

Wheat varieties (32)

Beckom$^{\phi}$, Bolac$^{\phi}$, Condo$^{\phi}$, Corack$^{\phi}$, Cutlass$^{\phi}$, LongReach Dart$^{\phi}$, DS_Darwin$^{\phi}$, DS_Spring, EGA Eaglehawk$^{\phi}$, EGA Gregory$^{\phi}$, EGA Wedgetail$^{\phi}$, Emu Rock$^{\phi}$, Hatchet CL Plus$^{\phi}$, HTWYT_012, Janz, LongReach Lancer$^{\phi}$, Livingston$^{\phi}$, LongReach Flanker$^{\phi}$, LPB12-0391, LPB12-0494, LPB12-0648, LongReach Reliant$^{\phi}$, Mace$^{\phi}$, Mitch$^{\phi}$, Scepter$^{\phi}$, LongReach Spitfire$^{\phi}$, Sunguard$^{\phi}$, Sunmate$^{\phi}$, Suntop$^{\phi}$, LongReach Viking$^{\phi}$, VO7176-69, Wallup$^{\phi}$.

Sowing date (SD)

SD1: 20 April
SD2: 19 May
SD3: 1 June

Results

The grain yield, when averaged over all varieties for each sowing time, was SD1 4.39 t/ha, 0.78 t/ha higher than SD2 (3.61 t/ha). SD2 was 1.01 t/ha higher yielding than SD3 (2.60 t/ha).

The lower grain yield from SD2 and SD3 were likely the result of poor establishment due to wet conditions post-sowing and waterlogging for the majority of the growing season and grain filling period.

There was a significant ($P = 0.05$) interaction between sowing date and variety. Scepter$^{\phi}$ (6.17 t/ha) yielded the highest from SD1, Cutlass$^{\phi}$ (4.38 t/ha) from SD2 and Viking$^{\phi}$ (3.22 t/ha) was the highest yielding variety from SD3.

The fast maturing lines such as Hatchet CL Plus$^{\phi}$, Condo$^{\phi}$, LongReach Spitfire$^{\phi}$ and Livingston$^{\phi}$ were low yielding from SD1. The early maturing lines flowered during August and suffered frost damage from the 27 August frost event. Hatchet CL Plus$^{\phi}$ yielded the lowest from SD1 and SD2 (2.48 t/ha and 2.67 t/ha respectively) (Table 2).

Some varieties had large interactions with sowing date, e.g. EGA Gregory$^{\text{Ⓓ}}$, Wallup$^{\text{Ⓓ}}$ and Scepter$^{\text{Ⓓ}}$. EGA Gregory$^{\text{Ⓓ}}$ and Wallup$^{\text{Ⓓ}}$ were low-yielding from SD1 and higher yielding from SD2 and SD3. Scepter$^{\text{Ⓓ}}$ was relatively high yielding from SD1 and SD2 and relatively low yielding from SD3.

Table 2. Grain yield and rank of 32 wheat varieties sown on three sowing dates at Condobolin, 2016.

Variety	**Sowing date**					
	SD1 – 20 April		**SD2 – 19 May**		**SD3 – 1 June**	
	Yield (t/ha)	**Rank**	**Yield (t/ha)**	**Rank**	**Yield (t/ha)**	**Rank**
Beckom	5.36	5	3.80	13	2.99	4
Bolac	5.16	8	3.69	16	2.78	10
Condo	3.40	28	3.87	9	2.38	23
Corack	4.07	20	3.61	17	2.50	20
Cutlass	5.51	3	4.38	1	2.94	5
LongReach Dart	3.83	23	2.86	31	2.31	28
DS_Darwin	4.62	14	3.83	11	2.68	13
DS_Spring	3.70	24	3.54	20	2.56	18
EGA Eaglehawk	5.33	6	3.79	14	2.75	11
EGA Gregory	3.99	21	4.20	2	2.94	6
EGA Wedgetail	5.51	4	3.94	7	3.10	2
Emu_Rock	3.63	25	3.10	28	2.50	19
Hatchet CL Plus	2.48	32	2.67	32	2.48	22
HTWYT_012	3.01	30	3.40	23	2.32	27
Janz	4.99	10	3.52	22	2.49	21
LongReach Lancer	5.06	9	3.88	8	2.57	17
Livingston	2.95	31	3.12	27	2.05	31
LongReach Flanker	3.57	26	4.08	5	2.83	8
LPB12-0391	4.36	18	3.38	25	2.37	24
LPB12-0494	4.31	19	3.31	26	2.36	25
LPB12-0648	5.63	2	4.11	3	3.08	3
LongReach Reliant	3.31	29	3.39	24	2.28	29
Mace	4.68	13	3.53	21	2.73	12
Mitch	4.99	11	3.82	12	2.66	14
Scepter	6.17	1	4.11	4	2.62	15
LongReach Spitfire	3.43	27	3.55	19	2.59	16
Sunguard	4.54	16	2.99	29	2.00	32
Sunmate	4.62	15	2.94	30	2.11	30
Suntop	4.47	17	3.74	15	2.32	26
LongReach Viking	5.16	7	3.85	10	3.22	1
V07176-69	4.80	12	3.56	18	2.81	9
Wallup	3.91	22	4.06	6	2.91	7
l.s.d ($P<0.05$)	0.56					

Grain quality

There was a significant ($P = 0.05$) interaction between the variety and sowing date for protein, screenings and test weight (Table 3).

The grain protein decreased for most varieties with the later sowing date(s). This decrease might be due to the waterlogged conditions for much of the growing season and the high rainfall during September, which coincided with the grain filling period.

Table 3. Protein (%), screenings (%) and test weight (kg/hL) of 32 wheat varieties sown on three sowing dates at Condobolin, 2016.

Variety	**Sowing date**								
	SD1 – 20 April			**SD2 – 19 May**			**SD3 – 1 June**		
	Protein (%)	**Screenings (%)**	**Test weight (kg/hL)**	**Protein (%)**	**Screenings (%)**	**Test weight (kg/hL)**	**Protein (%)**	**Screenings (%)**	**Test weight (kg/hL)**
Beckom	11.41	21.51	81.66	10.01	31.26	83.29	10.16	46.07	83.20
Bolac	12.32	12.21	82.51	10.82	27.74	82.89	10.66	35.35	81.59
Condo	13.37	34.31	82.00	11.12	49.76	83.93	11.10	72.18	83.08
Corack	13.00	13.11	80.98	11.68	31.73	82.33	11.15	40.83	82.22
Cutlass	11.27	26.87	81.47	9.92	31.10	82.04	10.28	42.62	80.36
LongReach Dart	14.98	11.28	81.36	11.76	32.55	83.20	11.20	44.13	82.76
DS_Darwin	12.90	19.00	82.63	10.54	30.04	83.47	10.52	40.78	83.60
DS_Spring	12.21	29.42	82.22	10.55	37.16	83.65	10.15	52.17	83.09
EGA Eaglehawk	11.42	26.84	82.50	10.74	34.37	82.48	10.77	34.04	81.79
EGA Gregory	11.83	43.61	82.42	10.87	33.34	84.14	10.36	46.88	83.70
EGA Wedgetail	10.76	18.24	81.20	10.76	24.95	80.92	10.37	35.02	80.12
Emu Rock	13.16	19.88	79.27	11.69	42.84	81.63	11.51	58.16	81.04
Hatchet CL Plus	16.24	11.87	76.48	12.34	28.31	81.38	11.79	43.25	80.87
HTWYT_012	14.76	4.68	79.24	11.74	14.59	83.14	11.00	30.69	82.54
Janz	12.38	12.70	82.90	10.92	20.86	84.48	10.87	34.60	83.09
LongReach Lancer	12.93	24.88	82.37	11.87	30.29	83.60	11.79	36.07	82.81
Livingston	14.89	13.78	80.62	11.54	31.62	83.47	11.72	46.53	82.37
LPB12-0391	12.68	9.47	83.07	11.19	18.40	84.33	10.68	29.13	83.47
LPB12-0494	12.81	13.29	79.92	11.24	45.98	82.69	10.68	57.12	83.06
LPB12-0648	11.18	22.40	84.57	10.67	32.24	84.19	10.74	33.58	83.91
LongReach Flanker	11.49	33.86	82.89	10.26	31.79	84.57	10.33	41.93	83.53
LongReach Reliant	12.29	36.58	83.14	10.44	41.99	84.44	10.11	59.12	83.86
Mace	13.37	10.44	81.47	10.85	26.32	82.44	10.29	36.95	82.32
Mitch	10.33	22.40	81.34	8.98	33.60	82.18	9.31	51.03	81.08
Scepter	12.42	23.07	82.36	10.02	35.09	83.41	10.46	59.61	82.75
LongReach Spitfire	15.13	17.68	81.71	12.73	31.66	83.69	12.01	45.17	83.32
Sunguard	12.22	35.58	82.66	11.16	33.50	83.38	11.05	42.50	82.08
Sunmate	12.34	30.90	81.53	10.39	57.17	83.06	10.51	63.13	81.88
Suntop	12.56	32.86	81.17	10.64	43.94	83.58	10.18	59.93	82.66
LongReach Viking	11.93	9.65	83.45	10.43	24.85	84.56	9.79	29.86	84.16
V07176-69	11.90	27.85	82.55	10.58	31.37	83.80	9.95	36.47	83.56
Wallup	14.47	3.79	79.94	11.7	12.28	83.02	11.45	12.78	83.28
Min	10.33	3.79	76.48	8.98	12.28	80.92	9.31	12.78	80.12
Mean	12.72	21.06	81.68	10.98	32.27	83.23	10.72	43.68	82.60
Max	12.64	43.61	84.57	12.73	57.17	84.57	12.01	72.18	84.16
l.s.d. ($P = 0.05$)									
SD	0.16	4.42	0.43						
Variety	0.35	3.90	0.38						
Variety × SD	0.61	7.06	0.71						

There was a significant difference in test weights between the three sowing dates. Test weights from all varieties were above the wheat receival standard (68–76 kg/hL).

Screenings were high in this experiment ranging from 3.79% for Wallup$^{\text{⦶}}$ to 43.61% for EGA Gregory$^{\text{⦶}}$ from the 20 April SD, 12.28% for Wallup$^{\text{⦶}}$ to 57.17% for Sunmate$^{\text{⦶}}$ from the 19 May SD and 12.78% for Wallup$^{\text{⦶}}$ to 72.18% for Condo$^{\text{⦶}}$ from the 1 June SD (Table 3). This was, in part, due to the waterlogged conditions that occurred during the growing season.

Summary

Sowing varieties in the correct sowing window means they are more likely to achieve their potential yield. This experiment is part of the Variety Specific Agronomy Packages project, for which experiments have been conducted within NSW for a number of years.

In 2015, the first SD was 1.16 t/ha higher yielding than the third SD. This yield difference was due to a very dry spring during the grain-filling period. In 2016, there was a difference in yield of 1.79 t/ha from SD1 to SD3. This difference might have been due to waterlogging during the early establishment and the grain-filling period for SD2 and SD3.

The potential to maximise grain yield is increased when variety selection is matched to a sowing time. Hatchet CL Plus$^{\text{⦶}}$ is an early-maturing variety. For SD1 and SD2 it flowered during August and was affected by the 27 August frost event and was the lowest-yielding variety in both of these sowing dates.

Acknowledgements

This experiment was part of the project 'Variety Specific Agronomy Packages for southern, central and northern New South Wales', DAN00167, 2012–17, with joint investment by GRDC and NSW DPI.

Thanks to the operational and technical officers at Condobolin ARAS and Dr Neroli Graham for statistical analyses.

Effect of sowing date on heading date and grain yield of fifteen barley and five wheat varieties – Matong 2016

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

Key findings

- The highest grain yields were attained from mid May sowing across all barley varieties.
- Longer-season varieties were high yielding in the 2016 season.
- Oxford achieved the highest grain yields for both sowing dates.
- Lodging was prevalent in 2016, significantly reducing grain yield of susceptible varieties in the first sowing.

Introduction

This experiment was conducted to investigate the effect of sowing date on heading date and grain yield of 15 commercially relevant barley varieties compared with five fast-developing wheat varieties.

Site details

Location	"Yarrawonga", Matong NSW
Soil type	Brown chromosol
Previous crop	Canola
Sowing	Direct drilled with DBS tynes spaced at 240 mm using a GPS auto-steer system Target plant density: 150 plants/m^2
Fertiliser	100 kg N/ha mono-ammonium phosphate (MAP) (sowing) 40 kg N/ha (surface spread) 6 May 40 kg N/ha (surface spread) 30 June
Weed control	Knockdown: glyphosate (450 g/L) 1.2 L/ha Pre-emergent: Sakura® 118 g/ha + Logran® at 35 g/ha
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser 400 mL/ha In-crop: Prosaro® 300 mL/ha applied at GS30 and GS37
In-crop rainfall (April–October)	519 mm (long-term average is 319 mm)

Treatments

Fifteen barley and five wheat varieties were sown on three sowing dates: 26 April, 17 May and 1 June 2016 (Table 1). The site received above average rainfall from June–September, resulting in several waterlogging events during early vegetative growth. The wet conditions caused the third sowing time (1 June) to have poor establishment. It was later re-sown, but failed to establish a second time. No data was recorded for the third sowing date.

Table 1. Barley and wheat varieties included in the experiment at Matong, 2016.

Species	Variety
Barley	Biere, Commander$^{\phi}$, Compass$^{\phi}$, Explorer$^{\phi}$, Fathom$^{\phi}$, Flinders$^{\phi}$, GrangeR, La Trobe$^{\phi}$, Navigator$^{\phi}$, Oxford, Rosalind$^{\phi}$, Scope CL$^{\phi}$, Spartacus CL$^{\phi}$, Urambie$^{\phi}$, Westminster$^{\phi}$
Wheat	Beckom$^{\phi}$, Condo$^{\phi}$, Corack$^{\phi}$, Emu Rock$^{\phi}$, LongReach Spitfire$^{\phi}$

Results

The mid May sowing (17 May) resulted in the highest barley yields (Table 2), as with the 2014 and 2015 experiments at Matong. In contrast to the series of early frosts and the hot, dry finish in 2015, the mild conditions experienced later in 2016 resulted in an extended grain-filling period. The result was minimal grain yield penalties, which are often associated with later heading dates for barley varieties (Figure 1). The longer-season barley varieties, such as Oxford, Urambie$^{\phi}$, Navigator$^{\phi}$ and Westminster$^{\phi}$ achieved high yields (Table 2).

The mean grain yield of the five wheat varieties was 16% higher than the mean grain yield of the 15 barley varieties for the first sowing date and 14% higher for the second sowing date (Table 2).

There was lodging present in both sowing dates. For the first sowing date, there was significant lodging in susceptible varieties such as Compass$^{\phi}$, Commander$^{\phi}$, La Trobe$^{\phi}$ and Scope CL$^{\phi}$ (Table 2). Regrowth of later tillers was more apparent in lodged plots, resulting in variability in physiological maturity and delayed harvest.

Table 2. Grain yield, heading date (GS55) and lodging score (0, no lodging to 9, completely lodged) of barley and wheat varieties on two sowing dates at Matong in 2016.

Variety	Sowing date					
	26 April 2016			17 May 2016		
	Grain yield (t/ha)	Heading date (GS55)	Lodging score (0–9)	Grain yield (t/ha)	Heading date (GS55)	Lodging score (0–9)
Beckom*	5.39	5 Sep	4	5.81	23 Sep	0
Biere	3.68	26 Aug	6	4.50	10 Sep	3
Commander	3.97	12 Sep	7	5.36	27 Sep	6
Compass	3.70	20 Aug	8	4.14	27 Sep	7
Condo*	5.05	22 Aug	4	5.94	18 Sep	0
Corack*	4.92	23 Aug	1	6.08	17 Sep	0
Emu Rock*	5.35	17 Aug	1	6.21	15 Sep	1
Explorer	4.17	2 Sep	8	5.97	25 Sep	4
Fathom	4.17	4 Sep	7	5.49	22 Sep	1
Flinders	3.27	11 Sep	5	5.16	26 Sep	2
GrangeR	4.49	5 Sep	7	5.51	25 Sep	6
La Trobe	4.70	31 Aug	9	4.78	18 Sep	0
Navigator	5.05	25 Sep	2	5.61	7 Oct	0
Oxford	5.60	13 Sep	5	6.39	30 Sep	3
Rosalind	4.59	28 Aug	8	3.31	27 Sep	4
Scope CL	3.38	5 Sep	9	4.13	22 Sep	2
Spartacus CL	4.12	4 Sep	8	5.36	18 Sep	1
LongReach Spitfire*	4.66	19 Aug	3	5.63	17 Sep	1
Urambie	4.51	15 Sep	3	5.44	28 Sep	1
Westminster	4.22	15 Sep	5	5.78	30 Sep	0
Mean (barley)	4.24			5.12		
Mean (wheat)	5.07			5.94		
l.s.d. ($P<0.05$) barley varieties = 1.06 t/ha l.s.d. ($P<0.05$) wheat varieties = 0.96 t/ha						

* Wheat varieties; grey shading indicates highest-yielding variety for each sowing date.

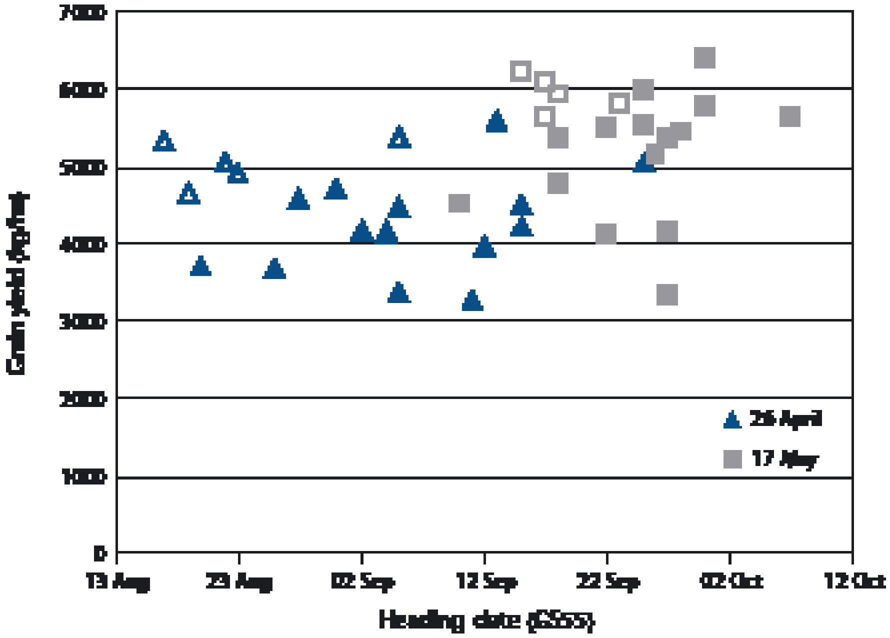


Figure 1. Heading date and grain yield of barley (solid marker) and wheat (open marker) varieties for two sowing dates at Matong, 2016.

Summary

The highest grain yields were from a mid May sowing in 2016 which, together with previous year's results (Slinger et al. 2015, 2016), suggests an optimum sowing window around the second week of May in southern NSW for many varieties. Varieties with different phenology patterns might suit earlier sowing opportunities, and will be investigated in 2017.

Longer-season varieties were high yielding in 2016. Oxford was the highest yielding for both sowing dates (SD1: 5.60 t/ha; SD2: 6.39 t/ha). However, it is important to make decisions based on results from a number of seasons. La Trobe⁽ᵈ⁾ has effectively replaced Hindmarsh⁽ᵈ⁾ as the benchmark variety in southern NSW and has been high yielding despite some issues with lodging in some areas in 2016.

References

Slinger, D, Madden, E, Podmore, C & Ellis, S 2015. *Southern cropping region trial results 2014*. NSW Department of Primary Industries.

Slinger, D, Madden, E, Podmore, C & Martin, C 2016. *Southern NSW research results 2015*. NSW Department of Primary Industries.

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 cooperation of Stephen, Michelle and Rod Hatty "Yarrawonga", Matong for hosting the experiment and technical support from Jessica Simpson and Hayden Petty.

Is it possible to increase barley yield potential in southern NSW?

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

Key findings

- Grain yield and lodging increased with additional nitrogen application for all varieties and plant growth regulator (PGR) treatments.
- Applying Moddus® Evo reduced lodging and increased grain yield of both Rosalind$^{⌽}$ and La Trobe$^{⌽}$.
- Applying PGRs did not significantly affect either lodging score or grain yield of Compass$^{⌽}$, despite it lodging severely.

Introduction

Recent improvements in barley genetics and agronomic management have resulted in growers achieving high barley yields. An experiment was conducted at Wagga Wagga in 2016 to determine whether optimising agronomic inputs could further increase barley yield.

Site details

Location	Wagga Wagga Agricultural Institute, NSW
Soil type	Red chromosol
Previous crop	Canola
Sowing	Direct drilled with DBS tynes spaced at 240 mm using a GPS auto-steer system Target plant density: 150 plants/m^2
Soil pH_{Ca}	5.1 (0–10 cm)
Mineral nitrogen at sowing (1.5 m depth)	142 kg N/ha
Fertiliser applied	100 kg N/ha mono-ammonium phosphate (MAP) (sowing)
Weed control	Knockdown: glyphosate (450 g/L) 1.2 L/ha Pre-emergent: Sakura® 118 g/ha + Logran® at 35 g/ha
Disease management	Seed treatment: Hombre® Ultra 200 mL/100 kg Flutriafol-treated fertiliser (400 mL/ha) In-crop: Prosaro® 300 mL/ha at GS30 and GS37
In-crop rainfall (April–October)	592 mm (long-term average is 355 mm)

Treatments

A complete factorial design (all possible combinations of treatment factors) consisting of treatment combinations of three varieties, seeding density, applied nitrogen and plant growth regulators (PGRs) were included (Table 1).

Results

Rosalind$^{⌽}$ had significantly higher grain yields than Compass$^{⌽}$ and La Trobe$^{⌽}$ across all treatments. Grain yield and lodging of all varieties increased with additional nitrogen. There were no significant interactions between nitrogen treatments, variety or PGR treatment.

Two applications of Moddus® Evo on La Trobe$^{⌽}$ and Rosalind$^{⌽}$ significantly reduced lodging and increased grain yield (Table 2). There was no effect from PGR application to Compass$^{⌽}$ on either lodging or grain yield despite Compass$^{⌽}$ having significantly higher lodging scores than La Trobe$^{⌽}$ and Rosalind$^{⌽}$. There was no significant effect of seeding density on either grain yield or lodging (data not presented).

Table 1. Treatment factors included in an experiment at Wagga Wagga, 2016.

Treatment factor	Description	
Variety	Compass$^{(b)}$	High yield potential, weak straw strength, medium–tall height
	La Trobe$^{(b)}$	High yield potential, moderately good straw strength, medium height
	Rosalind$^{(b)}$	High yield potential, good straw strength, medium height
Seeding density	150 plants/m^2	
	250 plants/m^2	
Nitrogen	Nil	
	Nil at sowing + 40 kg N/ha at GS22	
	40 kg N/ha at sowing + 40 kg N/ha at GS22	
	40 kg N/ha at sowing + 80 kg N/ha at GS22	
Plant growth regulator	No PGR	
	400 mL/ha Moddus® Evo at GS31–32	
	400 mL/ha Moddus® Evo at GS31–32 + 200 mL Moddus® Evo at GS37–39	

Table 2. Grain yield and lodging scores (0, no lodging to 9, completely lodged) for combination of treatment factors (variety, nitrogen and PGR treatments) at Wagga Wagga, 2016.

Variety	Nitrogen treatment	Grain yield (t/ha)			Lodging score (0–9)		
		PGR treatment			PGR treatment		
		No PGR	Moddus® Evo at GS31	Moddus® Evo at GS31 + 39	No PGR	Moddus® Evo at GS31	Moddus® Evo at GS31 + 39
Compass	Nil	6.16	6.25	6.46	6.5	4.7	3.2
	0_40	6.56	6.80	6.93	6.4	3.2	6.9
	40_40	6.80	7.09	6.55	6.6	6.3	7.5
	40_80	7.15	7.40	7.33	6.4	6.9	6.5
La Trobe	Nil	5.85	6.60	6.39	4.8	1.2	2.1
	0_40	5.55	7.06	6.24	7.7	3.6	3.2
	40_40	5.93	7.10	7.04	5.7	4.5	3.7
	40_80	5.06	6.63	7.60	8.3	5.3	4.5
Rosalind	Nil	7.57	7.30	8.71	2.7	2.3	2.8
	0_40	7.01	7.71	8.18	2.8	1.9	1.3
	40_40	7.44	8.75	8.18	3.7	3.9	1.8
	40_80	7.51	8.55	8.55	6.2	3.7	1.8
l.s.d. ($P = 0.05$) variety		0.27			0.6		
l.s.d. ($P = 0.05$) nitrogen		0.32			0.8		
l.s.d. ($P = 0.05$) PGR		0.28			0.6		
l.s.d. ($P = 0.05$) variety × PGR		0.48			1.2		

Treatment factors are described in Table 1.

Summary

Applying Moddus® Evo reduced lodging and increased grain yield in Rosalind$^{(b)}$ and La Trobe$^{(b)}$. However, it did not have a significant effect on lodging or grain yield in Compass$^{(b)}$. Strategically using PGRs in barley might offer opportunities for increasing grain yield in mid–high rainfall areas in specific varieties, where lodging is moderate. Further research will be undertaken in 2017 to explore varietal responses to PGRs and improving efficacy through timing PGR applications.

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 Jessica Simpson and Hayden Petty.

Effect of nitrogen fertiliser on grain yield and quality of eight barley cultivars – Condobolin 2016

David Burch and Nick Moody (NSW DPI, Condobolin)

Key findings

- Rosalind$^{\phi}$ (fast maturity) had the highest grain yield at all rates of applied nitrogen.
- Higher lodging at higher nitrogen rates reduced yield response to applied nitrogen in Compass$^{\phi}$, Commander$^{\phi}$ and Scope CL$^{\phi}$.
- High spring rainfall and mild growing conditions resulted in high yields and full use of applied nitrogen.

Introduction

Early season nitrogen (N) applications can increase cereal crop yield, however, excessive applications can affect grain size and decrease N-use efficiency. It can also induce lodging due to increasing plant biomass height. This experiment assessed the yield, quality and lodging susceptibility of eight barley varieties to five N applications.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Soil N at sowing	30 kg/ha (0–10 cm), 39 kg/ha (10–60 cm)
Experimental design	Randomised complete block design, varieties and N treatments randomised within three replicates
Sowing date	18 May 2016
Sowing	Sown using a six-row DBS plot seeder at 30 cm row spacings for 120 plants/m^2 target plant density
Fertiliser	70 kg/ha mono-ammonium phosphate (MAP) was applied at sowing, providing an additional 7 kg/ha of available N
Weed control	Pre-emergent weed control: WipeOut 450® 2 L/ha Post-emergent weed control: Axial® 100EC® 300 mL/ha + Adigor® 500 mL/100 L water
Pest control	Aphids: Primor WG® 150 g/ha
Growing season rainfall (1 April–30 September)	467 mm (long-term average is 192 mm)

Treatments

Nitrogen applied

Nitrogen applied as urea at sowing at 0, 30, 60, 90 and 120 kg N/ha

Varieties

Commander$^{\phi}$, Compass$^{\phi}$, Fathom$^{\phi}$, GrangeR, La Trobe$^{\phi}$, Rosalind$^{\phi}$, Scope CL$^{\phi}$, Spartacus CL$^{\phi}$

Results

Grain yield

The highest yielding variety across all N treatments was Rosalind$^{\phi}$, although it was equal to GrangeR at 0 kg N/ha (Table 1). Commander$^{\phi}$ had the lowest response to applied N, with a yield reduction of 0.26 t/ha recorded between 0 kg N/ha and 120 kg N/ha treatments. Commander$^{\phi}$ was the only variety that had a reduction in the total number of grains per square metre (Figure 1), with a total reduction of 3.9%, while the most responsive variety, Rosalind$^{\phi}$, increased total grain numbers by 34.5%.

Table 1. Grain yield (t/ha) of eight barley varieties at five rates of applied N at Condobolin in 2016.

Variety	**N applied (kg/ha)**				
	0	**30**	**60**	**90**	**120**
	Total available N (kg/ha)				
	76	**106**	**136**	**166**	**196**
	Grain yield (t/ha)				
Commander	5.1	5.3	4.7	5.0	4.8
Compass	4.6	5.0	4.9	4.9	5.1
Fathom	5.0	5.9	5.8	6.2	5.8
GrangeR	5.9	6.1	6.3	6.7	7.0
La Trobe	5.6	5.7	6.3	6.2	5.2
Rosalind	5.9	6.4	7.1	7.2	7.6
Scope CL	4.6	5.0	5.4	5.1	5.3
Spartacus CL	5.3	5.7	6.1	6.9	6.8
l.s.d. (*P* = 0.05) N rate = 0.33 t/ha; variety = 0.93 t/ha					

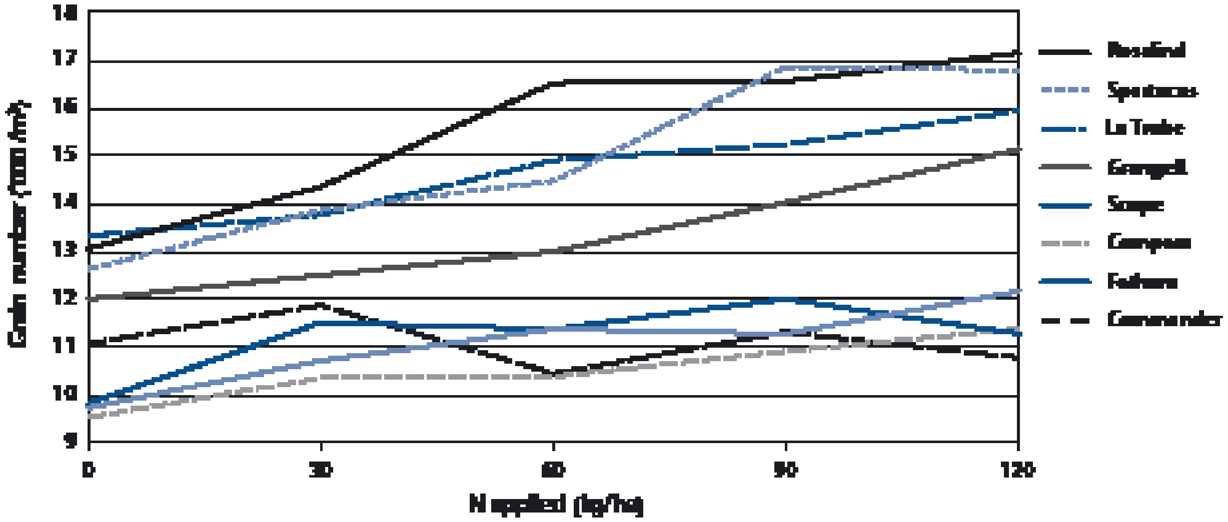


Figure 1. Grain number per square metre response of varieties to increasing rates of applied N in an experiment at Condobolin in 2016; l.s.d. ($P = 0.05$) N rate: 730 grains/m^2; variety: 100 grains/m^2.

There was a significant increase in tillers per square metre with increasing N rates, although increased tillers did not have a strong correlation with yield. Nitrogen treatments did not have a significant effect on grain weight per tiller. The total number of grains per square metre and grain yield had a linear correlation ($R^2 = 0.82$, Figure 2).

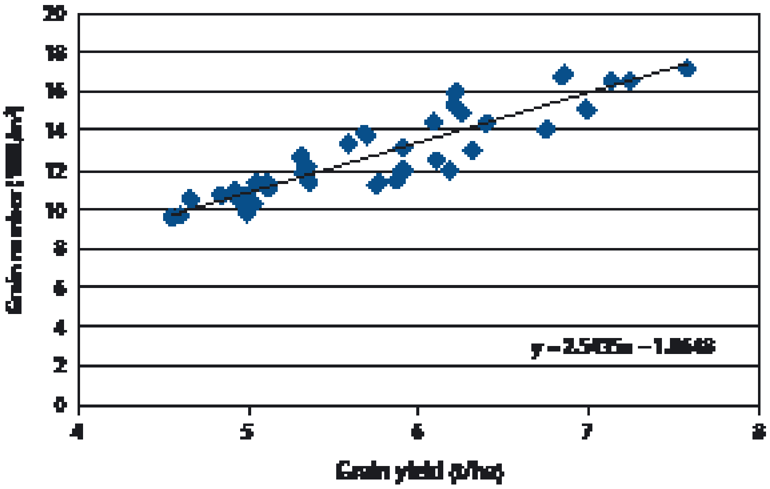


Figure 2. Grain number per square metre vs grain yield in an experiment at Condobolin in 2016; $R^2 = 0.82$.

Grain quality

There were significant differences between varieties for grain protein, screenings (% <2.2 mm), retention (% >2.5 mm), grain weight and hectolitre weight, but no significant interaction between N rate and variety. There were significant differences between N treatments for all quality traits except for hectolitre weight.

Screenings and retention of all treatments were above receival malt. Neither Spartacus CL$^{\phi}$ nor Fathom$^{\phi}$ (not a malt variety) reached the maximum acceptable protein concentration of 12% with the 120 kg N/ha treatments (Table 2). The wet and mild spring weather caused lower grain protein concentrations due to high grain yield.

Table 2. Protein (%) and grain weight (g/1000) of eight barley varieties treated with five rates of applied N.

Variety	N applied (kg/ha)									
	0		30		60		90		120	
	Protein (%)	Grain weight (g/1000)	Protein (%)	Grain weight (g/1000)	Protein (%)	Grain weight (g/1000)	Protein (%)	Grain weight (g/1000)	Protein (%)	Grain weight (g/1000)
Commander	8.9	46.2	9.5	44.6	10.5	44.6	10.4	44.3	11.1	44.8
Compass	9.4	47.9	9.8	48.5	10.0	47.7	10.8	45.3	11.2	45.0
Fathom	9.4	50.8	10.5	51.0	10.9	50.6	11.9	51.6	12.2	51.0
GrangeR	8.9	49.1	9.3	48.7	10.0	48.5	10.4	48.2	11.3	46.2
La Trobe	9.5	41.8	9.9	41.3	10.4	41.9	10.6	40.8	11.9	39.1
Rosalind	9.4	45.2	9.3	44.6	10.7	43.1	10.3	43.7	11.4	44.2
Scope CL	9.6	47.3	10.2	46.7	10.6	47.1	12.0	45.2	12.0	44.0
Spartacus CL	10.0	42.0	9.8	40.1	10.6	41.9	11.0	40.6	12.1	40.1
l.s.d. ($P = 0.05$) Protein: N applied = 0.3 t/ha; variety = 0.4 t/ha										
l.s.d. ($P = 0.05$) Grain weight: N applied = 0.74 mg; variety = 2.08 mg										

Lodging

Whilst increasing yield, higher N application rates significantly increased plant height and lodging with a strong linear correlation between N treatments with height and lodging ($R^2 = 0.96$ and 0.99 respectively). Plant height at maturity and biomass at anthesis had a linear correlation with lodging ($R^2 = 0.40$ and 0.41 respectively). Compass$^{\phi}$ and Commander$^{\phi}$ had the highest lodging scores (Figure 3).

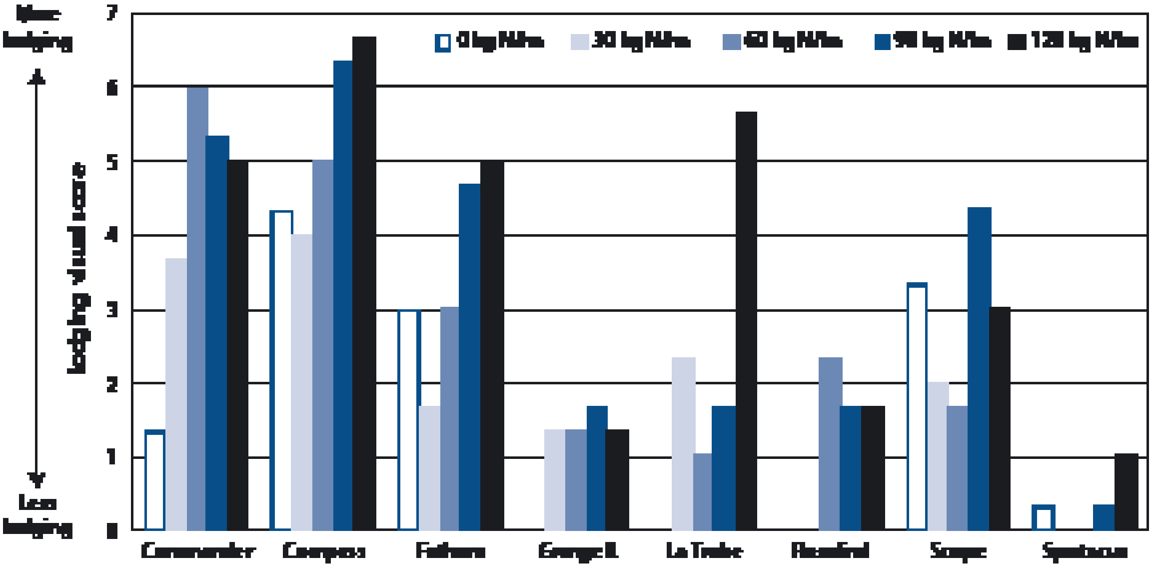


Figure 3. Visual lodging scores of eight barley varieties treated with five N rates. Lodging scores are between 0 (no lodging) and 9 (completely lodged). An absent bar indicates zero lodging observed; l.s.d. within variety ($P<0.05$) = 0.96.

Summary

Grain yield response to N applications depends on plant available moisture and lodging susceptibility. Nitrogen uptake during the plant's vegetative stage is stored in the photosynthetic tissue of the leaves and stem, increasing tillering and the photosynthetic area of the plant (van Herwaarden et al. 1998). Insufficient water availability during grain fill reduces the plant's capacity to translocate protein and carbohydrates from leaf to grain.

The 1000 grain weight decreased as applied N increased. There was no significant difference in grain weight per tiller but a significant increase in tiller number. In this experiment, increased tillers from higher rates of applied N was the main driver of higher yield. There was no interaction between varieties and N treatments as grain numbers per unit area increased (Figure 1). Sowing a high-yielding variety will produce optimum yields at all N applications.

Physiological factors such as biomass accumulation, tiller weight, straw strength, plant height and maturity all contribute to lodging susceptibility. Resistant varieties such as Rosalind$^{\phi}$ and Spartacus CL$^{\phi}$ are both semi-dwarf with low biomass accumulation. The lodging resistance of GrangeR might be an anomaly because it is late maturing and was harvested closer to its maturity date than the other varieties. Compass$^{\phi}$ and Commander$^{\phi}$ have good early season vigour, tall growth habits and early–medium maturity, which are all factors leading to an increased susceptibility to lodging.

References

Van Herwaarden, AF, Angus, JR, Richards, RA & Farquhar, GD (1998). 'Haying-off', the negative grain yield response of dryland wheat to nitrogen fertiliser II. Carbohydrate and protein dynamics. *Australian Journal of Agricultural Research* 49 (7) pp. 1083–1094.

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, Nick Hill, Ian Menz and Kate Gibson.

Effect of sowing date on yield and quality of twenty barley varieties – Condobolin 2016

David Burch, Nick Moody and Ian Menz (NSW DPI, Condobolin)

Key findings

- Slower maturing varieties had the highest yields in 2016, uncharacteristic of long-term yield trends in central west NSW, where weather conditions typically favour shorter-season varieties.
- While anthesis date is an important contributor to yield, high rainfall and a long grain-filling period diluted this association and was confounded by lodging, secondary tillering and waterlogging events.
- Highest yields were attained from the second sowing date (mid May), whilst late sowing dates suffered yield penalties due to poor plant establishment from waterlogging.

Introduction

Selecting an appropriate sowing date depends on factors such as variety, environment and risk of damage from frost and water stress. Sowing too early, or sowing an early-flowering variety, exposes crops to frost damage, while a late-flowering variety might not have sufficient time to fill grain before heat and moisture stress initiates senescence (plant maturity and death).

The central west of NSW is characterised by short growing periods with a relatively high risk of temperature and moisture stress during the grain-filling period (typically September and October). Regionally, growers prefer earlier sowing dates of late April to early May, with a preference for fast-maturing varieties that flower earlier. This experiment investigated the effect of sowing time on flowering date, grain yield and quality of 20 barley varieties at Condobolin Agricultural Research and Advisory Station.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Soil nitrogen	89 kg/ha (0–10 cm), 135 kg/ha (10–60 cm)
Experimental design	Split plot design, with sowing date blocked and varieties as sub-plots
Sowing	Sown using a six-row DBS plot seeder at 30 cm row spacings with 120 plants/m^2 the target plant density
Fertiliser	Fertiliser applications were applied as per regional farming practices. At sowing, 70 kg/ha mono-ammonium phosphate (MAP) was applied, providing an additional 7 kg/ha of available nitrogen (N). On 17 August, 30 kg N/ha was applied as urea on sowing dates two and three in response to heavy rainfall leaching N from the soil.
Weed control	Pre-emergent weed control: glyphosate (450 g/L) 2.0 L/ha In crop application: L.V.E. Agritone® 600 mL/ha, Ally® 5 g/ha
Growing season rainfall (1 April–30 September)	467 mm (long-term average is 192 mm)

Treatments

Sowing date (SD)

SD1: 26 April
SD2: 19 May
SD3: 1 June

Varieties

Bass$^{\Phi}$, Buloke$^{\Phi}$, Commander$^{\Phi}$, Compass$^{\Phi}$, Fathom$^{\Phi}$, Flinders$^{\Phi}$, Gairdner$^{\Phi}$, GrangeR, Hindmarsh$^{\Phi}$, La Trobe$^{\Phi}$, Litmus$^{\Phi}$, Navigator$^{\Phi}$, Oxford, Rosalind$^{\Phi}$, Schooner, Scope CL$^{\Phi}$, Spartacus CL$^{\Phi}$, Urambie$^{\Phi}$, Westminster$^{\Phi}$, Wimmera.

Results

Grain yield

The highest yielding variety was the long-season variety Urambie$^{\Phi}$ from SD1 (Table 1). The mid-season variety Fathom$^{\Phi}$ was the highest yielding from SD2 and SD3.

Record June and September rainfall caused a number of waterlogging events that affected plant establishment on SD3. Established plant numbers were reduced by an average of 45% compared with SD2 (data not presented).

There was a significant difference in yield between all three sowing dates, with mid May sowings the highest yielding overall.

Table 1. Grain yield rank, grain yield (t/ha) and flowering date of 20 barley varieties sown on three sowing dates (SD) at Condobolin, 2016.

Variety (maturity type)	SD1: 26 April			SD2: 19 May			SD3: 1 June		
	Yield rank	Yield (t/ha)	Flowering date	Yield rank	Yield (t/ha)	Flowering date	Yield rank	Yield (t/ha)	Flowering date
Bass (L)	9	4.64	2 Sep	15	5.03	21 Sep	3	4.38	30 Sep
Buloke (M)	20	2.46	24 Aug	12	5.42	15 Sep	10	4.02	25 Sep
Commander (M)	17	3.08	31 Aug	16	5.00	18 Sep	9	4.08	28 Sep
Compass (E)	15	3.31	20 Aug	6	5.73	7 Sep	4	4.29	24 Sep
Fathom (M)	7	4.96	25 Aug	1	6.98	7 Sep	1	4.99	22 Sep
Flinders (L)	2	5.87	3 Sep	10	5.49	19 Sep	7	4.20	7 Oct
Gairdner (M)	14	3.67	8 Sep	17	4.74	16 Sep	12	3.90	6 Oct
GrangeR (L)	6	5.09	27 Aug	9	5.49	19 Sep	17	3.46	7 Oct
Hindmarsh (E)	5	5.26	20 Aug	13	5.13	9 Sep	5	4.26	19 Sep
La Trobe (E)	10	4.52	21 Aug	8	5.51	9 Sep	11	3.95	21 Sep
Litmus (E)	19	2.78	17 Aug	19	4.59	11 Sep	18	3.37	24 Sep
Navigator (L)	4	5.29	12 Sep	3	6.05	25 Sep	6	4.25	8 Oct
Oxford (L)	8	4.90	3 Sep	18	4.72	25 Sep	19	3.33	14 Oct
Rosalind (E)	13	4.33	15 Aug	5	5.97	11 Sep	20	2.99	28 Sep
Schooner (M)	18	2.79	25 Aug	20	4.57	18 Sep	14	3.72	30 Sep
Scope CL (M)	16	3.15	25 Aug	7	5.51	14 Sep	13	3.86	25 Sep
Spartacus CL (E)	3	5.34	22 Aug	4	5.98	10 Sep	16	3.66	21 Sep
Urambie (L)	1	6.23	13 Sep	2	6.06	22 Sep	2	4.64	6 Oct
Westminster (L)	12	4.37	6 Sep	11	5.46	23 Sep	15	3.70	11 Oct
Wimmera (L)	11	4.47	5 Sep	14	5.03	19 Sep	8	4.15	6 Oct
Mean (SD)		4.33	28 Aug		5.42	15 Sep		3.96	30 Sep
l.s.d. ($P = 0.05$) Grain yield: sowing date 0.24 t/ha; variety 0.62 t/ha									

Effect of flowering date on yield

There was no correlation between flowering dates and yield (Figure 1). Due to record September rainfall, there was no moisture limitation during the spring grain-fill period, which often occurs in central western NSW. Varieties were grouped into phenology classes of early, mid-season and late flowering groups to determine if sowing date favoured any phenology type. There were no significant differences in yield based on phenology for SD2 or SD3. However, there was a significant yield advantage for late flowering varieties from SD1 with mid season varieties having the lowest yields.

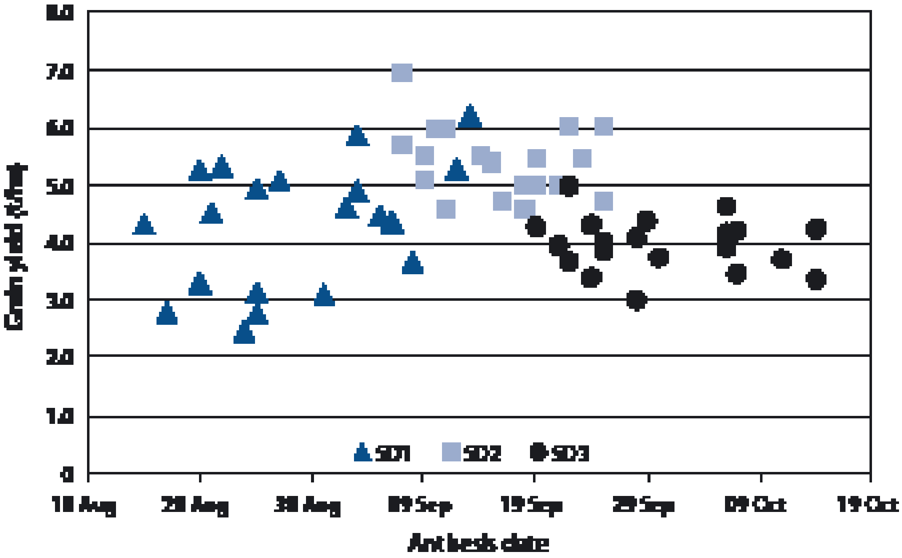


Figure 1. Anthesis date and grain yield for 20 barley varieties sown on three dates in Condobolin, 2016.

Grain quality

There were significant differences ($P<0.001$) between varieties for all quality traits (Table 2), although only protein concentration and 1000 grain weight were significantly different between varieties and sowing date. There was also a significant interaction between variety and sowing date.

Table 2. Grain quality traits for 20 barley varieties sown early (SD1), mid (SD2) and late season (SD3) in Condobolin, 2016.

Variety	Protein (%)			Screenings (%<2.2 mm)			Retention (%<2.5 mm)			1000 grain weight (g)		
	SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3
Bass	11.7	11.3	11.7	1.7	1.3	2.1	91.8	93.3	90.9	43.3	47.1	45.9
Buloke	11.7	11.1	10.7	7.3	9.8	6.7	67.6	68.4	73.4	40.1	42.7	46.0
Commander	11.6	9.6	10.2	7.8	4.1	2.6	72.6	85.5	90.5	39.0	42.2	45.7
Compass	11.4	9.5	9.7	3.2	1.4	4.5	85.3	93.2	92.8	42.3	46.9	47.7
Fathom	12.1	10.4	11.3	1.7	2.4	2.4	91.2	89.9	90.2	48.7	49.9	52.3
Flinders	11.3	11.1	11.1	3.0	3.2	2.6	86.1	85.3	86.1	38.7	39.7	41.0
Gairdner	11.9	11.0	11.2	8.3	8.4	6.7	72.5	69.5	73.1	41.9	42.3	44.9
GrangeR	11.9	9.9	10.7	1.7	2.3	2.4	91.4	86.1	86.8	44.7	44.4	45.5
Hindmarsh	12.3	10.3	11.4	5.9	7.6	5.7	80.0	73.4	81.5	36.8	37.7	42.8
La Trobe	11.7	9.8	10.7	4.5	5.6	5.2	80.7	77.7	82.1	37.5	39.2	41.5
Litmus	12.3	10.5	10.5	6.8	6.7	5.1	69.2	76.8	81.7	37.7	40.8	42.8
Navigator	10.3	9.8	10.1	7.2	1.4	1.8	76.4	93.0	90.6	36.0	42.5	42.9
Oxford	10.2	9.2	10.0	4.3	7.2	10.5	81.1	69.0	59.6	37.2	35.1	34.6
Rosalind	11.8	10.3	10.2	4.2	5.9	4.8	84.0	80.7	81.8	40.9	42.1	42.5
Schooner	12.5	11.4	12.1	3.2	4.0	1.9	82.3	83.4	89.7	40.0	42.1	45.2
Scope CL	11.5	10.8	10.9	5.6	8.5	5.9	72.2	71.2	73.6	40.1	43.7	46.3
Spartacus CL	11.7	10.4	10.8	3.7	4.8	5.1	84.7	79.5	82.4	37.1	39.3	40.8
Urambie	10.4	10.8	11.7	8.5	8.6	9.0	56.1	54.3	53.3	39.5	41.6	42.8
Westminster	10.1	10.0	11.4	3.3	1.9	3.6	82.8	88.6	82.9	39.7	44.4	43.6
Wimmera	12.2	10.7	11.0	4.6	3.6	3.8	81.1	83.5	82.0	38.0	39.9	42.6
Mean	11.5	10.4	10.9	4.8	4.9	4.6	79.5	80.1	81.3	40.0	42.2	43.9
l.s.d. ($P<0.05$) SD	0.21			ns			ns			0.57		
l.s.d. ($P<0.05$) Variety	0.55			1.4			3.85			1.48		

The Barley Australia standards dictate that malt quality barley must contain between 9% and 12% protein, retention (2.5 mm) above 70% and screenings (2.2 mm) below 7%. Some malt varieties did not achieve adequate screenings and retention rates despite overall favourable seasonal conditions. A number of late, secondary tillers were observed and could have affected grain quality and size.

Lodging was widespread in 2016, especially from SD1, with Rosalind⁽ᵈ⁾ and Spartacus CL⁽ᵈ⁾ demonstrating the best standing ability.

Late sowing in central western NSW would traditionally risk yield penalties due to moisture stress during grain fill. Due to exceptionally high rainfall in 2016, a major contributor to yield loss in SD3 was poor plant establishment at sowing (Figure 2), and subsequent reduced tillers per unit area. There was no significant difference in tiller numbers between SD1 and SD2. While there was no noticeable change in plant establishment or tiller counts for early and mid season sowings, both plant establishment, and subsequent tillers at maturity were significantly affected for the late season sowings (Figure 2).

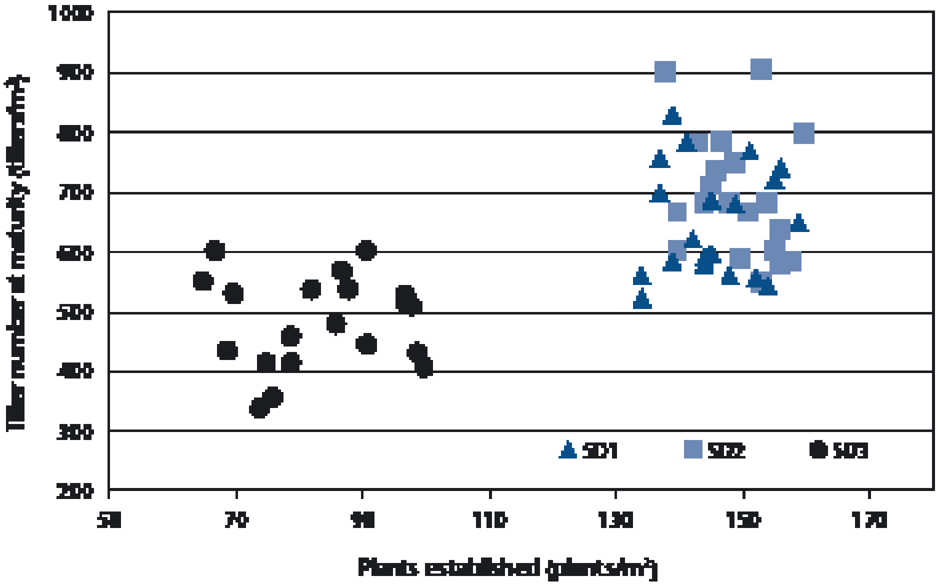


Figure 2. Plant establishment and tiller numbers at maturity for three sowing dates.

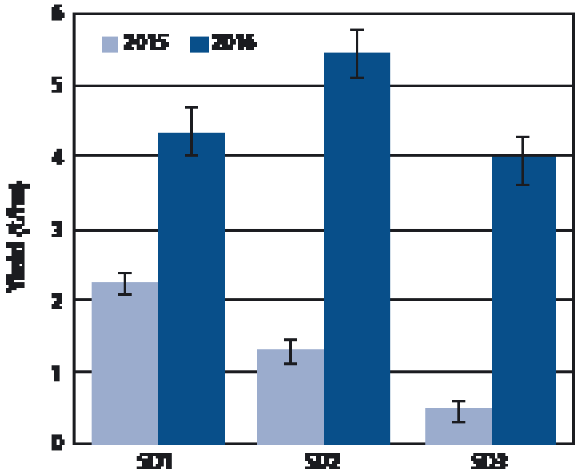


Figure 3. Yield of barley varieties sown on three dates in Condobolin in 2015 and 2016.

Summary

Factors to consider when selecting a suitable barley variety and sowing time are environment and plant genetics. The early sowing treatment (SD1) in this experiment was frost damaged and lodged, while late sowing treatments (SD2 and SD3) had poor plant establishment, partly as a result of unusually high rainfall.

The highest yielding variety in SD1, Urambie⁽ᵈ⁾, flowered 16 days later than the average flowering date of varieties in SD1, indicating that early sowings favoured longer season varieties in this experiment.

The relationship between flowering date and grain yield is partly related to moisture stress at grain fill. High rainfall in the 2016 growing season extended the grain filling period, which is uncharacteristic of the region. When making variety selection decisions, growers should take into account the relative risk of both frost during flowering and moisture stress during grain fill.

When making sowing decisions it is recommended to refer to data from multiple years. Figure 3 has compared yield in 2015 with 2016. The experiment in 2015 had a short growing season and severe moisture stress during grain fill. This is a common occurrence in central western NSW. The 2016 experiment had a long growing season with mid season sowings and mid to long season varieties were higher yielding. A low rainfall year has been proven to favour short season varieties.

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, Nick Hill, Ian Menz, Kate Gibson and Tara Burns. Statistical analysis performed by Dr Neroli Graham.

Interaction between plant density and nitrogen application in eight barley varieties in central west NSW – 2016

David Burch and Nick Moody (NSW DPI, Condobolin)

Key findings

- Nitrogen applications increased yield, mainly through increased tillering.
- Increased plant density reduced yield.
- Spartacus CL$^{\text{⊕}}$ and Fathom$^{\text{⊕}}$ had the highest yield at optimum nitrogen and plant density.
- Compass$^{\text{⊕}}$ and Commander$^{\text{⊕}}$ were the least responsive to nitrogen applications.

Introduction

Two field experiments were conducted at Condobolin and Goonumbla in central western NSW in 2016, to investigate the interaction between plant density and nitrogen (N) application on eight barley varieties of commercial significance.

Site details

Table 1. 2016 plant density × N application experiment site details.

Site details		Condobolin Agricultural Research and Advisory Station	Goonumbla, North Parkes mine site
Soil type		Red–brown chromosol	Red–brown clay/loam
Soil pH_{Ca}	0–10 cm	6.5	4.8
	10–60 cm	7.5	6.5
Fertiliser at sowing		70 kg/ha MAP	70 kg/ha MAP
Sowing date		18 May	21 May
Harvest date		1 December	6 December
Rainfall (Apr–Sep)		466.8 mm	524.5 mm
Previous crop		Wheat	Canola

Treatments

Nitrogen application

Nitrogen applied as urea at sowing at 0, 30 and 90 kg N/ha

Seeding density

Plants were sown for a target density of 75, 150 and 300 plants/m^2

Varieties

Commander$^{\text{⊕}}$, Compass$^{\text{⊕}}$, Fathom$^{\text{⊕}}$, GrangeR, La Trobe$^{\text{⊕}}$, Rosalind$^{\text{⊕}}$, Scope CL$^{\text{⊕}}$, Spartacus CL$^{\text{⊕}}$

Results

Grain yield

The Condobolin site was higher yielding than the Goonumbla site. Protein concentrations and retention did not significantly differ across sites, while test weight, screenings, tillers per square metre, and tiller weight were all significantly different by site ($P<0.001$). Spartacus CL$^{\text{⊕}}$ was the highest yielding variety at Condobolin (5.87 t/ha). Fathom$^{\text{⊕}}$ (4.82 t/ha) was the highest yielding variety at Goonumbla. The highest yielding treatment combination in both experiments was 90 kg/ha of applied N and a plant density of 150 plants/m^2. Plant densities of 300 plants/m^2 were lower yielding than sowing rates of 150 plants/m^2 (Table 2).

Significant differences occurred between varieties, plant density and N application. There was no variety × treatment interaction at the Goonumbla site, but significant interactions between variety and both plant density and N application were observed at Condobolin. The highest yielding treatment was Spartacus CL$^{\text{⊕}}$ at 150 plants/m^2 and 90 kg/ha applied N at Condobolin, and Fathom$^{\text{⊕}}$ at 300 plants/m^2 and 90 kg/ha applied N at Goonumbla.

Table 2. Grain yield of eight barley varieties sown at two different sites in central west NSW 2016, separated by plant density and nitrogen treatments.

Variety	Site	Plant density (plants/m^2)			N applied (kg/ha)		
		75	150	300	0	30	90
Commander	Condobolin	5.55	5.41	4.70	4.86	5.43	5.36
	Goonumbla	4.19	4.24	4.19	3.96	4.19	4.46
Compass	Condobolin	5.23	5.10	4.47	4.57	5.13	5.11
	Goonumbla	4.15	4.16	3.84	3.68	4.19	4.28
Fathom	Condobolin	5.90	5.91	4.81	4.97	5.84	5.81
	Goonumbla	4.73	4.88	4.85	4.24	4.85	5.37
GrangeR	Condobolin	5.76	5.95	5.85	5.31	5.80	6.45
	Goonumbla	4.75	4.67	4.71	4.02	5.03	5.10
La Trobe	Condobolin	5.97	6.18	5.57	5.61	6.16	5.95
	Goonumbla	4.09	4.27	4.11	3.70	4.10	4.67
Scope CL	Condobolin	5.17	4.82	4.37	4.53	4.84	4.99
	Goonumbla	3.95	4.17	3.87	3.29	4.14	4.56
Spartacus CL	Condobolin	5.76	6.03	5.84	5.01	5.56	7.05
	Goonumbla	4.49	4.60	4.49	3.98	4.42	5.18
Westminster	Condobolin	5.63	5.77	5.57	5.34	5.57	6.07
	Goonumbla	4.33	4.52	4.44	3.93	4.43	4.93
l.s.d. ($P<0.05$) Condobolin: variety 0.35 t/ha; plant density 0.12 t/ha; N applied 0.21 t/ha							
l.s.d. ($P<0.05$) Goonumbla: variety 0.30 t/ha; plant density 0.08 t/ha; N applied 0.19 t/ha							

Tables 3 and 4 illustrate that Spartacus CL$^{\phi}$ and Fathom$^{\phi}$ were the most responsive varieties to N application, while demonstrating no significant yield penalty as plant density increased. Compass$^{\phi}$ and Commander$^{\phi}$ demonstrated the least N response, while Compass$^{\phi}$ and Scope CL$^{\phi}$ had the greatest yield penalty as plant density increased. Compass$^{\phi}$ and Commander$^{\phi}$ were the only varieties that significantly decreased weight per tiller as N applications increased while they had no significant increase in tillers/m^2. There were significant differences in grain protein with variety and N application (Figure 1).

Table 3. The effect of increasing N applications on yield, quality and yield components. Varieties ranked in order of most to least responsive, with arrows indicating a significant increase or decrease in trait due to increasing N. 'NS' indicates no significant difference between 0 and 90 kg N/ha.

Variety	Increasing N applied (from 0 to 90 kg/ha)															
	Yield		Protein		Screenings		Retention		Test weight		Tillers/m^2		Weight per tiller		Grain weight	
Commander	↑	7	↑	1	↑	2	↓	3	NS	6	NS	8	NS	7	NS	2
Compass	↑	8	↑	6	↑	6	↓	6	↑	1	NS	5	↑	1	NS	4
Fathom	↑	2	↑	3	↑	1	↓	5	NS	4	↑	3	NS	2	NS	7
GrangeR	↑	3	↑	2	NS	8	NS	8	↑	3	NS	7	NS	8	NS	8
La Trobe	↑	5	↑	5	↑	5	↓	4	NS	5	↑	2	NS	6	NS	6
Scope CL	↑	4	↑	4	↑	4	↓	1	NS	7	NS	4	NS	3	NS	3
Spartacus CL	↑	1	↑	7	↑	3	↓	2	↑	2	↑	1	NS	4	NS	1
Westminster	↑	6	↑	8	NS	7	NS	7	NS	8	NS	6	NS	5	NS	5
P value (0.05)	<0.001		<0.001		<0.001		<0.001		<0.001		0.028		0.003		0.300	

Table 4. The effect of increasing plant density on yield, quality and yield components. Varieties ranked in order of most to least responsive, with arrows indicating a significant increase or decrease in trait due to increasing plant density. 'NS' indicates no significant difference between 75 plants/m^2 and 300 plants/m^2.

Variety	Increasing plant density (from 75 to 300 plants/m^2)															
	Yield		Protein		Screenings		Retention		Test weight		Tiller number		Weight per tiller		Grain weight	
Commander	↓	4	NS	5	↑	4	↓	4	↓	5	↑	1	↓	1	↓	5
Compass	↓	1	NS	3	↑	1	↓	2	↓	2	↑	8	↓	8	↓	2
Fathom	↓	3	NS	4	NS	7	NS	7	↓	4	↑	4	↓	4	↓	7
GrangeR	NS	6	NS	2	↑	3	↓	5	↓	7	↑	5	↓	2	↓	4
La Trobe	↓	5	NS	6	NS	6	↓	6	↓	6	↑	7	↓	5	↓	6
Scope CL	↓	2	NS	7	NS	5	↓	3	↓	1	↑	2	↓	3	↓	3
Spartacus CL	NS	8	NS	8	NS	8	NS	8	↓	8	↑	3	↓	7	↓	8
Westminster	NS	7	NS	1	↑	2	↓	1	↓	3	↑	6	↓	6	↓	1
P value (0.05)	0.005		0.208		0.006		<0.001		<0.001		<0.001		<0.001		<0.001	

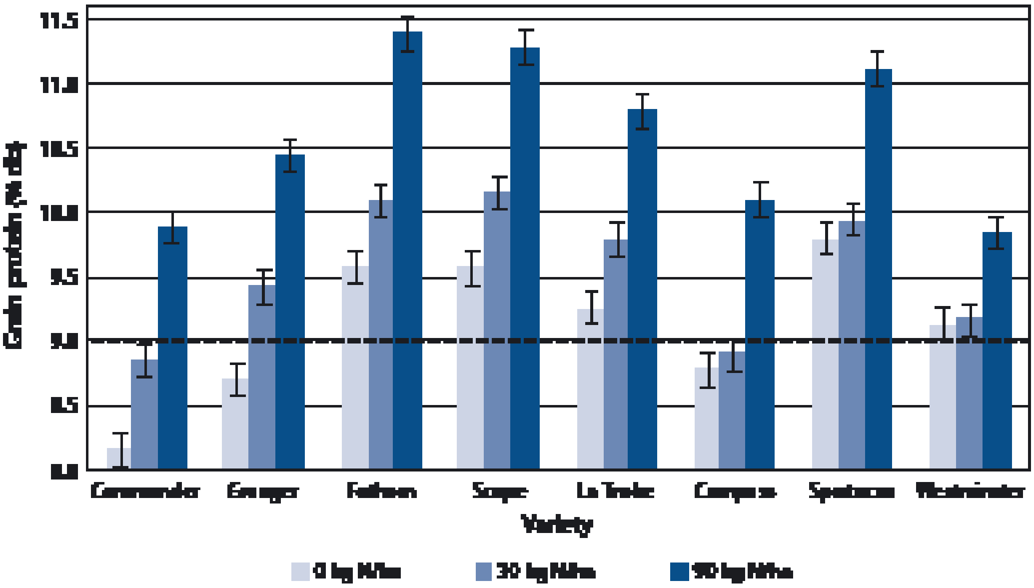


Figure 1. Grain protein concentration of eight barley varieties at three rates of applied N at two sites in central west NSW, 2016. Horizontal line indicates minimum protein concentration for malt standard. Error bars indicate significant (*P*<0.05) differences between N applications within varieties.

Grain quality

Grain protein concentration is an important quality trait for achieving malt grade. Industry receival standards require a dry matter protein concentration of 9–12%. Abundant rainfall at both sites in 2016 allowed for optimum N uptake, with an unseasonally high grain yield diluting available N and reducing protein concentrations. Commander$^{\text{(}}$ and Compass$^{\text{(}}$ did not achieve 9% protein concentration at 0 kg/ha or 30 kg/ha N applications, while GrangeR did not achieve minimum concentrations at 0 kg/ha. The varieties with the lowest protein concentration in all treatment combinations were Commander$^{\text{(}}$ and Compass$^{\text{(}}$, indicating that there is a genetic component to these varieties' capacity to suppress grain protein, rather than yield dilution. There was a significant interaction (*P* = 0.004) between variety and N application for grain protein.

Yield components

Tiller numbers for La Trobe$^{\text{(}}$ and Spartacus CL$^{\text{(}}$ were significantly higher at 30 kg/ha and 90 kg/ha of applied N compared with 0 kg/ha (Figure 2). Applying N at 90 kg/ha increased tiller numbers in Fathom$^{\text{(}}$ and Spartacus CL$^{\text{(}}$ compared with 0 kg/ha and 30 kg/ha applied N. La Trobe$^{\text{(}}$ responded to lower N applications with increased tillers, with a limited response as N applications increased. While no significant change was observed, this experiment indicated that applying higher N rates could have a negative effect on tillering in the Commander$^{\text{(b}}$ and Westminster$^{\text{(b}}$ varieties.

Increased N rates in this experiment did not significantly alter individual grain weight, although the number of grains per spike did significantly increase. Increased plant density significantly reduced grain weights and the number of grains per spike, offsetting yield gains from increased tillers per square metre. Total grains per square metre significantly increased with higher N, although not with plant density (Figure 3). High rainfall provided optimum conditions for tiller development in lower density sowings.

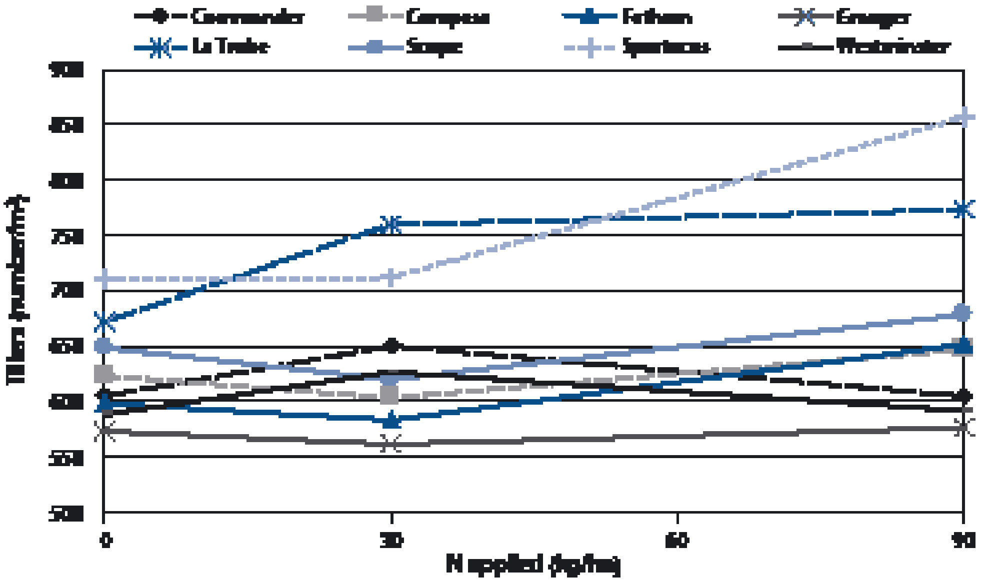


Figure 2. Mean tiller number (tillers per m^2) of eight barley varieties sown at three N rates and two sites in central west NSW.

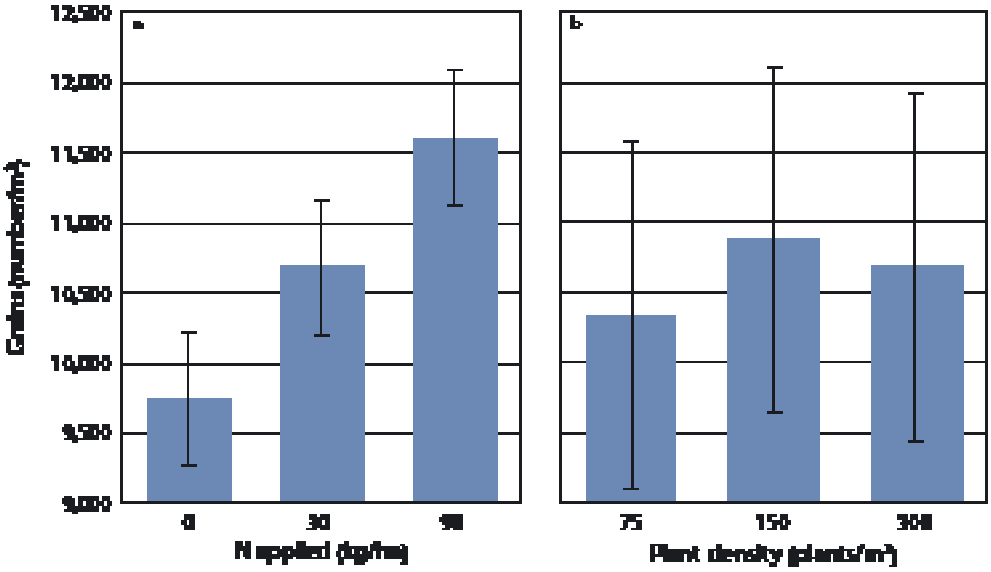


Figure 3. Change in total grains per square metre with increasing: (a) N applications; and (b) seed density. Error bars indicate significant ($P<0.05$) differences between treatments.
$P = 0.05$ (N application) <0.001; (plant density) 0.116.

Summary

The greatest driver in this experiment was N application, with plant density having mixed effects on different varieties, and higher densities negatively affecting yield and grain size. The growing season of 2016 was one of higher than average rainfall, allowing for optimum conditions during the grain-filling period following anthesis. As a result, every variety improved yield at higher N rates, as conditions allowed for optimum N conversion to grain assimilates, while remaining within malt specifications of less than 12% grain protein. In moisture-restricted environments where lower yields would be expected, high N applications would run a strong risk of exceeding 12% protein, making them unsuitable for malt. High N, in the absence of high moisture availability, is also known to decrease grain size, decreasing potential yield and increasing the risk of high screenings.

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 Condobolin technical support of Daryl Reardon, Nick Hill, Ian Menz, Kate Gibson, Tara Burns. Thanks to North Parkes Mines for providing the Goonumbla experiment site, and the NVT crop evaluation unit, Dubbo for sowing and harvest at Goonumbla.

Tailoring barley plant density to specific varieties in order to maximise yield and quality

David Burch and Nick Moody (NSW DPI, Condobolin)

Key findings

- In the unusually wet growing season of 2016, increasing the barley plant density did not increase the yield of all varieties.
- High tiller numbers reduced overall grain size.
- In ideal growing conditions, some varieties with lower plant densities of <125 plants/m^2 out-yielded higher density treatments.

Introduction

This experiment investigated the effect of plant density on grain yield and quality of 16 different barley varieties.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Soil nitrogen	30 kg/ha (0–10 cm), 39 kg/ha (10–60 cm)
Experimental design	Randomised complete block design, varieties and seed rates randomised within three replicates
Sowing date	24 May 2016
Sowing	Sown using a six-row DBS plot seeder at 30 cm row spacings; 70 kg/ha mono-ammonium phosphate (MAP) was applied at sowing, providing an additional 7 kg/ha of available N.
Weed control	Pre-emergent weed control: WipeOut 450® 2 L/ha In crop application: Axial® 100EC 300 mL/ha + Adigor® 500 mL/100 L water
Pest control	Targeting aphids: Primor WG® 150 g/ha
Growing season rainfall (1 April–30 September)	467 mm (long-term average is 192 mm)

Treatments

Varieties

Bass$^{\phi}$, Buloke$^{\phi}$, Commander$^{\phi}$, Compass$^{\phi}$, Fathom$^{\phi}$, Flinders$^{\phi}$, GrangeR, Hindmarsh$^{\phi}$, La Trobe$^{\phi}$, Oxford, Rosalind$^{\phi}$, Schooner, Scope CL$^{\phi}$, Spartacus CL$^{\phi}$, Urambie$^{\phi}$, Westminster$^{\phi}$

Seeding rate

Target established plant density of 75, 100, 125, 150 and 175 plants/m^2

Results

Both variety and plant density significantly affected yield (Table 1). The highest yielding treatments included GrangeR at 175 plants/m^2 and Westminster$^{\phi}$ at 125 plants/m^2. Both are characterised as long-season varieties, and high yields are likely due to the extended grain-filling period afforded by above-average rainfall in 2016, which is uncharacteristic of the Central West of NSW. A number of other varieties achieved similar yields, including the faster maturing La Trobe$^{\phi}$ at 100 plants/m^2 and Hindmarsh$^{\phi}$ at 125 plants/m^2.

There was also a significant ($P<0.001$) difference in tillering between varieties and plant densities, although higher plant densities did not always produce increased tiller numbers (tables 1 and 2).

Table 1. Grain yield of 16 barley varieties (t/ha) sown at five target plant densities at Condobolin, 2016.

Variety	**Target plant density (plants/m^2)**				
	75	**100**	**125**	**150**	**175**
Bass	5.61	5.27	5.73	5.06	6.10
Buloke	5.61	6.40	4.68	4.94	5.51
Commander	5.22	5.61	5.58	4.93	6.29
Compass	5.33	5.40	5.26	5.02	4.98
Fathom	5.81	5.98	6.47	5.91	5.67
Flinders	5.99	5.28	5.13	5.23	5.79
GrangeR	5.68	5.17	6.18	5.73	6.88
Hindmarsh	5.71	5.44	6.67	6.65	5.78
La Trobe	5.73	6.80	6.00	5.70	5.28
Oxford	5.82	5.78	5.73	6.36	6.52
Rosalind	6.06	6.08	6.01	6.19	5.77
Schooner	4.88	5.17	5.05	4.35	4.76
Scope CL	5.25	5.65	5.33	5.07	5.56
Spartacus CL	5.71	5.43	6.04	5.36	5.41
Urambie	5.99	4.95	5.82	5.34	6.07
Westminster	5.60	5.75	5.89	5.69	5.71
l.s.d ($P<0.05$)	variety 0.24 t/ha; density 0.13 t/ha				

Table 2. Number of tillers per square metre of 16 barley varieties (t/ha) sown at five target plant densities at Condobolin, 2016.

Variety	**Target plant density (plants/m^2)**				
	75	**100**	**125**	**150**	**175**
Bass	513	494	571	534	564
Buloke	548	649	614	688	690
Commander	482	516	627	708	712
Compass	567	556	507	650	698
Fathom	474	525	538	651	626
Flinders	595	586	663	641	681
GrangeR	459	460	482	532	604
Hindmarsh	588	577	560	753	684
La Trobe	670	655	689	715	663
Oxford	570	610	635	742	761
Rosalind	557	584	675	618	668
Schooner	559	533	502	482	540
Scope CL	557	663	682	695	692
Spartacus CL	671	707	641	744	750
Urambie	552	548	533	565	697
Westminster	483	542	485	571	591
l.s.d ($P<0.05$)	variety 66.7 tillers/m^2; density 37.3 tillers/m^2				

Yield component analysis

In the wet growing season of 2016, there was no relationship between yield and tiller number ($R^2 = 0.033$). Other yield components analysed were grain weight, grains per tiller and total number of grains per square metre, displayed in Table 3.

The yield component with the most consistent contribution to yield was number of grains per square metre (Figure 1). Grain weight demonstrated a small, but significant, decrease in size as tiller number increased (Figure 2), although the effect of increased plant density was highly dependent on variety, with varying responses in yield components by variety.

Increased seed rates did not affect protein, moisture, retention or screenings in 2016. There was a significant variety × plant density interaction for grain yield, although no other yield components showed an interaction.

Table 3. Performance of barley yield and quality traits at five plant densities. ANOVA F probabilities for plant density (PD), variety (V) and interaction.

	Target plant population (plants/m^2)					ANOVA F probability[a]		
	75	100	125	150	175	PD	V	PD × V
Yield component								
Grain yield (t/ha)	5.6	5.6	5.7	5.4	5.8	**	**	**
Tillers/m^2	553.4	575.3	587.8	643.0	663.8	**	**	NS
Grains/tiller	21.3	20.6	20.7	18.6	18.7	**	**	NS
Grain weight/tiller (g)	1.04	0.99	0.99	0.87	0.88	**	**	NS
No. grains/m^2	11627	11483	11854	11709	12 231	NS	**	NS
No. tillers per plant	7.3	5.7	4.7	4.3	3.7	**	**	NS
Grain harvested per plant (g)	7.5	5.5	4.6	3.6	3.3	**	**	NS
Total weight/m^2	1195	1188	1207	1251	1216	NS	**	NS
Quality								
Protein (% db)	9.8	9.6	9.7	9.6	9.6	NS	**	NS
Moisture	9.1	9.1	9.1	9.1	9.1	NS	NS	NS
Retention (%>2.5 mm)	94.98	94.71	94.54	94.73	93.85	NS	**	NS
Screenings (%<2.2 mm)	0.79	0.93	0.85	0.84	0.91	NS	**	NS
Grain weight (mg)	48.8	48.5	48.4	47.1	47.3	**	**	NS
Hectolitre weight (kg/hL)	70.50	70.20	70.22	70.15	70.18	*	**	NS

[a] NS = not significant; * and ** = indicate significance at the 0.05 and 0.01 levels of probability respectively.

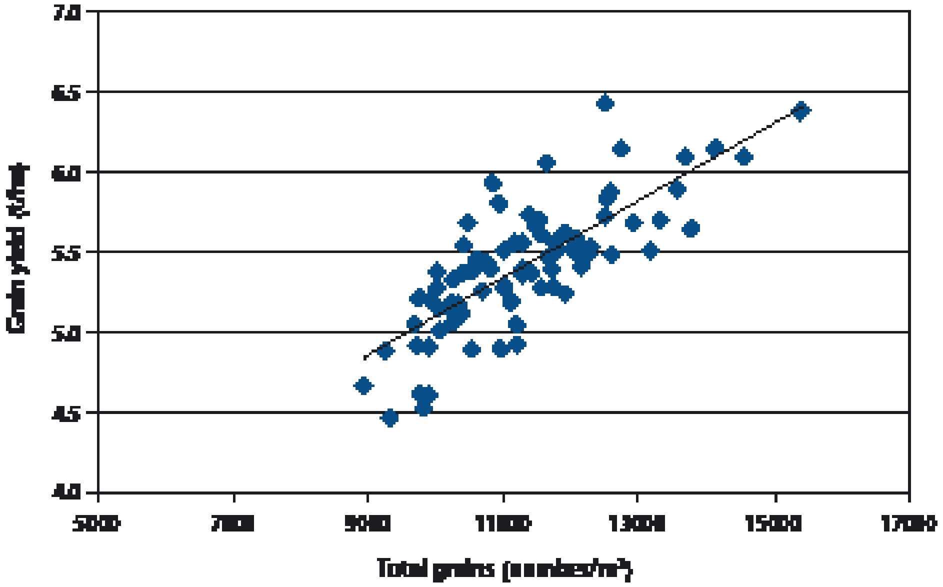


Figure 1. Total number of grains/m^2 compared with final grain yield (R^2 = 0.66).

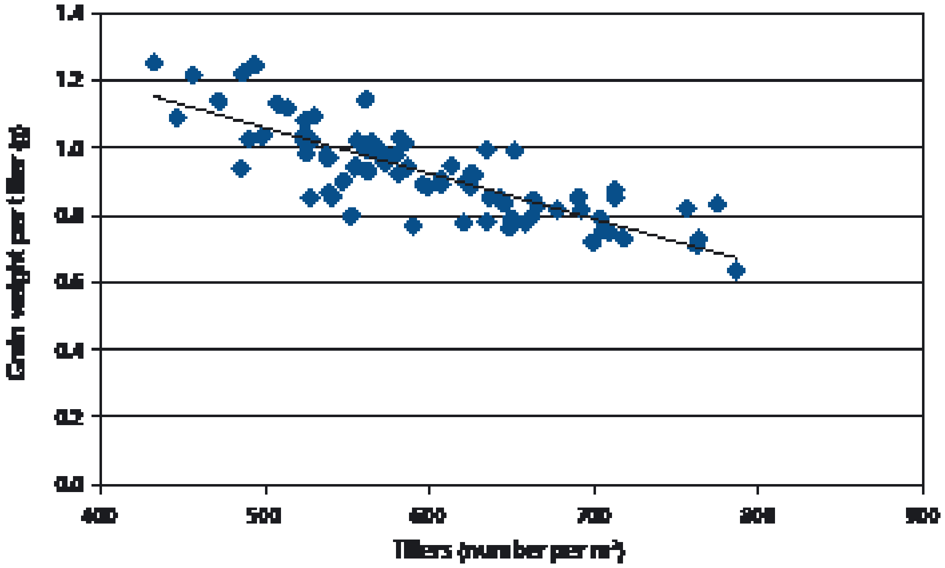


Figure 2. Effect of increased tiller numbers on grain weight per tiller (R^2 = 0.61).

While an increase in plant density did increase tiller numbers, the penalty on grain size and number of grains per head restricts any potential yield gains. As tillers per unit area increased, the number of tillers per plant decreased. Grains per tiller and individual grain weight also decreased as tiller numbers increased. These three variables contributed to grain yield in a manner specific to each variety, resulting in non-linear yield variation as plant density increased.

Summary

Significant differences were observed between varieties and seeding rates, however, there was not a strong relationship between seeding rates, yields and tillers. In 2016, the high rainfall and ideal spring produced an environment that stimulated optimum growth, which is not typical of the average Condobolin growing season.

A lack of differentiation between seeding rates indicated that barley has the capacity to maximise tillering when spacing, nutrients and moisture are sufficient, as was the case at Condobolin 2016.

While there was an interaction between plant density and environment for grain yield, there was no similar interaction for other yield components or quality traits (Table 2), such as protein, screenings and retention – again possibly a direct result of the 2016 growing season.

Grain yield corresponded with number of grains per unit area, rather than individual grain size, which did decrease as seed rates increased. As tillers per unit area increased, grain weight per tiller was decreased. It should be noted that 2016 was a year of uncharacteristically high rainfall with little moisture stress during grain fill. Long-season varieties, normally suited to high rainfall zones, yielded competitively with shorter season varieties more commonly grown around the Condobolin region. An environment with increased heat and moisture stress, particularly toward the end of the year, would have produced different relationships between seed rates and yield.

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, Nick Hill, Ian Menz and Kate Gibson. Postharvest analysis conducted by Alkira Gray, Brenton Gray and Leisl O'Halloran.

Effect of delayed harvest on yield and grain quality of sixteen barley varieties in central west NSW – 2016

David Burch (NSW DPI, Condobolin); **Denise Pleming** (NSW DPI, Wagga Wagga); **Nick Moody** (NSW DPI, Condobolin)

Key findings

- Grain yield and quality was significantly reduced in all varieties when harvest was delayed. Oxford and La Trobe⊕ suffered least yield penalty, while Bass⊕, and Fathom⊕ had the greatest yield losses.
- Yield losses and quality downgrades ranged from $75–300/ha in lost revenue in 2016, despite overall low prices and distinction between malt and F1 grades.

Introduction

When harvesting cereals, growers will often prioritise wheat over barley due to higher prices. This often leads to barley being harvested outside its optimum time, exposing it to the risk of weather damage. This can result in head loss, shattering or lodging leading to yield reductions, and weather-related quality damage affecting price at receival.

This experiment quantified the effect of delayed harvest on the grain yield and quality of 16 barley varieties.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Soil nitrogen	30 kg/ha (0–10 cm), 39 kg/ha (10–60 cm)
Experimental design	Latin square design, varieties randomised within three replicates
Sowing date	19 May 2016
Sowing	Sown using a six-row DBS plot seeder at 30 cm row spacings for a target plant density of 120 plants/m^2 70 kg/ha mono-ammonium phosphate (MAP) was applied at sowing
Weed control	Pre-emergent weed control: WipeOut 450® 2 L/ha In crop application: Axial® 100EC 300 mL/ha + Adigor® 500 mL/100 L water
Pest control	Targeting aphids: Primor WG® 150 g/ha
Growing season rainfall (1 April–30 September)	467 mm (long-term average is 192 mm)

Treatments

Harvest dates

Table 1. Harvest dates, number of days and rainfall between harvest events.

Harvest date	Days after harvest 1	Rainfall (mm)
22 Nov	NA	NA
20 Dec	29	47.5

Varieties

Bass⊕, Buloke⊕ Commander⊕, Compass⊕, Fathom⊕, Flinders⊕, GrangeR, Hindmarsh⊕, La Trobe⊕, Oxford, Rosalind⊕, Schooner, Scope CL⊕, Spartacus CL⊕, Urambie⊕, Westminster⊕

Results

Grain yield

There was a significant difference between both varieties and harvest dates. Grain yields were highest in the first harvest and significantly reduced in all varieties when harvest was delayed, with a mean yield loss of 23% (Table 2). Oxford and Rosalind$^{\Phi}$ were the highest yielding varieties when harvest was delayed, with Fathom$^{\Phi}$ suffering the greatest yield losses. There was no correlation between phenology type and yield losses.

Table 2. Grain yield of 16 barley varieties harvested on two dates at Condobolin, 2016. Varieties presented in order of grain yield as recorded on first harvest (22 November). Figures in parentheses rank varieties in order of yield reduction between harvest dates; l.s.d. ($P = 0.05$) variety 0.43 t/ha, harvest date 0.47 t/ha, variety × harvest date 1.09 t/ha.

Variety	Grain yield 22 Nov (t/ha)	Grain yield 20 Dec (t/ha)	Yield reduction (t/ha)
Bass	5.91	3.78	2.13 (15)
Westminster	5.51	3.83	1.68 (13)
Commander	5.36	4.28	1.08 (5)
Rosalind	5.32	4.06	1.26 (11)
Fathom	5.28	3.38	1.90 (16)
Spartacus CL	5.25	3.65	1.60 (14)
Buloke	5.12	3.88	1.24 (12)
Oxford	5.10	4.60	0.50 (2)
Scope CL	4.91	3.76	1.16 (10)
Urambie	4.82	3.82	1.00 (6)
Compass	4.79	3.70	1.09 (8)
Flinders	4.75	3.97	0.78 (4)
Hindmarsh	4.72	3.73	0.99 (7)
GrangeR	4.69	4.09	0.61 (3)
La Trobe	4.64	4.36	0.28 (1)
Schooner	4.62	3.55	1.06 (9)

Grain quality

All varieties and harvest times differed significantly for all quality traits, with the exception of protein content by harvest time ($P = 0.055$). Interactions were also observed for hectolitre weight, screenings and retention. Malting barley must meet minimum hectolitre weights of 65 kg/hL and maximum moisture levels of 12.5%. Delaying harvest resulted in nine varieties failing hectolitre weight standards, and 11 varieties exceeding moisture standards, although it should be noted that not all varieties in this experiment are accredited malting varieties (Table 3).

A note on falling numbers

Rainfall on mature cereal crops before harvest can lead to damage in the form of pre-harvest sprouting. Enzyme α-amylase activation breaks down the starchy grain endosperm into sugars intended to fuel growth of the developing seedling, and reduces germination efficiency. Malting quality barley is required to germinate (>98%) consistently under controlled conditions in the malthouse in order to produce adequate quality malt. Falling numbers testing is a method of indirectly measuring the level of α-amylase associated with pre-harvest sprouting via measuring the viscosity of a ground grain sample. Following grinding, samples are mixed into a slurry in a glass tube and placed in a boiling water bath. A standard weight is suspended at the top of the tube, and the time taken for the weight to fall a pre-determined distance is recorded. High viscosity indicates minimal α-amylase activation, while low viscosity and subsequent low falling numbers indicates pre-harvest sprouting activity. Grain samples with falling numbers below 300 seconds are deemed unsuitable for malt and are downgraded to feed at receival.

When harvested at the optimum time, 22 November, all barley varieties, except Scope CL$^{\text{(b}}$, had falling numbers above 300 seconds – above the threshold for malt classification.

After an additional 28 days and 47.5 mm of rain, falling numbers for all varieties fell significantly, with an average reduction from 351.2 seconds to 70.2 seconds (Figure 1). All malting varieties would be downgraded to feed if sold. All varieties dropped to less than 100 seconds, indicating extensive sprouting.

While there was a significant difference between harvest dates and varieties when harvested on 22 November, there was no significant difference between varietal falling numbers from the late harvest, due to high rainfall damaging all varieties.

Table 3. Grain quality of 16 barley varieties harvested on two different dates at Condobolin, 2016.

Variety	Harvest date	Protein (%)	Moisture (%)	Retention (%>2.5 mm)	Screenings (%<2.2 mm)	Hectolitre weight (kg/hL)
Bass	22 Nov	10.7	9.5	98.0	0.4	72.4
	20 Dec	10.5	12.5	99.1	0.3	65.7
Buloke	22 Nov	9.4	9.1	90.5	1.1	70.2
	20 Dec	10.2	12.8	95.9	0.4	64.8
Commander	22 Nov	8.8	9.1	93.9	1.7	70.0
	20 Dec	9.6	12.6	97.4	0.8	64.5
Compass	22 Nov	8.9	8.9	96.8	0.7	69.4
	20 Dec	8.1	12.6	98.1	0.4	62.8
Fathom	22 Nov	9.5	9.0	96.7	0.5	69.5
	20 Dec	9.7	12.7	98.2	0.4	62.5
Flinders	22 Nov	9.4	9.2	96.7	0.6	71.3
	20 Dec	9.6	12.7	98.4	0.4	65.4
GrangeR	22 Nov	8.4	9.1	95.2	1.1	70.8
	20 Dec	8.9	12.8	97.7	0.4	64.1
Hindmarsh	22 Nov	10.1	9.1	89.1	2.0	71.3
	20 Dec	10.0	12.7	93.2	1.3	65.0
La Trobe	22 Nov	9.1	9.2	90.9	1.6	70.8
	20 Dec	10.1	12.8	94.8	1.1	65.3
Oxford	22 Nov	8.0	8.9	89.7	1.2	69.3
	20 Dec	8.8	12.5	93.7	0.9	62.9
Rosalind	22 Nov	8.6	9.1	92.8	1.2	69.9
	20 Dec	9.4	13.0	96.4	0.8	63.2
Schooner	22 Nov	9.7	9.1	97.1	0.4	71.6
	20 Dec	10.1	12.3	98.3	0.4	65.0
Scope CL	22 Nov	9.7	9.2	92.8	0.7	70.4
	20 Dec	9.9	12.7	96.4	0.5	65.5
Spartacus CL	22 Nov	9.8	9.0	90.5	1.6	71.5
	20 Dec	9.7	9.4	96.5	0.8	64.9
Urambie	22 Nov	9.2	9.1	79.2	3.0	70.8
	20 Dec	10.1	12.4	92.4	1.3	63.8
Westminster	22 Nov	9.7	9.5	96.7	0.5	71.8
	20 Dec	9.5	12.8	98.7	0.2	65.0
l.s.d. (variety)		0.72	1.15	0.95	1.84	0.71
l.s.d. (harvest)		0.20	0.33	1.04	0.24	0.25
l.s.d. (harvest × variety)		NA	NA	1.91	0.43	0.93

Summary

Due to relatively low prices and small malt premiums, barley harvests are often postponed in preference for higher value wheat. This can expose the crops to inclement weather, affecting yield and quality. In this experiment, significant yield losses occurred due to delayed harvest. Harvest date one occurred at physiological maturity (22 November), with all varieties achieving their greatest yields. Harvest date two was 20 December, following 31.4 mm of rain on 16 December. Despite four days of warm, dry conditions, grain moisture content remained above receival standards for malting barley, while hectolitre weights dropped below malting grade. All varieties displayed significant reductions in falling numbers, making them unsuitable for malt. Lost revenue ranged from $75–300/ha (Figure 2), based on yield losses and quality downgrades from malt to F1 (for malt classified varieties). Lost revenue is a factor of barley prices and malt premium, which was low in 2016 due to high global stocks of barley. In years of high demand, particularly for malt, these losses would increase proportionally.

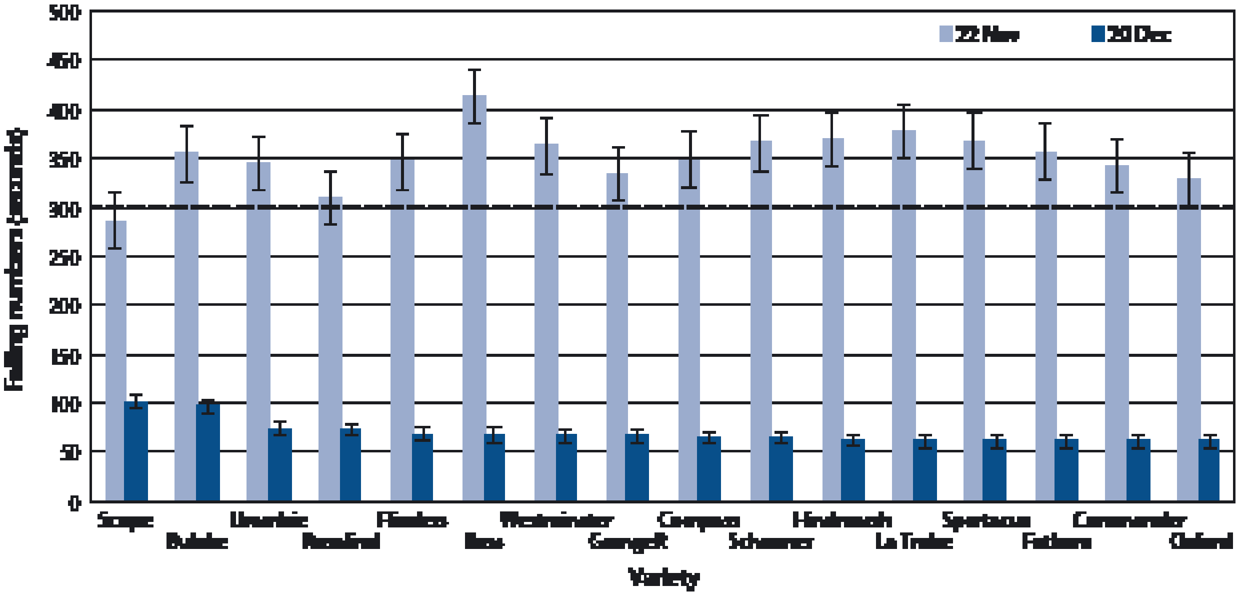


Figure 1. Falling numbers of 16 barley varieties harvested at an optimum time (22 November) and delayed by 28 days (20 December). Horizontal dashed line indicates threshold value of 300 seconds for malt standard; l.s.d. (*P* = 0.05) harvest 41.53 sec; variety 25.37 sec; harvest × variety 37.96 sec. Error bars indicate varietal l.s.d (*P* = 0.05).

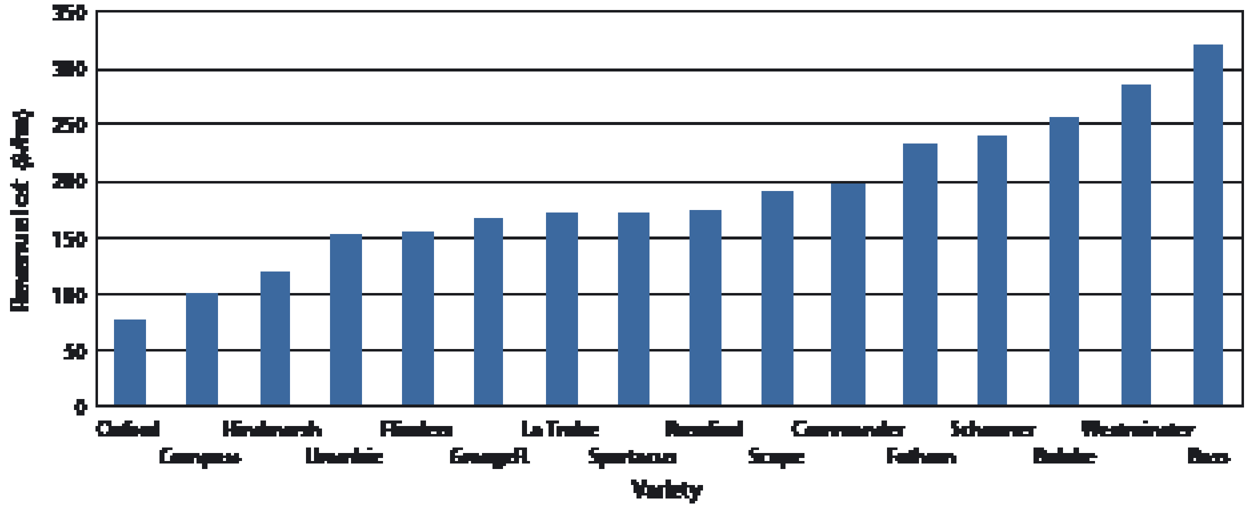
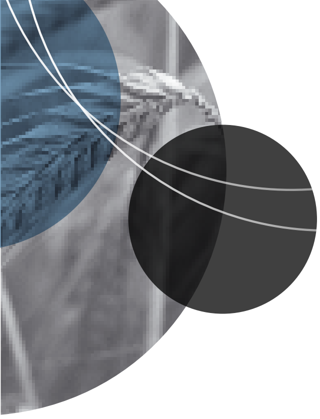


Figure 2. Revenue lost by variety following delayed harvest and weather damage. Revenue losses based on yield difference and downgrading of malt varieties to F1 following weather damage. Prices taken from Graincorp daily contract prices 24 March 2017 at the Condobolin site.

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, Nick Hill, Ian Menz, Kate Gibson and Natalie Taber.



Agronomy – canola

Effect of sowing date on phenology and grain yield of twelve canola varieties – Wagga Wagga 2016

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

Key findings

- Sowing canola early highlights the inherent differences in phenology.
- Slow-developing varieties maintained consistent yield across all sowing dates (late March to late April), whereas fast-developing varieties achieved their highest yield from late April sowing.
- Early flowering (from sowing fast-developing varieties early) reduced yield potential and exposed those treatments to greater disease pressure.

Introduction

Traditionally, canola sowing started around 25 April (Anzac Day) and finished in May. Recently there has been an increased interest in sowing canola early (late March to mid April). This experiment was designed to test the response of 12 canola varieties with varying phenologies and plant type to early sowing, compared with the more traditional sowing date in late April.

Site details

Location	Downside, approximately 25 km north-west of Wagga Wagga
Soil type	Gravelly red–brown chromosol
Previous crop	Faba beans
Fallow rainfall	243 mm (November 2015–March 2016)
In-crop rainfall	625 mm (April 2016–October 2016)
Soil pH$_{Ca}$	5.3 (0–10 cm, 29 April)
Soil nitrogen	133 kg/ha (0–120 cm, 29 April)
Nitrogen applied	Urea (46% nitrogen) 217 kg/ha, 28 March (broadcast and incorporated by plot seeder) Urea 217 kg/ha, 8 June (broadcast)
Soil phosphorus	31 mg/kg (Colwell)
Starter fertiliser	100 kg/ha mono-ammonium phosphate (11% nitrogen, 22.7% phosphorus, 2% sulfur), treated with 2.8 L/t flutriafol (500 g/L)

Treatments

Varieties

Archer, ATR Gem$^{\phi}$, ATR Stingray$^{\phi}$, Hyola® 559TT, Hyola® 575CL, Hyola® 725RT, Hyola® 600RR, IH30 RR, Nuseed Diamond, Nuseed GT-50, Pioneer® 44Y89 (CL), Pioneer® 45Y88 (CL)

Sowing date (SD)

SD1: 31 March
SD2: 13 April
SD3: 29 April

Results

Phenology

Archer was the slowest variety to start flowering from each sowing date (Figure 1). Nuseed Diamond was the fastest variety to start flowering from SD1 but ATR Stingray$^{\phi}$ was the fastest variety to start flowering from SD3. There was 19 days between the start of flowering for SD1 and SD3 for Archer, compared with 59 days for Nuseed Diamond. The ability of Archer to flower in a relatively tight flowering window, regardless of sowing date, means that it has a wide and flexible sowing window.

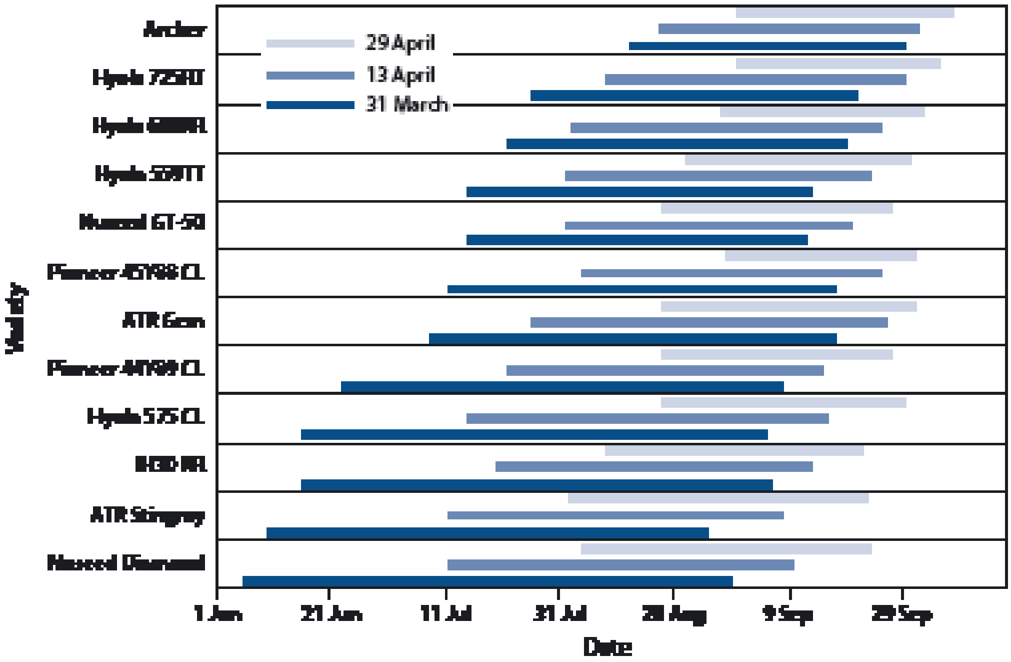


Figure 1. Flowering window of 12 canola varieties sown on three sowing dates at Wagga Wagga, 2016. The date at the left hand end of each line is the start of flowering (50% of plants with one open flower). The date at the right hand end of each line is the end of flowering (95% of plants with no flowers).

Grain yield

Slower developing varieties such as Archer, Nuseed GT-50 and Hyola® 600RR maintained consistent grain yield across sowing dates (Table 1). Nuseed GT-50 was the only variety to yield above 4 t/ha from each sowing date. The highest individual yield was Nuseed Diamond sown on 29 April at 4.8 t/ha.

Fast-developing varieties such as Nuseed Diamond, ATR Stingray$^{\phi}$, Pioneer® 44Y89 (CL) and Hyola® 575CL yielded less from early sowing. These varieties flowered too early to maximise biomass and seed number, and were exposed to more disease pressure (upper canopy blackleg and sclerotinia stem rot) from the early flowering.

Oil concentration

Oil concentration increased for all varieties as sowing was delayed from 31 March to 29 April. This result was not expected, as many experiments over a number of years have shown a decline in oil concentration with later sowing. The variety with the highest oil concentration, averaged across sowing dates, was Hyola® 600RR. The variety with the lowest average oil concentration was IH30 RR.

This experiment showed a strong interaction between variety and planting date. Fast-developing varieties flowered too early, which limited grain yield potential and exposed them to increased disease pressure. Slower-developing varieties flowered in a tighter window (across sowing dates) and maintained relatively consistent yield.

Table 1. Grain yield (t/ha) and oil concentration (at 6% moisture) of 12 canola varieties sown on three sowing dates at Wagga Wagga, 2016.

Variety	Grain yield (t/ha)			Oil concentration (%)		
	Sowing date			Sowing date		
	31 March	13 April	29 April	31 March	13 April	29 April
Nuseed Diamond	3.1	4.4	4.8	42.1	44.7	44.6
ATR Stingray	2.6	3.4	3.9	42.5	44.8	45.9
IH30 RR	3.4	3.1	3.9	41.4	42.9	44.4
Hyola 575CL	3.5	3.8	3.3	41.7	43.1	45.2
Pioneer 44Y89 CL	3.4	4.2	4.3	42.0	42.9	45.4
ATR Gem	3.5	3.8	3.3	44.1	45.3	47.0
Pioneer 45Y88 CL	3.7	3.8	4.1	41.8	43.4	44.8
Hyola 559TT	3.4	3.8	3.8	44.0	46.7	45.9
Nuseed GT-50	4.1	4.1	4.2	43.8	44.9	45.2
Hyola 600RR	3.9	4.1	4.4	43.8	46.0	47.1
Hyola 725RT	3.0	4.0	3.5	43.3	46.3	47.1
Archer	4.0	3.6	4.1	44.9	44.8	45.7
l.s.d. (*P*<0.05)	0.46			1.2		

Conclusion

Selecting a canola variety is difficult as the decision is often made long before a grower knows the likely planting date. This research shows that there are varieties, such as Archer, Hyola® 600RR and Nuseed GT-50, that are more flexible in their planting window. These varieties are able to regulate their development from early sowing so that they do not flower in early winter. Faster developing varieties such as Nuseed Diamond and ATR Stingray$^{\Phi}$ are inflexible in their planting window, therefore best suited to a later sowing time.

Acknowledgements

This experiment was part of the project 'Optimised Canola Profitability', CSP00187, 2014–19, with joint investment by NSW DPI, CSIRO and GRDC.

Thank you to the site cooperator Ben Beck and to technical support from Jess Simpson and Hayden Petty.

Determining critical growth periods of canola – Wagga Wagga 2016

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

Key findings

- All crops go through stages of development known as critical growth periods (CGP) where stress can reduce yield potential more than at any other time.
- Shading can be used to induce defined periods of stress on a crop to identify CGP.
- The critical growth period for canola was identified as approximately 100–400 degree days (°C.days) after the start of flowering (defined as 50% plants with one open flower).
- There was minimal effect of pre- and post-flowering stress on grain yield.

Introduction

Seed number and grain yield of crops are most sensitive to environmental stresses during specific growth stages or periods – termed critical growth periods (CGP). These periods have been identified for most winter crops in Australia, but not for canola. Artificial shading is used to reduce crop photosynthesis, and although the stress of shading might appear to be different to that caused by drought or heat, the physiological effect is the same – reduced photosynthesis and potential impacts on yield. The aim of this experiment was to determine the CGP of field-grown canola so that sowing date and variety can be selected to ensure that the CGP (the period when the crop is most sensitive to environmental stresses) occurs when the growing environment is likely to be the most favourable (a balance between adequate moisture, heat and frost stress, and adequate solar radiation).

Site details

Location	Downside, approximately 25 km north-west of Wagga Wagga
Soil type	Gravelly red–brown chromosol
Previous crop	Faba beans
Fallow rainfall	243 mm (November 2015–March 2016)
In-crop rainfall	625 mm (April 2016–October 2016)
Sowing date	2 May
Variety	Pioneer® 44Y89 (CL)
Soil $\mathrm{pH}_{\mathrm{Ca}}$	5.3 (0–10 cm, 29 April)
Soil nitrogen	133 kg/ha (0–120 cm, 29 April)
Nitrogen applied	Urea (46% nitrogen) 217 kg/ha, 28 March (broadcast then incorporated by plot seeder) Urea 217 kg/ha, 8 June (broadcast)
Soil phosphorus	31 mg/kg (Colwell)
Starter fertiliser	100 kg/ha mono-ammonium phosphate (11% nitrogen, 22.7% phosphorus, 2% sulfur), treated with 2.8 L/t flutriafol (500 g/L)

Treatments

Shading periods

Fifteen different shade periods (plus an untreated control) were applied to different canola plots for around 100 degree days (°C.days) (Table 1). The duration of 100 °C.days was equivalent to nine days for the first shade period (June), up to 13 days for the shade period in the colder, mid-winter period (July), and seven days for the final shade period in mid spring as temperatures increased (Table 1).

Table 1. Starting date and duration of 15 shade periods to determine critical growth periods for canola at Wagga Wagga, 2016.

Shading period	Start date	Duration (days)
Nil	N.A.	N.A.
1	7 June	9
2	16 June	12
3	28 June	13
4	11 July	11
5	22 July	13
6	4 August	12
7	16 August	10
8	26 August	10
9	5 September	9
10	14 September	8
11	22 September	9
12	1 October	6
13	7 October	7
14	14 October	7
15	21 October	7

The first shade period started when the crop was at the 4–6 leaf stage (Figure 1). The first six periods were all completed before the start of flowering. Flowering started on 17 August and finished on 26 September, with periods 7–11 falling within the flowering window. Periods 12–15 were all completed after flowering. The plots were hand-harvested on 8 November, 11 days after the final shading period was completed.

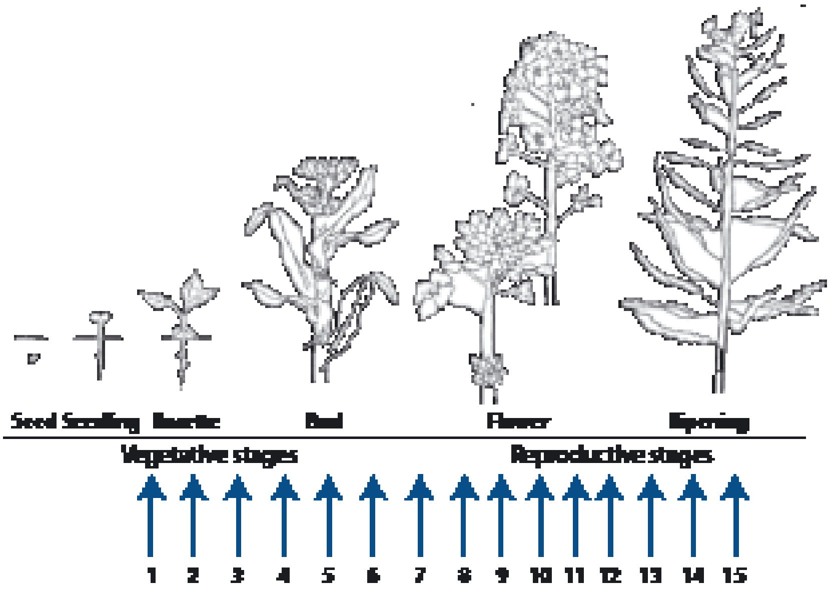


Figure 1. Timing of 15 shade periods (start of each period indicated by arrow) in relation to crop growth stage in an experiment to determine critical growth periods of canola at Wagga Wagga, 2016.

Shade shelters consisted of steel frames, two metres wide and three metres long. The frame was covered with green shade cloth that blocked 85% of incoming solar radiation. The height of the frame was raised throughout the growing season as the frames were moved onto increasingly taller plots, but was always kept approximately 50 cm above the crop canopy (Figure 2). The southern end remained open to ensure temperature and humidity within the covers did not deviate significantly from outside, at the same time minimising light entering the covered area.

Figure 2. Shade shelter on canola critical growth period experiment at Wagga Wagga on 23 June 2016. The lid was made to slide up the four corner poles throughout the year and remain approximately 50 cm above the crop canopy.

Results

Grain yield

Shade periods 8–10 showed a marked reduction in grain yield compared with the unshaded controls, and compared with other shade periods (Figure 3). Periods 8–10 all occurred within the flowering window with period 8 starting nine days after the start of flowering and period 10 finishing four days before the end of flowering. The largest effect of shading was at period 10 with a 37% lower yield than the unshaded control. There was either a small or no effect of shading on grain yield before flowering and after flowering finished.

As flowering will progress at different rates in different environments according to temperature, a thermal time approach should be used to define the CGP. In this experiment, together with a sister experiment conducted at Riverton in South Australia, the critical period for canola could be identified as the time from 100 °C.days to 400 °C.days after flowering started.

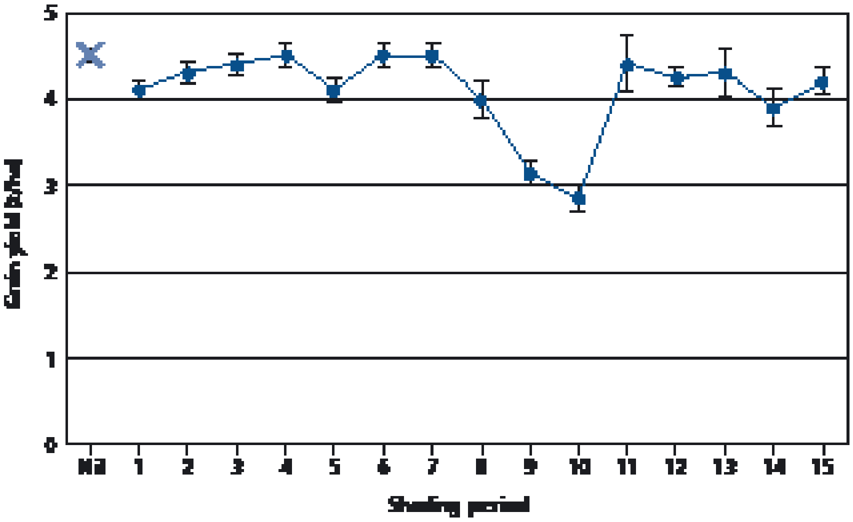


Figure 3. The effect of 15 separate periods of shading (●) on canola grain yield at Wagga Wagga, 2016. The unshaded control is marked as ✕.

Yield components

The unshaded control yielded approximately 133 000 seeds/m² with a seed size of 3.4 mg/seed. The lowest yielding shade period (period 10) had 48% less seeds/m² than the unshaded control.

An increase in seed size, from 3.4 mg to 4.0 mg (18%), provided some yield compensation during period 10, however, it did not compensate fully for the reduced seed number.

Summary

Growers and agronomists that make canola planting decisions in any environment need to ensure that the crop's critical period coincides with the optimum environmental conditions. In effect, the period when the crop is most sensitive to stress needs to be timed to when the growing environment has the least risk of stress (least risk of frost and heat, with optimum moisture and radiation availability). For canola, this critical period had not previously been clearly defined. This experiment clearly showed the critical period from 100 °C.days to 400 °C.days after the start of flowering.

The Optimised Canola Profitability project has characterised the phenology of many commercially available varieties, especially in their response to early sowing. This improved understanding of varietal phenology will enable growers and agronomists to select appropriate sowing dates to ensure that the critical period coincides with the optimum environmental conditions.

Acknowledgements

This experiment was part of the project 'Optimised Canola Profitability', CSP00187, 2014–19, with joint investment by NSW DPI, CSIRO and GRDC.

Thank you to the site cooperator Ben Beck and to technical support from Jess Simpson and Hayden Petty (NSW DPI) and Mel Bullock and Tim Hogarty (CSIRO).

Effect of flowering date on upper canopy infection by blackleg – Wagga Wagga 2016

Rohan Brill, Danielle Malcolm, Warren Bartlett and Sharni Hands (NSW DPI, Wagga Wagga);
Dr Susie Sprague, John Graham and Melanie Bullock (CSIRO, Canberra)

Key findings

- Blackleg infection of flowers, pods, branches and upper stems can be collectively termed as upper canopy infection (UCI).
- Early flowering of canola increases the risk of UCI.
- Fungicide can reduce disease levels and increase grain yield, but does not provide full disease control.
- Matching sowing date and varietal phenology so that flowering occurs in late winter will reduce UCI.

Introduction

Blackleg, caused by the fungus *Leptosphaeria maculans*, is found in all canola-growing regions of Australia. Yield loss has mostly been associated with crown cankers, which limit water and nutrient uptake. All above- and below-ground plant parts are susceptible to infection by the fungus, but infection on upper stems, branches, flowers and pods (termed upper canopy infection or UCI) has, until recently, been limited.

It is hypothesised that the increased level of UCI in recent seasons is due to crops flowering in an earlier window. Early flowering (early to mid-winter) exposes plants to greater levels of infection as spore release coincides with cool and moist conditions.

The aim of this experiment was to investigate the role of flowering time in upper canopy infection development, and determine any associated yield penalty.

Site details

Location	Downside, approximately 25 km north-west of Wagga Wagga
Soil type	Gravelly red–brown chromosol
Previous crop	Faba beans
Fallow rainfall	243 mm (November 2015–March 2016)
In-crop rainfall	625 mm (April 2016–October 2016)
Soil pH_{Ca}	5.3 (0–10 cm, 29 April)
Soil nitrogen	133 kg/ha (0–120 cm, 29 April)
Nitrogen applied	Urea (46% nitrogen) 217 kg/ha, 28 March (broadcast then incorporated by plot seeder) Urea 217 kg/ha, 8 June (broadcast)
Soil phosphorus	31 mg/kg (Colwell)
Starter fertiliser	70 kg/ha mono-ammonium phosphate (MAP) (11% nitrogen, 22.7% phosphorus, 2% sulfur)

Treatments

Variety

Pioneer® 44Y89 (CL): Blackleg rating moderately resistant (MR). Resistance group BC.

Fungicide

1. Nil.
2. Seed and fertiliser fungicide – Jockey® Stayer® (167 g/L fluquinconazole) applied to seed at 20 L/t and Intake® Combi Sapphire (500 g/L flutriafol) applied to MAP at 2.85 L/t.

3. Seed and fertiliser plus early foliar fungicide – as for treatment 2 plus application of Prosaro® (210 g/L prothioconazole and 210 g/L tebuconazole) at bud visible stage.
4. Seed and fertiliser and early foliar fungicide, plus flowering foliar fungicide – as for treatment 3 plus two applications of Prosaro® during flowering, targeted at 20% bloom and 50% bloom. This treatment is termed as 'full'.

Sowing date (SD)

SD1: 31 March
SD2: 13 April
SD3: 2 May

Methodology

The experiment was a full factorial (all combinations) of fungicide and sowing date. The sowing dates created different flowering dates to assess the effect of flowering date on disease infection levels. Fungicides were applied based on the crop growth stage.

Blackleg infection of pods, branches and upper main stems, as well as premature pod loss due to infection, was assessed at crop maturity by scoring 20 individual plants/plot. Each plant was given a separate score for each of the symptoms using a 0–4 scale, whereby:

0 = no disease symptom
0.5 = small amount of symptom present
1 = <10% pods or tissue area affected
2 = 10–29% pods or tissue area affected
3 = 30–49% pods or tissue area affected
4 = ≥50% pods or tissue area affected.

Table 1. Foliar fungicide application timing and start and end of flowering dates for treatments in each sowing date for Pioneer® 44Y89 (CL) canola at Wagga Wagga in 2016. Fungicide application at bud visible was applied to treatments 3 and 4. Fungicide application during flowering was only made to treatment 4.

Sowing date	Fungicide application date at bud visible	Start of flowering date	Fungicide application dates during flowering	End of flowering date
SD1: 31 March	26 May	22 June	27 June, 28 July	8 September
SD2: 13 April	16 June	17 July	28 July, 23 August	15 September
SD3: 2 May	28 July	18 August	23 August, 20 September	27 September

Results

Effect of fungicide pre-flowering

For SD1 and SD3, fungicide had no effect on grain yield or blackleg infection when applied before flowering, either to seed, with fertiliser or via foliar spray.

Fungicide treatment 2 increased grain yield for SD2 by 0.29 t/ha, but the reason for this was unclear.

The following section focuses on the comparison between treatments 1 and 4, effectively comparing 'nil' fungicide with a 'full' fungicide regime.

Effect of fungicide post-flowering

For SD1, flowering started on 22 June, and approximately monthly thereafter for each later sowing time (Table 1).

The amount of UCI (at maturity) was greatest from SD1 due to its very early flowering, and declined with later sowing dates (Table 2). Pod infection was the main symptom, with relatively low levels of main stem and branch infection. Applying fungicide during flowering for SD1 did not reduce blackleg incidence on pods (approximately 50% of pods), but did reduce premature pod loss. Approximately 25% of pods were prematurely lost in the SD1 treatment where no fungicide was applied, but this was reduced to less than 10% with two foliar fungicides applied at 20% and 50% bloom. The foliar fungicide applications to SD1 increased grain yield by 0.99 t/ha, but as pod infection was not fully controlled by two fungicide applications, the yield loss from blackleg was likely to be even greater.

Fungicide reduced pod infection incidence in the SD2 and SD3 treatments, however, premature pod loss was much lower for these two later sowing dates. The fungicides applied during flowering (20% and 50% bloom) resulted in a 0.29 t/ha grain yield benefit for SD2, but no benefit for SD3. There was also a benefit of 0.29 t/ha for SD2 from applying fungicide to seed and fertiliser (data not shown). Some grain yield benefit could possibly be attributed to controlling sclerotinia stem rot, however, incidence was low (<6%).

Table 2. Effect of sowing date and fungicide treatments on symptoms of upper canopy blackleg infection and grain yield of Pioneer® 44Y89 (CL) at Wagga Wagga in 2016.

Sowing date	Treatment	Pod infection (0–4 scale)	Premature pod loss (0–4 scale)	Main stem infection (0–4 scale)	Branch infection (0–4 scale)	Grain yield (t/ha)
31 March	Nil	3.87	1.78	1.38	1.40	2.88
	Full	3.48	0.74*	0.87*	0.63*	3.87*
13 April	Nil	2.78	0.15	0.27	0.16	2.99
	Full	1.58*	0.03*	0.08*	0.01*	3.57*^
2 May	Nil	2.00	0.13	0.26	0.36	2.91
	Full	1.22*	0.14	0.16	0.17*	3.01

^ There was a 0.29 t/ha yield advantage by the addition of fungicides to seed and fertiliser alone (data not shown).

* Indicates significantly different from Nil treatment for data within each sowing date.

Conclusion

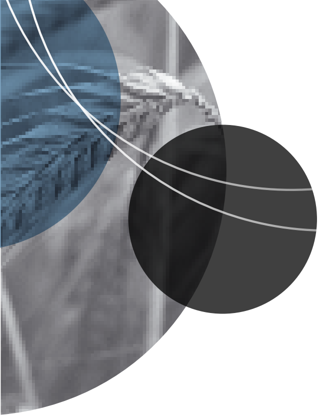
Crops flowering early in the winter period (June/July) are at greater risk of upper canopy infection of blackleg than crops flowering later (August). The greatest yield loss in this experiment was associated with high levels of premature pod loss due to blackleg infection, which occurred in the earliest flowering crop (SD1: 31 March). Premature loss of infected pods tends to occur close to harvest after flowering has finished, with the plant unable to compensate by producing more flowers or set more seeds per pod.

To ensure flowering occurs in the optimum window to avoid an unnecessary disease burden, sowing date and varietal phenology need to be matched. For example, selecting a slower variety such as Archer for a 31 March sowing would delay flowering until August while still enabling early sowing. Alternatively, consider the economics of fungicide application if earlier flowering provides a yield benefit.

Acknowledgements

This experiment was part of the projects 'Optimised Canola Profitability', CSP00187, 2014–19 and the 'National Canola Pathology Project', UM00051, 2013-18, with joint investment by NSW DPI, CSIRO and GRDC.

Thank you to the site cooperator Ben Beck and to technical support from NSW DPI staff Jess Simpson and Hayden Petty, and CSIRO staff Mick Neave and Timothy Hogarty.



Agronomy – pulses

Lentil sowing date – Rankins Springs 2016

Mark Richards (NSW DPI, Wagga Wagga), **Dr Neroli Graham** (NSW DPI, Tamworth), **Karl Moore, Russell Pumpa, Jon Evans and Scott Clark** (NSW DPI, Wagga Wagga)

Key findings

- Results from this experiment and previous research have proven that lentils can be successfully grown in southern NSW with sound agronomic planning and management.
- Across all varieties tested there was no significant difference between the 4 May and 20 May sowings, which validates the current sowing window recommendation from late April to mid May for the western region of southern NSW. Previous experiments have shown yield decline with a late May sowing.
- PBA Hurricane XT$^{\phi}$, PBA Jumbo2$^{\phi}$ and PBA Bolt$^{\phi}$ were the highest yielding commercial varieties, while PBA Ace$^{\phi}$ was significantly lower yielding in this experiment, which is not consistent with previous research.
- There was a significant reduction in seed weight when sowing was delayed for all varieties except PBA Ace$^{\phi}$, which showed no significant effect.

Aim

To compare growth, development and yield of current commercial lentil varieties and advanced breeding lines sown on two dates on a red, sandy loam soil at Rankins Springs in south-western NSW.

Site details

Location	'Hillview' Rankins Springs, RK & JG Eckermann, Paddock: Aloe
Soil type	Red, sandy loam, pH_{Ca} 5.4 (0–10 cm)
Experimental design	Randomised split plot design with sowing date in the main blocks and varieties in the sub-plots; three replications
Paddock history	Previous crop: wheat
Fertiliser	75 kg/ha grain legume starter (N 0: P 13.8: K 0: S 6.1) placed 50 mm below the seed 150 g/ha sodium molybdate, 16 June 2016
Plant population	Target: 120 plants/m^2
Sowing	Direct drilled using a six-row cone seeder on 300 mm row spacing using DBS tines and GPS auto-steer
Inoculation	Group F peat inoculant was mixed directly into an onboard water tank then pumped through micro tubes into each sowing furrow

Weed management	Commercial practices were used aiming for weed-free experiments, eliminating both weed competition and weed seed set Incorporated by sowing: Terbyne® (750 g/kg terbuthylazine) 850 g/ha, Triflur X® (480 g/L trifluralin) 1 L/ha, glyphosate (450 g/L) 2 L/ha, water 100 L/ha Post sowing: Select Xtra® (240 g/L clethodim) 500 mL/ha, Factor® (250 g/kg butoxydim) 180 g/ha, Supercharge® 100 mL/100 L, water 100 L/ha (5 August)
Insect management	Targeting Heliothis (*Helicoverpa* sp.), Lucerne flea (*Sminthurus virdis*) Fastac Duo® (100 g/L alpha-cypermethrin) 200 mL/ha, water 100 L/ha (6 September) Fastac Duo® (100 g/L alpha-cypermethrin) 200 mL/ha, water 100 L/ha (3 November)
Disease management	Targeting: Ascochyta blight (*Ascochyta lentis*), grey mould (*Botrytis fabae B. cinerea*) Penncozeb® 750DF (750 g/kg mancozeb) 2 kg/ha, water 100 L/ha (5 August) Howzat® (500 g/L carbendazim) 500 mL/ha, water 100 L/ha (6 September) Bravo® (720 g/L chlorothalonil) 1.5 L/ha, water 100 L/ha (26 September)
Harvest date	Desiccated 21 November – Reglone® (200 g/L diquat) 2.5 L/ha, water 100 L/ha Harvested 28 November

Soil analysis

Table 1. Site soil characteristics for 0–10 cm depth at Rankins Springs in 2016.

Characteristic	Depth (0–10 cm)
pH_{Ca}	5.4
Aluminium (KCL) (cmol+/kg)	1
Nitrate N (KCL) (mg/kg)	6
Ammonium N (KCL) (mg/kg)	1
Sulphur (mg/kg)	2.3
Phosphorus (Colwell) (mg/kg)	54
Organic carbon (OC) (%)	0.44

Season

The 2016 season at Rankins Springs was the wettest experienced in the past 36 years of records, with 517 mm of growing season rainfall (GSR), more than double the long-term average of 235 mm. While the experiment site had intermittent waterlogging across the growing season, drainage was sufficient to avoid crop damage. Pre-season rainfall (January to May) was variable, with an above-average January and a very dry February and March (Figure 1). Timely April rain contributed to favourable early sowing conditions. Rainfall during June, July and August was 63% above the long-term average, which filled the soil moisture profile leading into spring (Figure 1). This abundant winter moisture provided ideal conditions for growth and all early-sown pulses produced above average biomass for this environment. Despite the wet seasonal conditions, crop disease levels were generally low and the fungicide program contained the botrytis grey mould infection in susceptible lentil varieties.

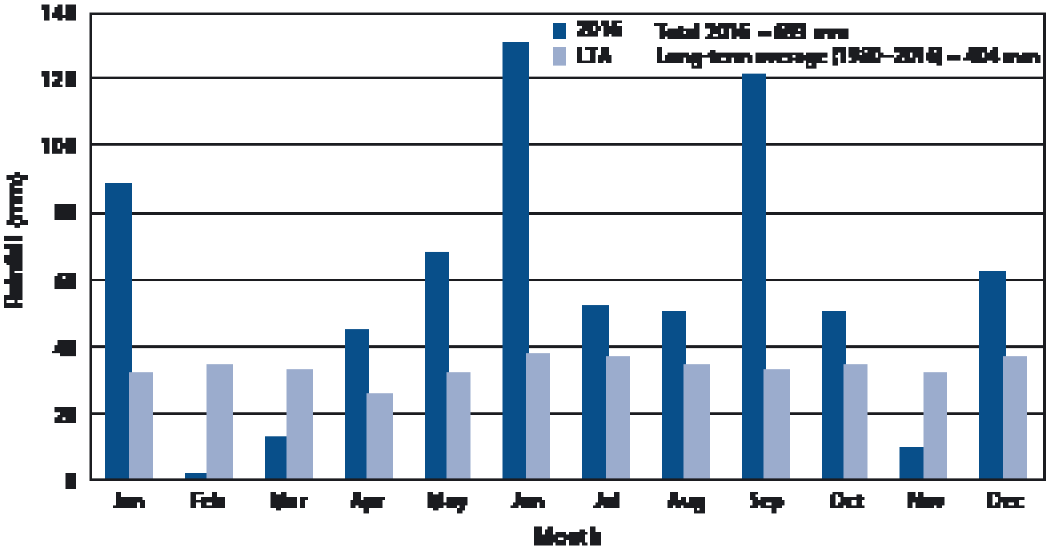


Figure 1. Monthly rainfall for 2016 and long-term average (LTA) rainfall for 'Hillview'.

Treatments

Varieties (8)

PBA Ace$^{\text{(b)}}$, PBA Bolt$^{\text{(b)}}$, PBA Hurricane XT$^{\text{(b)}}$, PBA Jumbo2$^{\text{(b)}}$, Nipper, CIPAL 1301, CIPAL 1422, CIPAL 1522

Sowing date (SD)

SD1: 4 May

SD2: 20 May

Results

Establishment

A lentil establishment of 120 plants/m^2 was targeted for each sowing date. Despite favourable environmental conditions at both sowing dates, the target population at the 4 May sowing date averaged 109.6 plants/m^2 across varieties and 123.8 plants/m^2 for the 20 May sowing date. PBA Jumbo2$^{\text{(b)}}$ achieved the lowest plant establishment of 95.9 plants/m^2 when averaged over the two sowing dates (Table 2) but this did not affect grain yield with the favourable seasonal conditions.

Table 2. Plant establishment of eight lentil varieties averaged over two sowing dates at Rankins Springs in 2016; l.s.d. ($P = 0.05$) = 16.7 plants/m^2.

Variety	Establishment (plants/m^2)
PBA Jumbo2	95.9
PBA Hurricane XT	110.5
Nipper	115.5
CIPAL 1522	119.6
PBA Ace	121.0
PBA Bolt	121.5
CIPAL 1301	124.2
CIPAL 1422	125.4

Flowering

Varietal differences in days-to-flowering were observed between the eight lentil varieties, while no interaction between genotype and sowing date were evident. The advanced breeding line CIPAL 1522 was the earliest to flower at 107.5 days when averaged over the two sowing dates, while Nipper was significantly later to flower at 118 days after sowing, when compared with all other varieties (Figure 2).

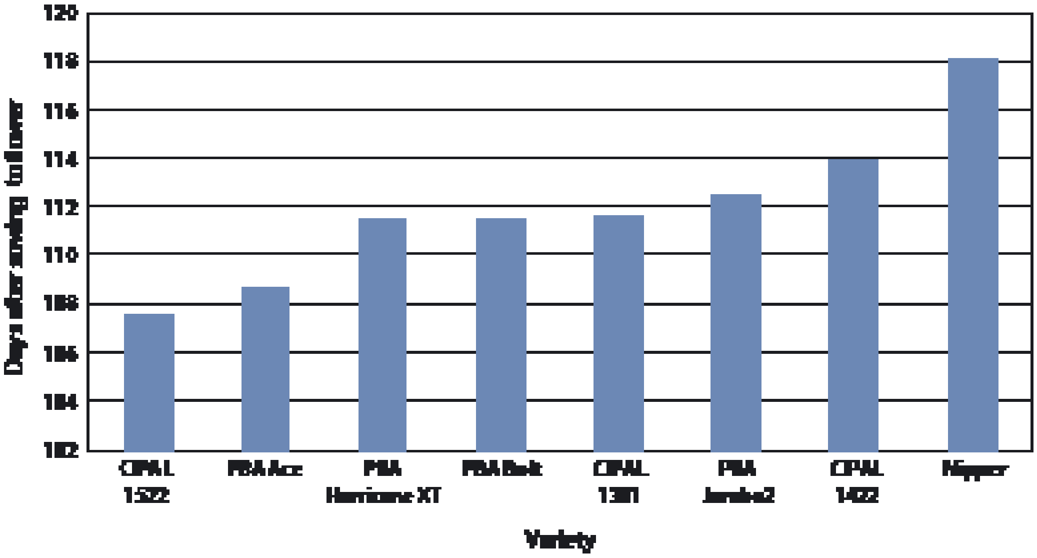


Figure 2. Days after sowing to flowering for eight lentil varieties averaged over the two sowing dates at Rankins Springs in 2016; l.s.d. (*P* = 0.05) = 3.2 days.

Grain yield

Growing season rainfall (April–October) of 517 mm in 2016 helped the site achieve a mean grain yield of 2.96 t/ha. Averaged across all varieties, there were no significant differences in yield between the two sowing dates of 4 May and 20 May, which might have been influenced by ample water throughout the growing season coupled with a mild spring to aid pod formation and seed fill.

PBA Hurricane XT$^{(\phi)}$, PBA Jumbo2$^{(\phi)}$ and PBA Bolt$^{(\phi)}$ were the three highest yielding commercial varieties when averaged across the two sowing dates (Figure 3). PBA Ace$^{(\phi)}$ was significantly lower than the highest yielding varieties in this experiment, which is not consistent with previous research conducted in this region.

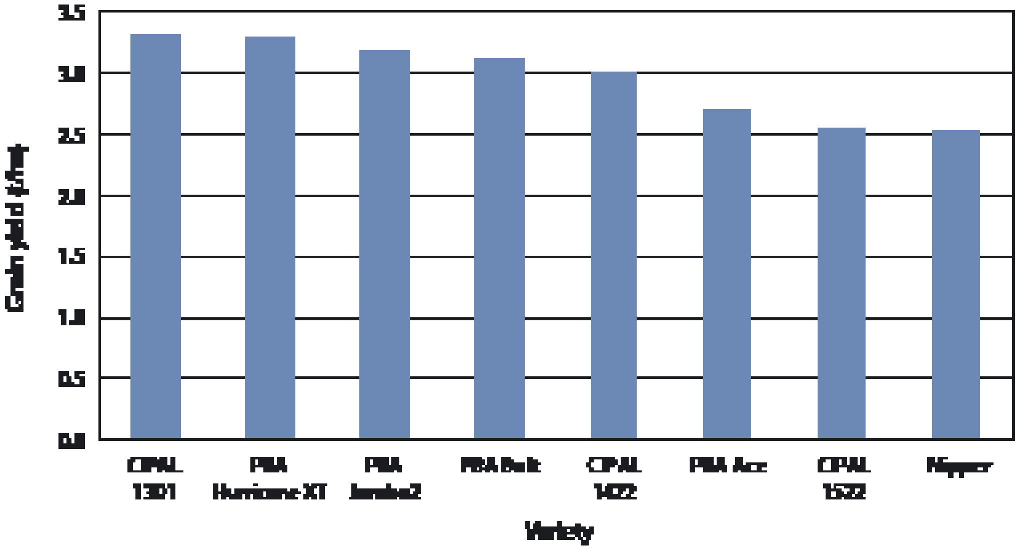


Figure 3. Grain yield of eight lentil varieties averaged over the two sowing dates at Rankins Springs in 2016; l.s.d. (*P* = 0.05) = 0.31 t/ha.

Seed size

Delaying the sowing date from 4 May until 20 May resulted in reduced seed weight from 3.9 g/100 seeds to 3.7 g/100 (data not shown). There was a significant reduction in seed weight when sowing was delayed for all varieties except PBA Ace$^{(\phi)}$, which showed no significant effect (Figure 4). This is an important factor to consider when growing lentil, as seed size is an important marketing trait.

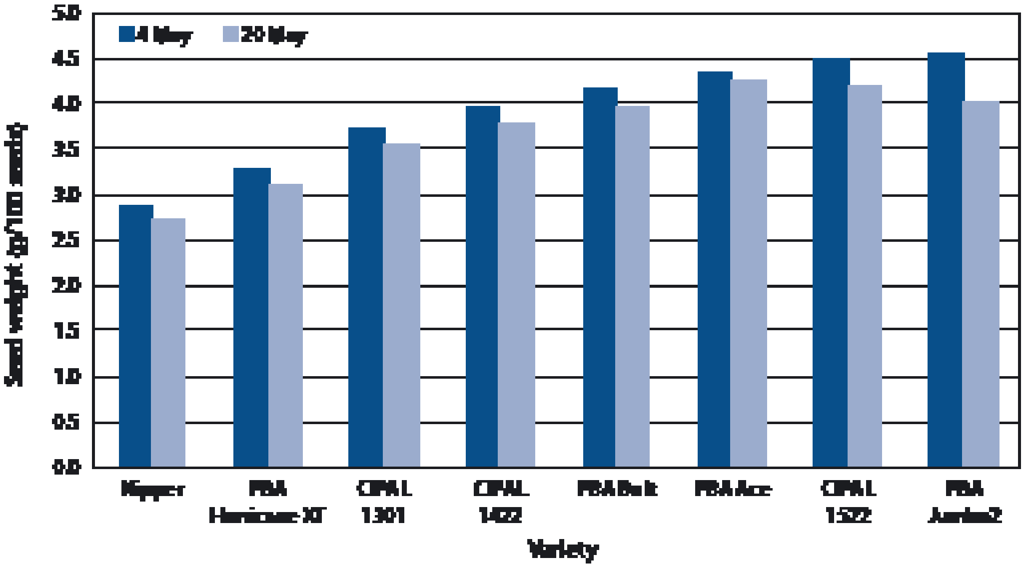


Figure 4. Seed weight of eight lentil varieties sown on two sowing dates at Rankins Springs in 2016; l.s.d. ($P = 0.05$) = 0.14 g/100 seeds.

Summary

Given the growing season rainfall of 517 mm at Rankins Springs in 2016 was 282 mm or 162% higher than the long-term average of 235 mm, the high grain yield from this experiment must be considered in context. Soil type and drainage over this experimental site was sufficient to minimise the impact of high rainfall and intermittent waterlogging. High growing season rainfall, in conjunction with favourable spring conditions and minimal disease pressure, resulted in equivalence between the 4 May and 20 May sowing dates for grain yields. The highest yielding lentil variety was CIPAL 1301, with statistically similar yields to the commercial varieties PBA Hurricane XT$^{(\phi)}$, PBA Jumbo2$^{(\phi)}$, PBA Bolt$^{(\phi)}$ and PBA Ace$^{(\phi)}$.

Appropriate sowing date is one of the most critical management factors for lentil production systems in southern NSW; it determines plant growth, disease pressures and grain yield. Research from 2013 until 2016 has indicated the optimum time to sow lentil in southern NSW is between late April and mid May in the south-western cropping region (later than lupin and faba bean, but earlier than field pea). In the eastern cropping region, early to late May (7–10 days later than the south-western region) is the optimum time.

Sowing outside these dates severely compromises growth and grain yield potential. Sowing lentil earlier than recommended encourages biomass accumulation, which can lead to increased disease pressures as well as increased lodging and reduced seed quality.

Reduction in seed weight occurred when sowing was delayed from 4 May (3.9 g/100seeds) to 20 May (3.7 g/100 seeds) irrespective of variety, which is important to meet premium market requirements. Varietal differences in seed weight were recorded with CIPAL 1522, PBA Ace$^{(\phi)}$ and PBA Jumbo2$^{(\phi)}$ all achieving over 4 g/100 seeds, while Nipper was 2.8 g/100 seeds.

Results from this experiment support previous research showing that lentil can be successfully grown in southern NSW with sound agronomic planning and management. Careful consideration must be given to variety selection, paddock selection (i.e. soil pH and drainage), sowing date, herbicide residues, weed control, harvest timing and market opportunities.

Acknowledgements

Thank you to Kim and Nick Eckermann for their ongoing support of pulse research and providing the experiment site.

Thank you to Karl Moore, Russell Pumpa, Scott Clark and Jon Evans for technical assistance and Dr Neroli Graham for biometric support.

Lentil sowing date – Wagga Wagga 2016

Mark Richards (NSW DPI, Wagga Wagga), **Dr Neroli Graham** (NSW DPI, Tamworth), **Karl Moore, Russell Pumpa, Jon Evans and Scott Clark** (NSW DPI, Wagga Wagga)

Key findings

- A favourable growing season in 2016 produced results that supported previous work showing the importance of sowing within the recommended sowing window.
- No significant yield difference was found when lentil was sown on 6 May and 17 May, when averaged across varieties.
- Delay in sowing from 6 May to 2 June resulted in a 34% yield reduction and from 17 May to 2 June a 26% yield reduction across varieties.
- PBA Hurricane XT$^{\phi}$, PBA Jumbo2$^{\phi}$ and PBA Ace$^{\phi}$ were the highest yielding commercial varieties, when averaged across sowing times.
- The results from this experiment indicate the importance of sowing within the recommended sowing window to maximise the height from ground level to bottom pod to maximise the ease of harvest.

Aim

To compare growth, development and yield of current commercial lentil varieties and advanced breeding lines sown on three dates on a red–brown earth at Wagga Wagga in southern NSW. This information will be used to confirm and update current agronomic recommendations for lentil in this region.

Site details

Location	Wagga Wagga Agricultural Institute, Paddock 15
Soil type	Red–brown earth, pH_{Ca} 5.7 (0–10 cm)
Experimental design	Randomised split plot block design with sowing date in the main blocks and varieties in the sub-plots; three replications
Paddock history	The previous crop was barley; the paddock was burnt before sowing to remove stubble load
Fertiliser	75 kg/ha grain legume starter (N 0: P 13.8: K 0: S 6.1) placed 50 mm below the seed 150 g/ha sodium molybdate, 16 June
Plant population	Target: 120 plants/m^2
Sowing	Direct drilled using a six-row cone seeder on 300 mm row spacing using DBS tines and GPS auto-steer
Inoculation	Group F peat inoculant was mixed directly into an onboard water tank then pumped through micro tubes into each sowing furrow
Weed management	Commercial practices were used aiming for weed-free experiments, eliminating both weed competition and weed seed set Fallow weed control: glyphosate (450 g/L) 2 L/ha, water 100 L/ha Incorporated by sowing: Terbyne® (750 g/kg terbuthylazine) 850 g/ha, Triflur X® (480 g/L trifluralin) 1 L/ha, Boxer Gold® (800 g/L prosulfocarb + 120 g/L S-metolachlor) 2.5 L/ha, water 100 L/ha Post sowing: Select Xtra®(240 g/L clethodim) 500 mL/ha, Factor® (250 g/kg butroxydim) 180 g/ha, Supercharge® 100 mL/100 L (16 June), water 100 L/ha Brodal Options® (500 g/L diflufenican) 150 mL/ha (10 August), water 100 L/ha

Insect management	Targeting Heliothis (*Helicoverpa* sp.), Fastac Duo® (100 g/L alpha-cypermethrin) 200 mL/ha, water 100 L/ha (24 October)
Disease management	Targeting: Ascochyta blight (*Ascochyta lentis*) and grey mould (*Botrytis fabae B. cinerea*) Penncozeb® 750DF (750 g/kg mancozeb) 2 kg/ha, water 100 L/ha (4 August) Howzat® (500 g/L carbendazim) 500 mL/ha, water 100 L/ha (26 August) Howzat® (500 g/L carbendazim) 500 mL/ha, water 100 L/ha (20 September)
Harvest date	7 December

Soil analysis

Table 1. Site soil characteristics for 0–10 cm and 10–30 cm depth at Wagga Wagga in 2016.

Characteristic	Depth (0–10 cm)	Depth (10–30 cm)
pH_{Ca}	5.7	5.2
Aluminium (KCL) (cmol+/kg)	<0.10	<0.10
Nitrate N (KCL) (mg/kg)	54	20
Ammonium N (KCL) (mg/kg)	1	2
Sulphur (mg/kg)	9	9.8
Phosphorus (Colwell) (mg/kg)	60	22
Organic carbon (OC) (%)	0.79	0.47

Season

The 2016 growing season at Wagga Wagga was an exceptional growing season, with abundant rainfall combined with mild temperatures. Growing season rainfall recorded was 525 mm (April–October) 60% higher than the long-term average of 328 mm. Marginal moisture was recorded at the first sowing date as only 11 mm of rain fell during April (Figure 1). This is in contrast to the rainfall that fell during May and June, where double the long-term average with 102 mm and 100 mm, respectively was recorded (Figure 1). June through to October received well above the long-term average rainfall leading to a full soil moisture profile for sustained spring growth.

Air temperatures from June to August were higher than the long-term average values (Figure 1). This was in part due to the higher atmospheric moisture levels during May to August, which resulted in the average daily minimum temperatures being higher than average. This might have contributed to high levels of plant growth across the winter. The period from August to October, when flowering and grain fill occur, also received favourable environmental conditions with fewer frosts than the long-term average.

Treatments

Varieties (8)

PBA Ace$^{(\phi)}$, PBA Bolt$^{(\phi)}$, PBA Hurricane XT$^{(\phi)}$, PBA Jumbo2$^{(\phi)}$, Nipper, CIPAL 1301, CIPAL 1422, CIPAL 1522

Sowing date (SD)

SD1: 6 May
SD2: 17 May
SD3: 2 June

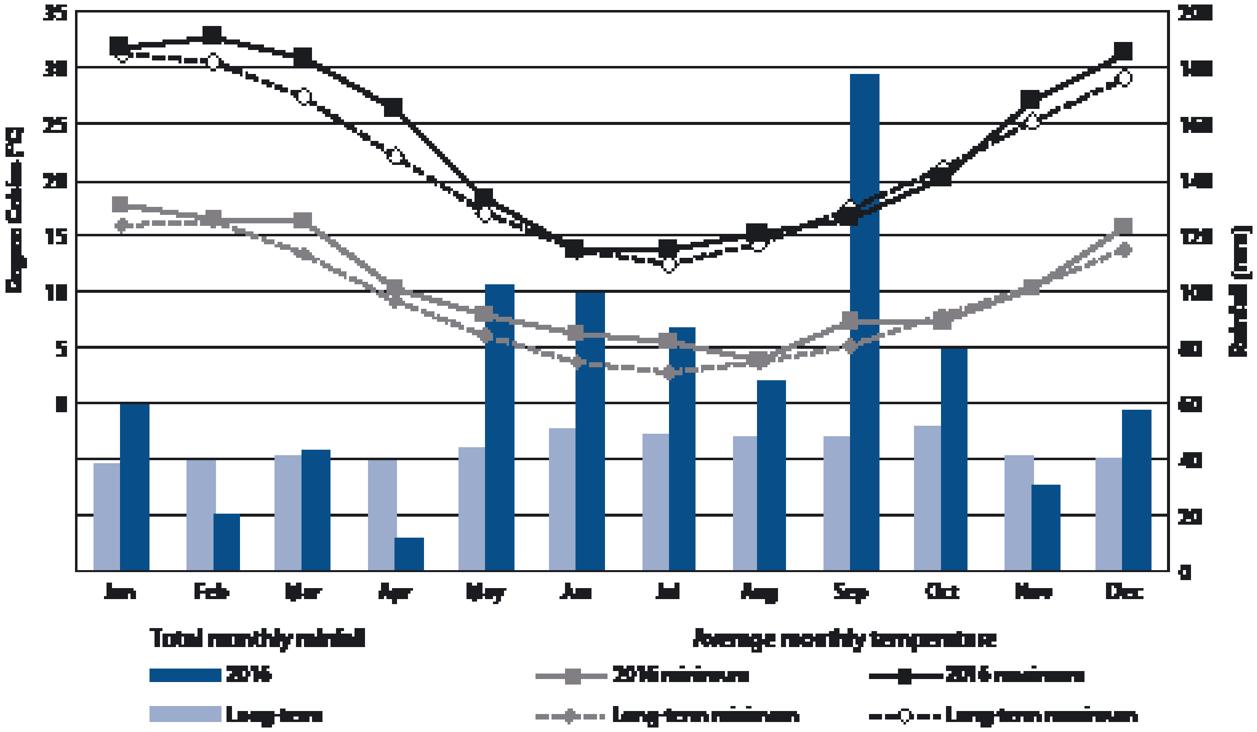


Figure 1. Monthly rainfall and temperature for Wagga Wagga Agricultural Institute in 2016 and the long-term average.

Results

Establishment

Lentil in southern NSW has a recommended target plant density of 110–130 plant/m^2. Therefore, sowing rates are adjusted according to seed size and germination percentages. For small-seeded lentil varieties such as PBA Hurricane XT$^{(\phi)}$, this approximates to 45–55 kg/ha; for medium-sized varieties such as PBA Ace$^{(\phi)}$ the sowing rate is approximately 55–70 kg/ha; for the large-seeded varieties such as PBA Jumbo2$^{(\phi)}$ and PBA Giant$^{(\phi)}$, the sowing rate is about 75–90 kg/ha.

A target density of 120 plants/m^2 was intended for each of the three sowing dates. Plant establishment of 127.6 plants/m^2 was achieved at the 17 May sowing date, similar to the targeted density when averaged over all varieties. Establishment at 6 May and 2 June sowing dates was significantly lower than the targeted plant population, with 89.5 plants/m^2 and 98.4 plants/m^2 respectively. It could not be determined if the establishment response to sowing time was due to herbicide damage, sowing depth, soil moisture, or an interaction between these factors.

There was a significant difference between varieties for plant establishment when averaged over the three sowing dates. Nipper and PBA Jumbo2$^{(\phi)}$ had significantly lower plant establishment rates, with 93.5 plants/m^2 and 101.7 plants/m^2, respectively, lower than the other six lentil varieties or advanced breeding lines (Table 2).

Table 2. Established plant populations (plants/m^2) for eight lentil varieties averaged across sowing dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 11.3 plants/m^2.

Variety	Establishment (plants/m^2)
CIPAL 1301	114.0
CIPAL 1422	104.3
CIPAL 1522	101.7
Nipper	93.5
PBA Ace	110.4
PBA Bolt	108.6
PBA Hurricane XT	107.0
PBA Jumbo2	101.7

Grain yield

The delay in sowing from 6 May until 2 June resulted in a 34% yield reduction from 3.16 t/ha to 2.08 t/ha (data not shown); the delay in sowing from 17 May until 2 June resulted in a 26% yield reduction across varieties – a 0.74 t/ha drop from 2.82 t/ha (data not shown).

The reduction in yield was greatest between the second and third sowing dates, indicating that timely sowing was essential to maximise yield potential within the recommended sowing window. Even ideal grain filling conditions could not compensate for the delayed sowing effect.

PBA Hurricane XT$^{\phi}$ was the highest yielding variety with 3.03 t/ha when averaged over the three sowing dates, which was similar to PBA Jumbo2$^{\phi}$ (2.90 t/ha) and CIPAL 1422 (2.78 t/ha). Nipper had the lowest average yield over the three sowing dates with 2.26 t/ha, similar to CIPAL 1301 with 2.51 t/ha (data not shown).

There were significantly differing varietal responses to the three sowing dates within the eight lentil varieties. All varieties showed a reduction in grain yield when sowing was delayed. PBA Jumbo2$^{\phi}$ had stable grain yield across the three sowing dates, with only a 15% reduction when sowing was delayed from 6 May until 2 June (Figure 2). This stability indicated that there is minimal potential yield loss with delayed sowing for PBA Jumbo2$^{\phi}$. In contrast, Nipper had a reduced yield of over 33 % when sowing was delayed by two weeks from 6 May until 17 May, and 48% reduction when sowing was delayed until 2 June (Figure 2).

For all varieties except Nipper and PBA Bolt$^{\phi}$, there was no significant difference in grain yield when sown on 6 May or 17 May. The reduction in yield between the 17 May sowing and the 2 June sowing was significant (Figure 2) for all varieties except Nipper and PBA Jumbo2$^{\phi}$.

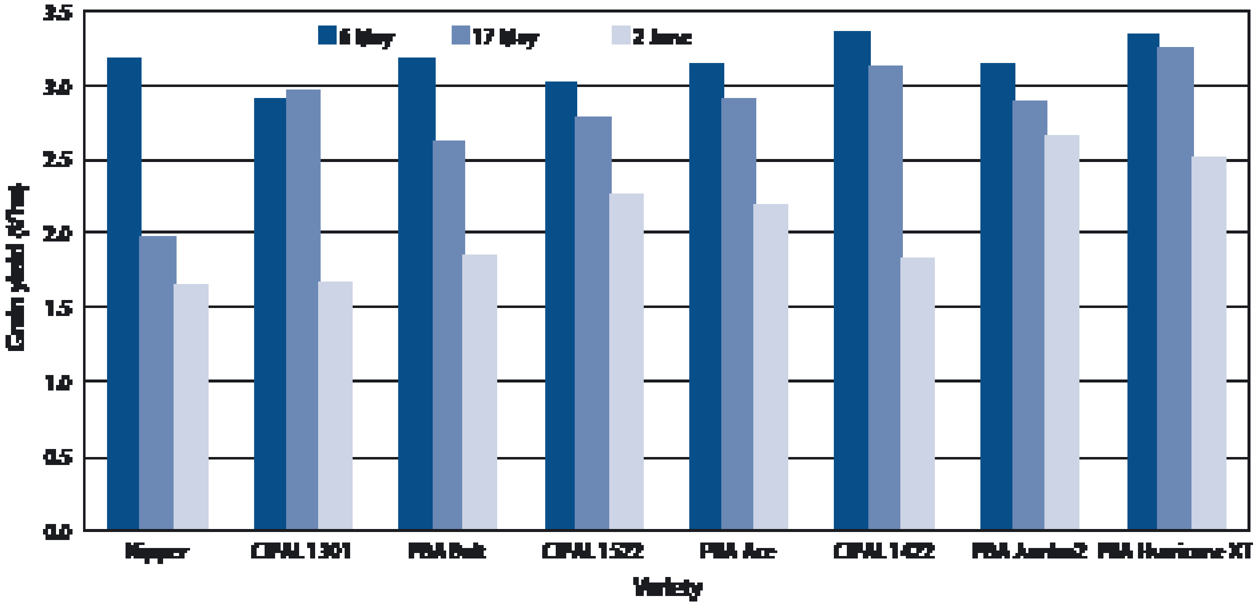


Figure 2. Grain yield for eight lentil varieties sown on three sowing dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 0.50 t/ha.

Bottom pod height

The height of the lowest pod from the ground is important as it affects harvest effectiveness and efficiency. The height from bottom pod to ground decreased as sowing date was delayed. There was a 3 cm or 10% reduction in height when sowing was delayed by two weeks to 17 May and an 11 cm or 36% reduction when sowing was delayed a further two weeks until 2 June, when compared to 35.2 cm for the 6 May sow date (data not shown).

Two varieties and two advanced breeding lines had heights to bottom pods that were over 30 cm, they included CIPAL 1422 (35.1 cm) CIPAL 1522 (30.0 cm) PBA Ace$^{\phi}$ (34.2 cm) and PBA Jumbo2$^{\phi}$ (34.2 cm).

Height to bottom pods was affected by variety and sowing date interaction. PBA Hurricane XT$^{\phi}$ had no difference in height to bottom pod irrespective of sowing date (Figure 3), but its overall height was lower when compared with other varieties. Most lentil varieties showed no significant reduction in height to bottom pod when sowing date was delayed until 17 May, including CIPAL 1301, PBA Hurricane XT$^{\phi}$, CIPAL 1522, PBA Jumbo2$^{\phi}$, PBA Ace$^{\phi}$ and CIPAL 1422 (Figure 3), yet reduction in height to bottom pod was significant when sowing was delayed until 2 June (Figure 3). Nipper had high height to bottom pod for the 6 May sowing date, but a more than 10 cm reduction for the 17 May and 14 cm for the 2 June sowing date (Figure 3).

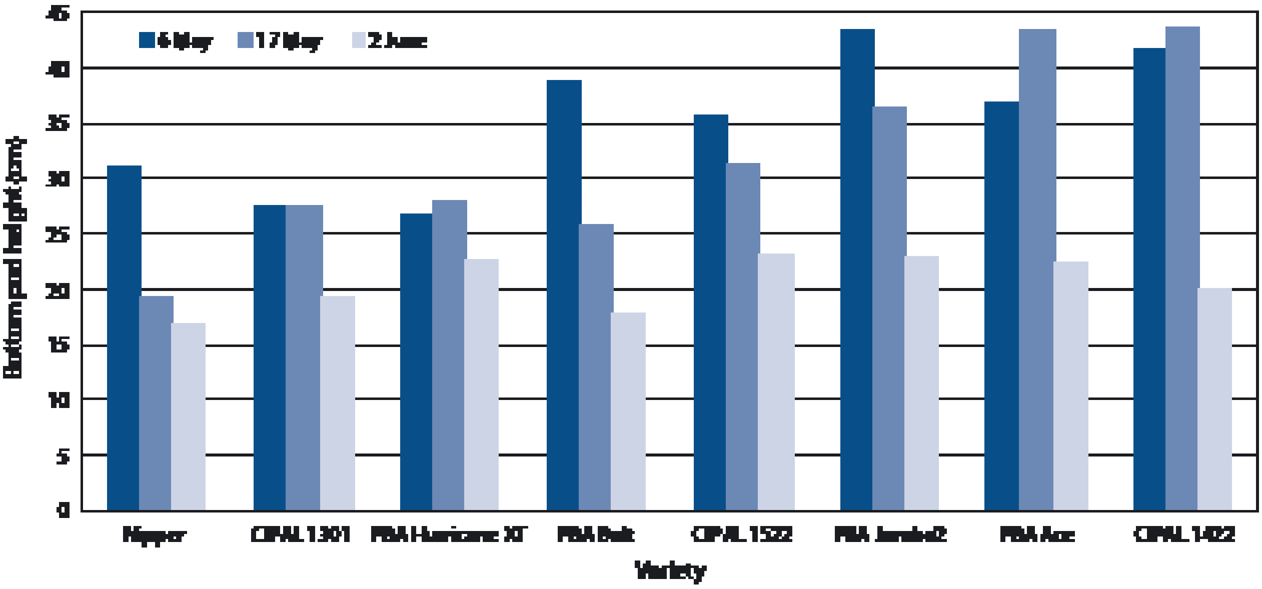


Figure 3. Bottom pod height from ground level for eight lentil varieties sown on three sowing dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 7.2 cm.

Dry matter production

Ideal growing conditions across the 2016 growing season were conducive to producing high above-ground biomass. High biomass averaged across the eight varieties of 9.05 t/ha was accumulated at the 6 May sowing date, but was reduced by 19% or 1.7 t/ha when sown on 17 May and by 51% or 4.4 t/ha when sown on 2 June. Varietal differences in dry matter accumulation were also recorded. The highest biomass accumulator was PBA Ace$^{\phi}$ with 8.1 t/ha while PBA Bolt$^{\phi}$ was the lowest with 5.9 t/ha. Most varieties accumulated similar levels of biomass at the 6 May and 17 May sowing dates with significant reduction for the delayed sowing on 2 June (Figure 4).

Dry matter accumulation for individual varieties varied across the three sowing dates. For seven of the eight varieties, (the exception being Nipper), there was little difference in dry matter when sown at the beginning and in the middle of the sowing window (Figure 4). There was another marked reduction in accumulation when sowing was delayed until 2 June. However, in contrast, for Nipper there was a significant loss of dry matter accumulation between the 6 May and 17 May sowing dates (Figure 4).

Seed size

Seed size and colour (red and green) are the major determinants of market suitability for lentil. In this experiment, variety significantly affected seed weight with a range from 2.7 g/100 seeds for Nipper to 4.4 g/100 seeds for PBA Jumbo2$^{\phi}$.

There were significant differences across the varieties by sowing date interaction. PBA Hurricane XT$^{\phi}$, CIPAL 1522 and PBA Jumbo2$^{\phi}$ had significantly higher seed weight at the 6 May sowing date, while the 17 May and 2 June seed weights were lower yet similar (Figure 5). In contrast, CIPAL 1422 and PBA Bolt$^{\phi}$ had a slightly higher seed weight when sown later at the 2 June sowing date than the 6 May and 17 May sowing dates (Figure 5).

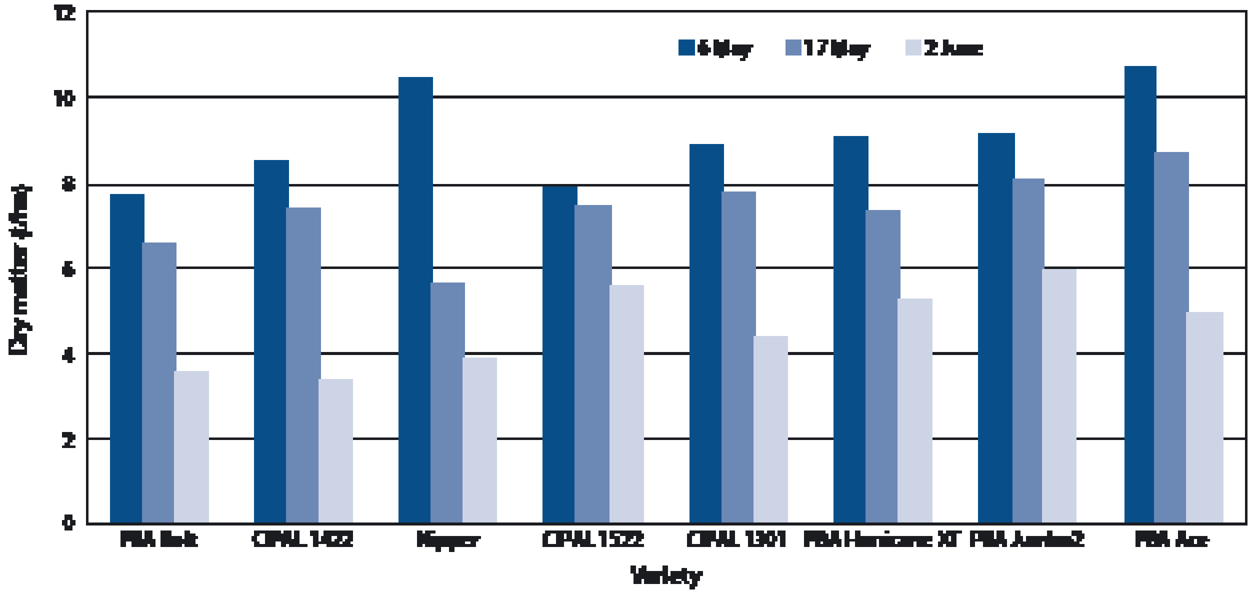


Figure 4. Dry matter production for eight lentil varieties sown on three sowing dates at Wagga Wagga in 2016; l.s.d. (*P* = 0.05) = 1.8 t/ha.

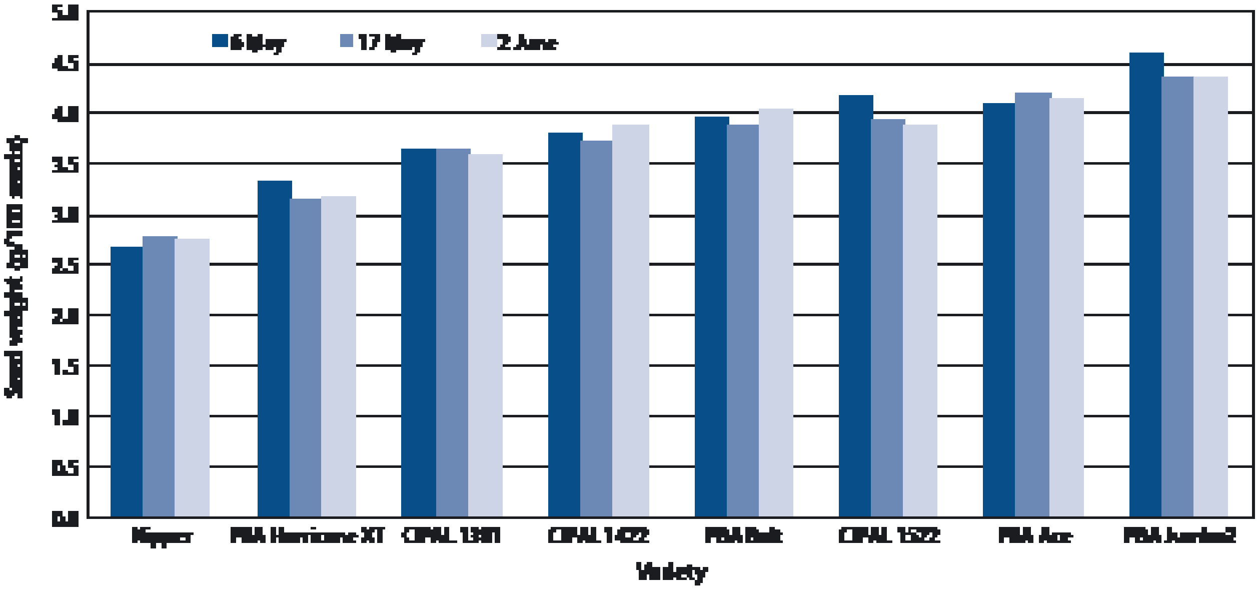


Figure 5. Seed weight for eight lentil varieties sown on three sowing dates at Wagga Wagga in 2016; l.s.d. (*P* = 0.05) = 0.1 g/100 seeds.

Summary

Paddock selection, sowing date and varietal selection are critical management factors for lentil production in southern NSW. Sowing early within the recommended planting window determines plant growth, grain yield and profit for these lentil crops. Results from recent agronomy experiments based in southern NSW indicate the optimum time to sow lentil in the western cropping region of southern NSW is late April through to mid May (later than lupin and faba bean, but earlier than field pea). In the eastern cropping region, the optimal time to sow lentils is early to late May (7–10 days later than the south-western region). Sowing beyond these dates severely compromises growth, production and yield.

Reduced grain yields were recorded when sowing was delayed. There was a 0.34 t/ha yield reduction when sowing was delayed from 6 May to 17 May (within the recommended sowing window), with a sharp reduction of 0.74 t/ha when sowing was further delayed to outside the sowing window. PBA Hurricane XT$^{(D)}$ and PBA Jumbo2$^{(D)}$ had the highest yields with 3.03 t/ha and 2.90 t/ha, respectively.

Some varieties showed more stability than others when sown over the sowing window with respect to grain yield. PBA Jumbo2$^{\phi}$ had only a 15% reduction when sowing was delayed to outside the sowing window (Figure 2).

Higher yield potential needs to be combined with improved height to bottom pod to enable more efficient harvesting. Timely sowing increased height to bottom pod with improvements of up to 11 cm when crops were sown at an appropriate time. Several varieties and advanced breeding lines showed high height to bottom pod, irrespective of sowing date, including PBA Jumbo2$^{\phi}$, PBA Ace$^{\phi}$ and CIPAL 1422 with heights close to or exceeding 40 cm (Figure 3).

Seed size is a determinant of market and price received by primary producers; two varieties PBA Jumbo2$^{\phi}$ and PBA Ace$^{\phi}$ had seed weight higher than 3.5 g/100 seeds.

Sowing date is critical for maximum grain yield, dry matter, height to bottom pod, and seed size. In addition to sowing within the planting window, varietal selection for specific farming practices and location need to be assessed for maximum profitability for lentils within southern NSW.

Acknowledgement

Thank you to Karl Moore, Russell Pumpa, Scott Clark and Jon Evans for technical assistance and Dr Neroli Graham for biometric support.

Lupin sowing date – Wagga Wagga 2016

Mark Richards (NSW DPI, Wagga Wagga), **Dr Neroli Graham** (NSW DPI, Tamworth), **Karl Moore, Russell Pumpa, Jon Evans and Scott Clark** (NSW DPI, Wagga Wagga)

Key findings

- No significant yield difference was found when lupins were sown on 28 April, 17 May or 2 June, when averaged across varieties in 2016.
- PBA Gunyidi⚗ and PBA Jurien⚗ were the highest yielding commercial narrow-leafed varieties, when averaged across sowing times.
- *Albus* varieties yielded significantly higher from the 17 May sowing when compared with the earlier sowing date (28 April) and later sowing date (2 June).

Aim

To compare growth, development and yield of current commercial lupin varieties and promising advanced breeding lines sown on three dates on a red–brown earth at Wagga Wagga in southern NSW. This information will be used to confirm and update current agronomic recommendations for lupin in this region.

Site details

Location	Wagga Wagga Agricultural Institute, Paddock 15
Soil type	Red–brown earth, pH_{Ca} 5.7 (0–10 cm)
Experimental design	Randomised split plot design with sowing date in the main blocks and varieties in the sub-plots; three replications
Paddock history	Previous crop was barley; the paddock was burnt before sowing to remove stubble load
Fertiliser	75 kg/ha grain legume starter (N 0: P 13.8: K 0: S 6.1) placed 50 mm below the seed 150 g/ha sodium molybdate, 16 June
Plant population	Target: 40 plants/m^2
Sowing	Direct drilled using a six-row cone seeder on 300 mm row spacing using DBS tines and GPS auto-steer
Inoculation	Group G peat inoculant was mixed directly into an onboard water tank then pumped through micro tubes into each sowing furrow
Weed management	Commercial practices were used, aiming for weed-free experiments, eliminating both weed competition and weed seed set Fallow weed control: glyphosate (450 g/L) 2 L/ha, water 100 L/ha Incorporated by sowing: Terbyne® 850 g/ha, Triflur X® 1 L/ha, Boxer Gold® 2.5 L/ha, water 100 L/ha Post sowing: Select Xtra® 500 mL/ha, Factor® 180 g/ha, Supercharge® 100 mL/100 L (16 June), water 100 L/ha; Simazine 900® 850 g/ha (26 August), water 100 L/ha
Insect management	Targeting *Helicoverpa* sp. – Heliothis, Fastac Duo® 200 mL/ha, water 100 L/ha (24 October) Karate Zeon® 30 mL/ha, water 100 L/ha (2 December)
Harvest dates	12 December for *L. angustifolius* (narrow-leaf) 20 December for *L. albus*

Soil analysis

Table 1. Site soil characteristics for 0–10 cm and 10–30 cm depth at Wagga Wagga in 2016.

Characteristic	Depth (0–10 cm)	Depth (10–30 cm)
pH_{Ca}	5.7	5.2
Aluminium (KCL) (cmol+/kg)	<0.10	<0.10
Nitrate N (KCL) (mg/kg)	54	20
Ammonium N (KCL) (mg/kg)	1	2
Sulphur (mg/kg)	9	9.8
Phosphorus (Colwell) (mg/kg)	60	22
Organic carbon (OC) (%)	0.79	0.47

Season

The 2016 growing season at Wagga Wagga was exceptional. Growing season rainfall recorded was 525 mm (April–October), 60% higher than the long-term average of 328 mm. With only 11 mm of rainfall in April, soil moisture was marginal for early sowing. May and June received double the long-term average with 102 mm and 100 mm, respectively (Figure 1). Rainfall from June to October was above the long-term average and resulted in high soil moisture levels during spring (Figure 1).

Average daily maximum temperatures for the months from June to August inclusive were slightly higher than the long-term average (Figure 1). Due to the high atmospheric moisture levels, the average daily minimum temperatures from May to August were significantly higher than average (Figure 1). Higher minimum and maximum air temperatures up until August could have contributed to the higher plant growth during winter. In conjunction with the above average rainfall and mild air temperatures, there were fewer than expected frosts from August to October.

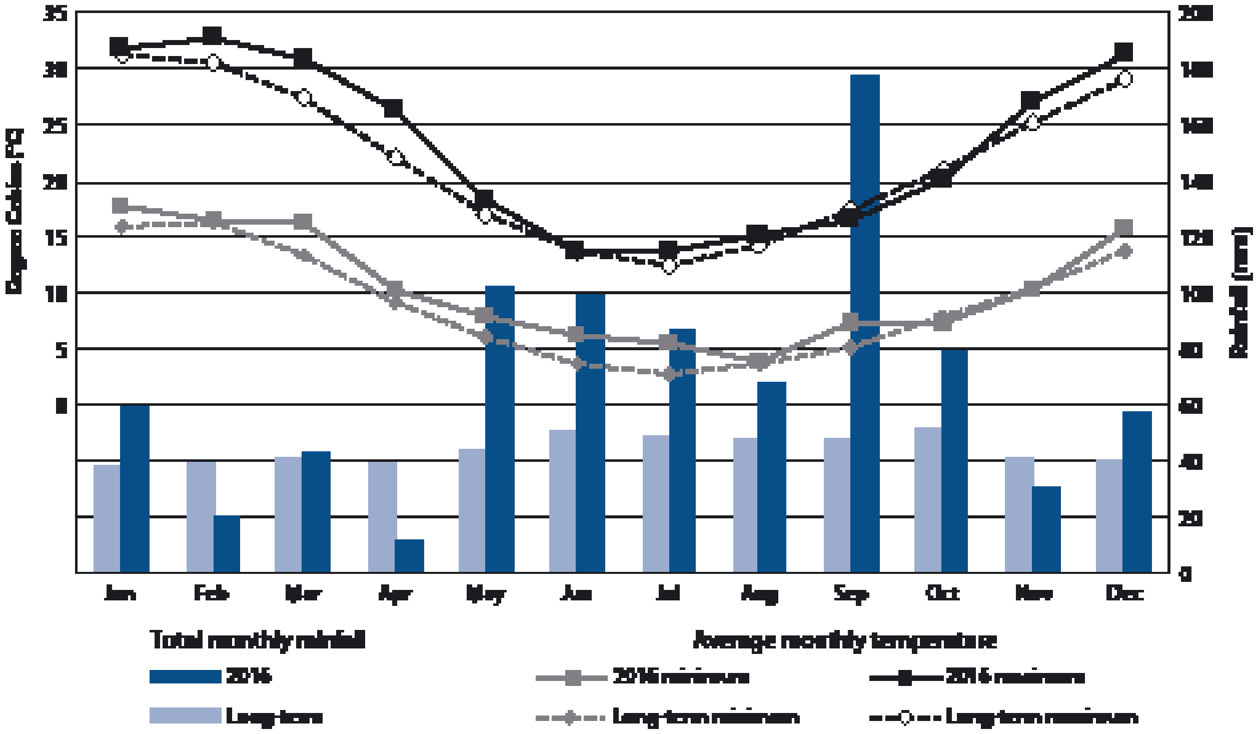


Figure 1. Monthly rainfall and temperature for Wagga Wagga Agricultural Institute in 2016 and the long-term average.

Treatments

Varieties (12)

L. angustifolius: PBA Barlock$^{\phi}$, PBA Gunyidi$^{\phi}$, Jenabillup$^{\phi}$, Jindalee$^{\phi}$, Mandelup$^{\phi}$, PBA Jurien$^{\phi}$, Wonga$^{\phi}$, WALAN 2533$^{\phi}$
L. albus: Kiev Mutant, Luxor$^{\phi}$, Rosetta$^{\phi}$, WK 338$^{\phi}$

Sowing date (SD)

SD1: 28 April
SD2: 17 May
SD3: 2 June

Results

Establishment

Lupin establishment for each sowing date was close to the targeted population of 40 plants/m^2. Varieties sown on 17 May achieved 49.7 plants/m^2, which was slightly, but significantly, higher than those sown on 28 April or 2 June with 39.7 plants/m^2 and 35.7 plants/m^2 respectively (data not shown).

There was a slight difference in establishment between the species with the eight *angustifolius* varieties having an average establishment of 40 plants/m^2, while the four *albus* varieties were, on average, 12% higher with 45 plants/m^2 (Table 2).

Table 2. Established plant populations (plants/m^2) for 12 lupin varieties averaged over three sowing dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 5.7 plants/m^2

Species	Variety	Establishment (plants/m^2)
L. angustifolius	Jenabillup	37.6
L. angustifolius	Jindalee	35.9
L. angustifolius	Mandelup	40.7
L. angustifolius	PBA Barlock	40.9
L. angustifolius	PBA Gunyidi	37.2
L. angustifolius	PBA Jurien	45.0
L. angustifolius	WALAN 2533	40.0
L. angustifolius	Wonga	41.7
L. albus	Kiev Mutant	49.9
L. albus	Luxor	45.3
L. albus	Rosetta	47.8
L. albus	WK 338	38.1

Flowering

Most of the *angustifolius* varieties had the longest time to 50% flowering when sown on 17 May (the middle sowing date), while a slightly lower number of days to flowering were achieved for the first and third sowing date (Table 3). In contrast, the *albus* varieties and Jindalee$^{\phi}$ had the longest days from sowing to 50% flowering at the first sowing date, with fewer days to flower as sowing was delayed (Table 3).

Mandelup$^{\phi}$ was the earliest *angustifolius* variety to reach 50% flowering when sown on 28 April (Table 3). This early flowering response significantly increases the risk of frost damage when sown earlier than the recommended sowing window.

Jindalee$^{\phi}$ was the slowest of the *angustifolius* varieties to flower, and might reflect that Jindalee$^{\phi}$ was the only *angustifolius* variety tested to have a known vernalisation requirement that delayed its flowering significantly at all sowing dates when compared with all other *angustifolius* varieties (Table 3).

Kiev Mutant and WK 338$^{\phi}$ were the quickest to 50% flowering of the *albus* lupin varieties, while Rosetta$^{\phi}$ was the slowest (Table 3).

Table 3. Days to 50 % flowering and flowering period (days) for the eight varieties on three sowing dates at Wagga Wagga in 2016. Days to 50% flowering l.s.d. ($P = 0.05$) = 1.0 days, Flowering duration l.s.d. ($P = 0.05$) = 2.8 days.

Species	**Variety**	**Days to 50% flowering**			**Flowering duration (days)**		
		28 April	**17 May**	**2 June**	**28 April**	**17 May**	**2 June**
L.angustifolius	Mandelup	102.8	107.8	101.7	72.6	51.3	42.6
L.angustifolius	PBA Jurien	105.7	106.6	100.8	67.5	52.0	45.4
L.angustifolius	PBA Gunyidi	106.1	107.5	103.6	71.2	51.8	46.1
L.angustifolius	WALAN 2533	106.4	107.2	101.9	67.9	52.3	44.9
L.angustifolius	Jenabillup	106.4	109.5	102.3	69.5	49.5	47.3
L.angustifolius	PBA Barlock	106.9	110.0	104.5	72.8	53.1	45.9
L.angustifolius	Wonga	108.0	111.8	105.8	72.7	52.4	47.3
L.angustifolius	Jindalee	130.2	121.3	116.9	58.6	52.7	41.5
L. albus	Kiev Mutant	105.4	106.3	99.9	81.7	65.8	57.4
L. albus	WK 338	107.7	106.6	101.6	89.8	67.6	62.4
L. albus	Luxor	111.1	109.4	105.2	87.6	71.0	60.8
L. albus	Rosetta	124.8	116.1	108.7	73.7	64.4	56.0

In contrast to the time to 50% flowering, there was a significant decline in flowering duration when sowing was delayed from 28 April, irrespective of the lupin species (Table 3). The decrease between first and second sowing date ranged from 5.9 days for Jindalee$^{\phi}$ and 22.2 days for WK 338$^{\phi}$. The decrease was larger for all varieties between the second and third sowing dates except Jindalee$^{\phi}$, ranging from 2.2 days for Jenabillup$^{\phi}$ to 11.2 days for Jindalee$^{\phi}$ (Table 3).

Grain yield

Given a very long and favourable season and 525 mm of growing season rainfall at Wagga Wagga in 2016, there was no statistically significant effect of sowing date on grain yield from either the 28 April or 2 June sowing date when averaged across varieties. Grain yields averaged across sowing dates showed that *albus* lupin had the four highest values: Rosetta$^{\phi}$ had 3.34 t/ha while the lowest *albus* was Kiev Mutant with 3.12 t/ha. PBA Gunyidi$^{\phi}$ (3.06 t/ha) was the highest yielding *angustifolius* followed by WALAN 2533$^{\phi}$ (2.85 t/ha) and PBA Jurien$^{\phi}$ (2.84 t/ha).

Albus lupins showed a range of yield patterns at the three sowing dates. Rosetta$^{\phi}$ had decreased yields when sowing was delayed, possibly due to its slower maturity. WK 338$^{\phi}$, Luxor$^{\phi}$ and Kiev Mutant had the highest yield when sown on 17 May (Figure 2). Luxor$^{\phi}$ and Kiev Mutant had no difference in grain yield between the first and third sowing dates, while WK 338$^{\phi}$ did (Figure 2).

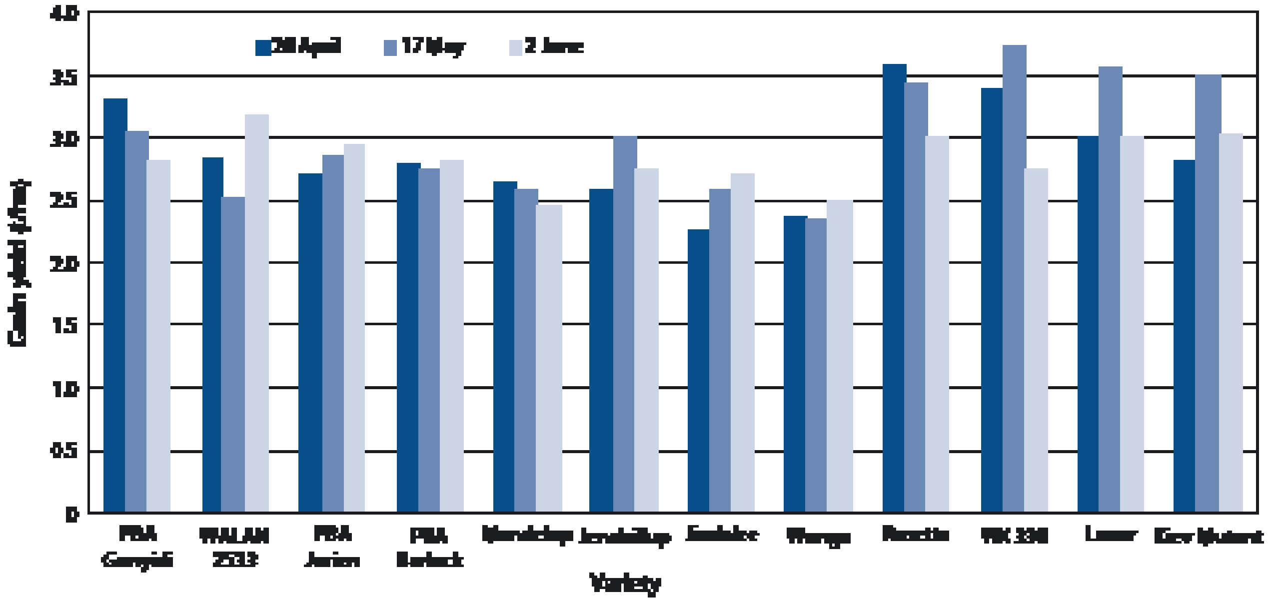


Figure 2. Grain yield of 12 lupin varieties sown on three dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 0.29 t/ha.

Angustifolius varieties were more divergent in yield response to sowing date. PBA Gunyidi$^{(\phi)}$ and Mandelup$^{(\phi)}$ had the highest yields when sown at the earliest time within the window on 28 April (Figure 2), which contrasted to PBA Jurien$^{(\phi)}$ and Jindalee$^{(\phi)}$, which had increased grain yield at the latest sowing date of 2 June. Grain yield for PBA Barlock$^{(\phi)}$ and Wonga$^{(\phi)}$ was stable over the sowing window, while Jenabillup$^{(\phi)}$ performed better when sown on 17 May (Figure 2). Further research into lupin phenology is required to develop management guidelines tailored to individual species and varieties to maximise yield potential.

Seed size

There was a reduction in seed weight as the four *albus* lupin varieties were delayed in sowing from 28 April to 2 June (Figure 3). Seed weight reduced by 5.7% across the *albus* varieties from the 28 April to the 17 May sowing date with a further 12.5% reduction when sowing was delayed to 2 June (Figure 3). In contrast, there was no difference in the seed weight of *angustifolius* lupin varieties across the three sowing dates, demonstrating plasticity over the sowing season (Figure 3). Jindalee$^{(\phi)}$ had the lowest seed weight within the *angustifolius* varieties with 10.5 g/100 seeds whilst WALAN 2533$^{(\phi)}$ had the highest with 14.8 g/100 seeds.

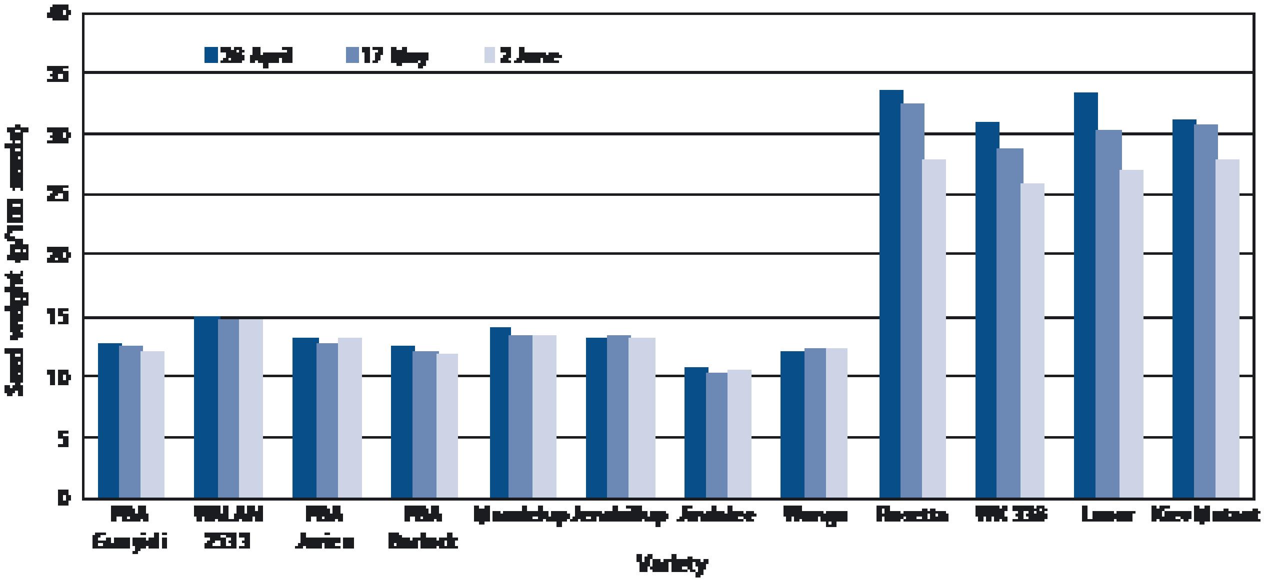


Figure 3. Seed weight of 12 lupin varieties sown on three dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 1.0 g/100 seeds.

Summary

Growing season rainfall (525 mm) at this site was 297 mm above the long-term average (328 mm). High rainfall, in conjunction with milder winter and spring temperatures, delivered higher yields than have normally been experienced, therefore, the results from this experiment must be considered in context. Favourable spring conditions ensured that pod formation and seed development was not greatly affected by high spring temperatures and decreasing soil moisture, resulting in no difference in grain yield due to sowing date.

Albus lupins had the four highest grain yields of the 12 varieties. Rosetta$^{(\phi)}$ had 3.34 t/ha, whilst Luxor$^{(\phi)}$ had 3.19 t/ha. PBA Gunyidi$^{(\phi)}$ 3.06 t/ha had the highest yield for the *angustifolius* varieties when averaged over the three sowing dates. Varietal response to sowing date differed, thus making it essential to tailor management programs to individual varieties to gain maximum yield.

Albus lupin varieties had larger seeds when compared with *angustifolius* varieties. In addition, *albus* varieties showed different responses to sowing time. There was a reduction in *albus* seed size when planting was delayed beyond 28 April. This reduction was not observed for the *angustifolius* varieties.

This experiment highlights the need to understand competing agronomic traits to allow for maximised grain yield while optimising seed size, plant establishment, and flowering timing and duration.

Further phenology research is required in southern NSW to develop specific agronomic management guidelines for currently available varieties of both lupin species. A better understanding of the interaction of genotype, environment and management is required to help reduce the seasonal variation in lupin crop performance and to maximise profitability.

Acknowledgement

Thank you to Karl Moore, Russell Pumpa, Scott Clark and Jon Evans for technical assistance and Dr Neroli Graham for biometric support.

Lupin sowing date – Rankins Springs 2016

Mark Richards (NSW DPI, Wagga Wagga), **Dr Neroli Graham** (NSW DPI, Tamworth), **Karl Moore, Russell Pumpa, Jon Evans and Scott Clark** (NSW DPI, Wagga Wagga)

Key findings

- Given a very long and favourable season and 517 mm of growing season rainfall at this site, an above average site mean yield of 4.04 t/ha was obtained in this experiment.
- Averaged across species, *angustifolius* were 19% and 10% higher yielding than *albus* at 4 May and 20 May sowing date respectively.
- PBA Jurien$^{(b)}$ and Mandelup$^{(b)}$ were the only varieties to show a significant yield reduction as sowing was delayed to 20 May.

Aim

To compare growth, development and yield of current commercial lupin varieties and advanced breeding lines sown on two dates on a red sandy loam soil at Rankins Springs in southern NSW.

Site details

Location	'Hillview' Rankins Springs, RK and JG Eckermann, Paddock: Aloe
Soil type	Red, sandy loam, pH_{Ca} 5.4 (0–10 cm)
Experimental design	Randomised split plot design with sowing date in the main blocks and varieties in the sub-plots; three replications
Paddock history	The previous crop was wheat
Fertiliser	75 kg/ha grain legume starter (N 0: P 13.8: K 0: S 6.1) placed 50 mm below the seed 150 g/ha sodium molybdate, 5 August
Plant population	Target: 40 plants/m^2
Sowing	Direct drilled using a six-row cone seeder on 300 mm row spacing using DBS tines and GPS auto-steer
Inoculation	Group G peat inoculant was mixed directly into an onboard water tank then pumped through micro tubes into each sowing furrow
Weed management	Commercial practices were used aiming for weed-free experiments, eliminating both weed competition and weed seed set Incorporated by sowing: Terbyne® 850 g/ha, Triflur X® 1 L/ha, glyphosate (450 g/L) 2 L/ha, water 100 L/ha Post sowing: Select Xtra® 500 mL/ha, Factor® 180 g/ha, Supercharge® 100 mL/100L, water 100 L/ha (5 August)
Insect management	Targeting Heliothis (*Helicoverpa* sp.), Fastac Duo® 200 mL/ha, water 100 L/ha (6 September)
Disease management	Penncozeb® 750DF 2 kg/ha, water 100 L/ha (5 August)
Harvest date	Harvested: 27 November – *L. angustifolius* Harvested: 21 December – *L. albus*

Soil analysis

Table 1. Site soil characteristics for 0–10 cm depth at Rankins Springs in 2016.

Characteristic	Depth (0–10cm)
pH_{Ca}	5.4
Aluminium (KCL) (cmol+/kg)	0.1
Nitrate N (KCL) (mg/kg)	6
Ammonium N (KCL) (mg/kg)	1
Sulphur (mg/kg)	2.3
Phosphorus (Colwell) (mg/kg)	54
Organic carbon (OC) (%)	0.44

Season

The 2016 season at Rankin Springs was the wettest in the past 36 years of records, with 517 mm of growing season rainfall (GSR), well above the long-term average of 235 mm. While the experiment site had intermittent waterlogging across the growing season, drainage was sufficient to avoid crop damage. Pre-season rainfall (January to May) was variable, with an above-average January and a very dry February and March (Figure 1). However, timely April rain contributed to favourable early sowing conditions. Rainfall during June, July and August was 63% above the long-term average, which filled the soil moisture profile leading into spring (Figure 1). This abundant winter moisture provided ideal conditions for growth and all early-sown pulses produced above average biomass in this environment when compared with other years. Frost events in August resulted in some flower and pod abortion. Despite the wet seasonal conditions, crop disease levels were negligible.

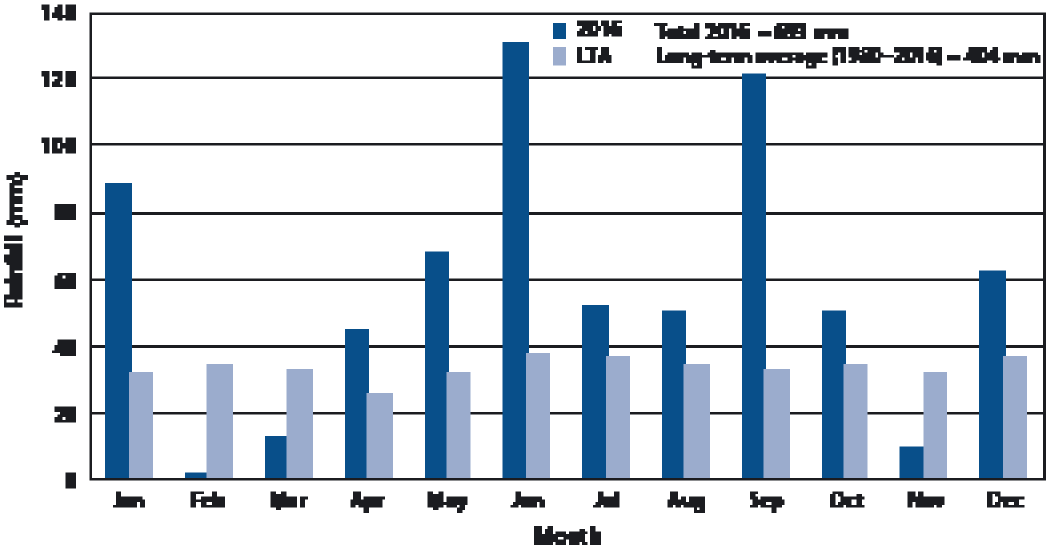


Figure 1. Monthly rainfall for 2016 and long-term average (LTA) rainfall for 'Hillview'.

Treatments

Varieties (12)

L. angustifolius (narrow leaf): PBA Barlock$^{(b)}$, PBA Gunyidi$^{(b)}$, Jenabillup$^{(b)}$, Jindalee$^{(b)}$, Mandelup$^{(b)}$, PBA Jurien$^{(b)}$, Wonga$^{(b)}$, WALAN 2533$^{(b)}$

L. albus (broad leaf): Kiev Mutant, Luxor$^{(b)}$, Rosetta$^{(b)}$, WK 338$^{(b)}$

Sowing date (SD)

SD1: 4 May

SD2: 20 May

Results

Establishment

Lupin establishment for both sowing dates was slightly higher than the target population of 40 plants/m^2. Crops sown on 4 May achieved 49.7 plants/m^2, which was similar to those sown on 20 May at 46.7 plants/m^2 (data not shown).

There was a slight difference in establishment between the two lupin species with the eight *angustifolius* varieties having an average establishment of 47 plants/m^2, while the four *albus* varieties were, on average, 10% higher with 51 plants/m^2 (Table 2).

Table 2. Plant establishment of 12 lupin varieties averaged over the two sowing dates at Rankins Springs in 2016; l.s.d. ($P = 0.05$) = 6.1 plants/m^2).

Species	**Variety**	**Establishment (plants/m^2)**
L. angustifolius	Mandelup	41.7
L. angustifolius	WALAN 2533	42.8
L. angustifolius	Jenabillup	45.5
L. angustifolius	Jindalee	45.7
L. angustifolius	PBA Gunyidi	46.4
L. angustifolius	PBA Barlock	48.9
L. angustifolius	Wonga	51.1
L. angustifolius	PBA Jurien	53.7
L. albus	Rosetta	43.2
L. albus	Luxor	51.4
L. albus	WK 338	51.4
L. albus	Kiev Mutant	56.6

Flowering

Across varieties, there was no difference in the average number of days to 50% flowering for the two sowing dates. There were genotypic differences in days to 50% flowering with WK 338$^{\phi}$ and Kiev Mutant being the quickest to flower at 97 days, while Jindalee$^{\phi}$ was the longest at 118 days. Jindalee$^{\phi}$ was the slowest of the *angustifolius* varieties to flower reflecting that the variety was the only *angustifolius* variety tested to have a known vernalisation requirement, which delayed its flowering significantly for both sowing dates when compared with all other *angustifolius* varieties.

Table 3. Days to flowering for 12 lupin varieties sown on two dates at Rankins Springs 2016; l.s.d. ($P = 0.05$) = 1.6 days.

Species	**Variety**	**Sowing dates**	
		4 May	**20 May**
L. angustifolius	WALAN 2533	97.4	100.6
L. angustifolius	PBA Barlock	97.8	103.1
L. angustifolius	Mandelup	97.9	100.5
L. angustifolius	Jenabillup	98.4	102.7
L. angustifolius	PBA Gunyidi	98.7	101.9
L. angustifolius	Wonga	99.0	104.4
L. angustifolius	PBA Jurien	99.1	100.4
L. angustifolius	Jindalee	122.5	114.1
L. albus	WK 338	98.3	96.0
L. albus	Kiev Mutant	98.4	96.3
L. albus	Luxor	106.9	102.7
L. albus	Rosetta	114.1	107.0

There were two major patterns in response to days to 50% flowering and sowing date. For all *L. angustifolius* varieties except Jindalee$^{\phi}$, the number of days to 50% flowering was fastest for the 4 May sowing date (Table 3). There were differences between the two sowing dates of between one and five days for these varieties (Table 3).

In contrast, the four *albus* varieties and Jindalee$^{\phi}$ had the longest time to 50% flowering for the first sowing date, with decreasing days to 50% flowering as sowing was delayed (Table 3). There was also a grouping within the *albus* varieties, with WK 338$^{\phi}$ and Kiev Mutant having between 96 and 99 days respectively for 50% flowering at either sowing date, while Luxor$^{\phi}$

and Rosetta$^{\phi}$ took longer to flower ranging from 103 to 114 days over the two sowing dates, respectively (Table 3). A longer flowering duration, enhanced by an earlier start to flowering in this environment, allowed for a larger number of flowering nodes and hence yield plasticity and better insurance against environmental stresses during flowering and pod-fill.

Grain yield

Grain yield, when averaged for the two species, showed that narrow leaf varieties were 19% and 10% higher than *albus* when sown on 4 May and 20 May, respectively.

Given a very long and favourable season from 517 mm of growing season rainfall at this site in 2016, there was no effect of sowing date on grain yield for the 4 May or 20 May sowing dates. Grain yields averaged across the two sowing dates showed that *angustifolius* varieties had the four highest values. The highest yielding variety was PBA Barlock$^{\phi}$ with 4.46 t/ha, which was similar to PBA Jurien$^{\phi}$ with 4.42 t/ha, followed by PBA Gunyidi$^{\phi}$ and WALAN 2533$^{\phi}$ with 4.4 t/ha and 4.3 t/ha, respectively.

The highest yielding *albus* was WK 338$^{\phi}$ (3.86 t/ha) followed by Luxor$^{\phi}$ (3.80 t/ha), Rosetta$^{\phi}$ (3.61 t/ha) and Kiev Mutant (3.59 t/ha).

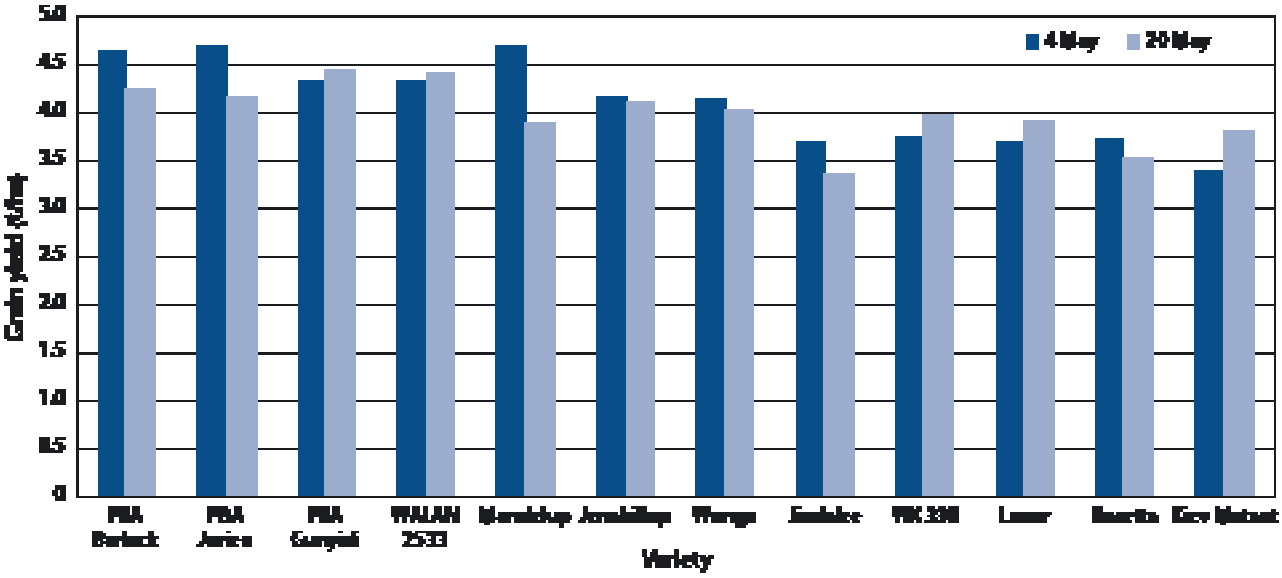


Figure 2. Grain yield of 12 lupin varieties sown on two dates at Rankins Springs in 2016; l.s.d. ($P = 0.05$) = 0.45 t/ha.

There was a range of responses from the varieties to sowing date. Varieties such as PBA Jurien$^{\phi}$ and Mandelup$^{\phi}$ had a significantly reduced grain yield of 0.54 t/ha (11%) and 0.79 t/h (17%), respectively, when sowing was delayed from 4 May to 20 May (Figure 2). Both PBA Gunyidi$^{\phi}$ and WALAN 2533$^{\phi}$ had high and stable yields over both sowing dates (Figure 2). The *albus* varieties WK 338$^{\phi}$, Luxor$^{\phi}$ and Kiev Mutant showed a slight improvement in yield when sowing was delayed (Figure 2). Differing responses show the importance of varietal management packages and their need to be tailored to individual species and varieties to maximise yield potential.

Seed size

When averaged across varieties, there was a slight reduction in seed weight from 21.7 g/100 seeds to 20.1 g/100 seeds when sowing date was delayed from 4 May to 20 May. There was a marked, but expected, difference in seed weight between the *angustifolius* (13.3–18.8 g/100 seeds) and *albus* (29.8–31.1 g/100 seeds) varieties. Seed weight for the *albus* varieties was over twice that of *angustifolius* varieties.

An interaction between sowing date and genotype was observed. Averaged across the four *albus* varieties, seed weight was 12% higher for the 4 May sowing than the 20 May sowing (Figure 3).

Within the eight *angustifolius* varieties there was no effect of sowing date on seed weight except for Mandelup$^{(b)}$, which had a significantly lighter seed weight (9%) when sown on 20 May (later in the sowing window). Interestingly, WALAN 2533$^{(b)}$ had a heavier seed weight at both sowing dates when compared with all other *angustifolius* varieties.

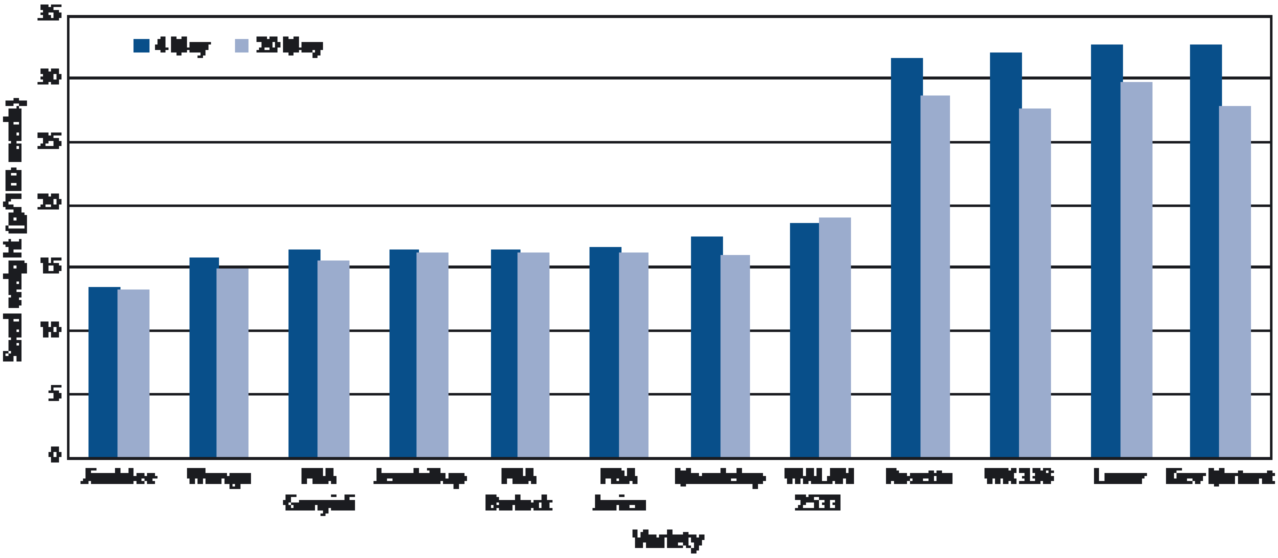


Figure 3. Seed weight of 12 lupin varieties sown on two dates at Rankins Springs in 2016; l.s.d. ($P = 0.05$) = 0.8 g/100 seeds.

Summary

Given that the growing season rainfall (517 mm) at Rankin Springs in 2016 was 282 mm, or 162% higher than the long-term growing season rainfall average (235 mm), the high yield results from this experiment must be considered within that context. Due to the favourable spring conditions, there was no response to sowing date, with less than 0.1 t/ha difference between the two sowing dates. There were differing patterns of yield responses to sowing date with varieties such as PBA Barlock$^{(b)}$ and PBA Jurien$^{(b)}$ having high yields when sown early in the sowing window, contrasting to WK 338$^{(b)}$ and Luxor$^{(b)}$, which had the highest yields when sown late in the sowing window. This reinforces the importance of individual varietal management practices to maximise yield potential under a range of environmental conditions.

Sowing date influences environmental conditions that are experienced during flowering and thus affect yield. Lupin crops sown too early risk flowering and early pod development during a time of high frost risk; when crops are sown too late, temperatures are rising and stored soil moisture is reducing, meaning the potential yield is reduced from poor pod development.

Varietal differences in days to 50% flowering, in conjunction with environmental conditions, influence the sowing timing. For *albus* lupin in 2016, the highest yield and seed weights were obtained when sown 4 May, earlier in the recommended sowing window. This varied to the eight *angustifolius* varieties that showed a range of responses to sowing date in both grain yield and seed weight when sown within the recommended sowing window.

Results from this experiment indicate that further research is required to better understand lupin varietal response to sowing date in this environment, so improved agronomic management guidelines can be developed.

Acknowledgements

Thank you to Kim and Nick Eckermann “Hillview” Rankins Springs for their ongoing collaboration and support of pulse research through provision of the field site.

Thank you to Karl Moore, Russell Pumpa, Scott Clark and Jon Evans for technical assistance and Dr Neroli Graham for biometric support.

Faba bean sowing date – Wagga Wagga 2016

Mark Richards (NSW DPI, Wagga Wagga), **Dr Neroli Graham** (NSW DPI, Tamworth), **Karl Moore, Russell Pumpa, Jon Evans and Scott Clark** (NSW DPI, Wagga Wagga)

Key findings

- The optimum time to sow faba beans in southern NSW was late April–mid May.
- Even in a favourable season such as 2016 there was a 10% yield penalty when sowing was delayed from 17 May to 2 June.
- Average seed size reduced by 8% when sown outside the recommended window.
- PBA Nasma$^{\text{⍉}}$, Fiesta VF, and PBA Zahra$^{\text{⍉}}$ were the highest yielding commercial varieties.
- Advanced breeding lines AF10089 and AF09169 had significantly higher grain yields, particularly at the 28 April sowing date when compared to other sowing dates.
- Flowering duration for PBA Samira$^{\text{⍉}}$ and PBA Zahra$^{\text{⍉}}$ was stable across sowing dates, but reduced for PBA Nasma$^{\text{⍉}}$ as sowing was delayed.

Aim

To compare growth, development and yield of current commercial faba bean varieties and advanced breeding lines sown on three dates on a red brown–earth at Wagga Wagga in southern NSW.

Site details

Location	Wagga Wagga Agricultural Institute, Paddock 15
Soil type	Red–brown earth, pH_{Ca} 5.7 (0–10 cm)
Experimental design	Randomised split plot design with sowing date in the main blocks and varieties in the sub-plots; three replications
Paddock history	The previous crop was barley; paddock was burnt before sowing to remove stubble load
Fertiliser	75 kg/ha grain legume starter (N 0: P 13.8: K 0: S 6.1) placed 50 mm below the seed 150 g/ha sodium molybdate, 16 June
Plant population	Target: 30 plants/m^2
Sowing	Direct drilled using a six-row cone seeder on 300 mm row spacing using DBS tines and GPS auto-steer
Inoculation	Group F peat inoculant was mixed directly into an onboard water tank then pumped through micro tubes into each sowing furrow
Weed management	Commercial practices were used, aiming for weed-free experiments, eliminating both weed competition and seed set Fallow weed control: glyphosate (450 g/L) 2 L/ha, water 100 L/ha Incorporated by sowing: Terbyne® 850 grams/ha, Triflur X® 1 L/ha, Boxer Gold® 2.5 L/ha, water 100 L/ha Post sowing: Select Xtra® 500 mL/ha, Factor 180 g/ha, Super charge® 100 mL/100 L (16 June), water 100 L/ha Simazine 900® 850 g/ha (SD1: 25 August, SD2 and SD3: 26 August), water 100 L/ha
Insect management	Targeting Heliothis (*Helicoverpa* sp.) Fastac Duo® 200 mL/ha, water 100 L/ha (24 October)

Disease management	Targeting chocolate spot (*Botrytis fabae* and *B. cinerea*) and ascochyta blight (*Ascochyta fabae*) Penncozeb® 750DF 2 kg/ha, water 100 L/ha (14 July) Penncozeb® 750DF 2 kg/ha, water 100 L/ha (4 August) Howzat® 500 mL/ha, water 100 L/ha (26 August) Howzat® 500 mL/ha, water 100 L/ha (20 September) Bravo® 1.5 L/ha, water rate 100 L/ha (11 October)
Harvest date	9 December

Soil analysis

Table 1. Site soil characteristics for 0–10 cm and 10–30 cm depth at Wagga Wagga in 2016.

Characteristic	Depth (0–10 cm)	Depth (10–30 cm)
pH_{Ca}	5.7	5.2
Aluminium (KCL) (cmol+/kg)	<0.10	<0.10
Nitrate N (KCL) (mg/kg)	54	20
Ammonium N (KCL) (mg/kg)	1	2
Sulphur (mg/kg)	9	9.8
Phosphorus (Colwell) (mg/kg)	60	22
Organic carbon (OC) (%)	0.79	0.47

Season

The 2016 growing season at Wagga Wagga was exceptional with growing season rainfall of 525 mm (April–October), 60% higher than the long-term average of 328 mm. April only received 11 mm of rainfall, which resulted in marginal moisture at sowing (Figure 1). Monthly rainfall for May and June was double the long-term average with 102 mm and 100 mm respectively (Figure 1). Rainfall from June to October was above the long-term average and resulted in a full soil moisture profile during spring.

Average daily maximum temperatures for June to August inclusive were slightly higher than the long-term average (Figure 1). Due to the high atmospheric moisture levels, the average daily minimum temperatures from May to August were significantly higher than average (Figure 1). Higher minimum and maximum air temperatures to August could have contributed to the higher plant growth during winter. In conjunction with the above average rainfall and milder air temperatures, there were fewer than expected frosts from August to October.

Treatments

Varieties (8)

PBA Nasma⟮, PBA Samira⟮, PBA Zahra⟮, Nura⟮, Farah⟮, Fiesta VF, AF09169, AF10089

Sowing date (SD)

SD1: 28 April
SD2: 17 May
SD3: 2 June

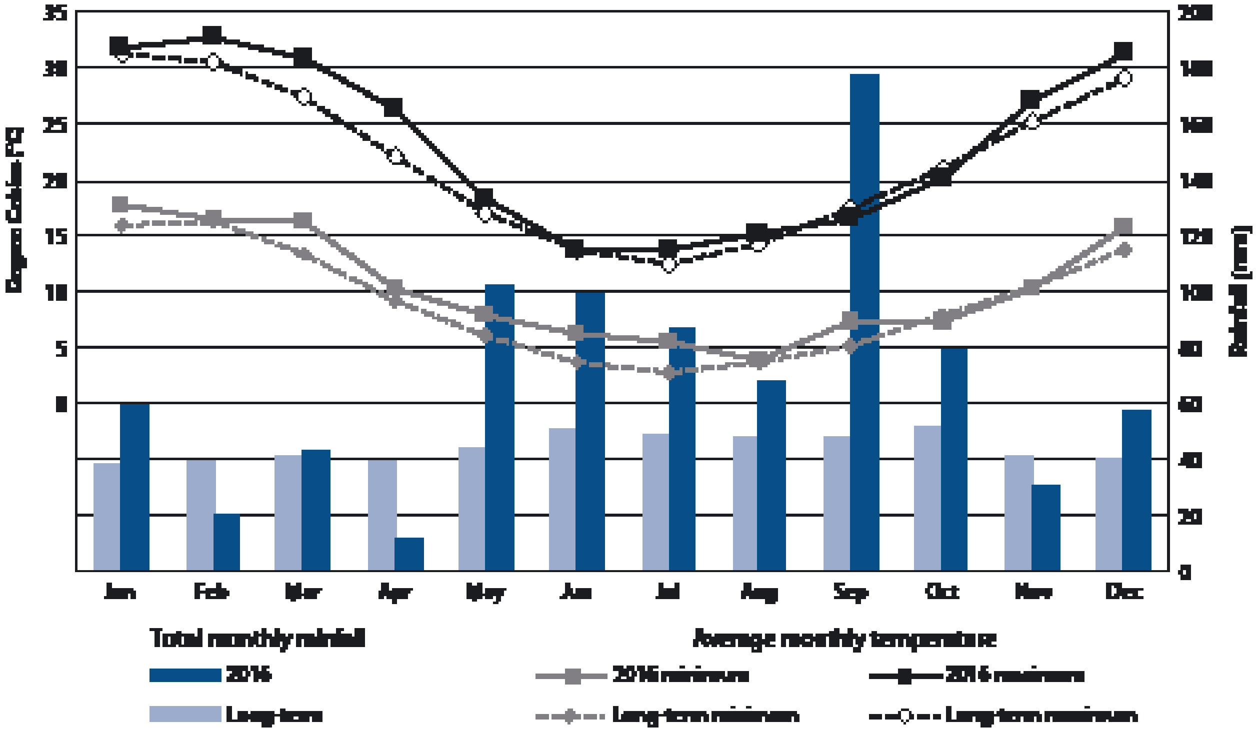


Figure 1. Monthly rainfall and temperature for Wagga Wagga Agricultural Institute in 2016 and the long-term average.

Results

Establishment

Plant establishment varied across the three sowing dates; the targeted plant population was 30 plants/m^2. Plant establishment for the 28 April and 17 May sowing dates were similar with 37.9 plants/m^2 and 37.3 plants/m^2 respectively, yet higher than the target population. When the sowing date was delayed until 2 June, the plant population was significantly lower with 31.2 plants/m^2 (Table 2), when averaged across the eight varieties. As seed for each variety was from the same source and packed at the same time, the reduced establishment at the 2 June sowing showed that delayed sowing can have a significant effect on successful plant establishment.

Table 2. Established plant counts, days to 50% flowering and flowering duration for three sowing dates averaged over eight lupin varieties at Wagga Wagga in 2016.
Plant establishment l.s.d. ($P = 0.05$) = 2.7 plants, Days to 50 % flowering l.s.d. ($P = 0.05$) = 1.0 days, Flowering duration l.s.d. (P=0.05) = 2.4 days.

Sowing date	Plant establishment (plants/m^2)	Days to 50% flowering	Flowering duration (days)
28 April	37.9	99.8	69.3
17 May	37.3	96.5	55.0
2 June	31.2	91.1	49.7

Flowering

Variety, sowing date and their interaction all significantly affected days to 50% flowering and flowering duration. When averaged across all varieties, there was a reduction in both days to 50% flowering, from 99.8 days to 91.1 days and flowering duration from 69.3 days to 49.7 days when sowing was delayed from 28 April to 2 June, respectively (Table 2).

PBA Nasma$^{\text{⌽}}$ was the quickest variety to 50% flower at 86.4 days after sowing, significantly faster than all other varieties. In contrast, Nura$^{\text{⌽}}$ was slowest to 50% flower at 103.5 days after sowing, a variation of approximately 18 days between the fastest and slowest variety to flower. In addition, Fiesta VF and PBA Nasma$^{\text{⌽}}$ had the longest flowering duration with 63.8 days and 61.4 days, respectively, compared with Nura$^{\text{⌽}}$ and PBA Samira$^{\text{⌽}}$ which flowered for the shortest time with 50.2 days and 52.5 days respectively.

There were two differing patterns of days to 50% flowering and flowering duration. The first group, Nura$^{\phi}$, PBA Samira$^{\phi}$ and PBA Zahra$^{\phi}$ had a large and significant reduction in days to 50% flowering when sowing was delayed, whilst their flowering duration was more stable over this period as exemplified by the variety Nura$^{\phi}$ (Figure 2).

In contrast, the second group, PBA Nasma$^{\phi}$, Fiesta VF, Farah$^{\phi}$, AF09169 and AF10089 had significantly shorter flowering duration when sowing was delayed, with a more stable number of days to 50% flowering and reduced flowering duration, as exemplified by the variety PBA Nasma$^{\phi}$ (Figure 2).

Faba bean are indeterminate, continuously flowering until physiological maturity. Pod abortion and poor pod development can reduce the potential maximum yield. Pod abortion can be caused through high maximum air temperatures, frosts and low soil moisture conditions.

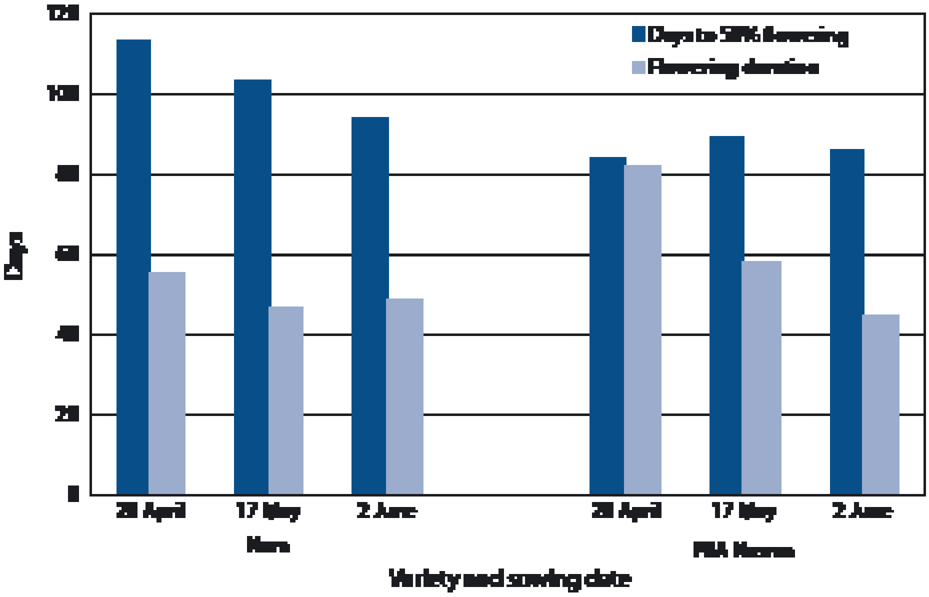


Figure 2. Days to 50% flowering and flowering duration for two faba bean varieties on three sowing dates at Wagga Wagga in 2016; days to 50% flowering l.s.d. ($P = 0.05$) = 2.6 days and flowering duration l.s.d. ($P = 0.05$) = 2.4 days.

Grain yield

There was a significant difference in grain yields across the three sowing dates. Grain yield achieved when sown on 28 April (4.11 t/ha) over all varieties was the same as the 17 May sowing date (4.13 t/ha), with both dates being within the recommended sowing window. This contrasted to the lower yield of 3.69 t/ha, a 10% reduction, when faba bean were sown outside the recommended window. The advanced breeding lines AF10089 and AF09169 had a significantly higher yield than all other varieties with 4.46 t/ha and 4.42 t/ha, respectively. PBA Samira$^{\phi}$ (3.78 t/ha), Farah$^{\phi}$ (3.73 t/ha) and Nura$^{\phi}$ (3.54 t/ha) had the lowest grain yield of the eight varieties when averaged across the three sowing dates.

There was significant variety by sowing date variation with PBA Nasma$^{\phi}$ and the two advanced breeding lines, AF09169 and AF10089, showing a reduction in grain yield with delayed sowing (Figure 3). This indicates that sowing these varieties in the earliest part of the recommended window is critical to maximise yield potential. Fiesta VF and PBA Samira$^{\phi}$ showed a more flexible response to sowing date with little to no loss of yield when sowing was delayed from 28 April until 2 June (Figure 3). PBA Zahra$^{\phi}$, Farah$^{\phi}$ and Nura$^{\phi}$ all showed a maximum grain yield when sown on 17 May with a reduction when sown earlier or later than this time (Figure 3), indicating that sowing within the middle of the window is important for optimising grain yield from these varieties.

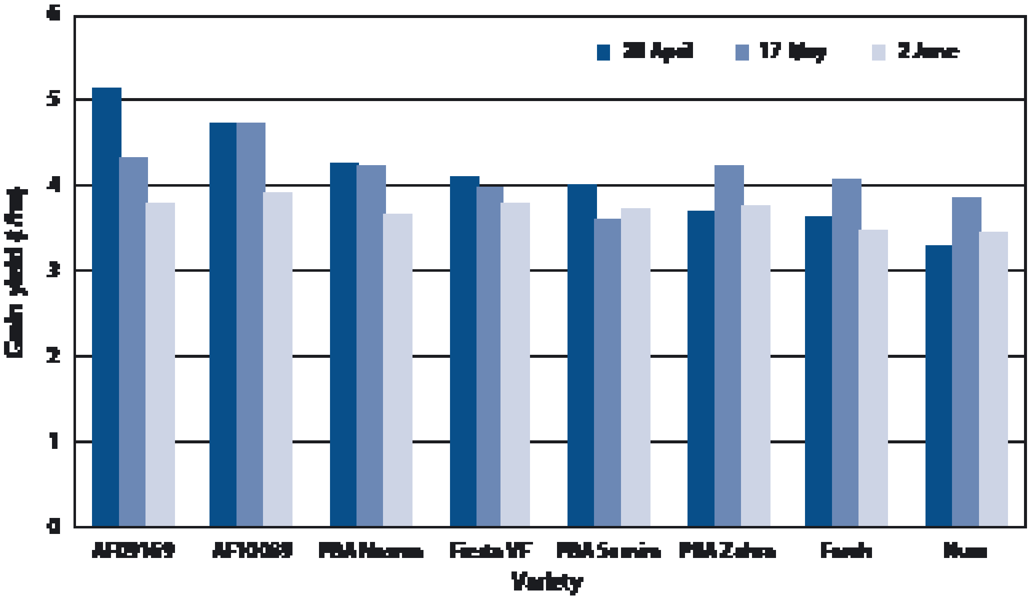


Figure 3. Grain yield for eight faba bean varieties sown on three sowing dates at Wagga Wagga in 2016; l.s.d. (*P*=0.05) = 0.57 t/ha.

Lodging

Lodging resistance is an important aspect of crop agronomy in faba bean as it confers improved harvest efficiency and enhanced fungicide penetration. Lodging in faba bean canopies contributes to fungal disease through poor airflow, which leads to higher humidity levels conducive to disease development.

There was significant reduction in lodging levels when sowing was delayed past 28 April. The average lodging score of all varieties was 7.8 for the 28 April sowing date, 4.1 for the 17 May sowing date and 1.8 for the latest sowing date of 2 June. There was genetic variation for lodging with a range from 2.4 for PBA Nasma⏀ to 6.6 for PBA Samira⏀.

Lodging varied for varieties when sown on the three sowing dates. PBA Nasma⏀ showed significantly improved lodging resistance when compared with all other varieties for the 28 April and 17 May sowing dates, except for the advanced breeding line AF09169 for the second sowing date (Figure 4). PBA Samira⏀, Fiesta VF and Farah⏀ showed high levels of lodging for both the first and second sowing dates (Figure 4). Considering that the first two sowing dates are within the recommended sowing window, the lodging score was above six, an exceptionally high value, indicating that there was a high tendency to lodge even when sown at an appropriate time.

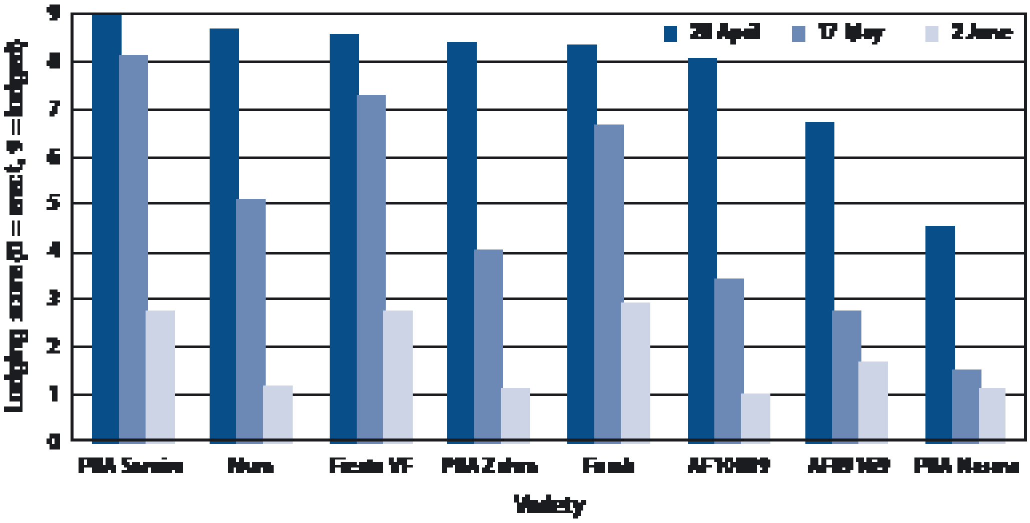


Figure 4. Lodging score for eight faba bean varieties sown on three sowing dates at Wagga Wagga in 2016; l.s.d. (*P* = 0.05) = 1.5 units.

Seed size

Across the varieties, seed weight tended to decrease with each later sowing date, from 63.6 g/100 seeds at the 28 April sowing date to 58.6 g/100 seeds at 2 June sowing date. Seed weights for 17 May and 2 June were 5.7% and 7.9% lighter than the 28 April sowing date, respectively. Farah had the lowest seed weight with 55.2 g/100 seeds, which was 14% lighter than the heaviest PBA Nasma at 65.3 g/100 seeds when averaged across three sowing dates.

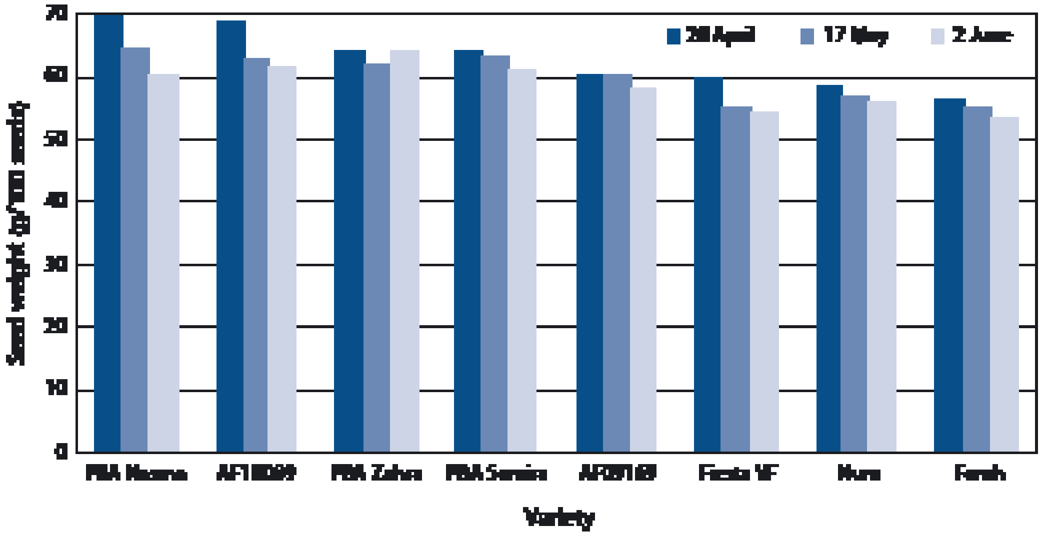


Figure 5. Seed weight for eight faba bean varieties for three sowing dates at Wagga Wagga in 2016; l.s.d. ($P = 0.05$) = 3.3 g/100 seeds.

PBA Nasma$^{(\phi)}$, AF10089 and Fiesta VF showed significant seed size increase at the first sowing date when compared with the second sowing date (Figure 5). In addition, PBA Nasma$^{(\phi)}$ also had a significant reduction in seed size between the second and third sowing dates (Figure 5). This could have resulted from the earlier maturity when compared with other varieties when soil moisture levels were not limiting.

For the faba bean varieties, PBA Zahra$^{(\phi)}$, PBA Samira$^{(\phi)}$, AF09169, Nura$^{(\phi)}$ and Farah$^{(\phi)}$, there was seed size stability across the three sowing dates that encompass the recommended sowing window.

Summary

Results from this experiment support previous research showing the importance of sowing faba bean within the recommended sowing window. The recommended sowing window in southern NSW is from late April until the middle of May. Crops sown before late April can result in excessive plant height, plant biomass, lodging and increased disease risk, whilst sowing after mid May can result in short plants, restricted dry matter accumulation and low grain yield potential.

A grain yield of approximately 4.1 t/ha was achieved when sown within the sowing window (28 April and 17 May). There was a 10% yield penalty when sowing was delayed from 17 May to 2 June, which is outside the recommended sowing window. The advanced breeding lines showed increased yield potential, especially when sown early within the recommended sowing window. There were variations between the varietal lines tested, showing the importance of individual varietal crop management to maximise yield potential.

Differing flowering patterns were seen between the eight faba bean varieties tested. Nura$^{(\phi)}$, PBA Samira$^{(\phi)}$ and PBA Zahra$^{(\phi)}$ showed significant reduction in days to flower with the delayed sowing date, leaving the days to flower across all sowing dates similar, irrespective of actual sowing date.

This contrasted to the flowering pattern of PBA Nasma$^{(\phi)}$, Fiesta VF, Farah$^{(\phi)}$, AF09169 and AF10089, where the days to flowering was fairly constant over the three sowing dates, but the flowering duration reduced significantly across sowing dates. Further research into crop management and time to 50% flowering and flowering duration needs to be undertaken to illustrate if these differences are seen in other years. This sowing date × phenology interaction is very important as it drives grain yield, especially in dry winter and spring seasons, or in highly frost-prone environments.

Mild winter and spring environmental conditions resulted in high lodging scores, with an average score at the first sowing date of 7.8, nearly twice the score at the 17 May sowing date at 4.8 and nearly four times at 1.8 for the 2 June sowing date. High lodging scores can result in complications with harvesting and harvest efficiency. All varieties except PBA Samira$^{\phi}$, Fiesta VF and Farah$^{\phi}$ had significantly lower lodging scores at the second sowing date. For each sowing date, the variety PBA Nasma$^{\phi}$ had the lowest lodging scores, showing resistance to lodging under southern NSW environmental conditions.

Seed size decreased with delayed sowing dates, with an approximate 5% and 8% reduction in weight from the 63.6 g/100 seeds at 28 April sowing date. Under the environmental conditions experienced in southern NSW in 2016, PBA Nasma$^{\phi}$ had slightly superior seed size when compared with PBA Zahra$^{\phi}$ and PBA Samira$^{\phi}$.

Timely sowing, in conjunction with appropriate varietal selection and management, can result in high yields in excess of 4 t/ha through long flowering duration and large seed size, offset against higher lodging and lodging severity when crops are sown within the recommended sowing window.

Growers also need to be aware that in cool, moist, extended springs, even late April sowings can be subject to greater disease pressure and require careful monitoring and implementation of a disease management strategy.

This experiment has also identified that PBA Nasma$^{\phi}$, a northern NSW varietal release, has the potential to adapt to growing within the southern NSW region, extending the available current varieties. Further research into agronomic management is required to maximise yields from PBA Nasma$^{\phi}$ in southern NSW as this variety exhibits contrasting phenotypic characters to the currently recommended southern varieties, PBA Samira$^{\phi}$ and PBA Zahra$^{\phi}$.

Acknowledgement

Thank you to Karl Moore, Russell Pumpa, Scott Clark and Jon Evans for technical assistance and Dr Neroli Graham for biometric support.

Faba bean sowing date – Lockhart 2016

Mark Richards (NSW DPI, Wagga Wagga), **Dr Neroli Graham** (NSW DPI, Tamworth), **Karl Moore, Russell Pumpa, Jon Evans and Scott Clark** (NSW DPI, Wagga Wagga)

Key findings

- Across all varieties tested, there was no significant response to sowing time, which validates the current sowing window recommendation. Therefore, the optimum time to sow faba bean at Lockhart in 2016 was late April–mid May.
- PBA Nasma⦶ and Fiesta VF were the two highest yielding commercial varieties.
- The advanced breeding lines AF10089 and AF09169, developed by Pulse Breeding Australia (PBA) were significantly higher yielding than all other varieties.
- PBA Samira⦶ and Nura⦶ yielded significantly higher when sown on 18 May compared to 28 April.
- Crop lodging was significantly less for the 18 May sowing date.
- PBA Nasma⦶ flowered 17 and 14 days earlier than PBA Samira⦶ and PBA Zahra⦶ at 28 April, and eight and six days earlier at 18 May.

Aim

To compare growth, development and yield of current commercial faba bean varieties and advanced breeding lines sown on two dates on a brown clay loam at Lockhart southern NSW.

Site details

Location	'Orange Park' paddock 001, Lockhart NSW
Soil type	Brown clay loam, pH_{Ca} 5.6 (0–10 cm)
Experimental design	Randomised split plot design with sowing date in the main blocks and varieties in the sub-plots; three replications
Paddock history	The previous crop was barley; paddock was burnt to remove stubble load
Fertiliser	75 kg/ha grain legume starter (N 0: P 13.8: K 0: S 6.1) placed 50 mm below the seed 150 g/ha sodium molybdate, 16 June
Plant population	Target: 30 plants/m^2
Sowing	Direct drilled using a six-row cone air seeder on 240 mm row spacing using DBS tines and GPS auto-steer
Inoculation	Group F peat inoculant was mixed directly into an onboard water tank then pumped through micro tubes into each sowing furrow
Weed management	Commercial practices were used aiming for weed-free experiments, eliminating both weed competition and weed seed set Fallow weed control: Roundup DST® (470 g/L glyphosate) 743 mL/ha, water 100 L/ha (8 January) Fallow weed control: Roundup DST® 1.2 L/ha, Amicide Advance 700® 476 mL/ha, Invader® 600 at 50 mL/ha, water 100 L/ha (5 February) Incorporated by sowing: Terbyne® 850 g/ha, Sencor® 700WG 250 g/ha, water 100 L/ha Post sowing: Select Xtra® 500 mL/ha, Factor® 180 g/ha, Supercharge® 100 mL/100 L, water 100 L/ha (8 August)

Disease management	Targeting chocolate spot (*Botrytis fabae* and *B. cinerea*) and ascochyta blight (*Ascochyta fabae*) Penncozeb® 750DF 2 kg/ha, water 100 L/ha (8 August) Penncozeb® 750DF 2 kg/ha, water 100 L/ha (16 September) Howzat® 500 mL/ha, water 100 L/ha (20 September) Bravo® 1.5 L/ha, water 100 L/ha (11 October)
Harvest date	15 December

Soil analysis

Table 1. Site soil characteristics for 0–10 cm depth at Lockhart in 2016.

Characteristic	Depth (0–10 cm)
pH_{Ca}	5.6
Aluminium (KCL) (cmol+/kg)	0.1
Nitrate N (KCL) (mg/kg)	18
Ammonium N (KCL) (mg/kg)	1
Sulphur (mg/kg)	7.1
Phosphorus (Colwell) (mg/kg)	54
Organic carbon (OC) (%)	1.4

Season

The 2016 season at Lockhart was one the wettest experienced, with 568 mm of growing season rainfall (GSR) from April to October, well above the long-term average. While the experiment site experienced intermittent waterlogging across the growing season, drainage was sufficient to avoid crop damage.

Pre-season rainfall from January to May varied; a very dry February and March (Figure 1) after a wet January resulted in soil moisture being marginal at sowing. Timely April rain contributed to good early sowing conditions. Rainfall from May to November was significantly higher than the long-term average, which filled the soil moisture profile leading into spring (Figure 1). This abundant winter moisture provided ideal conditions for plant growth and reproductive crop phases.

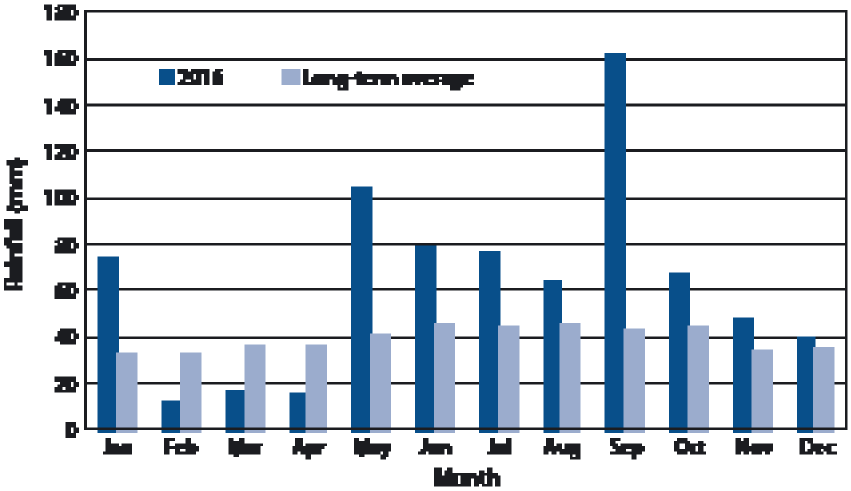


Figure 1. Monthly rainfall for Lockhart in 2016 and the long-term average.

Treatments

Varieties (8)

PBA Nasma$^{\phi}$, PBA Samira$^{\phi}$, PBA Zahra$^{\phi}$, Nura$^{\phi}$, Farah$^{\phi}$, Fiesta VF, AF09169, AF10089

Sowing date (SD)

SD1: 28 April
SD2: 18 May

Results

Establishment

Establishment was similar for the two sowing dates with 37.8 plants/m^2 and 34.9 plants/m^2 respectively when averaged over the eight varieties. All varieties had similar plant establishment at both sowing dates.

Grain yield

The advanced breeding lines AF10089 (4.12 t/ha) and AF09169 (3.63 t/ha) had significantly higher yields than all other varieties. PBA Nasma$^{\phi}$, PBA Samira$^{\phi}$, PBA Zahra$^{\phi}$, Farah$^{\phi}$ and Fiesta VF had similar yields, which were lower than the two advanced breeding lines.

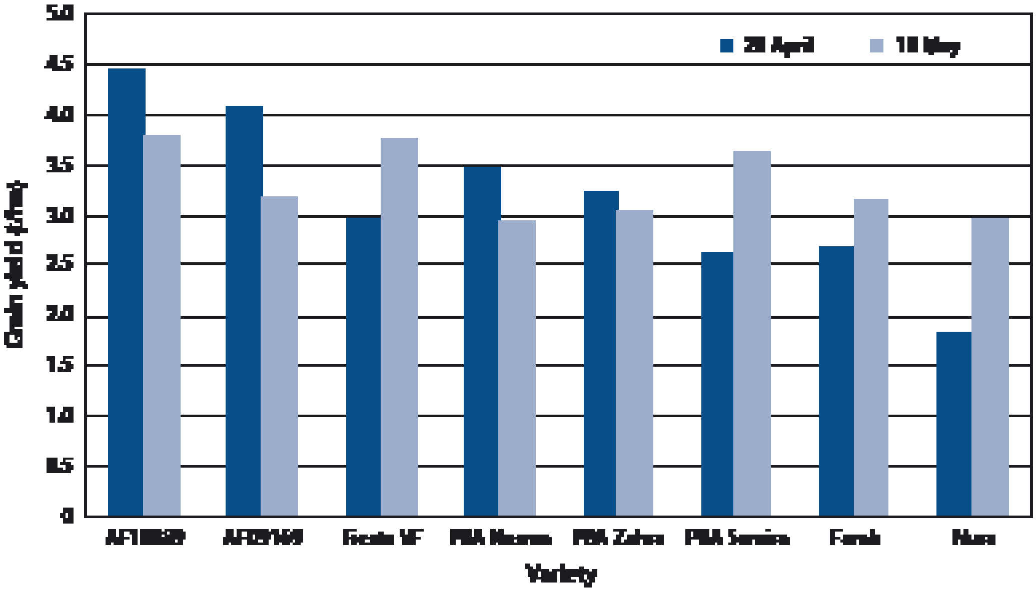


Figure 2. Grain yield for eight faba bean varieties sown on two sowing dates at Lockhart in 2016; l.s.d. ($P = 0.05$) = 0.85 t/ha.

The grain yield from AF09169 was significantly higher (22%) at SD1 than the later sowing on 18 May (Figure 2). PBA Nasma$^{\phi}$, AF10089 and PBA Zahra$^{\phi}$ had slightly higher grain yields at the 28 April sowing date compared with the 18 May sowing date. In contrast, PBA Samira$^{\phi}$ and Nura$^{\phi}$ had significantly higher grain yields when sown on 18 May – SD2 (Figure 2).

Days to 50% flowering

There was a reduction in the number of days to achieve 50% flowering when sowing was delayed from 28 April (100 days) until 18 May (95 days). There were significant genetic differences in days to 50% flowering with PBA Nasma$^{\phi}$ 90.5 days, to Nura$^{\phi}$ with 104.3 days when averaged across sowing dates.

Lodging

Sowing date significantly affected lodging score when averaged across all varieties. The average lodging score for SD1 on 28 April was 3.0, which was over twice the score for SD2 on 18 May with 8.4, where 1 = lodged and 9 = completely erect. There was variation between the varieties for lodging as Farah$^{\phi}$ had the highest lodging score with 4.6, while the advanced breeding line AF09169 had the least when averaged over the two sowing dates at 6.6 (Figure 3).

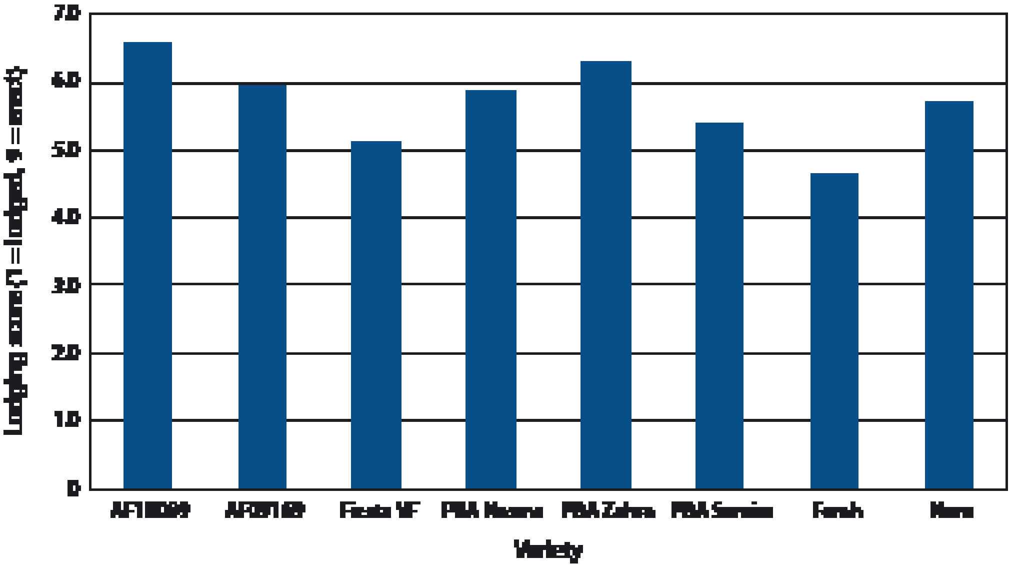


Figure 3. Lodging score (1 = lodged, 9 = erect) for eight faba bean varieties averaged over two sowing dates at Lockhart in 2016; l.s.d. (*P* = 0.05) = 0.9.

Seed size

Seed weight was heaviest at the earliest sowing date of 28 April with an average across all varieties of 70.4 g/100 seeds, which was 11% greater than that of the later sowing date of 62.3 g/100 seeds. There was a 25% variation in seed size with respect to variety, as PBA Nasma$^{\phi}$ had the heaviest seed weight with 77.3 g/100 seeds whilst Farah$^{\phi}$ had the lightest with 57.4 g/100 seeds when averaged across sowing dates. PBA Nasma$^{\phi}$ was significantly larger than all other varieties when averaged across sowing dates. This contrasted its seed size measurement in 2015 which was relatively small when compared to other varieties.

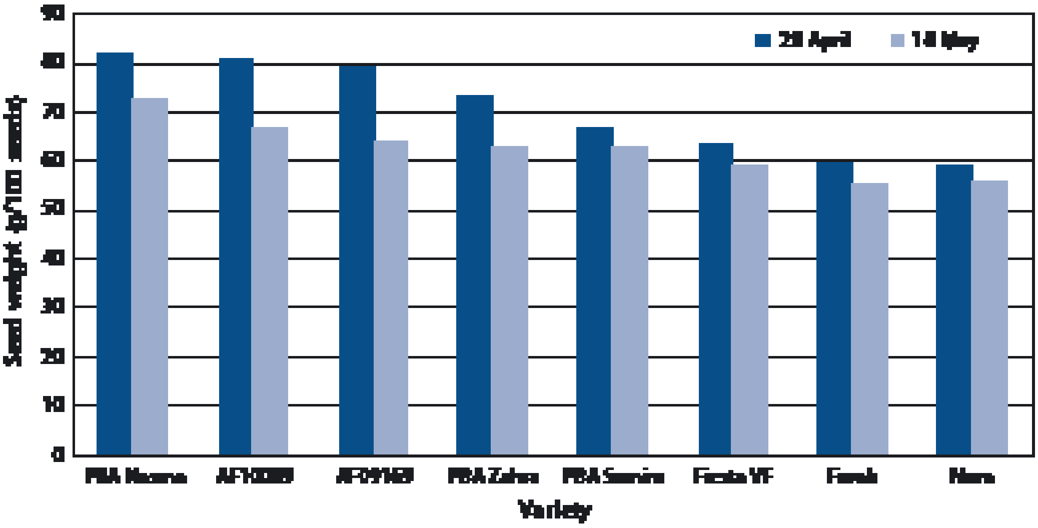


Figure 4. Seed weight for eight faba bean varieties sown on two sowing dates at Lockhart in 2016; l.s.d. (*P* = 0.05) = 3.9 g/100 seeds.

All varieties except PBA Samira$^{\phi}$ and Nura$^{\phi}$ had significant difference in seed weight between the first and second time of sowing (Figure 4). The difference between sowing dates for seed weight was greatest for advanced breeding lines AF10089 and AF09169 with 13.9 g/100 seeds and 14.9 g/100 seeds, respectively. Contrasting the non-significant difference between sowing was Nura$^{\phi}$ and PBA Samira$^{\phi}$ with 3.3 g/100 seeds and 3.5 g/100 seeds, respectively (Figure 4).

Interestingly, PBA Samira$^{\phi}$ and Nura$^{\phi}$ were the only varieties which yielded significantly higher when sown on 18 May compared to 28 April and were also the only varieties where seed weight was not significantly reduced by delayed sowing (figure 2 and 4).

Summary

Given the above average growing season rainfall (568 mm) with plenty of moisture throughout the growing season and grain fill period at Lockhart, the high yield results from this experiment must be considered in context. The similarity in grain yield, 3.16 t/ha and 3.31 t/ha at the two sowing dates of 28 April and 18 May, respectively was in part due to the high moisture levels throughout the growing season coupled with the mild winter and spring temperatures. There were differing responses to sowing date for grain yield with varieties, such as AF09169, AF10089 and PBA Nasma$^{\text{Ⓓ}}$ having higher yields when sown earlier on 28 April whilst PBA Samira$^{\text{Ⓓ}}$, Fiesta VF and Nura$^{\text{Ⓓ}}$ had higher yields when sown later on the 18 May.

The recommended sowing window for faba bean in Wagga Wagga, southern NSW is from late April until the middle of May. Sowing before late April might possibly cause crops to become excessively tall with high biomass that can lead to lodging and increased disease risks. Sowing after the middle of May decreases plant biomass and grain potential.

Lodging scores were highest for the first sowing date when compared with the second, due to ideal growing conditions and very few frosts. Fiesta VF had the highest lodging score (1.8) for the first sowing time.

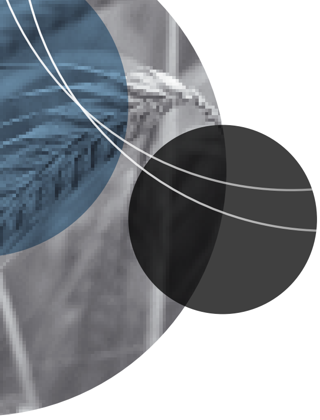
PBA Nasma$^{\text{Ⓓ}}$ and the two advanced breeding lines AF10089 and AF09169 had high seed weight over 63 g/100 seeds at both sowing dates, and more than 78 g/100 seeds when sown at the first sowing date.

PBA Nasma$^{\text{Ⓓ}}$, AF10089 and AF09169 have exhibited high grain yield in combination with low lodging and large seed size under these environmental conditions. Sowing within the recommended window for each particular variety helps maximise yield potential. Further research into agronomic management is required to maximise yields from PBA Nasma$^{\text{Ⓓ}}$ in southern NSW as this variety exhibits contrasting phenotypic characters to the currently recommended southern varieties PBA Samira$^{\text{Ⓓ}}$ and PBA Zahra$^{\text{Ⓓ}}$.

Acknowledgements

Thank you to John Stevenson, manager Warrakirri Cropping, Lockhart for the support of pulse research through provision of the experiment site.

Thank you to Karl Moore, Russell Pumpa, Scott Clark and Jon Evans for technical assistance and Dr Neroli Graham for biometric support.



Nutrition & soils

Response of six wheat varieties to applied nitrogen – grain yield and grain quality – Goonumbla 2016

Ian Menz, Nick Hill and Daryl Reardon (NSW DPI, Condobolin)

Key findings

- Short season variety, Condo$^{\phi}$ yielded the highest (5.75 t/ha).
- There was no significant difference between applying 40 + 40 kg N/ha (5.77 t/ha) split application and the single 80 kg N/ha (5.75 t/ha).

Introduction

This experiment evaluated the response to applied nitrogen (N) rates on grain yield and grain quality of six current varieties in the medium rainfall region of central western NSW. This experiment is part of a large set of experiments sown across NSW in a range of agronomic zones.

Site details

Location	Goonumbla
Soil type	Red-brown clay/loam
Previous crops	Wheat 2012, barley 2013, field peas brown manured 2014, canola 2015 Available N before sowing (February 2016) 69.62 kg N/ha (0–60 cm)
Fertiliser	70 kg/ha mono-ammonium phosphate (MAP) + Jubilee at 400 mL/ha (fungicide on fertiliser)
Sowing date	21 May
Growing season rainfall (1 April–30 September)	524.5 mm
Harvest date	1 December

Management

The experiment was sown into adequate moisture and established quickly and evenly. It was well maintained and weed-free throughout the season. Weed control at the site consisted of both grass and broadleaf herbicide applications. A pre-emergent mix was applied consisting of glyphosate at 1 L/ha + Triflur X® at 1.5 L/ha + Logran® at 50 g/ha. In-crop herbicide application consisted of Axial® at 300 mL/ha + Adigor® at 500 mL/100 L of water for grass control. Precept® at 1 L/ha + Lontrel™ at 300 mL/ha was applied for broadleaf control. Prosaro® at 400 mL/ha was applied for disease control.

Season conditions

The growing season rainfall at the experiment site was above average with Goonumbla receiving 524.5 mm for the growing season (April to September 2016) (Table 1). The site was elevated. No below zero frost events were recorded at the site.

Table 1. Monthly rainfall 2016 and long-term average (LTA), Goonumbla.

	Monthly rainfall (mm)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	In-crop
2016	111.0	5.0	29.0	44.0	51.0	114.0	93.0	63.5	159.0	35.0	43.0	50.5	798.0	524.5
LTA	57.6	49.1	47.4	41.4	47.2	49.5	49.1	49.2	41.8	52.4	49.5	53.0	587.2	278.2

Treatments

Wheat varieties

Condo⟨D⟩, EGA Gregory⟨D⟩, LongReach Lancer⟨D⟩, LongReach Spitfire⟨D⟩, Suntop⟨D⟩, LongReach Viking⟨D⟩

Nitrogen rates

0, 20, 40, 80, 40 + 40 split* and 160 kg N/ha sowing

*Split application 40 kg N/ha at sowing + 40 kg N/ha at first node stage (Z31)

Results

Grain yield

There was a significant difference (*P*<0.05) between the grain yield of the six varieties (Figure 1) and the response of grain yield to the applied N (Figure 2).

The highest-yielding varieties were Condo⟨D⟩ (5.75 t/ha) and Suntop⟨D⟩ (5.73 t/ha). LongReach Spitfire⟨D⟩ (5.19 t/ha) yielded the least.

There was a significant difference (*P*<0.05) between the N rates averaged across all the varieties. As applied N increased, so did the grain yield. The 160 kg N/ha treatment of applied N achieved the highest yield (6.26 t/ha). There was no significant difference between the split application of 40 + 40 (5.77 t/ha) and 80 kg N/ha (5.75 t/ha) (Figure 2).

Grain quality

There was a significant difference (*P*<0.05) in grain quality, protein, screenings and test weight between the six varieties (Table 2) and the six applied N rates (Table 3). The interaction between variety and N rates was not significant.

The grain protein concentrations in this experiment were low, ranging from 9.1% to 9.8%, below the wheat receival standard for Australian Premium White – APW (13% to 10.5%). This could be due to the high rainfall during the growing season leaching the available N down the soil profile away from the plant roots.

Screenings percentages were well in excess of the receival standards for the 5% milling grade. This could be due to the waterlogged conditions for this growing season. Screenings ranged from 7.42% for LongReach Viking⟨D⟩ to 16.67% for Condo⟨D⟩ (Table 2). Screenings were lower when higher rates of N were applied. Screenings in the 20 kg N/ha treatment were 3.2% higher than in the 160 kg N/ha of applied N.

Suntop⟨D⟩ (146.9 kg N/ha) had the highest grain nitrogen yield (Table 2). The highest grain nitrogen yield N treatment was 160 kg N/ha (173.3 kg N/ha). Zero applied N yielded 111.1 kg N/ha grain nitrogen, which was 62.2 kg N/ha less than the 160 kg N/ha treatment (Table 3).

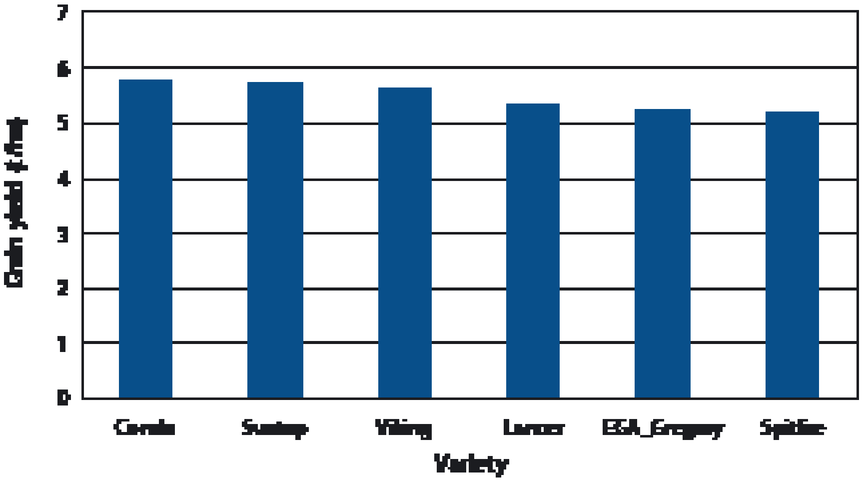


Figure 1. Grain yield (t/ha) of six wheat varieties sown at Goonumbla 2016; l.s.d. ($P<0.05$) = 0.204 t/ha. Meaned over nitrogen rates, applied as per treatment section.

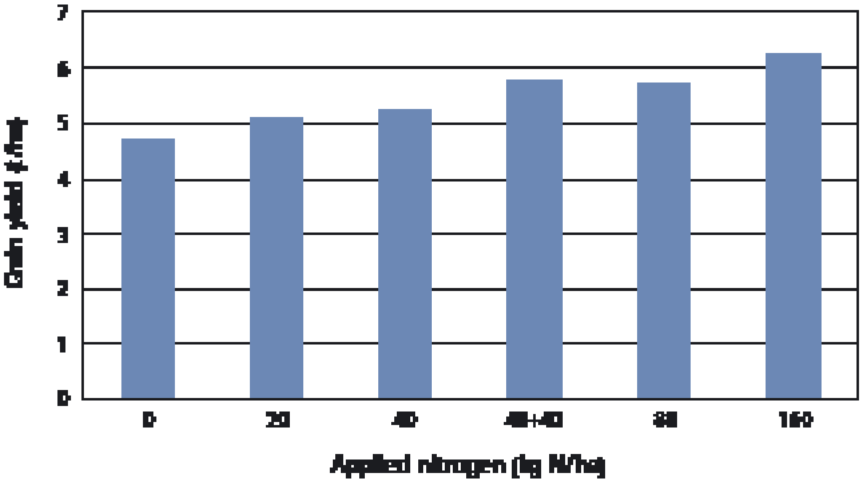


Figure 2 Grain yield (t/ha) of wheat (mean of six varieties) at six applied nitrogen rates at Goonumbla 2016; l.s.d. ($P<0.05$) = 0.205 t/ha.

Table 2. Grain quality of six current wheat varieties meaned over N rate at Goonumbla 2016.

Variety	Grain protein (%)	Grain nitrogen yield (kg N/ha)	Screenings (%)	Test weight (kg/hL)
Condo	9.2	140.2	16.7	84.8
EGA Gregory	9.1	127.5	12.9	86.8
LongReach Lancer	9.6	136.5	11.5	85.8
LongReach Spitfire	9.8	139.2	9.0	85.7
Suntop	9.5	146.9	9.5	85.6
LongReach Viking	9.1	136.0	7.4	86.3
l.s.d. ($P<0.05$)	0.2	6.2	0.2	0.3

Table 3. Grain quality of the mean of six wheat varieties sown at six applied N rates at Goonumbla 2016.

Nitrogen rate (kg N/ha)	Grain protein (%)	Grain nitrogen yield (kg N/ha)	Screenings (%)	Test weight (kg/hL)
0	8.9	111.1	12.5	85.1
20	9.0	121.1	12.7	85.3
40	9.1	127.8	11.9	85.5
40 + 40	9.6	149.1	10.4	85.8
80	9.4	143.8	10.0	85.8
160	10.4	173.3	9.5	85.9
l.s.d. ($P<0.05$)	0.2	6.3	1.3	0.3

There were significant differences in grain protein between varieties and applied N rates. There was a varietal and treatment range for grain protein percentage ranging from 8.5% (EGA Gregory⊕, 0 kg N/ha applied N) to 11.3% (LongReach Spitfire⊕, 160 kg N/ha applied N) (Figure 3). LongReach Spitfire⊕ had the highest protein with 11.3% in the 160 kg N/ha treatment, which was significantly higher than the other varieties.

Higher grain protein concentration was recorded from the increased N applied up to 160 kg N/ha. There was an increase in protein percentage when N was applied in a split format (40 + 40) compared with the single application of 80 kg N/ha at sowing.

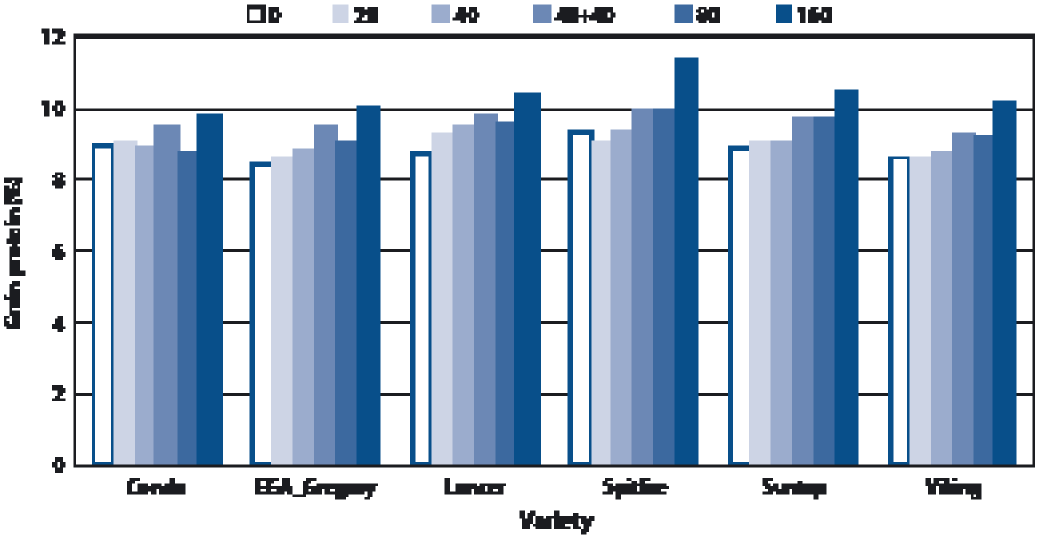


Figure 3. Grain protein (%) of six current wheat varieties at six applied nitrogen rates (kg N/ha) sown at Goonumbla 2016; l.s.d ($P<0.05$) = 0.43%.

Summary

The 2016 growing season rainfall at Goonumbla was well above average with a wet June (114 mm) and a wet September (159 mm), other months also had above average rainfall. The site, though elevated, had periods of waterlogging during June and September. The high rainfall and the waterlogging events could have contributed to the lower grain protein results by limiting the plant root growth thereby reducing the ability to source available nitrogen.

The short season variety, Condo⊕ was the highest yielding (5.75 t/ha), but had the highest screenings (16.67%) and lowest test weight (84.80 kg/hL). The mid-season varieties Suntop⊕ and LongReach Viking⊕ were the second and third highest yielding (5.73 t/ha and 5.62 t/ha respectively). These two varieties had low screenings and high test weights.

The screenings percentage was exceptionally high in this experiment. It was above the 5% specified as receival maximum for milling grade wheat. The high screenings could have been due, in part, to the wet conditions during the growing season, which might have caused root death resulting in lower nutrient and water uptake causing stress during grain filling.

Grain yield ranged from 4.73 t/ha for 0 kg N/ha applied nitrogen to 6.26 t/ha for the 160 kg N/ha applied nitrogen. This response could have been a result of soil-available nitrogen being moved down the soil profile and not being available to plant roots.

Acknowledgements

This experiment was part of the project 'Variety Specific Agronomy Packages for southern, central and northern New South Wales', DAN00167, 2012–17, with joint investment by GRDC and NSW DPI.

Thanks to North Parkes Mines for the experiment site, technical officers at Condobolin Agricultural Research and Advisory Station and the Crop evaluation unit, Dubbo, and Dr Neroli Graham for statistical analyses.

Improving nitrogen fertiliser use efficiency in wheat using mid-row banding

Graeme Sandral, Dr Ehsan Tavakkoli, Dr Felicity Harris, Eric Koetz (NSW DPI, Wagga Wagga) **and Dr John Angus** (Graham Centre, Wagga Wagga)

Key findings

- Nitrogen offtake in grain was higher with mid-row banding urea than urea broadcast and incorporated by sowing for both Beckom$^{\phi}$ and LongReach Spitfire$^{\phi}$ at the 80, 120 and 160 rates of N application.
- Apparent fertiliser recovery in grain was also higher from mid-row banding urea than from urea broadcast and incorporated by sowing in five of the possible eight treatment comparisons.
- Soils cored at stem elongation from the mid-row banding treatment showed higher ammonium levels in the top 20 cm and lower nitrate concentration at 60–100 cm than urea broadcast and incorporated by sowing.
- Roots proliferated around and below the original mid-row banding. These results indicate potential for mid-row banding to improve N use efficiency.

Introduction

Fertiliser costs represent a significant component of variable costs for growing grain crops and are estimated to represent 15–20% of all cash costs and 20–25% of variable costs. The high cost of fertiliser has caused grain growers to focus on nutrient management in an attempt to control input costs and reduce financial risk. Typically, nitrogen (N) fertiliser is applied to wheat at sowing (e.g. mono-ammonium phosphate – MAP and di-ammonium phosphate – DAP) and again in the vegetative phase around stem elongation as urea. The in-crop efficiencies of fertiliser N retrieval vary greatly, with approximately 44% in above-ground plant parts, 34% in soil, and 22% not recovered (Pilbeam 1996). Increases in the efficiency with which wheat extracts fertiliser N from the soil can result in significant fertiliser savings. In this experiment, we compare three methods of N supply to wheat:

1. surface spread in front of the seeder (early May)
2. mid-row banding at sowing (early May)
3. surface spread at stem elongation (late July).

The difference method was used to evaluated the efficiency of each.

Site details

Location	Wagga Wagga Agricultural Institute, Wagga Wagga
Soil type	Red chromosol, pH_{Ca} 5.1 in the 0–10 cm layer with a starting N content of 142 kg/ha down to 150 cm, measured on 4 May 2016
Experimental design	Randomised complete block design with six rates of N used in each of three methods of N application, all of which were tested on two varieties of wheat in a four-replicate experiment (Table 1)
Stubble management	Experiment was direct drilled into light 1.0 t/ha canola stubble on 5 May 2016
Fertiliser	At sowing phosphorus (P) as triple super was drilled 50 mm below seed at a rate of 25 kg P/ha
Sowing date	5 May 2016
Plant population	The mean plant density achieved was 125 plants/m^2 counted at DC14 There were no significant treatment effects on plant density
Sowing	The experiment was direct drilled with DBS tynes spaced at 240 mm

Weed management	Weed management included glyphosate (450 g/L) at 1.2 L/ha plus 2,4-D (625 g/L) at 320 mL/ha during the fallow period (January–April 2016) Weed control was undertaken by applying the pre-emergent Sakura® (pyroxasulfone 850 g/L) at 118 g/ha and Logran® (triasulfuron 750 g/L) at 35 g/ha on 4 May 2016 and was incorporated at sowing
Insect management	Aphids were controlled at late stem elongation by applying Aphidex® (Pirimicarb 500 g/kg) at 250 g/ha
Disease management	Precautionary disease control was implemented. Seed was treated with Hombre® Ultra (imidacloprid 360 g/L and tebuconazole 12.5 g/L) at 200 mL/100 kg. Prosaro® (prothioconazole 210 g/L and tebuconazole 210 g/L) was 300 mL/ha at DC 30 and 37 to prevent and/or supress rust infections.
Harvest date	15 December 2016
Rainfall	A total of 587 mm rainfall was recorded at the experiment site during 2016. The growing season rainfall (GSR) was 368 mm.

Treatments

Table 1. Varieties, N rates and N application methods.

Variety	N rate (kg/ha)	N application method
Beckomⓓ	0	Banding: mid-row banding (4 May)
LongReach Spitfireⓓ	25	PreSowing: spread pre-sowing (4 May)
	50	DC30: spread at growth stage DC30 (14 July)
	80	
	120	
	160	

Note: All nitrogen applied as urea.

Measurements

Nitrogen take-off

Nitrogen take-off was estimated by protein (%) ÷ 5.7 (conversion constant) × grain yield (t/ha).

Nitrogen fertiliser use efficiency (NUE)

NUE is estimated by (N take-off from plots where N is applied) minus (N take-off from plots where no N applied), divided by rate of N fertiliser added.

Seed measurements

Grain protein and grain seed quality were estimated using NIR (Foss Infratec 1241 Grain Analyzer) and seed imaging (SeedCount SC5000R) respectively.

Economic returns

Economic returns after N costs were calculated using 2017 prices × grain yield (t/ha) at the plot level. Grain value per tonne was either $160 (ASW1, <10.5% protein), $181 (APW1 >10.5% protein), $209 (H2 >11% protein) or $243 (APH2 >13% protein). Test weight, screenings and stained grain were within grain category standards so were not included in the calculations. Cost of N was assumed to be $1/kg of N (i.e. $460/tonne of urea at 46% N).

Results

Nitrogen use efficiency

Nitrogen take-off in grain was used as an estimate of NUE. Applying N at sowing using mid-row banding and surface spreading N at stem elongation (DC30) had higher N take-off than N spread and incorporated at sowing (Table 2). This efficiency difference was evident across most N rates from 50 kg N/ha to 160 kg N/ha and occurred even when different N partitioning (yield verses protein) was evident between the two wheat varieties (Beckomⓓ – high yields verse LongReach Spitfire$^{(D)}$ – high protein). The highest N take-off occurred at 160 kg N/ha, while the highest grain yields were achieved at 120 kg N/ha.

Economic returns after considering N costs, wheat variety, grain protein, screenings, test weight and stained grain are estimated for Beckom$^{(D)}$ and LongReach Spitfire$^{(D)}$ respectively. Returns for Beckom$^{(D)}$ were highest in the N banding treatment at 80 kg N/ha ($1,409), while the highest return for the DC30 and pre-sowing treatments occurred at 120 kg N/ha ($1,397 and $1,343 respectively). Returns for LongReach Spitfire$^{(D)}$ were highest in the N banding treatment at 120 kg N/ha ($1,420) and highest for the DC30 and pre-sowing treatments at 160 kg N/ha ($1,347 and $1,305 respectively). Mid-row banding was more profitable for LongReach Spitfire$^{(D)}$ with 120 kg N/ha of banded compared to other methods and rates of N application.

Table 2. Grain yield (t/ha), protein (%), N take-off (kg N/ha) and net return after N costs for Beckom$^{(D)}$ and LongReach Spitfire$^{(D)}$ calculated at the plot level.

Treatment	**Beckom$^{(D)}$**				**LongReach Spitfire$^{(D)}$**			
	Grain yield (t/ha)	**Protein (%)**	**N take-off (kg/ha)**	**Net after N costs ($/ha)***	**Grain yield (t/ha)**	**Protein (%)**	**N take-off (kg/ha)**	**Net after N costs ($/ha)***
nil_0	5.9	10.5	110.9	1,019	5.2	10.6	97.0	891
seed_25	6.2	10.3	111.7	1,030	5.6	10.8	106.0	955
Banding_50	6.8	11.3	133.7	1,201	5.7	12.9	130.2	1,247
Banding_80	7.1	12.0	150.2	**1,409**	6.0	13.5	141.4	1,322
Banding_120	**7.3**	12.2	155.7	1,399	**6.3**	13.9	154.8	**1,420**
Banding_160	**7.3**	**12.7**	**161.9**	1,360	6.2	**14.6**	**159.2**	1,355
DC30_50	6.8	11.0	132.2	1,248	5.6	12.5	123.9	1,174
DC30_80	7.0	11.5	142.4	1,340	5.9	13.2	136.8	1,253
DC30_120	**7.3**	12.4	157.2	**1,397**	**6.2**	13.2	144.8	1,292
DC30_160	**7.3**	**12.7**	**161.9**	1,363	**6.2**	**14.5**	**157.2**	**1,347**
PreSowing_50	6.6	10.5	122.2	1,079	5.7	12.6	125.4	1,147
PreSowing_80	6.9	11.3	137.8	1,225	5.7	12.6	127.0	1,166
PreSowing_120	**7.2**	11.8	147.7	**1,343**	**6.1**	12.9	137.9	1,252
PreSowing_160	7.1	**12.1**	**151.6**	1,333	6.0	**13.4**	**141.7**	**1,305**
l.s.d. $P = 0.05$	0.3	0.90	7.6	114	0.3	0.92	7.6	114

Note: Bold indicates the highest value within each nitrogen treatment.

* Economic returns after N costs are based on: $1/kg of N; and wheat price $160/t (ASW1), $181/t (APW1 >10.5% protein), $209/t (H2 >11% protein), $243/t (APH2 >13% protein).

Nitrogen profiles

Figure 1 shows soil nitrogen in samples taken from plots sown to Beckom$^{(D)}$ with 160 kg N/ha applied. N applied pre-sowing and measured at DC31 was converted to nitrate and leached down the soil profile to a depth of 60–100 cm (Figure 1a). The mid-row band method of N application had large amounts of N present as ammonium in the 10–20 cm layer (Figure 1b), which did not leach below the coring depth even under very wet conditions conducive to leaching. N applied to the soil surface at DC30 (14 July) and measured at DC31 (29 July) was largely in the ammonium form in the 0–10 cm layer (Figure 1c).

Nitrogen recovery

The proportion of apparent fertiliser N recovery in grain was higher for LongReach Spitfire$^{(D)}$ than Beckom$^{(D)}$. There was also a tendency for the proportion of apparent fertiliser N recovery in grain to be higher in mid-row banding compared with the pre-sowing method of N application; although this did not occur at all N rates (Figure 2).

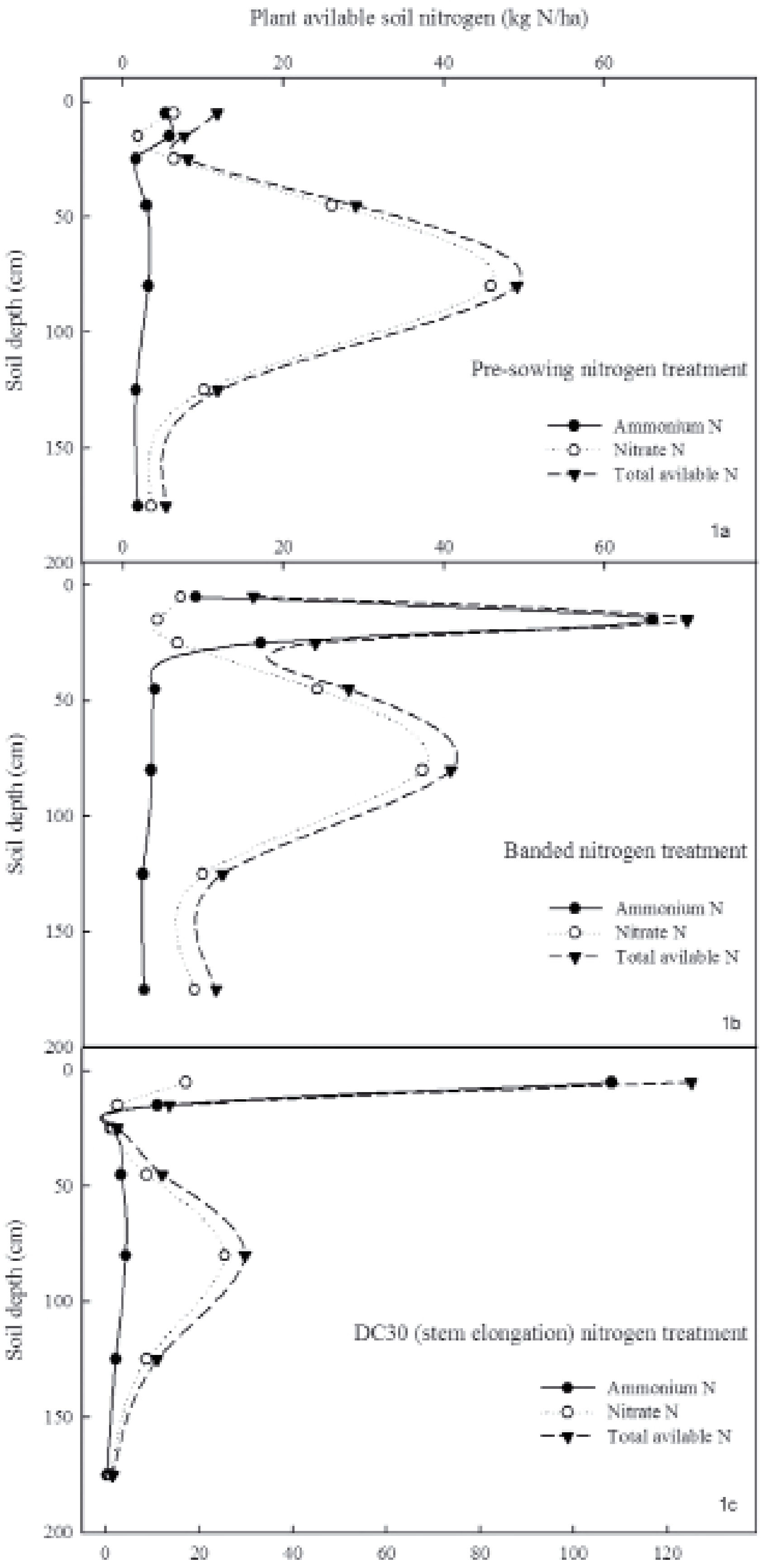


Figure 1. Soil nitrate (dotted line, open circle), ammonium (solid line, closed circle) and total soil available N (dashed line, closed triangle), (kg/ha) measured at DC31 (last week of July) from plots sown to Beckom$^{\Phi}$ with 160 kg N/ha applied as spread pre-sowing, mid-row banded or spread at DC30. Soil measurement depths were 0–10 cm, 10–20 cm, 20–30 cm, 30–60 cm, 60–100 cm, 100–150 cm and 150–200 cm. For graphing purposes, the soil depth data is presented at the following depths 5 cm, 15 cm, 25 cm, 40 cm, 80 cm, 125 cm and 175 cm. Topdressing of urea at DC30 occurred 15 days before soil coring.

Root proliferation

Root length (cm) next to banded urea was measured in the 160 kg N/ha treatments at anthesis on variety Beckom$^{\phi}$, by taking soil cores 6 cm away from the crop row and 6 cm away from the mid-row band (Table 3). Total root length in the 10–20 cm layer was significantly ($P = 0.05$) higher for the mid-row banding N treatment than for the other treatments. Total root length in the pre-sowing N treatment was significantly higher than the other treatments in the 60–100 cm layer. Root length proliferation in nutrient-rich sections of the soil has been shown in other species to significantly increase the efficiency of nutrient retrieval and is a promising feature of this research.

Table 3. Root length (cm) of variety Beckom$^{\phi}$ at anthesis measured in the 160 kg N/ha treatments for depths 0–10 cm, 10–20 cm, 20–30 cm, 30–60 cm, 60–100 cm and 100–150 cm.

Treatment	**Depth (cm)**						
	0–10	**10–20**	**20–30**	**30–60**	**60–100**	**100–150**	**Total**
nil_0	2247	204	148	771	1035	65	4470
Banding_160	2375	1126	373	901	1436	49	6260
DC30_160	2160	510	210	755	1243	35	4913
PreSowing_160	1427	546	218	860	1716	70	4837
l.s.d. ($P = 0.05$) = 341							

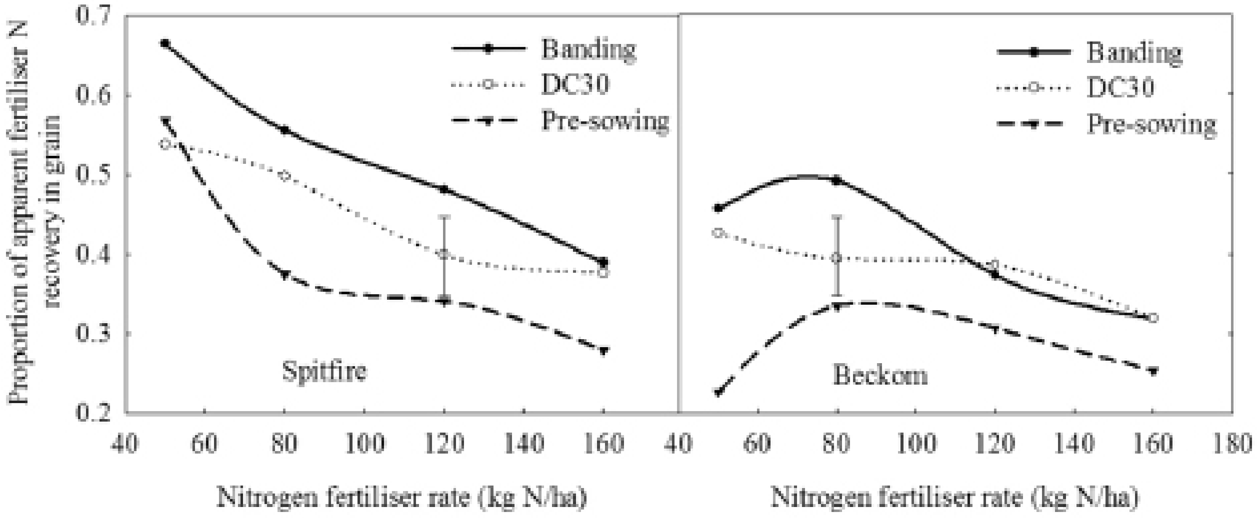


Figure 2. Apparent fertiliser-N recovery in grain for varieties Spitfire and Beckom in relation to three methods of N application and four N rates.

Summary

Mid-row banding of N shows promise as a strategy to improve N-use efficiency in wheat. This work has shown that banding urea creates an ammonium tube in the soil that is not readily leached. It also shows that wheat can proliferate root length around the ammonium band (Table 3), which has been shown to increase nutrient use efficiency in other species. The highest N removal rates were achieved by banding; the most profitable rate of applied N was lower for banded N fertiliser than for applied N from other application methods.

Reference

Pilbeam CJ (1996). Effect of climate on the recovery in crop and soil of 15N-labelled fertilizer applied to soil. *Fertilizer Research*. Vol 45: 209–215.

Acknowledgements

This experiment was internally funded by NSW DPI, with technical support from BinBin Xu, Vincent Van Der Rijt, Graeme Poile, Wayne Pitt, Andrew Price, Hugh Kanaley, Greg McMahon, Jessica Simpson and Hayden Petty.

Decisions used by NSW grains industry advisers to determine nitrogen fertiliser management recommendations

Dr Graeme Schwenke (NSW DPI, Tamworth); **Luke Beange** (NSW DPI, Dubbo); **John Cameron** (Independent Consultants Australia Network – ICAN, Hornsby)

Key findings

- Making nitrogen (N) management decisions requires an understanding of soil and plant science, and soil test interpretation.
- Training new agronomists is a priority.
- Senior NSW agronomists identified crop yield expectation as guided by soil moisture at sowing (or at the time of N decision making) as the most important determinant of N fertiliser requirement.
- Further research will increase the understanding of how management practices affect potentially large gaseous N losses.
- Changing from legume pasture-crop sequences to continuous cropping in many central and southern areas of New South Wales is posing new questions for managing N supply. Less frequent pasture legume phases with their N-fixation benefits to the soil is seen as a substantial loss of N-buffering capacity.
- Despite most advisers choosing soil testing as a key approach for determining N fertiliser required, many of their clients had a lower confidence in soil testing, citing 'high perceived variability in soil nitrate results in the lead up to sowing'.

Introduction

There is concern that grower and adviser decisions related to nitrogen (N) management in field crops are often inaccurate, despite the range of decision tools available to inform and assist. Factors that potentially contribute to sub-optimal decisions on N management include variable rainfall patterns, climate change, declining soil organic matter, using no-tillage, and a declining frequency of legumes in farming systems. A survey was conducted to improve our understanding of how advisers make decisions relating to field crop N nutrition in order to better target assistance to Australian grain growers and their advisers to reduce the uncertainty and financial risk associated with N management.

The survey was conducted across Australian grains regions to better understand the knowledge, perceptions, current practices, and the assumptions underpinning the practices of grain industry advisers when providing advice on N management. This information, combined with a literature review of Australian research into N processes in cropping soils, will help identify knowledge gaps and develop new research programs for grain growing areas.

This paper presents the findings from the NSW component, which included an on-line survey of grains industry advisers and subsequent detailed interviews with a state-wide selection of selected senior respondents to further examine their responses.

Survey details

A multiple choice survey, based on common questions developed by the national project team, was used to gauge the practices of grains consultants. Hardcopy surveys and email requests were sent out to advisers throughout New South Wales from September to November 2015 using the online portal, Survey Monkey. In total, 132 advisers responded from across the NSW grains area. Of these, 105 provided their postcode, which enabled the geographical spread of respondents to be mapped (Figure 1). Forty-seven percent of respondents were from the northern region, 20% from central and 33% from southern NSW. Given that each adviser represents a client base, the survey results encapsulate advice given to a large cross-section of the NSW grains farming sector.

In addition to the survey, more detailed phone interviews were conducted for 45–70 minutes with 11 senior advisers, grouped by three regions within the state: northern, central and southern NSW. During the phone interviews, the original survey questions were revisited, with the responses explored further using additional open questions and pre-determined prompts.

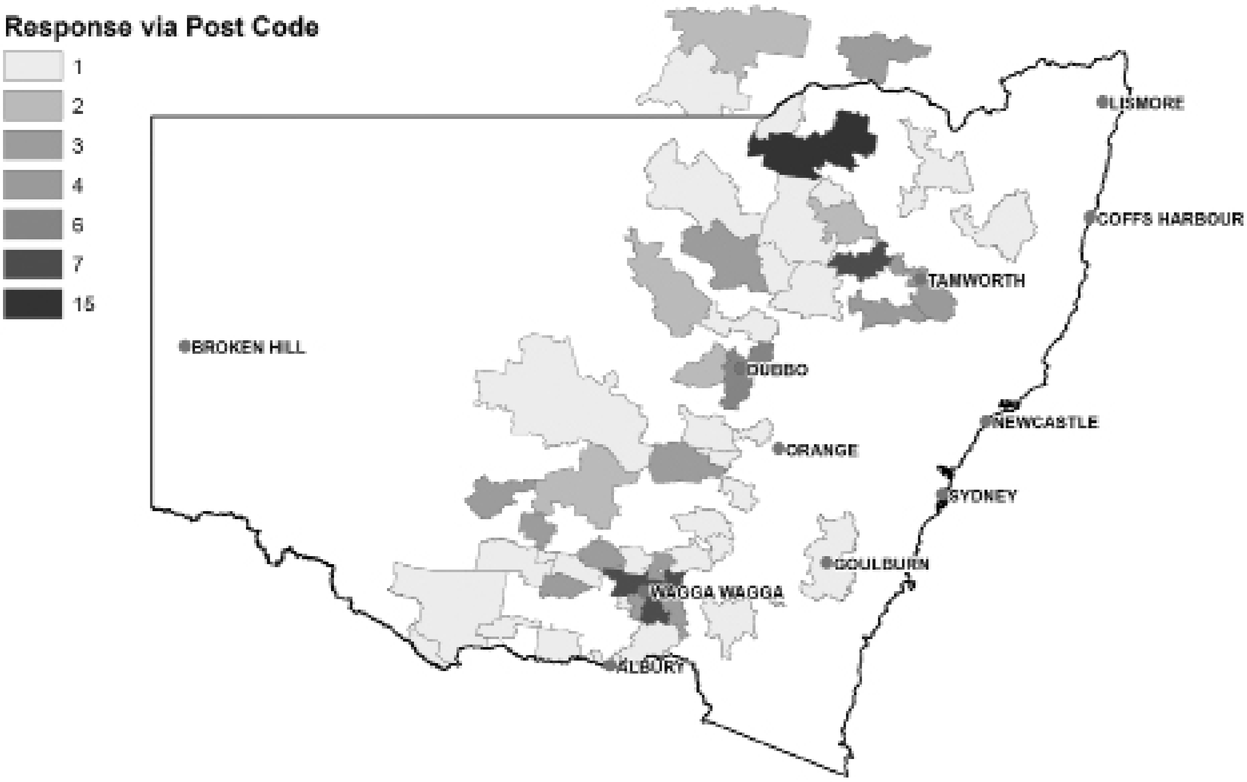


Figure 1. The geographical frequency and distribution of survey respondents by region.

Results

- Soil moisture at sowing (or at the time of N application decision-making) was identified as the most important determinant of N fertiliser requirement by nine of the 11 senior agronomists interviewed. Other factors considered important included: seasonal conditions, crop rotation, soil testing, financial risk, in-season crop assessment and previous paddock history.
- Respondents used decision support systems (DSS) for some of their decision making. Several of the interviewed advisers said they used DSS tools to help them understand issues and to challenge their thinking under certain circumstances. The learning gained from the DSS is then applied in future decision making. Examples of DSS used in northern NSW included SoilMate™ (Back Paddock Company) and N Balance (Herridge 2011). The John Angus N model/spreadsheet was similarly well respected and used by senior advisers in southern NSW. Yield Prophet was used by several senior advisers (mainly in southern NSW), primarily for helping to develop more accurate yield estimates based on soil water present at the time of decision making. Accurate soil characterisation was considered core to this system's accuracy.
- Senior advisers gained their knowledge from leading experts by attending GRDC Updates, formal training events and personal contact, as well as experience with their own clients. There is an ongoing need for adviser access to expert advice, plus the availability of detailed and well-delivered training targeted to advisers' needs.
- Senior advisers reported that a client's attitude to risk influences their N recommendation, with more conservative growers aiming for a lower input/lower risk system. In some instances, the amount of N applied is limited by available funds rather than a cost/benefit estimate. However, in the higher yielding, more reliable cropping zones of the state, advisers recommend applying higher rates of N fertiliser to maximise long-term profit, and growers generally follow this advice.
- N contribution from legumes is considerable in southern NSW where long pasture phases, dominated by lucerne, are often an integral part of the farming system. However, in central west NSW, farmers are moving away from pasture ley mixed farming to continuous

cropping. Advisers in the centre and north of the state highlighted the low contribution of N from crop and pasture legumes in these areas as a major constraint to production.

- Most advisers believe they have a very good understanding of the mechanisms behind their approach to N recommendations and factors such as mineralisation rates, yield, N and protein budgeting. As a result, most respondents felt their recommendations were generally reliable with the occasional failure when seasonal conditions were contrary to predictions, as occurred in the 2015 season.
- Most advisers felt that their N fertiliser recommendation needed to be within 10–15% of yield potential, and that their prediction of yield potential needed to be within 10–25% of the actual yield. Greater accuracy is not possible due to the many variables affecting yield and the inherent variability in parameters measured or estimated through rules of thumb.
- Soil tests were considered moderately to very important, with testing often used as a tool to help determine recommendations. Senior advisers said it was uneconomic to test as rigorously as was required to achieve a high level of accuracy, and moreover a significant number of growers had confidence issues with soil testing, with perceived high variability in soil nitrate results often reported in the period before sowing. Northern region advisers stratified soil tests by depth increments and were likely to carry out soil testing earlier in the fallow period than their southern counterparts, as N fertiliser is more likely to be applied pre-sowing in this region. In southern NSW, testing is conducted nearer to sowing as N is mostly applied post-sowing.
- Eighty percent of advisers indicated that they account for pre-sowing mineralisation in their recommendations, with 70% also accounting for in-crop mineralisation. Estimates of N mineralisation were usually based on rules of thumb derived from years of research and practical on-farm experience.
- When making recommendations, 86% of advisers accounted for how efficiently plants absorb N, with interviewed advisers commonly using a factor of 50% conversion efficiency of N fertiliser to grain N.
- N losses (leaching or gaseous) were accounted for by 40% of advisers. The understanding of gaseous N losses was better in northern NSW, where research over the past few years had been well publicised, than in southern NSW where no recent field work had been conducted.
- In the online survey, denitrification as di-nitrogen gas (N_2) was considered the major source of N loss by 40% of advisers, with a further 31% of respondents stating leaching and 23% stating ammonia volatilisation as the cause for losses from the system. Greater emphasis was placed on denitrification as the key loss pathway in interviews with senior advisers. However, as denitrification losses were generally associated with significant waterlogging events that were difficult to predict and sporadic in most regions, losses due to these pathways were generally seen as outlier events and not considered in N budgeting.

Conclusions and recommendations

- Senior advisers highlighted the importance of rigorous training in N decision-making, understanding the background soil and plant science involved, and soil test interpretation for the next generation of agronomists. They supported the availability of training courses that included representation from highly experienced local agronomists.
- The understanding of gaseous N losses requires further research, development and extension to the grains industry. Recent field research in the north was limited in scope and produced challenging outcomes that are already leading to large practice changes for when and how N fertiliser is applied. Further research and development work is warranted to answer more of the practical questions growers and advisers are asking in regards to losses associated with certain alternative practices.
- The northern NSW results on N loss pathways are less relevant to advisers in the central and southern NSW regions where N application timing, soil type and climate are quite different from the north. N loss research is recommended for the lighter-textured soils, more typical of central and southern NSW, in regards to the potential for N volatilisation losses from surface N application. Economic outcomes from the various strategies being practiced are

also needed. Nitrogen loss research should focus less on expensive slow-release products and more on optimising results from urea, the cheapest N source.

- Research into better soil water measurement was highlighted as a priority area, especially given the importance all advisers place on this when making N-fertiliser decisions for the cropping season. Zonal management within paddocks is not possible with single site characterisations, so atypical areas of paddocks are over- or under-fertilised.
- Applying N fertiliser early, ahead of a winter cropping season, is a well-established practice in the northern grains region. However, what is not known is how well the pre-applied N might be protected from denitrification resulting from later flooding events. Greater knowledge on specific N use within the profile during the cropping season would assist with decisions related to the accessibility of late-applied N for plant uptake.
- State-wide, agronomists highlighted N mineralisation as an area for greater understanding with regards to the differences caused by climatic conditions, especially rainfall. Better understanding of the N produced from both native organic matter and recent legume pasture residues was also requested.
- There are several useful decision-support tools currently available, with the suggestion to combine the best points of each into one package, preferably available as an app with grower-friendly reports.
- Some advisers noted that farmers don't always have confidence in the accuracy of pre-sowing soil nitrate testing results. This might be related to a range of factors including poor sampling methods, incorrect sample handling, insufficient sample numbers, inadequate service from laboratory analysts, or inaccurate interpretation of the results. Soil testing is often regarded as an expensive option, with some advisers looking for quicker, more cost-effective methods for estimating soil mineral N.
- Some senior advisers see variety-specific N management packages as key areas for continued research funding, as results from some new varieties have been quite different in terms of N uptake and protein outcomes.

Reference

Herridge DF (2011). *Managing legume and fertiliser N for northern grains cropping.* (Grains Research and Development Corporation: Kingston, ACT, Australia).

Acknowledgements

This survey and follow-up interview series was part of the project ‘Organic matter and nutrient availability’, UQ00079, a collaborative project with joint investment by GRDC and the state agencies and universities in Queensland, NSW, Victoria, and Western Australia. Special thanks to Fiona Pearson (NSW DPI) for transcribing the hard copy surveys, to Georgia Rose and Erica McKay (ICAN) for collating the survey data and transcribing the interviews, and to Helen Squires (NSW DPI) for producing the map.

Managing subsoil acidity – project overview

Dr Guangdi Li, Richard Hayes, Dr Ehsan Tavakkoli, Helen Burns, Salahadin Khairo and Dr Neil Coombes (NSW DPI, Wagga Wagga); **Caixian Tang, Peter Sale and Clayton Butterly** (La Trobe University, Melbourne); **Dr Sergio Moroni and Dr Jason Condon** (Charles Sturt University, Wagga Wagga); **Dr Peter Ryan** (CSIRO, Canberra); **Tim Condon** (Delta Agribusiness, Harden)

Key findings

- Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia.
- More aggressive methods, such as deep ripping in conjunction with lime or other amendments, are being tested to achieve rapid changes to pH at depth.
- A long-term field experiment was established to study changes in the chemical, physical and biological properties of soil under vigorous soil amelioration techniques.

Introduction

Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia (Pinkerton & Simpson 1986; Scott et al. 1997). Approximately 50% of Australia's agriculture zone (~50 million hectares) has a surface soil pH <5.5 in calcium chloride (pH_{Ca}); half of this area also has subsoil acidity (Dolling et al. 2001).

Soil acidification is accelerated by:

- nitrate leaching under certain crop rotations
- using ammonium-based fertilisers
- regular removal of plant products, such as grain or hay.

The major constraint to plant production on acid soils is aluminium (Al) toxicity, which inhibits root growth even at very low concentrations. Smaller root systems limit nutrient and water uptake and increase the plants' vulnerability to periodic droughts.

Applying lime to the surface is a common practice used to combat soil acidity. However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after decades of regular application, which is inefficient and expensive. Li et al. (2010) reported that pH increased at 0.044 pH units per year at 15–20 cm by maintaining an average pH_{Ca} of 5.5 at 0–10 cm with lime, indicating that it would take approximately 23 years to raise the subsurface soil pH by one unit based on 20 years of data from a long-term liming experiment (known as MASTER) near Wagga Wagga, NSW. At the current commercial recommended rate of 2.5 t/ha every 6–10 years, most of the alkalinity added is consumed in the topsoil with very little remaining to counteract subsoil acidification. Thus more aggressive methods, such as deep ripping in conjunction with lime or other amendments, are required to deliver soil amendments to the subsoil directly and achieve more rapid changes to pH at depth.

It has been reported that organic amendments could be used to improve the subsoil acidity, because the decarboxylation reactions can potentially increase soil pH, decrease Al toxicity and generally improve conditions for root growth (Tang et al. 2013). This has not previously been tested in a field environment in the target region.

This project investigates placing lime deep into the subsoil where it is most needed, with or without organic amendments to achieve more rapid changes to pH at depth. Novel amendments, such as magnesium silicate, reactive phosphate rock, and calcium nitrate, are being tested in different soils with different crop species in both controlled environments and under field conditions.

The aim of the project is to manage subsoil acidity through innovative amelioration methods that increase productivity, profitability and sustainability on farms. Specifically the objectives of the project are to:

- conduct a scoping study to highlight the range of potential traits and mechanisms that might improve wheat, canola and pulse performance in acid soils where Al toxicity limits production

- assess and develop innovative techniques to improve efficacy of liming, such as the deep placement of lime with inorganic or organic amendments
- develop and use novel materials, such as magnesium silicate, reactive phosphate rock and calcium nitrate as alternatives to lime for ameliorating subsoil acidity
- assess the economic impact for the proposed treatments which prevent or ameliorate subsoil acidification by considering their costs, yield benefits and residual values.

Methodology

This project brings 10 scientists from four research organisations: the NSW Department of Primary Industries, La Trobe University, Charles Sturt University and CSIRO in partnership with four leading grower groups (Farmlink Research, Holbrook Landcare Network, Riverine Plains and Southern Farming Systems) in the main grain production regions of south-eastern Australia where acid soils are prevalent. The project consists of six components as shown in the program logic framework (Figure 1), each described in more detail below.

Scoping study

Dr Peter Ryan completed the scoping study, 'Genetic potential for yield improvements in Australia's major grain crops on acid soils'. The review provided an overview of current knowledge of acid soil tolerance in the major winter crops species: wheat, canola and pulses. The review listed known mechanisms and genes controlling Al and manganese (Mn) tolerance and proposed strategies for improving tolerance in certain species. The review also identified knowledge gaps, which would provide guidelines for future research. Contact Dr Peter Ryan at peter.ryan@csiro.au for more details on the scoping study.

Laboratory/glasshouse experiments

A series of laboratory incubation studies and soil column experiments have been or are to be conducted under controlled conditions. The overall objectives are to:

- compare the effectiveness of a range of inorganic and organic amendments and their combinations to ameliorate soil acidity
- optimise the application rates and application depth in soil profiles to identify the most effective amendment treatments.

The best amendment treatments will be applied at optimum rates to various soil depths to validate the effectiveness under field conditions. The organic amendments tested so far in laboratory/glasshouse experiments include poultry litter, poultry manure, mature dairy compost, sheep manure, biochar, biosolids, lucerne pellets, and crop residues from field peas, vetch, oats and wheat. The inorganic amendments used are lime, dolomite, magnesium silicate, gypsum, calcium nitrate and reactive phosphate rock. A couple of experiments investigated the effectiveness of combinations of lime or magnesium silicate with lucerne pellets, respectively. In those column experiments, the selected amendments were placed at different depths or combinations of depths to mimic the situations in the field where lime is surface, subsurface or to the whole soil profile.

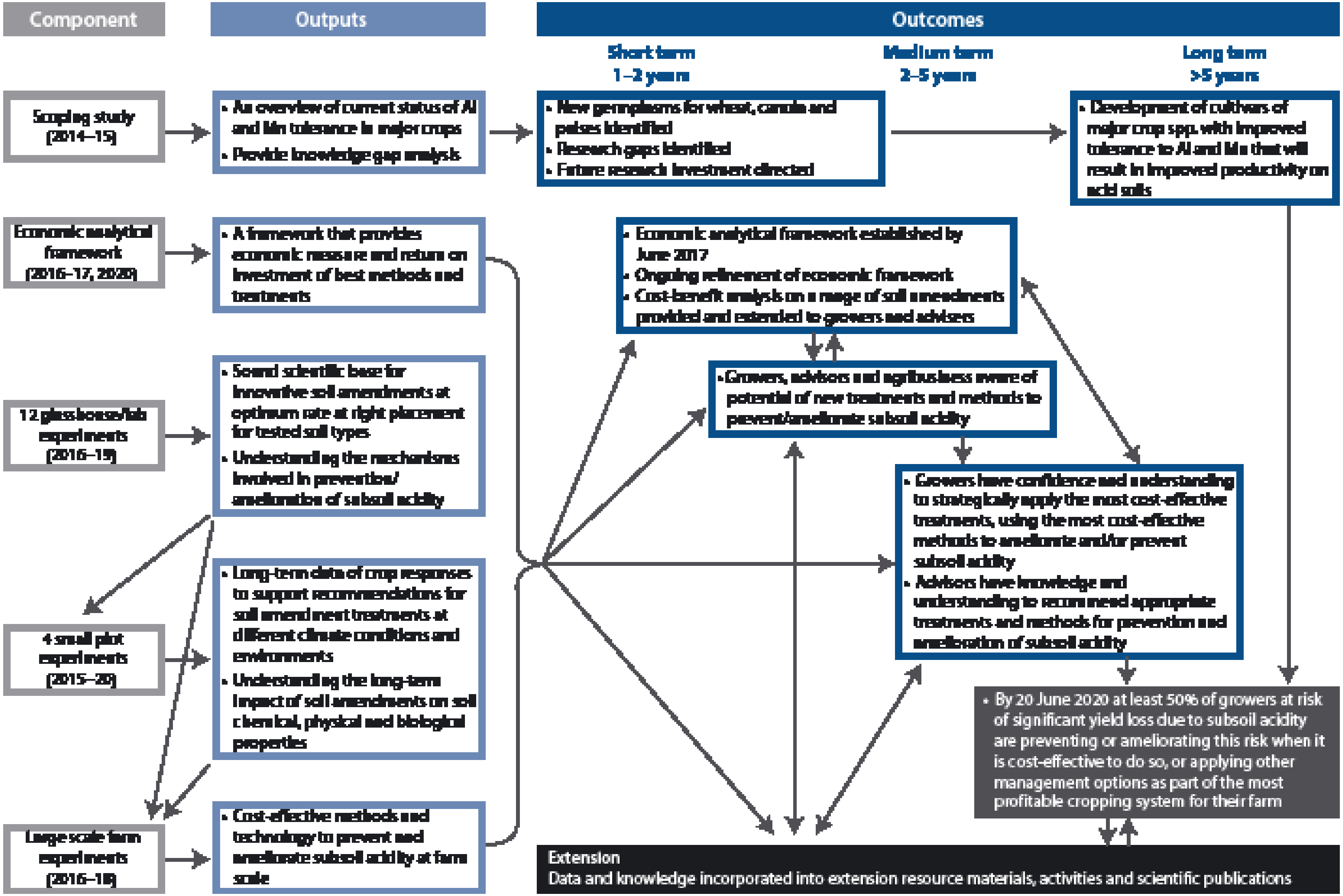


Figure 1. Program logic frame work for 'Innovative approaches to managing subsoil acidity in the southern grain region'.

Small plot experiments

Four small plot experiments have been, or are to be, established across southern NSW and northern Victoria. The changes in soil chemical, physical and biological properties, and crop responses to soil amendments are being monitored. One of the field sites was established in 2016 as a long-term experiment. There were six treatments with two major contrasts:

- surface liming vs deep liming
- deep placement of lime vs deep placement of organic amendment (Table 1).

Treatments 2–5 are regarded as core treatments included in all field experiments, which will enable a multi-site analysis.

Table 1. Soil amendment and treatment description at the long-term site.

Treatment	Depth (cm)	Target pH	Lime rate (t/ha)	Organic amendment rate (t/ha)*	Treatment description
1. Control	0–10	–	–	–	No amendment
	10–30	–	–	–	
2. Surface liming*	0–10	5.5	3.8	–	Lime incorporated into 0–10 cm
	10–30	–	–	–	
3. Deep ripping only*	0–10	5.0	2.5	–	Lime incorporated into 0–10 cm
	10–30	–	–	–	Deep ripping to 30 cm
4. Deep placement of lime*	0–10	5.0	2.5	–	Lime incorporated into 0–10 cm
	10–30	5.0	3.0	–	Deep placement of lime at 10–30 cm
5. Deep placement of organic amendment*	0–10	5.0	2.5	–	Lime incorporated into 0–10 cm
	10–30	5.0	–	15	Deep placement of organic amendment at 10–30 cm
6. Deep placement of lime and organic amendment	0–10	5.0	2.5	–	Lime incorporated into 0–10 cm
	10–30	–	3.0	15	Deep placement of lime and organic amendment at 10–30 cm

* Core treatments, included in all field experiments.

Large-scale on-farm experiments

Eight large-scale on-farm experiments have been, or are to be, established over four years, conducted by the four grower groups: Farmlink Research, Holbrook Landcare Network, Riverine Plains and Southern Farming Systems. Each site will be in place for at least three years to monitor crop response to soil amendments. Four core treatments described in small plot experiments are arranged in a randomised complete block design with three replicates. Plot size is 10 m × 100 m.

All soil amendments are to be implemented by a 3-D (dual depth delivery) Ripping Machine (Li & Burns 2016). The custom-built machine, designed and fabricated by Adam and Richard Lowrie, NSW Department of Primary Industries, can deliver inorganic and organic amendments, or combinations of products, at two depths (10–20 cm and 20–30 cm). The machine can also deliver liquid nutrients/fertilisers at depth. The 3-D Ripping Machine produces an even, firm seedbed that is suitable for sowing immediately after the amendments are in place (Figure 2).

Figure 2. 3-D Ripping Machine, designed and fabricated by NSW Department of Primary Industries staff. (Photo by Guangdi Li)

Economic analytical framework

An economic model will be developed to undertake a short- and long-term financial analysis on data from both small plot experiments and large-scale field experiments. The economic model will evaluate the financial implications and the productivity and profitability changes resulting from the subsoil acidity amelioration. Enterprise gross margins for the specific crops will be developed and compared at the early stages of the economic evaluation, but a long-term financial analysis will be conducted at the end of the project period.

Extension and communication

Extension is an essential part of the project and plays an important role in grower adoption. Farmers, private and public advisers and consultants continue to be engaged through project planning meetings, workshops, field days and regional updates to ensure that the research outputs are delivered to end-users. The research findings will be available to the wider scientific community at relevant conferences and in appropriate scientific journals. Contact Helen Burns at helen.burns@dpi.nsw.gov.au for information related to extension and communication activities.

Principles and design of long-term field experiment

Long-term experiments are probably the most difficult type of experiments to design. The prerequisites for setting up a long-term experiment are the secured tenure of land, continuous funding and dedicated scientists. A number of principles must be carefully considered when establishing a long-term experiment:

- the site must be representative of large areas
- the treatments should be simple, but focused on the big questions
- the plots should be large enough to allow detailed sampling and subsequent modification if necessary
- crop rotations should be considered to minimise the risk of weed, pest and disease build-up wherever possible
- a clearly-defined experimental protocol should be developed to ensure data collected is scientifically sound and statistically valid, but with the flexibility to allow tactical changes
- soil samples, and possibly plant samples, should be archived to enable future analysis when new, perhaps more accurate, analytical techniques are developed, or answer new research questions that were not considered in the original design.

Site selection

There are several rigorous selection criteria applied when selecting a long-term field site. The site must be:

- secured for long-term use and a cooperative collaborator is essential
- located in the high rainfall cropping zone (>550 mm), representative of large areas in the region
- acidic to depth. We were targeting pH_{Ca} 4.0–4.5 at 0–10 cm, pH_{Ca} <4.3 and exchangeable aluminium (Al) >20% at 10–20 cm, pH_{Ca} <4.5 and exchangeable Al >10% at 20–30 cm
- flat, uniform and big enough (8–10 ha) to accommodate the necessary treatments.

From September 2014 to February 2015, the project team screened about 100 paddocks in southern NSW from Culcairn and Henty in the south to Cootamundra and Binalong in the north, by taking 3–5 soil cores at 0–10, 10–20 and 20–30 cm depths. The initial screening was based upon prior knowledge of acid soil distribution from a soils database created as a result of the Acid Soil Action Research Program NSW Government in 1997–2003 (Scott et al. 2007), as well as recommendations from private and public agronomists and farm advisers in the region. Additional soil samples based on EM38 survey maps were taken from the most promising sites to confirm their suitability and avoid excessive spatial variability. In early 2015, a long-term field experiment site was chosen and established at Dirnaseer, west of Cootamundra, NSW. The soil at 10–30 cm depth was acidic with levels of exchangeable Al likely to be toxic to crops, but surface-applied lime is not likely to reach this depth in the short–medium term (Figure 3).

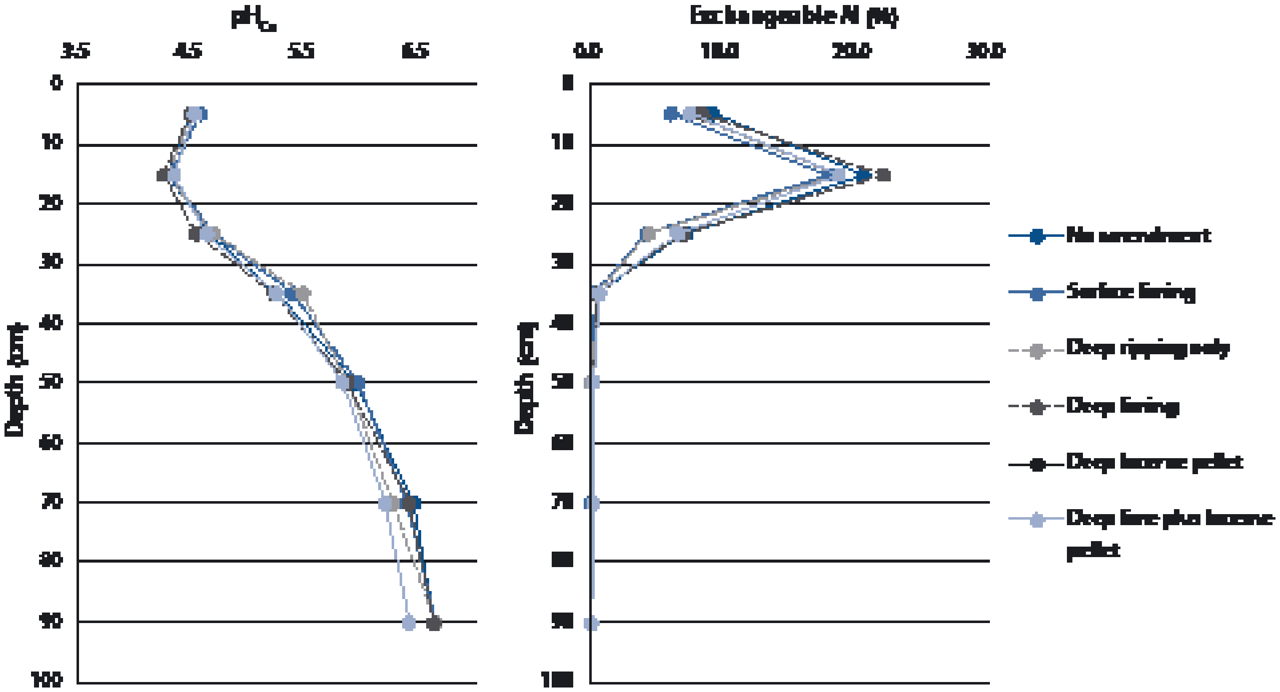


Figure 3. Soil pH and exchangeable Al profile at the long-term site at Dirnaseer, west of Cootamundra, NSW.

Treatment and experimental design

There were four crops with six soil-amendment treatments arranged in a fully phased design (Table 2). The crop sequence is in a 4-year rotation: wheat (*Triticum aestivum*); canola (*Brassica napus*); barley (*Hordeum vulgare*); pulse. Faba bean (*Vicia faba*) is the preferred pulse phase due to its sensitivity to soil acidity, but field peas (*Pisum sativum*) will be used in this phase if breaking autumn rains occur later than mid May. One of the features of the phased design is that each crop appears once in any given year to:

1. assess responses of different crops to different soil amendments
2. compare underlying treatment effects taking account of seasonal variation.

The experiment was designed for at least two 4-year crop rotation cycles, or one 8-year soil amendment cycle. The second soil amendment cycle will proceed unless soil processes being monitored have reached equilibrium within the first amendment cycle. See detailed treatments description in Li et al (2017) in this book.

Table 2. Crop rotation cycle and soil amendment cycle at each phase.

		Phase 1	Phase 2	Phase 3	Phase 4	Crop rotation cycle	Soil amendment cycle
Year 1	2016	W1	C2	B3	P4	Crop cycle 1 starts in year 1	Soil amendments implemented in year 1
Year 2	2017	C2	B3	P4	W1		
Year 3	2018	B3	P4	W1	C2		
Year 4	2019	P4	W1	C2	B3		
Year 5	2020	W1	C2	B3	P4	Crop cycle 2 starts in year 5	
Year 6	2021	C2	B3	P4	W1		
Year 7	2022	B3	P4	W1	C2		
Year 8	2023	P4	W1	C2	B3		
Year 9	2024	W1	C2	B3	P4	Crop cycle 3 starts in year 9	Soil amendments re-applied in year 9
Year 10	2025	C2	B3	P4	W1		
Year 11	2026	B3	P4	W1	C2		
Year 12	2027	P4	W1	C2	B3		
Year 13	2028	W1	C2	B3	P4	Crop cycle 4 starts in year 13	
Year 14	2029	C2	B3	P4	W1		
Year 15	2030	B3	P4	W1	C2		
Year 16	2031	P4	W1	C2	B3		

Crop code: W1, crop at phase 1 as wheat; C2, crop at phase 2 as canola; B3, crop at phase 3 as barley; P4, crop at phase 4 as pulse.

Experimental protocol and dataset

A comprehensive experimental protocol has been developed to ensure that the data collected is scientifically sound and statistically valid. Agreed sets of measurements have been clearly listed in the protocol to meet the minimum requirements by agronomists, soil chemists, soil physicists, economists as well as system modellers. In addition, a detailed electronic field diary was created to keep field records, such as details of fertilisers, herbicides and insecticide applied, general observations of weeds, pests and diseases and any other factors considered relevant to future interpretation of the results. This is essential, as it is often the case that the scientist who writes up the long-term experiment is not the scientist who conducted the experiments (Leigh et al. 1994).

Archiving samples

All soil samples, and possibly plant samples if necessary, will be archived for long-term storage. The value of a long-term experiment is greatly reduced if samples are not archived (Martin et al. 1998). Archived samples provide for two important contingencies:

1. samples can be reanalysed when new, perhaps more accurate analytical techniques are developed
2. they allow researchers to examine historical questions that were not considered in the original design.

Only if historical samples are available can new analytical techniques be used to answer new questions, or just to provide better answers to the original questions.

References

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

Leigh RA, Prew RD & Johnston AE 1994. The management of long-term agricultural field experiments: procedures and policies evolved from the Rothamsted classical experiments. In *Long-term Experiments in Agricultural and Ecological Sciences* (eds RA Leigh & AE Johnston), pp. 253–268. CAB International: Wallingford, Oxon, UK.

Li G, Conyers M & Cullis B 2010. Long-term liming ameliorates subsoil acidity in high rainfall zone in south-eastern Australia. *Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World.* Eds RJ Gilkes & N Prakongkep. Brisbane, Australia, 1–6 August 2010, pp. 136–139. International Union of Soil Science.

Li GD & Burns H 2016. Managing subsoil acidity: 3-Ripping Machine. Available at http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/689152/Managing-subsoil-acidity-issue-2-3-D-ripping-machine.pdf [Accessed 3 March 2017].

Martin B, Grace P, Bennett J, Cullis B, Godwin D & Mason W 1998. Guidelines for long-term agronomic experiments in Australia. Grains Research and Development Corporation, Land and Water Resources Research and Development Corporation, Canberra.

Pinkerton A & Simpson JR 1986. Responses of some crop plants to correction of subsoil acidity. *Australian Journal of Experimental Agriculture*. Vol. 26: 107–113.

Scott BJ, Conyers MK, Poile GJ & Cullis BR 1997. Subsurface acidity and liming affect yield of cereals. *Australian Journal of Agricultural Research*. Vol. 48: 843–854.

Scott BJ, Fenton IG, Fanning AG, Schumann WG & Castleman LJC 2007. Surface soil acidity and fertility in the eastern Riverina and Western Slopes of southern New South Wales. *Australian Journal of Experimental Agriculture*. Vol. 47: 949–964.

Tang C, Weligama C & Sale P 2013. Subsurface soil acidification in farming systems: its possible causes and management options. In *Molecular Environmental Soil Science*, (eds J Xu & DL Sparks), pp. 389–412. Springer: Springer Dordrecht Heidelberg New York London.

Acknowledgements

‘Innovative approaches to managing subsoil acidity in the southern grain region’ is a project with joint investment by NSW DPI and GRDC (DAN00206, 2015–20).

Richard Lowrie, Adam Lowrie, Graeme Poile, Albert Oates, Andrew Price, Binbin Xu and Yan Jia (NSW Department of Primary Industries), and Dr Alek Zander and Kerry Schirmer (Charles Sturt University) provide quality technical support.

Managing subsoil acidity – preliminary results from the long-term field experiment

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)

Key findings

- Significant crop biomass responses were observed on wheat, barley and canola crops at anthesis.
- The large crop biomass responses under organic amendment treatments were largely due to extra nutrients from lucerne pellets.
- The dramatic crop biomass responses observed at anthesis on canola and barley crops did not translate into grain yield under treatments with lucerne pellets applied, due to severe lodging.
- Soil chemical, physical and biological properties will 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.

Introduction

A long-term field experiment was set up to run for at least two, 4-year crop rotation cycles, or one 8-year soil amendment cycle in 2016. 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 of soil chemical, physical and biological properties under vigorous soil amelioration techniques, over the longer term.

Site description and treatments

The site is located at Dirnaseer, west of Cootamundra, NSW. Soil pH in $CaCl_2$ (pH_{Ca}) was 4.5 at 0–10 cm, ~ 4.3 at 10–20 cm, and <4.5 at 20–30 cm. The exchangeable aluminium (Al) was >20% at 10–20 cm.

There were four crops in rotation arranged in a fully-phased design. The crops are in a sequence: wheat (*Triticum aestivum*); canola (*Brassica napus*); barley (*Hordeum vulgare*); pulse [faba bean (*Vicia faba*) or field pea (*Pisum sativum*), depending on seasons]. One feature in the phased design is that each crop appears once in any given year to:

1. assess responses of different crops to different soil amendments
2. compare underlying treatment effects taking account of seasonal variation. See experimental design in details in Li et al. (2017), in this book.

There were six treatments within each crop, arranged in a split-plot design with three replicates.

- Treatment 1 (control). No amendment, representing the 'do nothing' approach.
- Treatment 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 eight years. The assumption is that pH_{Ca} 5.5 is high enough to balance acid-addition from the production system in the surface 0–10 cm and enable excess alkalinity to move down the profile over time (Li et al. 2001; Li et al. 2010).
- Treatment 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 surface, incorporated into 0–10 cm depth after plots were ripped, to achieve an average pH_{Ca} of 5.0 over eight years.
- Treatment 4 (deep placement of liming). Lime was placed at three depths (surface, 10–20 cm and 20–30 cm). Approximately 5.0 t/ha of lime was applied in total to achieve a target pH_{Ca} ≥5.0 throughout the whole soil profile, which should eliminate pH restrictions to plant growth for most crops.

- Treatment 5 (deep placement of organic amendment). 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 rate was calculated to achieve a target pH_{Ca} of 5.0 at the corresponding depths based on the alkalinity of lucerne pellets. The surface was limed to pH_{Ca} 5.0 as per treatment 3.
- Treatment 6 (deep placement of lime and organic amendment). A combination of treatments 4 and 5 to maximise benefits of lime and organic amendment.

Results

It was extremely wet in 2016. The annual rainfall was 54% more than the long-term average (615 mm). From May–October, the site received over 60% more rainfall than the long-term average for each month, particularly in September where the site received 204 mm of rain (Figure 1).

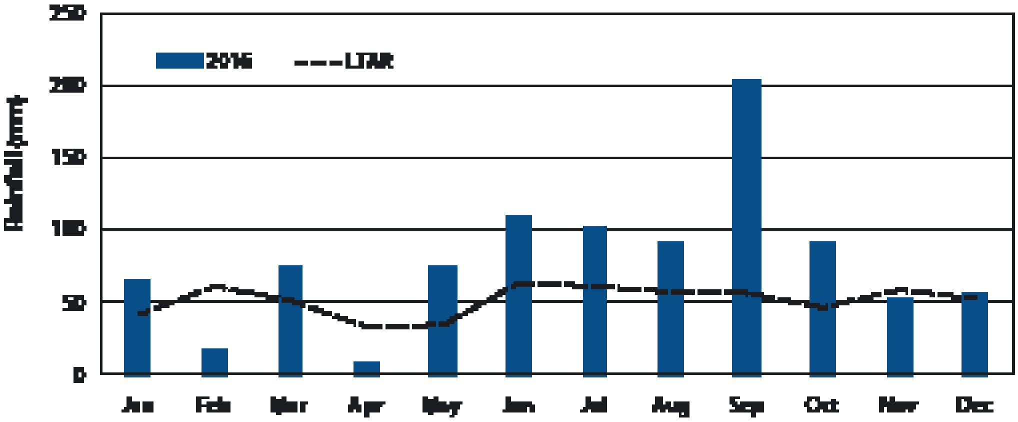


Figure 1. Monthly rainfall for 2016 and long-term average rainfall (LTAR) at Dirnaseer, west of Cootamundra, NSW. Total rainfall in 2016 was 947 mm, LTAR is 615 mm.

Visible responses to the soil treatments in the early growth of the wheat, barley and canola in August were unexpected so soon after the treatments were applied (Figure 2). Crop biomass at anthesis showed that while surface liming and deep ripping alone improved crop growth of wheat by about 15% and canola by about 25%, dry matter production was increased by a further 10–15% when lime and/or lucerne pellets were placed into the subsoil (Figure 3). Dry matter production in the barley was 15–35% greater for all deep amendment treatments, compared with the control. No response was observed for surface liming and deep ripping treatments for barley crops. The field pea response was much smaller compared with other crops (Figure 3).

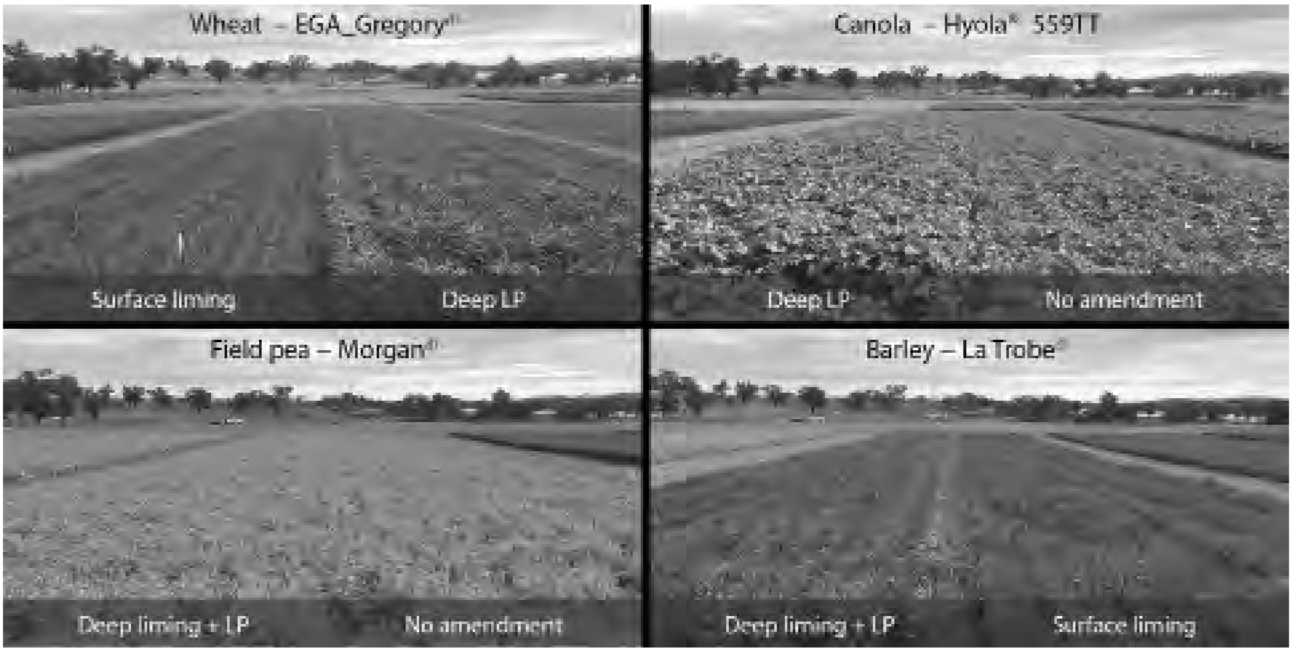


Figure 2. Crop responses to different soil amendments in late August 2016.

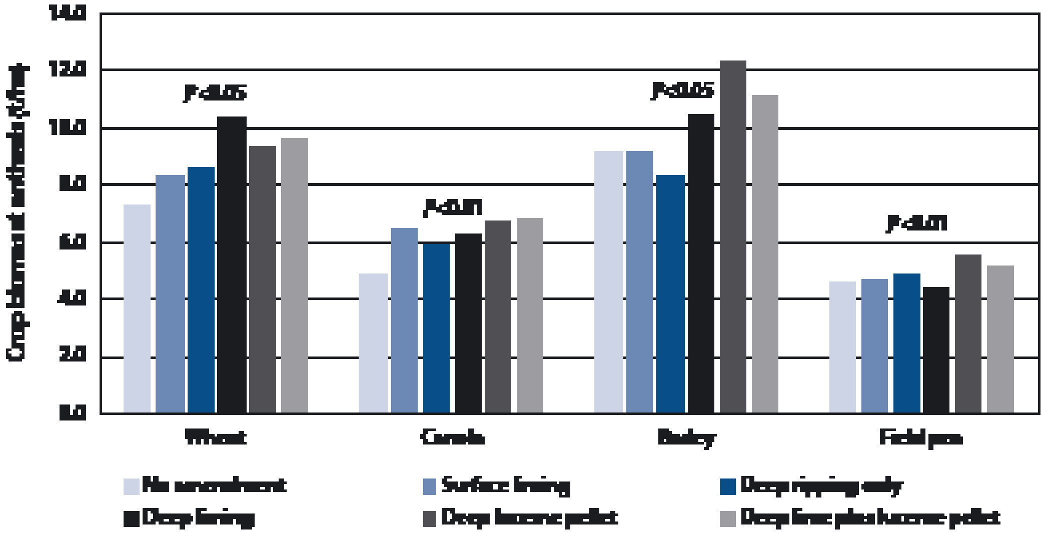


Figure 3. Crop biomass at anthesis in response to different soil amendments.

The dramatic crop biomass responses of the cereal and canola crops from treatments with lucerne pellets applied (treatments 5 and 6) were largely due to extra nutrients supplied from lucerne pellets (31 g/kg nitrogen, 451 g/kg carbon, 3 g/kg sulphur, 1.6 g/kg phosphorus and 16.6 g/kg potassium). Soil tests in late August 2016 showed that treatments with lucerne pellets applied (treatments 5 and 6) had about 70–100 kg/ha of extra mineral N available to crops in the 0–60 cm soil profile compared with other treatments (Figure 4).

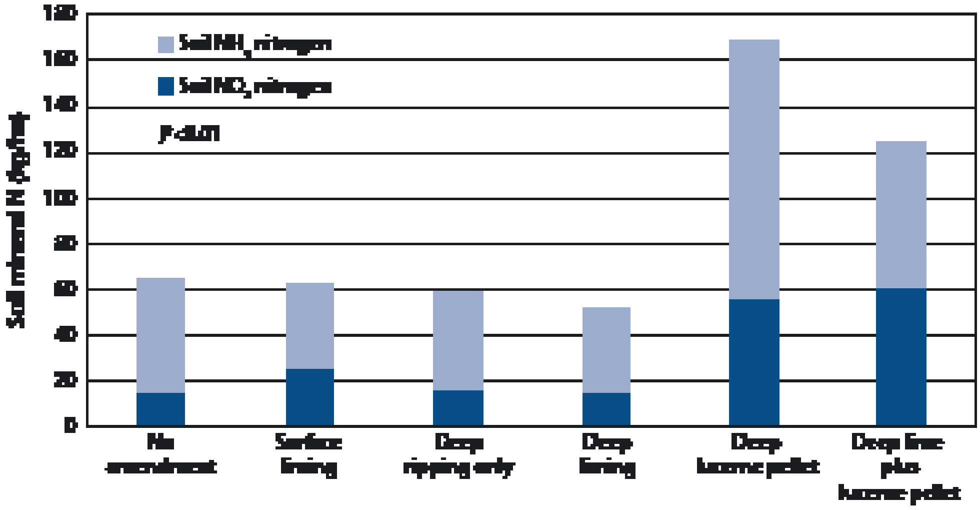


Figure 4. Soil mineral nitrogen under different soil amendments on wheat crops in late August 2016.

At crop harvest, the effect from surface liming diminished and no significant grain yield increases were recorded (Figure 5). However, both the deep ripping only and the deep liming treatment increased grain yield by up to 20% for both wheat and barley crops. The lack of any further crop response from adding lime at depth was expected, as the lime did not have sufficient time to react and increase soil pH to benefit the 2016 crops. Detailed soil testing will track changes in pH over time, and we expect that the deep-placed lime will continue to increase subsoil pH for about 18 months after application, and should produce a grain yield response in the 2017 crops.

The highest wheat grain yield was obtained from the two organic amendment treatments, as expected (Figure 5). Unfortunately, the dramatic dry matter response observed at anthesis on canola and barley crops in treatments with lucerne pellets did not translate into increased grain yield. The combination of high nitrogen levels and ideal spring growing conditions resulted in severe lodging after flowering, which is likely to have affected grain yield. There were no treatment effects on field pea grain yield.

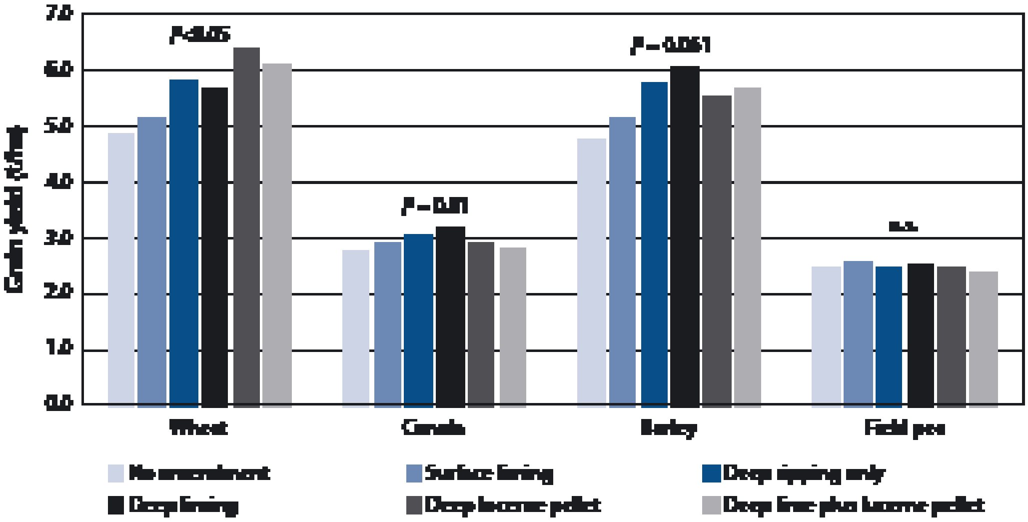


Figure 5. Grain yield at harvest in response to different soil amendments.

Future research

The research team will continue to monitor soil chemical, physical and biological properties to understand the soil–plant interactions and the factors driving the differences in crop response to the various treatments. We are particularly interested in understanding the residual effects of the amendments and how they could improve crop productivity through, for example, more efficient nutrient and water use. It is essential that growers who operate cropping systems on soils affected by subsoil acidity have this information in order to adapt the new technologies we are testing. We acknowledge that this technology requires considerable investment and therefore an important component of the project is a financial assessment. Costs and yield benefits will be analysed, as well as the economic impact and investment potential for the various treatments, taking into account the long-term residual value of the amendments on increasing subsoil pH.

References

Li G, Conyers M & Cullis B 2010. Long-term liming ameliorates subsoil acidity in high rainfall zone in south-eastern Australia. *Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World*. Eds RJ Gilkes & N Prakongkep. Brisbane, Australia, 1–6 August 2010, pp. 136–139. International Union of Soil Science.

Li GD, Helyar KR, Conyers MK, Cullis BR, Cregan PD, Fisher RP, Castleman LJC, Poile GJ, Evans CM & Braysher B 2001. Crop responses to lime in long-term pasture–crop rotations in a high rainfall area in south-eastern Australia. *Australian Journal of Agricultural Research*. Vol. 52: 329–341.

Acknowledgements

‘Innovative approaches to managing subsoil acidity in the southern grain region’ (DAN00206, 2015–20) is a project with joint investment by NSW DPI and GRDC.

Boosting pulse crop performance on acidic soils

Helen Burns, Dr Mark Norton and Peter Tyndall (NSW DPI, Wagga Wagga)

Key findings

- Acidic soil layers below 5 cm adversely affect root growth and architecture, nodulation, plant vigour, N_2 fixation and yield potential of acid-sensitive pulses.
- Moderately (pH_{Ca} 4.6–5.0) and severely (pH_{Ca} <4.5) acidic layers in the 5–20 cm soil profile are not detected using soil samples collected over standard profile depths of 0–10 cm and 10–20 cm.
- Finer sampling at 5 cm intervals is recommended to detect pH stratification.
- The current standard industry practice of spreading lime with no incorporation and sowing with knife point press wheels or disc seeders confines the lime effect to the surface layers.
- Careful paddock selection and forward planning is required to correct pH stratification in the topsoil (0–10 cm).
- Lime application and incorporation with a full cultivation operation at least 6–12 months before sowing acid-sensitive species could be necessary.
- Appropriate lime rates should be used to ensure pH_{Ca} >5.5 in the entire top 10 cm layer.
- The effect of pH stratification on more acid-tolerant species, including canola, lucerne and cereals, should also be monitored.

Introduction

While faba bean, lentil and chickpea, are generally acknowledged as being sensitive to soil acidity, they can be successfully grown on slightly acidic soils (pH_{Ca} >5.0–6.0) in the high rainfall zone (HRZ) and medium rainfall zones of south-eastern Australia, albeit with somewhat inconsistent yields. This paper identifies factors limiting the production and N_2 fixation of pulse crops grown on acidic soils in the south-eastern Australia HRZ.

In NSW these regions are dominated by acidic soils (0–10 cm; pH_{Ca} <6.0). Acid-tolerant lupin species make up 49% of the southern NSW pulse cropping area (Richards & Gaynor 2016), while adoption of more acid-sensitive, but higher value, species, such as faba bean, lentil and chickpea is limited by yield inconsistency, variable prices and perceived high production risk.

Little agronomic research has reported on the response of pulses to soil acidity. Guidelines for pulse tolerance to soil acidity are inconsistent and vague, for example a well-known authority proposes the ideal pH_{Ca} for faba bean is 6.0–8.0, but he has also indicated that pH_{Ca} >5.2 may be suitable (Eric Armstrong pers. com.). The optimal pH_{Ca} range for *Rhizobium* spp. used for faba bean, lentils, chickpea, vetch and field pea is >6.0 with the appropriate rhizobia species sensitive to pH_{Ca} <5.0 (Drew et al. 2012).

The environment to which the rhizobia and host plant are exposed influences the success of the complex nodulation process (Cregan & Scott 1998). Effective nodulation is essential to optimise the early growth, vigour and production potential of pulses sown into (N) nitrogen-depleted soils. Consultation with growers indicates that while the inoculation process and use of the appropriate rhizobia strain are well understood, the management required to avoid biotic and abiotic stresses that compromise the nodulation process, is not.

Numerous studies report acidic layers at 5–15 cm (to 20 cm in sandy soils) in both agricultural and non-agricultural systems (e.g. Conyers & Scott 1989; Paul, Black & Conyers 2003). We have taken that work a step further to investigate the effect of soil acidity below 5 cm depth on nodulation and plant growth. Pulse crop and soil data collected from commercial paddocks in 2015 and 2016 have shown the detrimental effect of moderately to severely acidic layers below 5 cm on root growth, nodulation and crop vigour. We conclude that even at sites where lime application has increased soil pH sufficiently to enable acceptable production from canola and lucerne crops, pH stratification and moderately (pH_{Ca} 4.6–5.0) and severely (pH_{Ca} <4.5) acidic layers below 5 cm depth can still be present and limit pulse crop growth, production and N_2 fixation.

Our findings are likely to be relevant to acid-sensitive pulses grown on acid soils across all rainfall zones. Furthermore, the severity of the acidity below 5 cm depth at a number of sites is sufficient to affect the productivity of the main crop and pasture species, including cereals, canola and lucerne. The widespread adoption of minimum disturbance systems on acidic soils, with the consequent failure to effectively incorporate surface-applied lime, is contributing to intense pH stratification of the surface soil. The research component of this project (not reported here) addresses the questions of the relative importance of lime rate and lime incorporation on overcoming pH stratification to improve legume nodulation and thus growth, N_2 fixation and yield.

Survey methodology

In 2015 and 2016, a total of 39 commercial legume crops were monitored in NSW, Victoria, SA and Tasmania (Figure 1). The 2015 sites were chosen to achieve geographical spread across acid soil regions of the target zones and included 12 paddocks of faba bean, two of narrow-leaf lupin and one of field pea. Sodosols were the dominant soil type at these sites. In 2016 an additional five growers were engaged in order to investigate a broader range of pulses and soil types – sodosols, chromosol and rudosols (alluvial). Sites monitored in 2016 were sown to faba bean (14), narrow-leaf lupin (2), chickpea (3) and lentil (3).

Figure 1. The acidic soil region of the high rainfall cropping zone of south-eastern Australia showing the location of paddocks monitored in 2015 and 2016.

A uniform, one hectare area of crop was selected at each site. Soils were sampled at depths of 0–10 cm and 10–20 cm, with pH measured using the calcium chloride method through Nutrient Advantage Laboratories.

Each year, crop plants were assessed 2–3 months post-emergence for nodulation effectiveness. Plants with intact root systems were collected at random from the designated areas and scored for nodulation using the Columbia protocol (British Columbia Ministry of Forests 1991). Scores were allocated for:

- plant growth and vigour
- nodule number
- nodule position
- nodule colour
- nodule appearance

with all parameters of equal weighting and 25 (5 × 5) the maximum possible total score.

In 2015, crops with low nodulation scores (<18) were investigated further. Root growth was assessed *in situ* and soil samples were collected at 2.5 cm intervals to a depth of 15 cm and tested for pH using a Manutec® Soil pH Test Kit. In 2016, root growth was assessed *in situ* and soil cores were collected from all sites and divided into increments of 2.5 cm to a depth of 10 cm; and 5 cm increments between 10–20 cm. Soil pH was measured in the NSW DPI Wagga Wagga laboratory.

Results and discussion

Faba bean was the most commonly grown pulse species in this study, enabling us to identify common constraints across the NSW, SA and VIC environments, which are also likely to be relevant to other acid-sensitive legume species. We found that faba bean nodulation was adversely affected by low soil pH in both 2015 and 2016.

Soil acidity and nodulation

The nodulation scores analysis for faba bean crops and pH_{Ca} of 0–10 cm soil samples from the monitored paddocks (Figure 2) showed a strong correlation ($r^2 = 0.88$) between soil acidity and nodulation scores (0 = nil nodules present, to a maximum of 25 = all plants with effective nodules). The form of inoculant used (peat slurry, freeze dried or granular) did not have a significant effect.

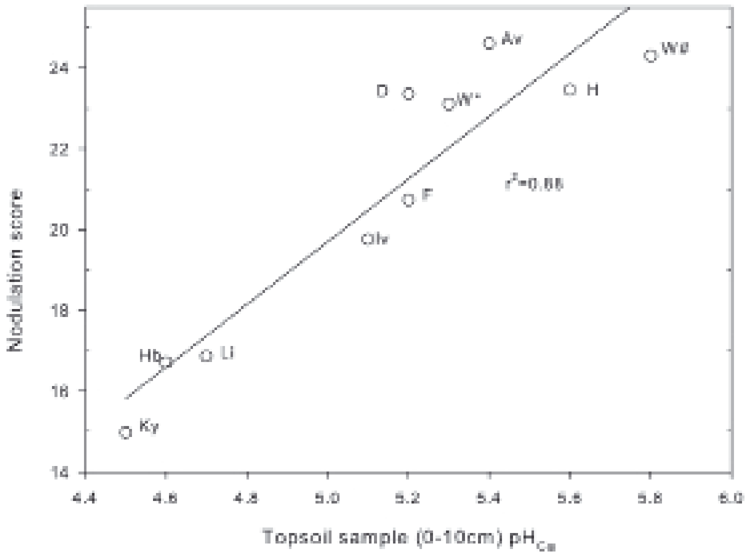


Figure 2. The effect of topsoil pH (0–10 cm) on faba bean nodulation across the south-eastern Australian high rainfall zone in 2015. Sites of sampling include Kybybolite, SA (Ky), Holbrook, NSW (Hb), Lismore, Vic (Li), Inverleigh, Vic (Iv), Frances, SA (F), Darlington, Vic (D), Willaura, Vic (W), Avoca, Tas (Av) and Henty, NSW (H). W* = after wheat, W# = after canola.

The monitored crops fell into two distinct categories:

1. vigorous, well nodulated crops
2. those with a nodulation score below 18, which included extremely variable crops that showed symptoms of nitrogen deficiency within two to three months of emergence, particularly at the Holbrook and Kybybolite sites (both Sodosol soils), recording nodulation scores of 17 and 15, respectively.

Although the percentage of exchangeable aluminium at the Holbrook site was 8% in the 0–10 cm and 35% at 10–20 cm soil depths, the percentage of exchangeable aluminium at both Kybybolite and Lismore was <2%. Therefore, it appears that low pH affected the nodulation process and reduced nodulation, irrespective of aluminium levels.

All 2015 sites, with the exception of Kybybolite, had received applications of lime within the past 5 years. Lime had been applied at the Holbrook site in 2010 and again in 2015 at a rate of 2 t/ha. In 2015, lime and retained stubble from the 2014 wheat crop was mixed in the surface layers using a speedtiller.

The association between nodulation score and soil pH_{Ca} was also evident in crops assessed in 2016. In this paper we will focus on a faba bean crop growing on red chromosol (red-brown earth) at Junee sites J1 and J2 (shown as the squares labelled J1 and J2) in Figure 3; and the chickpea crop growing on dermosol (red-brown earth) at Woodstock, east of Cowra (shown as squares labelled W1 and W2). The nodulation scores for these sites were 20.5 and 16.6 for Junee and 20.7 and 15.5 for Woodstock.

Sites J1 and J2 are within the same paddock at Junee, which received an unincorporated blanket lime application at 1.13 t/ha in 2011.

Sites W1 and W2 are also within the same paddock at Woodstock. Lime had been applied at 2.5 t/ha in 2008 and incorporated using a disc plough. In 2016, the grower established test strips, with and without prilled lime. Using knife points, he drilled the lime to a depth of about 10 cm, through the fertiliser box of his combine, which was set to deliver prilled lime at a rate of 290 kg/ha. GPS guidance allowed him to then sow the chickpea directly over the prilled lime row with a second run.

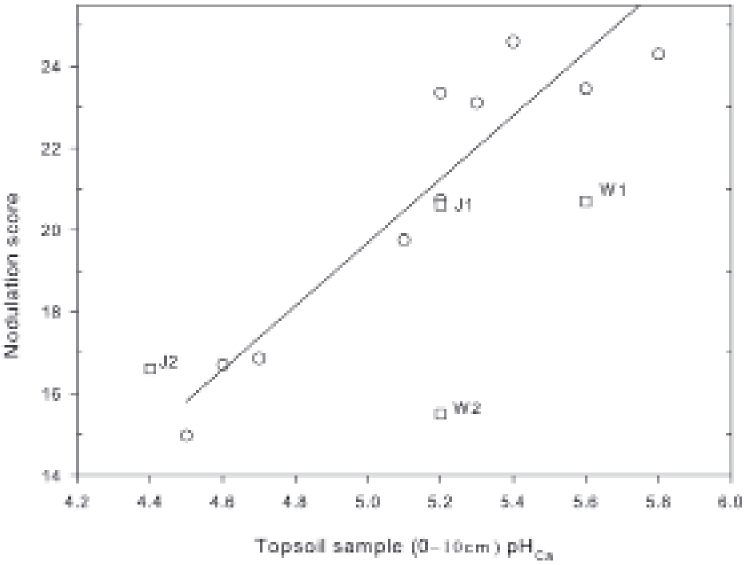


Figure 3. The effect of topsoil pH (0–10 cm) on faba bean nodulation across the south-eastern Australian high rainfall zone in 2015 (open circles) with four additional sites added in 2016 (open squares), marked as J1 and J2 representing sites at Junee growing faba bean crops, with W1 and W2 sites at Woodstock growing chickpea.

Soil pH stratification

The response of the 2015 faba bean crops to soil pH at Holbrook, NSW, Kybybolite, SA, and the 2016 sites at Junee, NSW (J1 and J2) and the chickpea crop at Woodstock, NSW (W1 and W2, Figure 3) are consistent with the observations made on all monitored crops growing in acidic soils, across the range of soil type and seasonal conditions experienced in 2015 and 2016.

As shown in Tables 1 and 2, composite soil samples taken at depths of 0–10 cm and 10–20 cm, which are traditionally used by growers and advisers to guide decisions on acid soil management, failed to detect significant variation in soil pH down the profile at the Holbrook, Junee or Woodstock sites.

The severe pH stratification identified by testing at 2.5 cm layers demonstrated that lime incorporation was ineffective under the no-till systems adopted by the majority of participating growers. The lime was concentrated in the surface layers with little movement of the lime effect below the surface layers (0–5 cm). Clearly, topdressing and no-till systems are ineffective in neutralising acidity below about the 5 cm depth. Failure to incorporate lime limits lime reactivity and potential crop response, which is an opportunity cost to growers.

The effect of acidic layers on faba bean root development and nodulation

Despite the Holbrook site receiving 4 t/ha of lime since 2010, incorporation with a speedtiller was ineffective in mixing the lime below 5 cm. Finer soil sampling of the topsoil indicated that at a sowing depth of about 6 cm the faba bean seedlings and rhizobia were exposed to a hostile environment (pH$_{Ca}$ <4.4), two pH units more acid than the surface soil (pH$_{Ca}$ 6.5). Nodulation was poor and the crop was showing symptoms of severe nitrogen deficiency within three months of emergence. Root growth was restricted to the surface 6 cm and did not penetrate into the severely acidic soil below 5 cm.

The results and observations from the Kybybolite site are included to highlight the impact of low pH on faba bean growth and nodulation. Root hair development was poor and plant roots were stunted, thickened and distorted, all symptoms typical of aluminium toxicity. However, with exchangeable aluminium levels of <2%, it is likely that low pH at this site is primarily responsible for the restricted root growth, reduced rhizobial activity and inefficient nodulation process as reported by Cregan and Scott (1998).

The Junee sites were from lower slope (J1) and mid slope (J2) areas within the same paddock. The soil tests from J1 indicate slight acidity (pH$_{Ca}$ >5.0) from 0–7.5 cm, tending toward moderately acid (pH$_{Ca}$ >4.6) from 7.5–15.0 cm. Plant roots from this area appeared healthy and were well nodulated (nodulation score of 20.6), but root growth was restricted to the top 10 cm. The moderately acidic layers at 7.5–15 cm (pH$_{Ca}$ approx. 4.6) could be responsible for the shallow rooting depth, but the intermittent waterlogging experienced during July to September of 2016 were likely to have compounded the stress caused by the acidic layers.

Table 1. The pH$_{Ca}$ measurements of 0–10 cm and 10–20 cm depths fail to detect the pH stratification in the soil profile at the Holbrook, Kybybolite or Junee sites, compared with tests from finer sampling increments. Soil conditions at each site were reflected in the appearance of faba bean plants.

Soil depth (cm)	**Holbrook site 2015**		**Kybybolite site 2015**		**Junee 1 site 2016**		**Junee 2 site 2016**	
	Soil pH$_{Ca}$		**Soil pH$_{Ca}$**		**Soil pH$_{Ca}$**		**Soil pH$_{Ca}$**	
	Nodulation score – 17		**Nodulation score – 15**		**Nodulation score – 20.6**		**Nodulation score – 16.6**	
	Composite sample	**Sub samples***	**Composite sample**	**Sub samples***	**Composite sample**	**Sub samples**	**Composite sample**	**Sub samples**
0–2.5	4.6 (Grower's paddock soil test – 5.2)	6.5	4.5	4.2	5.2	5.5	4.4	4.9
2.5–5.0		5.6		NA		5.4		4.6
5.0–7.5		4.4		NA		5.2		4.2
7.5–10.0		4.2		4.0		4.6		4.1
10.0–15.0	4.1	4.1	5.7	NA	4.8	4.6	4.4	4.2
15.0–20.0		4.1		NA		5.0		4.6
Plant appearance	Plants yellow, stunted. Roots concentrated in top 6 cm; stunted thickened and distorted, typical aluminium toxicity. Roots of <10% of plants extend below 10 cm. Dark coloured roots due to disease – likely due to multiple stresses.		Very poorly nodulated, stunted, yellow plants. Root growth confined to top 10 cm; roots stunted, thickened and distorted. Soil testing <2% aluminium. Minimal root hair development. The site had no history of lime.		Healthy, vigorous plants well nodulated, 35 cm tall at first node stage (Sept.). Healthy dense roots, finer root hairs superior to J2 plants. Roots restricted to top 10 cm.		Most plants yellow, less vigorous, less root hair development than J1 plants. Height 15–25 cm. Most root growth in the top 4 cm, minimal root growth below 4 cm. Root disease evident most plants.	

*Sub samples were not collected from same location as composite samples. pH$_{Ca}$ for Hb and Ky sub samples were estimated using Manutec Soil pH Test Kit; pH$_{water}$ was converted to pH$_{Ca}$ using the relationship: $pH_{Ca} = 1.012pH_W - 0.768$ (Conyers & Davey 1988).

The J2 soil tests indicated moderate acidity in the surface 2.5 cm (pH$_{Ca}$ 4.9), tending to severe acidity from 5.0–15.0 cm, with pH$_{Ca}$ ranging from 4.6 at 2.5 cm, to as low as 4.1 at 7.5–10 cm. In contrast with plants from the J1 site, J2 plants were stunted and showed symptoms of severe nitrogen deficiency two months after sowing. Root growth was restricted to the surface layers (0–4 cm), root hair development was considerably less than J2 plants, and plants were not as well nodulated.

The majority of plants collected from the J2 site showed symptoms of root disease, in contrast with the relatively healthy J1 plants. It is likely the disease infection was a secondary, physiological response to the more hostile soil conditions (i.e. acidity, waterlogging) at J2. The lower incidence of infection observed in plants from J1 suggests that the higher pH in the root zone might have improved the plants health and made them less susceptible to damage and infection. The plants were not screened for specific root diseases, but there are likely to be many different species present, such as Pythium, Rhizoctonia, Fusarium or Phytophthora (K Lindbeck pers. comm.).

The Junee paddock is gently undulating and has a history of lucerne pasture, canola and wheat production. A 2013 soil pH$_{Ca}$ test result from this paddock of 5.4 for the 0–10 cm soil depth failed to detect the variability in soil acidity across the paddock. The blanket lime rate of 1.3 t/ha, applied in 2011, but not incorporated (all subsequent crops being direct drilled with a knife point press wheel seeder), was inadequate to ameliorate the severe acidity to a depth of 10 cm at the J2 site.

The effect of acidic layers on root development and nodulation of chickpea

The test strips of prilled lime established by the grower at the Woodstock sites provided an opportunity to determine the effect of soil acidity on chickpea.

The composite 0–10 cm soil pH readings from samples at the W1 (prilled lime applied at 290 kg/ha) and W2 sites (no prilled lime) were pH_{Ca} of 5.6 and 5.2, respectively (Table 2). Finer sampling of the topsoil layers of W2 indicated that at a recommended sowing depth of 5–7 cm, seed and rhizobia would have been placed in a moderately acidic layer (pH_{Ca} 4.8). The incorporated prilled lime at the W1 site created a more suitable soil environment for the rhizobia and young seedlings, with a pH_{Ca} of 5.5.

Although the nodulation score for the plants growing in the nil lime (W2) indicated poor nodulation (a nodulation score of 15.05 compared with 20.7 at the W1 site), the W2 test strips did not show the obvious associated clinical symptoms of nitrogen deficiency and restricted root growth observed in affected faba bean crops. It was only when plant roots were inspected and scored for nodulation and root growth and then compared with those from the limed strips (W1) that the impact of the more acidic layers below 5.0 cm became clear.

Table 2. The pH_{Ca} measurements of test strips at Woodstock showing the effect of incorporating 290 kg/ha of prilled lime drilled to a depth of 10 cm in the seeding rows. Nodulation scores, plant appearance, nodule number and weight reflect the different soil conditions.

Soil depth (cm)	**Woodstock 1 site (+ lime 2016)**		**Woodstock 2 site (nil lime 2016)**	
	Soil pH_{Ca}		**Soil pH_{Ca}**	
	Composite sample	**Sub samples**	**Composite sample**	**Sub samples**
0–2.5	5.6	5.9	5.2	5.9
2.5–5.0		5.8		5.4
5.0–7.5		5.5		4.8
7.5–10.0		5.2		4.6
10.0–15.0	4.9	4.7	4.8	4.7
15.0–20.0		5.1		4.9
Plant appearance	Plants generally healthy and vigorous, good root development (Aug. and Nov. sampling). Roots more dense, abundance of root hairs compared with W2 plants. In Nov., roots and nodules concentrated in surface 10–12 cm. Minimal evidence of root disease or discolouration.		Aug. and Nov. – shoot growth similar to W1 plants, but root growth relatively poor; shorter, less dense, fewer root hairs. Aug. – root disease evident on most plants. Infection not severe enough to cause plant death, but root pruning and discolouration was evident at Nov. sampling. Nov. – roots and nodules concentrated in surface 6 cm.	
Nodule development (Aug 2016)	Nodulation score – 20.7 Nodule number/20 plants – 172 Nodule weight/20 plants – 1.69 g		Nodulation score – 15.05 Nodule number/20 plants – 140 Nodule weight/20 plants – 1.24 g	

The lime treatment appeared to improve root growth, root hair development and nodulation when the sites were first inspected in August. Nodule number and weight was 23% and 36% greater, respectively, on plants from the W1 strips compared with W2 plants. In addition, plants from W1 strips showed very little evidence of root disease. In contrast, root disease was evident on most plants sampled from W2. The increased susceptibility of chickpea seedlings growing in acidic soils to disease was similar to that observed in faba bean at the J2 site.

By November 2016, chickpeas from W1 and W2 strips were flowering and had reached a height of about 40 cm. Again, there were no obvious differences in shoot growth between the test strips, but differences between the W1 and W2 strips were obvious when the roots were inspected.

The depth and density of roots, root hair abundance and nodulation were superior for plants from the W1 strips, obviously benefiting from a pH_{Ca} ranging from 5.9 at 0–2.5 cm to 5.2 at 7.5–10 cm. Roots and nodules extended to a depth of 10–12 cm. Conditions at the site were extremely wet from July to October, therefore it is not possible to conclude if root development was restricted to the surface 12 cm as a result of intermittent waterlogging or the moderately acid layer at 10–15 cm (pH_{Ca} 4.7). It is probable that the combination of these environmental stresses adversely affected root development.

In contrast, the roots of the W2 plants were restricted to the surface 6 cm; root hair and nodule numbers were considerably less than on W1 plants. The pH_{Ca} of the surface 5 cm (5.9 at 0–2.5 cm and 5.4 at 2.5–5.0 cm) appeared to have been satisfactory for surface roots and nodulation development, but increased acidity from 5–10 cm (4.8 at 5.0–7.5 cm and 4.6 at 7.5–10 cm) restricted root growth and nodule development in these moderately acidic layers. The disease observed on W2 plants in August was still present in November.

Differences in the chickpea root appearance and nodulation suggest a response to the added and incorporated prilled lime within the seeding row, although, using yield maps to compare the test strips this did not translate into a harvest yield response.

Other factors affecting nodulation and early pulse growth

Management practices that caused severe damage to pulse crops monitored in 2015 and 2016 included:

- crop damage caused by sulfonyl urea (SU) herbicide applied in the previous 12 months. Ineffective incorporation of lime produces an elevated pH in the surface soil layers and delays the breakdown of sulfonyl urea herbicides, e.g. triasulfuron.
- adding zinc to inoculant slurries during the inoculation process. Zinc is toxic to rhizobia and when mixed with the inoculant resulted in extremely poor nodulation. If zinc is to be used on pulses, growers should ensure it is not placed in close proximity to the rhizobia at time of sowing, but rather applied in the fertiliser mix, separated from the seed, or sprayed onto the crop as a foliar application.

Conclusion

Effective nodulation underpins productive and profitable pulse crops. When detailed soil pH results were aligned to root growth and pulse crop nodulation, it was concluded that previously undetected, but severely acidic layers were likely to be a major factor in acid-sensitive pulses inconsistent performance on slightly (pH_{Ca} >5.0) and moderately acidic soils (pH_{Ca} 4.6 to 5.0) in the medium and high rainfall zones.

The impact of acidic layers on root hair development was apparent in all monitored crops. As discussed by Drew et al. (2012) the main pathway for rhizobial infection of commonly grown temperate legume species is via root hairs. The exception is lupin.

At all sites recording poor nodulation (Hb, Ky, J2 and W2), the seed and rhizobia encountered an acidic layer (pH_{Ca} 4.4, 4.5, 4.2 and 4.8, respectively) at 5.0–7.5 cm in the profile, which appears to have been sufficient to disrupt the infection process. Optimal nodulation requires pH conditions favourable to both the rhizobia and host plant. These results suggest that although management strategies such as lime pelleting of seed to raise pH in the seed's immediate vicinity could improve rhizobial survival in the short term, pelleting is unlikely to improve soil pH sufficiently to improve root hair development and significantly improve nodulation.

While most growers are effectively managing disease and weeds and are sowing recommended varieties, our findings highlight the need to review basic agronomic principles. Management of pulses sown in acidic soils must focus on promoting the nodulation process and minimising or avoiding environmental stresses. The results from this project, reinforced by grower experience, indicate that well nodulated, vigorous pulse crops have the ability to withstand multiple stresses, including infection by root diseases and transient waterlogging. The 2015 and 2016 experiences indicate that timely sowing, early in the recommended sowing window, allows plants and nodules to establish before cold temperatures slow growth and rhizobial function. Quoting one of the collaborating growers:

'Variety is not as important as agronomy… it's clear from what we are seeing we need to pay more attention to soils and agronomy.'

Faba bean is proving to be 'the canary in the coal mine' for detecting acidic layers. The dramatic clinical symptoms expressed by faba bean plants exposed to acidic layers has helped highlight the extent and severity of pH stratification, even in soils that have had a long history of lime application. From observations at the Woodstock site, shoot growth of other acid-sensitive species such as chickpea (and we suspect lentil, canola and lucerne) do not demonstrate the dramatic response to acidic layers or obvious clinical symptoms exhibited by faba bean. For these crops, we recommend close inspection of the roots in conjunction with finer soil sampling to check for the presence of acidic subsurface layers.

The negative impact on agricultural production of shallow subsurface acidic soil layers is well documented. The presence of these layers effectively places a ceiling on production potential and reduces efficiencies in water and nutrient use. The severity of the acidic layers identified in this study suggests that relatively acid-tolerant species, including barley, canola, lucerne and many wheat varieties, are probably suffering a yield penalty at pH_{Ca} <4.7 in the top 15 cm.

The traditional 0–10 cm soil sampling procedure is not detecting pH stratification. Finer sampling at 5 cm intervals to a depth of 20 cm is needed to verify the presence and depth of acidic layers.

The severe pH stratification identified by testing finer layers demonstrates that lime was concentrated in the surface 0–5 cm layers under the no-till systems adopted by the majority of participating growers. This study indicates that current acidic soil management and liming programs are inefficient in neutralising subsurface acidity or counteracting acidification below the surface layers. Lime rates, frequency and method of lime application need to be reviewed. A rapid solution to severe pH stratification in the 0–10 cm layers requires an aggressive approach, including incorporation with full cultivation and appropriate lime rates to ensure pH_{Ca} >5.5 in the entire surface 10 cm. This will improve lime reactivity, help the lime effect move to deeper in the profile, and increase potential crop response.

References

British Columbia Ministry of Forests (1991). *Field guide to nodulation and nitrogen fixation assessment*.

Conyers MK & Scott BJ (1989). The influence of surface incorporated lime on subsurface acidity. *Australian Journal of Experimental Agriculture* 29, 201–207.

Conyers MK & Davey BG. (1988). Observations on some routine methods for soil pH determination. *Soil Science* 145, 29–36.

Cregan P & Scott B (1998). Soil acidification – an agricultural and environmental problem. In *Agriculture and the environmental imperative*. (Eds JE Pratley & A Robertson). pp. 98–128. (CSIRO Publishing: Melbourne).

Drew E, Herridge D, Ballard R, O'Hara G, Deaker R, Denton M, Yates R, Gemell G, Hartley E, Phillips L, Seymour N, Howieson J & Ballard N (2012). *Inoculating legumes: a practical guide*. Grains Research and Development Corporation. Available at: https://grdc.com.au/GRDC-Booklet-InoculatingLegumes

Paul KI, Black S & Conyers MK (2003). Development of acidic subsurface layers of soil under various management systems. *Advances in Agronomy* 78, 187–213.

Richards M & Gaynor L (2016). *Southern NSW pulse survey* 2015–16. NSW Department of Primary Industries, Wagga Wagga.

Robertson M, Kirkegaard J, Peake A, Creelman Z, Bell L, Lilley J, Zhang H, Kleven S, Duff C, Lawes R & Riffkin P (2016). Trends in grain production and yield gaps in the high-rainfall zone of southern Australia. *Crop and Pasture Science* 67, 921–937.

Acknowledgements

These surveys were part of the project 'N fixing break-crops and pastures for high rainfall zone acid soils', DAN00191, 2014–18, with joint investment by GRDC and NSW DPI and in collaboration with CSIRO Food and Agriculture, Holbrook Landcare Network and Mackillop Farm Management Group.

The contribution of the 21 growers participating in this project and their willingness to share their experience is greatly appreciated.

Grazing management is linked to increased soil carbon in southern NSW

Dr Susan Orgill (NSW DPI, Wagga Wagga); **Dr Jason Condon** (Charles Sturt University, Wagga Wagga); **Dr Mark Conyers** (NSW DPI, Wagga Wagga); **Stephen Morris** (NSW DPI, Wollongbar); **Douglas Alcock** (Graz Prophet Consulting, Cooma); **Dr Brian Murphy** (NSW Office of Environment and Heritage, Cowra); **Dr Richard Greene** (Australian National University, ACT)

Key findings

- Grazing treatment had no influence on pasture sward composition when averaged over seasons.
- Grazing, rather than the type of grazing management, increased soil carbon under native pastures.
- Soil under cell-grazed pastures had a significantly greater carbon stock to 0.30 m compared with ungrazed pastures (32.9 t C/ha vs 25.6 t C/ha), however, there was no difference between cell and tactically grazed (29.5 t C/ha) pastures.

Introduction

Grazing management is a known influence of organic carbon (OC) accumulation in agricultural soil, but there is conflicting evidence on the extent. This study compared OC and nitrogen (N) stocks at the conclusion of a five-year grazing trial on a fertilised native pasture in south-eastern Australia. The study included three grazing treatments: ungrazed, tactically grazed (set stocking with biannual rest periods) and cell grazed (intense stocking with frequent long rest periods).

Site details

Site

The replicated trial was conducted on a commercial sheep property near Berridale in south-eastern NSW. The trial was part of the Monaro Research, Development and Demonstration of Sustainable Grassland Management Project 2005–2010 (MRDSGM; SECMB C1/8) (Pope et al. 2011). Berridale has an average annual rainfall of 582 mm (1947–2015), which is summer dominant, and average annual maximum and minimum temperatures of 18 °C and 4 °C (Bureau of Meteorology). There was below average annual rainfall for the five years before the trial started, and for all years of the trial with the exception of 2007 (Figure 1).

The site was native grassland dominated by native perennial grass species, including wallaby grasses (*Rytidosperma* spp.), speargrasses (*Austrostipa* spp.) and snowgrass (*Poa sieberiana*). Naturalised annual grasses, legumes and weeds were also present. The site had been grazed by sheep since the early 1900s and had never been cultivated. Before the trial was established, the site had no fertiliser applied and no introduced pasture species sown. The stocking rate before the experiment was three dry sheep equivalent (DSE) per hectare.

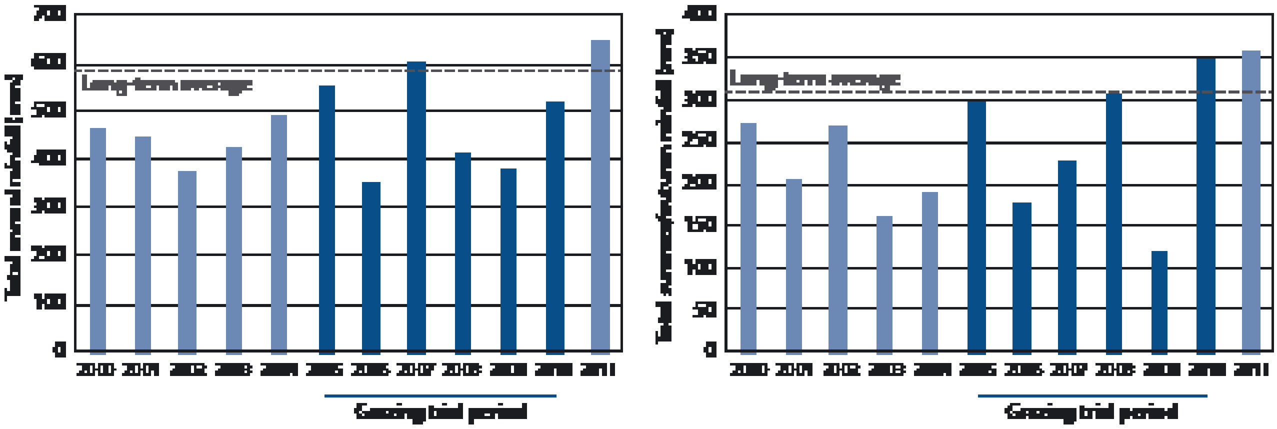


Figure 1. Annual rainfall and summer plus autumn; December to May rainfall (mm) for the Berridale grazing trial site for 2000–2011. Data was taken from the Berridale Bureau of Meteorology station (071022) and incomplete years (2000–2006) substituted by the nearest station: Cooma airport (070217). Long-term average is from the Berridale Bureau of Meteorology station (071022) and calculated from 1947 to 2015.

Soil type

The soil is classified as a brown chromosol (Australian Soil Classification) derived from biotite granodiorite. The A1 horizon (0–0.08 m) is a sandy loam, with a pH_{Ca} of 5.0 and cation exchange capacity (CEC) of 5.8 cmol+/kg. The A2 horizon (0.08–0.32 m) is a light sandy clay loam, with a pH_{Ca} of 5.3 and CEC of 3.6 cmol+/kg. The B2 horizon (0.32–0.45 m) is a medium clay, with a pH_{Ca} of 5.5 and CEC of 11.1 cmol+/kg.

Fertiliser

The grazing treatments selected for this study were located within a high fertiliser treatment, with subterranean clover (*Trifolium subterraneum*) broadcast before grazing started. The high fertiliser treatment aimed to rapidly achieve the Colwell P target (>30 mg/kg) with 250 kg/ha of single superphosphate applied annually in autumn, after which the maintenance phosphorus (P) was applied based on the stocking rate. In 2006, gypsum (125 kg/ha) was applied to address sulphur (S) deficiencies.

Grazing trial design

Grazing treatments, ungrazed, tactically grazed and cell grazed, were replicated across three fields that had similar soil–landscape attributes and were located within 500 m of one another. The grazing treatment plots (three small fenced areas in each field; 10 m × 10 m) were established in October 2005 and grazed by Merino wethers. The ungrazed plots were excluded from grazing for the duration of the trial. The tactically grazed plots were rested for 4–6 weeks over late spring/summer and late summer/autumn to allow seed set and recruitment. The cell grazed plots were grazed four to five times a year by mob stocking, with long and variable rest periods between grazing. Every 80 to 120 days, the cell grazed plots were grazed for one day at a stocking density that was estimated at approximately 300–400 DSE/ha during grazing and an average annual stocking rate that represented the background stocking rate of the field. For more information see Pope et al. (2011).

Results

Pasture composition

When the functional groups of annuals, perennials and legumes were considered, grazing treatments did not affect sward composition when averaged over seasons (Figure 2). However, there was a significant ($P<0.05$) interaction between season and grazing treatment on the annual grass composition. This was due to tactically grazed pastures having a greater proportion of annual grasses than the cell and ungrazed treatments in 2006 (Figure 2). This response is likely due to their first closure in autumn 2006 as part of the treatment plan. From 2005 to 2009 there was no grazing treatment effect on pasture composition. There was a significant ($P<0.05$) effect of season on pasture composition in 2010, coinciding with above-average summer and autumn rainfall (Figure 1), and resulting in increased legumes and consequent decline in perennial grasses (Figure 2). The perennial grass, annual grass and legume species were primarily one of four species; *Rytidosperma* spp (wallaby grass) and *Austrostipa* spp (spear grass) for the perennial grass species, *Vulpia* spp (silver grass) for the annual grass species (although annual grasses represented less than 5% of the total pasture composition) and *Trifolium arvense* (hare's foot clover) for the legume species.

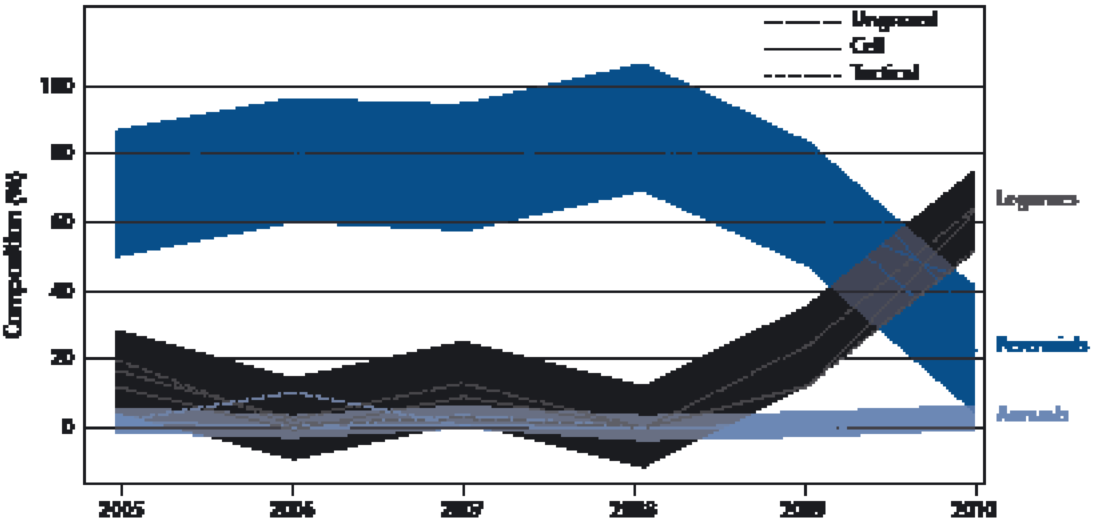


Figure 2. Percentage of perennial grasses, annual grasses and legumes for the ungrazed, cell grazed and tactically grazed treatments. Samples collected in spring 2005–2010. An approximate 95% confidence region for the ungrazed treatment is indicated by shading.

Soil carbon

There was a significantly ($P<0.05$) higher stock of OC in the 0–0.30 m soil layer (calculated on an equivalent soil mass – ESM) under the cell-grazed treatment compared with the ungrazed treatment; 32.9 t C/ha vs 25.6 t C/ha respectively (Table 1). However, there was no difference in OC stocks between the cell and tactically-grazed treatments (32.9 t C/ha vs 29.5 t C/ha respectively) suggesting that it was the presence of grazing, rather than that type of grazing management that influenced OC stocks. When OC stocks for individual soil layers were compared (on a soil-depth basis), the effect of grazing treatment was statistically important ($P<0.05$) and reasonably consistent across all soil layers (Table 1).

We propose that a combination of factors contributed to a greater OC stock in soil OC under grazed pastures including:

- differences in plant shoot/root allocation
- root growth and root turnover with defoliation under grazing
- lower plant productivity where grazing is excluded due to shading and nutrient tie-up.

Summary

This study demonstrated that removing grazing is unlikely to increase soil C stocks under native pastures in southern Australia, and that actively grazing pastures can significantly increase soil C stocks. Whilst there was no significant difference in soil C between cell or tactical grazing treatments, cell-grazing native pastures significantly increased soil C in the 0–0.30 m soil layer compared with the ungrazed treatment on a shallow granite-derived soil. Unlike other grazing studies where grazing management is suggested to increase C stocks in the surface soil as a response to trampling and manure, statistically important increases were only detected when the 0–0.30 m soil layer was compared across treatments.

There was no difference detected in labile C or N stocks due to grazing treatment, which may indicate that the differences in soil C stocks were not from short-term accumulation of particulate OM, such as seasonal pasture growth, but might be from longer-term (5 years) management.

Despite lower than average rainfall during the trial, soil C under native pastures on shallow granite-derived soil responded to grazing management. It is unknown whether cell grazing would affect soil C stocks under introduced pastures under similar conditions, or in the more fertile and productive basalt- and deep granite-derived soils of the Monaro region, which already have higher C stocks.

Table 1. Mean total OC, total N and labile C stock (t/ha) for the 0–0.30 m layer (in 2011) calculated on an equivalent soil mass (ESM), and in soil layers to 0.40 m calculated based on soil depth. Least significant difference (l.s.d.) and standard error of means (sem) presented.

Carbon and nitrogen stocks (t/ha)	Soil depth (m)	Grazing treatment			l.s.d.	sem
		Ungrazed	Tactical	Cell		
OC stock	0–0.30 (ESM)	25.6	29.5	32.9	7.1	1.8
Total N stock	0–0.30 (ESM)	2.5	2.7	2.7	0.7	0.2
Labile C stock	0–0.30 (ESM)	7.3	8.1	9.1	2.9	0.7
OC stock – soil layers	0–0.05	8.4	9.5	10.6	3.4	0.9
	0.05–0.10	5.8	6.1	7.4		
	0.10–0.20	7.2	8.6	8.6		
	0.20–0.30	4.2	5	6.3		
	0.30–0.40	4.7	4.5	5.5		
Total N stock – soil layers	0–0.05	0.7	0.8	0.8	0.3	0.1
	0.05–0.10	0.6	0.5	0.5		
	0.10–0.20	0.7	0.7	0.7		
	0.20–0.30	0.6	0.6	0.6		
	0.30–0.40	0.7	0.6	0.6		
Labile C stock – soil layers	0–0.05	2.9	3.1	3.4	1.3	0.3
	0.05–0.10	1.7	1.7	2.4		
	0.10–0.20	1.8	2.1	2		
	0.20–0.30	0.9	1.2	1.4		
	0.30–0.40	1.2	0.9	1.2		

Furthermore, these results are from the conclusion of a replicated grazing trial conducted with small plot treatments, which brings the benefits of controlling environmental factors that influence soil C, such as climate, topography, aspect, soil type, controlling grazing pressure and reducing the spatial variability of soil C. However, grazing management occurs at the farm scale, and particularly for the cell-grazing treatment, measuring changes in soil C is likely to be more complex with field size, number of cells, distance to water, and variations in soil properties and pasture composition likely to influence the grazing treatment effects and soil C interactions.

This study provides evidence that there is the potential for agricultural soils to have higher soil C stocks as a result of grazing management compared with no grazing in the short term.

References

Pope, L., Alcock, D., Powells, J., Garden, D.L., Grigulis, K., Hackney, B., Johnston, W., Norton, M., Orchard, B., Smith, R., Shields, C., 2011. Final report: Southern Rivers Catchment Management Authority Project: SECMB C1/8. Monaro Research, Development and Demonstration of Sustainable Grassland Management, New South Wales Department of Primary Industries, Australia.

Acknowledgements

The authors would like to acknowledge the Monaro Research, Development and Demonstration of Sustainable Grassland Management Project 2005–10 for trial and pasture data. This paper was part of a PhD thesis through Charles Sturt University and is published in the journal: *Land Degradation & Development*. DOI: 10.1002/ldr.2560.

Increasing soil organic carbon with nutrient application: exploring the concept in the laboratory

Dr Susan Orgill (NSW DPI, Wagga Wagga); **Dr Jason Condon** (Charles Sturt University, Wagga Wagga); **Dr Clive Kirkby** (CSIRO, Canberra); **Beverley Orchard, Dr Mark Conyers** (NSW DPI, Wagga Wagga); **Dr Richard Greene** (Australian National University, ACT); **Dr Brian Murphy** (NSW Office of Environment and Heritage, Cowra)

Key findings

- Organic carbon accumulation in soil did not approach an upper limit.
- Increases in organic carbon accumulation were due to accumulated microbial detritus (i.e. dead microorganisms and microbial products).
- Soil with the lowest organic carbon concentration at the start of the experiment accumulated the greatest mass of stable organic carbon.
- Nutrients applied based on humus nutrient ratios promoted organic carbon stabilisation in soil.

Introduction

Identifying soil with a large potential to accumulate organic carbon (OC) could maximise the mitigation benefits of carbon (C) sequestration and help producers decide if they should prioritise resources to achieve increases in soil OC. The purpose of this laboratory-based incubation experiment was to determine if an upper limit to OC accumulation in soil was approached with increasing C input in basalt- and granite-derived soils.

Site and experiment details

Site

Six permanent pasture sites, three with basalt-derived soil and three with granite-derived soil, were identified as having the highest OC concentration for their parent material class from a field survey in the Monaro region in south-eastern Australia (Orgill et al. 2014). Soil characteristics are presented in Table 1.

Table 1. Mean soil characteristics including soil type (Australian soil classification; ASC), dominant mineralogy and particle size.

Soil type	ASC, mineralogy and particle size	OC (%)	BD (g/cm^3)
Basalt-derived	Dermosol: smectite with >44% clay-sized particles		
0–0.10 m		6.25	0.88
0.40–0.50 m		2.10	1.57
Granite-derived	Kurosol: quartz with >46% sand-sized particles, and increasing clay (mainly kaolin) in subsoil		
0–0.10 m		3.26	0.85
0.40–0.50 m		0.04	1.58

Experimental design and treatments

Two soil layers (0–0.10 m and 0.40–0.50 m) were sampled from each of the six sites for this experiment. The treatment and measurement schedule for this experiment is provided in Figure 1.

Soil samples were incubated at 25 °C for up to 146 days, with soil moisture maintained at 70% field capacity. The experiment consisted of three soil incubation cycles, with four treatments applied at the start of each cycle:

1. soil only (control)
2. soil and nutrients only (nutrients)
3. high organic matter (OM) and nutrients (approximating a field equivalent of 12.4 t DM/ha or 2 years pasture growth; HOMN)
4. very high OM and nutrients (31.1 t DM/ha or 5 years pasture growth; VHOMN).

At the beginning of cycle one ^{13}C-labelled OM was applied. Nutrient application rates were calculated using the concentration of nutrients required for 30% efficiency in retaining C from the applied OM and based on the nutrient ratios of humus reported in the literature, that is carbon (C; 10): nitrogen (N; 0.83): phosphorus (P; 0.20): sulphur (S; 0.14) (Kirkby et al. 2011). The experiment was designed as a four replicate split-plot design with cycle randomised to main plots within a replicate, and treatment by soil sample randomised to sub-plots (jars) within main plots.

At the conclusion of the incubation cycle, soil samples were collected and oven dried at 40 °C. Dried samples were gently hand ground using a mortar and pestle, sieved to <2 mm and any remaining recognisable plant material (i.e. undecomposed OM) that was approximately 0.4–2 mm was removed.

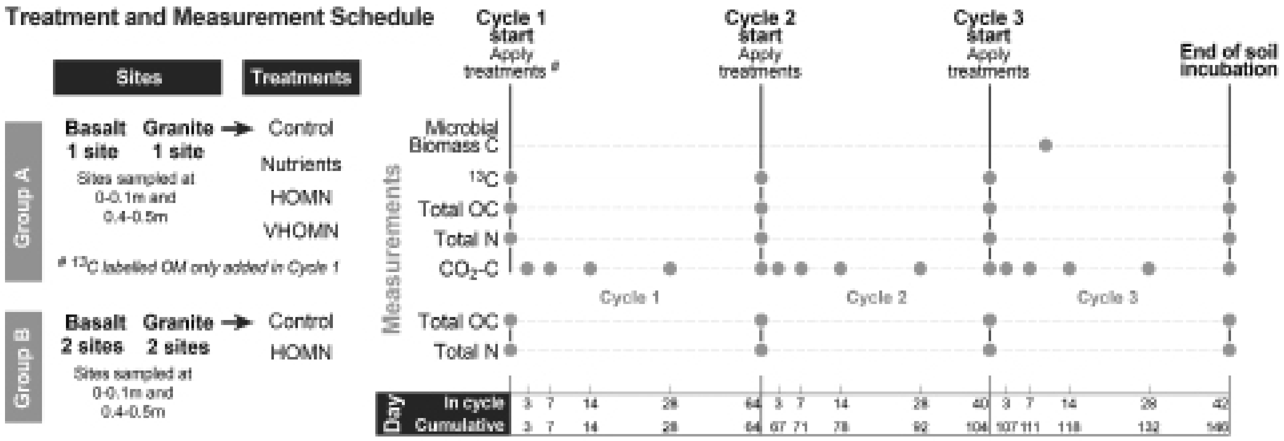


Figure 1. Schematic representation of the soil incubation experiment, including: sites (6), parent material (basalt and granite), soil depth (0–0.10 m and 0.40–0.50 m), treatments (control, nutrients, high organic matter plus nutrients; HOMN and very high organic matter plus nutrients; VHOMN), treatment applications (3), cycles (3) and measurement schedule (dots).

Results

Total organic carbon

Regardless of parent material or soil depth, there was no difference in total OC concentration between the control and nutrients only treatments, or within these treatments with incubation cycle. In contrast, adding OM and nutrients increased the concentration of total OC for both parent material ($P<0.001$) and soil depths ($P<0.05$). Total OC concentration increased with each HOMN and VHOMN treatment application. For example, in the basalt-derived 0–0.10 m soil, the VHOMN treatment increased total OC from 7.20% to 7.32%, 7.79% and 8.49% (0.5 se) in cycles one, two and three respectively. The increase in total OC was compared with the C added (Figure 2) and overall produced a linear trend. This increase was greater at depth ($P<0.001$) and was influenced by parent material ($P<0.05$). According to the C saturation concept, an asymptotic relationship (i.e. where the plotted line approaches, but does not reach a certain value) between OC concentration and C inputs indicates C saturation. However, regardless of initial OC concentration there was no asymptotic behaviour between C inputs and OC accumulation in soil observed in this study (Figure 2). Thus, OC accumulation was not approaching an upper limit at OM application rates ranging from 12.4 t DM/ha to 93.3 t DM/ha (equivalent to 5.4–40.6 t C/ha).

Interestingly, there was no significant increase in OC concentration between cycle two and three for the VHOMN treatment in the granite-derived 0.40–0.50 m soil and, while not conclusive; this might indicate that these soils may approach an upper limit to OC accumulation at a lower OC concentration due to the dominance of 1:1 clays.

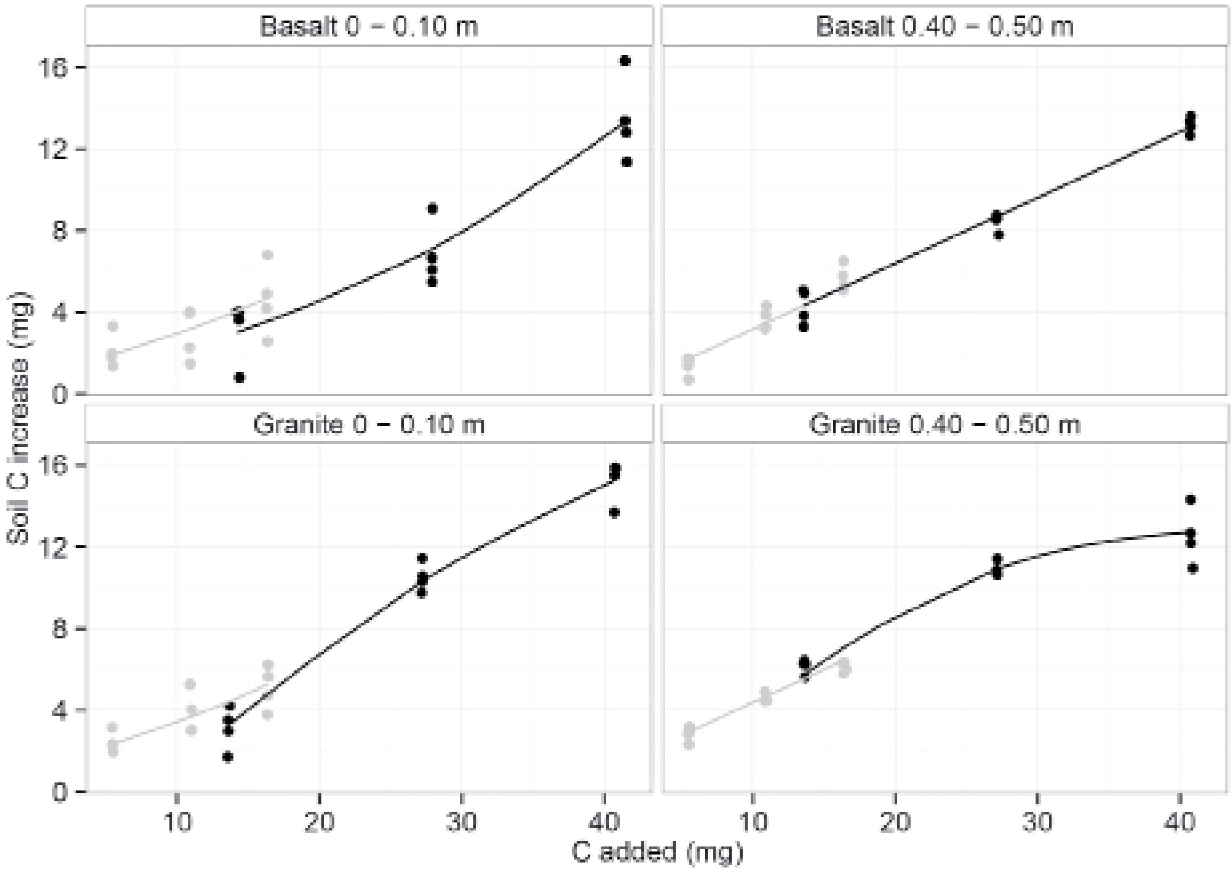


Figure 2. Relationship between the increase in soil C (mg/g; treatment less original C concentration) and the amount of C added (mg/g based on 43.51% C in OM) for basalt- and granite-derived 0–0.10 m and 0.40–0.50 m soil. Grey dots are the replicate values for cycles 1, 2 and 3 of the high organic matter plus nutrients (HOMN) treatment, and the grey line is the correlation. Black dots are the replicate values for cycles 1, 2 and 3 of the very high organic matter plus nutrients (VHOMN) treatment, and the black line is the correlation.

Microbial biomass carbon (MBC) and ^{13}C recovery

The two microbial parameters used in this study were respiration (CO_2) and MBC. Microbial biomass carbon is composed of both metabolically active and dormant microorganisms, while CO_2 derives primarily from active organisms. The retention of the ^{13}C isotope throughout the three incubation cycles indicated the stability of accumulated OC. Despite increasing microbial activity, as evidenced by increasing soil respiration and MBC (Figure 3), as well as a significant ($P<0.05$) narrowing of the C:N ratio, there was substantial ^{13}C recovery at the end of the soil incubation. This indicates that the increases in OC accumulation were at least partly due to plant residues being converted into microbial detritus, which is a major component of the relatively stable pool of OC (i.e. humus) in soil. Furthermore, the mean recovery of ^{13}C in soil (between 19.8 and 25.9 (1.1 se) %) at the conclusion of the experiment is relatively consistent with the target of 30% efficiency in C retention from the applied OM on which the nutrient applications were based.

Summary

From the laboratory to the field…

These sites were under permanent pastures and literature indicates that such sites are close to C saturation, or have a small C saturation deficit. Despite this, the results from this laboratory study indicate that if OM and nutrient supply could be maintained at high levels, then these soils have the capacity to sequester more C. That is, at rates of up to 93.3 t DM/ha, no C saturation occurred.

However, we have presented a short-term (146 day) incubation experiment in a closed system. The issue of whether soil is approaching C saturation in the field or reaching equilibrium for that land use and management needs to be considered. To differentiate these in-field-based studies, climate and net primary productivity would need to be assessed. This would help to determine if constraints such as OM supply and decomposition, rather than inherent soil properties, were limiting OC accumulation in soil. Further, it is unlikely that current agricultural management in this environment could achieve such substantial increases in OM supply.

Regardless, our results support the theory that soil with a high OC concentration can continue to accumulate relatively stable OC where C and nutrient inputs are maintained. This biological OC stabilisation in soil needs to be considered to maximise the mitigation benefits of soil C sequestration in agricultural soil. Our study suggests a large potential for C sequestration in soils under permanent pastures in southern Australia, particularly as soil nutrition is something that can be managed.

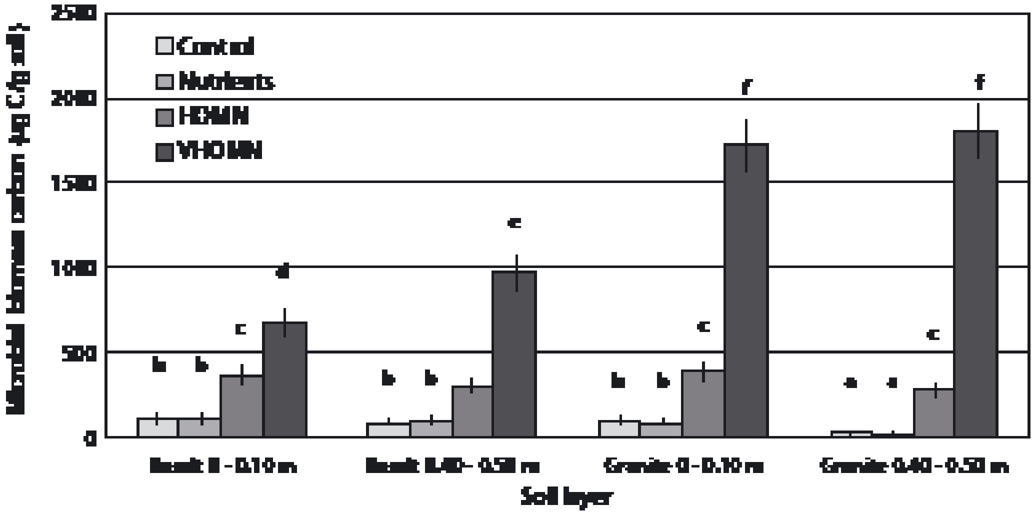


Figure 3. Microbial biomass carbon (µg C/g soil) at day 10 of cycle three for basalt- and granite-derived soil; 0–0.10 m and 0.40–0.50 m layers. Treatments include: control, nutrients, high organic matter plus nutrients (HOMN) and very high organic matter plus nutrients (VHOMN). Significant ($P<0.05$) differences indicated by different letters with testing completed using cube root data (5% l.s.d. was 1.01 on this scale). Error bars are approximate standard error as analysis was on the cube root scale.

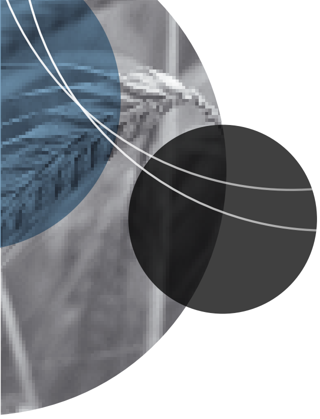
References

Kirkby CA, Kirkegaard JA, Richardson AE, Wade LJ, Blanchard C, Batten G (2011). Stable soil organic matter: A comparison of C:N:P:S ratios in Australian and other world soils. *Geoderma* 163(3–4), 197-208.

Orgill SE, Condon JR, Conyers MK, Greene RSB, Morris SG, Murphy BW (2014). Sensitivity of soil carbon to management and environmental factors within Australian perennial pasture systems. *Geoderma* 214–215, 70-79.

Acknowledgements

This research was supported by joint investment by the Australian Government Department of Agriculture and Water Resources (National Soil Carbon Program) and NSW Department of Primary Industries. Claudia Keitel and Janani Vimalathithen (University of Sydney) are acknowledged for the stable isotope analysis and Albert Oates (NSW DPI) for the particle size analysis. The cooperation of the land holders in the Monaro regions whose properties were sampled is also acknowledged. This paper was part of a PhD thesis through Charles Sturt University and is published in the journal: *Geoderma* 285:151–163.



Crop protection

Southern NSW paddock survey – 2014 to 2016

Dr Andrew Milgate, Tony Goldthorpe and Brad Baxter (NSW DPI, Wagga Wagga)

Key findings

- The frequency of winter cereals in the rotation have a large impact on crown rot inoculum build up.
- Monitoring paddocks over time is a powerful way to help crown rot management and the PreDictaB™ soil tests are an effective method for achieving this.
- The dominant wheat–canola rotation in southern NSW is increasing the region's level of risk to losses caused by crown rot.
- Not all paddocks behave the same way and factors other than crop type are affecting crown rot behaviour.

Introduction

This report describes some of the findings to date of a longitudinal survey of soil and stubble-borne diseases in southern NSW (sNSW) farming systems. In total, 93 representative paddocks are being monitored as a part of the study when in their cereal phase. We will focus specifically on the crown rot inoculum in this report.

Fusarium pseudograminearum (Fp) and *Fusarium culmorum* (Fc) are the two most common causal agents of the crown rot disease. Crown rot restricts the flow of water and nutrient through the xylem resulting in stress during the critical grain-fill stage. This can result in pinched grain or heads with no grain, otherwise known as whiteheads. Crown rot infects winter cereals only, including barley, bread wheat, triticale and durum wheat in order of decreasing tolerance to the pathogen.

Crown rot is favoured by wet, cool winters and dry, hot spring conditions. It can be identified early in the growing season as stunted yellow plants or single dead tillers. More reliable identification can occur in periods of moisture stress – typically, honey-coloured stem browning extending from the sub-crown internode upwards to the first or second node. As opposed to take-all, where all tillers on a single plant will express whiteheads, crown rot will cause whiteheads in scattered single tillers. Yield loss can still occur without the expression of whiteheads.

The incidence of crown rot in sNSW farming systems has been increasing over the past decade. However, before this study, no replicated systematic surveys had been conducted in the region to inform industry of the extent of the issue. This study serves to identify the crown rot risk to the industry and link with research on rotation impacts and grower practice at a whole-paddock scale.

Methods

Soil and stubble samples were collected, starting at a permanent GPS location, sampling from the centre moving outwards in a spiral pattern. Ten soil cores and 10 pieces of stubble were collected at 10 points along the spiral. The samples were bulked, homogenised and a sub sample taken for analysis. The sub sample comprised 500 g of soil and 30 random pieces of stubble 4–5 cm long, ensuring the crown was present on the stubble.

The samples were then analysed using PreDictaB™, which estimates the amount of a pathogen present in the soil and stubble by DNA analysis. In this instance, Fp and Fc are the main focus, however, various other cereal, oil seed and pulse diseases can be identified during the DNA assay process.

Results and discussion

Crown rot was present in 55% of the paddocks surveyed in 2014 and 80% of paddocks in 2015. Pre-sowing data shows that 63% of the 2016 paddocks sampled had crown rot present. However, due to the favorable season for crown rot, this number is likely to increase when the postharvest PreDictaB™ data is available. Our data indicates that crown rot increased throughout the growing season in paddocks that had crown rot before sowing.

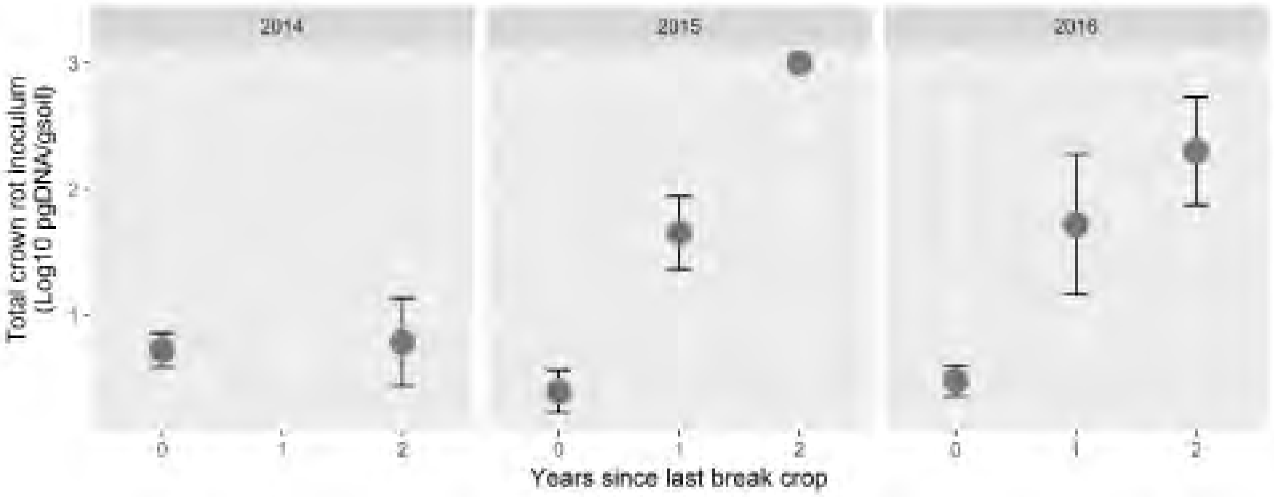


Figure 1. Number of years since a non-cereal break crop's effect on pre-sowing levels of crown rot (Fp + Fc) before sowing 2014–2015, measured by PreDictaB™ analysis. Log risk levels: below detection = <0.6, low = 0.6–<2.0, medium = 2.0–<2.5, high = ≥2.5 for bread wheats in southern NSW.

Topographic, climatic and human factors can influence variability in Fp and Fc inoculum build up. These can include: soil type, rainfall amount and timing, seasonal temperatures, agronomic factors, variety selection, crop rotations, break crop duration, weed control, stubble retention, cultivation and stubble burning.

Previous crop effects and risk factors

The survey has revealed clear trends in grower paddocks and the impact of choices in crop type. Figure 1 clearly shows that even after one year of winter cereal, the level of inoculum increases significantly and this continues to rise in subsequent years of continuous cereal crops. This trend is in line with research results. What is important to point out, is that this result comes directly from current grower practices in southern NSW.

It is well established that host crops such as wheat, allow for the build up and maintenance of inoculum levels. Approximately half of the paddocks surveyed pre-sowing were in the medium and high risk categories for crown rot following a cereal crop, (Figure 1). This translates to a potential yield loss of between 5–60% if a cereal crop is grown (McKay et al. 2015).

The number of years since sowing a break crop between cereals can significantly influence the amount of inoculum within a paddock. A break crop can include any crop that is not a cereal. Pulses and oil seed crops are common examples. Figure 1, shows the significant rise in the crown rot risk as the number of years of continuous cereal increases.

The first cereal crop sown following a break crop (0 years) has a significantly reduced crown rot risk compared with those sown after one or two cereal crops. The first year following a break crop (0 years), essentially has a risk factor of below detectable level, which results in a 0–5% potential yield loss (McKay et al. 2015). One year since a break crop, or two consecutive cereal crops, increases the risk to a low–moderate risk – a 0–30% potential yield loss (McKay et al. 2015). Two years since a break crop, or three consecutive cereal crops, increases the crown rot risk to high. This could potentially result in a 15–60% yield loss under the right conditions. This estimate is based on bread wheat in sNSW; the risk factor for durum wheat is significantly higher.

The potential yield loss underlies the importance of using break crops in a rotation to manage crown rot inoculum. If high levels of inoculum are present, one, two or more years in a fallow, pulse or an oil seed crop might be needed to bring the inoculum levels down to a suitable point to allow cereals to be sown without the increased risk of economic loss.

The survey is beginning to reveal the impact that non-host crops can have on crown rot inoculum levels. The box plot in Figure 2 shows that wheat and canola are the most frequent crops within the surveyed paddocks. There is a large variation in the amount of inoculum present within these paddocks (Figure 2). Paddocks that were sown in the previous year to canola have, on average, lower inoculum levels, but the range of values is similar to the paddocks sown to wheat.

The unexpected high level of inoculum persisting in some canola paddocks requires further examination. In this report we have only considered the immediate previous crop effect on crown rot inoculum in Figure 2. If additional rotation years are taken into account, we would expect to identify crop sequences that are associated with these phenomena. However, our preliminary analysis of two years of rotations did not reveal any obvious trends and will need more data and analysis to identify potential causes (data not shown).

The dominance of wheat and canola in the sNSW rotations means there is not yet enough data to draw conclusions on the impact of other crop types. However, the patterns displayed thus far support the existing research results that non-host species such as lupins reduce crown rot risk significantly.

Paddock specific trends

The survey is providing the clear result that not all paddocks behave in the same manner over time. This is due to the complex interactions occurring between soil, rainfall, rotation and pathogen. The cooperators treat all paddocks within the survey set differently. However, some paddocks show interesting inoculum trends based on similar rotations, but have different location, topographic and climatic characteristics.

The inoculum levels of the four paddocks shown in Figure 3, are typical of sNSW farming systems. Each paddock comes from a mixed farming enterprise with a focus on both cropping and livestock. These paddocks have pasture, wheat and canola rotations.

There was a rapid buildup of crown rot in paddock 6 over the three-year period with a continuous winter cereal rotation (Figure 3). Inoculum levels in this paddock increased from a low risk before sowing in 2014 to a high risk within the season. This risk level translates to a potential yield loss of 15–60% (McKay et al. 2015) for the 2015-sown wheat crop.

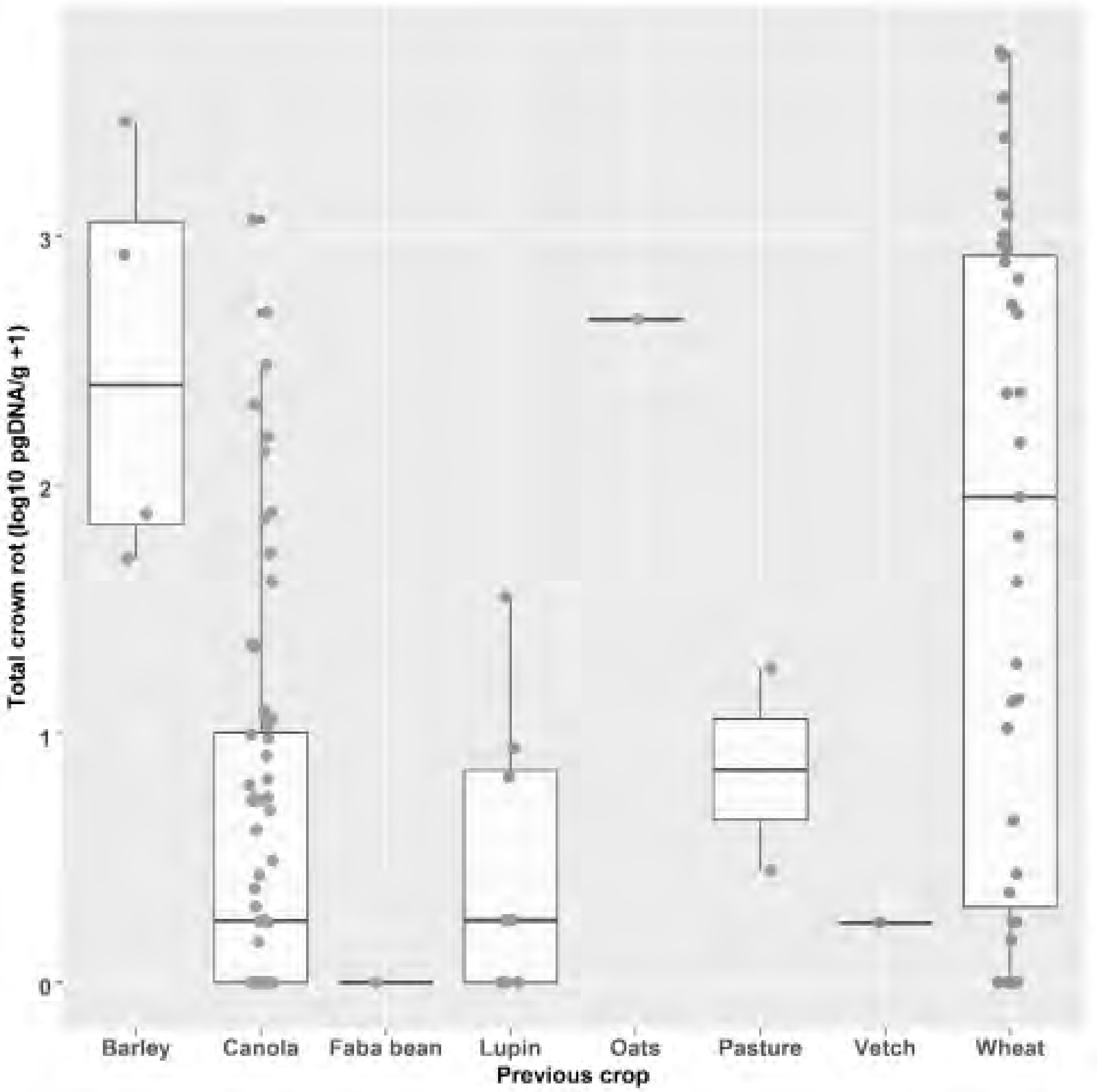


Figure 2. Previous crop effects on the background levels of total crown rot inoculum (*Fusarium pseudograminearum* and *Fusarium culmorum*) before sowing 2014–2016 measured by PreDictaB™ analysis in 120 paddocks from southern NSW. Log risk levels: below detection = <0.6, low = 0.6–<2.0, medium = 2.0–<2.5, high = ≥2.5 for bread wheats in southern NSW.

The inoculum survived over the 2014–2015 and 2015–2016 summer, which then resulted in a high risk starting level for the 2015 and 2016 wheat crops. In this instance, the paddock had reached a high level and continued to maintain the levels of inoculum expected with repeated sowing of susceptible crop species.

The inoculum levels of paddock 33 (Figure 3) had a similar trend to paddock 6. The paddock started at below detectable levels of crown rot in 2014 through to a high level before sowing in 2016. Paddock 33 has a very different soil type; heavier and typical of gilgai soil types compared with the lighter red, clay loams of paddock 6. Inoculum levels in paddocks 6 and 33 are typical of the steady increase in inoculum in a cereal-on-cereal rotation.

The increase in crown rot inoculum in paddocks 3 and 11 are not typical of the usual increase patterns. Paddock 3 was sown to three consecutive wheat crops from 2014 to 2016. However, the crown rot levels remained below detectable–low levels.

The low levels of crown rot in paddock 3 over the three years are not typical and might be explained by the grower adopting an integrated approach to disease management through using a combination of sowing a moderately susceptible wheat variety, burning stubble and inter-row sowing. Sowing cereal-on-cereal for three consecutive years is not advised. Further measuring of inoculum in this paddock and others with similar management will be conducted over the next two years.

There was a rapid buildup in inoculum in paddock 11 during the growing seasons 2014–2016 and a rapid decline over each summer. This paddock has heavy, grey clay typical of river flats. The increase during the growing season and then the decline over summer could be attributed to interactions between rainfall, soil type and agronomic practices.

These paddocks highlight that growers need to understand how their own paddocks are responding to the interaction with stubble-borne diseases and that the PreDictaB™ test provides a tool to do this.

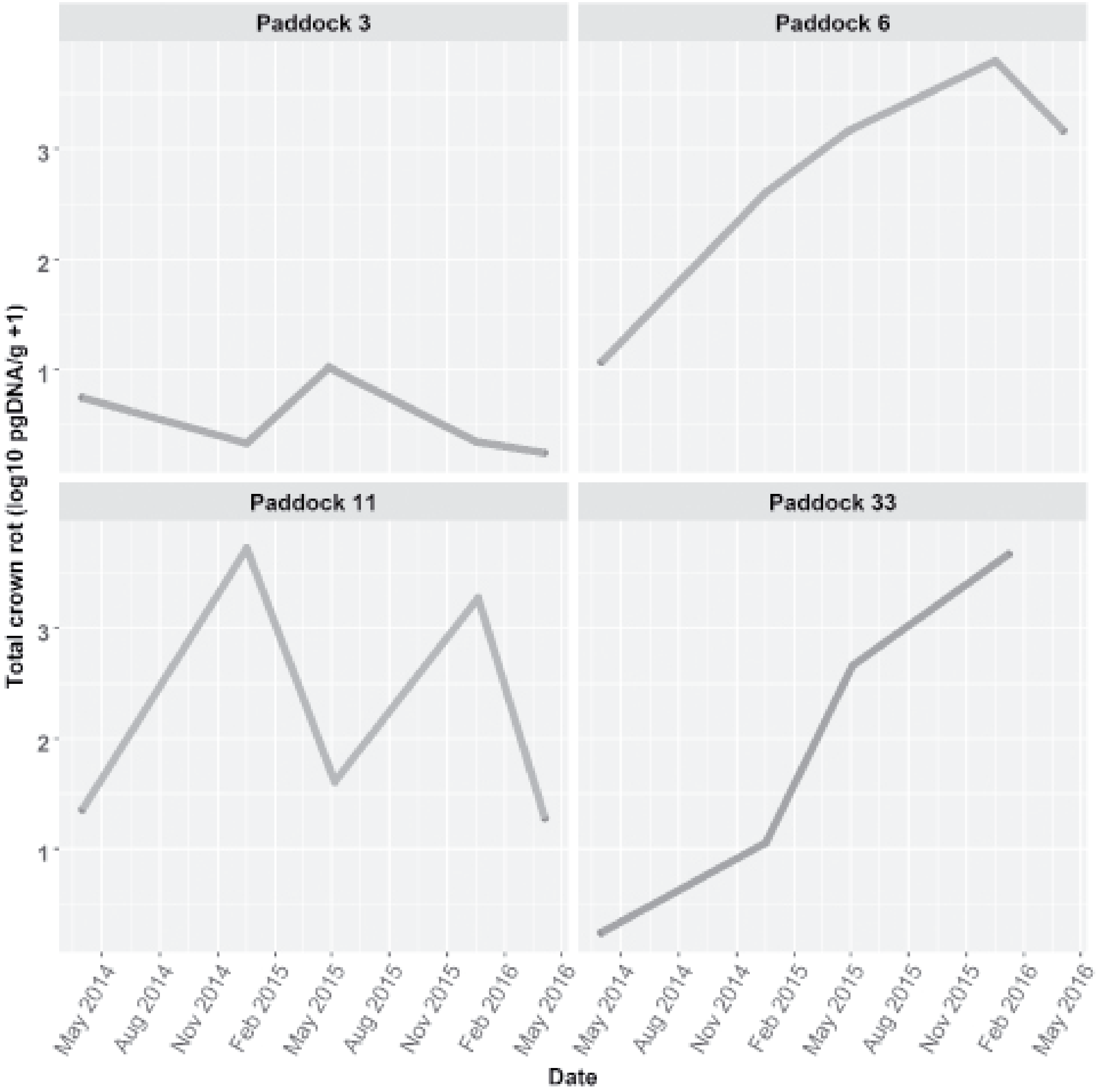


Figure 3. Crown rot inoculum changes over time of four individual paddocks during the growing season. Measurements taken pre-sowing and postharvest from 2014 to 2016. Total crown rot is the combined inoculum of *Fusarium pseudograminearum* and *Fusarium culmorum*. Log risk levels: below detection = <0.6, low = 0.6–<2.0, medium = 2.0–<2.5 and high = ≥2.5 for bread wheats in sNSW.

Implications for growers

All paddocks will build up crown rot inoculum at different rates depending on the management practices. The climatic conditions of 2014 and 2015 were conducive to developing high levels of crown rot across southern NSW. Cool, wet winters followed by a relatively dry spring allowed low levels of crown rot to increase to medium–high levels in some paddocks. Many of the survey paddocks observed with high levels of crown rot also have other diseases present such as take-all, creating disease complexes that can exacerbate yield losses.

Cereals increased the pre-sowing levels of crown rot when compared with canola and other non-host species as the previous crop. However, canola does not always lower inoculum levels and these situations require further investigation.

The current recommendation to growers in the presence of high levels of crown rot is to remove cereals from the paddock's rotation. Sow a pulse or oil seed crop to allow the inoculum to break down and, if possible, do so for more than one season. If a cereal must be grown, consider sowing barley. Due to the earlier maturity of barley and its higher tolerance, this can potentially negate the effects of crown rot during the grain-fill stage. However, it must be noted that barley is a susceptible crop to crown rot and it will not reduce the inoculum build up during the growing season.

References

McKay A, Mayfield A & Rowe S, eds, 2015. *Broadacre soilborne disease manual: PreDictaB™ DNA soilborne disease DNA tests.* South Australian Research and Development Institute.

Acknowledgements

Thank you to the growers who allow access to their paddocks for the survey data to be collected and the agronomist who facilitated the access.

All technical components of conducting these experiments were carried out by Tony Goldthorpe, Brad Baxter (NSW DPI), Chris Minehan (Rural Management Strategies), James Whitley (previously Riverina Co-op), Tim Tarlington (Riverina Co-op) and Will Haines (Landmark).

The southern NSW paddock survey has been conducted under the 'National crown rot management program – Southern NSW component', DAN00175, 2014–18 with joint investment by GRDC and NSW DPI.

Responsiveness of wheat and barley varieties to crown rot in southern NSW

Dr Andrew Milgate, Brad Baxter and Tony Goldthorpe (NSW DPI, Wagga Wagga)

Key findings

- Winter cereal varieties differ in their levels of yield loss and responsiveness to crown rot and growers can use these rankings to improve production in the presence of this disease.
- Grain yield and responsiveness to crown rot appear strongly correlated in these experiments.
- Grain yield losses vary between seasons with up to a 25% reduction measured in southern NSW.

Introduction

Crown rot of winter cereals in southern New South Wales is caused by *Fusarium pseudograminearum* and *Fusarium culmorum*. This disease is known to cause large economic losses across Australia in winter cereal growing regions. The disease can persist in the stubble over many years, thus making its control in farming systems difficult and requiring a multifaceted approach. One way to avoid or minimise losses is to grow varieties that show higher levels of tolerance to the disease. However, tolerance is difficult to measure and may only provide marginal benefits. In this series of experiments, we have quantified the extent of yield loss displayed in a number of commonly grown winter cereal varieties in southern New South Wales across four years.

Tolerance to a disease can be defined as the ability of a variety to perform despite infection by disease. This is different to major gene resistance, which normally means that a variety is able to repel the infection of a pathogen and thus avoid disease. In the case of crown rot, tolerance in the field is difficult to distinguish from partial resistance. This is because accurate means of determining infection levels are labour intensive and expensive. None of the varieties included in these experiments are known to have major gene resistance, but do vary subtly in their susceptibility.

Methods

Nine experiments were conducted in southern New South Wales at Wagga Wagga and Cowra between 2011 and 2015. The experimental designs were fully randomised with four replicates per genotype and treatment. Sowing dates were delayed until the first week of June in all the years to maximise the opportunity for moisture stress during grain filling and expression of crown rot.

Inoculum was applied using two different methods. In the experiments conducted between 2011 and 2013, spores of *F. pseudograminearum* were sprayed directly onto the varieties' seed. In the experiments from 2014 to 2015, the inoculum was applied as sterile seed infected with the pathogen. Treatments consisted of a control where no inoculum was applied (minus_CR) and a disease treatment where inoculum was applied (plus_CR).

The following traits were measured on each plot; grain yield, grain protein, thousand grain weight, test weight and screenings. The across-sites analysis was conducted using mixed linear models in ASREML using the R package. The varieties' responsiveness was estimated using a paired comparison by multivariate analysis. A total of 27 entries (figures 3 and 4) were tested across the five years with 22 wheat (12 in 2011–2012, 16 in 2013, 13 in 2014–2015) and five barley varieties included in the years 2014–2015.

Results and discussion

The addition of crown rot inoculum reduced grain yield in six of the nine experiments conducted. The magnitude of the reduction in grain yield varied between experiments and ranged from 0–25% (Figure 1). Grain yield loss was higher in experiments conducted in the years 2011 and 2014 when spring rainfall was generally lower. This result is consistent with the findings from crown rot yield loss experiments conducted in other regions of Australia.

The importance of variety response to crown rot infection can be seen by examining the sources of variance in these experiments and how large the effects are in comparison with each other. Variety contributed a larger proportion of the variance than the interaction term variety by treatment (Figure 2). The size of this interaction term changes across the experiments and is not always significant where crown rot has reduced grain yield.

What we can say from this analysis, is that where crown rot is present, varieties do perform differently, but that within the varieties and environments tested, this effect was not consistent or large. Environmental conditions such as the amount and timing of spring rainfall heavily influences crown rot effects.

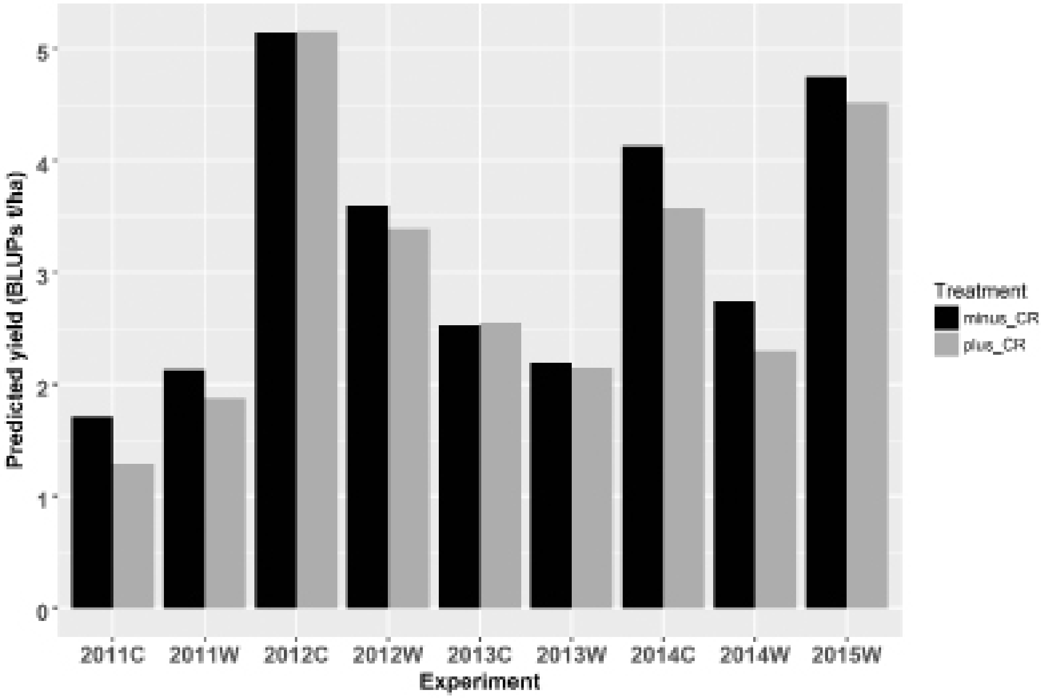


Figure 1. Predicted experiment mean grain yields of 22 wheat and five barley varieties grown at Wagga Wagga (W) and Cowra (C) in southern NSW between 2011 and 2015. The dark bars are the results for the control treatment (minus_CR) and the lighter bars are the results for the disease treatment (plus_CR).

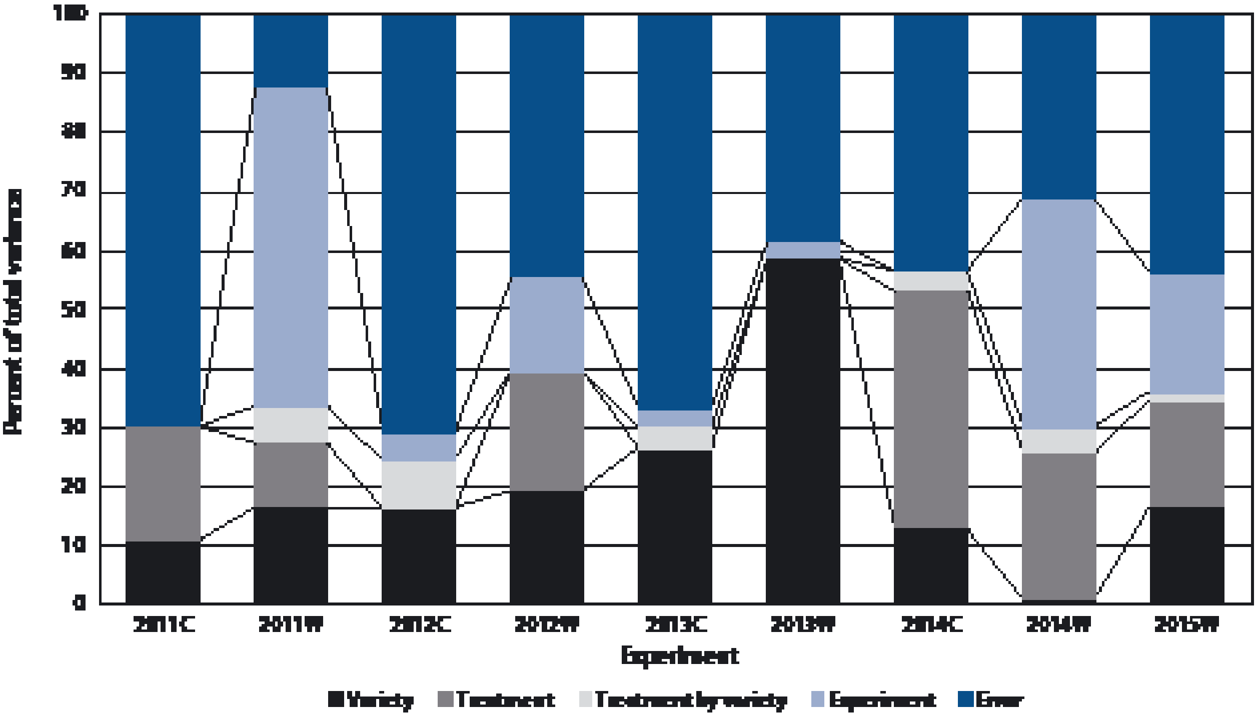


Figure 2. Variance components as a percentage of the total variance of grain yield for nine crown rot experiments grown at Wagga Wagga (W) and Cowra (C) in southern NSW between 2011 and 2015.

The grain yield response of individual varieties can first be examined by comparing them against each other in the presence of disease, compared with the absence of disease across all experiments (Figure 3). This comparison shows that there is a strong positive correlation between grain yield and grain yield in the presence of added crown rot. Barley varieties were higher yielding than the wheat varieties in these experiments in both presence and absence of crown rot infection. Growers could use this result to sow barley in paddocks where a known crown rot risk is high and non-host rotation crops are not an option.

Among the wheat varieties examined, Emu Rock$^{Ⓓ}$ is clearly higher yielding than other varieties in both the presence and absence of crown rot infection. The next highest yielding varieties were Waagan$^{Ⓓ}$ and LongReach Trojan$^{Ⓓ}$. The grain yield of some of the more popular varieties in southern NSW such as EGA Gregory$^{Ⓓ}$, EGA Wedgetail$^{Ⓓ}$, LongReach Spitfire$^{Ⓓ}$ and LongReach Crusader$^{Ⓓ}$ during 2011–2015 was lower in both the presence and absence of disease. This means grower profitability could have been improved over the past five years in paddocks that had high crown rot levels through better variety choice. This is an important finding considering a large portion of the cropping area of southern NSW is sown with a wheat-on-wheat rotation and has significant levels of crown rot inoculum present.

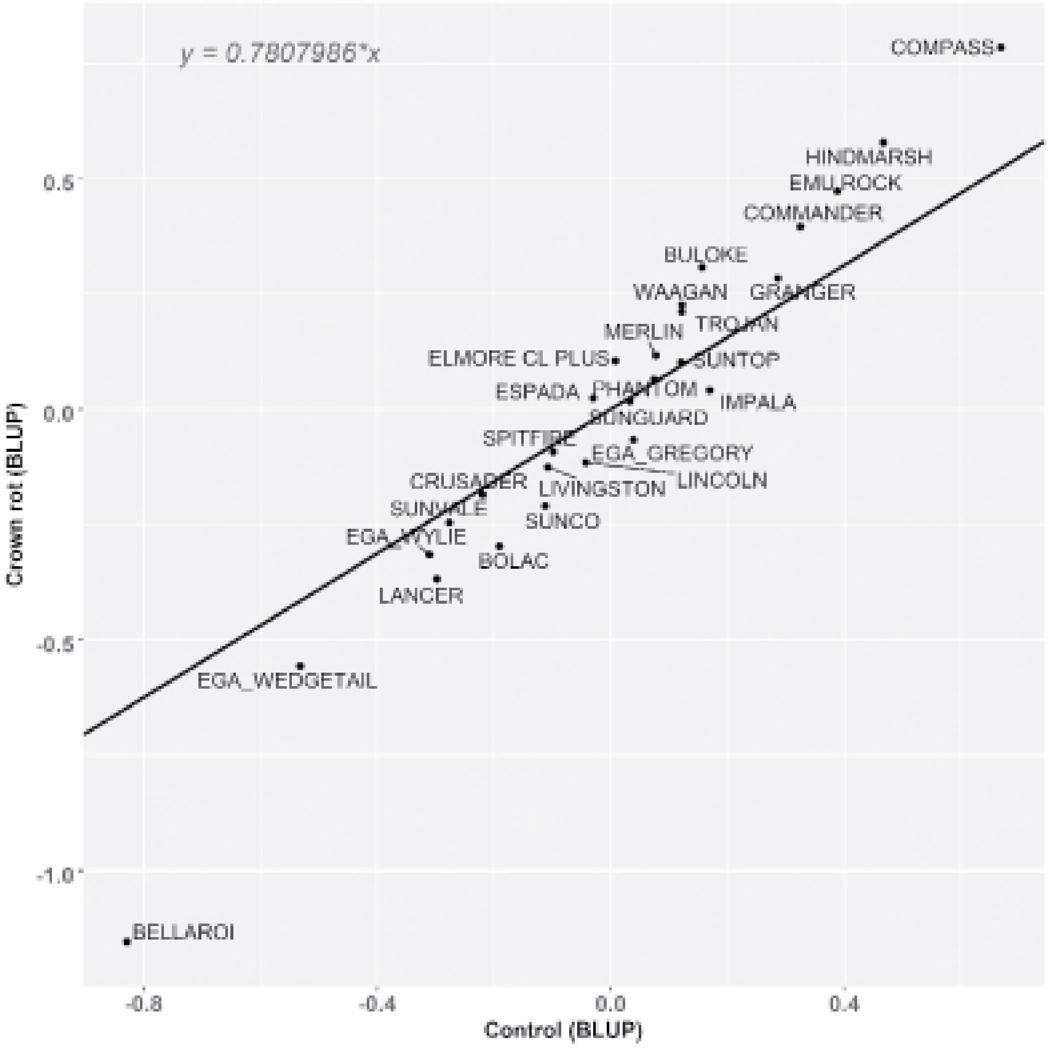


Figure 3. Grain yield BLUP of 22 wheat and five barley varieties in the presence and absence (control) of crown rot across nine experiments grown at Wagga Wagga and Cowra in southern NSW between 2011 and 2015.

Next we can look at the varieties' responsiveness to crown rot by removing the bias effect of overall grain yield performance. This measures how responsive a variety is to crown rot by calculating the distance above or below it from the regression line in Figure 3. By plotting the responsiveness value against grain yield in the absence of crown rot (Control BLUP), we can estimate if there are varieties that may not be high yielding, but have high levels of responsiveness where crown rot is present. For example, among the barley varieties, Buloke$^{Ⓓ}$

has a higher level of responsiveness compared with Commander⁽ᵇ⁾, even though it was lower yielding in these experiments (Figure 4). For the wheats, Elmore CL PLUS⁽ᵇ⁾ is more responsive than LongReach Impala⁽ᵇ⁾, which can be seen more clearly in Figure 4. However, the ranking of the top varieties is relatively stable between the two methods of comparison.

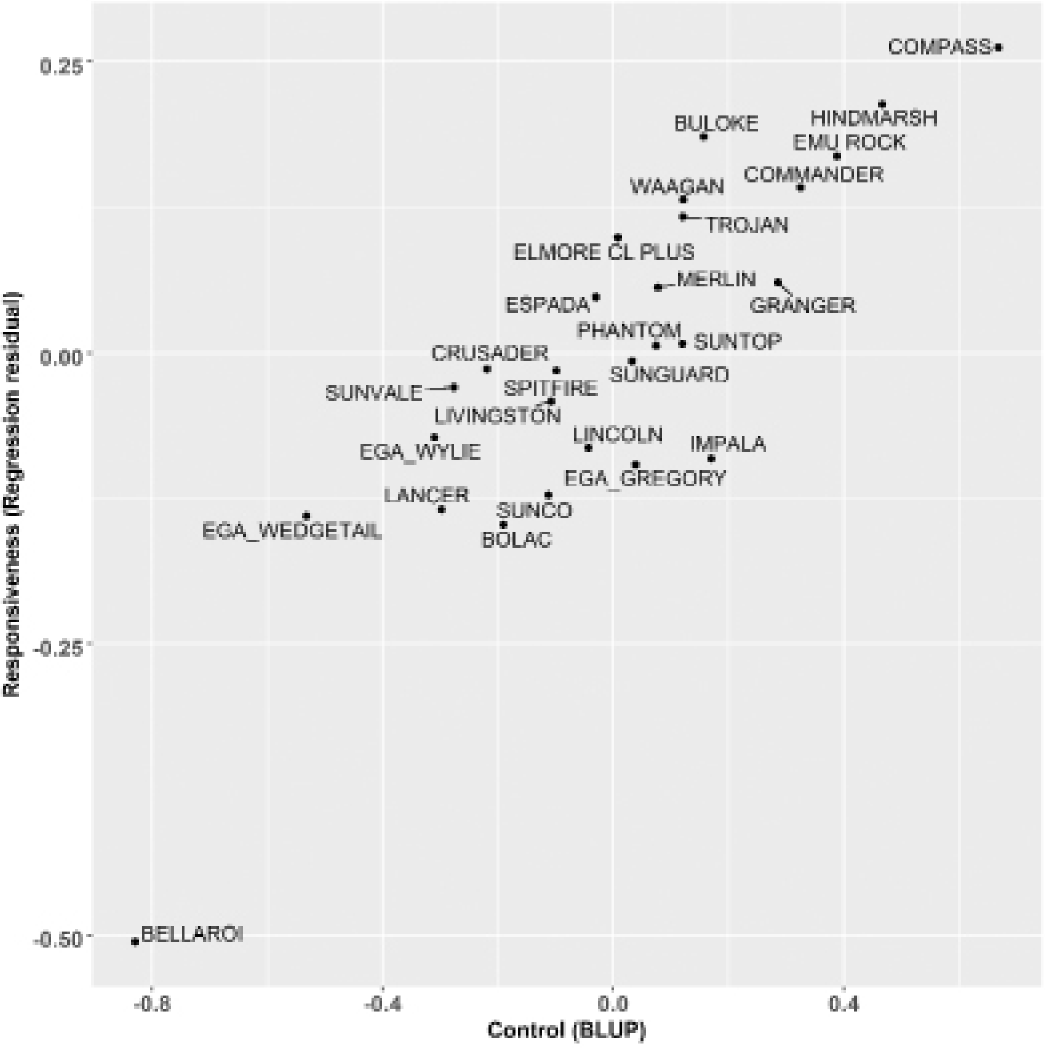


Figure 4. Responsiveness (Regression residual) and grain yield in the absence (control) of crown rot of wheat and barley varieties across nine experiments grown at Wagga Wagga and Cowra in southern NSW between 2011 and 2015. Varieties with responsiveness (regression residuals) of 0.00 and above have an increasingly positive responsiveness in the presence of crown rot inoculum.

There is an apparent strong correlation between the grain yield in the presence and absence of crown rot in southern NSW. One possible reason for this could be in the way varieties are developed through wide testing for grain yield across many sites and years, combined with a high incidence of crown rot within the farming system and in the experiments. This is likely to result in breeding material being regularly exposed to low to moderate levels of crown rot infection and selection of the highest yielding varieties will therefore remove the lower yielding lines in the presence of this disease. The genetic control of grain yield is under the influence of many genes and this is likely to be the case for responsiveness or tolerance to crown rot as well, which means that variety improvement through this approach is incremental and not simple. These experiments provide some evidence that there is a genetic basis to yield in the presence of this disease, or potential quantitative resistance, and that grain yield in crown rot managed experiments could be used as a cost effective measure of this trait in a genomic breeding strategy.

The effects of crown rot on quality traits have also been measured, but will not be discussed in detail in this paper. In summary, crown rot has a detrimental effect on grain quality. These effects were sometimes evident even when grain yield was not affected. For example, grain protein was reduced in six of the nine experiments in the presence of crown rot. Reductions in protein content ranged from 0–0.8%. This has obvious implications for growers' profitability in meeting grain specifications and through reduced nitrogen efficiency from applied nitrogen fertiliser.

Implications for growers

Winter cereal varieties in these experiments differ in their yield performance and responsiveness to crown rot infection. This can make a measurable difference to variety profitability when the disease is present. Growers choosing the highest yielding variety in their region of southern NSW are, in general terms, more likely to be choosing from more positively responsive material. Varieties we have identified with negative responsiveness such as EGA Wedgetail⁽ᐩ⁾, should be sown in paddocks with lower crown rot risk to avoid yield loss. Equally, growers can select either barley or wheat varieties with a known higher yield in the presence of crown rot, to sow in cereal-on-cereal paddocks to maximise yield.

Acknowledgements

This experiment has been conducted under the 'National crown rot management program – Southern NSW component', DAN00175, 2014–18, with joint investment by GRDC and NSWDPI.

All technical components of conducting these experiments were carried out by Tony Goldthorpe, Brad Baxter and Michael McCaig (NSW DPI).

Efficacy of different foliar fungicides to manage sclerotinia stem rot in canola

Dr Audrey Leo, Gerard O'Connor, Beverley Orchard and Dr Kurt Lindbeck (NSW DPI, Wagga Wagga)

Key findings

- Fungicides with different active ingredients had similar efficacy.
- Timing application was the most important factor in reducing sclerotinia stem rot development.
- Disease levels were reduced across all treatments, in particular at 30% bloom and the multiple applications at both 30% and 50% bloom stages.
- Yield increases were observed across all treatments, regardless of the fungicide's active ingredients.

Introduction

This study aimed to compare the efficacy of three different foliar fungicides in managing sclerotinia stem rot in canola. Applying foliar fungicides is the only foliar disease management strategy available for Sclerotinia. Currently there are a number of registered fungicides in Australia to manage the disease. These products contain active ingredients including iprodione, procymidone, and prothioconazole plus tebuconazole. The efficacy of fungicides in general depends on the active ingredient, application timing, fungicide rate and the environmental conditions.

Site details

The Sclerotinia fungicide evaluation experiment was conducted at the Wagga Wagga Agricultural Institute. This site represents the medium–high rainfall cropping region of southern NSW with intensive canola production and frequent Sclerotinia development. The experiment was sown on 6 May 2016 and relied on natural background inoculum to develop the disease. The above average spring rainfall was adequate to favour disease expression.

Treatments

Varieties

The conventional hybrid variety, Nuseed Diamond was used. Seed was treated with Jockey® and sown with Impact In-Furrow®-treated fertiliser.

Fungicide

Three currently registered fungicides were evaluated for their efficacy (Table 1). Each fungicide was applied at bloom stages 10%, 30% and 50%, and a treatment at both 30% and 50%. A nil treatment was included in the experiment as a control. The experiment was in a randomised block design with four replications.

Table 1. Fungicides and their active ingredients used in the experiment.

Fungicide	Active ingredients	Application rate*
Prosaro® 420 SC	125 g/L prothioconazole and 125 g/L tebuconazole	450 mL/ha
Rovral® Liquid	250 g/L iprodione	2 L/ha
Sumisclex® 500 SC	500 g/L procymidone	1 L/ha

* The commercially registered rate of application was used in this experiment.

Assessment

The guide to assess 10%, 30% and 50% bloom stages was adapted from the Canola Council of Canada bloom assessment guide (http://www.canolacouncil.org/canola-encyclopedia/diseases/sclerotinia-stem-rot/).

Sclerotinia was assessed at the end of the growing season by counting the number of infected plants at two central locations within each plot. Different types of infection were recorded: main stem (MS), lateral branch (LB) and basal (B). The total number of healthy and infected plants was recorded to calculate the percentage of plant infection. Grain yield was recorded from the experiment.

Results and discussion

The fungicide evaluation experiment showed that all fungicides tested were able to significantly reduce Sclerotinia development when compared with the nil treatment (Table 2). Different active ingredients were also shown to respond similarly when applied at a specific bloom stage. This indicated that no specific fungicide was consistently more effective in reducing the disease level. However, a significant reduction in disease was observed with respect to timing of fungicide application. A single application at the 30% bloom stage, as well as multiple applications at 30% and 50% bloom stages, reduced the disease level by an average of 25% and 30% respectively across all fungicides.

The results also showed that all fungicide treatments yielded significantly higher than the nil treatment (Table 2). Prosaro® was found to significantly improve canola yields when compared to Sumisclex® at 10%, 30% and 30% + 50% bloom stages. However, Prosaro did not significantly improve yield when compared to Rovral® at all bloom stages. Significant yield increase was apparent at all treatments across different bloom stages when compared to the nil treatment (Table 3).

Table 2. Effect of different fungicides on yield (t/ha) and Sclerotinia plant infection (%) at different bloom stages of canola.

Time of application	Fungicide	Yield (t/ha)	Infection (%)
10% bloom	Rovral®	2.49	17.62
	Sumisclex®	2.48	15.97
	Prosaro®	2.67	16.72
30% bloom	Rovral®	2.55	13.73
	Sumisclex®	2.54	11.09
	Prosaro®	2.73	8.63
30% + 50% bloom	Rovral®	2.68	6.03
	Sumisclex®	2.67	3.48
	Prosaro®	2.86	5.20
50% bloom	Rovral®	2.45	15.16
	Sumisclex®	2.44	19.30
	Prosaro®	2.62	27.83
Nil		2.30	35.85
l.s.d. ($P = 0.05$)		0.19	0.67

Table 3. Effect of fungicide applied at different bloom stages on yield (t/ha) of canola.

Time of application	Yield (t/ha)
10% bloom	2.56
30% bloom	2.62
50% bloom	2.52
30% + 50% bloom	2.75
l.s.d. ($P = 0.05$)	0.14

Summary

The fungicide evaluation experiment was conducted to examine the effectiveness of different active ingredients currently available to manage Sclerotinia in canola. Different fungicides had similar efficacy in controlling the disease. This indicated that a range of registered fungicides can be effective at reducing potential disease levels.

A fungicide products' efficacy depends on timing the application correctly. This was apparent in the experiment where fungicide applications at the 30% bloom stage and multiple applications at 30% and 50% bloom stages resulted in the best disease control, regardless of the fungicide used. If a single fungicide application is to be used to control Sclerotinia, early application at 30% bloom stage is the optimal time of application as it protects the main stem from early infection and the greatest yield loss potential.

In this study, the yield response was not consistent with the level of infection that developed across many of the treatments, except for the multiple-time application treatment. Fungicide performance depends on many factors such as background pathogen levels, crop growth stage and the environmental conditions that determine the disease pressure in the field. Therefore, results from this study are seasonal and site specific. Further assessment on fungicide efficacy is required to confirm yield benefits relative to different environmental conditions.

Acknowledgements

This study is part of the 'National Canola Pathology Project', UM0051, 2013–18, with joint investment by GRDC and NSW DPI.

The authors would like to thank Dr Sujeewa Rathnayake and Vincent West for technical support.

Petal survey and sclerotinia stem rot development in canola across central and southern NSW, and northern Victoria – 2016

Dr Audrey Leo, Gerard O'Connor, Dr Kurt Lindbeck (NSW DPI, Wagga Wagga)

Key findings

- Wet conditions from June to September resulted in high levels of petal infestation.
- High-disease-risk districts were identified as having high intensity canola production, reliable spring rainfall (particularly during flowering) and long flowering periods.
- Petal infestation levels were similar to that of 2015, but above average rainfall in August and September in southern NSW and northern Victoria favoured sclerotinia stem rot development.

Introduction

Petal testing for sclerotinia stem rot fungus can provide information on the presence and levels of Sclerotinia ascospores in canola-growing regions. Apothecia, the fruiting bodies of the fungus, germinate in early winter and release airborne ascospores, which can colonise canola petals. Infested petals fall into the canola crop canopy and become lodged against the leaf and branch axils. When weather conditions are favourable, ascospores on infested petals germinate and infect plant tissues which eventually lead to Sclerotinia.

The petal survey was conducted to identify the drivers for Sclerotinia development in different districts, with the aim of understanding how background inoculum levels and environmental conditions influence the disease development in a given year.

Material and methods

Site details

Weekly petal samples were collected from 31 commercial canola crops. Locations in NSW were divided into three meteorological regions: Riverina; South West Slopes; and Central West Slopes and Plains. All petal samples from northern Victoria were collected from commercial canola crops located at Dookie and Rutherglen (Table 1).

Table 1. Locations of petal test survey in central and southern NSW, and northern Victoria.

Riverina	South West Slopes	Central West Slopes and Plains	Northern Victoria
Mayrung	Griffith	Condobolin	Rutherglen
Barooga	Mirrool	West Wyalong	Dookie
Rennie	Coolamon	Quandialla	
Corowa	Temora	Grenfell	
Lockhart	Junee	Parkes	
Alma Park	Cootamundra	Cowra	
Morven	Harden	Canowindra	
Daysdale		Manildra	
Wagga Wagga			

Details recorded weekly for each paddock were:

- time of sowing
- time of fungicide application
- date of sample collection
- bloom stage
- variety
- nearest town location
- presence of apothecia
- presence of stem lesions
- background information on Sclerotinia incidence in the district.

At the end of the growing season, the percentage of main stem infection was also recorded by counting the number of main stem infected plants out of a total of 100 plants in five locations (four corners and one central location). Each location is at least 10 metres apart.

Sample collection and analysis

Flower heads were collected weekly from each site during the flowering period. Whenever possible, flower heads were sampled from areas within the crop where no foliar fungicide had been applied. Samples were sent to NSW DPI at Wagga Wagga for analysis. Random petals from the flower heads were plated onto agar and inspected after five days. Counts were taken for the number of petals per sample that produced a Sclerotinia colony.

Results and discussion

Petal test survey

Sites within the Riverina (Table 2), the South West Slopes (Table 3) and Rutherglen in northern Victoria (Table 5) had an 80–100% petal infestation early in the flowering period. Most of the Central West Slopes and Plains (Table 4), and Dookie in northern Victoria (Table 5) had relatively low petal infestation (40–60%) compared with other regions.

There was high disease pressure at sites within the Riverina and South West Slopes where Sclerotinia epidemics are known to frequently occur given the reliable spring rainfall and intensive canola production. Most sites in the Riverina and the South West Slopes showed high levels of petal infestation early in the growing season, which was most likely due to apothecia germinating in the field in early winter; the prolonged wet conditions were suitable for colonising emerging petals. Most sites within the Riverina also had high levels of petal infestation throughout the growing season. Mayrung, Barooga and Rennie had lower overall petal infestation, due presumably to lower rainfall during the flowering period and lower annual rainfall. This pattern was also observed in the South West Slopes where higher levels of petal infestation were detected at Temora, Junee and Cootamundra with the increased rainfall compared with other sites in the region. Although the highest amount of rainfall was recorded in Harden, its lower petal infestation could be due to the history of low intensity canola and Sclerotinia-susceptible crops grown in the paddock.

Other regions such as the Central West Slopes and Plains recorded the lowest petal infestation levels across all sites, indicating the lowest disease pressure region. Even though the Central West Slopes and Plains had experienced the same amount of rainfall as parts of the Riverina and the South West Slopes, the low petal test results could be due to the low background inoculum levels in the region, most likely a result of less intensive canola production.

In the northern Victoria region, all three sites had similar rainfall and a moderate level of petal infestation during the growing season.

When the 2016 survey data was compared with the 2015 data, the levels of petal infestation within the Riverina, the South West Slopes and northern Victoria were similar between years, but the above average rainfall throughout the growing season allowed infested petals to develop into stem lesions more severely in 2016 compared with the drier spring conditions in 2015. The only difference in petal infestation was found in the Central West Slopes and Plains where levels increased in 2016 compared with 2015. Increasing petal infestation in the Central West Slopes and Plains was most likely due to the significantly higher rainfall received in 2016, which favoured prolonged germination of apothecia in the field.

The collated data on the percentage of stem infection development at individual sites showed that levels ranged from less than 1% to 10% (data not shown). This was relatively low considering the wet conditions experienced in 2016, suggesting that applying foliar fungicide during the flowering period effectively controlled the disease. Consistent with previous studies, the percentage of petal infestation did not have any correlation with the percentage of Sclerotinia infection.

Table 2. Percentage of Sclerotinia-infested petals, total rainfall during flowering and total annual rainfall at the Riverina sites.

Week no. **Date**	**Mayrung**	**Barooga**	**Rennie**	**Corowa**	**Daysdale**	**Alma Park 1**	**Alma Park 2**	**Morven**	**Wagga Wagga 1**	**Wagga Wagga 2**	**Lockhart 1**	**Lockhart 2**
1 3 Jul–10 Jul											100	
2 10 Jul–17 Jul							88					
3 17 Jul–24 Jul						100	90					
4 24 Jul–31 Jul					100	100	100	100			100	98
5 31 Jul–7 Aug			96		100	100	100	100	100	100	100	98
6 7 Aug–14 Aug	46		22	68	100	100	72	94	100	100	78	92
7 14 Aug–21 Aug	22			90	44	98	78	54	90	66	58	60
8 21 Aug–28 Aug			36	98	64	90	60	98			54	90
9 28 Aug–4 Sep	56		56	56	86	100	78	94	44	60	100	60
10 4 Sep–11 Sep	14	38	60	52	54	86	70	74	88	98	54	58
11 11 Sep–18 Sep	36	38	52	72	70	84	76	50	98	98	52	66
12 18 Sep–25 Sep	18	0	40	96	58	78	80	94	80	94	76	40
13 25 Sep–2 Oct		0	74		48	100	44	52	96	96	84	2
14 2 Oct–9 Oct		18	6			100	100	48	0	22	12	
15 9 Oct–16 Oct		20						28	20	76		
16 16 Oct–23 Oct		14						32		38		
Total rainfall during flowering (mm)	196.2	214.8	229.5	224.3	229.5	254.6	254.6	249.2	298.5	298.5	273.2	273.2
Total annual rainfall (mm)	566.4	600.0	700.0	707.4	700.0	804.4	804.4	736.8	773.8	773.8	759.6	759.6

0–20%	21–40%	41–60%	61–80%	81–100%

Table 3. Percentage of Sclerotinia-infested petals, total rainfall during flowering and total annual rainfall at the South West Slopes sites.

Week no. Date	**Griffith**	**Mirrool**	**Coolamon**	**Temora**	**Junee**	**Cootamundra 1**	**Cootamundra 2**	**Harden**
1 3 Jul–10 Jul								
2 10 Jul–17 Jul								
3 17 Jul–24 Jul								
4 24 Jul–31 Jul	98							
5 31 Jul–7 Aug	70			100				
6 7 Aug–14 Aug	54			98			100	
7 14 Aug–21 Aug	24	86	44	92	96		96	
8 21 Aug–28 Aug				44	94	100	82	
9 28 Aug–4 Sep	36	74	68	86	62	98	30	22
10 4 Sep–11 Sep	16	34	36	42	80	94	96	12
11 11 Sep–18 Sep		40		100		86	56	58
12 18 Sep–25 Sep			36			86	92	84
13 25 Sep–2 Oct				96	100	96	96	60
14 2 Oct–9 Oct					62	84	70	44
15 9 Oct–16 Oct					100	60	36	26
16 16 Oct–23 Oct								
Total rainfall during flowering (mm)	247.0	297.5	268.8	304.4	272.0	369.5	369.5	329.2
Total annual rainfall (mm)	686.2	805.5	793.6	703.6	833.6	947.2	947.2	876.0

0–20%	21–40%	41–60%	61–80%	81–100%

Table 4. Percentage of Sclerotinia-infested petals, total rainfall during flowering and total annual rainfall at the Central West Slopes and Plains sites.

Week no. Date	Condobolin	West Wyalong	Quandialla	Grenfell	Parkes	Cowra	Canowindra	Manildra
1 3 Jul–10 Jul							4	
2 10 Jul–17 Jul	64							
3 17 Jul–24 Jul	74							
4 24 Jul–31 Jul	44							
5 31 Jul–7 Aug	58		100					
6 7 Aug–14 Aug	22			64				
7 14 Aug–21 Aug	22	46	48	56				
8 21 Aug–28 Aug	0	10	16	16				
9 28 Aug–4 Sep	8	68	34	16	36	98		4
10 4 Sep–11 Sep	4	24	6	22	20	92	20	66
11 11 Sep–18 Sep	4		4	14	48	6		2
12 18 Sep–25 Sep	4		6	36		98	60	
13 25 Sep–2 Oct	6	4	8		10	2	30	0
14 2 Oct–9 Oct		0	0			0		
15 9 Oct–16 Oct						0		
16 16 Oct–23 Oct								
Total rainfall during flowering (mm)	215.3	258.2	253.9	337.3	305.8	268.9	265.6	321.0
Total annual rainfall (mm)	698.6	762.6	700.6	921.5	833.2	802.8	895.4	940.4

0–20% 21–40% 41–60% 61–80% 81–100%

Table 5. Percentage of Sclerotinia-infested petals, total rainfall during flowering and total annual rainfall at the northern Victoria sites.

Week no.	Date	Dookie 1	Dookie 2	Rutherglen
1	3 Jul–10 Jul			
2	10 Jul–17 Jul			
3	17 Jul–24 Jul			
4	24 Jul–1 Jul			
5	31 Jul–7 Aug	44	44	
6	7 Aug–14 Aug	24	20	
7	14 Aug–21 Aug	66	82	
8	21 Aug–28 Aug	26	42	
9	28 Aug–4 Sep	60	68	98
10	4 Sep–11 Sep	40	44	50
11	11 Sep–18 Sep	68	74	36
12	18 Sep–25 Sep	80	26	54
13	25 Sep–2 Oct	42	74	66
14	2 Oct–9 Oct	0	4	64
15	9 Oct–16 Oct			
16	16 Oct–23 Oct			
Total rainfall during flowering (mm)		227.6	199.0	230.6
Total annual rainfall (mm)		687.8	687.8	642.4

0–20%

21–40%

41–60%

61–80%

81–100%

Summary

This survey was conducted to identify the drivers for sclerotinia stem rot epidemics by comparing the level of petal infestation in different meteorological regions.

The results have shown that Sclerotinia ascospores were present in every canola crop sampled in southern NSW and northern Victoria, and that the highest levels of petal infestation occurred early in the growing season when conditions were cool and wet. However, in some cases for certain districts which traditionally develop disease every year, high levels of petal infestation were observed throughout the entire flowering period. The highest levels of infestation were found in districts that have reliable spring rainfall and high intensity canola production, specifically districts within the Riverina and the South West Slopes regions.

Levels of petal infestation in 2016 were similar to 2015 levels, indicating that environmental conditions within the crop canopy are more important in Sclerotinia development compared with petal infestation alone.

Acknowledgements

This study is part of the 'National Canola Pathology Project', UM0051, 2013–18, with joint investment by GRDC and NSW DPI.

The authors would like to thank growers and agronomists who participated in this study, and Dr Sujeewa Rathnayake for technical support.

Effect of timing of fungicide application to manage sclerotinia stem rot in canola

Dr Audrey Leo, Gerard O'Connor, Beverley Orchard and Dr Kurt Lindbeck (NSW DPI, Wagga Wagga)

Key findings

- Sclerotinia stem rot levels were reduced with a single foliar fungicide applied at 10% and 30%, and multiple applications at the 30% and 50% bloom stages.
- Multiple applications at the 30% and 50% bloom stages had the most significant effect in reducing disease.
- Significant yield benefits were measured when multiple fungicide applications were applied during the growing season.

Introduction

Foliar fungicide application is used to manage sclerotinia stem rot development in canola. Canola plants become more susceptible to Sclerotinia infection once flowering starts. To date, the commercial recommended time of application is 20–50% bloom, when petals start to senesce and fungicide applications can effectively penetrate the crop canopy. However, it is not known if earlier or later fungicide applications are beneficial and reduce Sclerotinia development. This study was undertaken to determine the optimal timing for fungicide application during the growing season to reduce Sclerotinia development.

Site details

The fungicide application timing experiment was conducted at Wagga Wagga Agricultural Institute and at Alma Park. These sites represent the medium–high rainfall cropping region of southern NSW with intensive canola production and frequent Sclerotinia development. Sowing date for the experiment was 28 April and 6 May 2016 for Alma Park and Wagga Wagga, respectively. Both sites relied on natural Sclerotinia infection to develop.

Treatments

Varieties

The conventional hybrid variety, Nuseed Diamond was used for both experiments. Seed was treated with Jockey® and sown with Impact In-Furrow®-treated fertiliser.

Fungicide

Prosaro® 420 SC (450 mL/ha) was applied at nine different timings according to specific growth stages (% bloom), and the combination of growth stages and rainfall events (% bloom–strategic). Single fungicide treatments were applied at 10%, 30%, 50%, and above 50% (late fungicide application – LFA) bloom stages. A multiple fungicide treatment was applied at both 30% plus 50% bloom stages. Strategic treatments were applied before rainfall events at growth stages 10%, 30% and 50% bloom stages. A single 48-hour treatment was included based upon estimating a prolonged period of wet weather given the available forecasts. Nil treatment was included as a control. Each experiment was in a randomised block design with four replications.

Assessment

The guide to assess 10%, 30% and 50% bloom stages was adapted from the Canola Council of Canada bloom assessment guide (http://www.canolacouncil.org/canola-encyclopedia/diseases/sclerotinia-stem-rot/).

Sclerotinia stem rot was assessed at the end of the growing season by counting the number of infected plants in two central locations within each plot. Different types of infection were recorded: main stem (MS), lateral branch (LB) and basal (B). The total number of healthy and infected plants was recorded to calculate the percentage of plant infection. Experiments were later harvested for yield.

Results and discussion

The fungicide experiment at Wagga Wagga showed that the level of Sclerotinia infection was significantly reduced (average 10%) when single fungicide treatments were applied at the 10%

and 30% bloom stages, and at a 30% bloom strategic stage compared with the nil treatment (Table 1). This infection was further reduced with multiple fungicide applications at 30% plus 50% bloom stages, which also increased yield compared with the nil treatment. Single applications after 50% bloom stage (LFA) and 48-hour strategic were ineffective in reducing the infection levels.

At Alma Park, the effects of the fungicide applied at the 10% and 30% bloom stages on Sclerotinia significantly reduced stem infection by around 45% compared with the nil treatment (Table 2). Multiple fungicide applications at the 30% plus 50% bloom stages further reduced stem infection by 8% compared with a single application. A significant yield response was only observed in the treatments with two fungicide applications. A late fungicide application and 48 hour strategic treatment were not significantly different from the nil.

Although both experiments showed differences between the levels of infection at different fungicide timings, yield responses were not consistent. Only applications at both 30% and 50% bloom stages gave a significantly higher yield compared with the nil treatment. It is highly likely that factors other than Sclerotinia affected yields at both sites.

Table 1. Effect of fungicide timing on yield (t/ha) and plant infection (%) to manage sclerotinia stem rot at Wagga Wagga Agricultural Institute in 2016.

Treatment	Yield (t/ha)	Infection (%)
Nil	2.57	24.41
10% bloom	2.75	13.60
30% bloom	2.81	16.38
30% bloom (strategic)	2.61	12.33
50% bloom	3.05	19.57
50% bloom (strategic)	2.67	19.07
30% + 50% bloom	3.18	7.87
30% + 50% bloom (strategic)	3.03	4.64
LFA	2.68	30.68
48 hour rainfall (strategic)	2.43	19.28
l.s.d. (*P* = 0.05)	0.42	0.72

Table 2. Effect of fungicide timing on yield (t/ha) and plant infection (%) to manage sclerotinia stem rot at Alma Park in 2016.

Treatment	Yield (t/ha)	Infection (%)
Nil	2.11	59.71
10% bloom	2.47	25.59
10% bloom (strategic)	2.28	24.21
30% bloom	2.40	13.40
50% bloom	2.50	11.31
50% bloom (strategic)	2.02	40.60
30% + 50%	2.95	3.48
LFA	2.12	58.65
LFA + 50% (strategic)	2.64	15.02
48 hour rainfall (strategic)	2.44	55.82
l.s.d. (*P* = 0.05)	0.40	0.69

Summary

Fungicides are an important tool in managing sclerotinia stem rot in canola. Fungicide application at the critical developmental stages is crucial to reduce disease development and increase returns. In this study, two single fungicide timings at either 10% or 30% bloom stages significantly reduced the level of Sclerotinia at both sites. However, multiple applications of fungicide during the growing season at the 30% plus 50% bloom stages was the most effective.

At these bloom stages, the foliar fungicide applied provided critical early and subsequent protection where senescent petals are abundant and when conditions for infection are likely. Application beyond the 50% bloom stage was too late and ineffective in reducing disease, most likely due to a combination of infection event timing and poor penetration of the fungicide into the crop canopy.

With no significant difference in yield across many of the treatments, except at multiple applications at both 30% plus 50% bloom stages compared with the nil treatment at Wagga Wagga experimental site, more data is needed to compare fungicide efficacy from only a single fungicide application.

Acknowledgements

This study is part of the 'National Canola Pathology Project', UM0051, 2013–18, with joint investment by GRDC and NSW DPI.

The authors would like to thank Dr Sujeewa Rathnayake and Vincent West for technical support.

Comparison of canola varieties for sclerotinia stem rot development in southern NSW – 2016

Dr Audrey Leo, Gerard O'Connor, Beverley Orchard and Dr Kurt Lindbeck (NSW DPI, Wagga Wagga)

Key findings

- Some early flowering varieties developed significantly higher levels of sclerotinia stem rot infection.
- Variety response to infection and yield could be relative to other factors such as infection timing and plant biomass.

Introduction

To date, there are no Australian canola varieties with known resistance to sclerotinia stem rot. Anecdotally, variation has been observed in levels of Sclerotinia development between canola varieties, either in commercial crops or at experimental sites. Often the major factor driving susceptibility to Sclerotinia infection is when flowering starts. Once flowering starts, the susceptibility to infection increases significantly, as canola petals capture fungal ascospores and spread the pathogen into the crop canopy, which can then develop into stem lesions. Varieties that start flowering early in the growing season have a greater chance of developing stem infection due to prolonged exposure to infested senescent petals. This chance is even higher when it coincides with the ascospore release in early winter, and exposure to prolonged periods of cool, wet weather that favour disease development. Early main stem Sclerotinia infection is known to cause more yield loss compared with late main stem or branch infection.

The aim of this study was to determine what effect the start of flowering had on Sclerotinia development. Two canola experiments using a range of varieties with different flowering times were conducted in southern NSW.

Site details

Two experiments were conducted at the Wagga Wagga Agricultural Institute and at Alma Park. These sites represent the medium–high rainfall cropping region of southern NSW with intensive canola production and frequent Sclerotinia development.

Treatments

Varieties

Six commonly grown canola varieties with a range of maturity timing were used (Table 1). Seed was treated with Jockey® and sown with Impact In-Furrow®-treated fertiliser. Each experiment was in a randomised block design with four replications. No artificial pathogen inoculation or foliar fungicide was applied to the experiments during the growing season. Sowing date for the experiments was 28 and 29 April 2016 for Alma Park and Wagga Wagga, respectively.

Table 1. Canola varieties included in the 2016 Sclerotinia experiments.

Variety	Maturity*	Type	Date of 30% bloom	
			Wagga Wagga	Alma Park
Nuseed Diamond	Early maturing	Conventional hybrid	18 August 2016	17 August 2016
ATR Stringray$^{\Phi}$	Early maturing	Open pollinated	28 August 2016	24 August 2016
ATR Gem$^{\Phi}$	Early–mid maturing	Open pollinated	30 August 2016	1 September 2016
ATR Wahoo$^{\Phi}$	Mid–late maturing	Open pollinated	5 September 2016	10 September 2016
Hyola® 650TT	Mid–late maturing	Hybrid	28 September 2016	1 September 2016
Archer	Mid–late maturing	Hybrid	5 September 2016	7 September 2016

* Variety maturity varies depending on the location and the time of sowing. This relative maturity timeline is adopted from the NSW DPI *Winter crop variety sowing guide 2016*.

Assessment

Commencement of flowering and bloom stages were recorded for each variety by counting the numbers of open flowers and pods on the main stem. The guide to assess bloom stages was adapted from the Canola Council of Canada Bloom assessment guide (http://www.canolacouncil.org/canola-encyclopedia/diseases/sclerotinia-stem-rot/).

Sclerotinia was assessed at the end of the growing season by counting the number of infected plants at two central locations within each plot. Different types of infection were recorded: main stem (MS), lateral branch (LB) and basal (B). The total number of healthy and infected plants was recorded to calculate the percentage of plant infection. Experiments were later harvested for yield.

Results and discussion

Both experiments showed a significant difference in the level of Sclerotinia development between some varieties and when flowering started (Table 2). Nuseed Diamond was the first variety to start flowering (tables 3 and 4) and showed a significantly higher level of Sclerotinia development compared with other varieties. Varieties that matured later, such as Archer and ATR Wahoo$^{(D)}$, had significantly lower infection levels. Although ATR Stingray$^{(D)}$ is an early-maturing variety, the infection level was relatively low and did not differ from ATR Wahoo$^{(D)}$ or Archer.

This study also showed that Hyola® 650TT had the second highest infection level at both sites, most likely due to the variety developing its full bloom earlier than the other early–mid maturing varieties, ATR Gem$^{(D)}$ and ATR Stingray$^{(D)}$. Archer, which is a mid–late maturing hybrid, developed full bloom at a slower rate compared with Hyola® 650TT (tables 3 and 4), which could explain the lower infection rate at both experiment sites.

Yield was different for each variety at Wagga Wagga, but not at Alma Park (Table 2). There was no correlation between infection levels and yield.

The results demonstrated that variety choice and hence, timing of commencement of flowering could be a useful tool for growers to reduce the risk of Sclerotinia development.

Table 2. Effect of Sclerotinia on yield (t/ha) and plant infection (%) of six canola varieties at Wagga Wagga and Alma Park in 2016.

Variety	**Yield (t/ha)**		**Plant infection (%)**	
	Wagga Wagga	**Alma Park**	**Wagga Wagga**	**Alma Park**
Archer	2.46	2.07	9.28	3.63
Nuseed Diamond	2.01	2.08	39.23	57.95
ATR Gem	1.83	2.04	10.52	12.38
Hyola 650TT	2.43	1.98	27.13	25.56
ATR Stingray	1.90	1.91	4.13	18.65
ATR Wahoo	2.23	2.07	3.92	1.14
l.s.d. ($P = 0.05$)	0.17	2.03	0.87	0.85

Table 3. Bloom stage (%) development at Wagga Wagga in 2016.

Variety	**11 August**	**18 August**	**25 August**	**7 September**	**16 September**
Archer	<5%	<5%	<5%	30 %	>60%
Nuseed Diamond	10 %	30 %	50%	>60%	>60%
ATR Gem	<5%	<5%	10%	40%	60%
Hyola 650TT	<5%	<5%	10%	60%	>60%
ATR Stingray	5%	10%	20%	40%	>60%
ATR Wahoo	<5%	<5%	<5%	30%	60%

Table 4. Bloom stage (%) development at Alma Park in 2016.

Variety	10 August	17 August	24 August	30 August	7 September	12 September	20 September
Archer	<5%	<5%	<5%	5%	30%	50%	>60%
Nuseed Diamond	10%	20%	50%	50%	>60%	>60%	>60%
ATR Gem	<5%	<5%	10%	20%	40%	50%	>60%
Hyola 650TT	<5%	<5%	5%	20%	50%	>60%	>60%
ATR Stingray	5%	10%	30%	30%	50%	50%	60%
ATR Wahoo	<5%	<5%	<5%	5%	20%	40%	60%

Summary

These two experiments showed that some early-maturing varieties could develop a higher level of Sclerotinia compared with later-maturing varieties due to the earlier start of flowering. However, it also indicated that the interaction between the Sclerotinia infection level and yield loss is complex. Low levels of infection might not necessarily translate to higher yield and vice versa. This could be due to several factors such as infection timing, the amount of rainfall received at the site as well as the canopy architecture and characteristics of the variety. The differential response of each variety to Sclerotinia loss has implications for growers when choosing the right variety for different sowing times and growing regions.

Acknowledgements

This study is part of the 'National Canola Pathology Project', UM0051, 2013–18, with joint investment by GRDC and NSW DPI.

The authors would like to thank Dr Sujeewa Rathnayake and Vincent West for technical support.

Post-emergent herbicidal options for witch grass (*Panicum capillare*) control in summer fallows

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

Key findings

- It is difficult to effectively control witch grass in summer.
- No single herbicide treatment achieved 100% control.
- Glyphosate-based herbicide treatments were the best performers, achieving 86–88% control.
- The mixture of glyphosate + simazine had residual control on subsequent emergences.

Introduction

Witch grass (*Panicum capillare* L.) is an annual grass indigenous to North America. It has invaded many non-native ranges throughout the world, from subtropical to temperate areas including Asia, South America (Argentina and Chile), New Zealand, Australia, Morocco, Russia and many European countries (Clements et al. 2004). In Australia, the earliest herbarium record of witch grass was collected from the Roseworthy Agricultural College, South Australia in 1911, followed by the second earliest collection in Sydney in 1927 (AVH 2017). It is now widely distributed in NSW, VIC, SA and WA. A recent summer weed survey in the regions from the Western Plains through to the Riverina districts showed that witch grass was the second most prevalent annual summer weed, with the top-ranked weed being flaxleaf fleabane (*Conyza bonariensis* L.) (Weston et al. 2016).

The prevalence of witch grass is associated with its high seed production, tumble-weed like spreading mechanism and staggered emergence. It is a prolific seed producer, producing up to 56,400 seeds per plant in the absence of competition (Stevens 1932). Witch grass sheds seeds when mature, however, it has a unique seed-dispersing mechanism, similar to the tumbleweed. Its mature spherical inflorescence easily breaks from the plant and can be spread long distances by wind. Large piles of grass inflorescence often engulf country roads and streets, fencelines, yards, garages, sheds and houses in wet summers in southern Australia. Removing the inflorescences from the front doors, yards and garages has been a daunting task for many local residents.

Witch grass has a hard seed coat and possesses strong innate dormancy (Brecke 1974; Baskin & Baskin 1986). It is a C_4 grass (Hattersley 1984). The lower water requirement of plants with the C_4 photosynthetic pathway, along with higher optimal temperatures, makes it highly adaptable to the hot and dry summer conditions, contributing to its invasiveness.

Witch grass starts to emerge in early October in southern NSW, with major emergence occurring between October and December, followed by limited emergence throughout January and February (unpublished data). Brecke (1974) found that witch grass mostly emerged from near or on the soil surface (0–2.5 cm), with limited emergence occurring below 5 cm of burial.

Witch grass often infests summer crops in the northern hemisphere such as corn, soybeans, and sorghum, as well as in winter wheat. In southern NSW, witch grass thrives in bare areas of winter crops and grows rapidly soon after crop harvest due to the removal of crop competition. It is also a weed in degraded pastures under drought conditions (Philips 2010).

Information on its impact on crop yield is scarce. However, if left uncontrolled, it quickly grows to a thick mat, depleting soil moisture and nutrients during the summer period, which will affect the coming season for crop growth.

Witch grass can pose significant animal health issues. It has been found to accumulate nitrate and could be toxic to livestock under certain conditions (Kingsbury 1994). Hepatogenous photosensitisation was also reported in Merino sheep grazing on witch grass in Australia (Quinn et al. 2014). Care should therefore be taken when grazing on heavily infested land.

Witch grass is an alternative host to a range of pests and diseases, including cereal aphids such as *Rhopalosiphum padi* L. and *R. maidis* Fitch (Kieckhefer & Lunden 1983), western corn rootworm (*Diabrotica virgifera virgifera* LeConte) (Chege et al. 2005), *Wheat streak mosaic virus* (Christian & Willis 1993; Coutts et al. 2008), and planthoppers *Sogatodes oryzicola* Muir and *S. cubanus* Crawford, which are important vectors of the rice *Hoja blanca virus* (Thresh 1981).

There are limited effective control options for witch grass. The aim of this research was to identify effective post-emergent herbicidal options for witch grass control.

Materials and methods

A field experiment was established in southern NSW in canola stubble that had a high level of witch grass, with an initial plant density of 500 plants per square metre, determined by randomly counting five quadrats (0.5 × 0.5 m) from each replicate across the field site. Herbicide treatments were applied using a 2 m hand-operated boom fitted with Teejet 11002 nozzles, delivering 100 L/ha spray volume at 2 bar pressure. Herbicides were applied on 17 December 2016 following 55 mm of rain which fell on 15 December 2016. A total of 16 treatments were compared, including the untreated control. A randomised complete block design was used with four replicates. The plot size was 2 × 9 m.

Herbicide efficacy was monitored 31 days post herbicide application on 17 January 2017. Plant numbers were recorded from two random quadrats (0.5 × 0.5 m) each plot. Visual control rating was also undertaken in comparison with the untreated control plots.

Results

Only four glyphosate-based herbicide treatments achieved more than 85% control on witch grass based on the visual rating results (Table 1). These treatments also had less than 25 witch grass plants per square metre after one month of herbicide application. The four treatments included glyphosate, glyphosate + haloxyfop, glyphosate + simazine and glyphosate + metolachlor. Adding haloxyfop, metolachlor or simazine did not significantly improve control. However, adding simazine did have a residual impact on new plant emergence (Figure 1).

Table 1. Post-emergent herbicide control efficacy on witch grass (December 2016).

Treatment ID	Group	Active ingredient (concentration)	Rate (mL or g/ha)	Adjuvant, application rate	Weed count* (plants/m^2)	Visual rating* (%)
Verdict™ 520	A	Haloxyfop (520 g/L)	400 mL	Uptake™, 0.5 L/100 L	72	84
Wildcat® 110 EC	A	Fenoxaprop (110 g/L)	900 mL	BS 1000, 0.25 L/100 L	128	54
Targa®	A	Quizalofop-p-ethyl (99.5 g/L)	750 mL	BS1000, 0.2 L/100 L	154	33
Factor* WG	A	Butroxydim (250 g/kg)	180 g	Supercharge®, 1 L/100 L	112	59
Status®	A	Clethodim (240 g/L)	400 mL	Supercharge®, 1 L/100 L	124	68
Verdict™ 520 + Nuquat®250	A + L	Haloxyfop (520 g/L) + paraquat (250 g/L)	150 mL + 1600 mL		162	23
Verdict™ 520 + Weedmaster® Argo	A + M	Haloxyfop (520 g/L) + glyphosate (540 g/L)	150 mL + 1000 mL		13	88
Nuquat® 250	L	Paraquat (250 g/L)	1600 mL		140	20
Weedmaster® Argo	M	Glyphosate (540 g/L)	1000 mL		24	88
Basta®	N	Glufosinate (200 g/L)	5000 mL		109	71
Balance® 750 WG	H	Isoxaflutole (750 g/kg)	50 g		163	15
Dual Gold®	K	S-metolachlor (960 g/L)	1500 mL		169	16
Balance® 750 WG + Nuquat®250	H + L	Isoxaflutole (750 g/L) + paraquat (250 g/L)	50 g + 1600 mL		110	31
Weedmaster® Argo + Simazine WDG	M + C	Glyphosate (540 g/L) + simizine (900 g/kg)	1000 mL + 2000 g		18	86
Weedmaster® Argo + Dual Gold®	M + K	Glyphosate (540 g/L) + S-metolachlor (960 g/L)	1000 mL +1500 mL		16	88
Control					185	0
				l.s.d ($P = 0.05$)	46.8	31.5

* Herbicides were applied 17 December 2016 two days after 55 mm of rain.

** Weed count and visual rating were conducted on 17 January 2017.

Among the Group A herbicides (fops and dims), haloxyfop was the most effective, achieving 84% control on witch grass (Figure 1). All other Group A herbicides had limited effects (23–68%), including a lower rate of haloxyfop mixed with paraquat. Paraquat and glufosinate alone were also ineffective, controlling only 20% and 71% of witch grass, respectively.

Summary

Effective post-emergent herbicidal control of witch grass has been limited. No herbicide treatments achieved complete control, even the herbicide treatments that were applied to stress-free weeds after a significant rainfall event.

Glyphosate-based herbicide treatments achieved the best results. The glyphosate + simazine mixture achieved acceptable residual control on subsequent emergences.

Further studies should evaluate double-knock options and other post-emergent mixtures. In addition, soil-applied residual herbicides should be further explored in future studies, as witch grass has multiple emergences during the growing season.

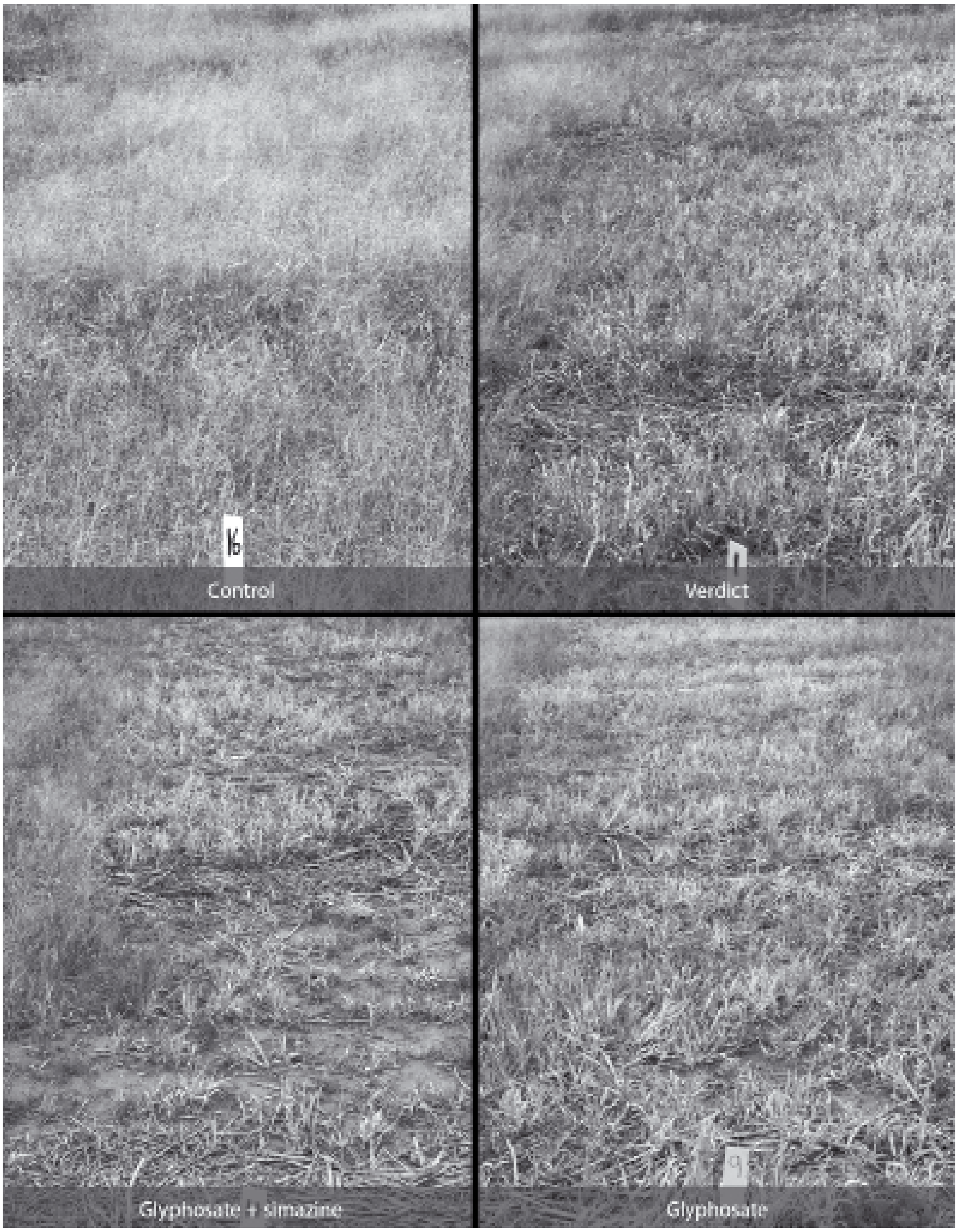


Figure 1. Impact of selected herbicide treatments on witch grass.

References

AVH (Australia's Virtual Herbarium), (2017). http://avh.ala.org.au/occurrences/search?fq=&sort=occurrence_date&taxa=panicum%20capillare#tab_recordsView (accessed 22 Mar 2017).

Baskin, JM & Baskin, CC (1986). Seasonal changes in the germination responses of buried witchgrass (*Panicum capillare*) seeds. *Weed Science* 34:22–24.

Brecke, BJ (1974). Life cycle studies of *Panicum dichotomiflorum* Michx. and *Panicum capillare* L. MS. Thesis. Cornell University, Ithaca, NY.

Chege, PG, Clark, TL & Hibbard, BE (2005). Alternate host phenology affects survivorship, growth, and development of western corn rootworm (Coleoptera: Chrysomelidae) larvae. *Environmental Entomology* 34:1441–1447.

Christian, ML & Willis, WG (1993). Survival of *Wheat streak mosaic virus* in grass hosts in Kansas from wheat harvest to fall wheat emergence. *Plant Disease* 77:239–242.

Clements, DR, Ditommaso, D, Darbyshire, SJ, Cavers, PB & Sartonov, AD (2004). The biology of Canadian weeds. 127. *Panicum capillare* L. *Canadian Journal of Plant Science*. 84:327–341.

Coutts, BA, Strickland, GR, Kehoe, MA, Severtson, DL & Jones, RAC (2008). The epidemiology of *Wheat streak mosaic virus* in Australia: case histories, gradients, mite vectors and alternative hosts. *Australia Journal of Agricultural Research* 59:844–853.

Hattersley, PW (1984). Characterization of C_4 type leaf anatomy in grasses (Poaceae). Mesophyll: bundle sheath area ratios. *Annals of Botany* 53:163–179.

Kieckheffer, RW & Lunden, AO (1983). Host preferences and reproduction of four cereal aphids (Hemiptera: Homoptera: Aphididae) on some common weed grasses of the Northern Plains (USA). *Environmental Entomology* 12:986–989.

Kingsbury, JM (1964). *Poisonous plants of the United States and Canada.* Prentice Hall, Englewood Clifs, NJ.

Phillips, N (2010). There's no panic – it's a witch hunt! *Agriculture Today*. June 2010.

Quinn, JC, Kessell, AE & Weston, LA (2014). Secondary plant products causing photo-sensitization in grazing herbivores: their structure, activity and regulation. *International Journal of Molecular Sciences* 15:1441–1465.

Stevens, OA (1932). The number and weight of seeds produced by plants. *American Journal of Botany* 19:784–794.

Thresh, JM (ed.) (1981). Pests, pathogens and vegetation: *The role of weeds and wild plants in the ecology of crop pests and diseases*. Pitman Advanced Publishing Program, Boston, MA.

Weston, LA, Brown, W, Haque, S & Broster, J (2016). Status of key summer fallow weeds in the Riverina: an update. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Status-of-key-summer-fallow-weeds-in-the-Riverina-an-update.

Acknowledgements

This experiment was part of the project 'Improving IWM practice of emerging weeds in the southern and western regions', UA00149, 2014–17, a collaborative weed project between The University of Adelaide and NSW DPI, with joint investment by GRDC and NSW DPI.

Investigating the current herbicide resistance status of problem weeds in northern cotton farming systems

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

Key findings

- Understanding key drivers and processes in controlling awnless barnyard grass (*Echinochloa colona*), feathertop Rhodes grass (*Chloris virgata*), fleabane (*Conzya bonariensis* L), windmill grass (*Chloris truncata*) and sowthistle (*Sonchus oleraceus* L).
- Investigating the impact on weed control of pupae busting and the potential impact of removing this tillage operation.
- Demonstration of integrated weed management principles, including controlling ‘escape’ weeds and the impact on seed set, to encourage industry to adopt the research outputs.
- Glyphosate resistance is emerging in cotton farming systems.

Introduction

This project addresses the rapidly escalating issue of herbicide resistant weeds in the cotton farming system. It aims to increase the research capacity within NSW DPI and the cotton industry, building on current and previous years of weeds research supported by NSW DPI, Cotton Research and Development Corporation (CRDC), Grains Research and Development Corporation (GRDC) and other research projects. This research will provide new information to cotton growers in support of MyBMP, expanding knowledge and information in WEEDpak, the *Guide to integrated weed management in cotton*, as well as scientific and other industry publications.

Weeds are a significant threat to all farming systems in northern NSW. The Australian cotton industry has rapidly adopted glyphosate-tolerant cotton since its introduction 13 years ago, and it currently accounts for the majority of sown crops. Accordingly, weed management practices have changed, with growers moving from applying residual herbicides in anticipation of a weed problem, to resolving weed issues with glyphosate in combination with other chemical or cultural methods for weed control.

These changes have resulted in a shift in the weed species found across cotton growing regions. Increasingly the broadleaf weeds flax leaf fleabane and sowthistle dominate weed spectrums in cotton crops, with increasing weed burdens in the non-cotton component of the rotation. Other important weeds include the emerging threat of awnless barnyard grass and increasing problems with feathertop Rhodes grass and windmill grass.

Methodology

A combination of surveys, field and glasshouse experiments, laboratory studies and observations in commercial cotton fields will be conducted during the term of the project.

The controlled environment experiments will be conducted at the Wagga Wagga Agricultural Institute. Glasshouses and growth cabinets will be used to impose a range of treatments. Treatments will be applied at various weed growth stages under different regimes including temperature, rainfall/soil moisture and herbicides. Different populations of awnless barnyard grass have been collected (Figure 1) and molecular studies conducted. These populations and seed collected from observed ‘escapes’ in the survey might also be used in the controlled environment studies.

The experiments will be conducted using standard randomised complete block or factorial designs with a minimum of four replicates. The field experiment to be conducted at the Australian Cotton Research Institute (ACRI) will also be replicated with plots of at least 50 m by 8 rows to allow for weed patchiness, a typical issue with weed experiments. The selected field at ACRI has a high background level of weeds and will be brought back into production to allow this research to be undertaken. A Roundup Ready Flex cotton variety will be planted in the field to allow these weeds to be managed during the season. A combination of tillage, pre, post and residual herbicides will be compared across growing seasons to examine the effects on weed species when pupae busting is removed from the program.

Figure 1. Weed survey 2016–17.

Summary

The expansion of the cotton industry in southern NSW has provided an opportunity for capacity building within NSW DPI in weeds research. A coordinated weed survey of problem weeds in conjunction with CottonInfo staff has collected a range of weed species from northern and southern cotton valleys. These weeds will be screened for resistance to glyphosate and, in addition, the grass weeds will be screened for herbicide resistance to Group A herbicides.

Initial results from 144 fields sampled in the 2014–15 season indicate resistance to glyphosate in 20% of sowthistle, 90% of fleabane, >80% of windmill grass and 20% of feathertop Rhodes grass samples. Final preparations are underway for the awnless barnyard grass screening. These results will be combined with the 2016–17 season survey to compile a benchmark for the industry for herbicide resistance in the major weed species in cotton farming systems. The 2016–17 surveys were focused on emerging weed issues as well as the above species.

Acknowledgements

‘Hard to control weeds in the northern cotton farming systems’, DAN1402, 2013–18, is a project with joint investment by the CRDC and NSW DPI.

The authors acknowledge technical support by Tim Grant, Technical Assistant ACRI, Narrabri and the CottonInfo Regional Extension Officers.

Evaluating weed competitiveness of eighteen barley varieties in the presence of oats – Condobolin 2016

Nick Moody and David Burch (NSW DPI, Condobolin)

Key findings

- The presence of oats reduced barley yields from no significant reduction up to 31.27%.
- Varieties Fathom$^{(l)}$ and Commander$^{(l)}$ were the most effective varieties at suppressing oat development.
- Bass$^{(l)}$ and Buloke$^{(l)}$ demonstrated no significant yield reduction in the presence of oats.

Introduction

Herbicide options for in-season control of grass weeds in cereal crops can be limited. While some products are marketed specifically for wild oat control in cereals, herbicide applications must be timed correctly, or they can be ineffective, damage the crop, and encourage herbicide resistance in future weed generations. One cultural, non-chemical management strategy is to select a cereal variety with sufficient early season vigour to out-compete weeds, precluding, or reducing reliance on herbicide use. This experiment used oat weed surrogates to assess the competiveness of 18 commercial barley varieties for their capacity to suppress or out-compete weeds during the season.

Site details

Location	Condobolin Agricultural Research and Advisory Station
Soil type	Red–brown chromosol
Soil nitrogen	30 kg/ha (0–10 cm), 39 kg/ha (10–60 cm)
Experimental design	Randomised complete block design, varieties, and weed treatments randomised within three replicates
Sowing date	23 May 2016
Sowing	The experiment was sown using a six-row DBS plot seeder at 30 cm row spacings 70 kg/ha mono-ammonium phosphate (MAP) was applied at sowing
Weed control	Pre-emergent weed control: WipeOut 450® 2 L/ha
Pest control	Targeting aphids: Primor WG® 150 g/ha
Growing season rainfall	467 mm (long-term average is 192 mm)

Treatments

Weed surrogate

Wintaroo oats (*Avena sativa* L.) were used as a surrogate for wild or black oats (*Avena fatua*, L.). Seeds were distributed onto the surface of experimental plots with a DBS plot airseeder with raised tines at a target plant density of 60 plants/m^2 before sowing. As plots were sown, some oat seeds were incorporated into the soil, simulating natural weed seed distribution. Barley varieties were sown in accordance with regional farming practices at a target density of 125 plants/m^2.

Varieties

Bass$^{(l)}$, Buloke$^{(l)}$, Commander$^{(l)}$, Compass$^{(l)}$, Fathom$^{(l)}$, Flinders$^{(l)}$, Gairdner$^{(l)}$, GrangeR, Hindmarsh$^{(l)}$, La Trobe$^{(l)}$, Maritime$^{(l)}$, Oxford, Rosalind$^{(l)}$, Scope CL$^{(l)}$, Spartacus CL$^{(l)}$, Urambie$^{(l)}$, Wesminster$^{(l)}$, Wimmera

Methodology

A 1.2 m^2 section of each plot was harvested by hand. Oat and barley tillers were separated, counted and threshed. Following machine harvest, plot grain yields were weighed, and a representative sub-sample was taken with oat and barley grains separated by hand. The subsequent ratio of barley to oats was used to calculate barley plot yields.

Results

Grain yield

As oat biomass increased per square metre, barley yields decreased (Figure 1). There was no significant difference in total biomass/m^2 in the presence or absence of oats ($P = 0.43$), although the number of total tillers (barley and oats) decreased in the presence of oats ($P = 0.07$). There was a significant effect on the yield in oat-affected plots compared with the control (oat free) plots ($P<0.001$) (Table 1). All varieties had a yield penalty in the presence of oats apart from Bass$^{\text{⦶}}$ and Buloke$^{\text{⦶}}$, which showed no significant yield difference. The most affected varieties were GrangeR, Spartacus CL$^{\text{⦶}}$ and Urambie$^{\text{⦶}}$ (Table 2).

Table 1. Performance of barley yield components in the presence and absence of Wintaroo oats. ANOVA F probabilities for variety (V), oat treatment (T), and interaction.

Yield component	Weed treatment		ANOVA F probability[a]		
	Nil	Oats	V	T	V × T
Grain yield (t/ha)	4.28	3.45	NS	**	NS
Tillers (number/m^2)	647	516	**	**	NS
Grain weight (mg)	47.29	46.34	**	**	NS
Grains/tiller	18.35	19.51	**	*	NS
Grain weight per tiller (g)	0.87	0.90	**	NS	NS
Grain number/m^2	11649	9904	NS	**	NS
Dry matter/m^2	1018	787	**	**	NS
Dry matter/tiller (g)	1.051	0.976	**	**	NS
Harvest index	0.45	0.48	**	**	NS

[a] NS = not significant; * and ** = at the 0.05 and 0.01 levels of probability respectively.

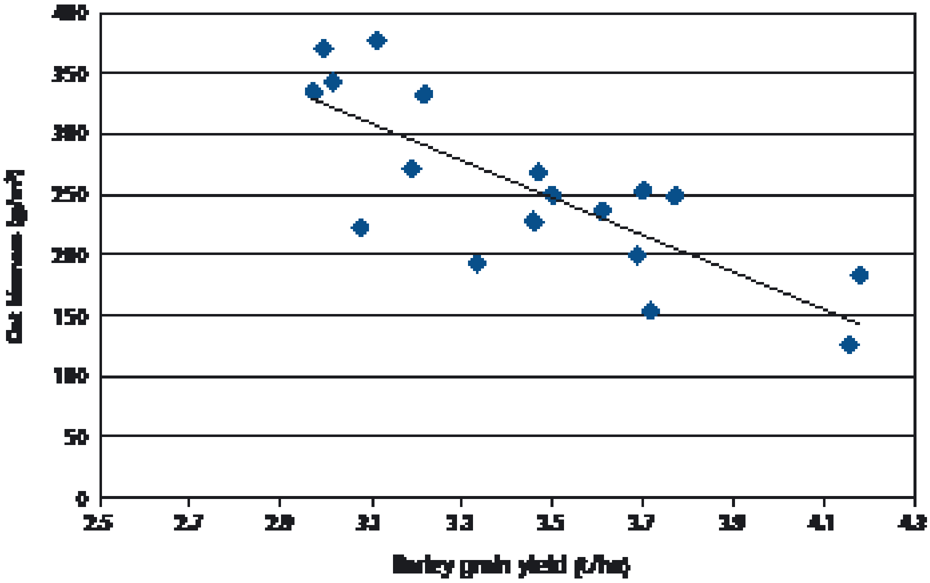


Figure 1. Relationship between oat biomass collected from experimental plots and barley yield ($r^2 = 0.62$).

Yield component analysis

The presence of oats significantly influenced all yield components except for grain weight per tiller (Table 1). Varietal competitiveness was assessed by comparing the percentage change in yield component due to the presence of oats (Table 2) compared with oat-free control plots.

Table 2. Percentage change in yield components in the presence of oats.

Variety	Yield	Grain weight	Tillers/m^2	Grains/tiller
Bass	0.2	–0.8	–11.4*	15.8*
Buloke	–0.6	–2.2*	–23.8*	18.3*
Commander	–15.4*	0.0	2.9	–9.7*
Compass	–19.3*	–3.1*	–9.9*	–19.1*
Fathom	–13.3*	1.0*	–26.3*	–0.1
Flinders	–12.4*	0.6	–16.1*	–2.2
Gairdner	–13.1*	–0.3	–13.0*	4.8*
GrangeR	–32.4*	–4.8*	–23.5*	–2.2
Hindmarsh	–18.5*	–0.5	–15.1*	4.4
La Trobe	–16.8*	–0.6	–13.7*	14.6*
Maritime	–10.5*	–3.2*	–21.5*	8.1*
Oxford	–23.1*	–4.5*	–26.6*	12.9*
Rosalind	–29.5*	–3.3*	–36.7*	6.1*
Scope CL	–14.24*	–1.4*	–20.1*	15.2*
Spartacus CL	–31.27*	0.8	–43.5*	23.3*
Urambie	–29.84*	–3.9*	–14.1*	8.9*
Westminster	–28.95*	–5.1*	–34.7*	8.5*
Wimmera	–29.74*	–5.1*	–5.3	–4.3

* indicates a significant ($P = 0.05$) treatment effect.

Varietal capacity to supress oats

Measuring dry oat biomass/m^2 at harvest demonstrated some correlation ($r^2 = 0.41$) with yield. While the capacity to suppress weed development is associated with reduced yield losses, some varieties, such as Flinders$^{\phi}$ and Gairdner$^{\phi}$ demonstrate small yield reductions with average oat suppression. Meanwhile, Fathom$^{\phi}$ and Commander$^{\phi}$ demonstrated the strongest capacity ($P<0.001$) to suppress oat development, although ranked sixth and eighth for yield losses in the presence of oats ($P = 0.007$) (Figure 2).

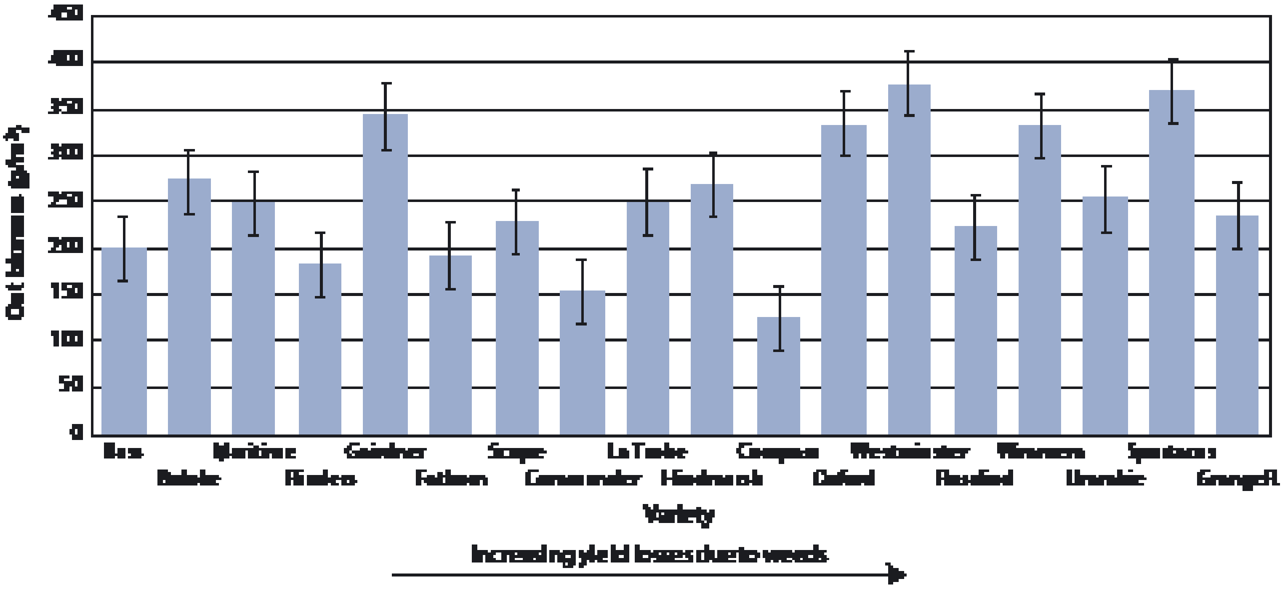


Figure 2. Total biomass of oats recorded within experimental plots. X axis ranked in order of the percentage yield loss for each respective variety in the presence of oats. Error bars indicate 5% l.s.d. between varieties for total oat biomass present per square metre.

While early season oat suppression is important for maximising yield, other mechanisms contribute to specific varieties' capacity to perform in the presence of oats. The normalised difference vegetation index (NDVI) was recorded for each plot on 11 June, at approximately GS21 with a Trimble hand-held GreenSeeker unit. NDVI can be used to assess photosynthetic biomass, providing an indication of early season vigour. No correlation was found between early season NDVI scores and changes in yield and tillering as a result of oat presence, when compared with control, non-oat plots.

Summary

Water limitation at grain fill is commonly a major yield determinant in central western NSW, although record rainfall in June and September favoured longer-season varieties in 2016 in contrast to early-flowering varieties, which perform well in average rainfall seasons.

The barley varieties used in this experiment varied widely in morphology and phenology. Despite this variation and yield losses in oat treatments, there was no single trait that led to superior oat suppression. While oat suppression and high competitiveness in barley have previously been correlated with early season vigour and plant height (Watson et al. 2006), this experiment indicated that a combination of traits such as early season vigour, shading effects and environmental suitability contribute to oat suppression through diverse mechanisms.

References

Watson, PR, Derksen, DA & Van Acker, RC (2006). The ability of 29 barley cultivars to compete and withstand competition. *Weed Science* 54: 783–792.

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, Nick Hill, Ian Menz and Kate Gibson. Postharvest technical analysis conducted by Alkira Gray, Brenton Gray and Leisl O’Halloran.

Resistance to phosphine in stored grain insects from farm storages in south-eastern Australia: 2016

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

Key findings

- Almost 20% of all stored grain insects collected had strong resistance to phosphine.
- Rusty grain beetle resistance is the most serious, as it is beyond label rates to control.
- Strong resistance in lesser grain borer is the main problem in New South Wales; rice weevil in South Australia.

Background

Most Australian grain markets demand that all stored grain is free of live insects. Currently, there are limited options available for controlling insect pests, and all now require sealed, gas-tight storages, which might be limited on some farms.

Phosphine, a fumigant, is the most commonly used, with over 80% of stored grain treated with this product. This product is cheap, considered to be residue-free (meaning it is accepted by most markets), effective at controlling all life stages of all major stored grain pests and does not require a licenced fumigator. However, over-reliance on this product has led to the development of resistance in all the major stored grain pests.

There are two levels of resistance to phosphine: weak and strong, and the strengths of these differ with insect species. Currently, phosphine label rates are sufficient to control all life stages of strong resistant pests of all the major pest species, except the rusty grain beetle (RGB – *Cryptolestes ferrugineus*). NSW DPI first detected strong resistance in this species in 2006. It primarily evolved through repeated fumigations in non-gas-tight storages. Given that weak resistance is currently found in virtually all stored grain beetle populations, this study concentrated on detecting strong resistance.

This project was part of a national study that ran for nearly 20 years. The aim of these projects was to monitor and detect strong resistance to phosphine in the five major stored grain beetle pests, as well as record all details that might have led to any development of resistance, in order to control these outbreaks, develop a phosphine resistance management strategy and, consequently, prolong the life of this fumigant.

This study concentrates on the results from south-eastern Australia for 2016 and, as it was the final year of the project, relates the data to those of the past decade in order to provide an insight into the future of phosphine resistance.

Methodology

This study concentrates on strong resistance to phosphine in the five major stored grain beetle pests of south-eastern Australia: lesser grain borer (LGB – *Rhyzopertha dominica*), rice weevil (RW – *Sitophilus oryzae*), flour beetle (FB – *Tribolium castaneum*), saw-toothed grain beetle (SGB – *Oryzaephilus surinamensis*) and rusty grain beetle (RGB – *Cryptolestes ferrugineus*).

The majority of insects were obtained from randomly selected farm storages throughout the grain-growing regions of southern NSW (south of Dubbo), Victoria and South Australia. In addition, a small number of growers sent some samples. Farms were selected by driving around a district and calling in when silos were observed. Permission was obtained before any sampling.

To check for insects, approximately 1–2 kg of grain was extracted from the base of a silo, sieved and any live insects transferred to a plastic jar along with some untreated grain. Information was recorded on the storage, how long the grain had been stored and any chemical treatments applied to the grain. The insects were then transported to the entomology laboratory at Wagga Wagga Agricultural Institute where they were separated into species, provided with unique identifier numbers and cultured on the appropriate feed. Populations were considered separate if they were sourced from different storages (e.g. different silos). Consequently, one site may have multiple populations.

Once sufficient numbers were cultured, phosphine bioassays were conducted by placing 50 individuals in a plastic cup with air holes, and placing this in a desiccator. A known, discriminating dose of phosphine gas was then injected into the sealed desiccator. The gas was generated from phosphine tablets. Replicates, reference strains and controls (desiccators without any gas added) were included to ensure fidelity of results. After the specified exposure duration to the gas, insects were assessed as alive or knocked down. A population was defined as strongly resistant if any insect survived the high dose. Where possible, survivors were cultured and the population re-assessed to confirm the results.

Results

Species composition

During 2016, a total of 437 insect populations were collected from 145 farms throughout south-eastern Australia (35 NSW, 32 Vic, 78 SA) (Figure 1). In addition, there were a further 54 farms (12 NSW, 13 Vic, 29 SA) where no insects were found. The two main species collected were LGB and FB, comprising 33.4% and 24.5% of the samples, respectively.

Species composition was relatively similar across the three states, with no association between state and species collected (Chi-square: $P = 0.112$, DF = 8) (Figure 2). However, species composition can change from year to year as well as regionally, as was found in 2006 when RW was the dominant species collected from both Victoria (25.8%) and South Australia (45.2%), while FB was the primary pest in NSW (30.9%).

Phosphine resistance

When all species were combined, 18.3% of the 437 populations tested were found to have strong resistance to phosphine (Figure 3). This was a significant increase from 2011 and 2006 when resistance levels were 7.8% (590 populations) and 3.0% (167 populations), respectively. The highest levels were found in SA (22.6% of 261 populations), closely followed by NSW (19.6% of 97 populations). Victorian farms were much lower, with only 2.5% of the 79 populations detected with strong resistance to phosphine.

Looking at individual species, FB and RW had the highest proportions of strong resistance in 2016, with 27.1% and 26.2%, respectively, followed by LGB (19.9%), RGB (7.5%) and SGB (2.53%) (Figure 3). This was due to the high concentration of strong resistance found amongst SA populations (FB 39.4%; RW 37.2%). In contrast, in NSW, LGB and RGB, with 40.5% and 11.1% of populations strongly resistant respectively, were the species with the highest proportion of strong resistance. Only low levels of resistance were detected in Victoria (LGB: 4.4% and FB: 4.6%).

The proportion of strong resistance to phosphine throughout south-eastern Australia has increased since 2011 in all species except SGB; most notably in LGB, with an almost 500% increase. In 2006, the proportion of strong resistance detected was below 5% for all species except RGB. This was the year when strong resistance to phosphine in RGB was first detected in Australia, and none had yet been found in RW.

Summary

The abundance of strong resistance to phosphine in stored grain beetle pests on farms is both increasing and spreading. Almost 1 in 5 populations tested were detected with strong resistance to phosphine throughout south-eastern Australia. While detections in Victoria remained low, both NSW and SA experienced a notable increase.

The fact that, with the exception of RGB, all species, even ones with strong resistance, should be able to be controlled by current phosphine label rates implies that many current fumigation practices are not being performed according to the guidelines, most likely in non-gas-tight silos.

It is known that LGB, RGB and FB all fly and have been trapped several kilometres away from any grain source. This implies that the genes that control resistance are also dispersed over long distances. Australia relies on its reputation for high quality, insect-free grain to obtain premium prices. The spread of phosphine resistance, particularly in RGB, puts this reputation at risk.

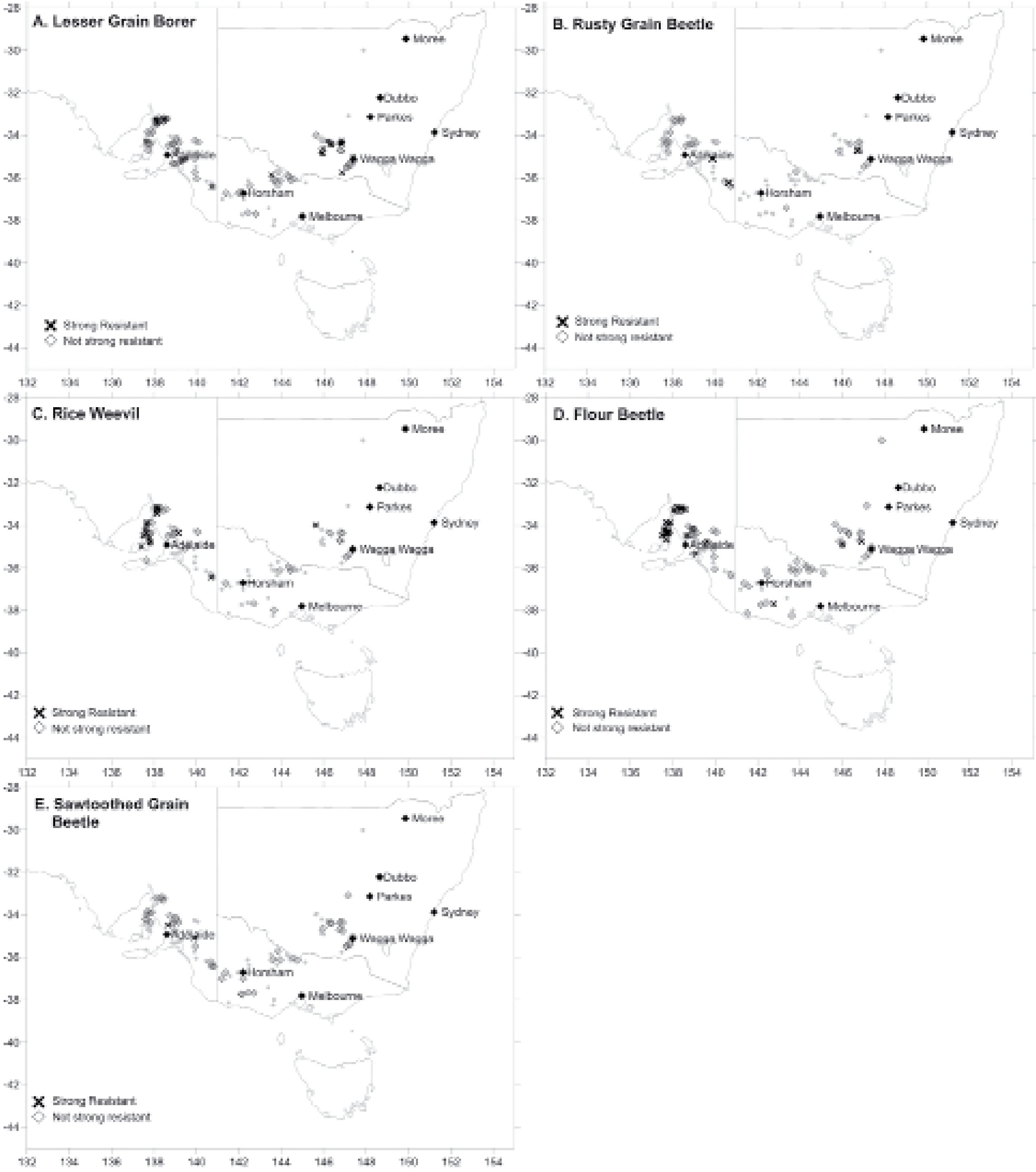


Figure 1. Locations of sampling sites (grey dots) and sites of strong resistance to phosphine in stored grain species: A–lesser grain borer; B–rusty grain beetle; C–rice weevil; D–flour beetle; and E–sawtoothed grain beetle (black ×) from 2016.

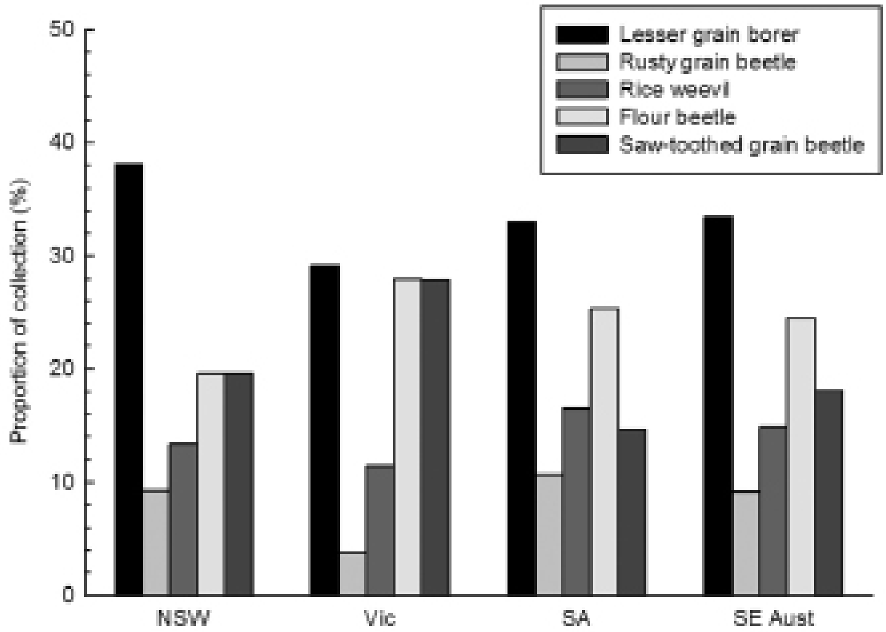


Figure 2. Proportions of stored grain beetle pests sampled from farms throughout south-eastern Australia in 2016.

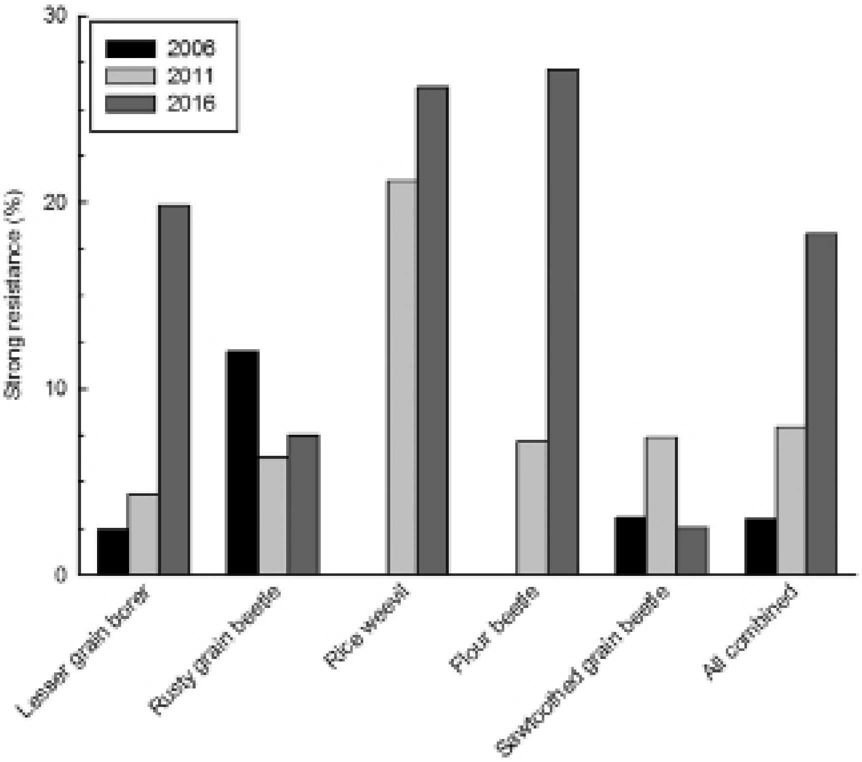


Figure 3. Combined levels of strong resistance to phosphine found in stored grain beetle pests sampled from farms throughout south-eastern Australia in the past decade.

Acknowledgements

This experiment was part of the project 'Delivering a collaborative monitoring program with industry to manage and facilitate trade', PBCR3160, with joint investment by Plant Biosecurity CRC and NSW DPI.

Control of powdery mildew on irrigated soybeans in southern NSW 2015–16

Mathew Dunn and Alan Boulton (NSW DPI, Yanco); **Mark Richards** (NSW DPI, Wagga Wagga)

Key findings

- Powdery mildew infection was observed during the 2015–16 season, although less severe than in previous seasons.
- Powdery mildew infection was found on all soybean varieties except Djakal, demonstrating its known resistance.
- Fungicide applications had no effect on the grain yield of Djakal, N005A-80 or P176-2 varieties, however, the Snowy$^{(b}$ variety had a significant increase in grain yield when treated with tebuconazole in a split application regime.

Introduction

Powdery mildew is a disease in soybeans caused by the fungal pathogen *Erisyphe diffusa* (*Microsphera diffusa syn.*). It thrives during periods of low temperature and high humidity with the potential to cause major production losses in Australia's tropical and subtropical soybean producing areas. It first appeared in the Riverina's (NSW) soybean crops during the 2011–12 season and has since consistently infected susceptible crops throughout the region.

A field experiment was conducted in the summer of 2015–16 at the NSW DPI Leeton Field Station to investigate the effect of powdery mildew and four fungicide treatments on the grain yield of two commercial soybean varieties (Djakal and Snowy$^{(b}$) and two unreleased breeding lines (N005A-80 and P176-2).

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
Plant population	Target: 35 plants/m^2
Sowing date	2 December 2015
Harvest date	20 April 2016

Treatments

Varieties

Djakal, Snowy$^{(b}$, N005A-80 and P176-2

Fungicide

Control, no fungicide applied
Tebuconazole 430 g/L (Folicur® SC) + 1 % Hasten™
Product A + 1% Hasten™

Fungicide application regime

Tebuconazole, 100% rate at full flower (R2)
Tebuconazole, 80% rate at full flower (R2) and 80% rate 2 weeks later
Product A, 100% rate at full flower (R2)
Product A, 50% rate at full flower (R2) and 50% rate 2 weeks later

Results and discussion

Powdery mildew infection

Overall the severity of powdery mildew in the 2015–16 season was low compared with previous seasons. The highest recorded severity in this season was 58% compared with >90% recorded for multiple treatments in the 2013–14 and 2014–15 seasons.

While all four fungicide treatments effectively reduced the powdery mildew severity in susceptible varieties, some treatments had more effect than others (Figure 1). The single and split application of Product A, as well as the split application of tebuconazole, were highly effective at reducing disease severity, while the single application of tebuconazole was not as effective.

Snowy⁽ᵇ⁾, N005A-80 and P176-2 all had received similar levels of powdery mildew infection for each treatment. Djakal demonstrated its known resistance to powdery mildew with no infection detected.

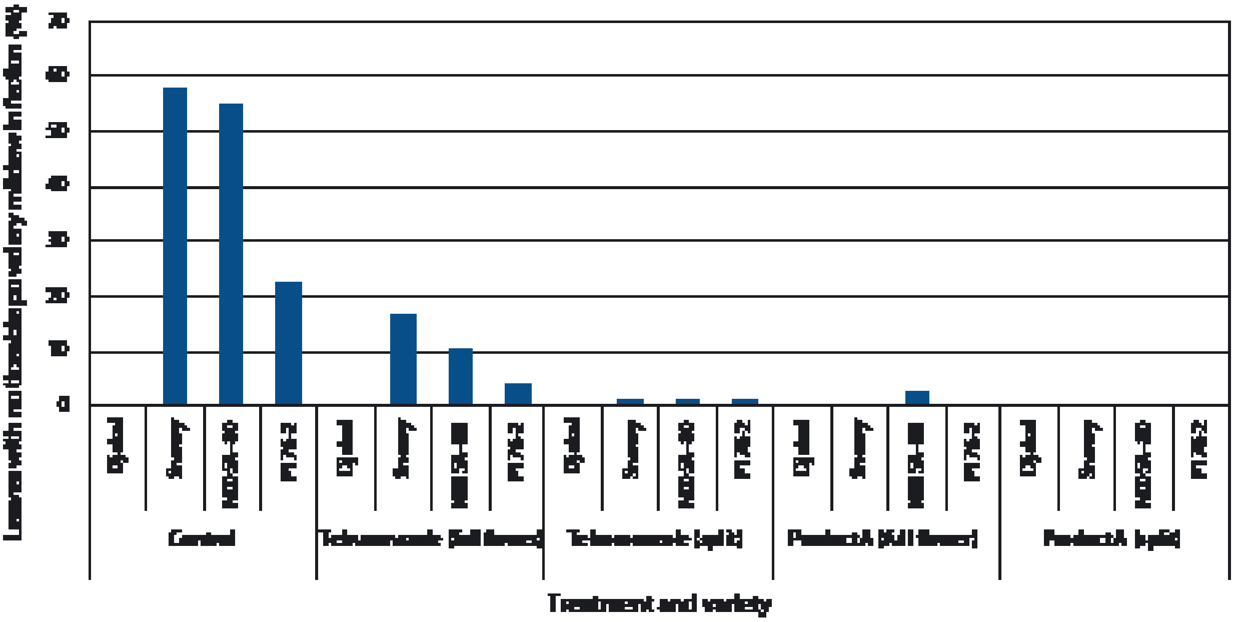


Figure 1. Fungicide efficacy on powdery mildew in four soybean varieties.

Yield

The grain yield of Djakal, N005A-80 and 176-2 did not vary significantly between fungicide treatments (Figure 2). This is likely due to low levels of powdery mildew infection, as well as the late onset of infection during the 2015–16 growing season. However, the split application of tebuconazole did result in a significant (14%) increase in grain yield for Snowy⁽ᵇ⁾. This effect was unique to the 'split application of tebuconazole' treatment and did not occur with the other fungicide treatments for Snowy⁽ᵇ⁾.

Tebuconazole has a permit for use (PER82518, expiry 31/03/22) in soybeans to control powdery mildew. Product A is not currently permitted in Australia for use on soybeans.

The powdery mildew infection that occurred during the 2015–16 season had no significant impact on seed size, protein or oil. However, the severity of powdery mildew infection was considered low compared with the northern growing regions where powdery mildew can cause significant leaf defoliation.

The results confirm that Djakal has a strong level of resistance to powdery mildew.

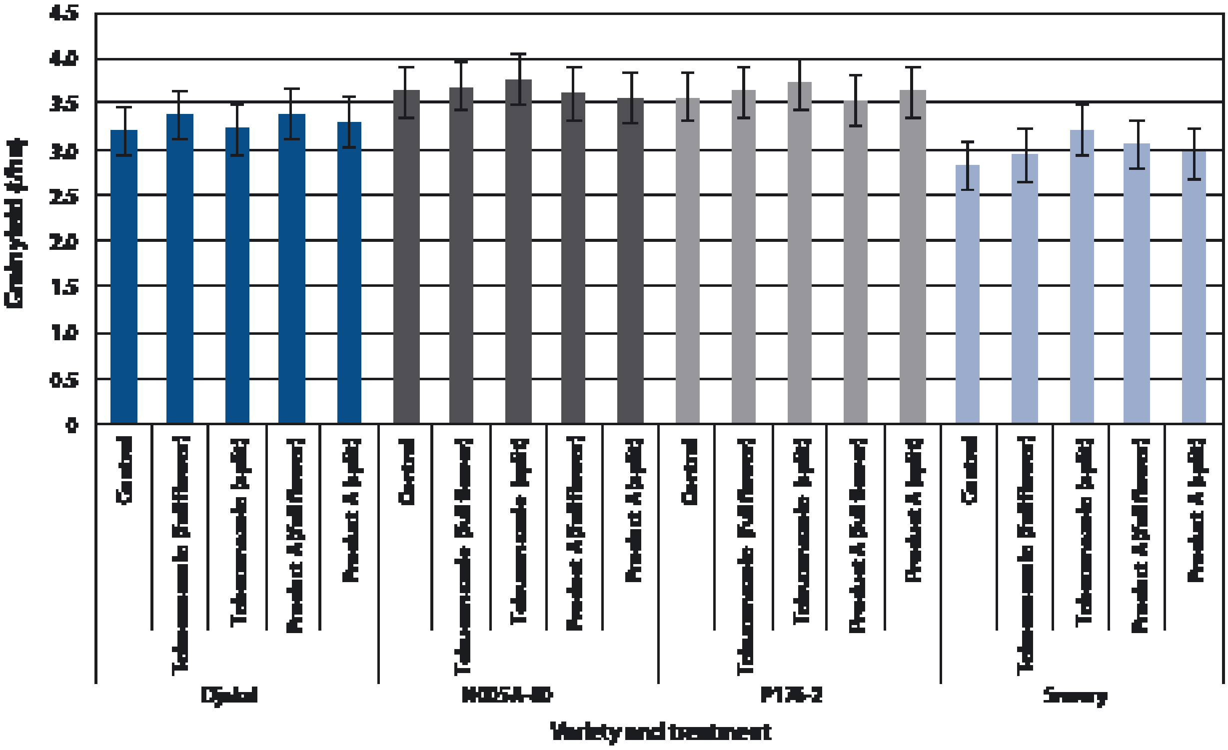


Figure 2. Effect of fungicide rate and timing on the grain yield of four soybean varieties. Bars denote l.s.d. ($P = 0.05$) = 0.27 t/ha.

Summary

Powdery mildew is a major disease affecting soybeans in the tropical and subtropical regions of northern Australia. In the past five seasons, the disease has appeared in the Riverina at varying levels of severity. While all fungicide treatments reduced the disease's severity in the 2015–16 season, its late onset, combined with the relatively low severity of powdery mildew, resulted in few significant yield responses.

NSW DPI will continue to research new breeding lines with powdery mildew resistance.

Acknowledgements

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

Thank you to John Dando, Paul Morris and Gabby Napier for their operational support.

Thrips threshold validation – commercial-scale experiments 2015–16

Dr Sandra McDougall, Dr Jianhua Mo, Sarah Beaumont, Alicia Ryan and Dr Mark Stevens (NSW DPI, Yanco)

Key findings

- Thrips pressure was lower in the earlier planted Whitton site.
- Thrips pressure reached the industry control threshold of 10 thrips/plant on 3 November while plants were still at the cotyledon to 1-leaf stage at the Darlington Point site, and only in some plots at Whitton on 9 November and most plots on 23 November when plants were at the 6–8 leaf stage.
- Onion thrips were the dominant thrips species observed during monitoring.
- Western flower thrips constituted less than 5% of thrips monitored.
- There was no yield difference between sprayed and unsprayed plots.

Introduction

Thrips are common seedling pests of cotton in most growing districts. They feed on growing terminals causing leaf distortion and sometimes death of the terminals. Heavy infestation can result in yield loss and delayed maturity. Most insecticides applied in the southern cotton production region are targeted against thrips. The cotton industry thrips spray threshold of 10 thrips per plant and >80% leaf area loss from seedling to 6-leaf stage was developed and validated in many research experiments in the northern production areas. The southern production areas have a shorter season; early crop establishment has been strongly linked to high yields in the south.

In the 2015–16 thrips threshold experiments, rain and spray rig breakdown prevented correct timing of insecticide applications at thresholds. Hence the two commercial-scale experiments became a comparison of three different insecticides applied at one or two applications during crop establishment versus an unsprayed control. The experiments are part of a project to validate whether the Australian Cotton Industry thrips threshold applies in southern NSW cotton production areas.

Site details

Location	Stotts Whitton block 15 near Irrigation Research and Extension Committee (IREC) demonstration site, Whitton Point Farms (PF), Darlington Point
Cooperators	Matt Stott (Owner PF and current leasee of IREC demonstration site); James Hill (agronomist for Matt) and farm operations staff
Sowing date	9 October 2015 (IREC); 16 October 2015 (PF)
First water	10 October 2015 (IREC); 18 October 2015 (PF)
Variety	Sicot 74BRF
Seed treatment	Dynasty® – azoxystrobin + metalaxyl-M + fludioxonil
Insecticide at planting	Lorsban® – chlorpyrifos
Irrigation	Furrow

Experiment design

Design	Randomised block-plot; four replicates
Plot size	IREC: 12 beds (two rows to a bed) × 1.8 m beds × 770 m = 1.66 ha PF: 12 beds (two rows to a bed) × 1.8 m beds × 600 m = 1.3 ha

Monitoring dates	IREC: 28 October, 9, 18, 23 November, and 2 December PF: 3, 11, 18, 23 November, 2 and 10 December
Sample unit	20 whole random plants
Spray dates	IREC: 16 November PF: 16 November and 4 December
Monitored	Thrips adults, nymphs and species composition
Hand harvest	IREC: 11 April PF: 24–25 May
Machine harvest	IREC: 15 and 18 April PF: 2 June
Analysis	Analysis of Variance (ANOVA), significant treatment effects were detected ($P<0.05$), treatment means were separated by Fisher's least significant difference (LSD).

Treatments

Whitton

T1: D2	Dynasty® fungicide seed treatment only
T2: D2C + R	Dynasty and Cruiser® seed treatment + Regent®
T3: D2 + R	Dynasty + Regent®
T4: D2 + E	Dynasty + Exirel®
T5: D2 + C	Dynasty + Canopy oil®

Point Farms

T1: D2 + 2 × R	Dynasty® fungicide seed treatment + 2 × Regent®
T2: D2C	Dynasty and Cruiser® seed treatment
T3: D2 + 1 × R	Dynasty + 1 × Regent®
T4: D2 + 2 × E	Dynasty + 2 × Exirel®
T5: D2 + 2 × C	Dynasty + 2 × Canopy oil®

Regent®	fipronil 200 g/L SC Group 2B; rate: 125 mL/ha
Exirel®	cyantraniliprole 100 g/L Group 28: rate: 600 mL/ha + Hasten™
Canopy oil®	paraffinic oil C27, 792 g/L 2%v/v

Results

IREC site

Rain on 21 October, 1–7, 12 and 13 November and spray rig breakdown on 11 November delayed any sprays applied by ground rig to 16 November when plants were at 6-leaf stage. Figure 1 shows the number of thrips nymphs per plant for three monitoring periods. On 28 October 2015 when plants were at 1–2 leaf stage (15 days after emergence – DAE) there were significantly lower numbers of nymphs in the plots with Cruiser® seed treatment. By 9 November with rain preventing earlier access, the crop was at 3–4 leaf stage, cupping was evident on most plants and the Cruiser® effect was no longer evident. The crop was sprayed on 16 November when the plants were at 6–7 leaf stage. Thrips numbers had increased and were highly variable, hence no treatment effects were evident in thrips counts on 23 November, a week after the spray application.

In 2015, similar to the 2014 season, onion thrips, *Thrips tabaci*, were the dominant thrips species. Western flower thrips, *Frankliniella occidentalis*, were more numerous, and tomato thrips *Frankliniella schultzei*, less numerous than in 2014 (Figure 2).

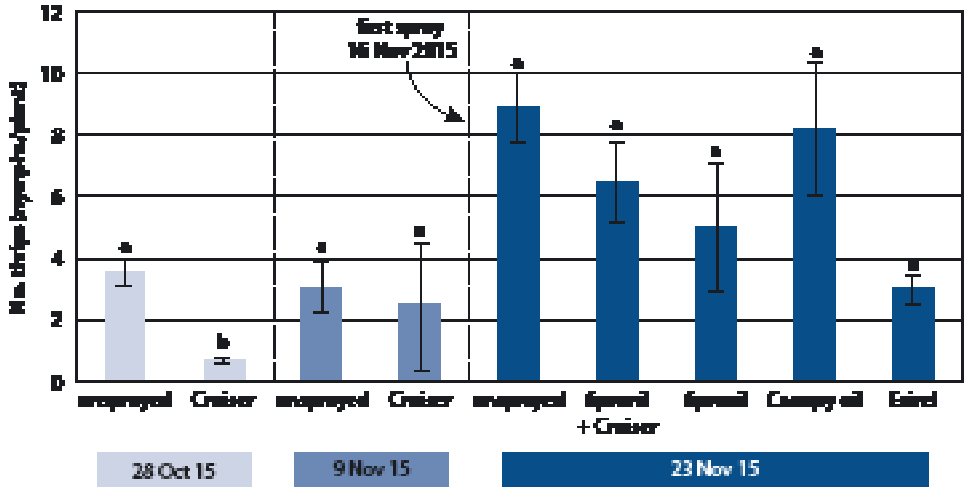


Figure 1. Number of thrips nymphs per cotton plant at three monitoring dates in October/November 2015 during crop establishment at the IREC site, Whitton NSW.

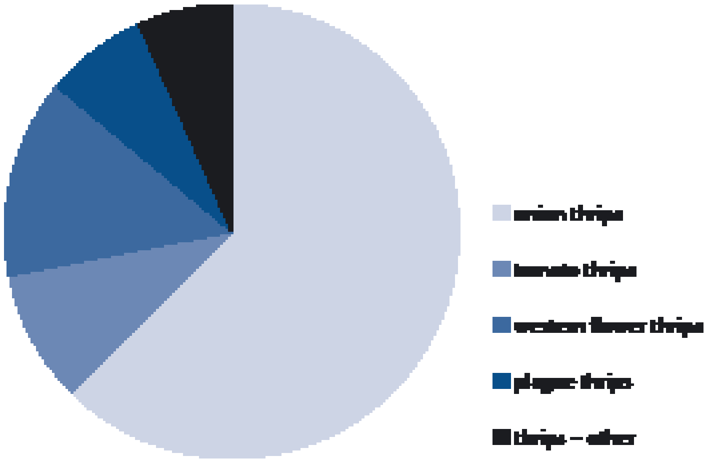


Figure 2. Adult thrips species observed in seedling cotton in November 2015 at the IREC site, Whitton NSW.

Harvest

In 2015, similar to the 2014 season, there was no significant yield difference between thrips control treatments (Figure 3).

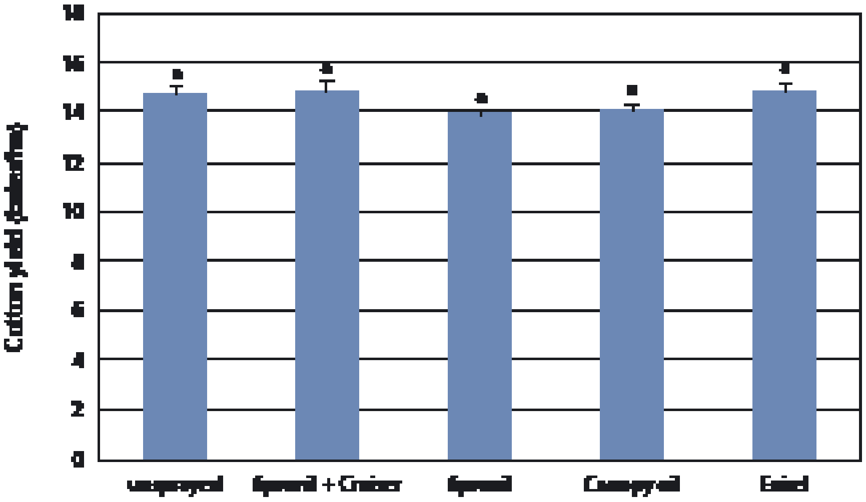


Figure 3. Machine harvest cotton yields by thrips treatment at Whitton site.

Point Farms site

Rain on 21 October, 1–7, 12 and 13 November, and spray rig breakdown on 11 November delayed any sprays applied by ground rig up to 16 November. This crop, sown a week later than the IREC cotton, was more patchy and slower to establish.

The Cruiser® seed treatment appeared to have no effect on numbers of nymphs per plant, approximately 10 DAE (Figure 4) and about 50% of plants were showing leaf cupping. Thrips numbers increased before the 16 November spray; most leaves at 4–5 node were cupped at spraying. Thrips numbers in the unsprayed plots on 16 November before spraying had already dropped off to 2.7 nymphs per plant. Note that the Cruiser®-treated plot did not receive a foliar spray, but the unsprayed plots did hence after 4 December there were no unsprayed treatments at Point Farms.

In both the Canopy oil® and Exirel® plots, replicate three had seven times more thrips than the other replicates, hence the very large error bar. If those replicates were removed, then the thrips numbers were similar to the unsprayed and Cruiser® treatments. The fipronil treatment was significantly more effective than the other treatments.

Over the next 9 days, the thrips numbers again were above 10 thrips per plant and, although the plants were at the 6–8 leaf stage, a second spray was applied to the Exirel®, Canopy oil® and one of the fipronil treatments. Both fipronil treatments (including the one not sprayed) and the Exirel® treatment had lower thrips numbers relative to the Canopy oil® or Cruiser®-only treatment.

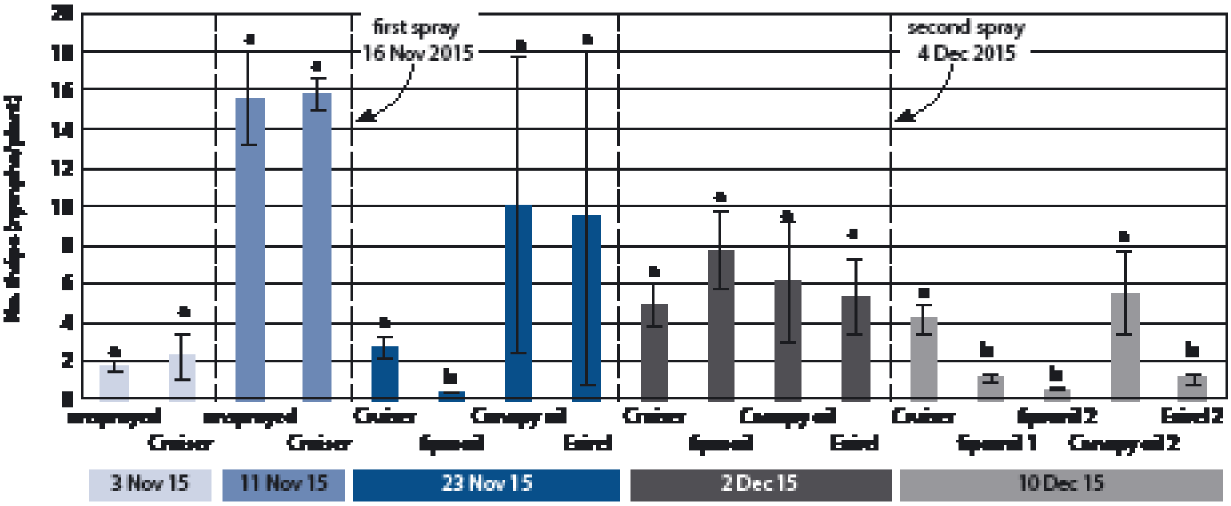


Figure 4. Number of thrips nymphs per cotton plant at five monitoring dates in November and December 2015 during crop establishment at Point Farms, Darlington Point NSW.

In 2015, similar to the 2014 season, onion thrips, *Thrips tabaci*, were the dominant thrips species. Plague thrips, *Thrips imaginis*, was more numerous in 2015 than 2014 and tomato thrips *Frankliniella schultzei* less numerous than in 2014 (Figure 5). There were fewer western flower thrips at the Point Farms site in both years than at the Whitton site.

Harvest

In 2015, similar to the 2014 season, there was no significant yield difference between thrips control treatments (Figure 6).

Summary

The cotton seedlings with Cruiser® seed treatment had fewer thrips than the untreated seed at the 1–2 leaf stage, but not at the 3–4 leaf stage at Whitton, and had no effect at Point Farms.

Thrips numbers were higher at Point Farms with around 16 thrips nymphs per plant on 11 November, which resulted in significant leaf cupping, whereas at Whitton there were between 2–3 thrips nymphs per plant on 9 November.

Wet conditions and a breakdown in the spray rig prevented any spray application until 16 November when the plants were at the 4–5 leaf stage (Point Farms) and 6–7 leaf stage (Whitton). Thrips numbers post-spray were highly variable across both experiment sites.

At Point Farms, the fipronil treatment delivered statistically fewer thrips nymphs seven days post spray compared with the other treatments, but not at 16 days post spray. There was no statistical difference in spray treatments at Whitton seven days post spray, although Exirel® and fipronil tended to lower thrips nymph numbers. A second spray at Point Farms on 4 December also resulted in fipronil and Exirel® significantly reducing thrips nymph numbers more than either Canopy oil® or Cruiser®-treated seed, but otherwise unsprayed, plants.

In 2015, similar to the 2014 season, onion thrips, *Thrips tabaci*, were the dominant thrips species. Western flower thrips, *Frankliniella occidentalis*, and plague thrips, *Thrips imaginis* were more numerous, and tomato thrips *Frankliniella schultzei*, less numerous than in 2014.

There were no significant differences in yields across treatments at either site. Yields at Whitton were around 14 bales per hectare and at Point Farms between 10–11 bales per hectare.

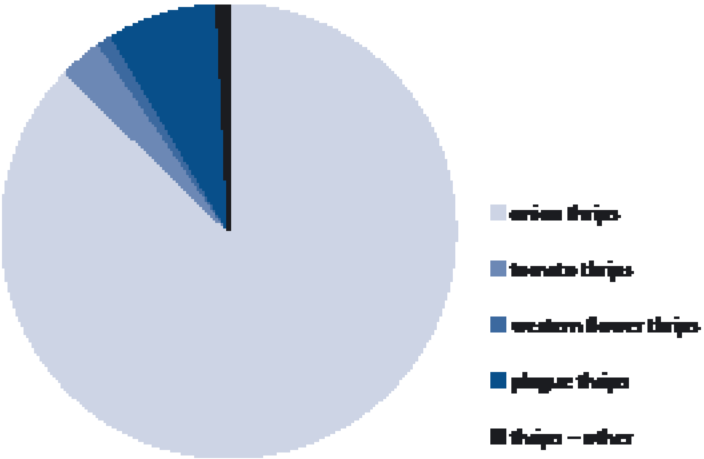


Figure 5. Adult thrips species observed in seedling cotton in November 2015 at Point Farms, Darlington Point NSW.

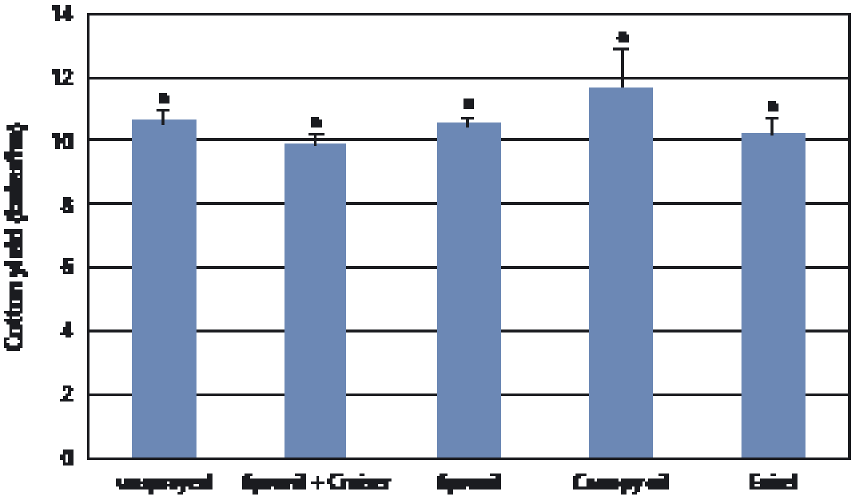


Figure 6. Machine harvest cotton yields by thrips treatment at Point Farms, Darlington Point NSW.

Acknowledgements

'Establishing Southern Cotton – IPM', DAN1501, 2014–17, is a project with joint investment by CRDC and NSW DPI.

We greatly appreciate the cooperation of the IREC demonstration farm committee, the Stott family and farm staff, James Hill, and Matt Watson. Thanks to Dupont and Caltex for supplying insecticides for the experiment. Thanks to Jorian Millyard (CSD) for the trailer scales for weighing modules. Thanks to Lewis Wilson (CSIRO) for advice.

New chemicals for thrips control in cotton 2015–16 experiment

Sarah Beaumont, Dr Sandra McDougall, Dr Jianhua Mo, Scott Munro and Alicia Ryan (NSW DPI, Yanco)

Key findings

- Thrips density can be highly variable within a field.
- Onion thrips (*Thrips tabaci*) was the most abundant species.
- Conclusions on the efficacy of the tested insecticides could not be made from this season's data.

Introduction

Introducing transgenic varieties of cotton into Australia has led to an increase in secondary pests that were once controlled by *Helicoverpa*-targeted sprays. Thrips is a group of sucking insects that has emerged as a significant early season pest. They feed on growing terminals causing leaf distortion and terminal death if the plant is heavily infested. This can cause delayed maturation and yield loss. Currently registered insecticides for thrips control in cotton are mostly organophosphates, which are highly toxic and disruptive to beneficial insects. To find more IPM-compatible options, we evaluated for a second season under field conditions, four new-generation insecticides that are either specialised against sap-sucking insects or known to have thrips control potential. In 2015–16 we added an additional three insecticides to the experiment (Table 1).

Site details

Location	Point Farms, Darlington Point, 34°39'15.3"S 145°53'26.8"E
Experiment period	17 November–15 December 2015
Sowing date and first water	18 October 2015
Variety	Sicot 74BRF
Seed treatment	Dynasty® – azoxystrobin+ metalaxyl-M+ fludioxonil
Insecticide at planting	Lorsban® – chlorpyrifos
Irrigation	Furrow
Establishment	Nine plants/m row
Harvest date	24–25 May 2016

Experimental design

Design	Randomised block design with five replicates
Plot size	90 cm rows × 4 rows × 20 m = 0.0072 ha
Replicates	Five
Buffer	One row either side, 2 m along rows
Spray applicator	Battery powered 15 L backpack sprayer (Rapid Spray®) × 2 with a four-row hand boom
Water rate	200 L/ha
Spray dates	18 and 25 November 2015
Monitoring dates	17 and 24 November, 2 and 15 December 2015

Sample unit	10 plants (excluding roots) from centre right row
Monitored	Adult and larval thrips plus thrips species composition
Harvest assessment	2 m hand-picked open bolls from centre left row of each plot
Analysis	Data was log transformed and analysed using Analysis of Variance (ANOVA), if significant treatment effects were detected (*P*<0.05) treatment means were separated by Fisher's least significant difference (LSD).

Treatments

Table 1. Insecticides and rates tested in the experiment.

Name	Active constituent	Rate	Adjuvant	Seasons tested
Exirel®	100 g/L cyantraniliprole	600 mL/ha	500 mL/100 L Hasten™	2014/15, 2015/16
Success™ Neo	120 g/L spinetoram	400 mL/ha	60 mL/100 L Agral®	2014/15, 2015/16
Sorcerer®	18 g/L abamectin	300 mL/ha		2015/16
Mainman®	500 g/kg flonicamid	400 g/ha		2014/15, 2015/16
Canopy oil®	792 g/L paraffinic oil	2 L/ha		2015/16
Shield®	200 g/L clothianidin	250 mL/ha	200 mL/100 L Maxx™	2015/16
Transform™	240 g/L sulfoxaflor	300 mL/ha	60 mL/100 L Agral®	2014/15, 2015/16
Control	water			2014/15, 2015/16

Results

Thrips assemblages

Thrips density was 12.5 thrips/plant at the first spray date and cotton seedlings were at the 2–3 leaf stage. The thrips population consisted of 83% onion thrips, 2% tomato thrips, 2% western flower thrips (WFT), 10% plague thrips and 3% other thrips before spraying (Figure 1A). The species composition had changed very little 14 days after the second spray (14 DAS2), with a slight increase in onion and tomato thrips and a slight decrease in WFT, plague thrips, and other thrips (Figure 1B).

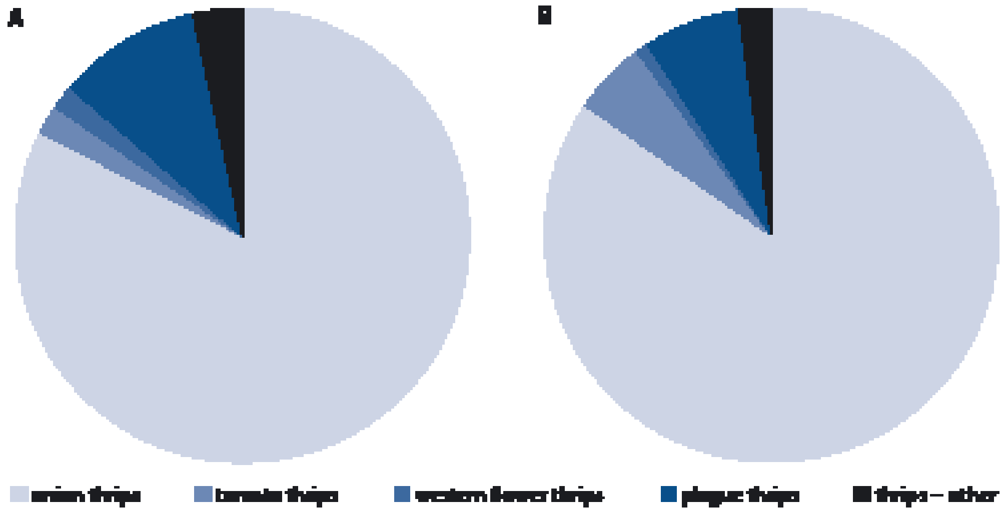


Figure 1. Thrips species composition observed on seedling cotton on 17 November 2015 (A) before starting spray treatments and (B) on 15 December 2015 after receiving two spray treatments on 18 and 25 November.

Efficacy for thrips control

The first spray had no effect on adult thrips density seven days after spraying (7 DAS1) (Figure 2). Seven days after the second spray (7 DAS2), adult density was reduced by some insecticide treatments more than others, however no insecticides were significantly more or less effective than the control. The lack of significant difference between treatments and the control remained at 14 days and 21 days after the first spray (7 days and 14 days after the second spray), except for more adult thrips in clothianidin-treated plots at 7DAS2.

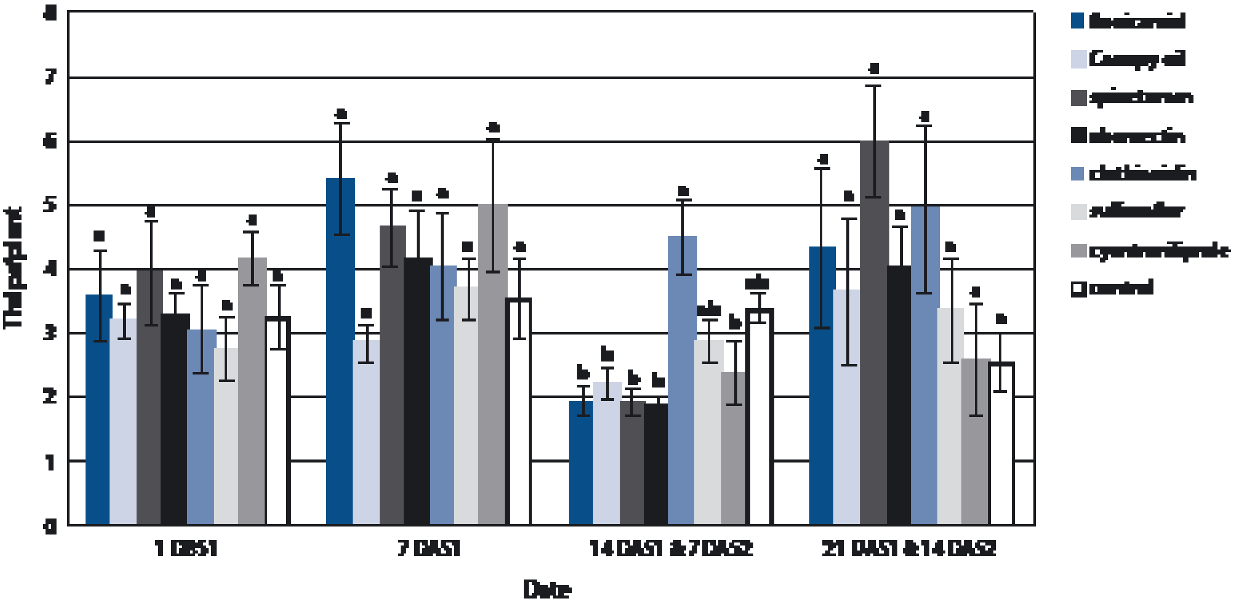


Figure 2. Mean adult thrips densities before and after sprays. Bars in the same group labelled with different letters are significantly different based on log transformed data at *P*<0.05 by Fisher's LSD following the detection of significant overall treatment effects using ANOVA. Data presented in graph is untransformed data and error bars indicate standard error. DBS: days before spray, DAS1 and DAS2: days after first and second spray.

All insecticide treatments and the water-sprayed control reduced larval thrips density from 7–14 thrips/plant to less than 2.5 thrips/plant at 7 DAS1 (Figure 3). As no insecticide was significantly more effective than the control, this reduction in larval thrips cannot be attributed to chemical action. Larval thrips density was not further reduced by any insecticide treatments at 7 DAS2; however, larval thrips populations increased with Canopy oil®, clothianidin and sulfloxaflor at 7 DAS2. Spinetoram suppressed larval thrips more effectively than Canopy oil® or sulfloxaflor following the second spray, however, these were not significantly more effective than the control. As with the adults, there were no significant effects on larval thrips at 14 DAS2.

In comparison with the 2014–15 experiment where thrips pressure was as high as 70 thrips per plant, this season's experiment did not identify any clear efficacy in the tested insecticides for thrips control. In 2014–15, all four tested insecticides reduced larval thrips by at least 50% 7 DAS1 and by as much as 77% following two spray treatments.

Harvest assessment

No significant differences were found in the seed cotton yield despite some treatments having a lower thrips density (Figure 4).

Summary

Onion thrips remained the most prevalent species throughout the experiment and there was little change in thrips species composition following the sprays. Due to the low thrips pressure and the highly variable nature of thrips densities within the experiment area it is not possible to make conclusions about the efficacy of the tested insecticides at controlling thrips in cotton based on the 2015–16 season data. Another season with greater thrips density would be required to make recommendations on the efficacy of these insecticides on thrips control in cotton.

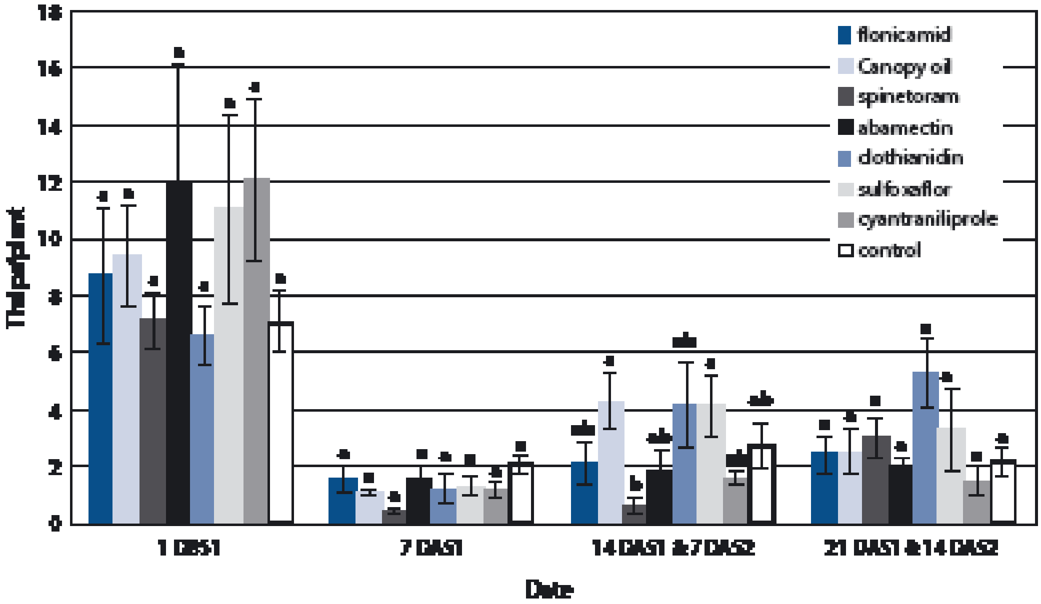


Figure 3. Mean larval thrips densities before and after sprays. Bars in the same group labelled with different letters are significantly different based on log transformed data at $P<0.05$ by Fisher's LSD following detecting significant overall treatment effects using ANOVA. Data presented in graph is untransformed data and error bars indicate standard error. DBS: days before spray, DAS1 & DAS2: days after first and second spray.

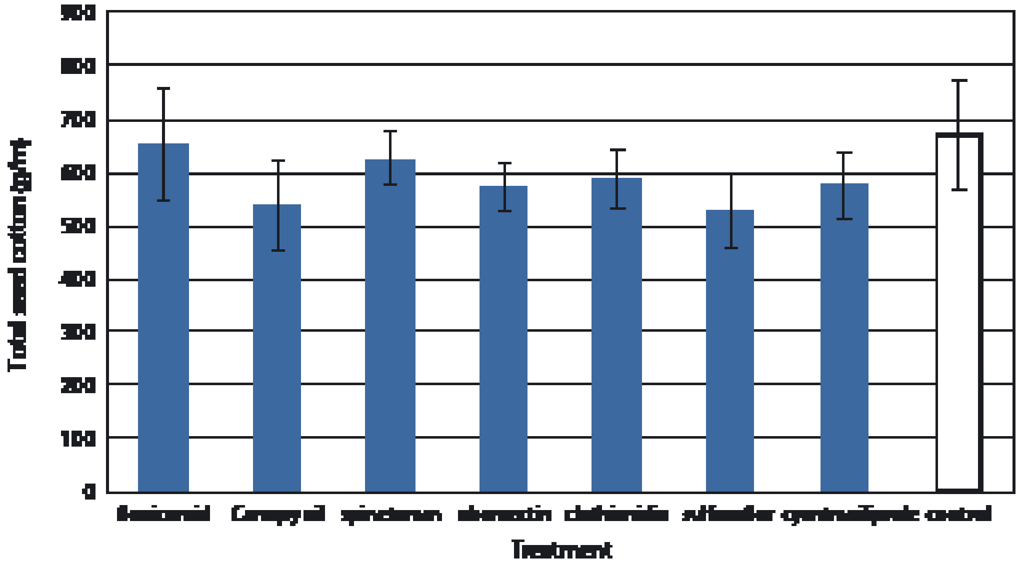
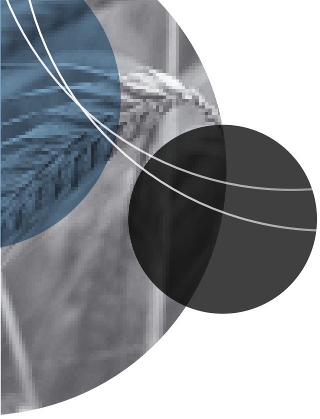


Figure 4. Mean seed cotton weight calculated from hand-harvested sub samples. Error bars indicate standard error. The differences are not significant; effects using ANOVA at a significance level of 0.05.

Acknowledgements

'Establishing Southern Cotton – IPM', DAN1501, 2014–17, is a project with joint investment by NSW DPI and CRDC.

We greatly appreciate the cooperation of Matt Stott and agronomists James Hill and Matt Watson on this project. We also appreciate the support from casual staff Emma O'Connell, Hannah Draper and Jack Dunne.



Irrigation & climate

Barley irrigation and seeding rate

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

Key findings

- In the wet winter of 2016, a single irrigation of a barley crop increased grain yield and grain quality but resulted in reduced water productivity.
- The 50 kg/ha seeding rate improved grain quality and reduced lodging compared with the 80 kg/ha seeding rate with no negative impact on grain yield.
- The waterlogged treatment (ponded for 48 hours) used an additional 0.41 ML/ha or 55% more water in one irrigation than the treatment that was ponded for only five hours.

Introduction

In 2016, an experiment was conducted at Leeton to investigate the irrigation water requirements of a barley crop and the impact that plant density, nitrogen (N), irrigation intensity and waterlogging have on grain yield and quality, water use and water productivity.

Site details

Location	Leeton
Soil type	Self-mulching heavy clay
Previous crop	Wheat
Sowing	20 May (disc drill at 18 cm row spacing)
Variety and seeding rates	La Trobe$^{\phi}$, 50 kg/ha and 80 kg/ha seed
Establishment	50 kg/ha – 90 plants/m^2 80 kg/ha – 160 plants/m^2
Sowing fertiliser	Di-ammonium phosphate (DAP), 125 kg/ha sown with seed
Topdressed nitrogen	8 August (Z32) – 0, 50, 100 and 150 kg N/ha
In crop rainfall	402 mm
Irrigation date	27 October

Treatments

Irrigation management treatment

There were three irrigation treatments (T) and four replicates in each treatment:

T1 – Rainfed (no irrigation)

T2 – Irrigated not waterlogged – one spring irrigation ponded for 5 hours before draining

T3 – Irrigated waterlogged – one spring irrigation ponded for 48 hours before draining.

Each of the irrigation treatments were in separate bays to allow water use to be accurately measured. Irrigation was applied to the two irrigated treatments on the same day.

Seeding rates

Each irrigation treatment was split for seeding rate treatments of 50 kg/ha and 80 kg/ha.

Nitrogen treatment

Four N treatments of 0, 50, 100, 150 kg N/ha were applied to each irrigation/seeding rate treatment at stem elongation (Z32).

Results

Grain yield

The rainfed treatment had a significantly lower grain yield than either of the irrigated treatments, but the difference was relatively small (0.27 t/ha) (Table 1). This small difference is likely due to the large amount of rainfall (402 mm) received during the growing season.

There was no significant difference in grain yield between the 50 kg/ha and 80 kg/ha seeding rates. The 80 kg/ha seeding rate treatment had higher dry matter and more tillers than the 50 kg/ha treatment, but this did not result in increased grain yield (Table 1). Despite the extended period of ponding, the waterlogged treatment grain yield was not significantly different from the non-waterlogged irrigation treatment.

Table 1. Growth, grain yield, grain quality and water productivity response of barley to irrigation, seeding rate and N topdressing in an experiment at Leeton in 2016.

Treatment		Total dry matter (kg/ha)	Tiller number (No/m^2)	Grain yield (t/ha)	Lodging score 1=standing, 9=flat	Grain protein (%)	Retention >2.5 mm (%)	Screenings <2.2 mm (%)	Water productivity (t/ML)
Irrigation	Rainfed	1282	813	6.15	4	9.77	73	9.3	1.53
	Non-waterlogged	1342	818	6.42	3	9.65	81	6.0	1.35
	Waterlogged	1373	799	6.47	4	9.82	80	6.4	1.25
	l.s.d. (*P*<0.05)	n.s.	n.s.	0.20	n.s.	n.s.	2	0.6	0.05
Seeding rate	50 kg/ha	1315	749	6.33	3	9.76	80	6.7	1.37
	80 kg/ha	1349	871	6.35	4	9.74	76	7.7	1.38
	l.s.d. (*P*<0.05)	30	46	n.s.	0.4	n.s.	2	0.9	n.s.
Topdressed nitrogen (kg N/ha)	0	870	552	4.32	2	8.26	91	2.3	0.93
	50	1332	777	6.49	4	8.81	85	4.1	1.41
	100	1505	927	7.06	5	10.21	72	9.5	1.53
	150	1621	983	7.49	5	11.71	64	13.0	1.63
	l.s.d. (*P*<0.05)	51	57	0.31	0.4	0.23	2	0.8	0.07

Water use & water productivity

The rainfed treatment received 4.0 ML/ha from rainfall during the growing season, while the non-waterlogged and waterlogged treatments received an additional 0.74 ML/ha and 1.14 ML/ha respectively from their one irrigation. The waterlogged treatment, which was ponded for 48 hours, used an additional 0.41 ML/ha or 55% more water than the single irrigation treatment, which was ponded for five hours. The increased water use associated with waterlogging was primarily due to increased infiltration over the extended period of ponded water.

The rainfed treatment had the highest water productivity of 1.53 t/ML compared with 1.35 t/ML and 1.25 t/ML for the one irrigation and waterlogged treatments respectively (Table 1).

While seeding rates had no significant effect on water productivity, applying N at stem elongation significantly increased water productivity (Table 1). There was a significant interaction between irrigation treatment and N topdressing rate for water productivity (Figure 1).

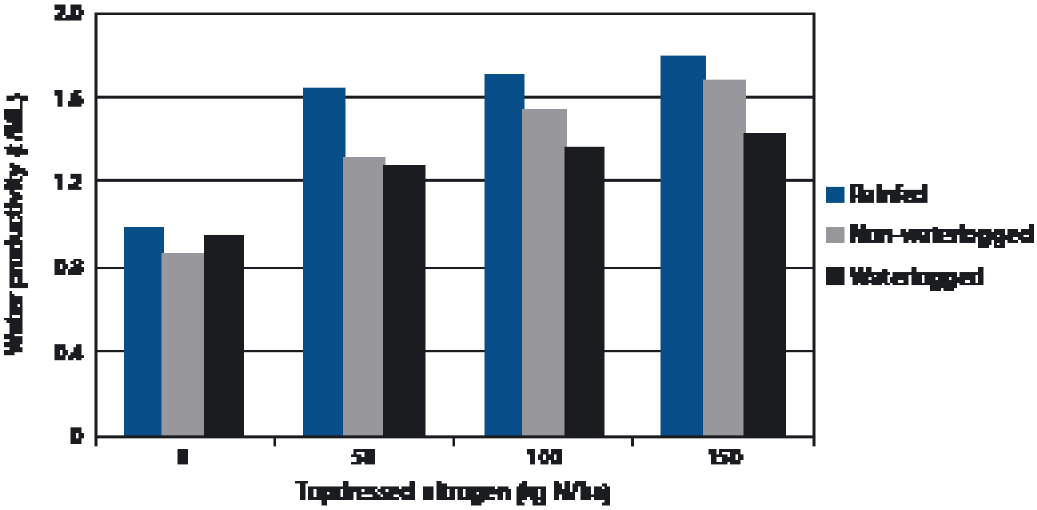


Figure 1. Water productivity (t/ML) of barley with three irrigation and four N treatments, averaged across seeding rate; l.s.d. (*P*<0.05) = 0.11.

Lodging

Lodging was a problem in winter crops in the 2016 season due to the very wet conditions. Although irrigation treatment had no effect on lodging, the higher seeding rate (80 kg/ha) resulted in significantly increased lodging compared with the lower seeding rate (50 kg/ha) (Table 1). The increased rate of topdressed N also significantly increased lodging (Table 1).

Grain quality

Grain protein increased significantly with higher rates of topdressed N, but was not affected by either irrigation treatment or seeding rate (Table 1).

The non-irrigated rainfed treatment produced lower grain quality than either of the irrigated treatments when averaged across seeding rate and nitrogen treatments. The rainfed treatment had significantly lower seed retention (>2.5 mm) and significantly higher screenings (<2.2 mm) than the two irrigated treatments. The 80 kg/ha seeding rate had smaller grain size, lower retention and higher screenings than the 50 kg/ha seeding rate (Table 1).

Increased rates of topdressed N significantly reduced grain retention and increased screenings, demonstrating a significant interaction between irrigation treatment and N rate (Figure 2). As the N topdressing rate increased, the percentage of screenings increased more for the rainfed treatment, than the two irrigated treatments (Figure 2).

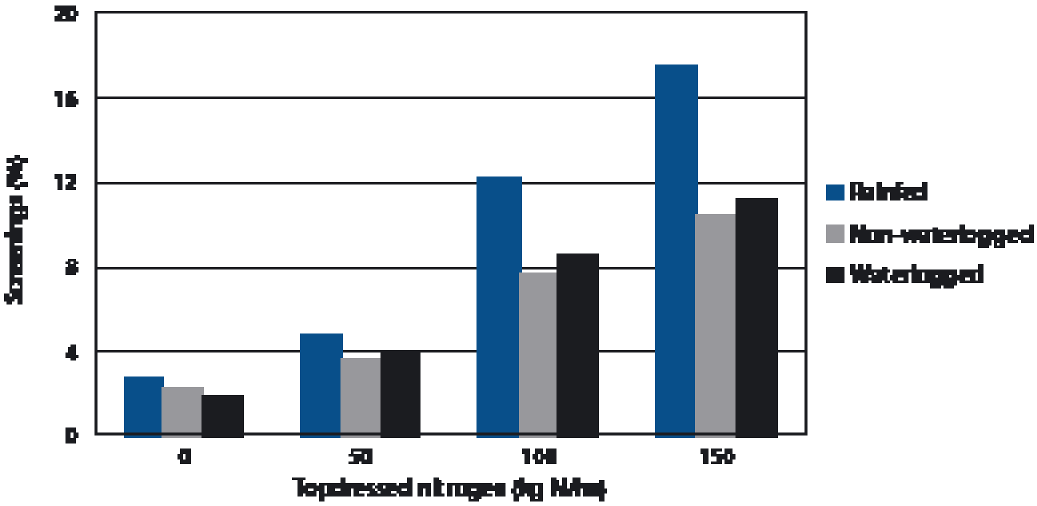


Figure 2. Grain screenings <2.2 mm (%) for seeding rate by N interaction, averaged across N treatments; l.s.d. (*P*<0.05) = 1.33.

Summary

The 2016 winter was particularly wet, with many commercial cereal crops suffering from severe waterlogging. The experimental site had acceptable surface drainage and soil structure, which resulted in little surface water ponding on the plots for any extended period of time, thus high grain yields were still able to be obtained.

The wet winter also resulted in the cereal crops having very shallow root systems, so when evapotranspiration rates increased in spring and rainfall slowed, the crops quickly suffered from moisture stress. Adding one irrigation did not produce a large increase in grain yield, but the benefit was obvious in grain quality, particularly at high N rates. Grain quality is a very important component in profitability with poor grain quality often resulting in lower prices in the marketplace.

Many growers use higher seeding rates than are required to achieve high grain yields. The current recommended seeding rate for barley with partial and full irrigation is 60–90 kg/ha and 70–110 kg/ha respectively. The results of this experiment are an example of a lower seeding rate producing equivalent grain yield, with the added benefits of improved grain quality and reduced lodging. Seeding rate recommendations for irrigated barley should be reviewed following further research conducted with a range of irrigation intensities.

Acknowledgements

This research is part of the 'Southern irrigated cereal and canola varieties achieving target yields' project, DAN00198, 2014–17, with joint investment by GRDC and NSW DPI.

Effect of plant density on irrigated soybeans in southern NSW

Mathew Dunn and Alan Boulton (NSW DPI, Yanco); **Mark Richards** (NSW DPI, Wagga Wagga)

Key findings

- Averaged across sowing densities Djakal, N005A-80 and P176-2 yielded the highest with 3.7 t/ha, 3.8 t/ha and 3.9 t/ha respectively, while Snowy$^{\phi}$ achieved a significantly lower grain yield of 3.2 t/ha.
- Grain yield of Djakal and N005A-80 did not vary significantly between target sowing densities. Both varieties maintained high yields even at the lowest target sowing density (15 plants/m^2).
- Lodging was exacerbated at higher sowing densities for all varieties except P176-2, which was consistently low across all sowing densities.
- The length of time to maturity did not vary significantly between target sowing densities for Snowy$^{\phi}$, N005A-80 or P176-2. However, Djakal's maturity length was extended by 4 days at the 60 plants/m^2 sowing density when compared with the three lower target plant densities.

Introduction

Seeding rate is an agronomic decision that producers can use to maximise soybean yields and economic returns. This 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	3 December 2015
Harvest date	19 April 2016

Treatments

Varieties

Djakal, Snowy$^{\phi}$, N005A-80 and P176-2

Target sowing densities

15, 30, 45 and 60 plants/m^2

Results

Maturity length

Target sowing density did not have a significant effect on maturity length; however, significant differences in maturity length between varieties were identified. Djakal reached physiological maturity first, 115 days after sowing (DAS), followed by N005A-80 (118 DAS), P176-2 (119 DAS) and Snowy$^{\phi}$ (121 DAS).

Lodging

Lodging in soybeans has the potential to reduce harvestability, increase harvest losses and reduce yields. Both target sowing density and variety had a significant ($P = 0.01$) effect on the severity of lodging.

Lower target sowing densities of Djakal, Snowy$^{\phi}$ and N005A-80 resulted in reduced lodging severity (Figure 1). For Djakal, Snowy and N005A-80, 15 and 30 plants/m^2 densities resulted in significantly lower lodging than the 60 plants/m^2 density. The lodging severity of P176-2 remained consistent across all target sowing densities.

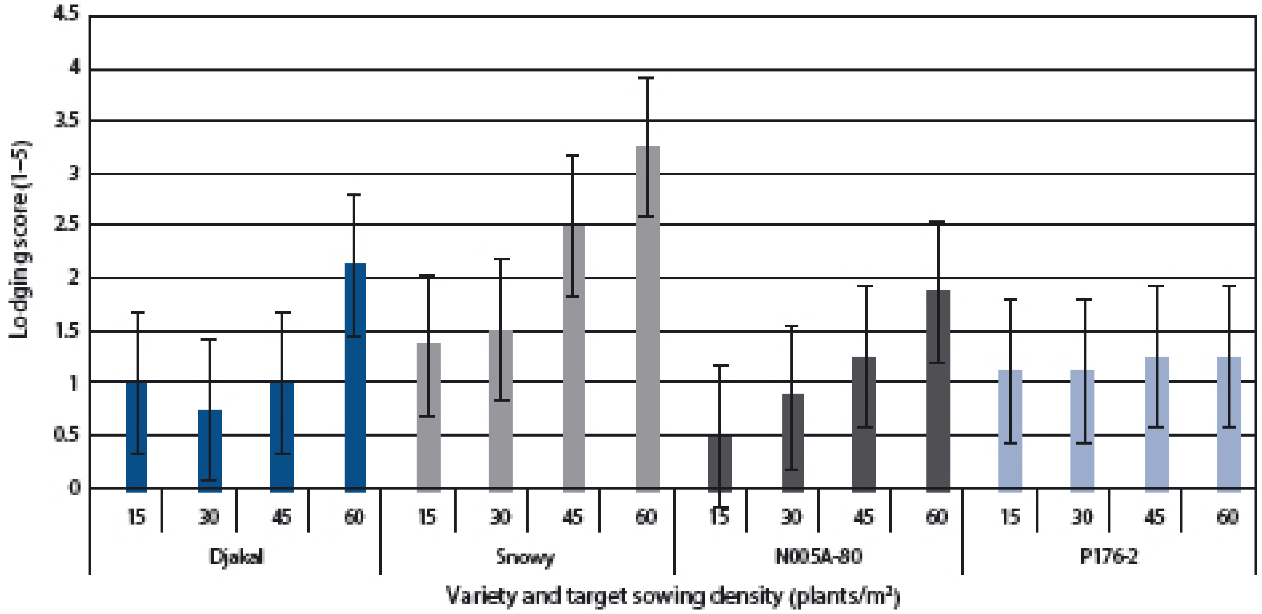


Figure 1. Effect of variety and target sowing density on lodging of four soybean varieties. Bars denote l.s.d. ($P = 0.05$) = 0.67 (1 = minimal lodging, 5 = severe lodging).

Grain yield

Both target sowing density and variety were found to have a significant ($P = 0.01$) effect on grain yield. Grain yield was maximised for Snowy(b) and P176-2 at the 45 plants/m² density, while Djakal and N005A-80 achieved consistent grain yields across all target sowing densities (Figure 2).

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(b) was significantly lower yielding at 3.2 t/ha.

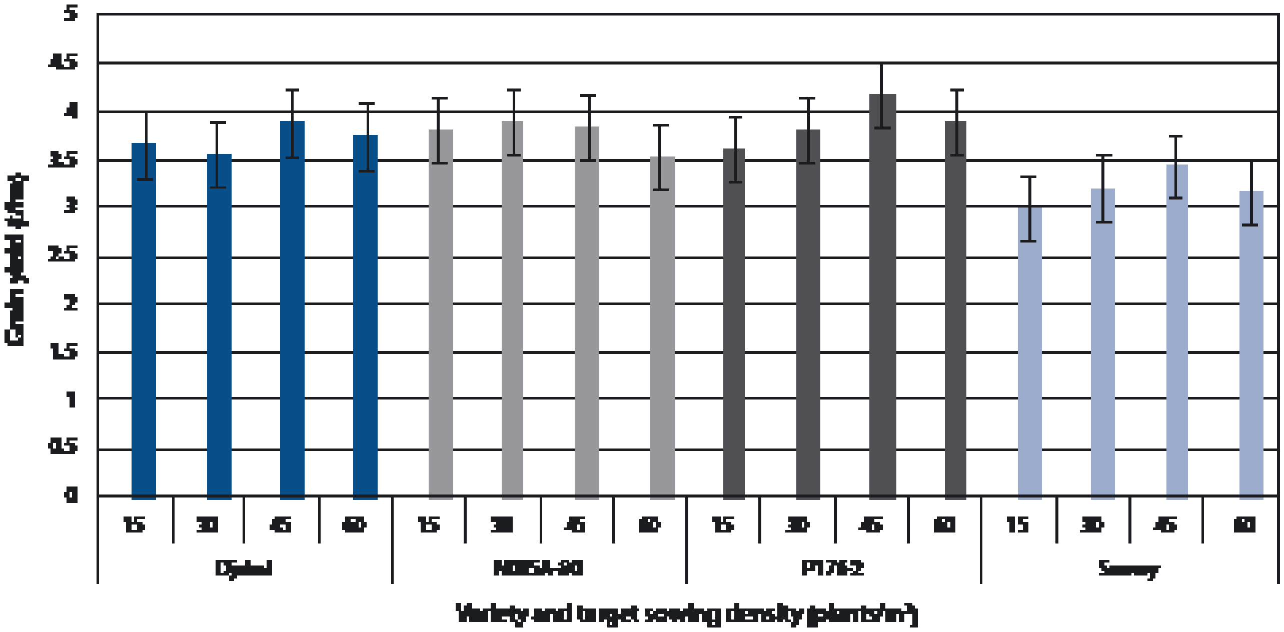


Figure 2. Effect of variety and target sowing density on grain yield of four soybean varieties. Bars denote l.s.d. ($P = 0.05$) = 0.34 t/ha.

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 targeted sowing density below 35 plants/m^2, however, this is not recommended. Targeted sowing densities above 50 plants/m^2 can 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 GRDC and NSW DPI.

Thank you to John Dando, Paul Morris and Gabby Napier for their operational support.

Effect of sowing date on irrigated soybeans in southern NSW 2015–16

Mathew Dunn and Alan Boulton (NSW DPI, Yanco); **Mark Richards** (NSW DPI, Wagga Wagga)

Key findings

- For all varieties, the middle sowing date (4 December) resulted in higher grain yields than the early (11 November) or late (23 December) sowing dates.
- Varieties, N005A-80 and Bidgeeᶲ consistently achieved the highest seed protein concentrations.
- Varieties, Snowyᶲ and Bidgeeᶲ achieved consistent seed protein concentrations across the three sowing dates, while later sowing dates reduced the seed protein of Djakal, N005A-80 and P176-2 varieties.

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 photo-period 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. Early (11 November) and late (23 December) sowing times were chosen as dates earlier and later than ideal, while the middle (4 December) sowing date represents the middle of the ideal sowing window for the region.

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
Harvest date	21 April 2016

Treatments

Varieties

Djakal, Snowyᶲ, Bidgeeᶲ, N005A-80 and P176-2

Sowing dates

11 November 2015, 4 December 2015 and 23 December 2015

Results

Grain yield

Both sowing date and variety significantly affected grain yield. Grain yield was highest for the middle sowing date (4 December), while the early (11 November) and late (23 December) sowing dates resulted in significantly lower yields (Figure 1).

Averaged across sowing dates, Djakal, N005A-80 and P176-2 achieved the highest grain yields at 3.2 t/ha, 3.1 t/ha and 3.1 t/ha respectively, while Snowyᶲ and Bidgeeᶲ achieved grain yields of 2.7 t/ha and 2.4 t/ha respectively (Figure 2).

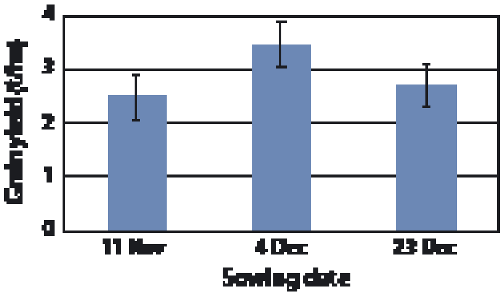


Figure 1. Effect of sowing date on soybean grain yield averaged across all varieties. Bars denote l.s.d. (*P* = 0.05) = 0.4 t/ha.

Seed protein

Sowing date, variety and the interaction between sowing date and variety had a significant effect on seed protein concentration. Snowy ⁽ᶲ⁾and Bidgee⁽ᶲ⁾ achieved consistent seed protein concentrations across sowing times, while the seed protein concentration for Djakal, N005A-80 and P176-2 varieties was reduced at later sowing dates.

Averaged across sowing dates, N005A-80 had the highest seed protein concentration (Figure 3) followed by Bidgee⁽ᶲ⁾, Snowy⁽ᶲ⁾, P176-2 and Djakal at 45.4%, 44.4%, 43.4%, 41.7% and 41.6% respectively.

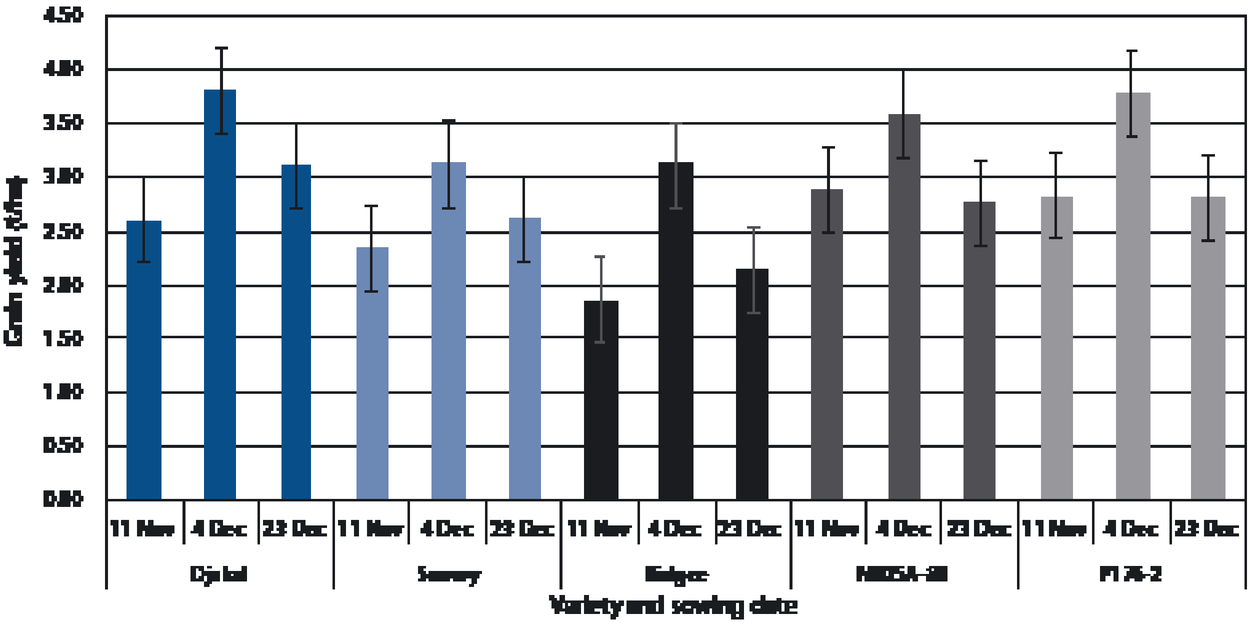


Figure 2. Effect of variety and sowing date on the grain yield of five soybean varieties. Bars denote l.s.d. (*P* = 0.05) = 0.4 t/ha.

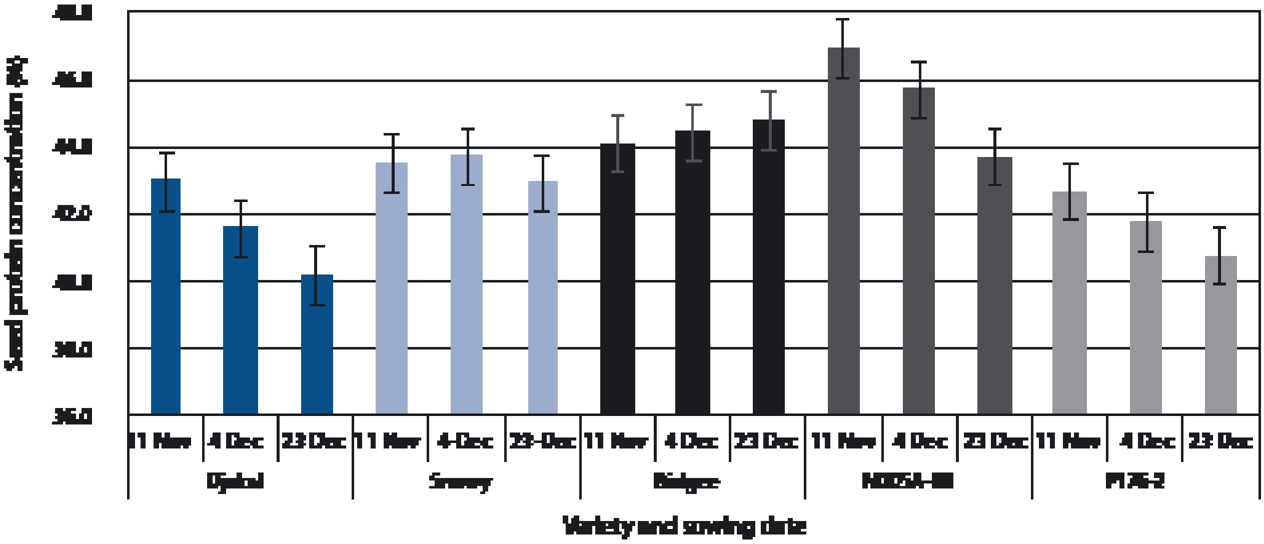


Figure 3. Effect of variety and sowing date on protein concentration (percentage on a dry matter basis) of five soybean varieties. Bars denote l.s.d. ($P = 0.05$) = 0.85%.

Summary

This experiment showed that sowing soybeans in southern NSW outside the optimum sowing window can result in significant yield losses. Not only did delaying sowing into late December reduce yield, but sowing too early (early November) also had a similar negative effect on yield.

Significant reductions in seed protein concentration occurred when sowing was delayed, however, this was not the case for Snowy⦸ or Bidgee⦸, both of which maintained consistent seed protein concentrations across sowing dates.

Acknowledgements

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

Thank you to John Dando, Paul Morris and Gabby Napier for their operational support.

Targeting 5 t/ha irrigated canola: effect of sowing date, variety choice and nitrogen management – Finley 2016

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

Key findings

- Nuseed Diamond achieved 5 t/ha grain yield from early sowing (watered for germination on 12 April).
- The high yield of Nuseed Diamond was due to its high biomass accumulation and high harvest index. ATR Bonito$^{\phi}$ was the lowest yielding variety, largely because it accumulated less biomass than hybrid non-TT varieties.
- Split nitrogen application resulted in higher grain yield than all nitrogen applied at sowing or all nitrogen delayed to the 8-leaf stage.

Introduction

Irrigated canola growers strive for a grain yield of 5 t/ha, however there is little information on management strategies to achieve this goal. This experiment was designed to assist growers with variety, nitrogen management and sowing date decisions to maximise irrigated canola yield potential. Five canola varieties were sown on two sowing dates in April and were watered with a lateral irrigator (45 mm total over three applications) to aid crop establishment. Three nitrogen (N) treatments were applied to determine the optimum timing of N application – early, split and delayed.

Site details

Location	10 km north-east of Finley
Soil type	Grey–brown chromosol
Previous crop	Wheat (irrigated)
Fallow rainfall	244 mm (November 2015–March 2016)
In-crop rainfall	427 mm rainfall (April 2016–October 2016) plus 45 mm irrigation (April)
Soil nitrogen	98 kg/ha (0–150 cm, 29 April)
Starter fertiliser	100 kg/ha mono-ammonium phosphate (11% nitrogen, 22.7% phosphorus, 2% sulfur), treated with 2.8 L/t flutriafol (500 g/L)

Treatments

Due to the wet conditions in 2016, only a small amount of irrigation was required. Three separate applications of 15 mm were made through a lateral irrigator in April to ensure timely crop establishment, with no further irrigation for the rest of the season.

Varieties

ATR Bonito$^{\phi}$, Nuseed Diamond, Pioneer® 44Y89 (CL), Pioneer® 45Y25 (RR), Pioneer® 45Y88 (CL)

Sowing date (SD)

SD1: 8 April – watered for germination on 12 April
SD2: 30 April

Nitrogen timing

Early – 300 kg N/ha applied at sowing
Split – 150 kg N/ha applied at sowing and 150 kg N/ha applied at 8-leaf stage
Delayed – 300 kg N/ha applied at 8-leaf stage

Results

Phenology

Nuseed Diamond was the fastest variety to start flowering (defined as when 50% of plants have one open flower) from SD1, taking 91 days from sowing. Pioneer® 45Y25 (RR) was the slowest variety to start flowering from SD1, taking 125 days from sowing. The 30 April sowing (SD2) delayed the flowering of Nuseed Diamond by an extra 22 days, but only by eight days for Pioneer® 45Y25 (RR). Nuseed Diamond development is driven only by thermal time, therefore warmer temperatures hasten its development. Slower varieties such as Pioneer® 45Y25 (RR) have small but consequential responses to vernalisation that can delay flowering from early sowing when conditions are warm.

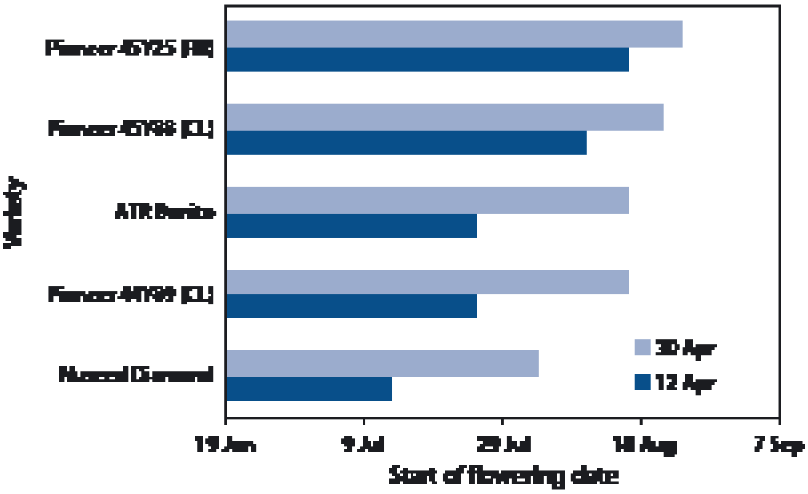


Figure 1. Start of flowering date (50% of plants with one open flower) of five canola varieties sown on two sowing dates at Finley, 2016.

Sowing date and variety choice

Variety choice was the most important factor affecting grain yield in this experiment, with an overall difference of 1.72 t/ha between the highest yielding variety (Nuseed Diamond) and the lowest yielding variety (ATR Bonito$^{(b)}$).

Nuseed Diamond was the highest yielding variety from both sowing dates and had approximately $400/ha higher gross income (based on canola at $500/tonne) than the next best variety, Pioneer® 44Y89 (CL).

The advantage of Nuseed Diamond for grain yield was likely due to its high conversion of biomass into grain yield (high harvest index). Nuseed Diamond averaged a harvest index of 0.30 compared with the next best varieties, Pioneer® 44Y89 (CL) and ATR Bonito$^{(b)}$ with a harvest index of 0.27. Pioneer® 45Y88 (CL) and Pioneer® 45Y25 (RR) both had a harvest index of 0.24. ATR Bonito$^{(b)}$ was lower yielding overall, because it grew less biomass than the hybrid non-TT varieties.

Differences in oil concentration were small relative to the differences in grain yield. ATR Bonito$^{(b)}$ from SD1 was the only variety to achieve 45% oil. The average oil concentration in this experiment was likely limited by the very high nitrogen application (300 kg N/ha).

There was evidence of varieties tabling in this experiment, but no lodging was observed.

Table 1. Grain yield (t/ha) and oil concentration (at 6% moisture) of five canola varieties sown on two sowing dates at Finley, 2016.

Variety	Grain yield (t/ha)		Oil concentration (%)	
	12 April	30 April	12 April	30 April
ATR Bonito	3.56	2.61	45.0	44.3
Nuseed Diamond	5.04	4.57	43.1	44.0
Pioneer 44Y89 (CL)	4.23	3.77	42.3	43.2
Pioneer 45Y25 (RR)	3.85	3.58	43.2	42.3
Pioneer 45Y88 (CL)	3.91	3.89	40.3	42.2
l.s.d. ($P<0.05$)	0.41		1.0	

Nitrogen management

For the early sowing date, the split N treatment was 0.28 t/ha higher yielding (averaged across all varieties) than the up-front N treatment, which was a further 0.33 t/ha higher yielding than the delayed N treatment. Grain yield was not affected by N management in the lower yielding SD2, which indicates that the differences between nitrogen timing is most likely to be observed when other factors such as sowing time are optimised.

Conclusion

For this experiment, management strategies that achieved 5 t/ha were:

1. variety choice (Nuseed Diamond)
2. sowing date (12 April)
3. nitrogen management (split application between pre- and post-sowing).

Nuseed Diamond appears an ideal plant type for irrigated canola, as it is able to grow large quantities of biomass and can effectively convert that biomass into grain yield.

Acknowledgements

This experiment was part of the project 'Southern irrigated cereal and canola varieties achieving target yields', DAN00198, 2014–17, with joint investment by GRDC and NSW DPI.

Thank you to the site cooperator Geoff McLeod for his ongoing cooperation (three years) and to Jess Simpson and Hayden Petty for technical support.

Targeting maximum yields of flood irrigated canola in southern NSW

Tony Napier, Daniel Johnston and Glenn Morris (NSW DPI, Yanco); **Dr Neroli Graham** (NSW DPI, Tamworth); **Cynthia Podmore, Luke Gaynor and Deb Slinger** (NSW DPI, Wagga Wagga)

Key findings

- Pioneer® 45Y88 (CL) was the highest yielding variety, averaging over 4 t/ha, with Nuseed Diamond and Pioneer® 45Y25 (RR) also achieving high yields.
- Sowing on 5 April resulted in higher grain yield, reduced lodging and lower oil content compared with sowing on 26 April.
- A plant population of 35–56 plants/m^2 resulted in higher grain yields than populations of 18 plants/m^2 or 68 plants/m^2.
- Applying 200 kg N/ha resulted in higher grain yields than 150 kg N/ha when the soil available nitrogen (N) at sowing was 64 kg/ha. Nitrogen rates above 200 kg N/ha resulted in no extra yield.
- Increasing N application rates above 200 kg N/ha reduced oil concentration.
- Crop lodging increased with plant populations above 35 plants/m^2 and N rates above 150 kg N/ha.

Introduction

Variety choice, agronomic management and their interactions influence the yield potential of irrigated canola crops. Results from previous experiments in the 'Southern irrigated cereal and canola varieties achieving target yields' project have demonstrated that varietal selection, combined with tactical agronomic management, can result in canola grain yields of greater than 4 t/ha in the Murrumbidgee Valley. Agronomic factors that have been shown to influence grain yield, oil content and lodging include N management, plant population and sowing date. Choosing the correct variety with the appropriate phenology for targeted sowing times maximises the probability of achieving high grain yields.

The third year of experiments was conducted in the winter growing season of 2016 with results reported in this paper.

Site details

Experiment 1	Split-plot design with two sowing dates as main plot and 12 varieties and two plant populations completely randomised within sowing date blocks. Each treatment was replicated three times.
Experiment 2	Randomised block design with 12 varieties and four N treatments. Each treatment was replicated three times.
Experiment 3	Randomised block design with 12 varieties and four plant density treatments. Each treatment was replicated three times.
Location	Leeton Field Station
Soil type	Self-mulching grey clay
Available N at sowing	64 kg/ha (0–60 cm)
Rainfall	Autumn: 147 mm Winter: 236 mm Spring (not including November rainfall): 184 mm Total 567 mm (5.7 ML/ha)
Sowing dates	Experiment 1: various dates as per Table 2 Experiments 2 and 3: 18 April 2016

Irrigation schedule	All three experiments were flood irrigated at or before sowing. Soil moisture monitoring at 30 cm and 60 cm depth was used to schedule a fully irrigated program to avoid moisture stress. The soil moisture monitoring demonstrated no moisture stress occurred during the growing season and no irrigation was required in spring.
Base fertiliser	SuPerfect 400 kg/ha (32 kg P/ha and 44 kg C/ha) MAP 150 kg/ha (15 kg N/ha and 15 kg P/ha) Gran-Am 150 kg/ha (30 kg N/ha and 36 kg S/ha) Urea 220 kg/ha (101 kg N/ha)
Topdressed fertiliser (at visible bud)	Experiments 1 and 3: urea 220 kg/ha (101 kg N/ha) Experiment 2: urea at various rates as per Table 3
Target plant population	Experiments 1 and 3: at various densities as per Table 4 Experiment 2: at 40 plants/m^2
Fungicides	Prosaro® (210 g/L prothioconazole and 210 g/L tebuconazole) at 400 mL/ha was applied twice to each experiment at the 6-leaf and 20% flowering stages
Harvest dates	Experiment 1: from 15 to 21 November Experiment 2: on 26 November Experiment 3: on 27 November
Yield assessment	Yield assessment was obtained using both a small plot harvester and hand cuts. The yield from the small plot harvester was consistently 25% to 30% lower than the yield obtained from the hand cuts. The yield assessment from the small plot harvester is used in this report. All harvest samples were standardised to 8% moisture content for grain yield and 6% moisture content for oil concentration.

Treatments

Three irrigated canola experiments were conducted at Leeton Field Station in 2016. The effects of varietal selection, sowing date, plant population and N management on grain yield, oil content and lodging were evaluated (tables 1, 2, 3 and 4).

These experiments were sown and harvested using small plot machinery. Sub samples of harvested grain were used to calculate oil content. Lodging assessments were conducted using a scale of 0–9, (0 = no lodging; 9 = flat on the ground). Each experiment contained three replicates: the N management and plant population experiments were randomised block designs; the plant population × sowing date experiment was a split plot design. Individual experiments were analysed using Genstat 18th edition (VSN International, 2015).

Table 1. Varieties evaluated in the three irrigated canola experiments at Leeton in 2016.

Experiment 1: Plant population × sowing date	Experiment 2: N management	Experiment 3: Plant population
Hyola® 600RR	Hyola® 600RR	Hyola® 600RR
Pioneer® 45Y88 (CL)	Pioneer® 45Y88 (CL)	Pioneer® 45Y88 (CL)
ATR Bonito$^{(|)}$	ATR Bonito$^{(|)}$	ATR Bonito$^{(|)}$
AV Garnet$^{(|)}$	AV Garnet$^{(|)}$	AV Garnet$^{(|)}$
ATR Gem$^{(|)}$	ATR Gem$^{(|)}$	ATR Gem$^{(|)}$
Nuseed Diamond	Nuseed Diamond	Nuseed Diamond
Nuseed GT-50	Nuseed GT-50	
Hyola® 559TT	Hyola® 559TT	
Victory® V3002	Victory® V3002	
Hyola® 575CL	Hyola® 575CL	
Pioneer® 44Y89 (CL)	Pioneer® 44Y89 (CL)	
Pioneer® 45Y25 (RR)	Pioneer® 45Y25 (RR)	

Table 2. Sowing dates evaluated in the irrigated canola experiment 1 at Leeton in 2016.

Treatment	Sowing dates
Sowing date 1 (SD1)	5 April 2016
Sowing date 2 (SD2)	26 April 2016

Table 3. Nitrogen treatments evaluated in the irrigated canola experiment 2 at Leeton in 2016.

N treatment	N rate at sowing (kg N/ha)	N rate at top-dressing (kg N/ha)	Total N applied (kg N/ha)
Very low (upfront) – VL	150	0	150
Low (split) – L	150	50	200
Medium (split) – M	150	100	250
High (split) – H	150	150	300

Table 4. Plant populations evaluated in the irrigated canola experiments 1 and 3 at Leeton in 2016.

Plant population treatment	Experiment 1: Plant population × sowing date (plants/m^2)		Experiment 3: Plant population (plants/m^2)	
	Target	Actual	Target	Actual
Very low – VL	–	–	10	18
Low – L	20	23	25	35
Medium – M	40	44	40	42
High – H	–	–	55	56
Very high – VH	–	–	70	68

Results

Grain yield

Variety had a significant effect on grain yield in all three experiments. Plant population and N rate also affected yield. Pioneer® 45Y88 (CL) yielded over 4 t/ha in all three experiments with Pioneer® 45Y25 (RR) and Nuseed Diamond also achieving grain yields close to 4 t/ha in each of the experiments (Table 5). Pioneer® 45Y88 (CL) achieved an average yield of over 5 t/ha when yield was measured by hand harvest. The lowest-yielding variety, ATR Bonito$^{(|)}$, yielded 24–27% less than Pioneer® 45Y88 (CL).

Table 5. Grain yield (t/ha) of 12 canola varieties evaluated in three irrigated canola experiments at Leeton in 2016.

Variety	Grain yield (t/ha)					
	Experiment 1: Plant population × sowing date		Experiment 2: N management		Experiment 3: Plant population	
ATR Bonito	3.11	h	3.24	h	3.20	d
ATR Gem	3.26	f g h	3.42	f g h	3.28	c d
AV Garnet	3.96	a b	3.59	e f	3.62	b
Hyola 559TT	3.44	e f g	3.24	g h	–	
Hyola 575CL	3.46	e f g	3.91	b c d	–	
Hyola 600RR	3.77	b c d	3.56	e f	3.51	b c
Nuseed Diamond	3.88	b c	4.09	b	4.18	a
Nuseed GT-50	3.59	c d e	3.76	c d e	–	
Pioneer 44Y89 (CL)	3.54	d e f	3.66	d e f	–	
Pioneer 45Y25 (RR)	3.99	a b	3.99	b c	–	
Pioneer 45Y88 (CL)	4.25	a	4.47	a	4.19	a
Victory V3002	3.19	g h	3.48	f g	–	
Average	3.62		3.70		3.66	
l.s.d. ($P = 0.05$)	0.297		0.266		0.242	

Numbers in the same column sharing a common letter are not significantly different.

Varieties responded differently to the two sowing dates in experiment 1. Several varieties, including AV Garnet$^{\text{(}\phi\text{)}}$, Hyola® 600RR, Nuseed GT-50, Pioneer® 44Y89 (CL), Hyola® 559TT and Victory® V3002 had higher yields for SD1 (5 April) compared with SD2 (26 April) (Figure 1). In contrast, the other six varieties did not differ in yield between the sowing dates, showing plasticity in sowing window opportunity.

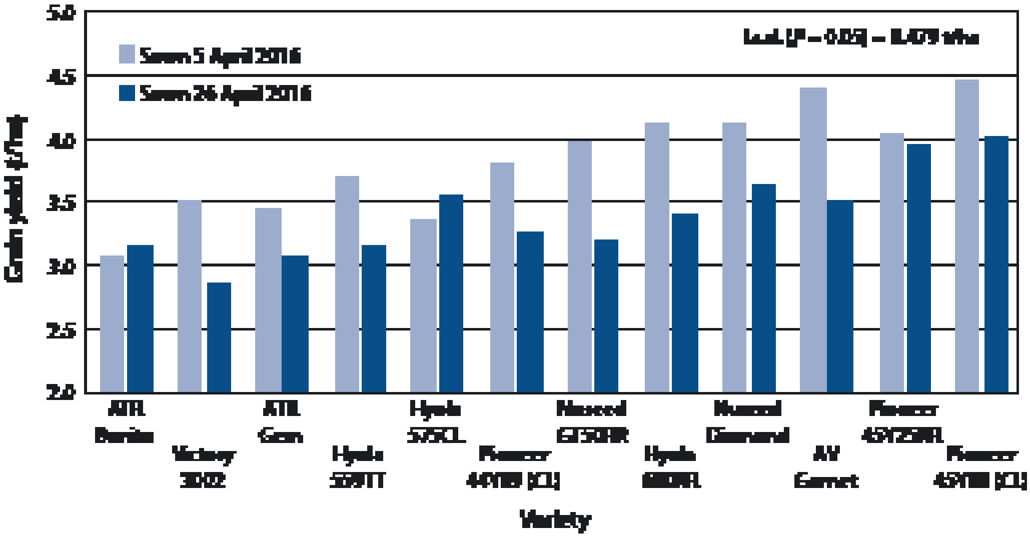


Figure 1. Grain yield (t/ha) of 12 canola varieties evaluated in the irrigated canola experiment 1 (plant population × sowing date) at Leeton in 2016.

Applying N affected grain yield with the VL treatment (150 kg N/ha at sowing) resulting in a lower grain yield (3.46 t/ha) than the three higher N rates. There was no difference in yield between the L (200 kg N/ha), M (250 kg N/ha) or H (300 kg N/ha) treatments with a mean yield of 3.72 t/ha, 3.85 t/ha and 3.79 t/ha respectively (Table 6).

Table 6. Grain yield, grain oil content and lodging score of four nitrogen treatments in the irrigated canola experiment 2 (N management) at Leeton in 2016.

N treatment	Grain yield (t/ha)		Oil content (%)		Lodging score (0–9)	
Very low – VL	3.46	b	46.91	a	1.34	a
Low – L	3.72	a	46.73	a	1.99	b
Medium – M	3.85	a	45.41	b	3.59	c
High – H	3.79	a	44.39	c	4.31	d
l.s.d. ($P = 0.05$)	0.16		0.60		0.37	

Numbers in the same column sharing a common letter are not significantly different.

Plant density affected grain yield with plant populations of 35, 42 and 56 plants/m^2 yielding higher than 18 and 68 plants/m^2 (Table 7).

Table 7. Grain yield, grain oil content and lodging score of five plant population treatments in the irrigated canola experiment 3 (plant population) at Leeton in 2016.

Population treatment	Grain yield (t/ha)		Oil content (%)	Lodging score (0–9)	
Very low – VL	3.31	c	45.5	2.65	a
Low – L	3.74	a b	45.7	2.98	a b
Medium – M	3.91	a	45.8	3.26	b
High – M	3.69	a b	45.1	4.49	c
Very high – VH	3.67	c	45.3	4.77	d
l.s.d. ($P = 0.05$)	0.23		n.a.	0.60	

Numbers in the same column sharing a common letter are not significantly different.

Grain quality

Variety influenced canola oil content in experiment 1 (plant population × sowing date) and experiment 2 (N management). AV Garnet⦹, Hyola® 559TT, ATR Bonito⦹, Nuseed Diamond and Pioneer® 45Y88 (CL) were in the significantly highest oil yielding group for both experiments (Table 8).

Table 8. Grain oil content (%) of 12 varieties evaluated in two irrigated canola experiments at Leeton in 2016.

Variety	Grain oil content (%)			
	Experiment 1: Plant population × sowing date		Experiment 2: N management	
ATR Bonito	44.70	a b	45.69	a b c d
ATR Gem	43.46	d e	45.53	c d e
AV Garnet	45.46	a	46.35	a b c
Hyola 559TT	45.02	a	46.39	a b c
Hyola 575CL	42.62	e	46.00	a b c d
Hyola 600RR	44.56	a b c	45.51	c d e
Nuseed Diamond	44.87	a b	46.19	a b c d
NuseedGT-50	44.73	a b	45.26	d e
Pioneer 44Y89 (CL)	43.30	d e	45.64	b c d
Pioneer 45Y25 (RR)	43.93	b c d	46.59	a b
Pioneer 45Y88 (CL)	44.77	a b	46.69	a
Victory V3002	43.52	c d e	44.51	e
Average	44.24		45.86	
l.s.d. ($P = 0.05$)	1.066		1.039	

Numbers in the same column sharing a common letter are not significantly different.

Sowing date affected oil content. Delaying sowing from SD1 (5 April) to SD2 (26 April) increased oil concentration (42.4%; 46.1% respectively) (data not shown).

Applying N significantly affected oil content. The oil percentage decreased as rates of N increased (Table 6). Applying 150 kg N/ha and 200 kg N/ha resulted in oil content of 46.91% and 46.73%, respectively with no statistical difference in oil content for these applied N rates. Applying N at 250 kg N/ha or 300kg N/ha caused reduced oil content (3% and 5% respectively).

Lodging

Varietal selection significantly affected lodging in each experiment, as did plant population, sowing date and N management. Varieties that displayed low lodging levels included Pioneer® 45Y88 (CL), Hyola® 575CL and Pioneer® 45Y25 (RR). In contrast, Hyola® 559TT, Hyola® 600RR and AV Garnet$^{(\phi)}$ were more susceptible to lodging (Table 9).

Table 9. Lodging score (0 = no lodging; 9 = flat on ground) of 12 canola varieties in three irrigated canola experiments at Leeton in 2016.

Variety	**Lodging score (0–9)**					
	Experiment 1: Plant population × sowing date		**Experiment 2: N management**		**Experiment 3: Plant population**	
ATR Bonito	3.32	e	3.56	d e	3.86	c
ATR Gem	3.12	d	3.07	c d	3.89	c
AV Garnet	2.67	c d	4.15	f	4.71	d
Hyola 559TT	5.26	f	3.88	e f	–	
Hyola 575CL	0.38	a	1.55	b	–	
Hyola 600RR	3.59	e	4.39	f	5.20	d
Nuseed Diamond	2.39	c	2.79	c	3.10	b
Nuseed GT-50	2.33	c	3.95	e f	–	
Pioneer 44Y89 (CL)	1.20	a b	2.07	b	–	
Pioneer 45Y25 (RR)	0.59	a	1.86	b	–	
Pioneer 45Y88 (CL)	0.32	a	0.33	a	1.03	a
Victory V3002	1.48	b	2.13	b	–	
Average	2.22		2.81		3.63	
l.s.d. ($P = 0.05$)	0.592		0.66		0.603	

Numbers in the same column sharing a common letter are not significantly different.

In experiment 3 (plant population) the VL density treatment had the lowest lodging score with an average of 2.65 and was statistically similar in lodging with the L density treatment (Table 7). The VH density treatment had the highest lodging score with an average of 4.77 and was significantly higher in lodging than all other density treatments. A significant trend was observed with the incidence of lodging increasing as plant density increased.

Sowing date also affected lodging with higher scores observed for SD2 – 26 April (2.62) compared with SD1 – 5 April (1.82) (data not shown). The reduced lodging at the earlier sowing date could, in part, be due to more advanced crops having better developed root systems and sturdier stems.

In experiment 2 (N management), lodging increased as N rates increased. The VL treatment (150 kg N/ha) had the lowest lodging score averaging 1.34, which was significantly lower than all other N treatments (Table 6). The H treatment (300 kg N/ha) had the highest lodging score with an average of 4.31 and was significantly higher than all other N treatments. A significant trend was observed with the incidence of lodging increasing as the N rate increased.

Summary

The 2016 irrigated canola experiments at Leeton Field Station demonstrated that varietal selection was one of the key drivers of yield potential in the Murrumbidgee Valley. Of the currently released varieties, Pioneer® 45Y88 (CL), Nuseed Diamond and Pioneer® 45Y25 (RR) achieved yields close to, or above 4 t/ha in each of the three experiments. The TT varieties of ATR Bonito$^{(\phi)}$, ATR Gem$^{(\phi)}$ and Hyola® 559TT were generally the lowest yielding varieties across the three experiments.

The highest yielding varieties (Pioneer® 45Y88 (CL), Nuseed Diamond and Pioneer® 45Y25 (RR)) demonstrated more resistance to lodging than the lower yielding varieties (ATR Bonito$^{\Phi}$, ATR Gem$^{\Phi}$ and Hyola® 559TT).

Sowing date, plant population and N rate all influenced lodging potential. Crop lodging increased with plant populations above 35 plants/m^2, N rates above 150 kg N/ha and for SD2 (26 April).

In combination with variety, sowing date was an important factor in maximising yield potential. Planting early in the sowing window (5 April) resulted in higher grain yields for most varieties.

Grain yield potential increased by 11% with increasing N fertiliser application from 150 kg N/ha to 250 kg N/ha. No differences in yield occurred between 200 kg N/ha and 300 kg N/ha.

Plant population maximised grain yield when populations were within the 35 plants/m^2 to 56 plants/m^2 range, with yield penalties for plant stands that were either too high (68 plants/m^2) or too low (18 plants/m^2).

The sowing date and N application rate both had a significant effect on grain oil content. The average oil content declined with the delay in sowing time, and also declined with every increase in N application.

These experiments demonstrate that canola grain yields above the targeted 4 t/ha can be achieved through correct varietal selection in conjunction with optimum sowing date, rate of N fertiliser and plant population.

Acknowledgements

The 'Southern irrigated cereal and canola varieties achieving target yields' project, DAN00198, 2014–17, with joint investment by GRDC and NSW DPI.

The support of Gabby Napier and Michael Hately with field assessments and data collection is greatly acknowledged.

Targeting maximum yields of irrigated wheat in southern NSW

Tony Napier, Daniel Johnston and Glenn Morris (NSW DPI, Yanco); **Dr Neroli Graham** (NSW DPI, Tamworth); **Cynthia Podmore, Luke Gaynor and Deb Slinger** (NSW DPI, Wagga Wagga)

Key findings

- Correct varietal selection and optimal agronomic management can result in irrigated wheat yields of over 10 t/ha.
- LongReach Cobra$^{\phi}$, LongReach Trojan$^{\phi}$ and Beckom$^{\phi}$ were the highest yielding varieties.
- Delaying nitrogen fertiliser application by applying the greatest amount at booting was shown to improve grain protein concentration and reduce lodging compared with applying more nitrogen at sowing.
- A plant population of 120 plants/m^2 was shown to yield more than higher plant populations whilst also minimising lodging.

Introduction

High-yielding irrigated wheat production depends on appropriate varietal selection for a given environment and tactical agronomic management. Experimental results from the 'Southern irrigated cereal and canola varieties achieving target yields' project in 2014 and 2015 demonstrated that the appropriate combination of variety and agronomic management can result in grain yields of over 10 t/ha in the Murrumbidgee and Murray valleys. Nitrogen management and plant population were also shown to affect yield, grain quality and lodging in these earlier experiments.

The third year of experiments for this project was conducted in the winter growing season of 2016 and results are reported in this paper.

Site details

Site 1	Location	Coleambally
	Experimental design	Randomised complete block design Variety (12) × plant population (4) × 3 reps
	Sowing date	4 May 2016
	Irrigation schedule	No irrigation applied
	Rainfall	Autumn: 97 mm Winter: 191 mm Spring: 167 mm Total: 457 mm (4.6 ML/ha)
	Base fertiliser	MAP 200 kg/ha
	Herbicides	MCPA 1.25 L/ha Lontrel™ 70 mL/ha
	Fungicides	Orius® 150 mL/ha
	Harvest date	2 December 2016
Site 2	Location	Finley
	Experimental design	Randomised complete block design Variety (12) × nitrogen management (4) × 3 reps
	Sowing date	3 May 2016

Irrigation schedule	One spring irrigation (29 October 2016) Total 0.8 ML/ha
Rainfall	Autumn: 80 mm Winter: 189 mm Spring: 178 mm Total: 447 mm (4.5 ML/ha)
Base fertiliser	MAP 150 kg/ha
Herbicides	Boxer Gold 2.0 L/ha Axial 300 mL/ha + Adigor® 500 mL/100 L water LVE MCPA 1.8 L/ha
Fungicide	Prosaro® 200 mL/ha (two applications)
Harvest date	12 December 2016

Treatments

Irrigated wheat experiments were conducted in southern NSW at Coleambally in the Murrumbidgee Valley and Finley in the Murray Valley. The experiment at Coleambally evaluated the effect of variety and plant population on yield and grain quality (tables 1 and 2), whilst the Finley experiment evaluated the effect of variety and nitrogen (N) timing on yield and grain quality (tables 1 and 3).

Harvest was conducted using a Kingaroy small plot harvester. Subsamples of the harvested grain were used to measure grain quality including screenings, grain protein and test weight. Grain yield and protein content were calculated at 12% grain moisture. Lodging assessments were conducted using a score of 0–9 with 0 indicating no lodging and 9 indicating the plants were flat on the ground. Individual experiments were analysed with Genstat 18th edition (VSN International 2015) using a spatial model.

Table 1. Varieties evaluated in the irrigated wheat experiments at Coleambally and Finley in 2016.

Varieties	
Coleambally	**Finley**
Suntop$^{\phi}$	Suntop$^{\phi}$
Corack$^{\phi}$	Corack$^{\phi}$
LongReach Cobra$^{\phi}$	LongReach Cobra$^{\phi}$
Kiora$^{\phi}$	Kiora$^{\phi}$
Wallup$^{\phi}$	Wallup$^{\phi}$
Chara$^{\phi}$	Chara$^{\phi}$
280913 (durum line)	280913 (durum line)
LongReach Lancer$^{\phi}$	LongReach Lancer$^{\phi}$
EGA Bellaroi$^{\phi}$	EGA Bellaroi$^{\phi}$
LongReach Trojan$^{\phi}$	LongReach Trojan$^{\phi}$
Mace$^{\phi}$	Beckom$^{\phi}$
EGA Gregory$^{\phi}$	DS Darwin$^{\phi}$

Table 2. Plant populations evaluated in the irrigated wheat experiment at Coleambally in 2016.

Target plant population
Very low: 80 plants/m^2
Low: 120 plants/m^2
Medium: 160 plants/m^2
High: 200 plants/m^2

Table 3. Nitrogen timing treatments evaluated in the irrigated wheat experiment at Finley in 2016.

Nitrogen treatment	Base (kg N/ha)	First node (kg N/ha)	Booting (kg N/ha)	Total (kg N/ha)
Early N	145	100	0	245
Late N 1	45	150	50	245
Late N 2	45	100	100	245
Late N 3	45	50	150	245

Results

Grain yield

There were significant ($P = 0.05$) differences between varieties for grain yield in the Coleambally and Finley experiments. The highest yielding variety at Coleambally was LongReach Cobra$^{\phi}$ (11.48 t/ha), which also yielded over 10 t/ha at Finley (Table 4). LongReach Trojan$^{\phi}$ was the second highest yielding variety in both experiments yielding 10.99 t/ha and 10.38 t/ha at Coleambally and Finley respectively (Table 4). Beckom$^{\phi}$ was the highest yielding variety at Finley (10.41 t/ha).

The advanced durum breeding line 280913 yielded lowest in both experiments with 7.67 t/ha at Coleambally and 3.53 t/ha at Finley. Lower yields were generally recorded at the Finley site. This could have been due to soil type, the effects of cold temperature events during anthesis, and possible increased crown rot infection due to wheat in the cropping rotation history.

Table 4. Grain yield (t/ha) and protein (%) of 14 wheat varieties evaluated in the irrigated wheat experiments at Coleambally and Finley in 2016.

Variety	Grain yield (t/ha)		Grain protein (%)	
	Coleambally	Finley	Coleambally	Finley
Durum				
280913	7.67	3.53	13.5	13.9
EGA Bellaroi	9.57	8.44	13.3	12.7
Bread				
Beckom	-	10.41	-	10.7
Chara	9.82	10.05	11.9	11.2
LongReach Cobra	11.48	10.10	12.0	11.9
Corack	9.66	8.06	12.3	12.7
DS Darwin	-	8.92	-	11.8
EGA Gregory	8.51	-	11.9	-
Kiora	9.17	10.01	11.9	11.0
LongReach Lancer	10.09	9.70	12.1	11.2
LongReach Trojan	10.99	10.38	11.4	10.8
Mace	9.56	-	12.5	-
Suntop	10.04	9.49	11.6	11.2
Wallup	9.42	7.97	13.0	13.3
Average	9.67	8.92	11.3	11.0
l.s.d. ($P = 0.05$)	0.24	0.46	0.2	0.3

High plant populations of 160 and 200 plants/m^2 had a lower grain yield compared with lower plant populations of 80 and 120 plants/m^2 (Table 5). There was also a significant ($P = 0.05$) interaction between variety and plant population in 2016.

LongReach Cobra$^{\phi}$, Corack$^{\phi}$, EGA Bellaroi$^{\phi}$, Mace$^{\phi}$ and EGA Gregory$^{\phi}$ all had significantly higher yields at the very low or low populations compared with the high population. LongReach Lancer$^{\phi}$ was the only variety that had a significantly lower yield from the very low population compared with the high population.

Differing responses to plant population and variety might have been due to differences in crop architecture and plant structure.

Table 5. Plant population treatments evaluated in the irrigated wheat experiment at Coleambally in 2016.

Plant population	Grain yield (t/ha)	Grain protein (%)	Screenings (%)	Lodging (Score 0–9)
Very low	9.71	12.24	4.03	1.71
Low	9.74	12.27	3.61	1.94
Medium	9.61	12.36	3.62	2.50
High	9.59	12.3	3.34	2.62
l.s.d. ($P = 0.05$)	0.14	n.a.	n.a.	0.39

Grain quality

Variety had a significant ($P = 0.05$) effect on grain protein content, screenings and test weight in both experiments. The advanced durum breeding line 280913 had high grain protein concentration in both experiments, 13.5% at Coleambally and 13.9% at Finley (Table 4). Other varieties that accumulated high protein concentrations were Wallup$^{\phi}$ and EGA Bellaroi$^{\phi}$. Beckom$^{\phi}$ had the lowest grain protein content at Finley with 10.7% (Table 4), however, it had the highest grain yield.

Grain protein concentration was higher when the bulk of the N application was delayed. The average grain protein content was 12.2% when the majority of N was applied at booting compared with 11.6% when the majority was applied at sowing. Grain protein concentration did not differ when plant population varied between 80 plants/m^2 and 200 plants/m^2.

Screenings ranged from 1.7% to 8.4% (average of 5.1%) in the Finley experiment compared with a range of 1.4% to 5.6% (average of 3.6%) in the Coleambally experiment (Table 6). There was a significant ($P = 0.05$) effect of variety in both experiments. Wallup$^{\phi}$ had the lowest screenings in both experiments with 1.7% at Finley and 1.4% at Coleambally (Table 6). Other varieties with low screenings included the advanced durum breeding line 280913, Mace$^{\phi}$ and LongReach Trojan$^{\phi}$. LongReach Lancer$^{\phi}$ had the highest screenings at Finley (8.4%) and Coleambally (4.9%). Chara$^{\phi}$ and Suntop$^{\phi}$ also had relatively high screenings (Table 6).

Table 6. Grain quality and lodging of 14 wheat varieties evaluated in the irrigated wheat experiments at Coleambally and Finley in 2016.

Variety	Screenings (%)		Test weight (kg/hL)		Lodging (score 0–9)	
	Coleambally	Finley	Coleambally	Finley	Coleambally	Finley
Durum						
280913	2.4	3.4	82.1	78.0	1.7	0.7
EGA Bellaroi	3.5	5.0	83.5	83.5	2.4	0.8
Bread						
Beckom	-	5.9	-	85.7		3.7
Chara	4.1	6.8	84.9	85.0	2.2	4.6
Corack	3.2	4.0	85.0	85.0	1.9	2.0
DS Darwin	-	5.8	-	86.2		3.8
EGA Gregory	4.8	-	84.6	-	3.2	
Kiora	5.6	4.7	84.9	86.0	2.0	4.4
LongReach Cobra	3.6	5.2	85.2	86.3	2.1	3.6
LongReach Lancer	4.9	8.4	86.4	86.1	2.3	4.6
LongReach Trojan	3.2	3.7	86.2	86.7	1.5	3.1
Mace	2.8	-	84.5	-	2.3	
Suntop	3.8	6.0	85.6	85.5	2.1	3.6
Wallup	1.4	1.7	85.4	83.4	2.5	3.7
Average	3.6	5.1	84.8	84.6	2.2	3.2
l.s.d. ($P = 0.05$)	1.0	1.1	1.3	0.9	0.7	0.7

Test weights at both Coleambally and Finley were above the minimum Grain Traders Association (GTA) receival standard of 76.0 kg/hL. LongReach Trojan$^{\phi}$ (86.2 and 86.7 kg/hL), LongReach Lancer$^{\phi}$ (86.4 and 86.2 kg/hL) and DS Darwin$^{\phi}$ (86.2 kg/hL) had the highest test weights in both experiments (Table 6). The advanced durum breeding line 280913 had the lowest test weight with 82.1 kg/hL and 78.1 kg/hL at Coleambally and Finley respectively (Table 6). Plant population at Coleambally and N treatments at Finley had no significant effect on screenings or test weight.

Lodging

Lodging was affected by variety, plant population and N management. Lodging was slightly higher at the Finley experiment with an average lodging score of 3.2 compared with 2.2 at the Coleambally site (Table 6). EGA Gregory$^{\phi}$ had a lodging score of 3.2, the highest at Coleambally; Coleambally was a low lodging site. LongReach Lancer$^{\phi}$, Chara$^{\phi}$ and Kiora$^{\phi}$ had high lodging scores, over 4.0, at Finley (Table 6). The advanced durum breeding line 280913 and Corack$^{\phi}$ had high tolerance to lodging with low lodging scores in both experiments (Table 6).

Lodging severity increased as the plant population increased ($P = 0.05$). Plant populations of 80 plants/m^2 and 120 plants/m^2 had significantly lower lodging than plant populations of 160 plants/m^2 and 200 plants/m^2.

Timing of N application also significantly affected lodging severity. When the majority of N was applied at sowing, the lodging score was 3.7, which was significantly higher than the lodging score of 2.9 when applying the majority of the N was delayed until the booting stage.

Summary

Variety selection was a key driver of yield in both experiments, reinforcing previous findings. The varieties LongReach Cobra$^{\phi}$ and LongReach Trojan$^{\phi}$ achieved grain yields above 10 t/ha at both sites.

Grain yield was also influenced by varietal plant population interactions, with LongReach Lancer$^{\phi}$ achieving a higher yield at higher plant populations, contrasting with Mace$^{\phi}$, Corack$^{\phi}$ EGA Gregory$^{\phi}$, EGA Bellaroi$^{\phi}$, and LongReach Cobra$^{\phi}$, all of which yielded higher at lower plant populations. Overall, grain yield increased as plant population decreased from over 200 plants/m^2 to 120 plants/m^2.

Grain protein concentration increased as N application was delayed due to applied N being mobilised into the grain rather than plant biomass. Screenings were higher at Finley than Coleambally, with several varieties having high screenings that could influence varietal selection.

Lodging was affected by variety, plant population and N management. EGA Gregory$^{\phi}$ was susceptible to lodging whilst Corack$^{\phi}$ was the most resistant variety. Lodging levels were lower as plant population reduced and the majority of N fertiliser was applied later in the growing season.

Variety selection should be based on yield potential, current farming system, crop rotation and pest and disease risk at individual properties. The maximum yield potential of varieties can be achieved through managing N application and plant population. Applying N fertiliser at booting can increase grain protein whilst reducing lodging which, in conjunction with plant populations of approximately 120 plants/m^2, maximised high yields and reduced lodging potential.

Acknowledgements

The ‘Southern irrigated cereal and canola varieties achieving target yields’ project, DAN00198, 2014–17, with joint investment by GRDC and NSW DPI .

We would like to acknowledge the Bellato and Lang families for allowing us to conduct the experiments on their properties and the support of Gabby Napier and Michael Hately with field assessments and data collection.

Benchmarking cotton productivity

Dr Iain Hume and Beverley Orchard (NSW DPI, Wagga Wagga); **Dr Janelle Montgomery** (Cotton Seed Distributors, Gwydir); **Robert Hoogers** (NSW DPI, Yanco)

Key findings

- Water use can be estimated easily with the (IrriSAT 2017) app.
- First flower, cut out and defoliation can be predicted.
- Cotton water productivity could be up to six bales per hectare below its potential.

Introduction

Water use efficiency is a key measure of cotton productivity (Boyce 2015). Crop water use is difficult to measure, but can be estimated using a web-based app (IrriSAT 2017). This app was developed for weather-based irrigation scheduling using a crop coefficient (Kc) estimated from satellite observations and reference crop evapotranspiration (ETo) estimated from scientific information for landowners (SILO) grids (Jeffery et al. 2001) Whole water use of cotton fields from the Murray Valley to Central Queensland was estimated for the 2014–15 and 2015–16 seasons.

Method

Modelling Kc from remotely sensed data

Estimating transpiration from satellite observations

The crop coefficient (Kc) is the ratio of crop evapotranspiration (ETc) to reference crop evapotranspiration (ETo) (Doorenbos & Pruitt 1977). ETo can be estimated from meteorological data; the Bureau of Meteorology has adopted the Penmann–Monteith equation (Monteith & Unsworth 1990) to calculate ETo. The normalised difference vegetation index (NDVI) can be used to estimate Kc using a linear relationship $Kc = 1.37 \times NDVI - 0.086$ (Trout, Johnson & Gartung 2008). The NDVI can be measured by satellite.

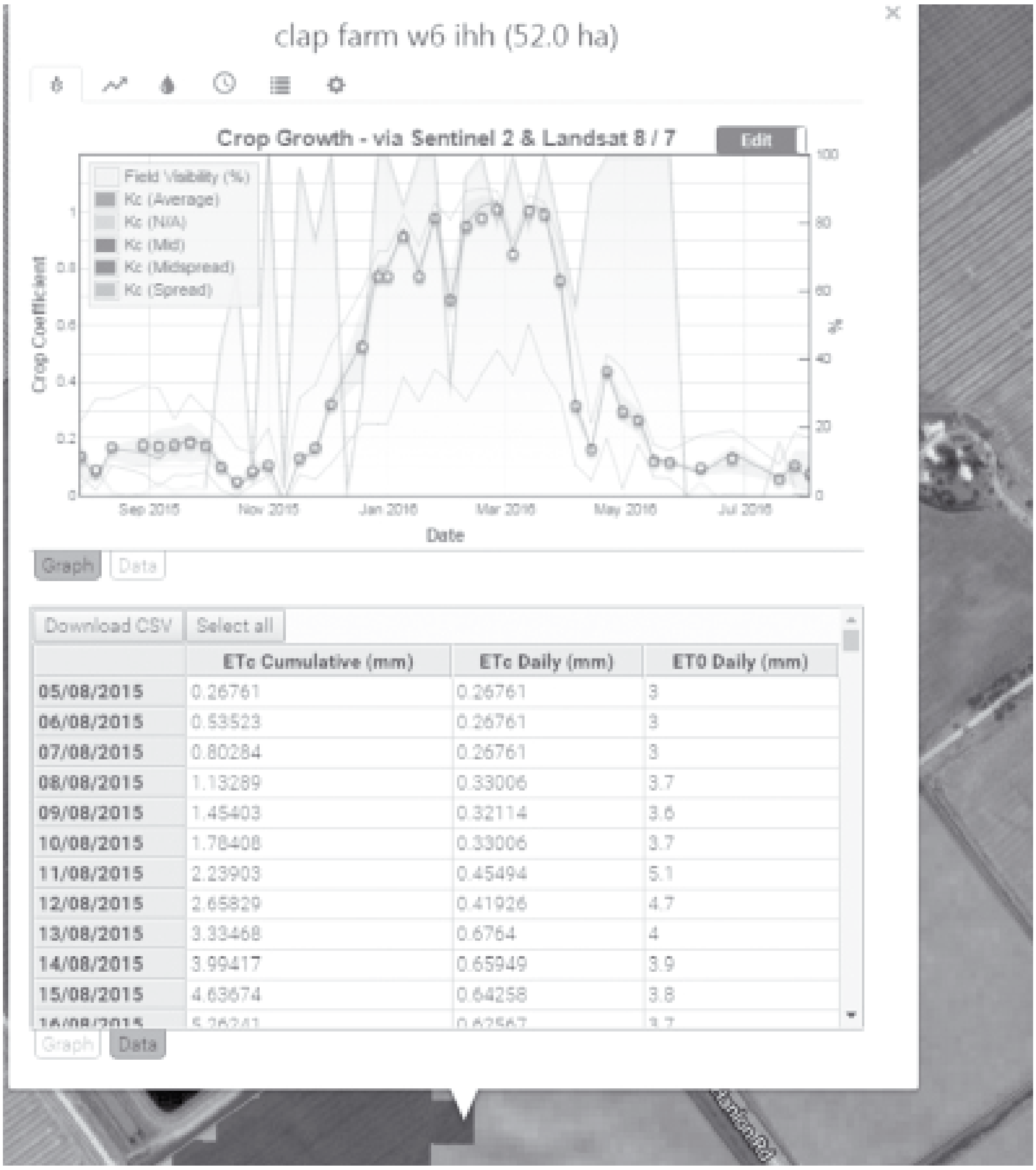
This study uses the NDVI of one or more of three satellites (Landsat 7, Landsat 8 or Sentinel 2). Mosaics of these data are produced in eight-day periods. The value of NDVI assigned to each mosaic was assumed to be observed on the first day of the observation window. The time series of these mosaics begins on 1 January each calendar year. When an observation window straddles the change of year, the same observations are used in the last window of the old year and the first period of the new year. Mosaics were populated in the following order:

1. Obtain cloud-free Sentinel 2 data
2. Obtain cloud-free Landsat 8 data
3. Obtain cloud-free Landsat 7 data.

Each mosaic could be a mix of two spatial resolutions: 10 m for the Sentinel 2 instrument and 30 m for the Landsat instruments. These satellites also have different spectral resolutions; the Sentinel 2 and Landsat 8 observe in similar spectral bands, while the spectral bands of the Landsat 7 instrument have different bandwidths.

Data acquisition

The satellite data is delivered as .csv files via a Google Earth engine interface and app (IrriSAT 2017). Fields of interest were drawn as polygons in the app or uploaded as .kml files (Figure 1). The Google Earth Engine App develops a time series of observations – one for each eight-day window. These observations are assumed to occur on the first day of each window. Each observation consisted of the percentage of the polygon visible to the satellite(s), the area-weighted minimum, mean and maximum Kc, and the lower and upper quartiles and median Kc of those visible polygons. The app also accesses reference crop evapotranspiration (ETo) from the BOM SILO grids (Jeffrey et al. 2001) and calculates crop evapotranspiration (ETc) $ETc = Kc \times ETo$.



	ETc Cumulative (mm)	ETc Daily (mm)	ET0 Daily (mm)
05/08/2015	0.26761	0.26761	3
06/08/2015	0.53523	0.26761	3
07/08/2015	0.80284	0.26761	3
08/08/2015	1.13289	0.33006	3.7
09/08/2015	1.45403	0.32114	3.6
10/08/2015	1.78408	0.33006	3.7
11/08/2015	2.23903	0.45494	5.1
12/08/2015	2.65829	0.41926	4.7
13/08/2015	3.33468	0.6764	4
14/08/2015	3.99417	0.65949	3.9
15/08/2015	4.63674	0.64258	3.8
16/08/2015	5.26241	0.62567	3.7

Figure 1. The IrriSAT app interface showing the eight-day time series of Kc in the upper window, and the daily time series of ETo and ETc in the lower window. Polygons of cotton fields can be seen in the background.

Processing the Kc time series

The raw Kc data suffers cloud contamination, which depresses the NDVI and Kc (see top panel of Figure 1). This contamination was removed from the time series of mean Kc values by fitting cubic smoothing splines (Verbyla et al. 1999) and accepting Kc values that lie between the upper 95% confidence interval for the upper quartile and the lower 95% confidence interval of the lower quartile for model fitting. Gompertz 4 parameter growth curves (Equation 1) were then fitted to the left (LHS) and right (RHS) hand sides of the Kc time series using nonlinear least squares regression in the R software package (Bates & Chambers 1992).

$$Kc = A + Ce^{-e^{-B(X-M)}} \qquad \text{Constraint : } C<0 \qquad \text{Equation 1}$$

Fitting splines and Gompertz (4 parameter) curves

A cubic smoothing spline was fitted to retained mean Kc observations using the asreml-R software package (Butler et al. 2009). The maximum turning point of the mean level spline was determined and the day on which this occurred was used as an initial estimate of when the LHS and RHS joined and was termed the division date. An initial fit of LHS and RHS Gompertz curves was made with upper asymptotes *A* constrained to be equal. Using the initial division date as a starting point, an iterative routine was used to refit the RHS and LHS Gompertz curves. This routine used the day corresponding to the midpoint of the days on which the upper LHS 4th derivative and the upper RHS 4th derivatives of the Gompertz curves were zero as the division date. The routine ran until convergence was achieved, measured by the change in division date of <0.1 days.

Curve fitting

Spline fitting might produce a better estimate of water transpired. However, properties of the Gompertz curve as determined by Calculus can be related to crop phenology, crop management and characteristics of the growing season. As LHS and RHS Gompertz curves were only constrained by the upper asymptote being equal, but otherwise unconstrained, non-symmetrical curves could be fitted to the growing season data to better reflect seasonal change and crop management.

Daily values of Kc were predicted from the curve. Days on which the second, third and fourth derivatives of the curves were equal to zero were calculated. These correspond to the inflexion points (or the day on which there is a maximum rate of change of Kc), the day on which the rate of change of the acceleration is zero, and the day on which the maximum rate of change of the acceleration occurs respectively. These values, along with the curve parameters, were used to characterise and compare Kc curves (see Figure 2).

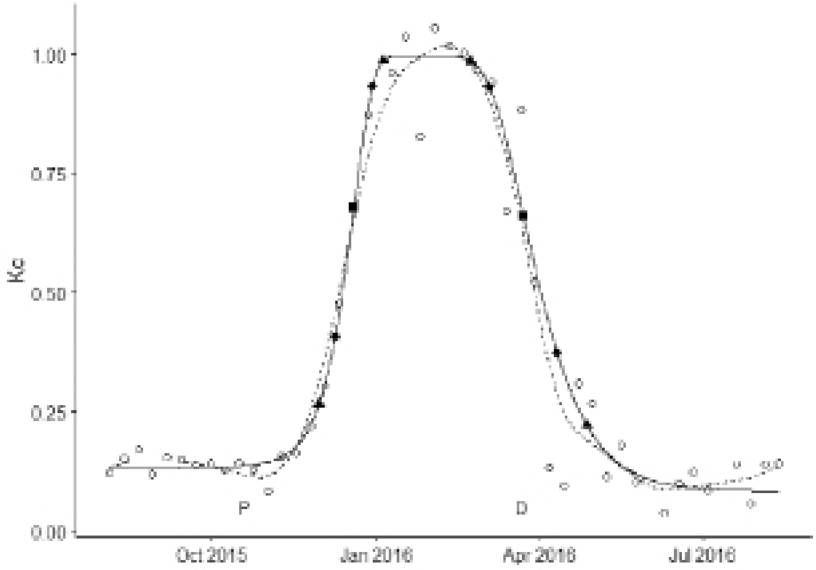


Figure 2. The time series of Kc of one cotton crop. The spline is shown as a dashed line and the fitted curve as a solid line. The curve's inflexion points (■), and where the third (■) and fourth (▲) derivatives equal zero are shown, as are the dates when the crop was planted (P) and defoliated (D).

Crop transpiration

The quantity of water transpired each day was calculated as the product of the Kc value predicted by the curves and the daily ETo extracted from the SILO gridded data (Jeffrey et al. 2001) by the IrriSAT app. These values were summed to obtain an estimate of the total amount of transpiration over various time periods during the crop season.

Field data

Fields were targeted where agronomic and irrigation data were being collected. These field data were provided by:

- Cotton Seeds Distributors (CSD) from their ambassador program for the 2014–15 and 2015–16 seasons
- two commercial cotton consultants for some of their clients for the 2015–16 growing season
- Gwydir Valley Irrigators Association (GVIA) from a trial of four irrigation methods that were tested over four seasons between 2009–10 and 2015–16 on one farm.

Key agronomic data are:

- the dates of planting
- first flower

- ‘cutout’
- defoliation and picking
- crop yield
- any hail or chemical damage.

Key hydrologic data are:

- quantities of irrigation
- in-season rainfall
- effective rainfall.

Not all data was available for all fields, the CSD data set was the most comprehensive.

Results

Ability to predict key agronomic events

The CSD data measured all the key agronomic and hydrologic parameters. They were able to predict key agronomic events with an accuracy of ±7 days (Table 1). This is a remarkable result given that the satellite data can be observed at any time within an eight-day window.

Table 1. The ability of fitted curve parameters to predict agronomic events, measured by the R^2 of the linear model between the predictor and the event and the standard error of the mean (SEM) of the prediction, the accuracy with which the mean of the event is predicted.

Event	2014–15			2015–16		
	Predictor	R^2	SEM	Predictor	R^2	SEM
First flower	Inflexion Pt LHS	63.3	7.37	3rd derivative (= 0) Upper LHS	71.7	7.07
Cutout	Divide	54.4	7.88	Divide	65.4	8.82
Defoliation	3rd derivative (= 0) Lower RHS	82.5	6.34	Inflexion point RHS	76.6	7.20
Picking	4th derivative (= 0) Lower RHS	75.0	10.20	4th derivative (= 0) Lower RHS	24.3	18.70

Benchmarking

Productivity variation

A large range in crop water use and yield was observed over five cotton seasons (Figure 3). The yield for a given amount of water used varied greatly and, at the extreme, the range in yield could be as wide as 12 bales/ha. This variation was present within the given years, with the 2015–16 season being the most variable (Table 2).

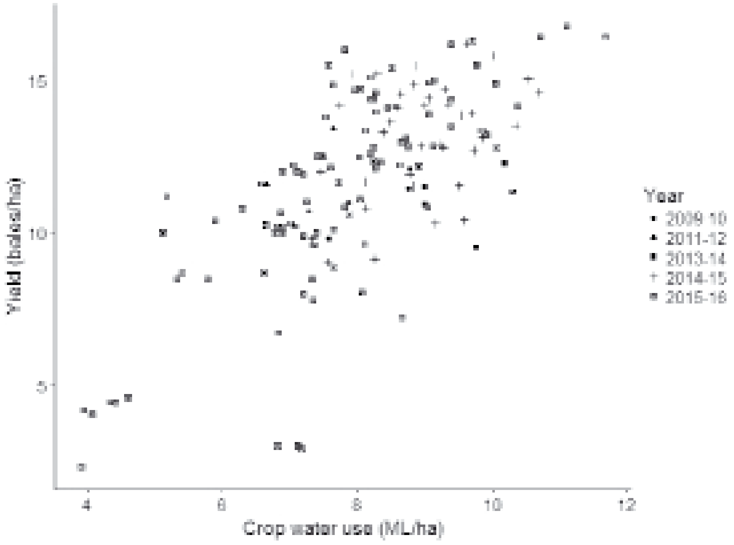


Figure 3. The variation in yield and crop water use over five cotton seasons.

Table 2. The mean and coefficient of variation (CV) yield and crop water use in six different seasons.

Season	Yield (bales/ha)		Crop water use (ML/ha)	
	Mean	CV	Mean	CV
2009–10	11.09	8.8	8.250	7.5
2011–12	12.05	9.7	7.270	6.0
2013–14	11.05	10.5	9.498	6.1
2014–15	13.07	14.9	8.965	9.5
2015–16	11.34	30.1	7.737	20.2

Industry patterns

The group of CSD fields are assumed to represent the range of productivity present in the Australian cotton industry. There were no statistical differences in the productivity or water use between 2014–15 and 2015–16. There were trends to lower production and less water use in 2015–16, however, this lower production occurred at marginally higher water use efficiency (Table 3).

Table 3. The median productivity and coefficient of variation (CV) of the CSD sites.

Season	Yield (bales/ha)		Crop water use (ML/ha)		Water use efficiency (bales/ML)	
	Med	CV	Med	CV	Med	CV
2014–15	13.52	14.9	8.97	9.5	1.437	14.21
2015–16	12.98	19.7	8.64	14.9	1.489	15.02

Regional patterns

None of the differences observed in the water use efficiency between 2014–15 and 2015–16 were statistically significant. There was a trend to increased water use efficiency in all regions during the 2015–16 season, except in Central Queensland (CQ) (Figure 4).

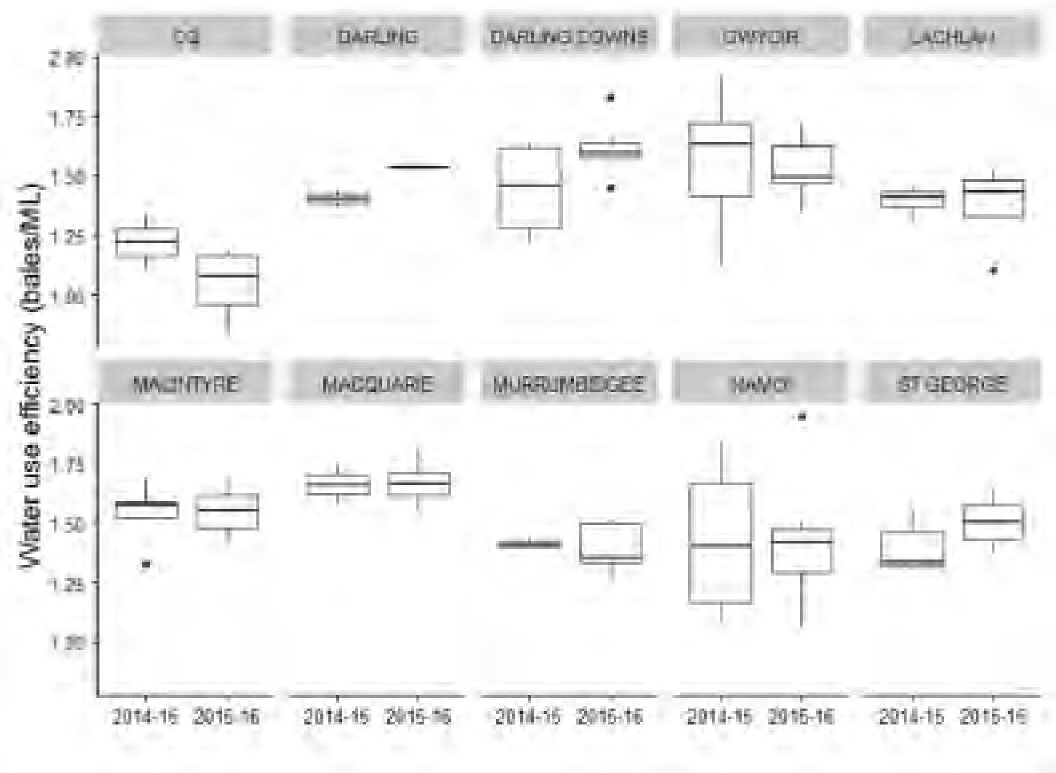


Figure 4. Regional water use efficiency over two seasons of CSD data in ten regions.

Water use efficiency of different groups on the Darling Downs

Irrigated cotton crops in the 2015–16 cotton season from the CSD data base, along with those of the clients of a consultant were compared. Only fields that did not suffer hail or herbicide damage were used in this comparison (Figure 5). The water use efficiency of the CSD fields was in the highest quantile of the whole CSD data set and had low variability. The water use efficiency of the consultant's client's fields was statistically similar, but had a wider range than the CSD fields. The consultant group contained both the most and least water-efficient crops.

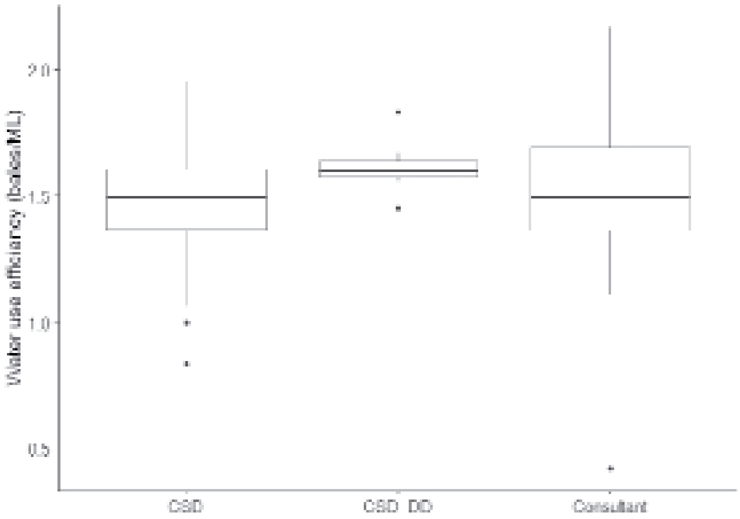


Figure 5. Water use efficiency on the Darling Downs during the 2015–16 cotton season. The range in water use efficiency of CSD ambassador fields in all regions (CSD), a subset of CSD Ambassador fields on the Darling Downs (CSD_DD) and those of a private consultant are shown.

Irrigation systems trial

There were significant differences between the water use efficiency in different years; 2011–12 and 2015–16 were more efficient than 2009–10 and 2013–14 (Figure 6). The irrigation systems had no measurable effect on the water use efficiency in a given year.

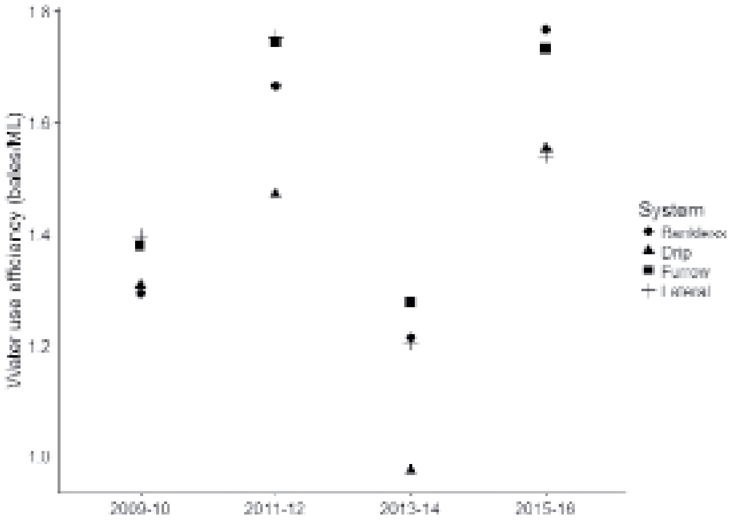


Figure 6. The water use efficiency of four irrigation systems over four irrigation seasons. These were tested on one farm in the Namoi Valley.

Summary

This study highlighted the efficiency with which data can be collected using modern, cloud-based technology, (IrriSAT 2017).

Our methods identify typical crop coefficient (Kc) curves for different regions and years. It might be possible to anchor these curves to different agronomic events (first flower, cutout and defoliation) and so allow the operational prediction of Kc and water use late in the season where irrigation management decisions are crucial and difficult.

The data sets we analysed are small, but highlight the potential of these new methods to produce metrics that allow comparative analysis both within years and between years. The most striking finding of this study was that cotton water productivity could be six bales/ha below its potential.

The work reported here shows the potential of these benchmark metrics. A time series of data for the extent of the cotton growing regions over a number of seasons is required to realise this potential. An extensive water productivity benchmarking system will need to engage on-ground collectors and custodians of agronomic data; agronomic consultants and cotton gins are the most likely candidates.

References

Bates DM & Chambers JM (1992). Nonlinear models. Chapter 10. *Statistical Models in S*. (Eds) J M Chambers and TJ Hastie. Wadsworth & Brooks/Cole, Pacific Grove, California.

Boyce Chartered Accountants (2015). Australian Cotton Comparative Analysis. Cotton Research and Development Corporation. http://www.boyceca.com/boyce-newsfeed/2015-australian-cotton-crop-analysis-released. Downloaded on 6 June 2017.

Butler D, Cullis BR, Gilmore AR & Gogel BJ (2009). *ASReml-R reference manual*, Version 3. Queensland Department of Primary Industies and Fisheries.

Doorenbos J & Pruitt WO (1977). Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24: *Crop water requirements*. Food and Agriculture Organization of the United Nations, Rome.

IrriSAT. (2017). IrriSAT, a cloud-based applicaton. Downloaded on 21 March 2017 from https://irrisat-cloud.appspot.com.

Jeffrey SJ, Carter JO, Moodie KB & Beswick AR (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software* 16: 309–330.

Monteith JL & Unsworth MH (1990). *Principles of environmental physics*. 2nd Ed. Chapman and Hall, New York.

Trout, TJ, Johnson LF & Gartung J (2008). Remote sensing of canopy cover in horticultural crops. *Horticultural Science* 43(2): 333–337.

Verbyla AP, Cullis BR, Kenward MG & Welham SJ (1999). The analysis of designed experiments and longitudinal data by using smoothing splines. *Applied Statistics*. 48(3): 269–311.

Acknowledgements

This research was a joint investment by NSW DPI and Cotton Research and Development Corporation (Project DAN1505, 2014–19). We are grateful to Cotton Seed Distributors Ltd. and Rob Boulton of Black Earth Agronomy for providing field data and mapping their fields into IrriSAT.

The influence of nitrogen fertiliser rate and irrigation management on crop nitrogen uptake, lint yield and apparent fertiliser recovery in sub-surface drip irrigated cotton

John Smith (NSW DPI, Yanco); **Dr Wendy Quayle** (Deakin University CeRRF, Griffith); **Carlos Ballester Lurbe** (Deakin University CeRRF, Griffith)

Key findings

- Nitrogen fertiliser management influences crop nitrogen uptake at defoliation and cotton lint yield.
- Irrigation management did not influence crop nitrogen uptake at defoliation, but significantly influenced cotton lint yield.
- The apparent nitrogen fertiliser recovery was 46% where the optimum fertiliser nitrogen rate was applied.
- Seed nitrogen concentration and nitrogen removal was influenced by nitrogen fertiliser application rate, but the effect was not consistent with rate.

Introduction

Cotton growers cannot afford to allow their cotton crop yields to be limited by nitrogen (N) deficiency (or other nutrients) and tend to manage this risk by over applying N fertiliser relative to the lint yield achieved (Rochester & Bange 2016). Analysing data from 147 irrigated commercial cotton crops over 2009–2014 revealed that 74% of the sites were considered to have over-applied N fertiliser (Smith et al. 2014). This assessment was based on the industry standard, nitrogen fertiliser use efficiency (NFUE) measure in which lint yield (kg/ha) is divided by applied N fertiliser (kg/ha) (Rochester 2011).

Irrigation opportunity time and soil type can have a substantial impact on the level of waterlogging, redox conditions and potential loss of N from the soil (Jamali, Quayle & Baldock 2015). However, information on the interaction of these is limited. The work described here was the first of its type undertaken in the cotton production area of southern NSW.

This research aimed to identify the impact of irrigation opportunity time and fertiliser N rates on fertiliser N response, lint yield and fertiliser N recovery in a sub-surface drip irrigation system.

Site details

Location	Whitton NSW (146°18'E, 35°54'S)
Soil type	Transitional red–brown earth
Previous crop	Cotton
Fertiliser planting date	25 September 2015
Cotton planting date	16 October 2015
Variety	Sicot 74BRF
Irrigation	The site was irrigated using a sub-surface drip irrigation system with the drip line placed approximately 300 mm below the soil surface in the middle of a 1.83 m bed. Normal practice is to water the cotton every day. After planting, siphon irrigation was used to water-up the crop. A second siphon irrigation was conducted at first flower to incorporate the nitrogen fertiliser that was spread on the field outside the experiment areas.
Harvest	3 rows × 2 m of row was hand harvested between 12–20 April 2016

Soil test results (0–30 cm)

Nitrate–N	7.9 mg/kg (0–30 cm)
P (colwell)	28.9 mg/kg
pH (water)	7.1
OC	6.4 g/kg
CEC	20.6 cmol/kg

Soil test results (30–90 cm)

Nitrate–N	6.2 mg/kg (30–90 cm)

Treatments

Structure

The field experiment was designed as a randomised split plot design with irrigation treatments as the main plots (six main plots) and N rate as the sub-plot. Nitrogen was sown in blocks of five N rates applied before planting the crop. Three of the main plots had four blocks of N rates and three had two blocks of N rates (Figure 1). This variation in N rate blocks within the irrigation treatment was done because of uncertainty at planting around the capacity of the irrigation system to be able to apply the desired irrigation treatment across so many valves. The blocks of N rates were used as replicates of the N treatments in the statistical analysis.

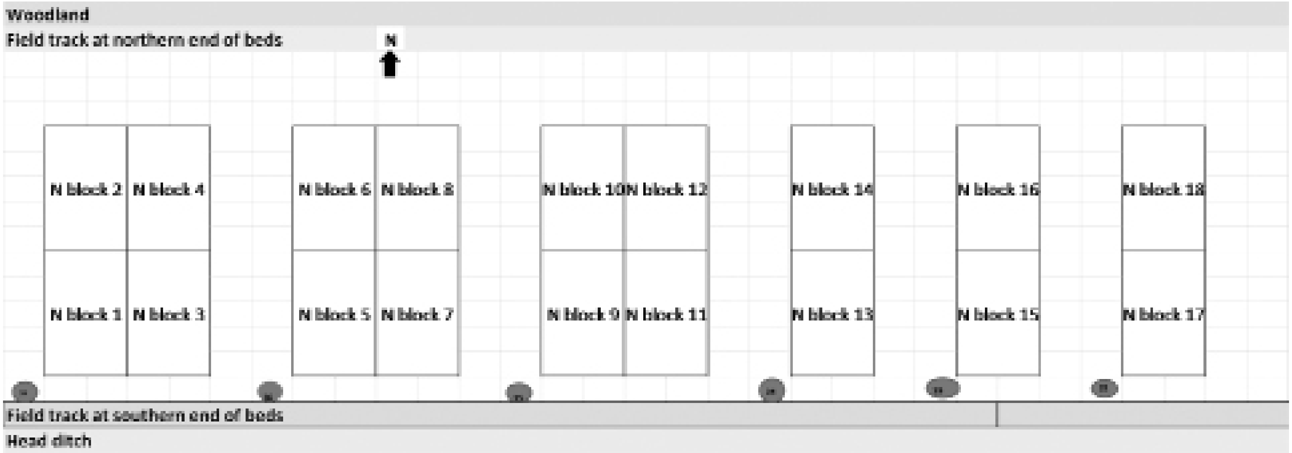


Figure 1. Field layout of the irrigation and nitrogen rate field experiment in cotton conducted at Whitton NSW in the 2015–16 cotton season. The circles represent the control valves of the sub-surface drip systems that controlled the irrigation treatment applied to each area. The nitrogen blocks consisted of five rates of nitrogen (0, 80, 100, 150, 250 kg N/ha) applied before planting.

Fertiliser and irrigation treatments

The two irrigation treatments applied were: irrigation every day (standard practice) and irrigation every second day. The irrigation control valves used to divide the fields into irrigation shifts were used to apply the irrigation treatments, based on the designed flow rate of the sub-surface drip irrigation system. The water was from an irrigation supply channel. The irrigation treatments were replicated three times across the field using six control valves in the field (Figure 1). The irrigation treatments were only imposed during the period from first flower to first cracked boll. Outside this period, the whole field was watered using the standard practice.

Five N fertiliser treatments were applied at 0, 80, 100, 150 and 250 kg N/ha. The N was applied as Anhydrous ammonia (82% N) approximately three weeks before planting of the cotton crop. No in-crop N applications were made to the experimental areas in the field.

Crop agronomy and measurements

Cotton was planted into beds on 90 cm row spacing with two rows per bed. Insect and weed control was managed by the farm consultants and carried out as needed. Plant growth regulators were used to control plant growth and provide a timely cut-out; the timing was based on decisions by the farm consultants. Above ground biomass was measured three times:

at first flower, first cracked boll and defoliation (within one week before the first defoliation spray being applied).

Nitrogen concentration of whole plants was calculated using the Dumas combustion method. Samples were collected by cutting one metre of plants along a row at the cotyledon node. The samples were then dried, weighed, mulched, ground and analysed. Crop N uptake was calculated by multiplying the N concentration (%) by the dry matter production (kg DM/ha). Apparent N fertiliser recovery (ANFR) was calculated by dividing the difference in crop N uptake between N-fertilised and unfertilised plots by the N fertiliser applied.

Crop N uptake was measured in the 0, 150 and 250 kg N/ha fertiliser N treatments at first flower and measured in the 0, 100, 150 and 250 kg N/ha fertiliser N treatments at defoliation. The internal nitrogen use efficiency (iNUE) was calculated using the formula; kg lint ÷ kg crop N uptake.

Lint yield was determined by hand picking 2 metres of three adjoining rows in each plot following the second chemical defoliation. Turn-out was determined by hand ginning a sub sample of the hand-picked seed-cotton. Nitrogen concentration of the cotton seed was determined using the Dumas combustion method to calculate seed N removal across the N rates.

Statistical analyses

Nitrogen uptake, lint yield and ANFR was analysed as an unbalanced two-way ANOVA test using GENSTAT 18.

The economic optimum N fertiliser rate and the N rate at maximum lint yield were estimated using the polynomial N fertiliser response curve. The economic optimum N fertiliser rate was defined as when the marginal cost of applying additional N fertiliser ($1.50/kg of N) equalled the marginal increase in returns from increased lint production ($2.20/kg) (Rochester & Bange 2016).

Results

Lint yield

Watering every second day produced a significantly (*P*<0.001) higher lint yield of 9.6 bales/ha than watering every second day, which produced 8.8 bales/ha. Applying N fertiliser significantly (*P*<0.001) increased lint yield from 7.4 bales/ha to a predicted maximum yield 10.13 bales/ha with 190 kg N/ha applied (Figure 2). The predicted economic optimum fertiliser N rate was 171 kg N/ha, producing a lint yield of 10.10 bales/ha.

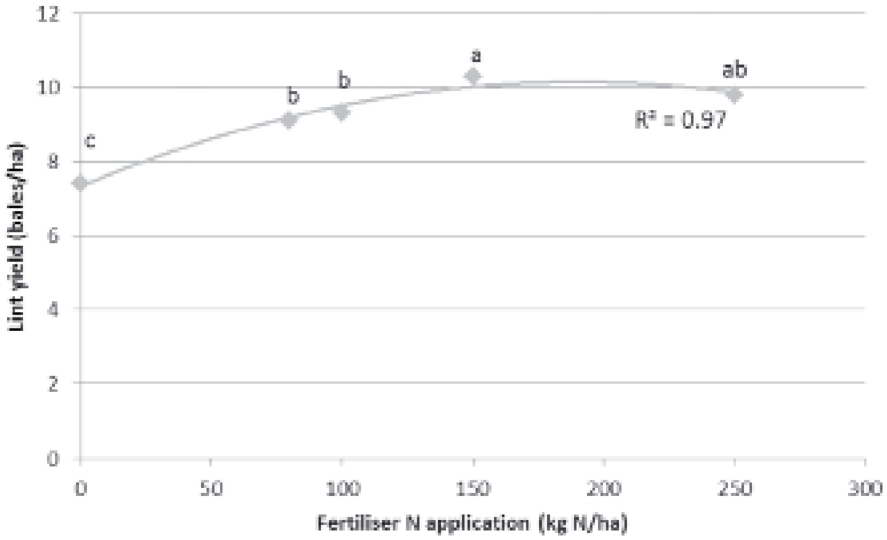


Figure 2. The response of cotton lint yield to applied nitrogen fertiliser.

The NFUE ranged from 25.8 at 80 kg N/ha to 8.9 at 250 kg N/ha. NFUE at the optimum N rate of 171 kg N/ha was 13.4.

Crop nitrogen uptake

Nitrogen rate had no significant effect on crop N uptake at first flower. The irrigation treatments had not been imposed before first flower and consequently no irrigation treatment effects on crop N uptake at first flower can be reported.

Irrigation management had no significant effect on crop N uptake at defoliation. Crop N uptake increased significantly ($P<0.001$) with increased N fertiliser application (Figure 3). There was no significant interaction between irrigation treatment and N application rate.

Crop N uptake was predicted to be 188 kg N/ha at the economic optimum N fertiliser rate of 171 kg N/ha. The difference between this amount and the crop N uptake from the unfertilised plots (109 kg N/ha) indicates that the deficit in soil supply of N was 79 kg N, which was met by fertiliser application.

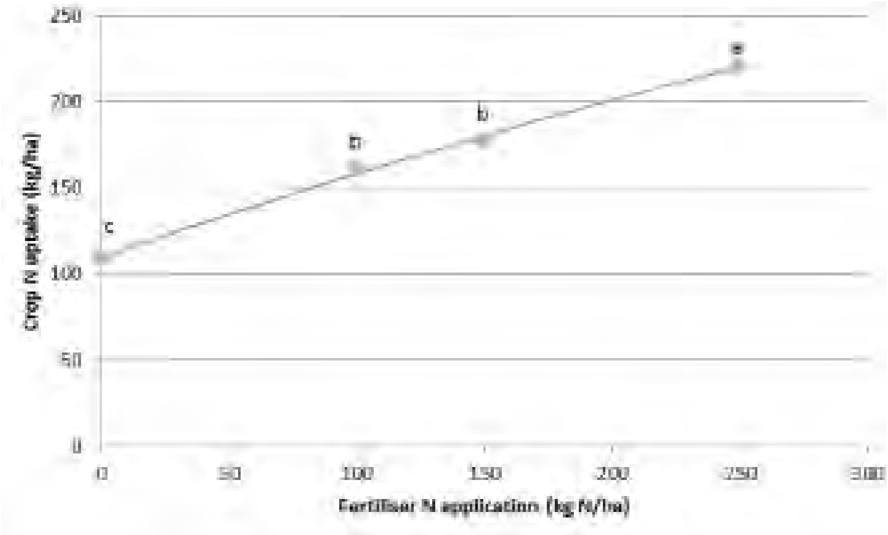


Figure 3. Crop N uptake response to fertiliser N application rates.

Irrigation treatment had no significant ($P = 0.05$) effect on iNUE. The iNUE declined ($P<0.001$) with higher N fertiliser rates ranging from 18.5 kg/kg with 0 N applied to 10.7 kg/kg when 250 kg N/ha was applied. The iNUE was 12.2 kg/kg at the predicted optimum fertiliser N rate.

Apparent nitrogen fertiliser recovery

The effects of irrigation treatment and N fertiliser rate on ANFR were not significant in this study. Across the range of N fertiliser rates from 100 to 250 kg N/ha, there was a declining trend of 60–48% ANFR, respectively.

The ANFR was 46% at the predicted optimum fertiliser N rate.

Seed N and N removal

Irrigation treatments had no significant ($P = 0.05$) effect on seed N concentration or N removal in seed. Applying N fertiliser significantly ($P = 0.001$) increased the amount of N removed in seed (Table 1).

Table 1. Comparison of seed N concentration with N fertiliser rate applied. Different letters within each column signify a significant difference between the N fertiliser rates that were applied.

N fertiliser rate (kg N/ha)	Seed N concentration (%)	N removal (kg N/ha)
0	3.8 b	68.8b
100	4.5ab	105.7a
150	4.9a	121.5a
250	4.6ab	114.2a

Discussion

Irrigation strategy

Lint yield was greater when water was applied every day compared with applying water every second day, suggesting that there was a period of moisture stress when water was applied every second day with the sub-surface drip irrigation system.

The irrigation strategy had no effect on crop N uptake or iNUE. No difference in crop N uptake suggests that there were similar levels of plant-available N even when there was more water applied when the crop was watered every second day. This highlights the benefit of drip irrigation systems where there is high irrigation efficiency (Burt et al. 2000) with minimal losses of water from deep drainage, thereby minimising any N leaching loss.

When water was applied every day, approximately 1.4 megalitres (ML) of water was applied during the treatment period compared with 1.7 ML when the water was applied every second day. Inappropriate or poor management of an irrigation system reduces water productivity by reducing yield and increasing water use. For example, Dunn et al. (2016) found a 55% reduction in water productivity in irrigated wheat when water was ponded for 48 hours during spring irrigation.

N fertiliser application

Lint yield, crop N uptake and iNUE were all influenced by the rate of applied N.

Crop N uptake increases with N fertiliser application (Rochester 2011), and high crop N uptake is required for high lint yields (Rochester & Bange 2016). The level of crop N uptake at the optimum N rate in this study (188 kg N/ha) is very similar to the 200–220 kg N/ha determined in commercial and experimental crops by Rochester (2011).

The iNUE at the optimum fertiliser N rate of this study (12.2 kg/kg) was within the optimum range established by Rochester (2011). More recently, it has been shown that cotton yields have increased in the order of 40% and crop N uptake has increased by approximately 140%, meaning that the ideal iNUE would have declined (Rochester & Bange 2016).

Apparent N fertiliser recovery

The ANFR when the optimum fertiliser was applied was 46%, but ranged between 60% and 48% across the N fertiliser rates in the present study. The ANFR at optimum fertiliser is consistent with that of Rochester and Bange (2016), which is higher that than of previous studies, but consistent with the increases in crop N uptake that have been recorded in recent crops.

Seed N and N removal

Seed N concentrations of 3.9% in the treatments where N was applied are higher than that considered adequate for the variety Sicot 74BRF (Rochester & Gordon 2014). Seed N was increased by N application, although the only significant differences were between the plots with no N applied and those with N applied.

A similar relationship existed between seed N and crop N uptake (data not shown) where there was a difference in the effect between the plots with no nitrogen and those with N applied. The relationship between seed N and crop N uptake shows some variability. Rochester (2012) was able to show a relationship suggesting it could be used as a measure of NUE. However, others have found that it is only effective in depicting deficiency (Malavolta et al. 2004), which is more consistent with the results here.

Although there was a continual increase in crop N uptake, the increased plant N was not translocated to the seed and N removal declined as applied N rates increased. It seems that more N remains in the vegetative parts of plant residues. Therefore, while N is not completely lost from the system, there is inefficient N use for lint production in the season of application. Nitrogen remaining in field residues is exposed to a greater risk of loss through mineralisation, denitrification and leaching.

References

Burt CM, Clemmens AJ, Bliesner R, Merriam JL & Hardy L (2000). *Selection of irrigation methods for agriculture*, ASCE, Reston, Virginia.

Dunn B, Dunn T, Hodges C & Dawe C (2016). Wheat - How many spring irrigations? *Farmers Newsletter*. Vol 194:18–21.

Jamali H, Quayle WC & Baldock J (2015). Reducing nitrous oxide emissions and nitrogen leaching losses from irrigated arable cropping in Australia through optimized irrigation scheduling. *Agricultural and Forest Meteorology*. Vol 208:32–9.

Malavolta E, Nogueira NGL, Heinrichs R, Higashi EN, Rodríguez V, Guerra E, de Oliveira SC & Cabral CP (2004). Evaluation of nutritional status of the cotton plant with respect to nitrogen. *Communications in Soil Science and Plant Analysis*. Vol 35, no. 7–8:1007–19.

Rochester IJ (2011). Assessing internal crop nitrogen use efficiency in high-yielding irrigated cotton. *Nutrient Cycling in Agroecosystems*. Vol 90, no. 1:147–56.

Rochester IJ (2012). Using seed nitrogen concentration to estimate crop N use-efficiency in high-yielding irrigated cotton. *Field Crops Research*. Vol 127:140–5.

Rochester IJ & Bange M (2016). Nitrogen fertiliser requirements of high-yielding irrigated transgenic cotton. *Crop and Pasture Science*. Vol 67, no. 6:641–648.

Rochester, IJ & Gordon, K (2014). Growing high-yielding nitrogen-efficient cotton. *17th Australian Cotton Conference, Our Fibre, Our Focus, Our Future*. Gold Coast, Queensland, Australia. http://www.crdc.com.au/sites/default/files/pdf/Cotton%20Conference%20-%20papers%20and%20e-summaries%20MR.pdf

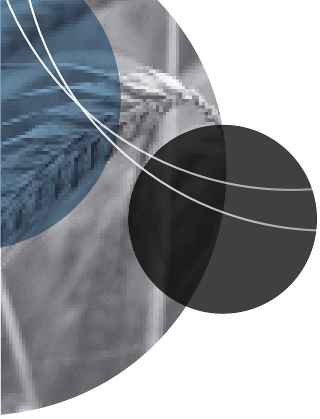
Smith J, Devlin A, Thomas A, Hunter G, O'Keeffe K, Dickinson S, Clift S & Waters W (2014). Nitrogen fertiliser use efficiency across the regions. *17th Australian Cotton Conference, Our Fibre, Our Focus, Our Future*. Gold Coast, Qld, Australia. http://www.crdc.com.au/sites/default/files/pdf/Cotton%20Conference%20-%20papers%20and%20e-summaries%20MR.pdf

Acknowledgements

The cooperation and management of the experiment site by Richard Stott, James Hill and Matt Watson, without which the experiment would not have been possible, is gratefully acknowledged.

The technical support provided by Anika Molesworth, John Hornbuckle, James Brinkhoff, Aydin Enez, Irsah Chowdhury, Gabby Napier, Hannah Draper and Jothyar Singh throughout the season was critical to the success of the experiment.

The project is supported by joint investment by the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit Programme, Cotton Research and Development Corporation, Rural Industries Research and Development Corporation and NSW DPI.



Other research

Age at puberty in southern Australian beef heifers – a heritable trait to improve herd fertility

Dr John Wilkins (NSW DPI, Wagga Wagga); **Tracie Bird-Gardiner, David Mula and Dr Kath Donoghue** (NSW DPI, Trangie); **Dr Robert Banks** (Animal Genetics and Breeding Unit, Armidale)

Key findings

- This reports on a pilot study using ultrasound imaging of ovarian function to monitor puberty in beef heifers by tracking the progressive development towards first ovulation in relation to the heifer's age.
- Age at puberty (AaP) varied widely between the herds studied, and trends were consistent with maturity type.
- The methodology was found practical for future data collection from industry herds to estimate genetic parameters relevant to reproduction.
- Further studies will allow the calculation of heritabilities and the generation of estimated breeding values (EBVs), as well as correlations with other production traits.
- The aim is to enhance selection and management strategies to improve herd fertility, thereby increasing production and profitability.

Background

Reproduction is a major driver of profitability in beef breeding enterprises. Attainment of puberty, the earliest opportunity to breed, is a key component of a female's lifetime reproductive performance. It has long been recognised that attainment of puberty is related to age and weight for age and associated with proportion of mature size. Determining the onset/age at puberty (AaP) in heifers can be a difficult and expensive procedure, but electronic technology now makes the task easier, by imaging the ovaries using ultrasound to detect the first ovulation.

Previous research in northern Australia (Johnston et al. 2009) with tropical beef females (*Bos indicus* and composite breeds) showed significant genetic variation for AaP, with medium to high estimates of heritability (>0.5), and genetic association with later reproductive performance. However, similar information for *Bos taurus* cattle in the southern Australian beef industry is scant (Donoghue et al. 2011, 2016). While there are many BREEDPLAN EBVs for growth and carcase traits that are commonly used in genetic selection programs (Graser et al. 2005), there is currently limited scope to improve fertility by this means. Days to calving is essentially the main BREEDPLAN fertility trait – the EBV is an indicator of genetic merit for lifetime calving rate. Having an EBV for AaP would add considerably to the options for selection through direct and correlated effects on reproduction, and complement the EBV for days to calving.

Traits with high heritability enable larger and faster responses to genetic selection. Although the estimates of heritability for AaP have been shown to be quite high in some *Bos indicus* genotypes, the genetic parameters for *Bos taurus* might be quite different and therefore require investigation to assess the value of generating an EBV for the trait. We therefore conducted a pilot study, as a forerunner to a funding request for a larger project, to establish a practical field procedure using ultrasound imaging to collect the large amount of data required to accurately estimate the genetic parameters relating to puberty and subsequent fertility. Following the results reported here, a new project to pursue this aim was approved (commenced January 2017) as part of a trans-Tasman multi-organisation collaborative R&D program to improve beef breeding efficiency and profitability.

Methodology

Animals

Data was collected from four groups of heifers. Three of these groups were specifically part of the pilot study (2015 and 2016), and we have also included data from a similar group that was examined four years previously (2009). Groups T2009, T2015 and T2016 were Angus heifers in the research herds run at NSW DPI Agricultural Research Centre, Trangie. Details of the background and management of these herds was described by Donoghue et al. (2011). The fourth group of heifers (C2015) were also Angus from a commercial cooperator's herd. All heifers were spring born and observations were carried out between eight and 15 months of age, following weaning and before their first mating, starting at liveweights between 270 kg and 300 kg.

Ultrasound observations

Heifers were examined by trans-rectal real-time ultrasound imaging using an Aloka SSD-500 unit fitted with a linear array 7.5 MHz transducer (Medtel Australia, Lane Cove, NSW 2066). The procedure is similar to that of manual pregnancy diagnosis commonly used for many years throughout the dairy and beef cattle industries and is described in the NSW standard operating procedure CAT37 *Cattle – Ultrasound examination of reproductive tract*. The heifers were held in a standard crush while each ovary was imaged and activity recorded. Prior ovulation was evidenced by the presence of a *corpus luteum* (CL), the structure formed following release of the ovum, or a *corpus albicans* (CA), the remains of the CL of the previous cycle. If neither were present, the size of the largest follicle (mm diameter) was noted.

Other measurements

At the same time as the ultrasound observations, the liveweight and ultrasound measured fat depth at the P8 site, and the height at the hips was also measured (Andrews 2015). The latter is an indicator of the animal's maturity type.

Results

The study's primary aim was to explore the technique's logistics. No treatments were applied, and it was not intended (nor statistically sound) to test differences between groups, since the data was confounded by effects of different years, management and herds. However, it can be seen in Figure 1 that there was wide variation in the progressive proportions of heifers having ovulated at various ages. The trends in age at first oestrus showed earlier onset of puberty in the T2009 and T2015 Trangie herds compared with the T2016 and the commercial herd C2015. This is consistent with the assessment of later maturity genotypes of the latter two groups, as indicated by frame scores. Mean frame scores estimated from hip heights were 4, 4, 5 and 5 for the T2009, T2015, T2016 and commercial herd respectively (higher scores indicate later maturity types, Andrews 2015).

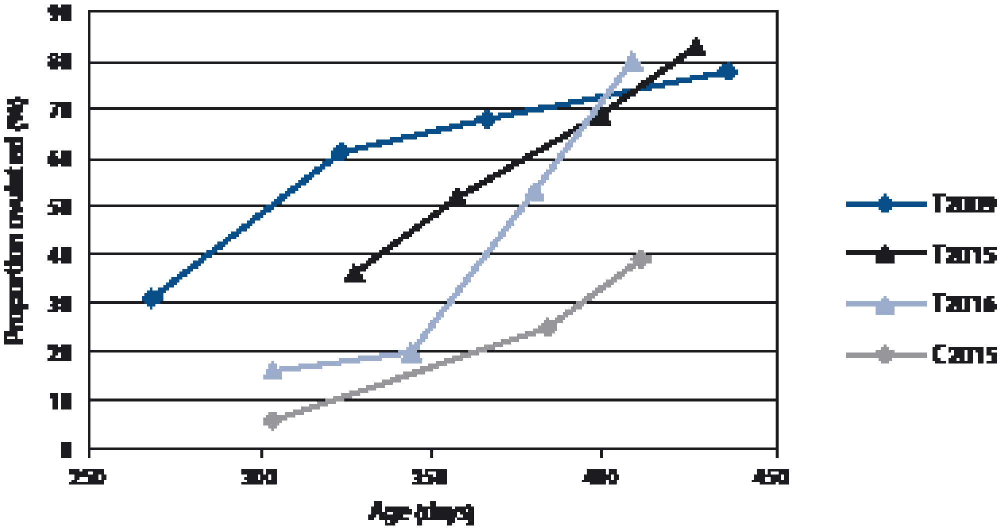


Figure 1. Accumulative proportions of heifers having ovulated against age at progressive scan events for various groups at Trangie (T2009, T2015 and T2016) and a commercial herd (C2015).

Conclusions and industry significance

Calculation of genetic parameters and generation of EBVs relating to puberty and subsequent performance are aimed at improving recommendations for breeding goals incorporating fertility, growth rate, mature size, and body composition traits. The outcomes and outputs are relevant to the whole of the beef industry with particular application in the cow/calf breeding sector. The pathways to adopting improved breeding strategies are envisaged to be mainly via BREEDPLAN EBVs and BREEDOBJECT $Indexes, which are used by many Angus and Hereford breeders, and also those running other beef breeds.

References

Andrews, T 2015. *Live cattle assessment* Primefact 622, NSW Department of Primary Industries. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/148355/live-cattle-assessment.pdf

Donoghue, KA, Arthur, PF, Wilkins, JF & Herd RM 2011. Onset of puberty and early-life reproduction in Angus females divergently selected for post-weaning residual feed intake. *Animal Production Science*. Vol 51(3): 183–190.

Donoghue, KA, Wilkins, JF, Bird-Gardiner, TL, Arthur, PF & Mula, DJ 2016. The impact of divergent selection for methane yield on age at puberty. *Animal Production in Australia*, 1219.

Graser, H-U, Tier, B, Johnston, DJ & Barwick, SA 2005. Genetic evaluation for the beef industry in Australia. *Australian Journal of Experimental Agriculture*. Vol 45: 913–921.

Johnston, DJ, Barwick, SA, Corbet, NJ, Fordyce, G, Holroyd, RG, Williams, PJ & Burrow, HM 2009. Genetics of heifer puberty in two tropical beef genotypes in northern Australia and associations with heifer and steer production traits. *Animal Production Science*. Vol 49: 399–412.

NSW Department of Primary Industries (Standard operating procedure) CAT37 (2015) Cattle – Ultrasound examination of reproductive tract'. http://www.dpi.nsw.gov.au/agriculture/livestock/animal-welfare/general/livestock/sop/cattle/ultrasound-reprod-tract

Acknowledgements

'Heifer puberty in southern Australian beef herds – pilot study', was a project with joint investment from NSW DPI and the Animal Genetics and Breeding Unit, Armidale. The collaboration of Mr Tom Gubbins and Dr Nicole Cheek is greatly appreciated.

Resistance of wheat varieties to grain shattering in the field

Dr Livinus Emebiri, Kerry Taylor, Beverley Orchard and Shane Hildebrand (NSW DPI, Wagga Wagga)

Key findings

- Grain shattering is a significant cause of grain yield loss in wheat, accounting for 11–13% of the variability in grain yield in this experiment.
- Genetic variation exists for grain shattering in Australian wheat varieties.
- However, grain shattering is also controlled by the environment, and this will influence choice of variety.

Introduction

Grain shattering refers to losses of individual grains from the enveloping glumes and the loss of entire florets or spikelets from wheat standing in the field (Figure 1). Grain loss from shattering in the field is a direct loss of income, as the more grains a grower can get into the machine at harvest, the greater the returns (Hofman & Kucera 1978). Hot, high velocity winds and low relative humidity are a major cause of grain shattering (Vogel 1938), but the variety's genetic make-up is also important (Porter 1959). The amount of shattering is influenced by factors such as grain plumpness, 1000-kernel weight and number of grains per head. Large kernels often lead to buckling and breaking of the outer glume, making the grain more easily removable from the spike (Vogel 1938). Although large kernel size and more grains per head are desirable characteristics in modern wheat varieties, they could also increase the propensity to shatter.

Compared with other crops such as soybean and canola, grain shattering in wheat receives little research attention. This paper provides preliminary data on the observed relative resistance of Australian wheat varieties to grain shattering in the field at Wagga Wagga and Leeton.

Figure 1. Grain shattering in standing wheat in the field.

Site details

Locations	Wagga Wagga Agricultural Institute irrigation area, Wagga Wagga Leeton Field Station, Leeton
Sowing dates	3 June 2015 (Leeton) 5 June 2015 (Wagga Wagga)
Herbicides	Pre-emergent trifluralin at 3 L/ha Pre-emergent chemical glyphosate (450 g/L) at 2 L/ha
Treatment	231 wheat varieties and genotypes at Wagga Wagga 219 wheat varieties and genotypes at Leeton
Experimental design	Spatially optimised incomplete block design, with 1.3 reps
Data collection dates	Wagga Wagga, 11 December 2015 Leeton, 9 December 2015
Method	Visual scoring on scale 1–9: 1 = No shattering 9 = Near-complete loss of the grains on spikes

Results

There were significant effects from site (Leeton vs Wagga Wagga, $P<0.001$), genotype ($P<0.001$) and genotype × site interactions ($P = 0.034$), but no significant block, row or range effects.

The grain shattering score at Wagga Wagga was highly correlated with that at Leeton ($R^2 = 0.968$; $P = <0.001$), indicating consistency of the scoring method used in this study. Varieties were more resistant at Wagga Wagga than at Leeton (Figure 2), possibly due to site differences in the time it took plants to mature before they were scored, that is, earlier flowering at one site implying earlier maturity. However, the average difference in flowering time between Wagga Wagga and Leeton was 2 days, and for any given variety, the maximum difference was less than a week (~4 days). There was no significant correlation between grain shattering and days to flowering at either Wagga Wagga or Leeton.

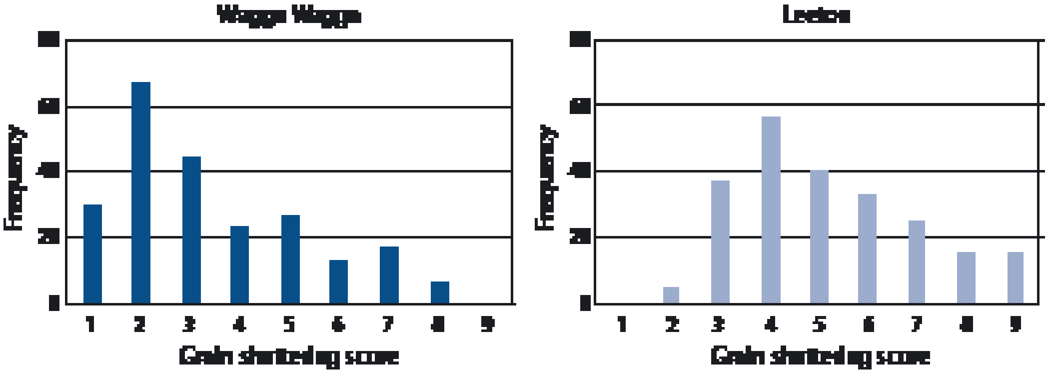


Figure 2. Grain shattering scores frequency distribution of wheat varieties in experiments at Wagga Wagga and Leeton in 2015.

On average, 20% of the varieties were classified as susceptible to grain shattering, while 26% were resistant. A subset of the wheat varieties and their characteristics are presented in Table 1. There was no effect from the varieties' year of release or spike morphology. The resistant lines were either awned or awnless, and although most of the susceptible varieties were awned, Clarke and De Pauw (1983) did not consider this a factor in shattering susceptibility of wheat genotypes.

Summary

The current research has shown that substantial genetic variation exists for grain shattering resistance in Australian wheat varieties. However, shattering is also subject to genotype–environment interactions. There is a need for further research in order to provide growers with wheat varieties able to sustain production against predicted increases in extreme weather events.

Table 1. A representative list of wheat varieties found to be resistant or susceptible to grain shattering in field experiments carried out at Wagga Wagga and Leeton.

Genotype	Status	Overall mean score for grain shattering	SE (mean)	Days from sowing to flowering	Year of Australian release	Spike morphology
SF Adagio	Resistant	0.86	0.73	137.7	2014	Awned
Mansfield	Resistant	0.89	0.73	140.3	2010	Awnless
Tennant	Resistant	1.07	0.73	141.3	1998	Awnless
Rudd	Resistant	1.27	0.89	137.0	2001	Awnless
LongReach Dart	Resistant	1.30	0.89	124.4	2012	Awned
SQP Revenue	Resistant	1.32	0.73	139.2	2009	Awnless
Shield	Resistant	1.40	0.89	129.8	2012	Awned
LongReach Merlin	Resistant	1.49	0.89	134.4	2012	Awned
Einstein	Resistant	1.52	0.79	139.8	2007	Awnless
Forrest	Resistant	1.55	0.73	134.9	2010	Awned
EGA2248	Resistant	1.59	0.66	127.4	2003	Awned
Derrimut	Resistant	1.61	0.67	129.7	2006	Awned
Brennan	Resistant	1.63	0.89	136.7	1998	Awnless
Calingiri	Resistant	1.63	0.66	129.0	1997	Awned
Emu Rock	Resistant	1.69	0.73	127.8	2011	Awned
Kite	Resistant	1.72	0.89	132.3	1973	Half awned
LongReach Scout	Resistant	1.73	0.66	127.6	2009	Awned
EGA Gregory	Susceptible	5.00	0.66	131.2	2004	Awned
Yandanooka	Susceptible	5.10	0.89	127.0	2008	Awned
Egret	Susceptible	5.30	0.66	131.3	1973	Awned
LongReach Impala	Susceptible	5.30	0.89	128.5	2011	Awned
Diamondbird	Susceptible	5.65	0.67	130.9	1997	Awned
Kunjin	Susceptible	5.68	0.73	128.0	2010	Awned
Hartog	Susceptible	5.97	0.66	129.7	1982	Awned
Cunningham	Susceptible	6.12	0.67	131.0	1991	Awned
EGA Bounty	Susceptible	6.17	0.66	131.5	2008	Awned
Naparoo	Susceptible	6.51	0.73	137.0	2007	Awnless
EGA Wills	Susceptible	6.62	0.66	131.3	2007	Awned
Sunstate	Susceptible	7.27	0.67	130.2	1992	Awned
Reeves	Susceptible	7.34	0.67	129.1	1989	Awned
Tasman	Susceptible	7.41	0.66	128.4	1993	Awned
EGA Burke	Susceptible	8.13	0.79	132.8	2006	Awned

References

Clarke, JM & Pauw, RM 1983. The dynamics of shattering in maturing wheat. *Euphytica*. Vol 32: 225–230.

Hoffman, V & Kucera, H 1978. Grain harvest losses. *Circular AE-627*, Cooperative Extension Service, North Dakota State University.

Porter, KB 1959. The inheritance of shattering in wheat. *Agronomy Journal.* Vol 51: 173–177.

Vogel, OA 1938. The relation of lignification of the outer glume to resistance to shattering in wheat. *Agronomy Journal.* Vol 30: 599–603.

Acknowledgements

This work was part of the project 'Genetic analysis of heat tolerance in wheat', UA00147, 2014–18, with joint investment by GRDC, NSW DPI and University of Adelaide.

Heat–moisture treatment of wheat flour and its application in noodle production

Dr Mahsa Majzoobi (NSW DPI, Wagga Wagga); **Naveed Aslam** (Graham Centre, Wagga Wagga);
Denise Pleming (NSW DPI, Wagga Wagga); **Ahsan Ghani** (Graham Centre, Wagga Wagga);
Dr Asgar Farahnaky (Charles Sturt University, Wagga Wagga)

Key findings

- Heat–moisture treatment can be successfully applied to wheat flour to change its functional properties.
- Treatment time and flour moisture content significantly affected the functional properties of the treated wheat flours.
- Lower flour moisture content and shorter treatment times are more appropriate to produce heat–moisture-treated wheat flour suitable for noodle production.

Introduction

Starch is a main component of cereal grains and the foods produced from them. It supports nutritional value, texture, sensory properties and the food's shelf-life. Efforts have been made to modify the native structure of starch in order to broaden applications; different modified starches (e.g. instant starch and cross-linked starch) have been developed and used widely in food processing.

Generally, starch is extracted from its source and then modified. However, there is a lack of information on the *in situ* starch modification, i.e. as in the grains or flour. The advantages of flour modification are related to the wider application of flour than starch in many foods, and saving time and cost of starch extraction. Although flour modification such as heat–moisture treatment (HMT) has been tried already on millet, sorghum and wheat flours (Sun et al. 2014; Majzoobi et al. 2015; Verdu et al. 2017), many aspects such as the possible effects on proteins, health effects and the quality of foods produced from modified flours have not been fully investigated.

HMT is a physical method for starch modification. In this method, starch with low moisture content (~35%) is heated at above gelatinisation temperature (84–120 °C) for about 1–16 hours. HMT can change the gelatinisation temperature and water interaction and increase resistant starch content. Resistant starch is a type of dietary fibre as well as a prebiotic. It resists acidic and enzymatic hydrolysis and hence can be used to develop low glycaemic index (GI) foods and exhibit health benefits (Gunaratne & Hoover 2002). It is well documented that the HMT, type of starch and moisture content have great impacts on the physicochemical properties of the modified starch. HMT starch has previously been used in noodle, bread and edible packaging development (Majzoobi et al. 2015; Marston et al. 2016).

The main purpose of this study was to produce HMT wheat flour under different treatment conditions in terms of flour moisture content and treatment time, and then to investigate the effects that the HMT had on the flours' pasting properties, water solubility and water absorption. The HMT flours were replaced with 20% of ordinary wheat flour in noodle production (as a common food around the world) and some quality aspects of the resulting noodles were studied.

Material and methods

Commercial wheat flour with a moisture content of 14.06% was purchased from a local market.

HMT of the wheat flour

HMT wheat flour was produced according to the method described by Chen et al. (2015) with some modifications. First, the moisture content of the flour was adjusted to 14%, 20% and 30%. Then flours in sealed glass jars were placed in an electrical oven set at 100 °C for two, six and 10 hours. Then they were removed, poured evenly over a tray, and dried further for 8 hours at 40 °C. The treated flours were then ground slightly to break any clumps, sieved to achieve a consistent particle size, and stored in sealed glass jars at room temperature for further tests. Abbreviated names were given to all samples such as 2HMT14 (code in tables) meaning 2 hours of treatment at 14% moisture content. The control sample was the untreated wheat flour.

HMT flour testing

The pasting properties of the flours were studied by a rapid visco analyser (RVA S4) using the standard method of the instrument according to Ragaee and Abdel-Aal (2006) with slight modification. Water absorption and water solubility of the treated flours were measured as per Rafiq et al.'s (2016) description.

Noodle sheet preparation

Briefly, 20% of wheat flour was substituted with HMT flour and mixed well. Then other ingredients including 1% NaCl, 0.6% Na_2CO_3, 0.4% K_2CO_3 and about 34% water were added and mixed to form a dough. The dough was then sheeted using a laboratory noodle machine (Imperia RME 220: IPS-Santambrogio-Torino, Italy) to a thickness of 1.45–1.5 mm and incubated in sealed plastic bags overnight at 25 °C.

Colour of the sheets

The brightness (L-value), yellowness (b-value) and redness (a-value) of the noodle sheets were measured using a Minolta Chromameter 410 fitted with a 50 mm head. The colour parameters were tested on the fresh sheets and on the stored sheets (incubated sheets at 25 °C for 24 hours after production).

Cooking time and water absorption during cooking

The sheets were shredded to form noodles with thickness of 1.5 ± 0.05 mm. Cooking time and water uptake of the noodles were evaluated using the Ritthiruangdej et al. (2011) method.

Results

Flour properties

Heating in excess water is a common process when preparing starch-based foods. During heating, viscosity increases initially and then reduces upon further heating and mixing. These changes are mainly due to starch gelatinisation followed by the pasting process. During cooling, viscosity increases, mostly because of starch gelation and retrogradation. All the described changes are influenced by starch type, molecular structure of amylose and amylopectin, amylose content and the presence of other components such as proteins and lipids.

Table 1 shows the pasting properties of the control compared with the HMT flour. HMT increased the pasting temperature of all samples, meaning that the gelatinisation process was delayed for these samples. Within the HMT samples, both increased moisture content of the flour and increased treatment time enhanced the pasting temperature.

The treatment time and flour moisture content affected both peak and final viscosities of the HMT samples. With increasing flour moisture content, peak and final viscosities of the HMT samples reduced dramatically. Therefore, within each group, samples prepared with 30% moisture content (i.e. 2HMT30, 6HMT30 and 10HMT30) had the lowest peak and final viscosities. Similar results have been reported for HMT wheat flour and arrowroot starch produced under different conditions. HMT enhances the amylose-lipid complex formation and a more ordered double helical amylopectin clusters compared to the structure of native starch. This rigid structure could prohibit starch water uptake and swelling and reduce starch solubility. This may be the reason for the marked reduction in pasting and final viscosities for the HMT samples (Gunaratne & Hoover 2002). In addition, protein denaturation due to HMT might cooperate with the increased hydrophobicity, and could further delay the HMT starch granules in wheat flour swelling, resulting in reduced viscosity (Chen et al. 2015).

Compared with the control samples, HMT flours treated for two and 6 hours and at 14% and 20% moisture content showed higher peak and final viscosities than the control, while further increasing the treatment time and flour moisture content resulted in reduced viscosity. It is possible that the strengthened structure of the HMT granules allowed them to remain intact for longer, continuing to take up water and thus contributing to increased viscosity. However, increasing the treatment severity (10 hours heating at different moisture contents) caused other changes, which decreased the viscosity.

Table 1. Pasting properties, water absorption and water solubility of the control and wheat flours modified by heat–moisture treatment (HMT).

Sample	Pasting temperature (˚C)	Peak viscosity (cP)	Final viscosity (cP)	Water absorption (%)	Water solubility (%)
Control	64.25 ± 0.28	174.34 ± 1.53	200.13 ± 1.59	69.0 ± 0.5	15.0 ± 0.9
2HMT14*	65.45 ± 0.78	301.54 ± 4.30	341.71 ± 1.36	113.2 ± 1.3	14.6 ± 1.1
2HMT20	68.43 ± 0.04	272.13 ± 4.07	320.30 ± 1.24	114.7 ± 5.9	12.6 ± 0.7
2HMT30	77.73 ± 0.32	134.96 ± 2.89	213.25 ± 7.19	131.6 ± 3.3	11.4 ± 0.3
6HMT14	66.25 ± 0.28	222.54 ± 2.89	311.00 ± 4.01	131.3 ± 2.6	10.4 ± 1.0
6HMT20	70.63 ± 1.38	195.71 ± 1.59	264.58 ± 3.77	124.4 ± 5.6	10.9 ± 0.2
6HMT30	82.23 ± 1.24	63.33 ± 1.65	97.88 ± 4.89	144.4 ± 10.2	10.2 ± 0.2
10HMT14	67.83 ± 0.81	174.71 ± 1.47	266.00 ± 5.42	139.0 ± 4.3	10.4 ± 0.1
10HMT20	72.13 ± 0.88	152.13 ± 2.42	223.79 ± 1.94	129.2 ± 14.4	14.4 ± 1.4
10HMT30	80.20 ± 0.07	55.46 ± 0.41	87.00 ± 0.35	115.9 ± 9.3	12.6 ± 0.3

Values are the average of at least duplicates ± standard deviation.

*Numbers before and after HMT are the treatment time (hours) and flour moisture content (%), respectively.

Similarly, Chen et al. (2015) reported that the HMT wheat flour produced by heating at 120 ˚C for 24 hours with a moisture content of 15–35%, had lower peak and final viscosities than the control. The different values can be related to the differences in the conditions used for preparing HMT flour, partial gelatinisation of the starch granules (as reported by Chen et al. 2015) and the extent of protein denaturation, which require further investigation.

Table 1 shows that the HMT reduced the water solubility while increasing the water absorption of the flour. For the 2HMT and 6HMT samples, increasing the moisture content and treatment time had a positive effect on starch water absorption while the opposite result was observed for the 10HMT flour. The water solubility of the 2HMT flours reduced slightly with increasing the flour moisture content, but remained unchanged for the 6HMT flours and increased for the 10HMT samples.

Noodle properties

Colour has a very strong influence on customer choice when purchasing a product. For yellow alkaline noodles, a bright yellow colour is preferred. L-value indicates product lightness with higher values representing greater brightness. The a-value indicates redness (positive values) or greenness (negative values) of the product. The b-value is related to blueness–yellowness, and higher positive values represent increased yellowness of the sample. In general, including HMT flour reduced the brightness and increased the redness of the noodle sheets, particularly for the 10 hour treatments. The yellowness of the sheets prepared with the 2HMT and 6HMT was very similar to the control, while the sheets produced with 10HMT had slightly greater yellowness. Storage for 24 hours resulted in decreased brightness, increased redness and no change to yellowness for all samples. Changes in the colour can be attributed to some interactions between flour components (i.e. proteins and carbohydrates) and water. Changes in surface integrity and uniformity as well as possible enzymatic browning can also affect light reflection.

Table 2 shows the cooking properties and firmness of the cooked noodles. Generally, the cooking time of all samples was in the range of 5.30 min to 5.42 min. Therefore, it can be concluded that the HMT had no effect on the cooking time of the samples. Cooking weight gain is attributed to the amount of water absorbed by the noodles during cooking, which can affect the texture and sensory attributes of the cooked product. The cooking weight gain of all samples was in the range of 94.43% to 113.45%. Overall, HMT samples had a lower cooking weight gain than the control. Treatment time and flour moisture content had no considerable effects on the cooking weight gain.

Table 2. Cooking properties and firmness of the noodles produced by replacing 20% HMT flour with wheat flour.

Sample	Cooking time (min)	Cooking weight gain (%)
Control	5.33 ± 0.02	113.45 ± 8.05
2HMT14*	5.31 ± 0.02	99.85 ± 2.85
2HMT20	5.31 ± 0.01	97.24 ± 3.35
2HMT30	5.31 ± 0.01	103.03 ± 3.22
6HMT14	5.42 ± 0.01	105.81 ± 5.22
6HMT20	5.38 ± 0.03	94.43 ± 4.66
6HMT30	5.33 ± 1.24	101.87 ± 6.44
10HMT14	5.30 ± 0.01	98.83 ± 5.38
10HMT20	5.31 ± 0.01	98.66 ± 5.38
10HMT30	5.31 ± 0.01	102.82 ± 6.02

Values are the average of at least duplicates ± standard deviation.
*Numbers before and after HMT are the treatment time (hours) and flour moisture content (%), respectively.

Summary

Starch modification has been a successful method to change the functional properties of starch for many years, while it is less common for flour. In this study, HMT was applied to modify wheat flour. HMT affected pasting properties, water solubility and water absorption of the flour. These properties were highly affected by the treatment time and flour moisture content. Noodles produced using 20% wheat flour instead of HMT flour exhibited a similar cooking time, lower cooking weight gains and duller colour compared with the control. To produce HMT flour suitable for noodle production treatments at lower moisture content and shorter time seems to be more appropriate compared to other conditions. Further studies are required to determine the amount of resistant starch content of the treated samples and the organoleptic properties of the noodles.

References

Chen, X., He, X., Fu, X. & Huang, Q. (2015). In vitro digestion and physichochemical properties of wheat starch/flour modified by heat-moisture treatment. *Journal of Cereal Science*, vol 63, pp. 109–115.

Gunaratne, A. & Hoover, R. (2002). Effect of heat-moisture treatment on the structure and physicochemical properties of tuber and root starches. *Carbohydrate Polymers*, vol 49, pp. 425–437.

Majzoobi, M., Pesaran, Y., Mesbahi, G., Gholmakani, M.T. & Farahnaky, A. (2015). Physicochemical properties of biodegradable films from heat-moisture treated rice flour and rice starch. *Starch*, vol 67, pp. 1053–1060.

Marston, K., Khouryieh, H. & Aramouni, F. (2016). Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake. *LWT Food Science and Technology*, vol 65, pp. 637–644.

Ragaee, S. & Abdel-Aal, E.M. (2006). Pasting properties of starch and proteins in selected cereals and quality of their food products. *Food Chemistry*, vol 95, pp 9–18.

Rafiq, S.I., Singh, S. & Saxena, D.C. (2016). Effect of heat-moisture and acid treatment on physicochemical, pasting, thermal and morphological properties of Horse Chestnut (*Aesculus indica*) starch. *Food Hydrocolloids*, vol 57, pp 103–113.

RACI (1995). Official Testing Methods. RACI Cereal Chemistry Division, Melbourne.

Ritthiruangdej, P., Parnbankled, S., Donchedee, S. & Wongsagonsup, R. (2011). Physical, chemical, textural and sensory properties of dried wheat noodles supplemented with unripe banana flour. *Kasetsart. J (Nat Sci)*, vol 45, pp 500–509.

Sun, Q., Han, Z., Wang, L. & Xiong, L. 2014. Physicochemical differences between sorghum starch and sorghum flour modified by heat-moisture treatment. *Food Chemistry*, vol 145, pp 756–764.

Verdu, S., Vasquez, F., Ivorra, E., Sanchez, A.J., Barat, J.M. & Grau, R. 2017. Hyperspectral image control of the heat-treated process of oat flour to model composite bread properties. *Journal of Food Engineering*, vol 192, pp. 45–52.

Acknowledgements

This experiment was part of the Research Centre Fellowship 'Effects of heat moisture treatment on wheat flour and noodle properties', funded by Graham Centre for Agricultural Innovation, (a partnership between NSW DPI and Charles Sturt University, Wagga Wagga, NSW) in 2016. The authors are grateful to Natalie Taber and Fiona Bennett for their technical support during this project.

Southern NSW research results 2017

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY