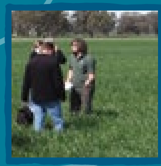
RiverinePlains

Research for the Riverine Plains 2015

A selection of research relevant to agriculture in the Riverine Plains

Farmers inspiring farmers





Research for the Riverine Plains 2015

Farmers promoting excellence in farming systems by providing quality information, leading research and sharing ideas for the economic, environmental and social benefit of the Riverine Plains.

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Acknowledgements

Welcome to the 2015 edition of *Research for the Riverine Plains*. This year we have collected a range of articles covering topics relevant to farming in the region, which we hope you find interesting and informative.

As the research portfolio of Riverine Plains Inc continues to evolve, we are proud to share the results of our research with you. These results provide local information on crop management in retained-stubble systems, nitrogen timing and efficiency, the potential to build soil carbon in cropping systems, and the profitability of various crop sequences.

In addition to research carried out by Riverine Plains Inc, we have also included results from other research organisations and industry bodies, which provide information relevant to our region and the agronomic issues we face. On behalf of Riverine Plains Inc, I would like to formally thank all authors for their willingness to share their results with our members.

We particularly recognise the ongoing support provided by the Grains Research and Development Corporation (GRDC) and the Australian Department of Agriculture (DA), which enables us to deliver research, development and extension (R, D & E) outcomes which address local issues.

A very special thanks to the Riverine Plains Inc staff and committee for their contribution to this publication. Thanks also to sub-editor Catriona Nicholls and graphic designer Josephine Eynaud for producing a professional publication, which presents technical information in a manner that is easy to interpret and understand.

We hope you enjoy reading *Research for the Riverine Plains 2015*, and we wish you all the best for the 2015 cropping season.

Dr Cassandra Schefe
Extension Officer, Riverine Plains Inc



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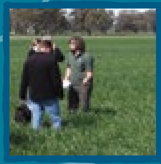

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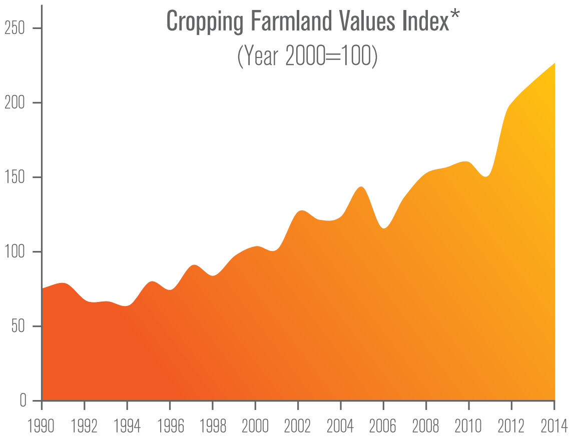
VICTORIAN FARMLAND VALUES INDEX 2014 - EXTRACT

AG ANSWERS
GROW WHAT YOU KNOW

The value of farmland reflects the strength and confidence of agricultural industries. The Victorian Farmland Values Index provides analysis at state, industry and regional levels, and is based on farmland sales data compiled since 1990. This extract presents some key points from the Victorian Farmland Values Index 2014.



* An index is a statistical measure used to track changes in a particular metric over time, allowing the aggregation of multiple data points into one relevant graph. The Farmland Values Index tracks the median farmland value using a base year of 2000, which will always equal 100. All years therefore relate back to 2000 – for example, if 2005 has a value of 132, then land values were 32% higher in 2005 than in 2000.

The median value of Victorian cropping land increased by 6.4% in 2014, following growth of 8% in 2013.

Although the Cropping Farmland Values Index appears volatile, the overall trend in cropping land values since 1990 is one of consistent growth.

SEASONAL SALES PATTERN

Late spring is a popular time for cropping farmland sales in the **NORTH EAST AND THE SOUTH WEST.**

All cropping regions have a lull in sales activity in **AUGUST.**

For a full version of the Victorian Farmland Values Index, please contact the Ag Answers team.

AG ANSWERS
P 1300 796 101
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ABOUT AG ANSWERS

Ag Answers is a specialist insights division of Rural Finance and Rural Bank. Recognising that good information is the key to making good business decisions, Ag Answers provides research and analysis into commodities, farmland values, farm business performance and topical agricultural issues to enable farmers to make informed decisions.

Units of measurement

Row spacings

Some trials carried out during 2014 have investigated the effect row spacings play in crop production.

Riverine Plains Inc recognises that while the research sector has moved toward metric representation of row spacings, most growers remain comfortable with imperial measurements.

Following is a quick conversion table for handy reference when reading the following trial result articles.

TABLE 1 Row spacing conversions

Inches	Centimetres
7.2	18.0
9.0	22.5
9.5	24.0
12.0	30.0
14.4	36.0
15.0	37.5

Standard units of measurement

Through this publication, commonly-used units of measurement have been abbreviated for ease of reading they include:

centimetres — cm

gigahertz — GHz

hectares — ha

kilograms — kg

kilojoules — kJ

litres — L

metres — m

millimetres — mm

tonnes — t

Cereal growth stages

Why are they important to cereal growers?

A growth stage key provides a common reference for describing crop development, so we can implement agronomic decisions based on a common understanding of which stage the crop has reached.

Zadoks cereal growth stage

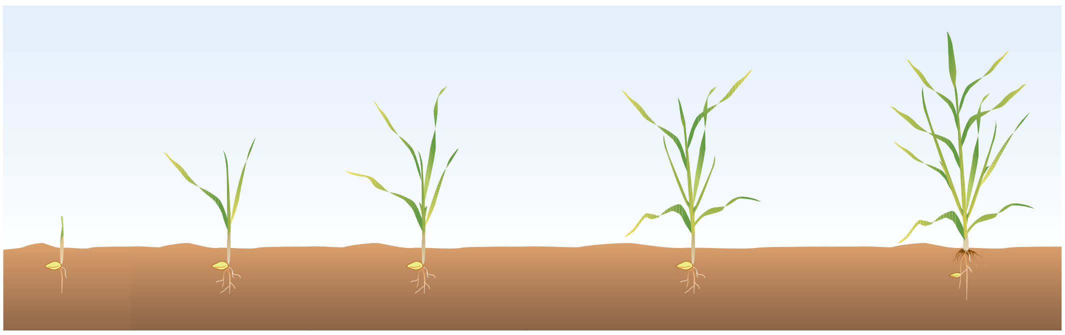
The most commonly used growth stage key for cereals is the:

- Zadoks decimal code, which splits the development of a cereal plant into 10 distinct phases of development and 100 individual growth stages.
- It allows the plant to be accurately described at every stage in its life cycle by a precise numbered growth stage (denoted with the prefix GS or Z e.g. GS39 or Z39)

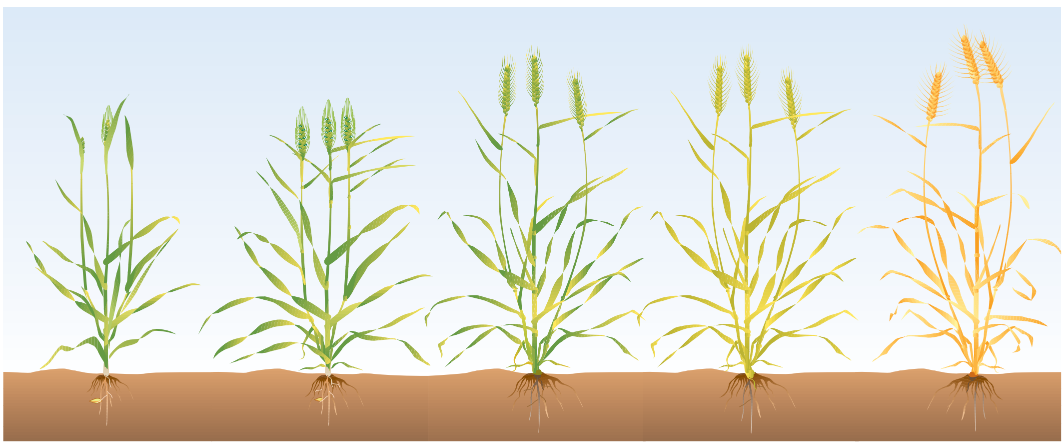
Within each of the 10 development phases there are 10 individual growth stages, for example, in the seedling stage:

- GS11 describes the first fully unfolded leaf
- GS12 describes two fully unfolded leaves
- GS13 describes three fully unfolded leaves
- GS19 describes 9 or more fully unfolded leaves on the main stem

This information has been reproduced with the permission of the Grains Research and Development Corporation (GRDC) and is taken from *Cereal Growth Stages: The link to crop management*, by Nick Poole.



Zadoks growth stage	GS00–09	GS10–19	GS20–29	GS30–39	GS40–49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting



Zadoks growth stage	GS 50–59	GS60–69	GS70–79	GS80–89	GS90–99
Development phase	Ear emergence	Flowering	Milk development (grain fill period)	Dough development (grain fill period)	Ripening

Preface

Trials versus demonstrations — what the results mean

Research on the Riverine Plains takes different shapes and forms, each of which has the potential to make an important contribution to increasing the understanding about agricultural systems in the area. However, it is important to keep in mind results from the different forms of research need to be analysed and interpreted in different ways.

It is important to understand the difference between trials and demonstrations in the use of results for benefit on farms. A replicated trial means that each treatment is repeated a number of times and an averaged result is presented. The replication reduces outside influences producing a more accurate result. For example, trying two new wheat varieties in a paddock with varying soil types and getting an accurate comparison can be obtained by trying a plot of each variety, say four times. Calculation of the average yield (sum of four plots then divided by four) of each variety accounts for variations in soil type.

Statistical tests for example, analysis of variance — ANOVA, least significant difference — LSD) are used to measure the difference between the averages. If there is no significant difference between treatments the results will be accompanied by the mark NS (meaning not significantly different). A statistically significant difference is one in which we can be confident that the differences observed are real and not a result of chance. The statistical difference is measured at the 5% level of probability, represented as ‘P<0.05’.

Table 1 shows an LSD of 0.5t/ha. Only Variety 3 shows a difference of greater than 0.5t/ha, compared with the other varieties. Therefore Variety 3 is the only treatment that is significantly different.

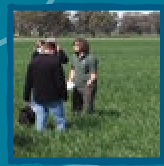
TABLE 1 Example of a replicated trial with four treatments

	Treatment	Avg yield (t/ha)
1	Variety 1	4.2
2	Variety 2	4.4
3	Variety 3	3.1
4	Control	4.3
	LSD (P<0.05)	0.5

A demonstration is a comparison of a number of treatments, which are not replicated. For example, splitting a paddock in half and trying two new wheat varieties or comparing a number of different fertilisers across a paddock. Because a demonstration is not replicated results cannot then be statistically validated. For example, it may be that one variety was favoured by being sown on the better half of the paddock. We can talk about trends within a demonstration but cannot say that results are significant. Demonstrations play an important role as an extension of a replicated trial that can be tried in a simple format across a large range of areas and climates.

Demonstrations are accurate for the paddock chosen under the seasonal conditions incurred. However, care must be taken before applying the results elsewhere.

Trials and demonstrations play a different role in the application of new technology. Information from replicated trials is not always directly applicable but may lead to further understanding and targeted research. Demonstrations are usually the last step before the application of technology on farm.



A word from the Chairman

John Bruce
Chairman 2015

Welcome to the 2015 edition of *Research for the Riverine Plains*.

Much has happened since the last edition was mailed out during September last year. As ever, we have been busy with our annual list of events and research projects and have also dedicated significant time to planning in order to ensure Riverine Plains Inc remains a vibrant and relevant organisation into the future.

Harvest last year provided a pretty positive result for most. Harvest weather was also reasonably kind, assisting a smooth completion of harvest for our research work. An early start also meant an earlier finish and time to enjoy some down-time over Christmas and into January.

On 5 February 2015 we honoured the memory of John Sykes by continuing to provide a forum for farmers to discuss the harvest that was, lessons learned and the challenges for the season ahead. This year's Buraja Meeting, now known as *Sykesy's Buraja Meeting* attracted a crowd of about 100 farmers. John had run the Buraja meeting since 1983 and Riverine Plains Inc was pleased to continue John's legacy by carrying on this traditional review and planning day.

During February, we also hosted the annual *GRDC Grains Research Update* at Corowa, About 130 farmers and advisors attended the day and heard from a range of speakers, including Malcolm Morrison from Canada, who addressed a range of canola productivity issues. Dual-purpose crops, nitrogen management, weed management and technological breakthroughs were also on the agenda and rounded out the productivity improvement discussions.

February continued to be a busy month as we also hosted United States' cover crop expert, Steve Groff, for a paddock walk at *Pine Lodge*. About 40 people attended, and heard about growing particular out-of-season crops specifically to retain soil cover to improve soil structure and the profitability of subsequent crops.

Riverine Plains Inc has been doing its part to improve the image of agriculture in the wider community. During October 2014, a group of Riverine Plains Inc members took on organising the grains tent for the inaugural *Tuppal Food and Fibre Festival*. Held at *Tuppal Station* (Tocumwal), the Riverine Plains Inc organising group created a series of displays showcasing the grains industry. Tent volunteers literally talked to thousands of visitors over the course of the event and in doing so were able to answer the questions of many 'non-farmers' about our industry. Many left with a more positive and deeper understanding of the role of farmers in growing food and of the career options available in the grains industry.

Farmers inspiring farmers

Research

Along with our full extension program, we also continue to successfully manage a sizeable research program. Developing (and implementing) projects is incredibly time consuming and requires a huge amount of planning. I would like to thank all those involved on our research sub-committee for ensuring Riverine Plains Inc continues to identify its research priorities and fulfil our existing project requirements. This work is critical if we are to remain at the forefront of farmer-driven research in the region.

The *Water Use Efficiency* project came to an end during 2014, with the results demonstrating the importance of row spacing, sowing density and nitrogen application on crop yield and water use efficiency (WUE) in the first wheat crop after canola. The results were compiled into the publication *Between the Rows*, which was distributed to members during March 2015. The booklet was produced in partnership with the Foundation for Arable Research (FAR) Australia, who collaborated in the delivery of the project, which highlights how well-conducted local research can lead to real outcomes and change for farmers.

The quality of the research throughout the *Water Use Efficiency* project contributed to the awarding of the prestigious 2014 Australian Museum Eureka Prize for Sustainable Agriculture to the *National Water Use Efficiency Initiative* (the national program of which we were a part). Congratulations to Adam Inchbold for his work as the Riverine Plains Inc project leader in this research.

Our *Stubble Initiative* project (which follows on from the WUE initiative) has already delivered a number of farm walks and discussion groups under the guidance of the Riverine Plains Inc Extension Officer Dr Cassandra Schefe. The project is investigating a range of agronomic measures to improve the profitability and sustainability of crops grown in stubble-retained systems. Project results from 2014 are presented on pages 6–41.

Final measurements for the *Soil Carbon* project will be taken during July 2015, with the final report due in September 2015. The project has been running since July 2012 and is providing important information on the potential to increase soil carbon in our cropping zone. Results and conclusions made to date are available on pages 42–49 and the full report will be produced next year and distributed to growers.

Riverine Plains Inc has also collaborated on a number of other projects and we are pleased to include some of these reports in this year's compendium.

Fast-track Ag Innovation

During October 2014, Riverine Plains Inc was one of just four groups in Victoria to receive a $150,000 grant from the new *Fast-track Ag Innovation* program. Funded by The William Buckland Foundation, in partnership with the Foundation for Rural and Regional Renewal (FRRR), the three-year program is designed to help farmer groups address one of their top three production constraints.

The *Fast-track Ag Innovation* program will support Riverine Plains Inc in exploring the effect of different stubble management treatments on soil nitrogen and the implications for nitrogen supply to crops throughout the growing season.

As part of this program, Riverine Plains Inc ran a well-attended stubble incorporation day at Howlong on 29 January 2015. Many machines and dealers were represented, which gave farmers the opportunity to assess the performance of each machine. The day was well received by members and future walks are planned to look at subsequent crop establishment and growth.

Print and other media

Riverine Plains Inc produces a number of written pieces for local and state print media. Our regular media releases enable us to share our news with the wider community and inform growers about upcoming events. We have also had some wonderful support from local print, radio and TV journalists who have attended our days and regularly report on our activities.

The Riverine Plains Inc *Grower Bulletin*, distributed via email, continues to be an important means of sharing relevant news about pests, disease and growing conditions throughout the region. Our website also contributes to keeping members and the agricultural industry up to date with important events, news and information.

Sponsorship

Riverine Plains Inc again received terrific support during 2014 from agribusiness in the form of sponsorship. We would like to sincerely thank all our sponsors and acknowledge their input in terms of trial contributions, project advice and input at field days, workshops and other presentations. These contributions allow Riverine Plains Inc to deliver information in ways that successfully meets the needs of our members.

Staff

On behalf of the committee and our members I would like to thank the entire team for the exceptional job they do in keeping the organisation operating at the highest level. Executive Officer Fiona Hart does a tremendous job in keeping Riverine Plains Inc on track with our members, sponsors and funding bodies. Finance Officer, Kate Coffey has been terrific in streamlining our financial management and Extension Officer Dr Cassie Schefe has been pivotal in improving our extension capabilities and also has been a significant contributor in a research capacity. Thanks also to Allison Courtney, our Research Coordinator who publishes the *Grower Bulletin* and assists the research sub-committee in their work, and Dr Bill Slattery who has been instrumental in his role as Soil Carbon Project Officer.

Committee

The Committee of Riverine Plains Inc is made up entirely of volunteers who give up their time to help run the group. Running a group of this size comes with a serious level of responsibility around financial and organisational governance and our committee is continually working on ways to improve the way we operate.

For this reason, we have been working to streamline our behind-the-scenes committee operations and have also been steadily working through a review of our constitution. Earlier this year, we also carried out a strategic review of the group and as a result, re-affirmed our strengths (our independence, our membership, our extension and research achievements, our professionalism, our ability to secure funding) and confirmed the direction and purpose of the group.

The strategic planning process also identified a number of areas where we could improve, and how we could make better use of the opportunities that present themselves.

I have to say the strength of the Committee and the passion shown individually and collectively is the biggest asset of the group and I would like to thank each volunteer for their ongoing contributions.

I would also like to recognise the ongoing support provided by funding bodies such as the Grains Research and Development Corporation (GRDC) and the Department of Agriculture (DA) which enables locally-based research to continue.

Riverine Plains Inc as an organisation takes a lot of pride and invests a lot of effort in producing our annual trial book. It is our flagship publication, which over the years has morphed from a humble photocopied collection of local trial results through to the professional and well thought-out document we have today. Not only is the trial book an important document for reporting results, but it also reflects more widely the care we take, as an organisation, in doing things properly, something our funders, sponsors and members recognise and appreciate.

We hope you enjoy the read and all the best for the 2015 season.

Maintaining profitable farming systems with retained stubble in the Riverine Plains region — project overview

Cassandra Schefe[1], Adam Inchbold[1], Nick Poole[2], Michael Straight[2] and Tracey Wylie[2]
[1] Riverine Plains Inc
[2] FAR Australia

Introduction

The *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project is managed by Riverine Plains Inc, supported by FAR Australia, the Precision Agriculture Laboratory and funded by the Grains Research and Development Corporation (GRDC) as part of an overarching national initiative focussed on maintaining the profitability of stubble-retained systems. This project started during 2013 and will run until June 2018.

Objectives

The project seeks to:

- investigate, demonstrate and extend cultural practices that will assist growers to adopt no-till stubble retention (NTSR) in medium and higher-rainfall environments;
- build on findings from the previous Riverine Plains Inc *Water Use Efficiency* (WUE) project; and
- extend the frontier of agronomic knowledge for crops grown in NTSR systems.

Background

It is widely accepted that as rainfall increases across cropping landscapes, the amount of stubble retention decreases. This often is because growers perceive that growing high-yielding crops in stubble-retained systems is more difficult than growing them in paddocks where the previous crop residue is removed (mainly through burning). It is also true to say that much agronomic knowledge has been gleaned from trials not carried out under a modern NTSR system, leaving a potential knowledge gap. These issues ring true for growers in the Riverine Plains area.

By addressing the negative impacts and perceptions of NTSR systems, advancing the agronomic frontier and building the capacity of growers and advisors working in these systems it is anticipated more growers across the Riverine Plains area will adopt them, and the WUE of these systems will increase.

Adoption of an NTSR system, or improving an existing NSTR system, is estimated to result in at least $50/ha of extra income from cropping each year. Additionally, a cost saving of about $60/ha/yr can be achieved through either reduced nutrient loss, normally seen in stubble removal, and/or a more appropriate allocation of inputs under an NTSR system.

Research

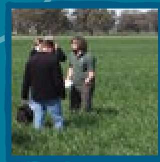
The research component of the Riverine Plains Inc *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project is comprised of a series of large and small plot trials. The first trials were established during 2014.

Using large-scale trials (focus farms) the research team is evaluating the impact of a single-year, one-off change in stubble management in an otherwise NTSR rotation. The result of these trials will help to determine if periodic active management of stubble in an NTSR system increases the sustainability and profitability of the system across the rotation. As different stubble management approaches are likely to perform better under different seasonal conditions, the four years of trials (2014–17) will provide information on crop performance under a range of seasonal climatic conditions.

The focus farm trials are located at Henty and Coreen/Redlands, NSW and Yarrawonga and Dookie, Victoria (Figure 1).

FIGURE 1 Locations of large block (focus farm) trials





The results from the focus farm trials can be found on pages 6–17.

A series of small plot trials has been established to address specific aspects of management in a NTSR system, in order to optimise the NTSR production system in the Riverine Plains region. The results from these trials have also been reported in this publication.

The small plot trials carried out during 2014 were:

1. early sowing and the interaction with row spacing, plant populations and variety in first wheat under full stubble retention (Barooga, Yarrawonga), page 18;
2. the interaction between plant growth regulator (PGR) and nitrogen application in early-sown first wheat (Redlands, Yarrawonga), page 38;
3. monitoring the response of nitrogen application to wheat under full stubble retention (Yarrawonga, Dookie), page 30; and
4. interaction between fungicide program and in-crop nitrogen timing for the control of yellow leaf spot (YLS) in early-sown wheat (Coreen), page 24.

Outcomes

The overarching outcome from this project will be to increase the adoption of NTSR systems across the Riverine Plains region. This will be achieved through increasing the profitability and sustainability of NTSR cropping systems by developing regional guidelines specific to the region, enabling growers and advisers to use rotational cultural control measures to enhance the sustainability of their NTSR farming systems.

Active stubble management to enhance residue breakdown and subsequent crop management — focus farm trials

Nick Poole, Tracey Wylie and Michael Straight
FAR Australia

Background

This report presents the results from the large plot focus farm trials of the *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project, as described in the introductory report on page 4.

Method

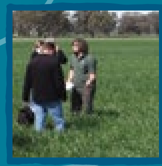
Different methods of stubble management were trialled in four large (farm-scale) replicated trials during 2014. All results were statistically analysed using analysis of variance (ANOVA), with means separated using the unrestricted least significant difference (LSD) procedure. The different trial treatments are outlined in Table 1.

TABLE 1 Stubble management project trial details

Trial details	Trial 1 Daysdale	Trial 2 Yarrawonga	Trial 3 Dookie	Trial 4 Henty
Treatments				
NTSR* (control)	✓	✓	✓	✓
NTSR^ + 40kg extra nitrogen at sowing	✓	✓	✗	✓
Cultivate	Two passes	One pass	Two passes	One pass
Cultivate + 40kg N/ha at sowing	Two passes	One pass	✗	One pass
Burn stubble	✓	✓	✓	✗
NTSR – long stubble	✗	✗	45cm	✗
NTSR — straw mown and removed	✗	✓	✓	✗
NTSR — stubble mulched and retained	✗	✗	✗	✓
NTSR — stubble mulched + 40kg extra nitrogen at sowing	✗	✗	✗	✓
NTSR — faba beans sown for forage	✓	✗	✗	✗
NTSR — faba beans sown for grain	✓	✗	✗	✗
Trial plot dimensions	40 x 15m	40 x 18m	40 x 12m	40 x 15m
Farm drill used for trial	Aus seeder DBS D-300 tine seeder	Aus seeder DBS tine knife point	Simplicity seeder/ knife point	John Deere 1590 disc seeder
Stubble loading (t/ha)	6.4	8.3	7.4	7.8
Stubble height (cm)	33	40	15	47
Soil type description	Heavy grey clay	Self-mulching red loam over grey clay	Red clay	Yellow podzol–yellow-brown earth
Row spacing (cm)	30	38	33.3	19
Crop and rotation position	Second wheat	Second wheat	Second wheat	Canola after wheat

* NTSR — no-till full stubble retention
^ 40kg extra nitrogen at sowing – an additional 40kg N/ha broadcast before cultivation or sowing date.
All cultivation was carried out with a Lely multidisc cultivator except Henty, where a K-Line Speedtiller cultivator was used.





Trial 1: Daysdale, NSW

Key points

- There was no economic return from burning, cultivating or adding additional nitrogen (N) at sowing when establishing wheat on wheat on a heavy grey clay.
- Burning first wheat stubble and adding additional nitrogen at sowing significantly reduced the severity of yellow leaf spot (YLS) *Pyrenophora tritici repentis* during tillering and was evident at grain fill, though disease levels were low (5% on Flag-1).
- The average wheat yield from all treatments was 3.19t/ha from a total harvest dry matter (DM) of 8.41t/ha.
- In the same trial, faba bean plots yielded 2.89t/ha as grain and 6.68t/ha was harvested as forage DM at the late pod-fill stage.

Sowing date: 24 April 2014
Rotation: Second wheat
Variety: Wheat cv Whistler, faba beans cv Fiesta
Stubble: Wheat (various treatments applied)
Rainfall:
GSR: 332.6mm (April–October)
Summer rainfall: 70.2mm
Soil nitrogen at sowing: 93kg N/ha in NTSR (control) and 56kg N/ha in multidisc (0–60cm)

Results

i) Establishment and crop structure

Top working (cultivating) the heavy clay soil at low soil moisture levels resulted in a cloddy seedbed with significantly lower plant establishment (plants/m^2) and poorer vigour compared with the burn and no-till full stubble retention (NTSR) control blocks. However there were no statistical differences at the end of tillering/start of stem elongation (GS31) or when head numbers were assessed at harvest (Table 2).

ii) Weed population

Initial differences in annual ryegrass (*Lolium rigidum*) populations following pre-emergence treatment of herbicides revealed a trend for faba beans to carry a higher level of ryegrass, however at harvest there was no difference (Table 3).

TABLE 3 Broadleaf and ryegrass weed populations 21 May 2014, crop three leaves unfolded (GS13) and ryegrass 19 November 2014, harvest (GS99)

	Weeds (m^2)		
	GS13		GS99
Treatment	Broadleaf	Ryegrass	Ryegrass
NTSR (control)	0^{a}	3^{ab}	6^{a}
Burn	1^{a}	1^{b}	9^{a}
Cultivate (two passes)	1^{a}	0^{b}	10^{a}
Cultivate (two passes) + 40kg N/ha	0^{a}	1^{b}	2^{a}
Faba beans as grain	1^{a}	12^{ab}	6^{a}
Faba beans as forage	0^{a}	16^{a}	3^{a}
Mean	0.37	5.37	6.00
LSD	1.69	13.29	8.59

Figures followed by different letters are regarded as statistically significant.

TABLE 2 Plant counts and vigour 15 May 2014, one-leaf stage (GS11); plant counts 21 May 2014, three leaves unfolded (GS13); tiller counts 6 August 2014, first node (GS31) and head counts 19 November 2014, harvest (GS99)

	Crop growth stage				
	GS11		GS13	GS31	GS99
Treatment	Plants/m^2	Vigour*	Plants/m^2	Tillers/m^2	Heads/m^2
NTSR (control)	109^{a}	8^{b}	121^{a}	330^{a}	317^{ab}
Burn	112^{a}	9^{a}	117^{a}	356^{a}	335^{a}
Cultivate (two passes)	86^{ab}	6^{c}	94^{b}	382^{a}	337^{a}
Cultivate (two passes) + 40kg N/ha	77^{b}	6^{c}	84^{b}	367^{a}	282^{b}
Mean	**96**	**7.31**	**104**	**359**	**317**
LSD	28	0.55	23	75	43

* Vigour — measured on a scale of 1–10 where 1 = poor vigour
Figures followed by different letters are regarded as statistically significant.

iii) Dry matter production and nitrogen uptake

There were no differences in DM production or nitrogen uptake due to the stubble treatments applied. The mean DM and nitrogen uptake in the wheat at harvest was 8.41t/ha and 79kg N/ha, respectively.

iv) Disease levels

Burning and the addition of 40kg N/ha at sowing significantly decreased yellow leaf spot (YLS) (*Pyrenophora tritici repentis*) infection relative to the NTSR control when assessed at tillering during June (Table 4). Although disease levels were very low (5% severity on flag-1) the effects of stubble management and nitrogen application were still evident at grain fill (Table 5).

TABLE 4 Yellow leaf spot severity and incidence of the two newest fully-emerged leaves (flag-7, flag-8), assessed 19 June 2014 main stem and two tillers (GS22)

	YLS at GS22			
	Severity (% leaf area infected)		Incidence (% leaves infected)	
Treatment	Flag-7	Flag-8	Flag-7	Flag-8
NTSR (control)	0.4[a]	3.1[ab]	32.5[a]	95.0[a]
Burn	0.1[b]	0.1[c]	5.0[b]	47.5[b]
Cultivate (two passes)	0.3[a]	3.5[a]	30.0[a]	97.5[a]
Cultivate (two passes) + 40kg N/ha	0.2[ab]	1.5[bc]	15.0[ab]	87.5[a]
Mean	**0.23**	**2.14**	**20.6**	**81.9**
LSD	0.25	1.94	21.7	20.4

Figures followed by different letters are regarded as statistically significant.

v) Yield and grain quality

The different treatments produced no significant differences in either wheat yield or quality (Table 6). The faba beans harvested as forage on 31 October 2014 yielded an average of 6.68t/ha and when taken through to grain yielded 2.89t/ha.

Commercial application

For the establishment of second wheat on heavy grey clay with a yield potential of just over 3t/ha there was no yield gain from actively managing stubble from the previous wheat crop.

In year one of this experiment there was no economic return from either burning, cultivating or adding additional nitrogen before crop establishment.

There was evidence that adding more nitrogen at sowing, and burning, significantly reduced the severity of YLS, factors that could have more relevance in a wetter spring with higher disease pressure.

TABLE 5 Yellow leaf spot severity, incidence and green leaf retention (GLR) assessed 15 October 2014 mid–late flowering (GS68–70) on flag and flag-1

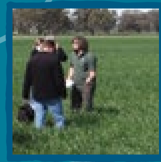
	YLS at GS68–70					
	Severity (% leaf area infected)		Incidence (% leaves infected)		GLR (% of leaf green)	
Treatment	Flag	Flag-1	Flag	Flag-1	Flag	Flag-1
NTSR (control)	0.68[ab]	5.4[a]	30.0[a]	67.5[a]	90.7[a]	53.1[a]
Burn	0.35[b]	1.5[b]	25.0[a]	55.0[a]	91.2[a]	57.8[a]
Cultivate (two passes)	1.00[a]	3.0[ab]	35.0[a]	65.0[a]	92.6[a]	49.1[a]
Cultivate (two passes) + 40kg N/ha	0.50[ab]	1.7[b]	37.5[a]	65.0[a]	91.1[a]	53.0[a]
Mean	**0.63**	**2.9**	**31.9**	**63.1**	**91.4**	**53.2**
LSD	0.65	3.0	20.7	21.4	4.0	16.0

Figures followed by different letters are regarded as statistically significant.

TABLE 6 Wheat yield, test weight, protein and screenings 27 November 2014, at harvest (GS99)

Treatment	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
NTSR (control)	3.17[a]	78.9[a]	8.1[a]	4.5[a]
Burn	3.10[a]	78.5[a]	8.1[a]	4.6[a]
Cultivate (two passes)	3.18[a]	79.1[a]	8.8[a]	4.2[a]
Cultivate (two passes) + 40kg N/ha	3.31[a]	78.3[a]	8.4[a]	5.0[a]
Mean	**3.19**	**78.7**	**8.4**	**4.56**
LSD	0.53	1.52	1.22	1.42

Figures followed by different letters are regarded as statistically significant.

Trial 2: Yarrawonga, Victoria

Key points

- Later-sown second wheat (20 May cv Young) established using no-till full stubble retention (NTSR) showed less dry matter (DM) production and nitrogen (N) uptake during stem elongation compared with crops where stubble was burnt, cultivated or removed.
- Although there were no statistical differences in yield, NTSR crops were the lowest yielding in a trial where yields ranged from 4.18–4.54t/ha.
- Burning significantly reduced yellow leaf spot (YLS) infection and decreased volunteer wheat populations before sowing compared with NTSR and cultivation treatments.
- NTSR crops had significantly lower test weights and higher screenings than crops established after stubble removal, burning or cultivation.

Sowing date: 20 May 2014

Rotation: Second wheat

Variety: Young

Stubble: Wheat (various treatments applied)

Rainfall:

GSR: 373mm (April–October)

Summer rainfall: 114mm

Soil nitrogen: 60kg N/ha NTSR (control), 51kg N/ha mulitdisc 0–60cm (8 May, before 35mm of rain during late April, early May)

Results

i) Establishment and crop structure

Establishment was lowest in the NTSR (control) blocks (131 plants/m^2), however there was no statistical difference between this and the other stubble treatments (Table 7). Visual vigour assessments indicated faster emergence and more uniform stands where straw was baled and removed, cultivated or burnt compared with the NTSR. Tillering was significantly lower in the NTSR control, however applying an extra 40kg N/ha at sowing increased tiller numbers to the levels observed in the burn or cultivated plots. By harvest, the number of heads in the NTSR control was comparable to the other stubble treatments.

ii) Weed populations

Weed populations in the trial were low. There were differences recorded in the growth of volunteer wheat before sowing, with burning giving the lowest volunteer population (Table 8). Assessments post emergence and at harvest showed weed populations to be very low and with no differences observed.

iii) Dry matter production

The NTSR control treatment produced significantly lower DM throughout the season than the other treatments. At harvest the differences were not significant except where extra nitrogen was added at sowing to the cultivated plots, however the lowest harvest DM results were associated with NTSR (Table 9).

TABLE 7 Plant counts and canopy vigour scores 6 June 2014, one-leaf stage (GS11); plant counts 17 June 2014 three leaves unfolded (GS13); tiller counts 28 August 2014, second node (GS32) and head counts 25 November 2014, harvest (GS99)

	Crop growth stage				
	GS11		GS13	GS32	GS99
Treatment	Plants/m^2	Vigour*	Plants/m^2	Tillers/m^2	Heads/m^2
NTSR (control)	131^{a}	5.3^{b}	174^{a}	240^{b}	311^{ab}
NTSR + 40kg N/ha	164^{a}	6.0^{ab}	191^{a}	303^{a}	355^{a}
Burn	170^{a}	7.3^{a}	195^{a}	301^{a}	300^{b}
Control + 40kg N/ha	164^{a}	6.0^{ab}	191^{a}	303^{a}	355^{a}
Remove straw	172^{a}	7.3^{a}	195^{a}	287^{a}	293^{b}
Cultivate (one pass)	150^{a}	6.8^{a}	175^{a}	304^{a}	326^{ab}
Cultivate (one pass) + 40kg N/ha	156^{a}	6.5^{ab}	172^{a}	325^{a}	320^{ab}
Mean	**157**	**6.5**	**184**	**294**	**317**
LSD	49	1.4	41	40	54

* Vigour — measured on a scale of 1–10 where 1 = poor vigour
Figures followed by different letters are regarded as statistically significant.

TABLE 8 Pre-sowing volunteer wheat 2 May 2014

Treatment	Weeds (m^2)
	Pre-sowing volunteers
NTSR (control)	7^{b}
NTSR + 40kg N/ha	15^{ab}
Burn	2^{b}
Remove straw	24^{ab}
Cultivate (one pass)	37^{a}
Cultivate (one pass) + 40kg N/ha	21^{ab}
Mean	**18**
LSD	28

Figures followed by different letters are regarded as statistically significant.

iv) Nitrogen uptake

Nitrogen uptake by the crop canopy by flowering was significantly lower in the NTSR and straw-removed no-till treatments (Table 10) compared with burning and cultivation, however greatest nitrogen uptake was measured where additional nitrogen was applied at sowing.

v) Yellow leaf spot control

When assessed at the start of stem elongation (GS30), burning had resulted in approximately 85% reduction of YLS compared with NTSR (control) on flag-7 (Table 11). Removing straw by raking reduced YLS in the crop. Cultivation was observed to have little or no effect.

At this site the differences in YLS infection after the booting stage were not assessed as disease levels were low all season.

Additionally, within each replicate plot, an area was set up to exclude a grower-applied application of fungicide (Folicur 150ml/ha applied on 12 August 2014 GS31) by placing a plastic sheet over a defined area during spraying. When these areas were assessed at GS32 and GS51 the applied fungicide was assessed to have had little or no effect on YLS severity and incidence relative to the untreated, area of the crop.

TABLE 9 Dry matter 28 August 2014, second node (GS32); 23 September 2014, mid-booting to start of ear emergence (GS45–51); 15 October 2014, mid-late flowering (GS65–69) and 25 November 2014, harvest (GS99)

Treatment	Dry matter (t/ha)			
	GS32	GS45–51	GS65–69	GS99
NTSR (control)	1.5^{b}	3.9^{b}	6.7^{c}	7.8^{b}
NTSR + 40kg N/ha	2.1^{a}	4.8^{a}	7.9^{ab}	8.5^{ab}
Burn	2.5^{a}	5.0^{a}	8.4^{a}	8.2^{ab}
Remove straw	2.4^{a}	4.9^{a}	7.3^{bc}	8.4^{ab}
Cultivate (one pass)	2.1^{a}	4.7^{a}	7.4^{bc}	7.8^{b}
Cultivate (one pass) + 40kg N/ha	2.3^{a}	5.1^{a}	7.8^{ab}	9.2^{a}
Mean	**2.1**	**4.8**	**7.6**	**8.3**
LSD	0.5	0.7	0.8	1.2

Figures followed by different letters are regarded as statistically significant.

TABLE 10 Nitrogen uptake in biomass 28 August 2014 second node (GS32); 23 September 2014, mid-booting to start of ear emergence (GS45–51); 15 October 2014, mid-flowering (GS65–69) and 25 November 2014, harvest (GS99)

Treatment	Nitrogen uptake in biomass (kg N/ha)			
	GS32	GS45-51	GS65–69	GS99
NTSR (control)	43^{b}	60^{b}	75^{c}	78^{bc}
NTSR + 40kg N/ha	46^{ab}	99^{a}	112^{a}	94^{b}
Burn	54^{ab}	73^{b}	96^{b}	83^{bc}
Remove straw	48^{ab}	65^{b}	72^{c}	58^{d}
Cultivate (one pass)	58^{a}	70^{b}	93^{b}	74^{cd}
Cultivate (one pass) + 40kg N/ha	58^{a}	107^{a}	104^{a}	131^{a}
Mean	**51**	**79**	**93**	**86**
LSD	13	15	14	16

Figures followed by different letters are regarded as statistically significant.



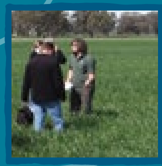


TABLE 11 Yellow leaf spot severity and incidence of the two newest fully-emerged leaves (flag-6, flag-7), assessed 22 July 2014, stem elongation (GS30)

	YLS (%) at GS30			
	Severity (% leaf area infected)		Incidence (% of leaves infected)	
Treatment	Flag-6	Flag-7	Flag-6	Flag-7
NTSR (control)	2.6^{a}	9.6^{a}	92.5^{a}	100.0^{a}
NTSR + 40kg N/ha	2.5^{ab}	7.9^{ab}	100.0^{a}	100.0^{a}
Burn	0.5^{c}	1.3^{c}	37.5^{b}	70.0^{b}
Remove straw	2.0^{b}	6.0^{b}	90.0^{a}	100.0^{a}
Cultivate (one pass)	2.6^{a}	9.4^{a}	92.5^{a}	100.0^{a}
Cultivate (one pass) + 40kg N/ha	2.5^{ab}	9.2^{a}	90.0^{a}	100.0^{a}
Mean	**2.1**	**7.2**	**83.8**	**95.0**
LSD	0.6	2.4	13.4	8.4

Figures followed by different letters are regarded as statistically significant.

vi) Yield and grain quality

Yields ranged from 4.18–4.54t/ha with no significant differences between treatments.

There were significant effects of treatment on grain quality with the lower-yielding NTSR treatments giving lower test weight and higher screenings than where stubble was cultivated, burnt or removed. Applying nitrogen at sowing significantly increased protein levels in the NTSR control treatment (Table 12).

Commercial application

In year one of this trial there was no significant evidence of a yield decrease from using NTSR in this later-sown second wheat rotation position. However, many other recorded characteristics (DM accumulation, nitrogen uptake, test weight and screenings) were less in the NTSR crops compared with crops grown using active stubble management such as burning, straw removal and cultivation. While active stubble management treatments have their own issues (reduced organic matter and nutrient return to the soil) the results suggest that later-sown (May) NTSR scenarios may be more responsive to active management than earlier-sown crops (April) where seedbeds are warmer, particularly if seedbeds are also wetter than normal for the time of year.

TABLE 12 Yield, protein, screenings and test weight 27 November 2014, harvest (GS99)

	Yield and quality			
Treatment	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
NTSR (control)	4.18^{a}	79.2^{c}	10.5^{bc}	5.4^{b}
NTSR + 40kg N/ha	4.18^{a}	78.2^{c}	12.0^{a}	10.0^{a}
Burn	4.43^{a}	82.1^{a}	9.9^{bc}	2.6^{d}
Remove straw	4.53^{a}	81.4^{ab}	9.6^{c}	2.9^{d}
Cultivate (one pass)	4.54^{a}	81.3^{ab}	9.9^{bc}	3.4^{cd}
Cultivate (one pass) + 40kg N/ha	4.30^{a}	80.9^{b}	11.1^{ab}	5.3^{bc}
Mean	**4.36**	**80.5**	**10.5**	**4.9**
LSD	0.46	1.0	1.2	1.9

Figures followed by different letters are regarded as statistically significant.

Trial 3: Dookie, Victoria

Key points

- Different active stubble management treatments produced second-wheat yields ranging from 4.98–5.85t/ha cv Corack.
- Stubble length of the previous crop had a significant effect on yield when adopting no-till stubble retention (NTSR). Long stubble (approximately 45cm) significantly decreased yield by 0.7t/ha in second-wheat crops compared with those established in short stubble (15cm).
- This yield reduction was associated with significantly lower dry matter (DM) production and nitrogen (N) uptake in the stem elongation phase of crop growth.
- NTSR crops grown on short stubble also showed significantly lower DM production compared with crops following burning, straw removal and cultivation (two passes), but the reduction was less pronounced and did not reduce yield.

Sowing date: 16 May 2014
Rotation: Second wheat
Variety: Corack
Stubble: Wheat (various treatments applied)
Rainfall:
GSR: 386mm (April–October)
Summer rainfall: 78mm
Soil nitrogen: 75kg N/ha NTSR (control), 88kg N/ha multidisc in 0–60cm (2 May 2014)

Results

i) Establishment and crop structure

The crop structure assessments revealed small but significant differences in plant establishment, vigour and tiller number (Table 13). Crops established in long stubble (approximately 45cm) had significantly lower plant establishment at the three-leaves-unfolded stage (GS13) than crops where stubble was burnt or raked and removed. Long stubble also reduced tillering relative to other establishment treatments. At maturity there was a degree of compensation in the crops established in long stubble, as there were no significant differences in head number.

ii) Weed populations

The various establishment treatments produced significant differences in the volunteer wheat population recorded at sowing, with two cultivation passes (top working) giving rise to four times the number of wheat volunteers compared with the no-till treatments (Table 14). Burning resulted in no wheat volunteers at assessment.

TABLE 14 Pre-sowing volunteer wheat 2 May 2014 and grass weeds 17 June 2014 three leaves unfolded (GS13)

Treatment	GS00 Volunteer wheat (plants/m^2)	GS13 Weeds (plants/m^2)
Short stubble (NTSR control)	12^{b}	0^{b}
Long stubble (NTSR)	8^{b}	2^{a}
Burn	0^{b}	1^{ab}
Remove straw	16^{b}	0^{b}
Cultivate (two passes)	52^{a}	1^{ab}
Mean	**18**	**0.67**
LSD	17	1.36

Figures followed by different letters are regarded as statistically significant.

TABLE 13 Plant counts and canopy vigour 30 May 2014, one-leaf stage (GS11); plant counts 17 June 2014, three leaves unfolded (GS13); tiller counts 28 August 2014, first node (GS31) and head counts 25 November 2014, harvest (GS99)

Treatment	Crop growth stage				
	GS11		GS13	GS31	GS99
	Plants/m^2	Vigour*	Plants/m^2	Tillers/m^2	Heads/m^2
Short stubble (NTSR control)	133^{a}	7.50^{cd}	136^{ab}	306^{a}	294^{a}
Long stubble (NTSR)	127^{a}	7.00^{d}	127^{b}	233^{b}	285^{a}
Burn	138^{a}	8.75^{a}	142^{a}	350^{a}	303^{a}
Remove straw	138^{a}	8.00^{bc}	142^{a}	306^{a}	301^{a}
Cultivate (two passes)	123^{a}	8.25^{ab}	134^{ab}	312^{a}	295^{a}
Mean	**132**	**7.90**	**136**	**301**	**296**
LSD	17	0.61	14	51	42

*Vigour — measured on a scale of 1–10 where 1 = poor vigour
Figures followed by different letters are regarded as statistically significant.



iii) Dry matter production

The main differences in crop DM production were associated with long stubble, with these crops producing significantly less DM than all other active stubble treatments when assessed from first node (GS31) to flowering (GS65) (Table 15).

For the same period of growth, crops established in burnt stubbles and after two cultivation passes produced the greatest amount of DM.

iv) Nitrogen uptake

In the stem elongation phase of crop growth the nitrogen uptake was significantly lower in the long-stubble treatment than all other treatments, including the NTSR control (short stubble) (Table 16). The greatest nitrogen uptake into the canopy by this growth stage was measured in the burnt treatment.

Disease levels were extremely low at this trial site with less than 1% disease severity and 25% disease incidence on leaves during early tillering. Even with these extremely low levels of yellow leaf spot (YLS) (*Pyrenophora tritici repentis*), burning stubbles resulted in crops with the lowest levels of infection (data not shown).

v) Yield and grain quality

Yields ranged from 4.98–5.85t/ha. Although second wheat crops grown after burning produced the highest yields (0.2–0.3 t/ha better than the next best treatments), the only difference in yield was measured with the crop grown in longer stubble, which yielded significantly less than all other establishment techniques (Table 17). The lower yield in this treatment also correlated with higher protein levels than those measured following burning or cultivating.

Commercial application

When reviewing the results from this trial work it is important to note they are the collation of only one year of data.

The most important application of this work arises from the influence of stubble length on DM production, tillering and final yield.

TABLE 15 Dry matter 14 August 2014, first node (GS31); 17 September 2014, start of ear emergence (GS51); 3 October 2014, mid-flowering (GS65) and 21 November 2014, harvest (GS99)

Treatment	Dry matter (t/ha)			
	GS31	GS51	GS65	GS99
Short stubble (NTSR control)	1.80^{b}	5.14^{c}	7.78^{b}	10.10^{ab}
Long stubble (NTSR)	1.34^{c}	4.02^{d}	6.85^{c}	9.86^{b}
Burn	2.11^{a}	5.94^{a}	9.12^{a}	11.18^{a}
Remove straw	2.01^{ab}	5.43^{bc}	8.39^{ab}	10.72^{ab}
Cultivate (two passes)	1.98^{ab}	5.65^{ab}	8.71^{a}	10.72^{ab}
Mean	**1.85**	**5.24**	**8.17**	**10.52**
LSD	0.23	0.49	0.86	1.18

Figures followed by different letters are regarded as statistically significant.

TABLE 16 Nitrogen uptake in biomass 14 August 2014, first node (GS31); 17 September 2014, start of ear emergence (GS51); 3 October 2014, mid-flowering (GS65) and 21 November 2014, harvest (GS99)

Treatment	Nitrogen uptake (kg N/ha)			
	GS31	GS51	GS65	GS99
Short stubble (NTSR control)	62^{b}	94^{ab}	97^{b}	114^{a}
Long stubble (NTSR)	45^{c}	82^{b}	112^{ab}	118^{a}
Burn	78^{a}	114^{a}	119^{ab}	125^{a}
Remove straw	67^{ab}	95^{ab}	125^{a}	111^{a}
Cultivate (two passes)	66^{ab}	100^{ab}	103^{ab}	125^{a}
Mean	**64**	**97**	**111**	**119**
LSD	12	26	23	24

Figures followed by different letters are regarded as statistically significant.

TABLE 17 Yield, protein, screenings and test weight 21 November 2014, harvest (GS99)

Treatment	Yield and quality			
	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
Short stubble (NTSR control)	5.66[a]	79.1[ab]	10.6[ab]	2.9[a]
Long stubble (NTSR)	4.98[b]	76.4[b]	11.6[a]	3.2[a]
Burn	5.85[a]	79.2[ab]	10.4[b]	3.0[a]
Remove straw	5.66[a]	77.5[ab]	10.9[ab]	3.3[a]
Cultivate (two passes)	5.56[a]	79.3[a]	10.3[b]	2.5[a]
Mean	**5.54**	**78.3**	**10.74**	**3.0**
LSD	0.45	2.9	1.05	0.8

Figures followed by different letters are regarded as statistically significant.

Long stubble (45cm) decreased yield by approximately 0.7t/ha compared with the NTSR control (short stubble) (15cm) and by 0.85t/ha compared with burnt stubbles. This reduction in yield appears to be linked with decreased DM production, particularly in the earlier stages of stem elongation.

How much the reduction in growth is a result of poor light interception compared with temperature cannot be determined from this trial, however the spindly winter growth characteristics of crops grown in long stubble would suggest a reduction in light when the sun is lower in elevation may be a strong contributor. When establishing crops between the rows of the previous crop it is important to consider stubble length in relation to the early growth of the crop.

Summary of results from three second-wheat trials

Comparing the establishment treatments that were common across all three trials (Daysdale, Yarrawonga and Dookie) revealed a small trend for increased yields with cultivation and burnt stubbles before sowing second wheat (Table 18). However none of the differences were statistically significant in the individual trials. The largest impact on second-wheat yield was stubble length at the Dookie site, where a 30cm increase in standing stubble length reduced yield by 0.7t/ha.

TABLE 18 Yield summary of the common treatments from the three large plot trials

Treatment	Yield (t/ha and % of NTSR control)						
	Trial 1 (Daysdale)		Trial 2 (Yarrawonga)		Trial 3 (Dookie)		
	(t/ha)	(% of control)	(t/ha)	(% of control)	(t/ha)	(% of control)	Mean
NTSR (control)	3.17	100	4.18	100	5.66	100	**100.0**
Burn	3.10	98	4.43	106	5.85	103	**102.3**
Cultivate (1–2 passes)	3.18	100	4.54	109	5.56	98	**102.3**
GSR (mm) (Apr–Oct)	333		373		386		

Trial 4: Henty, NSW

Key points

- Under moist mid-April sowing conditions, there was a significant yield advantage (0.45t/ha) with one shallow-pass cultivation before establishing canola, compared with crops sown directly into standing wheat stubble.
- The yield advantage of canola following a cultivation correlated to crops with higher vigour, early dry matter (DM) and greater nitrogen (N) uptake.
- There was no significant benefit to mulching the first wheat stubble before direct drilling canola.
- The addition of 40kg N/ha at sowing gave a significant yield increase to crops established directly into the first wheat stubble, but there was no significant advantage to the additional nitrogen where stubbles were cultivated or mulched.

Sowing date: 16 April 2014
Rotation: Canola following wheat
Variety: GT50 RR
Stubble: Wheat (various treatments applied)
Rainfall:
GSR: 390mm (April–October)
Summer rainfall: 85mm
Soil nitrogen: 62kg N/ha NTSR (control), 84kg N/ha multidisc in 0–60cm (31 March 2014)

Results

i) Establishment and crop structure

One-pass cultivation of the soil before establishment resulted in crops with significantly more vigour and earlier flowering in comparison to crops established with no-till full stubble retention (NTSR). Mulching the wheat straw had no effect compared with the NTSR. As NTSR with the disc drill flattened the stubble at establishment (Figure 1a versus Figure 1b), it is likely the NTSR (standing) treatment shared many characteristics with the mulched stubble; hence the lack of difference between them. The addition of 40kg N/ha did not significantly influence plant establishment, vigour or flowering. There was no evidence the addition of nitrogen influenced crop establishment or structure (Table 19).

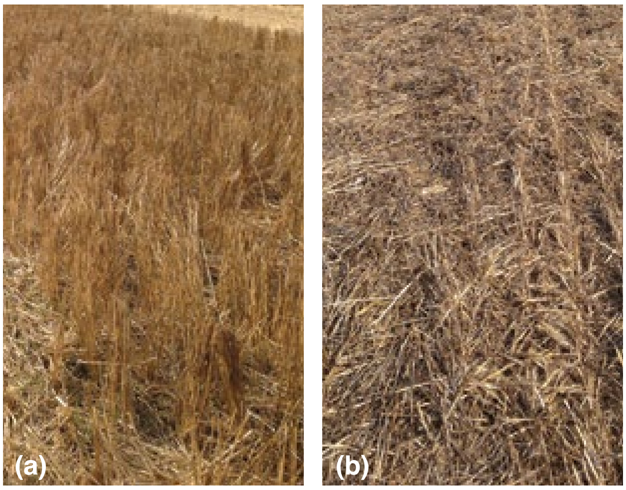


FIGURE 1 Comparison of NTSR before sowing (a) and NTSR after sowing (b)

TABLE 19 Plant counts and canopy vigour scores 21 May 2014, three leaves unfolded (GS13); raceme counts and percentage started flowering (%) 7 August 2014, yellow bud-start of flowering (GS59–61) and raceme counts 3 November 2014, harvest (GS99)

	Canopy composition (mean of nitrogen levels)				
	GS13		GS59–61		GS99
Treatment	Plants/m^2	Vigour*	Flower shoots/m^2	Flowering %	Raceme /m^2
NTSR (control)	33^{a}	4.3^{b}	79^{b}	26^{b}	278^{a}
Mulched	35^{a}	4.2^{b}	87^{b}	33^{b}	283^{a}
Cultivated (one pass)	37^{a}	6.3^{a}	110^{a}	40^{a}	268^{a}
Mean	**35**	**4.9**	**92**	**33**	**276**
LSD	9	0.3	19	7	39
Additional nitrogen at sowing (mean of establishment)					
Nil	33^{a}	4.8^{a}	99^{a}	30^{a}	275^{a}
40kg N/ha	36^{a}	5.0^{a}	86^{a}	35^{a}	278^{a}
LSD	7	0.3	15	6	32

* Vigour — measured on a scale of 1–10 where 1 = poor vigour
Figures followed by different letters are regarded as statistically significant.

There were no significant differences in broadleaf or grass weed populations in the trial (data not shown).

ii) Dry matter production

Crops established following one-pass cultivation with the K-Line Speedtiller tended to produce higher DM throughout the season, however these differences were not significant except at the green bud assessment. (Table 20).

The addition of extra nitrogen at establishment increased DM production up until flowering, after which there was no difference.

iii) Nitrogen uptake

Nitrogen uptake by the crop was greater after cultivation when measured at green bud (Table 21). The addition of nitrogen at establishment increased nitrogen uptake up to mid-flowering, after which there was no difference.

There were low levels of leaf phoma in the trial, the disease associated with blackleg in canola (caused by fungus *Leptosphaeria maculans*), but there were no differences due to treatment (data not shown).

iv) Yield and quality

Cultivating the soil resulted in significantly higher canola yields than the NTSR control treatment (Table 22). There was no difference in yield between mulching the wheat stubble compared with sowing straight into the stubble, likely due to flattening of the NTSR stubble by the seed drill and the resultant similarities between the two treatments. When all stubble management treatments were considered, the addition of 40kg N/ha at sowing resulted in a 0.15t/ha yield difference overall, which was not significant.

When individual treatments were compared, cultivation gave a significant yield advantage (0.45t/ha) over crops

TABLE 20 Dry matter 9 July 2014, green bud (GS51); 20 August 2014, mid-flowering (GS65); 7 October 2014, mid pod set (GS75) and 21 November 2014, harvest (GS99)

Treatment	Dry matter (t/ha)			
	GS51	GS65	GS75	GS99
NTSR (control)	1.72^{b}	5.32^{a}	7.66^{a}	9.43^{a}
Mulched	1.65^{b}	5.53^{a}	8.41^{a}	8.42^{a}
Cultivated (one pass)	2.25^{a}	5.67^{a}	9.70^{a}	10.03^{a}
Mean	**1.87**	**5.51**	**8.59**	**9.29**
LSD	0.45	0.95	2.24	2.33
Additional nitrogen at sowing (mean of establishment)				
Nil	1.57^{b}	4.70^{b}	8.46^{a}	8.76^{a}
40kg N/ha	2.18^{a}	6.31^{a}	8.72^{a}	9.83^{a}
LSD	0.37	0.78	1.83	1.90

Figures followed by different letters are regarded as statistically significant.

TABLE 21 Nitrogen uptake 9 July 2014 green bud (GS51); 20 August 2014, mid-flowering (GS65); 7 October 2014, mid pod set (GS75) and 21 November 2014, harvest (GS99)

Treatment	Nitrogen uptake (kg N/ha)			
	GS51	GS65	GS75	GS99
NTSR (control)	46^{b}	138^{ab}	99^{a}	109^{a}
Mulched	41^{b}	157^{a}	101^{a}	96^{a}
Cultivated (one pass)	60^{a}	125^{b}	96^{a}	108^{a}
Mean	**49**	**140**	**99**	**104**
LSD	13	28	27	31
Additional nitrogen at sowing (mean of establishment)				
Nil	40^{b}	112^{b}	88^{a}	94^{a}
40kg N/ha	58^{a}	167^{a}	110^{a}	115^{a}
LSD	11	23	22	57

Figures followed by different letters are regarded as statistically significant.



TABLE 22 Influence of establishment method (mean of nitrogen level) and nitrogen level (mean of establishment) on yield, oil content and protein at harvest (GS99), 24 November 2014

Treatment	Yield (t/ha)	Oil (%)	Protein (%)
NTSR (control)	2.22[b]	43.0[a]	22.7[a]
Mulched	2.25[b]	43.3[a]	23.1[a]
Cultivated (one pass)	2.55[a]	44.0[a]	21.9[a]
Mean	2.34	43.4	22.6
LSD	0.27	1.6	2.2
Additional nitrogen at sowing (mean of establishment)			
Nil	2.26[a]	43.6[a]	22.2[a]
40kg N/ha	2.42[a]	43.2[a]	23.0[a]
LSD	0.23	1.1	1.3

Figures followed by different letters are regarded as statistically significant.

TABLE 23 Influence of establishment method and nitrogen level on yield, oil content and protein at harvest (GS99), 24 November 2014

Treatment	Grain yield and quality	
	Yield (t/ha)	Oil (%)
NTSR (control)	2.02[c]	43.2[a]
NTSR + 40kg N/ha	2.42[ab]	42.7[a]
Mulched	2.29[abc]	43.8[a]
Mulched + 40kg N/ha	2.21[bc]	42.7[a]
Cultivated	2.48[ab]	43.7[a]
Cultivated + 40kg N/ha	2.63[a]	44.2[a]
Mean	**2.34**	**43.4**
LSD	0.36	1.85

Figures followed by different letters are regarded as statistically significant.

established directly into the standing wheat stubble (NTSR control treatment) (Table 23). The addition of 40kg/N ha significantly increased the yield of the NTSR control crop; with the mulched and cultivated crops the effect of nitrogen addition on yield was non-significant.

Commercial application

When making stubble management decisions keep in mind these results are from one year of data only.

With wetter conditions and an early break there was a significant yield advantage to canola established following cultivation compared with the NTSR control treatment. The yield advantage of canola following cultivation correlated to better vigour, higher early DM production and nitrogen uptake.

There was evidence that additional nitrogen at sowing could benefit NTSR crops under the moist mid-April conditions.

Although there was no evidence to suggest that mulching first wheat stubbles increased the subsequent canola crop productivity, it should be emphasised that direct drilling into the stubbles under these moister conditions (and with this drill on narrow row spacings) flattened the stubble rather than leaving it standing. Under drier conditions, or with a wider row spacing, the stubble may have stayed more erect following sowing, which could result in greater early shading and potentially impact on early growth, as was found to be the case at Dookie with second wheat establishment.

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Early sowing and the interaction with row spacing and variety in first wheat under full stubble retention

Nick Poole and Michael Straight
FAR Australia in conjunction with Riverine Plains Inc

Key points

- Two trials with first wheat sown during mid-April 2014 showed no difference in grain yield or quality as a result of being grown on 22.5cm or 30cm row spacings.
- Crops grown on a 37.5cm row spacing were 5–6% lower yielding than crops on the 30cm spacing.
- Although these are single-year results, they indicate the yield advantages of a narrow spacing (22.5cm) over 30cm, measured with later-sown wheat crops, may not be apparent when wheat crops are sown early (during mid-April).
- Trends suggesting higher dry matter (DM) production with a narrow row spacing, which were observed with later-sown crops, were still apparent in these earlier-sown crops, however this did not translate to higher grain yields.

Previous row spacing findings

Results from the Riverine Plains Inc *Water Use Efficiency (WUE)* project demonstrated that wheat grown on a narrow row spacing of 22.5cm was higher yielding than crops grown on wider rows (30–37.5cm). This difference in yield was correlated to lower dry matter (DM) production on wider rows, partly due to late canopy closure, with less sunlight interception compared with crops sown on narrower rows, which generate full ground cover earlier in the season.

All of the previous WUE project trials (2009–13) were sown in the mid May–early June sowing window, prompting the question; "would wider rows be more successful if wheat crops were sown earlier?" Earlier sowing would result in earlier canopy closure for all row spacings, which may influence the relative differences in DM production and final grain yield.

Method

To answer the question of the influence of early sowing on wheat row spacing, two trials were set up under the Riverine Plains Inc stubble project: *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* (2013–18). The two trials, one in Barooga, NSW and the other in Yarrawonga, Victoria, were sown 16 April 2014 and 17 April 2014; this is four to six weeks earlier than the previous WUE project trials.

Four varieties, Wedgetail (winter wheat), Eaglehawk, Lancer and Bolac (longer-season spring wheats) were sown at identical sowing rates per unit area at three row spacings: 22.5cm, 30cm and 37.5cm. The trial was established as a split plot design with row spacing as the main plot and variety as the sub plot, and replicated four times. Monoammonium phosphate (MAP) was applied at 70kg/ha at sowing with all subsequent management being the same across the trials in line with the host farmer's paddock management.



Trial 1: Barooga, NSW

Sowing date: 16 April 2014
Rotation: First wheat after canola
Varieties: Bolac, Eaglehawk, Lancer and Wedgetail
Stubble: Canola, unburnt
Rainfall:
GSR: 348mm (April–October)
Summer rainfall: 84mm
Soil mineral nitrogen: 73kg N/ha (0–60cm)

Results

i) Establishment and crop structure

The widest row spacing (37.5cm) had significantly lower plant establishment and tiller numbers in comparison to the 22.5cm and 30cm row spacings (Table 1). At harvest there was no significant difference in head numbers.

There were significant differences in establishment, tiller numbers and final head counts as a result of varietal selection, with Bolac and Wedgetail producing significantly more heads than Lancer and Eaglehawk (Table 1). The advantage in the number of heads produced can be related to higher plant populations established and tiller numbers.

TABLE 1 Plant counts 13 May 2014, three leaves unfolded (GS13), tiller counts 28 July 2014, targeted first node* (GS31–32) and head counts 18 November 2014, harvest (GS99)

	Crop structure (m^2)		
Row spacing (cm)	Plants	Tillers*	Heads
22.5	130^{a}	421^{a}	349^{a}
30	130^{a}	410^{a}	325^{a}
37.5	117^{b}	351^{b}	324^{a}
Mean	**126**	**394**	**333**
LSD	12	33	32
Variety			
Bolac	138^{a}	411^{b}	376^{a}
Eaglehawk	118^{b}	338^{c}	284^{b}
Lancer	106^{c}	343^{c}	313^{b}
Wedgetail	142^{a}	485^{a}	358^{a}
LSD	12	46	39

* Actual growth stages at tillering assessment to account for varietal development differences; Wedgetail GS31, Eaglehawk, Lancer and Bolac GS32.

ii) Dry matter production and nitrogen uptake

There was a trend for narrower row spacing to produce a greater amount of DM than wider rows, however only at first node (GS31) was the difference statistically significant (Table 2). At GS31, the 37.5cm row spacing produced significantly less DM than the 30cm spacing. The lower harvest head numbers recorded with Lancer and Eaglehawk were reflected in lower final harvest DM weights compared with Wedgetail and Bolac (Table 2). However, differences in DM production at GS31 did not translate to significant differences in nitrogen uptake at that time (Table 3).

TABLE 2 Dry matter 28 July 2014, first node* (GS31), 30 September, targeted start of flowering* (GS61–65) and 18 November 2014, harvest (GS99)

	Dry matter (t/ha)		
Row spacing (cm)	GS31	(GS61–65)*	GS99
22.5	2.9^{ab}	9.1^{a}	10.3^{a}
30.0	3.1^{a}	8.6^{a}	9.7^{ab}
37.5	2.7^{b}	8.4^{a}	9.6^{b}
Mean	**2.9**	**8.7**	**9.9**
LSD	0.3	1.1	0.6
Variety			
Bolac	3.2^{ab}	9.3^{a}	10.2^{ab}
Eaglehawk	2.5^{b}	8.2^{b}	9.1^{c}
Lancer	2.7^{ab}	8.6^{ab}	9.5^{bc}
Wedgetail	3.2^{a}	8.7^{ab}	10.6^{a}
LSD	0.6	0.9	0.9

* Actual growth stages GS61 assessment Eaglehawk GS61, Lancer and Bolac GS65, Wedgetail GS63

TABLE 3 Nitrogen uptake in biomass 28 July 2014, first node (GS31), 30 September 2014, start of flowering (GS61) and 18 November 2014, harvest (GS99)

	Nitrogen uptake in biomass (kg N/ha)		
Row spacing (cm)	GS31	GS61	GS99
22.5	60^{a}	92^{a}	101^{a}
30.0	68^{a}	89^{a}	84^{a}
37.5	62^{a}	91^{a}	90^{a}
Mean	**63**	**91**	**92**
LSD	9	18	25
Variety			
Bolac	60^{a}	89^{b}	95^{ab}
Eaglehawk	66^{a}	85^{b}	81^{b}
Lancer	57^{a}	82^{b}	86^{ab}
Wedgetail	71^{a}	107^{a}	105^{a}
LSD	14	13	24

TABLE 4 Yield, protein, screenings and test weight at harvest (GS99), 27 November 2014

Row spacing (cm)	Yield and quality			
	Yield (t/ha)	Protein (%)	Screenings (%)	Test weight (kg/hL)
22.5	3.85[ab]	11.8[a]	2.8[a]	77.5[a]
30.0	3.98[a]	11.9[a]	2.7[a]	78.9[a]
37.5	3.78[b]	11.8[a]	2.6[a]	79.2[a]
Mean	**3.87**	**11.9**	**2.7**	**78.5**
LSD	0.19	0.7	0.2	1.8
Variety				
Bolac	4.14[a]	11.2[b]	3.4[a]	79.9[a]
Eaglehawk	3.27[b]	12.4[a]	3.2[a]	78.5[a]
Lancer	4.02[a]	12.0[a]	2.2[b]	80.2[a]
Wedgetail	4.05[a]	11.9[a]	2.0[b]	75.5[b]
LSD	0.17	0.6	0.4	2.0

TABLE 5 Average biomass at harvest, yield (0% moisture), harvest index (HI), calculated water use efficiency (WUE), calculated transpiration, calculated evaporation/drainage and transpiration efficiency (TE)

Row spacing (cm)	Biomass[1] (t/ha)	Yield[1] (t/ha)	HI[2] (%)	WUE[3] (kg/mm)	Transpiration[4] (mm)	Evaporation[5] (mm)	TE[6] (kg/mm)
22.5	10.32	3.37	33.0	9.8	187.7	156.8	18.1
30.0	9.71	3.49	36.4	10.1	176.6	167.9	20.0
37.5	9.60	3.31	34.6	9.6	174.5	170.0	19.0
Mean	**9.88**	**3.39**	**34.7**	**9.8**	**179.6**	**164.9**	**19.1**
LSD	0.64	0.17	2.8	0.5	11.6	11.6	1.5

GSR (April–October) 315.1mm plus calculated soil water available on 1 April (29.4mm) — total 344.5mm

1. All harvest biomass and grain yield calculations are based on DM content (i.e. 0% moisture, rather than grain at 12.5% moisture as in section iii of this report).
2. Harvest index (HI) is calculated by dividing the final harvest yield by the final harvest biomass.
3. Water use efficiency (WUE) is calculated by dividing grain yield by the available soil water (mm).
4. Transpiration through the plant was based on a maximum 55kg biomass/ha.mm transpired for wheat.
5. Soil evaporation, drainage, or unused water is calculated as the water that remains unaccounted for after transpiration water has been subtracted from available soil water (stored in the fallow plus GSR).
6. Transpiration efficiency (TE) is calculated by dividing the final harvest yield per mm. water transpired through the plant.

iii) Grain yield and quality

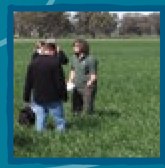
The optimum row spacing in terms of grain yield was 30cm, which was significantly higher yielding than crops sown on the 37.5cm spacing. There was no significant difference in yield between the 22.5cm and 30cm spacings. There were also no significant effects of row spacing on grain quality parameters of protein, screenings and test weight (Table 4).

In terms of variety performance, Eaglehawk yielded significantly less than the other varieties. Bolac had the lowest protein levels, and Wedgetail had the lowest test weight.

iv) Water use efficiency calculations

There were no significant differences in WUE due to row spacing (Table 5). Significantly higher DM production with crops grown on the narrow row spacing (22.5cm) did not translate to higher yields compared with those on the wider row spacings, resulting in a lower harvest index (HI). Although crops grown on the wider row spacings appeared to result in more efficient grain production per millimetre of water transpired through the plant (TE), this effect was negated by calculations indicating greater water losses though soil evaporation or unused water in crops on the wider rows.





Trial 2: Yarrawonga, Victoria

Sowing date: 17 April 2014
Rotation: First wheat after canola
Variety: Bolac, Eaglehawk, Lancer and Wedgetail
Stubble: Canola unburnt
Rainfall:
GSR: 372.8mm (April–October)
Summer rainfall: 113.6mm
Soil mineral nitrogen: 48kg N/ha (0–60cm)

Results

i) Establishment and crop structure

There were small but significant differences in crop establishment at different row spacings, with established plant populations varying from 101–113 plants/m^2 (Table 6). The narrow row spacing (22.5cm) produced significantly more tillers per unit area than wider row spacings. Trends in variety crop structure were similar to Trial 1 at Barooga, NSW, with Bolac and Wedgetail producing significantly higher plant populations, tillers and heads than Lancer and Eaglehawk (Table 6).

ii) Dry matter production and nitrogen uptake

The 22.5cm row spacing produced significantly more DM at the flowering and harvest assessments than crops sown on the 30cm and 37.5cm spacings (Table 7). Comparison of varieties revealed significantly less harvest DM with Lancer than the three other varieties. There was an indication that the significantly higher DM production measured with the narrow row spacing was associated with higher nitrogen uptake, although it was only significant at mid-flowering (Table 8). There were no differences in nitrogen uptake between varieties.

TABLE 6 Plant counts 13 May 2014, three leaves unfolded (GS13), tiller counts 26 August 2014, third node–flag leaf emergence (GS33–GS39) and head counts 25 November 2014, harvest (GS99)

	Crop structure (m^2)		
Row spacing (cm)	**Plants**	**Tillers***	**Heads**
22.5	101^{b}	359^{a}	359^{a}
30.0	113^{a}	319^{b}	321^{a}
37.5	106^{b}	288^{c}	318^{a}
Mean	**107**	**322**	**333**
LSD	5	19	24
Variety			
Bolac	110^{a}	337^{b}	352^{a}
Eaglehawk	95^{b}	299^{c}	306^{b}
Lancer	107^{ab}	281^{c}	301^{b}
Wedgetail	115^{a}	370^{a}	373^{a}
LSD	15	26	32

* Actual growth stages at the tillering assessment were; Bolac, Lancer GS39, Wedgetail, Eaglehawk GS33.

TABLE 7 Dry matter 4 August 2014, first node* (GS31–32), 2 October 2014, mid-flowering* (GS65–69) and 25 November 2014, harvest (GS99)

	Dry matter (t/ha)		
Row spacing (cm)	**GS31–32***	**GS65–69***	**GS99**
22.5	3.1^{a}	10.0^{a}	11.6^{a}
30.0	3.1^{a}	9.2^{b}	10.3^{b}
37.5	3.0^{a}	8.5^{b}	10.1^{b}
Mean	**3.1**	**9.2**	**10.7**
LSD	0.4	0.9	0.8
Variety			
Bolac	3.5^{a}	9.9^{a}	10.7^{ab}
Eaglehawk	2.8^{b}	9.1^{ab}	11.0^{a}
Lancer	2.9^{b}	8.7^{b}	10.1^{b}
Wedgetail	3.2^{ab}	9.3^{ab}	10.9^{a}
LSD	0.4	1.1	0.7

* Actual growth stages at GS31 assessment were; Bolac GS32, Wedgetail GS31, Eaglehawk GS32, Lancer GS32. Actual growth stages at GS65 assessment; Bolac GS69, Wedgetail GS65, Eaglehawk GS65, Lancer GS69.

TABLE 8 Nitrogen uptake in biomass 4 August 2014, first node–third node (GS31–GS33), 2 October 2014, mid-flowering (GS65) and 25 November 2014, harvest (GS99)

	Nitrogen uptake in biomass (kg N/ha)		
Row spacing (cm)	**GS31**	**GS65**	**GS99**
22.5	90^{a}	141^{a}	121^{a}
30.0	91^{a}	110^{b}	100^{b}
37.5	86^{a}	114^{b}	106^{ab}
Mean	**89**	**122**	**109**
LSD	10	24	18
Variety			
Bolac	98^{a}	122^{ab}	101^{a}
Eaglehawk	86^{b}	119^{b}	112^{a}
Lancer	81^{b}	113^{b}	105^{a}
Wedgetail	90^{ab}	134^{a}	119^{a}
LSD	12	15	22

iii) Grain yield and quality

Row spacing had no significant effect on grain yield, although the trends are identical to Trial 1 at Barooga, NSW with crops grown on the 30cm row spacing producing the optimum yield and crops sown on the 37.5cm spacing producing a lower yield than both the 22.5cm and 30cm spacings (Table 9). There were no effects of row spacing on grain quality measurements of protein, screenings and test weight. At this trial site Wedgetail and Lancer were significantly higher yielding than Bolac and Eaglehawk.

iv) Water use efficiency calculations

When comparing WUE, the significantly higher biomass produced on the narrow row spacing (22.5cm) led to significantly more water being used by the crop (calculated transpiration use) than on the wider row spacings (Table 10). The higher DM of crops grown on the narrow row spacing did not translate into higher grain yields, resulting in significantly lower harvest index (HI) and lower transpiration efficiency (TE). Despite the advantages of the wider row spacings in terms of HI and calculated TE there were no significant differences in calculated WUE due to row spacing since wider rows were calculated to have lost significantly more water through soil evaporation (and or other unused water).

TABLE 9 Yield, protein, screenings and test weight at harvest (GS99), 27 November 2014

Row spacing (cm)	Yield and quality			
	Yield (t/ha)	Protein (%)	Screenings (%)	Test weight (kg/hL)
22.5	4.49[a]	12.1[a]	6.81[a]	74.6[a]
30.0	4.55[a]	12.2[a]	6.96[a]	75.9[a]
37.5	4.27[a]	12.4[a]	7.09[a]	75.9[a]
Mean	**4.44**	**12.2**	**0.07**	**75.5**
LSD	0.29	0.3	0.02	2.4
Variety				
Bolac	4.01[b]	12.4[a]	11.46[a]	72.6[c]
Eaglehawk	4.22[b]	12.1[a]	10.79[a]	76.4[b]
Lancer	4.73[a]	12.4[a]	2.61[b]	79.5[a]
Wedgetail	4.79[a]	12.2[a]	2.96[b]	73.3[c]
LSD	0.28	0.3	0.02	2.3

TABLE 10 Average biomass at harvest, yield (0% moisture), harvest index (HI), calculated water use efficiency (WUE), calculated transpiration, calculated evaporation/drainage and transpiration efficiency (TE)

Row spacing (cm)	Biomass[1] (kg/ha)	Yield[1] (t/ha)	HI[2] (%)	WUE[3] (kg/mm)	Transpiration[4] (mm)	Evaporation[5] (mm)	TE[6] (kg/mm)
22.5	11.64	3.93	34.2	10.9	211.7	148.1	18.8
30.0	10.28	3.98	38.9	11.1	186.9	172.8	21.4
37.5	10.14	3.73	37.0	10.4	184.3	175.5	20.4
Mean	**10.69**	**3.88**	**36.7**	**10.8**	**194.3**	**165.5**	**20.2**
LSD	0.536	0.50	0.7	0.7	4.6	4.6	0.0

GSR (April–October) 320.1mm plus calculated soil water available on 1 April (39.7mm) — total 359.8mm

1. All harvest biomass and grain yield calculations are based on DM content (i.e. 0% moisture, rather than grain at 12.5% moisture as in section iii of this report).
2. Harvest index (HI) is calculated by dividing the final harvest yield by the final harvest biomass.
3. Water use efficiency (WUE) is calculated by dividing grain yield by the available soil water (mm).
4. Transpiration through the plant was based on a maximum 55kg biomass/ha.mm transpired for wheat.
5. Soil evaporation, drainage, or unused water is calculated as the water that remains unaccounted after transpiration water has been subtracted from available soil water (stored in the fallow plus GSR).
6. Transpiration efficiency (TE) is calculated by dividing the final harvest yield per mm. water transpired through the plant.

Commercial application

As these are only one-year results, exercise caution when interpreting these findings on farm. However since both trial sites gave similar yield results the indications are that when sowing wheat in the early window of mid-April the yield advantage of crops grown on a narrow (22.5cm) row spacing over a wide (30cm) row spacing has not been observed. These results are contrary to previous findings in the WUE project, whereby wheat crops were sown later in the main season window of mid-May to early June.

Acknowledgments

The trial was carried out as part of the Riverine Plains Inc GRDC-funded project *Maintaining profitable farming systems with retained stubble in the Riverine Plains region*.

Thanks go to the farmer co-operators, J and S Bruce Barooga, NSW and Telewonga Pty Ltd, Yarrawonga, Victoria.

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Interaction between fungicide program and in-crop nitrogen timing for the control of yellow leaf spot (YLS) in early-sown wheat

Nick Poole and Michael Straight
FAR Australia in conjunction with Riverine Plains Inc

Key points

- Positive yield responses from the control of yellow leaf spot (YLS) (*Pyrenophora tritici repentis*) were recorded despite disease levels not exceeding 10% on the top three leaves in this wheat-on-wheat rotation position.
- For the second year in succession there was a significant yield increase (0.23t/ha mean of two fungicide products) from two fungicide applications made at the late tillering stage and the second node stage (GS25 and GS32).
- The yield response from two fungicides corresponded to significantly better disease control than the untreated control and increased the crop canopy greenness.
- Although single fungicide timings produced little or no evidence of YLS control, significant yield increases were measured (0.13–0.14t/ha).
- Nitrogen timing (application of 40kg/ha nitrogen at either tillering (GS22) or first node stage (GS31)) had no significant effects on disease levels, yield or quality.

Location: Coreen, NSW
Sowing date: 28 April 2014
Rotation: Second wheat
Variety: Gregory
Stubble: Wheat unburnt
Rainfall:
GSR: 382.3mm (April – October)
Summer rainfall: 109.2mm

Method

The trial examined the influence of two nitrogen timings: 40kg N/ha applied at tillering (GS22) or first node (GS31) (Table 1) and four fungicide strategies (untreated, fungicide at late tillering — 2 July 2014, second node — 5 August 2104 and fungicide at both timings) on levels of yellow leaf spot (YLS) (*Pyrenophora tritici repentis*) as part of the Riverine Plains Inc *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project.

The trial was set up in a commercial crop of wheat (cv Gregory) in a wheat-on-wheat rotation position as a balanced split-split plot design with nitrogen timing as the main plot, fungicide timing as the sub plot and fungicide product as the sub-sub plot, replicated four times.

For each of the fungicide strategies, two fungicides were evaluated at their full rates at both timings: Tilt® 0.5L/ha and Prosaro® 0.3L/ha. A full list of nitrogen and fungicide treatments is presented in Table 2.

Data has been statistically analysed using analysis of variance (ANOVA), with means separated using the unrestricted least significant difference (LSD) procedure.

The crop had a plant population of 116 plants/m^2 and a tiller population of 250 tillers/m^2 when assessed at the second node stage (GS32) on 6 August 2014, one day after the final fungicide application.

Results

i) Disease assessment data

At the first fungicide application YLS was present on all the older leaves (Table 3), but the severity was still relatively low (up to 22.5%).

When assessed a month later on 6 August 2014 the disease had progressed onto newer leaves (flag-3 and flag-4). At this stage the different timings of nitrogen fertiliser had not had a significant effect on YLS levels. There was no significant difference between the two fungicide products evaluated. Fungicide applied at tillering (2 July 2014) significantly reduced disease severity on flag-3 and flag-4, however the level of control was little better than 50% control on flag-4 (Table 4).



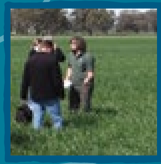

TABLE 1 Nitrogen application rates and timings

Nitrogen rates	28 April 2014 (sowing)	19 June 2014 (GS22)	14 July 2014 (GS31)	Total nitrogen applied
40kg/N applied	6kg N/ha	40kg N/ha	Nil	46kg N/ha
40kg/N applied	6kg N/ha	Nil	40kg N/ha	46kg N/ha

TABLE 2 Treatment list

Treatment		Active ingredient (g/ha ai)	Fungicide timing (mL/ha)		Nitrogen timing (kg N/ha)	
			GS25	GS32	GS22	GS31
1	Untreated		-	-	40	-
2	Untreated		-	-	-	40
3	Prosaro	Prothioconazole (63) and tebuconazole (63)	300	-	40	-
4	Prosaro	Prothioconazole (63) and tebuconazole (63)	300	-	-	40
5	Prosaro	Prothioconazole (63) and tebuconazole (63)	-	300	40	-
6	Prosaro	Prothioconazole (63) and tebuconazole (63)	-	300	-	40
7	Prosaro	Prothioconazole (126) and tebuconazole (126)	300	300	40	-
8	Prosaro	Prothioconazole (126) and tebuconazole (126)	300	300	-	40
9	Untreated[#]		-	-	40	-
10	Untreated[#]		-	-		40
11	Tilt	Propiconazole (250)	500	-	40	-
12	Tilt	Propiconazole (250)	500	-	-	40
13	Tilt	Propiconazole (250)	-	500	40	-
14	Tilt	Propiconazole (250)	-	500	-	40
15	Tilt	Propiconazole (500)	500	500	40	-
16	Tilt	Propiconazole (500)	500	500	-	40

[#] The trial is a balanced split-split plot design; hence the replication of the 40kg N/ha at GS22 untreated with fungicide and 40kg N/ha at GS31 untreated with fungicide treatments (9 and 10).

TABLE 3 Yellow leaf spot severity and incidence assessed 2 July 2014 three tillers–start of stem elongation stage (GS23–30) on the newest fully-emerged leaf (flag-5) and older leaves (flag-6, flag-7 and flag-8) just before fungicide application

GS23–30	YLS (%)			
	Flag-5	Flag-6	Flag-7	Flag-8
Disease severity	0.0	0.8	5.9	22.5
Disease incidence	0.0	58.8	97.5	100.0

When assessed at GS33, the disease had progressed onto flag-2, however severity was low at less than 7% in the untreated crop. There were no nitrogen timing effects evident in the levels of disease observed (Table 5). The only fungicide treatment observed to significantly reduce YLS infection severity and incidence on flag-2 was the two-spray program with applications at GS23–26 and GS32. There was a significant interaction between fungicide product and timing illustrating greater impact of a two spray program when Prosaro was used compared to Tilt (Figure 1). Disease incidence on flag-1 was reduced by all fungicide treatments. There were no significant differences between fungicide products.

Disease progress was slowed by the dry spring conditions such that at 50% ear emergence (GS55) YLS infection was less than 1% on the flag leaf and flag-1. There was evidence the application of fungicide did influence greenness of the crop canopy as measured by the Greenseeker® crop sensor using crop reflectance (normalised difference vegetation index — NDVI). The two-spray program gave significantly higher NDVI readings than the untreated crop at GS39 and GS55 (Table 6).

TABLE 4 Yellow leaf spot severity (% leaf area infected) and incidence (% of leaves infected) assessed 6 August 2014 second node stage (GS32), on the second newest fully-emerged leaf, flag-3 and flag-4.

	YLS (%)			
	Flag-3		Flag-4	
	Severity	Incidence	Severity	Incidence
Nitrogen timing				
GS22	1.3^{a}	68.8^{a}	8.1^{a}	98.6^{a}
GS31	1.2^{a}	71.3^{a}	8.8^{a}	99.4^{a}
Mean	**1.3**	**70.0**	**8.5**	**99.1**
LSD	1.05	19.22	4.05	1.99
Fungicide timing				
Untreated control	1.6^{a}	75.0^{a}	11.5^{a}	100.0^{a}
GS25	1.0^{b}	65.0^{a}	5.4^{b}	98.0^{a}
LSD	0.4	13.2	2.2	2.3
Product				
Prosaro	1.2^{a}	69.4^{a}	7.2^{a}	99.4^{a}
Tilt	1.4^{a}	70.6^{a}	9.7^{a}	98.8^{a}
LSD	0.7	13.1	3.2	2.6

Note: The newest emerged leaf (flag-2) had no disease as very newly emerged.

TABLE 5 Yellow leaf spot severity (% leaf area infected) and incidence (% of leaves infected) assessed 19 August 2014 third node stage (GS33), on the newest fully-emerged leaf flag-1 and flag-2

	YLS (%)			
	Severity		Incidence	
	Flag-1	Flag-2	Flag-1	Flag-2
Nitrogen timing				
GS22	0.9^{a}	5.5^{a}	50.3^{a}	94.1^{a}
GS31	0.9^{a}	5.5^{a}	50.6^{a}	94.4^{a}
Mean	**0.9**	**5.5**	**50.5**	**94.2**
LSD	0.53	1.31	14.65	7.68
Fungicide timing				
Untreated control	1.0^{a}	6.7^{a}	63.8^{a}	96.9^{a}
GS25	0.9^{a}	5.5^{ab}	48.8^{b}	93.8^{ab}
GS32	0.8^{a}	5.2^{ab}	50.6^{b}	94.4^{ab}
GS25 and GS32	0.8^{a}	4.5^{b}	38.8^{b}	91.9^{b}
LSD	0.44	2.04	12.43	4.6
Product				
Prosaro	0.9^{a}	5.3^{a}	49.7^{a}	92.2^{a}
Tilt	0.8^{a}	5.6^{a}	51.3^{a}	96.3^{a}
LSD	0.25	1.13	10.5	4.45

ii) Yield and quality results

Influence of nitrogen timing

There were no differences in yield or quality due to nitrogen timing during tillering or at first node.

Influence of fungicide timing

All fungicide timings generated a significant yield increase over the untreated control (Table 6). There was no difference in yield between the individual fungicide timings (GS22 vs GS32) both creating a 0.13–0.14t/ha yield increase. If both fungicide timings were used there was an additional 0.1t/ha yield increase giving a combined 0.23t/ha increase. There was a small but significant effect on screenings with fungicide application reducing screenings by approximately 1%.

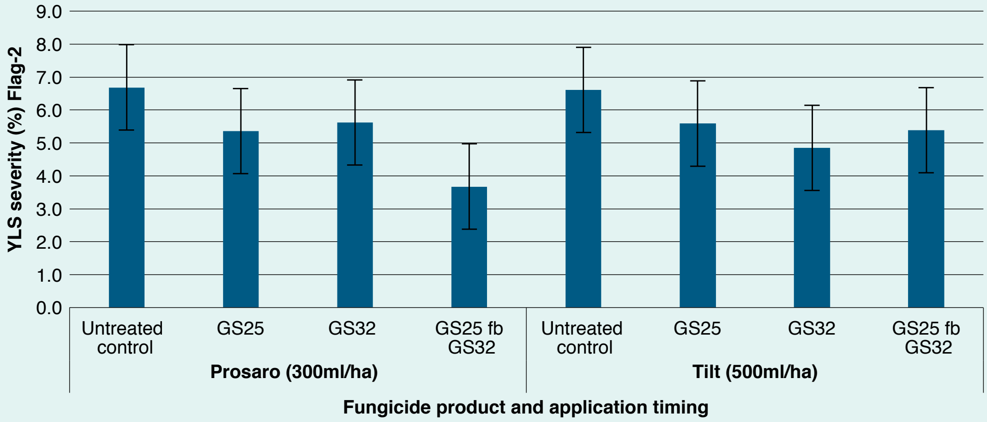

FIGURE 1 Interaction between fungicide application timing and product (mean of two nitrogen application timings)

* The error bars are a measure of LSD

TABLE 6 NDVI (scale 0–1) 6 August 2014 second node (GS32), 19 August 2014 third node (GS33), 5 September 2014 flag leaf fully emerged (GS39) and 16 September 2014 ear half emerged (GS55)

	NDVI			
	GS32	GS33	GS39	GS55
Nitrogen timing				
GS22	0.67[a]	0.65[a]	0.57[a]	0.52[a]
GS31	0.65[a]	0.65[a]	0.57[a]	0.52[a]
Mean	**0.66**	**0.65**	**0.57**	**0.52**
LSD	0.04	0.02	0.02	0.03
Fungicide timing				
Untreated control	0.66[a]	0.64[ab]	0.55[c]	0.51[b]
GS25	0.66[a]	0.65[ab]	0.57[ab]	0.53[a]
GS32	0.66[a]	0.64[b]	0.57[bc]	0.52[ab]
GS25 and GS32	0.66[a]	0.66[a]	0.58[a]	0.53[a]
LSD	0.01	0.01	0.01	0.01
Product				
Prosaro	0.66[a]	0.65[a]	0.56[a]	0.52[a]
Tilt	0.66[a]	0.65[a]	0.57[a]	0.52[a]
LSD	0.01	0.01	0.02	0.01

Influence of fungicide product

Although no differences were observed in disease control between Prosaro and Tilt, there was a significant yield advantage with Prosaro (0.06t/ha or 60kg/ha). There was also significantly higher protein with Prosaro, despite being the higher yielding treatment, which normally decreases the protein content through a dilution effect (Table 7).

There were two significant interactions indicating that Prosaro gave a significant yield response to a second application while Tilt did not. In addition the Prosaro treatments interacted positively with later nitrogen timing and a second fungicide spray (Figure 2).

Conclusions

For the second year in succession there have been responses to foliar fungicides for YLS control, despite yields being below 3t/ha and disease levels being relatively low (less than 10% on the top three leaves). In both years the crops had higher yield potential than 3t/ha but in both seasons the yield potential was reduced by frost.

These results do challenge current wisdom in two respects; firstly that fungicide application for YLS gives little value applied at late tillering, and secondly that despite low levels of disease on the top three leaves there were yield responses to application. Overall the yield differences are small (0.13–0.23 t/ha) but they are statistically (and potentially economically) significant.

TABLE 7 Yield, test weight, protein and screenings at harvest (GS99) 28 November 2014

	Yield and quality			
	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screening (%)
Nitrogen timing				
GS22	2.71[a]	77.9[a]	11.8[a]	5.3[a]
GS31	2.70[a]	77.7[a]	12.0[a]	6.0[a]
Mean	**2.70**	**77.8**	**11.9**	**5.6**
LSD	0.04	0.8	0.4	1.8
Fungicide timing				
Untreated control	2.58[c]	77.6[a]	12.0[a]	6.2[a]
GS25	2.72[b]	77.6[a]	11.9[a]	5.4[b]
GS32	2.71[b]	78.0[a]	11.7[a]	5.4[b]
GS25 and GS32	2.81[a]	77.9[a]	11.9[a]	5.5[b]
LSD	0.07	0.7	0.4	0.5
Product				
Prosaro	2.73[a]	77.6[a]	12.2[a]	5.9[a]
Tilt	2.67[b]	78.0[a]	11.5[b]	5.4[a]
LSD	0.03	0.4	0.4	0.7

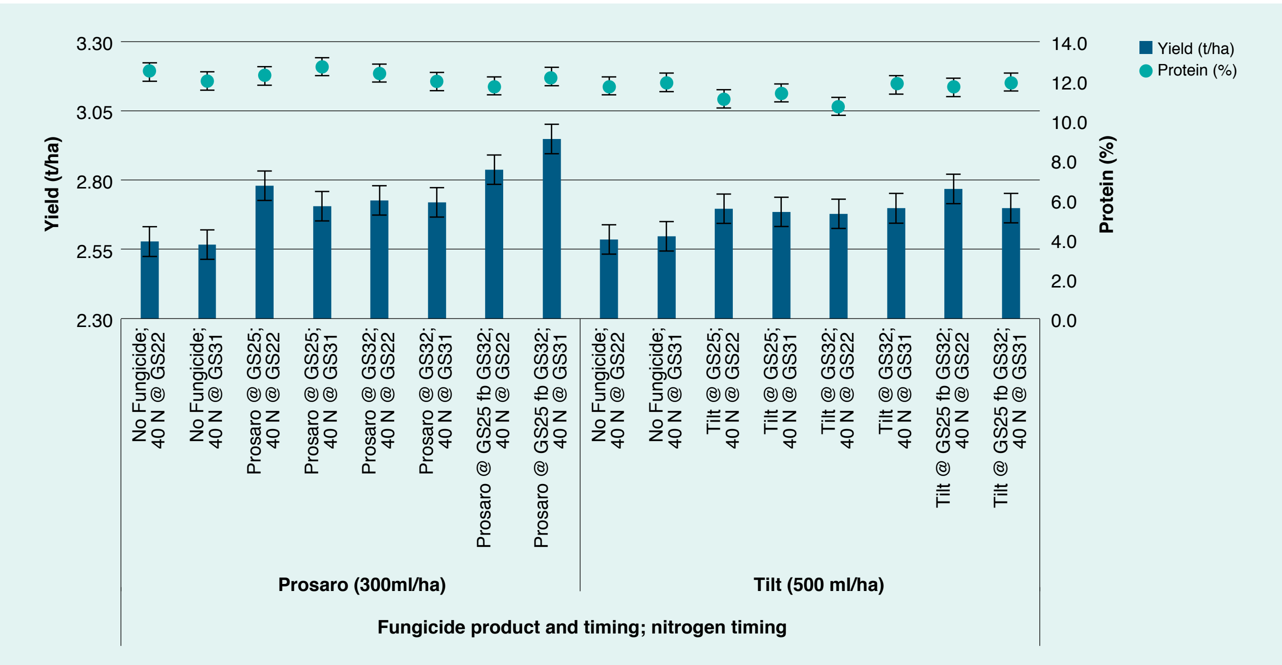

FIGURE 2 Influence of nitrogen timing, fungicide strategy on yield and protein, 28 November 2014

* The error bars are a measure of LSD

At $300/t such yield increases would generate gross income increases of 39–69$/ha. Allowing for cost of fungicide and application the return on input is approximately 2:1 for both one and two spray programs in this trial.

Acknowledgments

The trial was carried out as part of the Riverine Plains Inc GRDC-funded project *Maintaining profitable farming systems with retained stubble in the Riverine Plains region.*

Thanks go to the farmer co-operators, Tomlinson Ag at Redlands, NSW.

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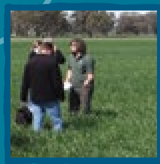

Monitoring the response of nitrogen application to wheat under full stubble retention

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Key points

- Two first-wheat trials sown early–mid May showed significant increases in yield where nitrogen (N) was applied. However, the timing of nitrogen application or whether the nitrogen was applied as a single or split application, gave no difference in yield.
- Normalised difference vegetation index (NDVI) assessments showed no differences in crop reflectance (crop canopy greenness) due to timing of nitrogen application. However there were NDVI differences due to the rates of nitrogen applied at the key growth stages (GS31 and GS33) where additional nitrogen could still be applied to the crop to assist in reaching yield potential.
- Nitrogen timing had no effect on tiller and head numbers, however a split application produced a taller crop canopy.
- Higher rates of nitrogen produced more dry matter (DM) and increased plant uptake of nitrogen, but the timing of application did not affect DM and nitrogen uptake.

Method

Two trials were set up under the Riverine Plains Inc stubble project: *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* at Yarrawonga and Dookie, Victoria. They were set up in established wheat crops, sown on 8 May 2014 at Yarrawonga and 15 May 2014 at Dookie. The trials were under host grower paddock practice, except for nitrogen application.

Trials were established as a split plot design with nitrogen rate as the main plot and nitrogen timing the sub plot, replicated four times. To maintain trial balance the trial included two untreated treatments. Data has been statistically analysed using analysis of variance (ANOVA), with means separated using the unrestricted least significant difference (LSD) procedure.

Trial 1: Yarrawonga, Victoria

Sowing date: 8 May 2014
Rotation: First wheat after canola
Variety: Cobra
Stubble: Canola unburnt
Rainfall:
GSR: 372.8mm (April – October)
Summer rainfall: 113.6mm
Soil mineral nitrogen: 67kg N/ha (0–60cm)

Nitrogen was hand-spread across the plots at three rates, 0, 60 and 120kg N/ha at two timings (Table 1). The first 50% of the split application treatments was applied at two true leaves (GS12). The remaining 50% of the split application treatments was applied at GS31 along with the full nitrogen rate of the remaining treatments. Rain followed the GS12 application of nitrogen on 1 June 2014 with 16.3mm falling, applications made on 23 July 2014 had 0.8mm of rainfall in the following five days.

i) Establishment and crop structure

The crop with the highest rate of nitrogen (120kg N/ha) produced significantly higher tiller numbers in comparison to the untreated control crop, however there was no significant difference in final head numbers due to nitrogen rate (Table 2).

TABLE 1 Nitrogen application rates and timings at Yarrawonga, Victoria, 2014

Treatment	30 May 2014 (GS12) (kg N/ha)	23 July 2014 (GS31) (kg N/ha)	Total nitrogen applied (kg N/ha)
1	-	-	nil
2	-	-	nil
3	30	30	60
4	-	60	60
5	60	60	120
6	-	120	120

Note: To maintain trial balance the trial included two untreated treatments.



TABLE 2 Tiller counts 6 August 2014, ear half emerged (GS55), head counts and crop height at harvest (GS99) 19 November 2014

Nitrogen rate (kg N/ha)	Crop structure		
	GS55	GS99	
	Tillers (m²)	Heads (m²)	Height (cm)
0	349^{b}	343^{a}	75.5^{b}
60	378^{ab}	374^{a}	76.0^{b}
120	393^{a}	358^{a}	78.4^{a}
Mean	**374**	**358**	**76.6**
LSD	40	43	2.2
Nitrogen timing			
GS31	358^{b}	346^{b}	76.0^{b}
GS12 & GS31	389^{a}	370^{a}	77.3^{a}
LSD	28	23	0.8

The highest rate of nitrogen significantly increased the height of the crop in comparison to the control (nil nitrogen) and 60kg N/ha treatments, although the differences were small (2.4cm).

Applying 50% of the nitrogen shortly after establishment, as part of a split application, significantly increased tiller numbers, head numbers and crop height when compared with the single application timing at GS31.

ii) Dry matter production and nitrogen uptake

There was a trend for the 120kg N/ha rate to produce the greatest amount of dry matter (DM) at each assessment timing, however this was only significant at GS30–31 and GS33 (Table 3).

At GS30–31, 120kg N/ha produced 0.38t/ha more DM than when 0 and 60kg N/ha had been applied, while at GS33 there was significantly less DM production where no nitrogen had been applied.

There was no difference in DM production between the single and split application of nitrogen.

Nitrogen uptake in the crop was assessed at the same time as DM production (Table 4). While there were no significant differences in nitrogen uptake between the single and split applications, there was a trend showing

TABLE 3 Dry matter 3 July 2014, mid tillering–stem elongation (GS24–30), 22 July 2014, stem extension — first node (GS30–31), 29 August 2014, third node (GS33), 15 September 2014, mid ear emergence (GS55), 29 September 2014, early flowering (GS62) and 19 November 2014, harvest (GS99)

Nitrogen rate (kg N/ha)	Dry matter (t/ha)					
	GS24–30	GS30–31	GS33	GS55	GS62	GS99
0	0.84^{a}	1.40^{b}	3.33^{b}	5.52^{a}	8.67^{a}	11.29^{a}
60	0.91^{a}	1.37^{b}	3.90^{a}	5.43^{a}	8.75^{a}	11.67^{a}
120	1.06^{a}	1.78^{a}	4.22^{a}	6.21^{a}	9.06^{a}	12.17^{a}
Mean	**0.94**	**1.52**	**3.81**	**5.72**	**8.84**	**11.07**
LSD	0.25	0.25	0.55	0.83	0.99	1.17
Nitrogen timing						
GS31			3.81^{a}	5.82^{a}	8.63^{a}	11.47^{a}
GS12 and GS31			3.81^{a}	5.63^{a}	9.02^{a}	11.95^{a}
LSD			0.49	0.47	0.86	0.73

TABLE 4 Nitrogen uptake 3 July 2014, mid tillering–stem elongation (GS24–30), 22 July 2014, stem extension – first node (GS30–31), 29 August 2014, third node (GS33), 15 September 2014, mid ear emergence (GS55), 29 September 2014, early flowering (GS62) and 19 November 2014, harvest (GS99)

Nitrogen rate (kg N/ha)	Nitrogen uptake (kg N/ha)					
	GS24–30	GS30–31	GS33	GS55	GS62	GS99
0	27^{a}	36^{b}	64^{b}	71^{b}	81^{b}	94^{b}
60	28^{a}	34^{b}	91^{a}	90^{a}	104^{b}	132^{a}
120	35^{a}	46^{a}	82^{ab}	96^{a}	140^{a}	136^{a}
Mean	**30**	**39**	**79**	**86**	**108**	**121**
LSD	10	6	20	14	24	21
Nitrogen timing						
GS31			76^{a}	82^{a}	104^{a}	116^{a}
GS12 and GS31			82^{a}	89^{a}	113^{a}	125^{a}
LSD			16	9	16	25

that nitrogen application increased nitrogen uptake, though the difference between rates was not consistent. From the second assessment timing, at GS30–31, there was significantly more nitrogen in the crop where 120kg N/ha was applied compared with the control, through to and including the assessment at harvest.

iii) Normalised Difference Vegetation Index (NDVI)

Crop reflectance measurements taken with a GreenSeeker® showed little difference in NDVI readings (crop reflectance measurement used as a surrogate canopy greenness reading) between the two different application timings of nitrogen. At the early flowering stage (GS62), the NDVI readings for the crop where no nitrogen was applied were significantly lower than where it was applied (Table 5, Figure 1).

At the start of stem elongation (GS31) the difference in NDVI reading between crops fertilised with additional nitrogen at two leaves fully emerged (GS12) and the untreated crop can give an indication of how responsive the site might be to nitrogen application. This is referred to as the response index (RI). For example, at GS31 120kg N/ha produced an NDVI score of 0.57 compared with 0.54 for the untreated crop. In this case the response index is approximately 0.57/0.54 = 1.055.

iv) Yield and grain quality

Early indications from crop canopy greenness measurements (NDVI) suggested the response to nitrogen was relatively small in this paddock, however the grain yield data suggested that while the trial site was relatively fertile, with 5t/ha yield when no nitrogen

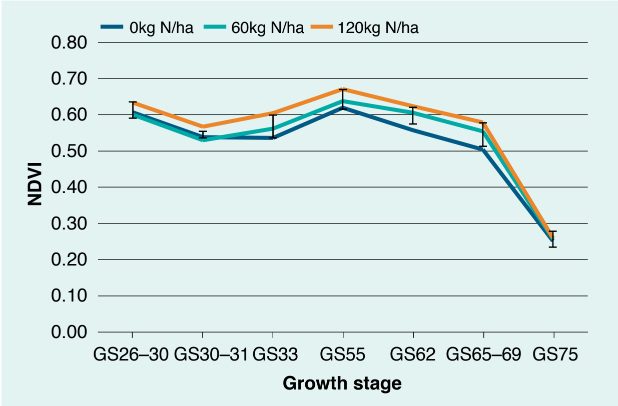

FIGURE 1 Influence of applied nitrogen rate on NDVI scale 0–1
* The error bars are a measure of LSD

was applied, there was still a yield response of 0.46t/ha (9%) from 60kg N/ha and 0.75t/ha (15%) from 120kg N/ha (Table 6). The application of 120kg N/ha created a significant yield and protein increase indicating 60kg N/ha was suboptimal for this situation. Applying the full rate of 120kg N/ha at GS31 resulted in a significantly higher protein content, when 60kg N/ha was applied the split application was more effective at increasing the protein content. For each additional input of 60kg N/ha there was a 1% increase in grain protein. Test weight and screenings showed no differences due to the rate of nitrogen applied.

There were also no differences between the two timings of nitrogen application for yield, test weight, protein and screenings (Table 6).

TABLE 5 NDVI scale 0–1, 3 July 2014, mid tillering–stem elongation (GS24–30), 22 July 2014, stem extension-first node stage (GS30–31), 29 August 2014, third node stage (GS33), 15 September 2014, mid ear emergence (GS55), 29 September 2014, early flowering (GS62), 16 October 2014, mid–late flowering (GS65–69) and 31 October 2014, mid-milk development (GS75)

Nitrogen rate (kg N/ha)	NDVI						
	GS24–30	GS30–31	GS33	GS55	GS62	GS65–69	GS75
0	0.61[ab]	0.54[ab]	0.54[b]	0.62[a]	0.56[b]	0.50[b]	0.25[a]
60	0.60[b]	0.53[b]	0.56[ab]	0.64[a]	0.61[a]	0.56[ab]	0.26[a]
120	0.63[a]	0.57[a]	0.61[a]	0.67[a]	0.63[a]	0.58[a]	0.26[a]
Mean	**0.61**	**0.55**	**0.57**	**0.64**	**0.60**	**0.55**	**0.26**
LSD	0.03	0.03	0.06	0.05	0.05	0.07	0.04
Nitrogen timing							
GS31			0.56[a]	0.64[a]	0.59[a]	0.54[a]	0.26[a]
GS12 and GS31			0.58[a]	0.65[a]	0.60[a]	0.55[a]	0.25[a]
LSD			0.05	0.02	0.02	0.02	0.03



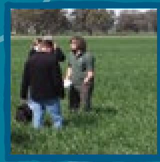

TABLE 6 Yield, test weight, protein and screenings at harvest (GS99), 27 November 2014

Nitrogen rate (kg N/ha)	Yield and quality			
	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
0	5.02[c]	80.4[a]	9.5[c]	6.9[a]
60	5.48[b]	80.2[a]	10.5[b]	6.5[a]
120	5.77[a]	79.8[a]	11.5[a]	5.5[a]
Mean	**5.42**	**80.11**	**10.49**	**6.3**
LSD	0.24	1.1	0.4	1.7
Nitrogen timing				
GS31	5.35[a]	80.0[a]	10.6[a]	6.4[a]
GS12 and GS31	5.50[a]	80.3[a]	10.4[a]	6.1[a]
LSD	0.18	4.1	0.5	1.08

Trial 2: Dookie, Victoria

Sowing date: 15 May 2014

Rotation: First wheat after canola

Variety: Corack

Stubble: Canola unburnt

Rainfall:

GSR: 386mm (April – October)

Summer rainfall: 78mm

Soil mineral nitrogen: 60 kg N/ha

Additional trial nitrogen was hand-spread across the plots at three rates, 0, 60 and 120kg N/ha at two timings (Table 7). The first 50% of the split application treatments was applied at one true leaf (GS11). The remaining 50% of the split application treatments was applied at GS31 along with the full nitrogen rate of the remaining treatments. Rain followed the GS11 application of nitrogen on 1 June with 27mm falling, applications made on 23 July 2014 had 2mm of rainfall in the following five days.

TABLE 7 Nitrogen application rates and timings at Dookie, Victoria, 2014

Treatment	15 May (sowing) (kg N/ha)	22 May (kg N/ha)	30 May (GS11) (kg N/ha)	31 July (GS31) (kg N/ha)	Total N applied (kg N/ha)
1	9.5	5	-	-	14.5
2	9.5	5	-	-	14.5
3	9.5	5	30	30	74.5
4	9.5	5	-	60	74.5
5	9.5	5	60	60	134.5
6	9.5	5	-	120	134.5

Note: To maintain trial balance the trial included two untreated treatments. Small amounts of nitrogen were applied to all treatments (including the untreated) prior to the trial being set up.

i) Establishment and crop structure

Nitrogen application significantly increased tiller production. At the higher nitrogen rate head numbers also increased relative to unfertilised crops. Where nitrogen was applied, the crop canopy height was significantly increased (6.7cm), in comparison to the untreated (nil nitrogen) crop. Varying the timing of nitrogen application did not affect tiller numbers or head numbers, although the split timing of nitrogen significantly increased crop height by 2.9cm (Table 8).

ii) Dry matter production and nitrogen uptake

There were clear differences in crop DM production between crops with nil nitrogen and 120kg N/ha, with the 120kg N/ha rate producing significantly more DM at each assessment (Table 9). Unlike Trial 1 at Yarrawonga (where there was no significant difference), DM production was significantly higher at both the start of ear emergence (GS51) and mid flowering (GS65) assessments, when nitrogen application was split across

TABLE 8 Tiller counts 11 September 2014, start of head emergence (GS51), head counts and crop height 21 November 2014 harvest (GS99)

Nitrogen rate (kg N/ha)	Crop structure		
	GS51	GS99	
	Tillers (m^2)	Heads (m^2)	Height (cm)
0	332[b]	260[b]	86.5[b]
60	381[a]	307[ab]	93.2[a]
120	393[a]	326[a]	95.2[a]
Mean	**369**	**298**	**91.7**
LSD	32	64	2.9
Nitrogen timing			
GS31	355[a]	286[a]	90.2[b]
GS11 and GS31	382[a]	309[a]	93.1[a]
LSD	32	45	0.8

TABLE 9 Dry matter 3 July 2014, mid tillering–stem elongation (GS24–30), 31 July 2014, stem extension–first node (GS30–31), 11 September 2014, start of ear emergence (GS51), 3 October 2014, mid flowering (GS65), and 21 November 2014, harvest (GS99)

Treatment	Dry matter (t/ha)				
Nitrogen rate (kg N/ha)	**GS24–30**	**GS30–31**	**GS51**	**GS65**	**GS99**
0	0.32^{b}	1.25^{c}	5.63^{b}	8.15^{c}	9.37^{b}
60	0.55^{a}	1.99^{b}	6.65^{a}	10.10^{b}	10.34^{ab}
120	0.59^{a}	2.27^{a}	6.41^{a}	11.31^{a}	10.78^{a}
Mean	**0.49**	**1.84**	**6.23**	**9.85**	**10.17**
LSD	0.10	0.21	0.44	0.36	1.37
Nitrogen timing					
GS31			5.88^{b}	8.92^{b}	10.20^{a}
GS11 and GS31			6.58^{a}	10.79^{a}	10.13^{a}
LSD			0.50	1.16	1.31

two timings. However, these differences did not follow through to harvest.

Nitrogen uptake followed similar trends to DM production with untreated crops taking up less nitrogen into the canopy than where nitrogen was applied (Table 10). At GS31 and GS51 there were significant differences due to the rate applied, with 120kg N/ha having the greatest nitrogen content in the crop canopy. The timing of nitrogen also showed that the split application produced significantly higher nitrogen uptake at both GS51 and GS65, however there was no difference at the final harvest assessment.

iii) Normalised Difference Vegetation Index (NDVI)

The greenness of the crop canopy at GS31 (measured with a Greenseeker) was significantly greater where nitrogen had been applied in a split treatment (Table 11, Figure 2). At all later NDVI assessments, carried out after the single nitrogen dose was applied at GS31, there was no significant difference in NDVI reading due to nitrogen timing. Crops fertilised with additional nitrogen above and beyond grower practice (0, 60 and 120kg N/ha) produced NDVI readings significantly different from each other at three assessment times (GS31, 51 and 71), with the highest rate of nitrogen producing the highest NDVI readings (the greener the crop).

At the start of stem elongation (GS31) the response index (RI) of crops treated with 120kg N/ha of the untreated was 1.16 (0.65/0.56 = 1.16) whereas the RI at Yarrawonga was smaller (0.57/0.54 = 1.055). These simple calculations would indicate that the yield response to nitrogen at Dookie was likely to be greater than at Yarrawonga. So was this the case?

Yield and grain quality

There was a significant yield increase from nitrogen application in this trial (Table 12). Both of the nitrogen rates applied (60kg N/ha and 120kg N/ha) out yielded the untreated crop by 1.14 and 1.34t/ha respectively. Timing of nitrogen application had no effect on yield in this trial.

TABLE 10 Nitrogen uptake 3 July 2014, mid tillering–stem elongation (GS24–30), 31 July 2014, stem extension–first node stage (GS30–31), 11 September 2014, start of ear emergence (GS51), 3 October 2014, mid-flowering (GS65), and 21 November 2014, harvest (GS99)

Treatment	Nitrogen uptake (kg N/ha)				
Nitrogen rate (kg N/ha)	**GS24–30**	**GS30–31**	**GS51**	**GS65**	**GS99**
0	15^{b}	40^{c}	66^{c}	57^{b}	54^{b}
60	29^{a}	59^{b}	111^{b}	100^{a}	85^{ab}
120	32^{a}	73^{a}	130^{a}	113^{a}	99^{a}
Mean	**25**	**57**	**102**	**90**	**79**
LSD	5	14	9	15	32
Nitrogen timing					
GS31			95^{a}	85^{a}	80^{a}
GS11 and GS31			110^{a}	96^{a}	78^{a}
LSD			20	12	32



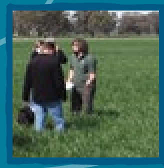

TABLE 11 NDVI scale 0–1 31 July 2014, stem elongation–first node (GS30–31), 11 September 2014, start of ear emergence (GS51), 3 October 2014, mid-flowering (GS65), 15 October 2014, grain watery ripe (GS71) and 30 October late milk (GS77)

Treatment	NDVI				
Nitrogen rate (kg N/ha)	GS30–31	GS51	GS65	GS71	GS77
0	0.56[c]	0.58[c]	0.57[b]	0.36[c]	0.17[b]
60	0.59[b]	0.71[b]	0.69[a]	0.39[b]	0.18[ab]
120	0.65[a]	0.78[a]	0.74[a]	0.44[a]	0.19[a]
Mean	**0.60**	**0.69**	**0.66**	**0.39**	**0.18**
LSD	0.04	0.05	0.06	0.02	0.02
Nitrogen timing					
GS31	0.56[b]	0.69[a]	0.67[a]	0.40[a]	0.18[a]
GS11 and GS31	0.64[a]	0.70[a]	0.66[a]	0.40[a]	0.17[a]
LSD	0.02	0.02	0.03	0.01	0.02

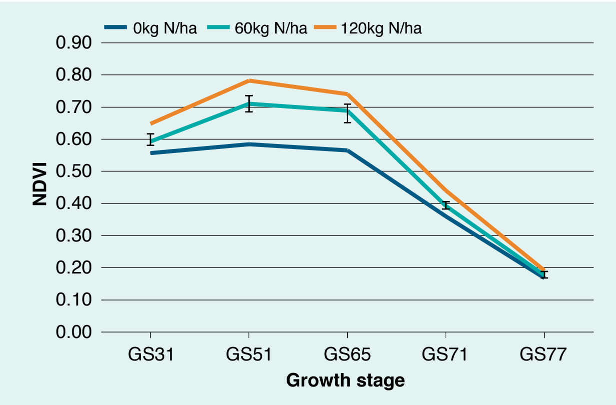

FIGURE 2 Influence of applied nitrogen rate on NDVI scale 0–1*

* The error bars are a measure of LSD

Crops receiving 120kg N/ha produced significantly lower test weights than the untreated crops and the 60kg N/ha treatment. The split timing treatments had significantly lower test weights than when a single application of nitrogen was applied.

The lowest grain protein was produced by the untreated crops with the highest grain protein resulting from the highest rate of nitrogen application. There were differences in grain protein due to timing, with the split application of nitrogen giving significantly higher protein than the single application of nitrogen.

The screening percentage was significantly higher by 0.6% in the untreated crop compared with the 60kg N/ha treatment. A single application of nitrogen resulted in a higher screening percentage compared with the split application.

Conclusions

The Dookie trial indicated greater differences in NDVI at the start of stem elongation between 60kg N/ha applied at one true leaf emerged and the untreated crop (this was manifest as a higher response index (RI) at the Dookie site; RI at GS31 = NDVI 60kg N/ha at sowing divided by NDVI nil nitrogen). In other words there was a bigger difference in crop canopy ground cover/greenness where nitrogen had been applied at Dookie than was observed at the Yarrawonga site from the same application in the window of GS11–12.

TABLE 12 Yield, test weight, protein and screenings 29 November 2014, harvest (GS99)

Treatment	Grain yield and quality			
Nitrogen rate (kg N/ha)	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
0	4.83[b]	81.8[a]	7.1[c]	2.7[a]
60	5.97[a]	81.7[a]	8.2[b]	2.1[b]
120	6.17[a]	79.7[b]	9.8[a]	1.9[b]
Mean	**5.66**	**81.1**	**8.4**	**2.2**
LSD	0.34	0.9	0.4	0.6
Nitrogen timing				
GS31	5.61[a]	81.4[a]	8.2[b]	2.4[a]
GS11 and GS31	5.70[a]	80.8[b]	8.5[a]	2.1[b]
LSD	0.17	0.2	0.1	0.3

At Yarrawonga the RI measured 1.05 while at Dookie it measured 1.16; these differences led to maximum grain yield responses to nitrogen of 14 and 27% (0.75 and 1.34t/ha for Yarrawonga and Dookie respectively). The ratios of the NDVI measurements at the two sites in effect suggested higher soil fertility at Yarrawonga, a result that was illustrated in the greater harvest off-take of nitrogen (83kg N/ha) at Yarrawonga compared with Dookie (54kg N/ha). The greater nitrogen supply at Yarrawonga was recorded in NDVI assessments throughout the season.

Acknowledgments

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The interaction between plant growth regulator (PGR) and nitrogen application in early-sown first wheat

Nick Poole and Michael Straight
FAR Australia in conjunction with Riverine Plains Inc

Key points

- In two first-wheat trials yielding 4.5–5.0 t/ha, the application of a plant growth regulator (PGR) (a single application of Chlormequat + Moddus at GS31–32) delivered no benefits in terms of yield or grain quality.
- The PGR application did not interact with additional nitrogen (N) applied in terms of yield or quality.
- The impact of PGR application on crop height was greater than the impact of nitrogen timing, however the differences in height were small (4.9cm at Redlands and 2.7cm at Yarrawonga).
- The grower-applied nitrogen at Redlands, at a rate of 75kg N/ha, and at Yarrawonga at a rate of 100kg N/ha, were shown to be optimum in terms of yield and quality, with no extra yield or protein resulting from the higher nitrogen application rates with Corack and Wedgetail.

Method

Trials were conducted in first wheat at Redlands, NSW (Trial 1) and Yarrawonga, Victoria (Trial 2), in order to examine the interaction between additional nitrogen (N) application above grower practice and the response to plant growth regulator (PGR). In both trials 0, 40 and 80kg N/ha were added on top of the nitrogen rate applied by the host farmer (Tables 1 and 2). Additional nitrogen was added at the tillering stage (GS23). The PGR, a mixture of Chlormequat (1L/ha) and Moddus (200mL/ha), was applied at Redlands on 29 July 2014, at 17°C and on 5 August 2014 at 13.7°C at the Yarrawonga site.

Trials were established as a split plot design where nitrogen rate was the main plot, and PGR application the sub plot — replicated four times. Data has been statistically analysed using analysis of variance (ANOVA), with means separated using the unrestricted least significant difference (LSD) procedure.

Trial 1: Redlands, NSW

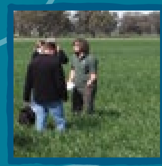
Sowing date: 6 May 2014
Rotation: First wheat after canola
Variety: Corack
Stubble management: Canola unburnt
Rainfall:
GSR: 382.3mm (April – October)
Summer rainfall: 109.2mm

TABLE 1 Nitrogen application rates and timings – Redlands, NSW Trial 1

Nitrogen treatment	6 May 2014 (sowing) (kg N/ha)	19 June 2014 (kg N/ha)	24 June (GS23–26 tillering) (kg N/ha)	18 July 2014 (kg N/ha)	Total nitrogen applied (kg N/ha)
Standard nitrogen applied	6	36.8	Nil	32.2	**75**
Standard + 40kg N/ha	6	36.8	40	32.2	**115**
Standard + 80kg N/ha	6	36.8	80	32.2	**155**

TABLE 2 Nitrogen application rates and timings – Yarrawonga, Victoria Trial 2

Nitrogen treatment	21 April 2014 (sowing) (kg N/ha)	11 June 2014 (kg N/ha)	24 June 2014 (GS23–26 tillering) (kg N/ha)	12 July 2014 (kg N/ha)	Total nitrogen applied (kg N/ha)
Standard nitrogen applied	8	46	Nil	46	**100**
Standard N + 40kg N/ha	8	46	40	46	**140**
Standard N + 80kg N/ha	8	46	80	46	**180**



i) Crop dry matter production

There was no effect of additional nitrogen or PGR application on dry matter (DM) production (Table 3).

ii) Crop reflectance using normalised difference vegetation index (NDVI)

Crop canopy greenness was measured with a Greenseeker®. Differences in crop canopy greenness due to additional nitrogen were small and at most assessments were not significant. PGR application significantly decreased NDVI, an observation noted in the same trials during 2013 (Table 4, Figure 1).

iii) Influence on crop height and final head number

Nitrogen and PGR application had no effect on final head numbers recorded at harvest (Table 5), however there was a significant interaction (p=0.03) between nitrogen and PGR treatments on crop height (data not presented). PGR treatments significantly reduced the crop height by approximately 5cm (averaged across all nitrogen levels) but this effect was greatest at the lower rates of nitrogen applied.

TABLE 3 Dry matter 10 September 2014, start of ear emergence (GS51), 1 October 2014, mid-flowering (GS65) and 19 November 2014, harvest (GS99) at the Redlands trial site

Treatment	Dry matter (t/ha)		
Nitrogen treatment	**GS51**	**GS65**	**GS99**
Standard (75kg N/ha)	5.13[a]	11.11[a]	13.82[a]
Standard + 40kg N/ha	5.52[a]	11.30[a]	13.79[a]
Standard + 80kg N/ha	5.37[a]	11.14[a]	13.21[a]
Mean	**5.34**	**11.18**	**13.61**
LSD	0.85	1.53	1.65
PGR treatment			
Untreated control	5.41[a]	11.19[a]	13.63[a]
Moddus + Chlormequat	5.27[a]	11.18[a]	13.58[a]
LSD	0.42	0.48	1.01

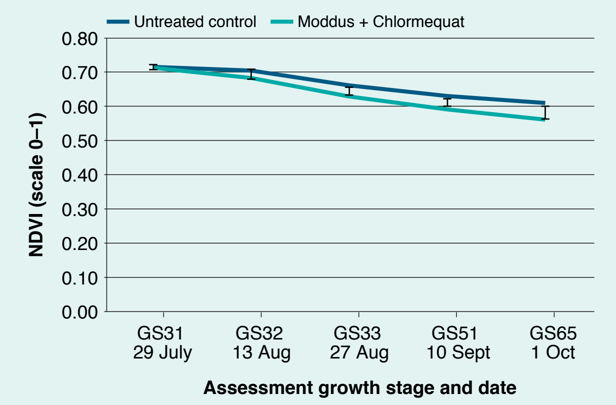


FIGURE 1 Influence of PGR on NDVI readings scale 0–1 at Redlands compared with the untreated control (UTC) (mean of 3 nitrogen rates)

* The error bars are a measure of LSD

TABLE 5 Crop height and heads/m² at harvest (GS99), 19 November 2014 at the Redlands trial site

Treatment	Height (cm)	Heads/m²
Nitrogen treatment		
Standard (75kg N/ha)	75.2[a]	284[a]
Standard + 40kg N/ha	76.1[a]	288[a]
Standard + 80kg N/ha	76.5[a]	288[a]
Mean	**75.9**	**287**
LSD	5.0	26
PGR treatment		
Untreated control	78.4[a]	285[a]
Moddus + Chlormequat	73.5[b]	289[a]
LSD	0.9	26

iv) Yield and quality

Extra nitrogen applied above the grower standard practice of 75kg N/ha did not increase final grain yield (Table 6). The additional 80kg N/ha significantly lifted grain protein by 0.75% and decreased screenings by approximately 1.5%. PGR application had no effect on yield or quality.

TABLE 4 NDVI scale 0–1 measured 29 July 2014, first node (GS31), 13 August 2014, second node (GS32), 27 August 2014, third node (GS33), 10 September 2014, start of ear emergence (GS51) and 1 October, mid-flowering (GS65) at the Redlands trial site

Treatment	NDVI				
Nitrogen treatment	**GS31**	**GS32**	**GS33**	**GS51**	**GS65**
Standard (75kg N/ha)	0.72[a]	0.70[a]	0.64[b]	0.60[b]	0.57[a]
Standard + 40kg N/ha	0.72[a]	0.70[a]	0.66[a]	0.61[ab]	0.59[a]
Standard + 80kg N/ha	0.71[a]	0.69[a]	0.64[b]	0.62[a]	0.60[a]
LSD	0.02	0.03	0.02	0.02	0.03
PGR treatment					
Untreated control	0.72[a]	0.71[a]	0.66[a]	0.63[a]	0.61[a]
Moddus + Chlormequat	0.71[a]	0.68[a]	0.63[b]	0.59[b]	0.56[b]
LSD	0.01	0.03	0.02	0.02	0.03

TABLE 6 Yield, test weight, protein and screenings at harvest (GS99), 28 November 2014 at the Redlands trial site

Treatment	Yield and quality			
Nitrogen treatment	**Yield (t/ha)**	**Test weight (kg/hL)**	**Protein (%)**	**Screening (%)**
Standard (75kg N/ha)	4.78[a]	81.8[a]	11.6[b]	6.4[a]
Standard + 40kg N/ha	4.94[a]	82.2[a]	12.0[ab]	5.4[ab]
Standard + 80kg N/ha	4.63[a]	81.6[a]	12.4[a]	5.0[b]
Mean	**4.78**	**81.9**	**12.0**	**5.6**
LSD	0.55	0.6	0.5	1.2
PGR treatment				
Untreated control	4.82[a]	81.6[a]	12.0[a]	5.6[a]
Moddus + Chlormequat	4.74[a]	82.1[a]	12.0[a]	5.6[a]
LSD	0.23	0.6	0.7	1.2

Trial 2: Yarrawonga, Victoria

Sowing date: 20 April 2014

Rotation: First wheat after canola

Variety: EGA Wedgetail

Stubble management: Canola unburnt but raked

Rainfall:

GSR: 372.8mm (April – October)

Summer rainfall: 113.6mm

i) Crop dry matter production

Although applying nitrogen above the standard practice of 100kg N/ha did not generate any additional DM when assessed at harvest, at the start of flowering there was a significant increase of approximately 0.5t/ha with additional nitrogen. PGR application significantly decreased DM production at the same flowering assessment, but again there was no effect at harvest (Table 7).

TABLE 7 Dry matter 10 September 2014, flag fully emerged (GS39), 1 October 2014, start of flowering (GS61), 26 November 2014, harvest (GS99) at Yarrawonga trial site

Treatment	Dry matter (t/ha)		
Nitrogen treatment	**GS39**	**GS61**	**GS99**
Standard (100kg N/ha)	6.16[a]	11.84[a]	15.76[a]
Standard + 40kg N/ha	6.28[a]	12.20[a]	16.03[a]
Standard + 80 kg N/ha	6.72[a]	12.57[a]	16.21[a]
Mean	**6.38**	**12.02**	**16.00**
LSD	0.72	0.81	2.41
PGR treatment			
Untreated control	6.56[a]	12.46[a]	16.09[a]
Moddus + Chlormequat	6.21[a]	11.94[b]	15.91[a]
LSD	0.45	0.46	0.67

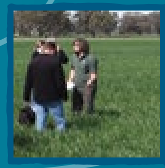
ii) Crop reflectance using NDVI

The Yarrawonga site appeared to be more responsive to nitrogen than the Redlands site as the additional nitrogen applied at this site significantly increased crop canopy NDVI scores. This indicated greater crop canopy greenness where additional nitrogen was applied. Similar to the Redlands site, PGR application significantly decreased crop canopy NDVI scores (Table 8, Figure 2).

TABLE 8 NDVI scale 0–1, 5 August 2014 first node (GS31), 19 August 2014 second node (GS32), 5 September 2014 third node to flag leaf fully emerged (GS33–39), 10 September 2014 flag leaf fully emerged (GS39) and 1 October 2014 start of flowering (GS61) at the Yarrawonga trial site

Treatment	NDVI				
Nitrogen treatment	**GS31**	**GS32**	**GS33–39**	**GS39**	**GS61**
Standard (100kg N/ha)	0.70[b]	0.68[c]	0.69[c]	0.68[b]	0.58[b]
Standard + 40kg N/ha	0.71[b]	0.70[b]	0.72[b]	0.72[a]	0.60[ab]
Standard + 80kg N/ha	0.73[a]	0.72[a]	0.75[a]	0.74[a]	0.63[a]
Mean	**0.71**	**0.70**	**0.72**	**0.71**	**0.60**
LSD	0.02	0.01	0.03	0.03	0.04
PGR treatment					
Untreated control	0.72[a]	0.72[a]	0.75[a]	0.74[a]	0.65[a]
Moddus + Chlormequat	0.71[a]	0.69[b]	0.69[b]	0.68[b]	0.56[b]
LSD	0.02	0.02	0.02	0.03	0.04





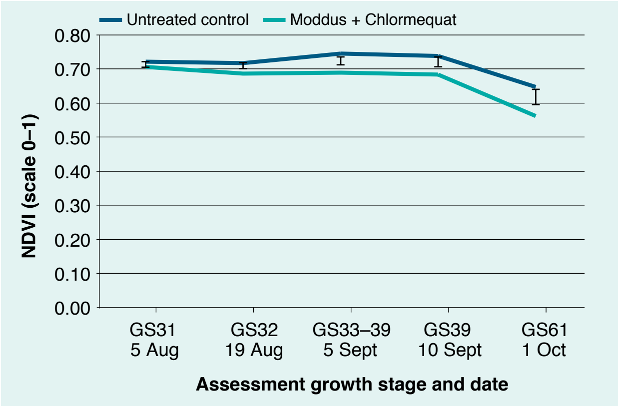


FIGURE 2 Influence of PGR on NDVI scale 0–1 at the Yarrawonga site, variety Wedgetail (mean of 3 nitrogen rates)
*The error bars are a measure of LSD

TABLE 9 Crop height and heads/m^2 at harvest (GS99), 26 November 2014 at the Yarrawonga trial site

Treatment	Height (cm)	Heads (m^2)
Nitrogen treatment		
Standard (100kg N/ha)	83.6^{a}	388^{a}
Standard + 40kg N/ha	83.5^{a}	409^{a}
Standard + 80kg N/ha	83.4^{a}	382^{a}
Mean	**83.5**	**393**
LSD	2.4	82
PGR treatment		
Untreated control	84.8^{a}	377^{a}
Moddus + Chlormequat	82.1^{b}	410^{a}
LSD	0.8	40

TABLE 10 Yield, test weight, protein and screenings at harvest (GS99), 26 November 2014 at the Yarrawonga trial site

Treatment	Yield and quality			
Nitrogen treatment	**Yield (t/ha)**	**Test weight (kg/hL)**	**Protein (%)**	**Screening (%)**
Standard (100kg N/ha)	5.11^{a}	76.8^{a}	11.2^{b}	1.2^{b}
Standard + 40kg N/ha	5.12^{a}	74.6^{b}	12.9^{a}	2.5^{a}
Standard + 80kg N/ha	5.11^{a}	73.9^{b}	13.3^{a}	3.1^{a}
Mean	**5.11**	**75.1**	**12.5**	**2.3**
LSD	0.45	1.01	0.60	0.74
PGR treatment				
Untreated control	5.18^{a}	75.2^{a}	12.3^{a}	2.1^{a}
Moddus + Chlormequat	5.04^{a}	75.1^{a}	12.6^{a}	2.4^{a}
LSD	0.21	0.64	0.38	0.58

iii) Influence on crop height and final head number

Nitrogen and PGR application had no effect on final head numbers recorded at harvest (Table 9). However, there was a significant interaction between nitrogen and PGR application on crop height, as was the case at the Redlands site. In the Yarrawonga trial the PGR application significantly decreased the crop height, by approximately 3cm (averaged across all nitrogen levels), with the greatest effect measured at the higher rates of nitrogen application (data not shown).

iv) Yield and quality

Additional nitrogen had no effect on final yield, but increased grain protein by approximately 1.5–2.0% depending on the rate of nitrogen applied. The extra nitrogen significantly increased screenings by 1.25–2.0% and significantly decreased test weight below the APW minimum of 74kg/hL. Application of PGR had no effect on yield or quality (Table 10).

Conclusions

The application of a PGR (Moddus + Chlormequat) to first-wheat crops yielding 4.5–5.0t/ha produced no benefits in the 2014 trials irrespective of the soil nitrogen levels, despite small but significant effects on crop canopy height and crop canopy greenness (measured as crop canopy reflectance). Though additional applications of nitrogen lifted final grain protein above the 11.0–11.5% range, there was no benefit to yield indicating that the standard grower practice (75kg N/ha at Redlands and 100kg N/ha at Yarrawonga) was optimal for the season. In addition, at the Yarrawonga site the additional nitrogen significantly increased screenings and reduced test weight.

Acknowledgments

The trial was carried out as part of the Riverine Plains Inc GRDC-funded project *Maintaining profitable farming systems with retained stubble in the Riverine Plains region.*

Thanks go to the farmer co-operators, Tomlinson Ag at Redlands, NSW and Telewonga Pty Ltd, Yarrawonga, Victoria.

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Increased soil carbon by accelerated humus formation from crop residues

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Key points

- Soil carbon (C) values have not significantly increased with fertiliser or stubble treatments over two years of measurement.
- Nitrous oxide (N_2O) emissions increased when fertiliser was applied onto stubbles post-harvest.
- While the effects of fertiliser addition on grain yield were inconsistent, stubble management was an important determinant of yield across all sites.

Aim

The aim of this ongoing project is to trial and demonstrate innovative on-farm practices that can increase the sequestration of carbon (C) in the soil under cereal crops, through accelerated residue decomposition and nutrient management to increase humus production.

A key component of the project is also to quantify the relative changes in soil carbon and N_2O emissions due to post-harvest fertiliser application. If increases in soil carbon are greater than the N_2O (greenhouse gas) emissions, then a positive, net gain in soil carbon sequestration can be demonstrated.

Background

This project is based on a CSIRO proof-of-concept study, carried out by Dr Clive Kirkby, which showed that soil humus (a stable form of soil carbon) could be increased over several years by adding nitrogen (N), sulphur (S), and phosphorus (P) fertiliser onto stubble residues soon after harvest.

Similar studies in Victoria and New South Wales, funded by the Australian Government Department of Agriculture — *Action on the Ground Program*, are applying Dr Kirkby's laboratory and plot studies to larger farm-scale operations.

Method

Three sites were established during 2012–13 to represent both dryland cropping and irrigated cropping conditions. Dryland sites were located at Rutherglen, Victoria and Culcairn, New South Wales, with an irrigated site at Tocumwal, NSW.

The three sites included replicated treatments of post-harvest-applied fertiliser, sowing fertiliser and stubble residue management as outlined in Table 1.

The rates of post-harvest fertiliser were determined according to the amount of carbon, nitrogen, phosphorus and sulphur in the stubble residues. Sowing fertiliser rates were based on existing rates used by the farmer co-operators. All fertilisers were applied at 0, 50 and 100% of the recommended rate.

Rates of post-harvest fertiliser applied during 2014 were similar between sites, although somewhat higher than rates applied during 2013. The higher rates for 2014 were due mainly to the low nutrient value of stubble residues, possibly as a consequence of the frost damage in the 2013 crop.

The fertiliser applied in both years was Granuloc 15 (containing 14.3% N, 12% P, and 10.5% S). Post-harvest fertiliser was applied during February of each year.

During 2014 crops were sown during April at Culcairn (24 April) and Tocumwal (25 April) and on 26 May at Rutherglen. Subsequent nitrogen fertiliser was applied at each site during the growing season (Table 2).

The average long-term annual rainfall at each of the sites is: 531mm at Rutherglen, 390mm at Culcairn and 398mm at Tocumwal. The annual rainfall for 2014 was: 562mm at Rutherglen, 449mm at Culcairn and 538mm at Tocumwal.

Soil characteristics at each site were recorded during 2012 and are described in Table 3. In general, the 2012 soil results revealed all three sites had high fertility, with moderate sodicity at Tocumwal in the surface soil and moderate sodicity below 30cm at the Rutherglen site.

Soil texture below the surface 10cm soil layer varied greatly across each of the sites. Subsoil textures varied from light to heavy clays with a range of granular material (buckshot at the Rutherglen site) and composition (dispersive at the Tocumwal site).



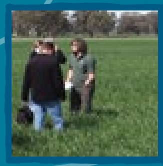


TABLE 1 Treatments applied at each site during 2014

Site	Stubble residue treatment				Harvest fertiliser (kg N/ha)			Sowing fertiliser (kg N/ha)		
					0%	50%	100%	0%	50%	100%
Rutherglen	Disced	Mulched	Standing	Burnt	0	52	103	0	7	14
Culcairn	Disced	Mulched	Standing	-	0	30	60	0	7	15
Tocumwal	Disced	Mulched	Standing	-	0	42	83	0	12	25

TABLE 2 Total amount of nitrogen fertiliser applied to stubble residue at each site during 2014 in the 100% fertiliser treatments (post-harvest and in-crop applications)

Site	Crop residue type	Nitrogen applied during 2014 (kg N/ha)									Total nitrogen (kg N/ha)
		Fertiliser at harvest (%)			Sowing fertiliser (%)			In-crop nitrogen fertiliser			
		0	50	100	0	50	100	Urea	Urea	SOA	
Rutherglen	Wheat			101			14	28	46		189
				101		7					182
				101	0						175
			51				14				139
			51			7					132
			51		0						125
		0					14				88
		0				7					81
		0			0						74
Culcairn	Wheat			59			14	41			114
				59		7					107
				59	0						100
			30				14				85
			30			7					78
			30		0						71
		0					14				55
		0				7					48
		0			0						41
Tocumwal	Wheat			80			25	46	58	9	218
				80		12					205
				80	0						193
			40				25				178
			40			12					165
			40		0						153
		0					25				138
		0				12					125
		0			0						113

TABLE 3 Main soil characteristics at each site, measured during 2012

Soil parameter	Rutherglen			Culcairn			Tocumwal		
	Soil layer (cm)								
	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
Soil pH ($CaCl_2$)	5.3	5.3	5.4	5.1	5.0	5.1	5.9	6.0	6.1
Soil pH (water)	6.0	6.1	6.4	5.7	5.9	6.1	6.7	7.0	7.1
Bulk density (gm/cm^3)	1.4	1.6	1.8	1.3	1.6	1.7	1.3	1.4	1.3
Colwell-P (mg/kg)	43	28	20	55	26	16	36	22	11
EC (dS/m)	0.15	0.09	0.06	0.16	0.08	0.05	0.19	0.15	0.15
Soil organic carbon (%)	1.9	0.9	0.5	2.0	0.9	0.5	1.2	0.7	0.6
ESP (% of CEC)	1.7	2.2	3.2	1.0	1.6	1.8	5.8	8.8	9.9

2014 crop results

Rutherglen, Victoria

Crop growth at the Rutherglen site was poor in the plots that did not receive any fertiliser, as shown in Figure 1. A wet start to the cropping season in the Rutherglen region (461mm of rainfall up to September), led to slow germination — in some areas wheat did not germinate at all (Figure 2).

Note the growth for the stubble-mulched treatment (second block from the top — see Figure 1) is denser and more vigorous than other stubble treatments for plots receiving fertiliser at all rates. These observations were not reflected in total biomass cuts taken at crop maturity during November. The total biomass for stubble burnt and disced treatments averaged 10.2t/ha compared with stubble mulched and standing stubble of 9t/ha. Although these results are not significantly different the yield results shown below would indicate that for stubble burning more of the nitrogen went into plant biomass production rather than grain yield.

FIGURE 1 Aerial picture of the Rutherglen site (21 September 2014)

Observations of stubble breakdown showed clear visual differences between treatments, which may have an influence in a very wet year. For example, where stubble was disced with a speed-tiller there was a clear placement of stubble at about 5cm below the soil surface (Figure 3). This stubble remained intact and had not broken down appreciably during the period from 25 February–23 September 2014. The disced treatments also remained wetter than other stubble treatments, especially compared with the stubble-mulched treatments, which appeared to shed the water down the slope into the disced treatments.

These agronomic observations were reflected in the final yield results obtained for 2014. Wheat grain yield at the Rutherglen site showed a significant difference between the stubble-mulched (chopped on the surface with a mower) treatment and the stubble burnt treatment, but no difference to that of the disced stubble treatment and the standing stubble treatment (Figure 4).

The yield map (Figure 5) and aerial photograph of the Rutherglen site (Figure 1) reflect the results shown in Figure 4, with higher-yielding areas observed as darker green (Figure 1) and lower-yielding areas as pink–red (Figure 5).

The post-harvest nitrogen fertiliser rates (Figure 5) are also shown as related to the broad treatment areas across the site from north to south.

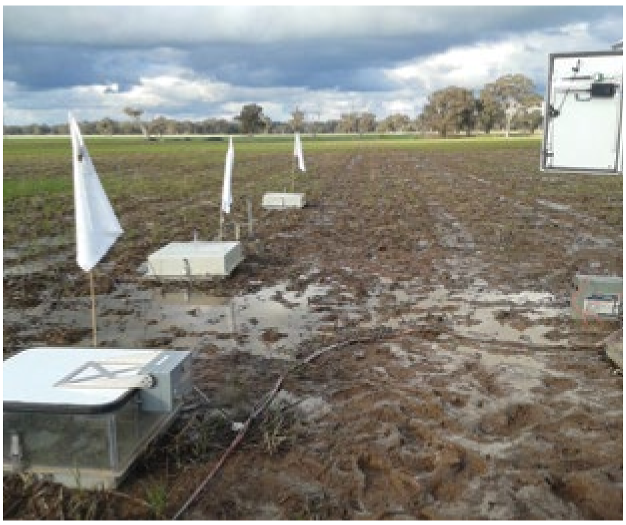


FIGURE 2 Wet conditions at the Rutherglen site near the greenhouse gas chambers (July 2014) showing poor germination

FIGURE 3 Section of soil from the disced stubble treatment showing intact wheat stubble buried about 5cm below the soil surface (September 2014)

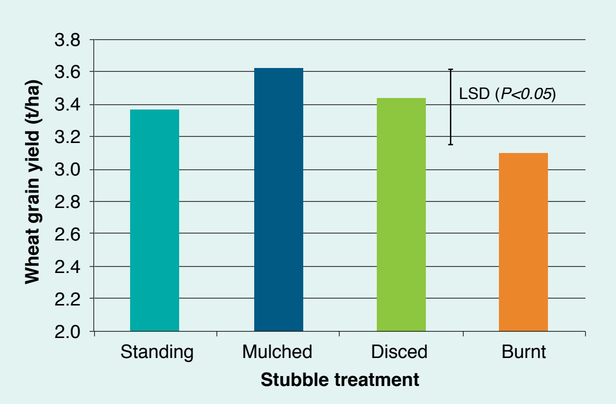


FIGURE 4 Grain yields for each of the stubble residue treatments at the Rutherglen site during 2014. Fertiliser treatments have been averaged within the stubble treatments

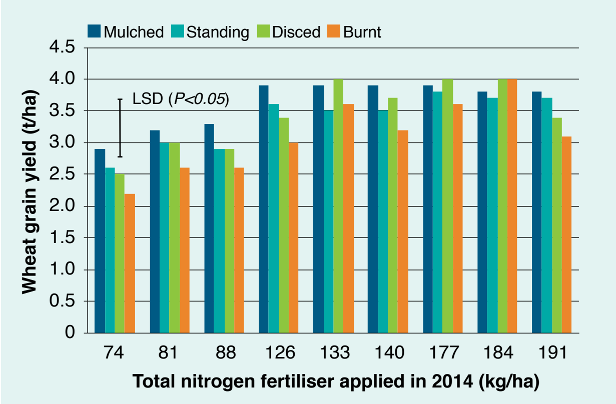


FIGURE 6 Grain yield at the Rutherglen site for all stubble treatments for different total nitrogen rates in 2014. The fertiliser rates are displayed as calculated in Table 2

While there were some significant differences in grain yield with higher amounts of nitrogen fertiliser, the trend with increasing fertiliser rate was not consistent. This trend is shown in Figure 5 where the lower-yielding areas of the yield map (red sections) align closely to the nil post-harvest nitrogen fertiliser treatment plots, while the higher-yielding areas of the map (green sections) align well with the higher fertiliser rates. The variation in grain yields within each individual fertiliser treatment are demonstrated in Figure 6 where the X-axis shows the total amount of nitrogen applied as related to the combined nitrogen for 2014 including post-harvest, sowing and in-crop fertiliser additions. While there are some significant differences in yield due to fertiliser application, as these are not consistent it is difficult to draw conclusions from them.

Culcairn NSW

Crop observations and measurements of total biomass at crop maturity at the Culcairn site did not identify any differences between fertiliser rates, although there was an observable negative response for the nil pre-sowing fertiliser and nil sowing fertiliser treatments compared with all other fertiliser treatments.

An aerial photograph of the site (Figure 7) identified a difference between stubble-disced (speed-tilled) treatments and the other stubble treatments. However this difference could not be linked to any other measured differences in crop vigour.

Canola yields for 2014 from stubble-disced treatments were significantly higher than the other two stubble treatments (Figure 8), reflecting the in-crop observations

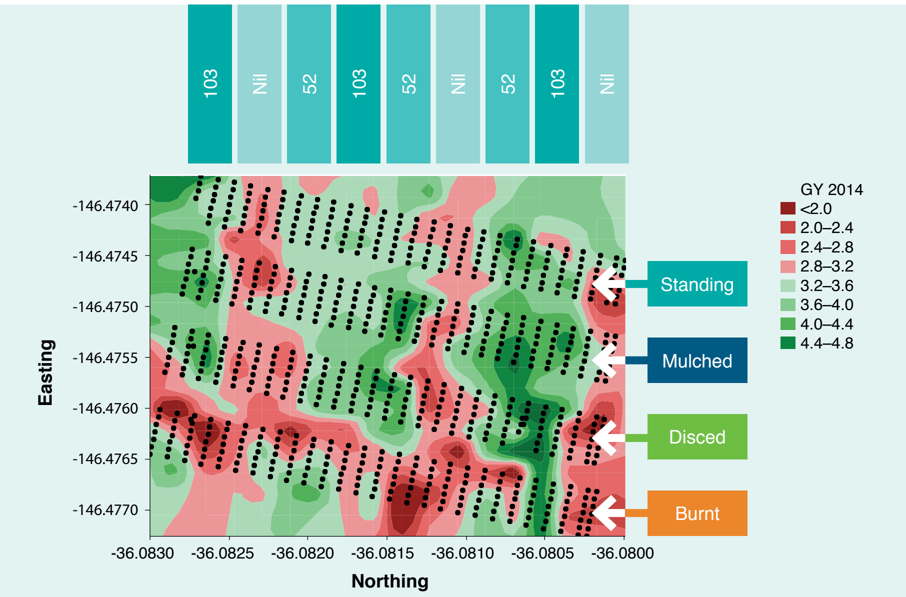


FIGURE 5 Grain yield map, site layout and post-harvest fertiliser treatments at the Rutherglen site for 2014

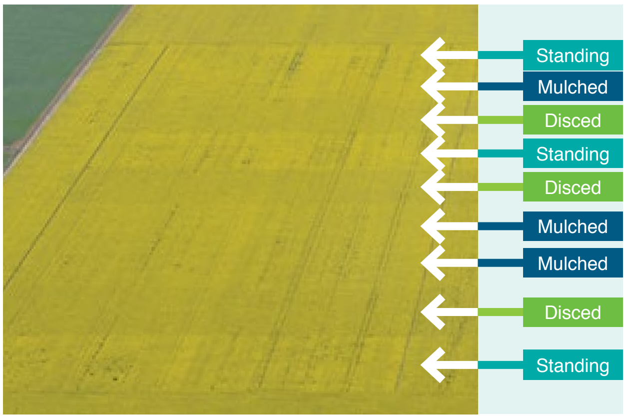


FIGURE 7 Aerial photograph of the Culcairn site (21 September 2014)

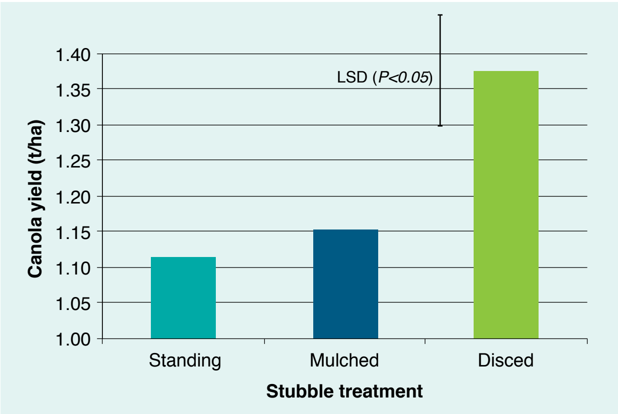


FIGURE 8 Grain yields for each of the stubble residue treatments at the Culcairn site during 2014. As there were no differences in yield in the fertiliser treatments, these have been averaged within the stubble treatments

shown in Figure 7. There was no significant difference between stubble-mulched and stubble-standing treatments. These yield results are reflected in the yield map (Figure 9), where the areas of highest yield displayed as dark green are consistently aligned with the stubble-disced treatments. There was less of an effect due to nitrogen fertiliser at this site.

Tocumwal NSW

Crop observations at the Tocumwal site showed an observable crop height difference between post-harvest fertiliser treatments across the site at ground level. These post-harvest fertiliser treatments were applied at right angles to the stubble treatments and were not obvious from an aerial photograph (Figure 10). However there was an observed difference between the stubble-standing treatments and all other stubble treatments from the aerial photograph, which was not obvious from the ground. These observations were however reflected in differences in harvest yield; for example canola yields from the disced and mulched treatments were significantly higher than the stubble-standing treatments (Figure 11).

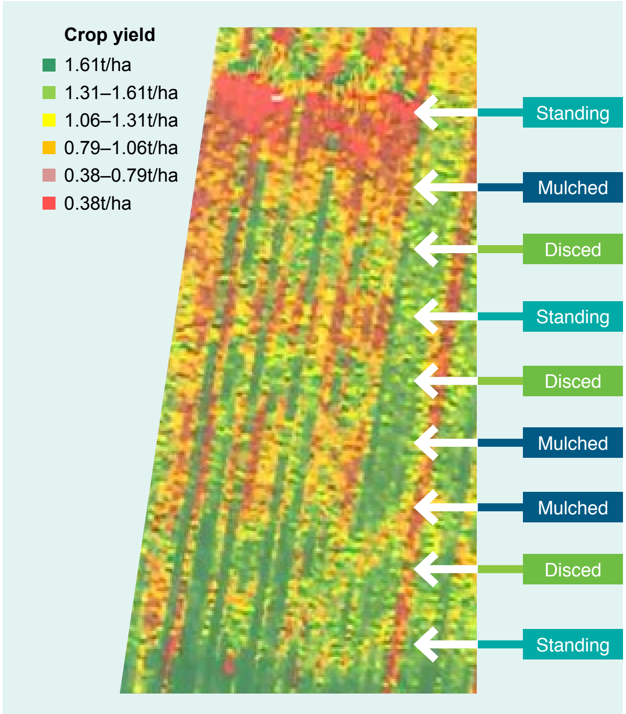


FIGURE 9 Grain yield map and site layout at the Culcairn site for 2014

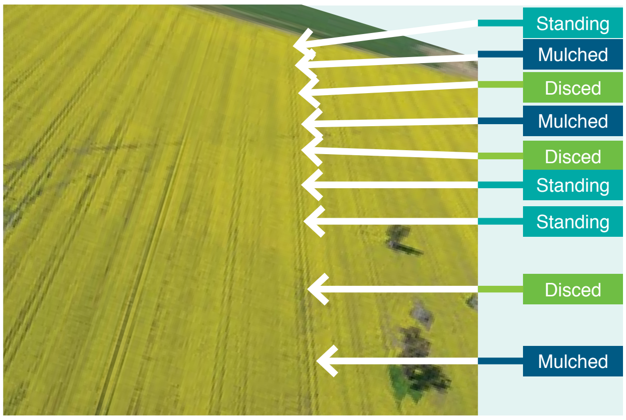


FIGURE 10 Aerial photograph of the Tocumwal site (21 September 2014)

Total soil carbon

There was no significant difference between total soil carbon measured in 2013 and 2014 for any of the three sites (Figure 12). There was also no significant difference in total soil carbon between stubble treatments in 2013 or 2014 at any of the three sites.

Results of total soil carbon from individual stubble treatments and each of the different rates of nitrogen applied during the year did not show a significant difference between the two sampling periods 2013 and 2014. This is demonstrated in Figure 12 where the X-axis shows the total amount of nitrogen applied as related to the combined nitrogen for 2014 including post-harvest,

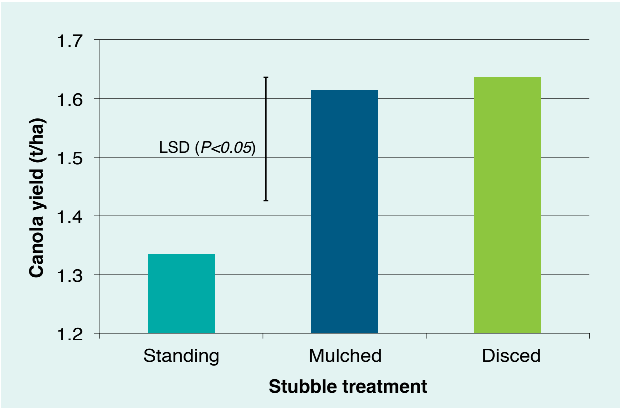


FIGURE 11 Grain yields for each of the stubble residue treatments at the Tocumwal site during 2014. As there were no differences in yield in the fertiliser treatments, these have been averaged within the stubble treatments

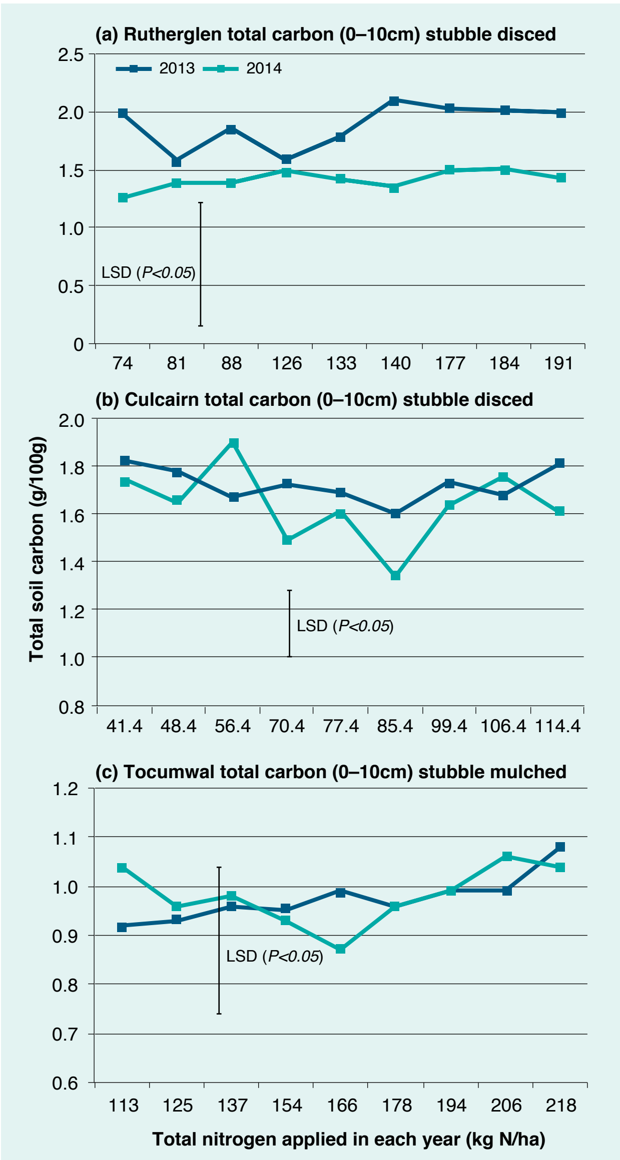


FIGURE 12 Total soil carbon from 2013 and 2014 for all fertiliser treatments within a specific stubble management treatment at the (a) Rutherglen site, (b) Culcairn site and (c) Tocumwal site

sowing and in-crop fertiliser additions. In fact all stubble treatments were consistent with total soil carbon between years, as presented for the Rutherglen site (Figure 13). The small but insignificant change in soil carbon between years is most likely due to spatial variability and for some stubble treatments the high degree of soil disturbance. For example when soil carbon is expressed as a total carbon mass using the bulk density of the soil for each stubble treatment and in each year, there is a significant decrease in total soil carbon for the disced treatment (Figure 14). This is consistent with a loss of soil carbon when using aggressive soil disturbance practices.

Spatial variability of soil carbon at each site was spread across a range of carbon values up to 1% (Figure 15). This variation in soil carbon across all sites, together with the small incremental change that might be expected with fertiliser applied to stubble residue, results in a high level of uncertainty in detecting a small change in soil carbon over two years. Additional sampling will be carried out during 2015 to allow for one additional year for soil carbon comparisons between treatments.

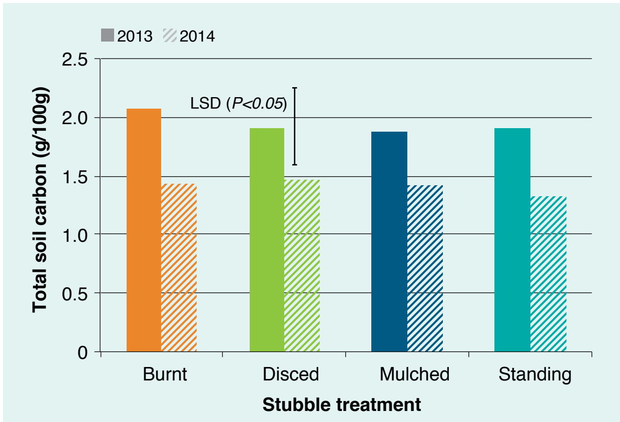


FIGURE 13 Total soil carbon for all stubble treatments at the Rutherglen site for 2013 and 2014

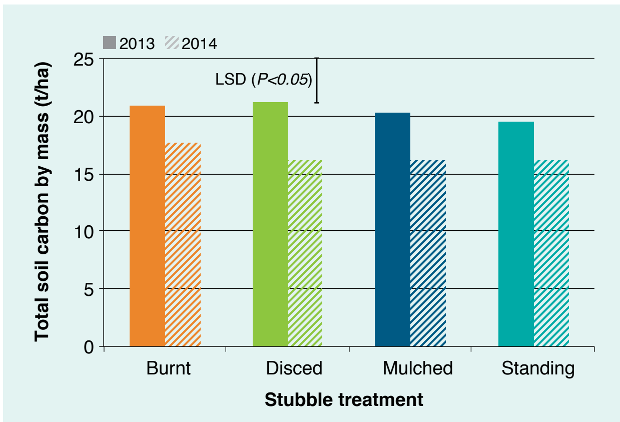


FIGURE 14 Total soil carbon mass for all stubble treatments at the Rutherglen site for 2013 and 2014

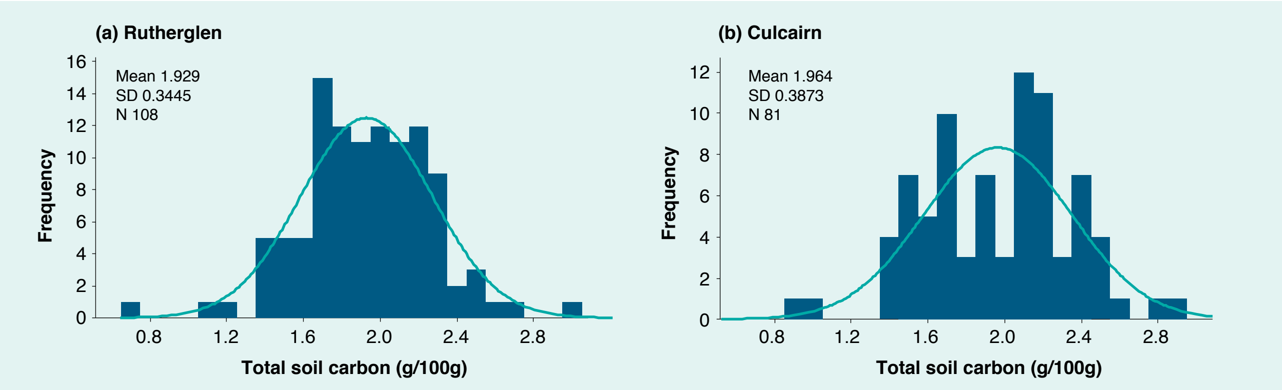


FIGURE 15 Soil carbon data from all plots at the Rutherglen and Culcairn sites during 2012, for the 0–10cm soil depth

Nitrous oxide emissions

Nitrous oxide emissions have been recorded at the Rutherglen and Culcairn sites since January 2014 for a period of at least 12 months. Results show substantially higher emissions of N_2O on plots with nitrogen fertiliser applied post-harvest compared with plots that did not receive post-harvest fertiliser. There has been no measurable increase in soil carbon so far in this project; it has only demonstrated an increased loss of N_2O through the application of nitrogen fertiliser onto stubble residues. The final soil carbon sampling carried out during 2015 will provide more information on the final carbon balance in this project.

Nitrous oxide emissions have been high from both the Rutherglen and Culcairn sites, most likely due to the large applications of nitrogen fertiliser onto stubble residues. The much higher emissions from the Rutherglen site (up to 600g N_2O-N/ha/day) are consistent with a soil that has been continuously wet during periods of hot weather (Figure 16). The Rutherglen site also had higher post-harvest fertiliser application than the Culcairn site, which would also contribute to the higher emissions measured.

Soil moisture was very high throughout April, May and June with an average volumetric water content of 34%. Values above 25%, equivalent to 60% water-filled pore space will be favourable for nitrous oxide emissions. The high N_2O emissions generated during September–October are consistent with other studies carried out in Australia where more than 50% of the overall emissions are generated late in the year or early in the following year when soil moisture is high, such as after heavy summer rain events.

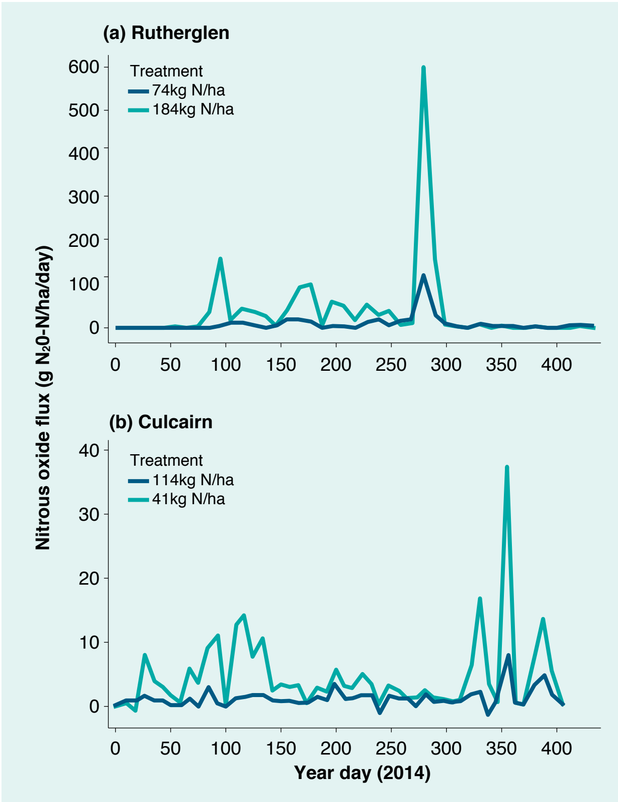


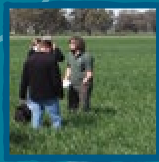
FIGURE 16 Nitrous oxide emissions from the Rutherglen and Culcairn sites from January 2014 to January 2015

Key observations

Crop growth/yield

Although the applications of post-harvest fertiliser provided relatively high rates of nitrogen to certain treatments (up to 103kg N/ha), the yield response to either the fertiliser applied post-harvest or the fertiliser applied at sowing was sporadic across the three sites. The Rutherglen site responded to the applied nitrogen whereas both Culcairn and Tocumwal were less responsive.





The 2014 grain yield data provides some interesting results for the various stubble treatments. The year was very wet throughout the growing period, conditions that would not favour stubble retention. Also both the canola sites (Culcairn and Tocumwal) showed significantly lower grain yield for stubble-standing treatments compared with stubble-disced (speed-tilled) treatments. In contrast, at the Rutherglen site (which was by far the wettest site) the grain yield for the stubble-standing treatment was not significantly different to that of the disced treatment.

These results tend to support the view that stubble discing, and potentially stubble mulching, are more likely to produce optimal grain yields in a wet year compared with stubble standing practices, which may be of more benefit in drier years.

Improved long-term weather forecasting would allow better planning of stubble treatments ahead of sowing. Also note that the stubble-disced treatments used on these sites were only a single pass with the speed tiller. More complete breakdown of stubble using multiple passes or other tillage machinery may have resulted in a different outcome. Additionally the losses in soil carbon for more aggressive tillage practices are likely to be even higher.

Soil carbon

Although this project has not shown a significant increase in soil carbon stocks with two years of fertiliser and stubble treatments, a third year may demonstrate a change, be it an increase or a decrease. For the start to the 2014 season there were several rainfall events of 10mm or more, during climatic conditions where the soil temperature in the surface profile remained high. These conditions are ideal for microbial activity and the production of humus carbon. Soil analysis will continue during 2015 with carbon fractions as well as further site sampling in July. If an increase in soil carbon is to be realised through the application of post-harvest fertiliser in these systems, then it should be shown in the results from 2015.

Nitrous oxide

The N_2O emissions at the Rutherglen site are large compared with normal practice, and would likely negate any positive effect of increased soil carbon values. However, the emissions were much lower at Culcairn, which is in a lower-rainfall zone. This indicates that post-harvest fertiliser application may be feasible in lower-rainfall areas, assuming a soil carbon benefit. After the final soil sampling is carried out in July the realistic potential to build soil carbon through post-harvest fertiliser application will be assessed, and the overall impact of that fertiliser on N_2O emissions will be evaluated.

Acknowledgements

These trials were carried out as part of the Riverine Plains Inc *Increased soil carbon by accelerated humus formation from crop residues* project and is supported by funding from the Australian Government Department of Agriculture's Clean Energy Future Plan — *Action on the Ground* program. Project partners include: Murray Local Land Services, North East Catchment Management Authority, the Irrigated Cropping Council, and property owners: Godde Farms Pty Ltd (Culcairn), EG Baker and Co (Rutherglen) and Glendaloch Pastoral Company (Tocumwal).

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Management strategies for improved productivity and reduced nitrous oxide emissions for wheat following peas or canola

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Key points

- The nitrogen (N) application strategy that maximised yield was not the same strategy that minimised nitrous oxide (N_2O) emissions.
- Applying 80% of nitrogen at sowing produced significantly higher yields than where 100% of nitrogen was applied at first node (GS31).
- Under very wet soil conditions following establishment (45% soil moisture for approximately two months), nitrogen applied at sowing produced crops with significantly higher dry matter (DM) and faster recovery than crops that were only fertilised at GS31.
- However, while nitrogen at sowing maximised yield, it also produced 4–6 times more N_2O emissions than where nitrogen was applied during early spring.
- The pattern and magnitude of N_2O emissions were similar when a wheat crop followed peas or canola.

Background to the trial

Nitrous oxide (N_2O) is an important greenhouse gas due to its high global warming potential (GWP), which means it can trap heat in the atmosphere, contributing to global warming. It is produced by soil microbial activity, which is increased in the presence of nitrogen (N) fertilisers and organic materials such as crop residues and livestock waste, particularly when soil conditions are anaerobic (void of oxygen). Recent research has shown there is a range of strategies to reduce N_2O emissions that may benefit growers both environmentally and economically. Some of these were evaluated in this trial. In addition to emitting N_2O emissions, soils also release dinitrogen (N_2) gas through denitrification, particularly under waterlogged conditions. The total quantity of nitrogen lost from cropping soils as dinitrogen gas is up to 20–30 times greater than the nitrogen lost as N_2O, however as dinitrogen makes up a large proportion of the gas in the Earth's atmosphere, measuring changes due to soil management is difficult. In comparison, as N_2O comprises only a small component of atmospheric nitrogen, it is technically easier to monitor changes in emissions due to management.

Aim

The aim of this project is to measure and demonstrate on-farm strategies that can reduce N_2O by trialling four key practices:

- use of legumes in the cropping rotation,
- application of nitrogen fertiliser at key stem elongation growth stages,
- use of precision farming tools to better measure nitrogen mineralisation,
- use of nitrification inhibitors.

Methodology

Location: Yarrawonga, Victoria

Plot size: 13.75m x 25m

Sowing date: 8 May 2014

Crop: Cobra wheat

Fertiliser: MAP @ 7kg N/ha at sowing
All in-season nitrogen applications as specified by treatments below

Paddock history (2013): Canola/peas

Two wheat trials were established adjacent to one another on two different crop histories (2013 — canola and peas). Each trial was subject to six nitrogen treatments, which were replicated four times. During 2014 the whole trial (ex-canola and ex-peas) was sown with Cobra wheat. The six nitrogen treatments were overlaid in a randomised complete block design and

included application as either incorporated by sowing (IBS) on 8 May 2014 or applied in-crop at first node (GS31) on 23 July 2014 as follows:

1) nil nitrogen applied (control)
2) 50kg N/ha applied as urea at first node (GS31)
3) 100kg N/ha applied as urea at first node (GS31)
4) 80kg N/ha as urea incorporated at sowing (IBS) and 20kg/ha as urea at first node (GS31)
5) 100kg N/ha applied as Entec urea (nitrification inhibitor) at first node (GS31)
6) *Real time tactical treatment (RTT) — determined using a Greenseeker®. At GS31, 53kg N/ha (as urea) was applied to the ex-peas wheat plots and 59kg N/ha (as urea) to ex-canola wheat plots.

** The (RTT) treatment (#6) used the difference in normalised difference vegetative index (NDVI) readings at GS30–31 from the nil nitrogen (#1) and IBS treatment (#4) in order to calculate the responsiveness of the soil to nitrogen application. As a result only 50–60kg N/ha was applied to the RTT treatment.*

(Note: All treatments had 7kg N/ha at sowing as monoammonium phosphate — MAP — including the nil nitrogen control).

Soil assessments

A number of measurements were taken throughout the season including N_2O monitoring in treatments 1 (nil), 3 (100kg N/ha at GS31) and 4 (80kg N/ha IBS and 20kg N/ha at GS31).

Sampling of N_2O emissions from the soil occurred once each week during the growing season and twice each week after the GS31 nitrogen applications for three weeks.

The emissions were collected in a manual chamber that allowed emissions from the soil to build up over a 60 minute period with gas samples being withdrawn from the chamber at 0, 30 and 60 minute intervals after the chamber was fastened into place. At the time of gas collection soil moisture content and temperature was also measured in the top 12cm of the soil using a hand-held time domain reflectometer (TDR) soil moisture meter and HOBO® temperature logger. Soil nitrogen was assessed in both the ex-canola and ex-peas blocks after sowing (on 12 June 2014) at depths 0–30cm and 30–60cm. The delay between sowing and soil nitrogen sampling was due to waterlogging at the trial site.

Crop structure assessments

Two fixed marker points per plot were used for crop structure assessments, with 2m of crop row assessed at each point. Plant establishment, tiller and head number were all assessed at these fixed marker points. Dry matter (DM) and nitrogen content were sampled at GS30 and GS31 for treatments 1 and 4 only and then at second node (GS32), flag leaf fully emerged (GS39), mid booting (GS45), start of flowering (GS61) and harvest (GS99) for all treatments.

Grain yield and quality

The trial was harvested on 27 November 2014. All plots were assessed for grain yield, protein, test weight, and screenings (<2.0mm screen).

Results and discussion

i) Soil nitrogen status

The use of legumes, such as peas, generally leaves higher residual levels of soil nitrogen. After sowing the previous pea and canola trial sites were assessed for soil nitrogen (Table 1). Note that samples were taken from nil nitrogen plots, which had received 7kg N/ha at sowing.

ii) Crop structure

There were no significant differences in plant population, but there was some evidence the earlier application of nitrogen increased final head numbers at harvest when sowing nitrogen was compared to treatment 5, using a nitrogen inhibitor at first node (GS31) (Figures 1 and 2).

iii) Dry matter

Nitrogen applied at sowing increased wheat DM production at flowering compared with the same amounts of nitrogen applied in crop (Figures 3 and 4). Application of the nitrification inhibitor reduced final DM to levels comparable with the nil nitrogen treatments and significantly lower than the same level of nitrogen applied as urea (following peas). The lower nitrogen rates tended to produce less DM, but the differences were not statistically significant in comparison to 100kg N/ha.

TABLE 1 Soil mineral nitrogen for ex-peas and ex-canola sampled 6 June 2014

Treatment	Mineral nitrogen (kg/ha)
Ex peas: 0–30cm	27.4
Ex peas: 30–60cm	26.4
Ex peas: Total	**53.8**
Ex canola: 0–30cm	22.9
Ex canola: 30–60cm	43.6
Ex canola: Total	**66.6**

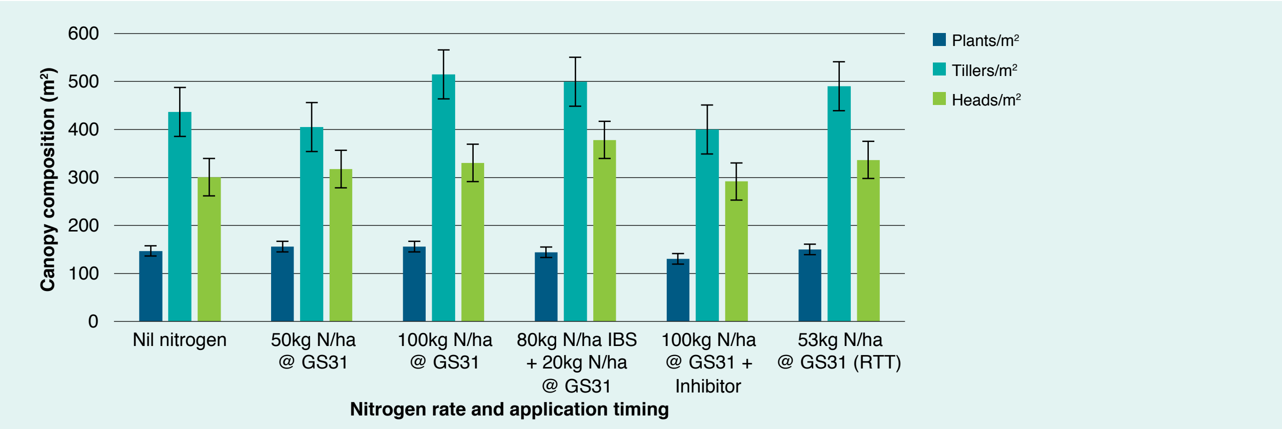


FIGURE 1 Plant, tiller and final head number/m² for Cobra wheat *following peas* for all nitrogen treatments

* The error bars are a measure of LSD

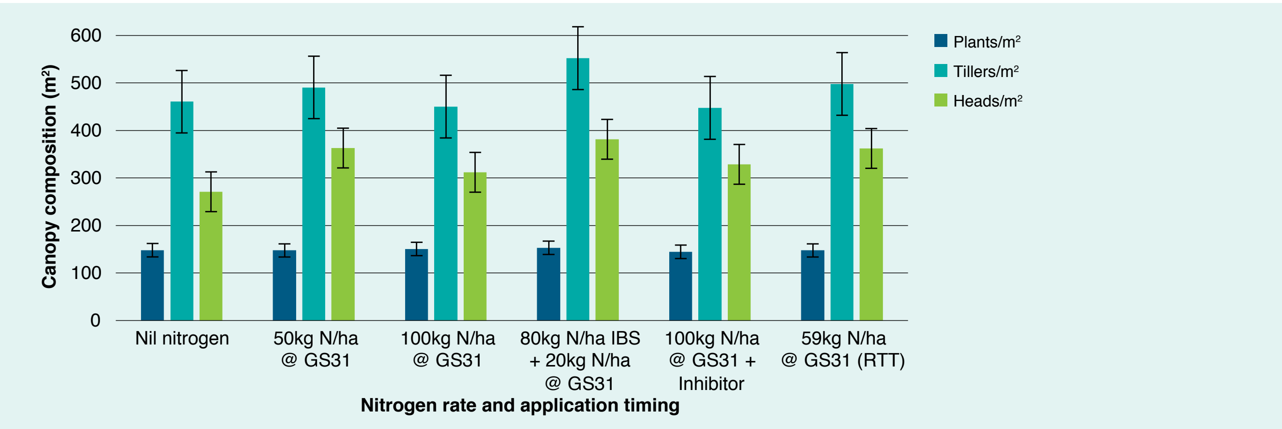


FIGURE 2 Plant, tiller and final head number/m² for Cobra wheat *following canola* for all nitrogen treatments

* The error bars are a measure of LSD

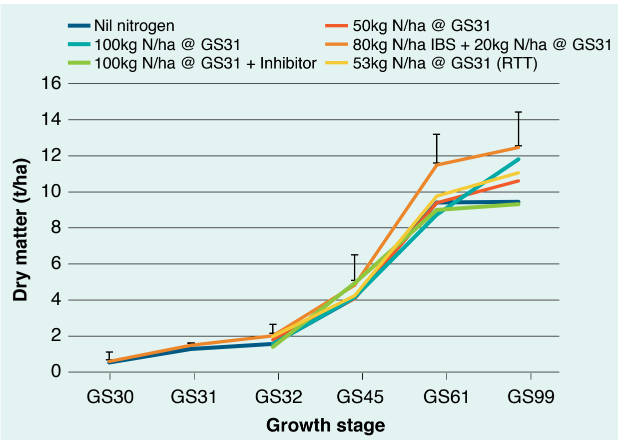


FIGURE 3 Dry matter production of Cobra wheat *following peas* for all nitrogen treatments

* The error bars are a measure of LSD

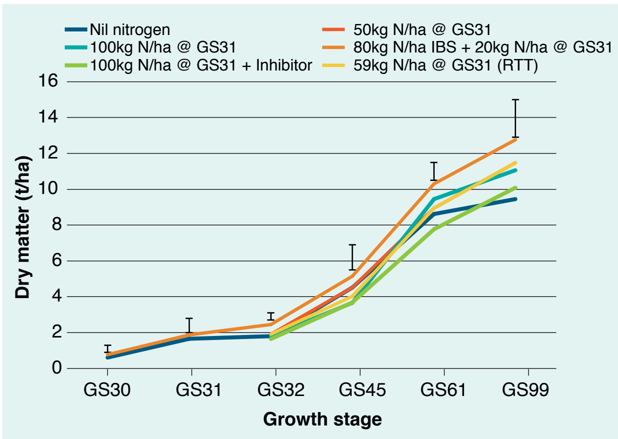
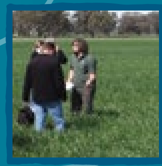


FIGURE 4 Dry matter production of Cobra wheat *following canola* for all nitrogen treatments

* The error bars are a measure of LSD





iv) Nitrogen uptake

Nitrogen uptake into the crop was lower where application rates were less than 100kg N/ha, however differences were not always statistically significant (Tables 2 and 3).

v) Grain yield and quality

The highest yields in wheat following peas and canola were measured where 80kg N/ha was applied at sowing with a follow-up application of 20kg N/ha at first node (GS31), the advantage was statistically significant following canola. There were no differences in yield between the in-crop nitrogen treatments and the nil-nitrogen plots, however the grain protein was significantly greater in all nitrogen treatments compared with the nil-nitrogen treatment (Tables 4 and 5). While the nil-nitrogen treatment yielded less than most other treatments, it still yielded more than 5t/ha, indicating high soil fertility and in-season nitrogen mineralisation.

vi) Nitrous oxide emissions

Nitrous oxide emissions were approximately four to five times higher when nitrogen was applied at sowing than when it was applied in crop at first node (GS31) in the spring (Table 6). The largest emissions from the upfront nitrogen treatments occurred during May and June when soils were at their wettest, following nitrogen application on May 8 (Figure 5). The total amount of nitrogen lost as N_2O was still less

TABLE 2 Nitrogen uptake in biomass *following peas* at: stem elongation (GS30), 10 July 2014; first node (GS31), 24 July 2014; second node (GS32) 12 August 2014; mid-booting (GS45), 8 September 2014; start of flowering (GS61), 8 October 2014; and harvest GS99, 20 November 2014

Treatment	GS30	GS31	GS32	GS45	GS61	GS99
Nil nitrogen	16^{a}	31^{a}	41^{b}	59^{a}	72^{cd}	76^{d}
50kg N/ha @ GS31			43^{b}	59^{a}	70^{d}	87^{cd}
100kg N/ha @ GS31			40^{b}	70^{a}	121^{ab}	139^{a}
80kg N/ha IBS 20kg N/ha @ GS31	23^{a}	46^{a}	56^{a}	84^{a}	130^{a}	123^{ab}
100kg N/ha @ GS31 + inhibitor			38^{b}	75^{a}	99^{bc}	96^{bcd}
53kg N/ha @ GS31 (RTT)			49^{ab}	83^{a}	110^{ab}	117^{abc}
Mean	**20**	**39**	**45**	**72**	**100**	**106**
LSD	15	2	14	31	27	30

TABLE 3 Nitrogen uptake in biomass *following canola* at: stem elongation (GS30), 10 July 2014; first node (GS31), 24 July 2014; second node (GS32), 12 August 2014; mid-booting (GS45), 8 September 2014; start of flowering (GS61), 8 October 2014 and harvest GS99, 20 November 2014

Treatment	GS30	GS31	GS32	GS45	GS61	GS99
Nil nitrogen	18^{a}	34^{b}	40^{b}	68^{a}	74^{c}	95^{c}
50kg N/ha @ GS31			50^{b}	65^{a}	79^{c}	105^{bc}
100kg N/ha @ GS31			40^{b}	58^{a}	110^{a}	144^{ab}
80kg N/ha @ IBS + 20kg N/ha @ GS31	30^{a}	58^{a}	67^{a}	73^{a}	107^{ab}	162^{a}
100kg N/ha @ GS31 + inhibitor			39^{b}	62^{a}	78^{c}	138^{abc}
59kg N/ha @GS31 (RTT)			49^{b}	58^{a}	95^{b}	112^{bc}
Mean	**24**	**46**	**47**	**64**	**91**	**126**
LSD	12	22	13	23	15	45

TABLE 4 Summary of grain yield, test weight, protein and screenings for Cobra wheat sown *following peas* with all nitrogen rates

	Yield and quality			
Nitrogen rate	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
Nil nitrogen	5.28^{b}	78.0^{a}	8.2^{c}	4.98^{a}
50kg N/ha @ GS31	5.84^{b}	78.4^{a}	10.3^{ab}	4.66^{ab}
100kg N/ha @ GS31	6.03^{ab}	78.3^{a}	11.2^{a}	3.74^{b}
80kg N/ha @ IBS + 20kg N/ha @ GS31	6.74^{a}	78.5^{a}	11.1^{a}	3.84^{b}
100kg N/ha @ GS31 + inhibitor	5.70^{b}	80.1^{a}	10.5^{ab}	4.62^{ab}
53kg N/ha @ GS31 (RTT)	5.58^{b}	77.9^{a}	10.0^{b}	4.22^{ab}
Mean	**5.86**	**78.5**	**10.2**	**4.34**
LSD	0.77	2.35	1.12	1.05

TABLE 5 Summary of grain yield, test weight, protein and screenings for Cobra wheat sown *following canola* with all nitrogen rates

Nitrogen rate	Yield and quality			
	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)
Nil nitrogen	5.45[b]	79.4[ab]	8.6[c]	4.73[a]
50kg N/ha @ GS31	5.92[b]	79.8[a]	10.1[b]	3.35[b]
100kg N/ha @ GS31	5.68[b]	78.1[ab]	11.7[a]	3.41[b]
80kg N/ha @ IBS + 20kg N/ha @ GS31	6.75[a]	77.8[b]	11.0[ab]	2.79[b]
100kg N/ha @ GS31 + inhibitor	5.48[b]	79.3[ab]	11.1[ab]	3.33[b]
53kg N/ha @ GS31 (RTT)	5.90[b]	78.7[ab]	11.2[ab]	2.99[b]
Mean	**5.86**	**78.9**	**10.6**	**3.43**
LSD	0.60	1.8	1.4	0.86

TABLE 6 Average nitrous oxide emissions for the period of 8 May–25 November for nitrogen fertiliser × crop history treatments at Yarrawonga, 2014

Treatment	May (23 days)	June (30 days)	July (23 days)	July post N (8 days)	August (31 days)	September (30 days)	October (31 days)	November (25 days)	Total for 201 days
	Nitrous oxide emissions (g N_20-N/ha)								
Following peas									
Nil nitrogen	41.5	179.2	12.4	6.8	12.2	10.2	7.9	17.1	**287.2**
100kg N/ha @ GS31	-	-	-	47.6	57.4	6.1	28	17.8	**389.9**
80kg N/ha @ IBS + 20kg N/ha @ GS31	472.1	1108.3	27.8	10.3	26.6	20.6	11.3	9.5	**1686.4**
Following canola									
Nil nitrogen	61.3	106.2	8	0	18.5	0	13.2	9.7	**211.5**
100kg N/ha @ GS31	-	-	-	8.1	77.2	16.4	23.9	39.1	**340.2**
80kg N/ha @ IBS + 20kg N/ha @ GS31	812.4	897.9	48.4	20.1	66	35.1	24.3	18.1	**1922.4**

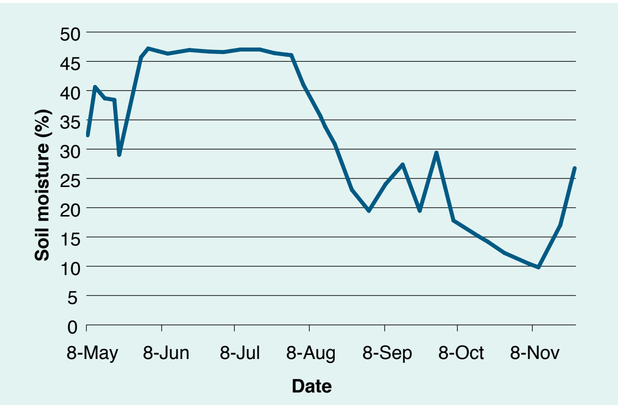


FIGURE 5 Average soil moisture in the top 12cm of the soil

than 2kg N/ha, however if this is representative of emissions of dinitrogen gas, it would represent total nitrogen losses of 33–50kg N/ha following peas, and 38–58kg N/ha following canola when nitrogen was applied at sowing. In comparison, if the N_2O losses from in-crop application of nitrogen were related to dinitrogen gas release in the same ratio, the total losses would be less than 8kg N/ha irrespective of previous crop.

In conclusion, nitrogen applied at sowing enabled the crop to better handle the very wet soil conditions in the eight weeks after establishment. The advantage of applying nitrogen at sowing was manifest in higher DM and grain yields, however it resulted in much higher N_2O emissions than equivalent amounts of nitrogen applied at early stem elongation.

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Thanks go to the Inchbold Family Yarrawonga, Victoria.

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MURRAY LOCAL LAND SERVICES

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Crop sequencing project reveals potential of broadleaf break crops

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Key point

- Data collected from two research experiments between 2012 and 2013, and on-farm data collected during 2014 indicates that pasture legume hay, faba beans and canola can be as profitable, and often more profitable, than wheat.

Aim

There is a wide-spread perception among growers and their advisors that broadleaf break crops, such as legumes and canola, are higher risk and/or not as profitable as cereal crops.

The aim of a recent Grains Research and Development Corporation (GRDC)-funded break-crop project (CSP000146) was to challenge this notion, and to partner with seven grower groups across the GRDC Southern Region to re-examine the relative profitability of canola or legume crops and pastures, and to quantify the potential beneficial impacts of break crops on the longer-term financial performance of subsequent wheat crops.

This paper presents the key findings generated from experiments carried out through participatory research between Riverine Plains Inc and CSIRO, which specifically focused on the question: "Can break crops be as profitable as wheat?".

Break crop profitability

Research experiments (2012 and 2013)

During 2012 and 2013, experimental trials were established on the Inchbold family property at Yarrawonga South, Victoria to address the renewed grower interest in growing break crops, and to help identify which break crop might be the most profitable in the Riverine Plains area.

Soil characteristics were: soil pH (0–10cm) ranged between 5.3–5.9 ($CaCl_2$) and increased with depth. Colwell P (0–10cm) ranged from 9–22 mg/kg and soil mineral nitrogen (N) (0–60cm) was 40–50kg N/ha.

Trial details are outlined in Table 1.

During both trial years (2012 and 2013) all crop and pasture species were sown with MAP @ 80kg/ha in plots 20m x 1.42m (2012) and 20m x 1.5m (2013), replicated four times in a randomised-block design.

Sowing was carried out either early May (faba beans, canola, arrowleaf clover, sub-clover and vetch), or early June.

All legumes were inoculated with standard peat inoculant and treatments were grown according to best practice management.

Both wheat and canola included a nil and plus nitrogen fertiliser treatments — 180kg urea (82.8kg N/ha) during 2012 and 200kg urea (92kg N/ha) during 2013.

Hay cut yields were calculated at 70% of peak biomass values. Grain crops were harvested at physiological maturity. Weeds, such as soursob, ryegrass and marshmallow, were an issue in some plots and were removed by hand.

On-farm case study (2014)

In addition to the experimental trials carried out on the Inchbold family property at Yarrawonga during 2012 and 2013, three paddocks on the Glover farm at Wilby (South of Yarrawonga), were sown as a commercial case study to: faba beans (Rana), lupins (Mandelup) and clover (mix of Mintaro clover and Balansa sub-clover for hay).

TABLE 1 Experimental break crop trial details, Yarrawonga South, 2012 and 2013

Year	Crop type and variety	Crop output (grain/hay)	Sowing rate (kg/ha)
2012	Faba beans cv Rana	Grain	160
	Chickpeas cv Slasher	Grain	130
	Canola cv Tawriffic	Grain	3
	Wheat cv Young	Grain	90
	Field peas cv Oura	Hay	130
	Vetch cv Morava	Hay	40
	Arrowleaf clover cv Zulu	Hay	8
	Sub-clover cv Antas	Hay	8
2013	Faba beans cv Rana	Grain	160
	Canola cv Tawriffic	Grain	3
	Wheat cv Young	Grain	90
	Sub-clover cv Antas	Hay	8



Soil tests taken during February 2014, in the lupin and faba bean paddock, showed that soil pH in the top 10cm ranged from 5–5.1 $CaCl_2$, Colwell P ranged 69–110 mg/kg and soil nitrate 19–22mg N/kg (about 24kg N/ha). Each paddock had 1t/ha lime applied during March 2014.

The clover mix was sown @ 8kg/ha during mid April and the lupins were sown @ 80kg/ha during late April. All pulses were inoculated with standard peat inoculant just before sowing. Both crops were sown using an RFM airseeder with MAP @ 90kg/ha on 22.5cm row spacings. The faba beans were broadcast (which is not recommended) at 160kg/ha during late April and worked in with MAP @ 90kg/ha. Although broadcasting seed is not ideal, good germination and plant establishment was still achieved due to excellent rainfall after sowing. However, lack of sowing depth did contribute to plants lodging during the season, which subsequently caused issues at harvest.

Grain yield and biomass was recorded for each faba bean, lupin and clover paddock, and grain yields were collated across the whole farm for wheat and canola. The costs of production were determined from the grower's own records and the value of grain or hay at the time of harvest were used to calculate gross margins.

Results

Experimental crop yields and gross margins (2012)

Flooding rainfall preceeded the 2012 growing season, with more than 300mm recorded during late February–early March. This rainfall provided excellent sub-soil moisture at sowing. However, growing season rainfall (GSR — April to October) was 213mm, which was below average.

The arrowleaf clover and sub-clover hay cuts provided higher gross margins than wheat due to the combination of high dry matter (DM) yields and high hay prices (Table 2).

The clover hay treatments have multiple advantages for subsequent crops because they are likely to contribute to higher available soil nitrogen, better weed control and higher soil water reserves due to the earlier cessation of water use during the growing season than the neighbouring grain crops that grew through to maturity.

Above-average prices were achieved for most grains; in particular wheat, faba beans and canola, which resulted in excellent gross margins for 2012.

Wheat yields showed a marked response to additional nitrogen, with a significant difference between the plus nitrogen fertiliser treatment (4.8t/ha) and the nil fertiliser treatment (4.1t/ha), but there was no significant effect of nitrogen fertiliser on canola yields.

Experimental crop yields and gross margins (2013)

The 2013 season had a dry start and finish, but rain fell at just the right time resulting in an average GSR (296mm; decile 5). An exceptionally late and severe frost on 18 October 2013 devastated some cropping areas in the region, and while the trial site was affected, the extent of damage was not as bad as other local crops.

Sub-clover hay provided the highest gross margin, which was buoyed by high hay prices. Wheat plus nitrogen fertiliser provided the second highest gross margin, followed by wheat without additional nitrogen. The canola and faba bean yields may have been more affected by the frost than the wheat (Table 3).

TABLE 2 Comparisons of grain yield, hay production, income, variable costs and gross margins at Yarrawonga South, 2012*

Treatment	Grain or hay yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)
Arrowleaf clover hay	4.3	1,324	229	1095
Sub-clover hay	4.0	1,252	229	1023
Wheat + nitrogen	4.8	1,310	323	987
Wheat - nitrogen	4.1	1,066	215	851
Faba bean	3.0	1,170	347	823
Canola + nitrogen	2.2	1,206	415	791
Canola - nitrogen	1.8	965	307	658
Vetch hay cut	3.5	815	224	571
Chickpea	1.7	799	265	534
Field pea hay	2.8	614	244	371

Crops arranged in order of descending gross margin.

Note: Grain and hay prices used in the calculations were current at the time of harvest. Variable costs were based on local practice and prices and are estimated as a guide only.

TABLE 3 Comparisons of grain yield, hay production, income, variable costs and gross margins at Yarrawonga South, 2013*

Treatment	Grain or hay yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)
Sub-clover hay	3.8	1,064	221	843
Wheat + nitrogen	4.6	1,164	323	841
Wheat - nitrogen	4.0	1,012	215	797
Canola + nitrogen	2.4	1,200	415	785
Faba beans	2.9	1,160	377	783
Canola - nitrogen	2.0	1,000	307	693

* Crops arranged in order of descending gross margin.
Note: Grain and hay prices used in the calculations were current at the time of harvest. Variable costs were based on local practice and prices. These figures are estimated as a guide only. Results were taken from only three reps of 15m x 1.5m due to weed infestations. Lupin and field pea treatments/results were dropped due to poor (patchy) establishment.

Commercial crop yields and gross margins (2014)

The 2014 growing season had a very wet start, recording 115mm during April with above-average rainfall persisting until July causing significant waterlogging at times during winter. August was exceptionally dry, recording only 2mm; however, there was follow-up spring rain, resulting in a total GSR of 325mm.

Faba beans did well in the wet winter conditions and the combination of high yield and excellent commodity prices resulted in the highest gross margin. This was despite additional growing costs from aerial applications of fungicide and insecticide due to poor trafficability.

Wheat had the second highest gross margin followed by canola, both of which received a total of 200kg urea (92kg N/ha) over the season.

The clover paddock grew and yielded well, although the return on hay was reduced by additional growing costs in comparison to previous years. The lupins also grew well on a well-drained paddock, but the yield was disappointing compared to how bulky the crop looked towards the end of spring.

The lupins were harvested a bit late so pod shattering during harvest, leading to grain losses, were likely to have contributed to the lower-than-expected yield (Table 4).

Conclusions

Results from experimental trials and a farm case study undertaken by GRDC Project CSP00146 in conjunction with the Riverine Plains Inc (two experiments and one on-farm case study 2012–14; reported here), Birchip Cropping Group in the Victorian Mallee (six experiments across two soil types, established sequentially between 2009–11; detailed results presented elsewhere) and FarmLink in southern NSW (four experiments established between 2011–13; results presented elsewhere) have demonstrated that given the environmental conditions and commodity prices that have prevailed since 2009, canola and legume break crops were frequently as profitable, and in a number of instances considerably more profitable, than wheat. While legume hay and faba beans proved to be the most profitable break crops in the Riverine Plains area, canola was generally the most profitable crop elsewhere.

The research team recognises the economic performance of break crops relative to wheat observed during the project reflects the favourable rainfall for growth, and/or the high prices received, for either canola, clover hay or faba bean in various years, and depressed prices for wheat.

TABLE 4 Comparisons of on-farm grain yield, hay production, income, variable costs and gross margins for commercial crops grown at Wilby, 2014*

Treatment	Grain or hay yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)
Faba beans	3.5	1,715	453	1,262
Wheat + nitrogen	4.3	1,161	323	838
Canola + nitrogen	2.8	1,232	415	817
Sub-clover hay	4.3	1,075	292	783
Lupins	2.5	1,025	297	728

* Crops arranged in order of descending gross margin.
Note: Grain and hay prices used in the calculations were current at the time of harvest. Variable costs were based on farmer records. These figures are estimated as a guide only.

The team is currently interrogating project results from all seven collaborating grower groups and plans to apply various simulation models to predict long-term trends in production and financial returns for different rainfall, cropping and grain price scenarios to extrapolate the findings beyond the growing seasons experienced during the project. These simulation runs will also be used to assess the relative risk of including break crops in otherwise cereal-dominant cropping sequences. Regardless of the outcomes growers and their advisors need to remember that in addition to their contribution to farm profitability, canola and legumes have been shown to provide less expensive and more effective control of herbicide-resistant ryegrass than is achievable in wheat, and that legumes also result in higher concentrations of soil mineral nitrogen for the benefit of subsequent cereal crops.

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Managing clethodim-resistant ryegrass in canola

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Key points

- Resistance to clethodim in annual ryegrass is increasing in Victoria and makes it difficult to control annual ryegrass in canola.
- Pre-emergent herbicides alone are insufficient to effectively manage annual ryegrass in canola.
- Crop-topping and windrow burning in canola offer an opportunity to reduce annual ryegrass seed set.

Background

Clethodim has been used to control annual ryegrass in broadleaf crops across southern Australia for the past two decades. However, repeated use of this herbicide has resulted in the development of clethodim resistance in many annual ryegrass populations.

In an effort to achieve acceptable control of such populations increased application rates of clethodim have become widespread industry practice, with the label rate increasing from 250mL to 500mL/ha. The higher rate has been found to have minimal effect on pulse crops, but there can be detrimental effects in canola. As a consequence, growers are reluctant to use higher rates of clethodim in canola, and are finding it increasingly more difficult to effectively control ryegrass in this important crop phase.

Aim

Trials were undertaken at Roseworthy and east of Frances, South Australia to evaluate alternative approaches for the control of clethodim-resistant ryegrass in canola.

Roseworthy trial

Method

At Roseworthy, a field trial was carried out during 2014 to evaluate the performance of pre-emergent and post-emergent herbicide options for the control of clethodim-resistant annual ryegrass in triazine tolerant (TT) and Clearfield (CLF) hybrid canola.

Annual ryegrass seedlings of the field population were sampled at 1–2 leaf growth stage and screened for resistance to clethodim (Select®) and butroxydim (Factor®).

A standard knife-point press-wheel system was used to sow the trials on 22.5cm row spacings. Sowing and fertiliser rates were undertaken as per district practice (Table 1).

Herbicide treatments were developed for experimental purposes only and several are not currently registered (identified as Products A, D, E in Table 4).

Pre-sowing herbicides were applied within a few hours of being incorporated by sowing (IBS), post-sowing pre-emergent herbicide applications (PSPE) were applied within days after sowing, before emergence (results are not presented) and post-emergent (POST) treatments were applied when the ryegrass had reached the 3–4 leaf growth stage.

Assessments included control of annual ryegrass (reduction in plant density and seed set), crop safety and yield.

Results

Herbicide screening showed the Roseworthy field population of annual ryegrass (S2) to be resistant to clethodim and butroxydim (Figure 1). The rate of clethodim required for 50% reduction in survival (LD50) and biomass (GR50) was more than 26-fold and 17-fold higher for resistant S2 population when compared with the susceptible control (SLR4).

The susceptible population was easily controlled with butroxydim, whereas the resistant S2 population required seven times more herbicide to obtain equivalent control.

At the Roseworthy trial, clethodim did not effectively control annual ryegrass in the TT canola during 2014 (Table 2). Rustler (propyzamide) was the best of the stand-alone pre-emergent herbicide options examined, although weeds that emerged through this treatment were highly competitive and reduced yield.

TABLE 1 Crop management and herbicide application details for Roseworthy, SA, 2014

Crop details and herbicide management	
Canola cultivars	TT — ATR Stringray and CLF — 45Y82
Sowing date	23 May 2014
Sowing rate (kg/ha)	3
Herbicide application timing	22 May (IBS), 23 May (PSPE), 2 July (POST)

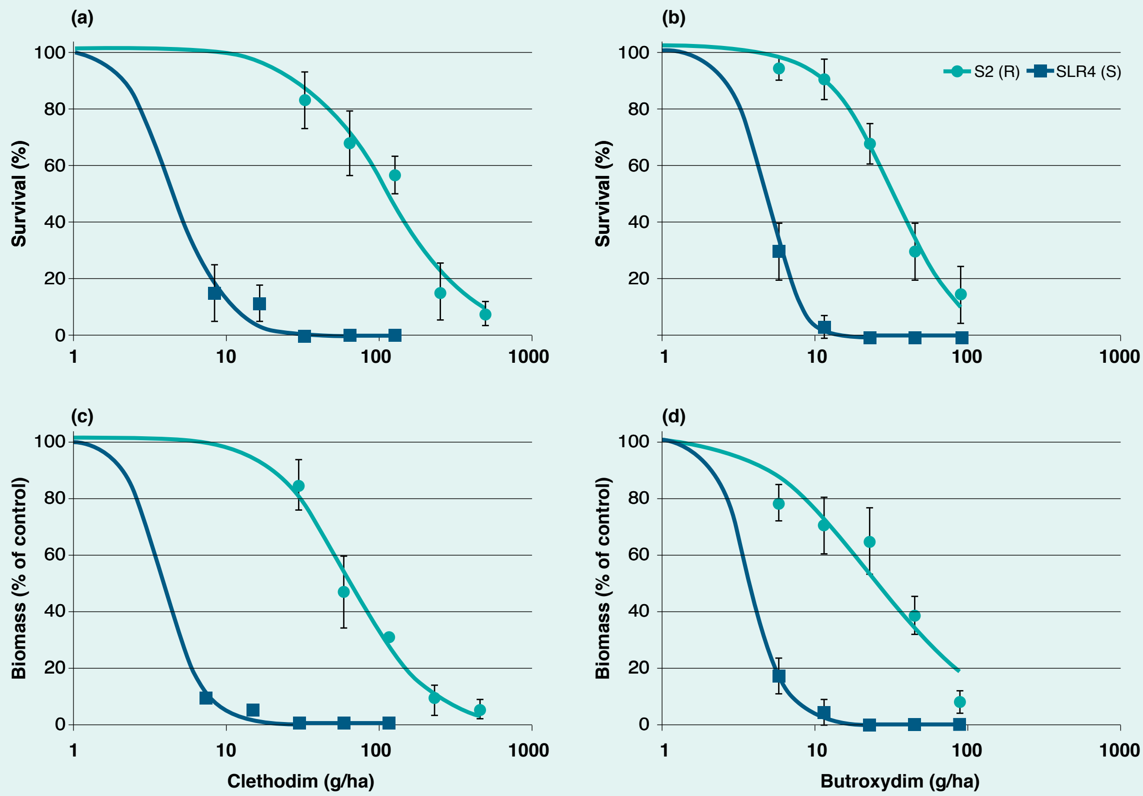

FIGURE 1 (a, b) Survival and (c, d) biomass (% of control) of resistant (●, S2) and susceptible (■, SLR4) ryegrass biotypes to clethodim (Select) and butroxydim (Factor) at Roseworthy, SA. Bars are SE of the mean

TABLE 2 Ryegrass plant numbers, seed production and grain yield for TT canola at Roseworthy, SA, 2014 following herbicide treatments to control clethodim-resistant annual ryegrass

Treatment			Ryegrass plants (plants/m²)	Ryegrass seed (seed/m²)	Grain yield (t/ha)
No.	IBS	POST			
1	Atrazine (1.5kg/ha)	Clethodim (500mL/ha)	522[ab]	6785[a]	1.69[abc]
2	Atrazine (1.5kg/ha)	Clethodim (500mL/ha) + Atrazine (1kg/ha)	361[a]	2956[a]	1.88[a]
3	Atrazine (1.5kg/ha)	Clethodim (500mL/ha) + Butroxydim (80g/ha)	282[a]	3274[a]	1.84[ab]
4	Product A		864[b]	51743[cd]	1.15[de]
5	Rustler (1L/ha)		354[a]	32781[bc]	1.49[cd]
6	Rustler (1L/ha)	Clethodim (500mL/ha)	324[a]	13396[ab]	1.74[abc]
7	Atrazine (1.5kg/ha)	Product D	876[b]	62124[d]	1.00[de]
8	Atrazine (1.5kg/ha)	Product E	308[a]	10996[a]	1.61[bc]
9	Product E		869[b]	51192[cd]	1.26[d]

Values with different letters within a column are significantly different (p=0.05)

Addition of clethodim to Rustler tended to stunt these weeds and reduce their competitiveness. The reduced rate of butroxydim (80g/ha), which can be used in canola, compared with pulse crops, makes this product less effective on annual ryegrass with low levels of butroxydim resistance.

Pre-emergent herbicides performed better in the CLF canola than in the open-pollinated TT canola due to the increased competition provided by the CLF hybrid (Table 3).

This enhanced competition can help limit seed production from surviving ryegrass plants. However, annual ryegrass has widespread resistance to the imidazolinone herbicides and this was evident at Roseworthy, as was

TABLE 3 Ryegrass plant numbers, seed production and grain yield for CLF canola at Roseworthy, SA, 2014 following herbicide treatments to control clethodim-resistant annual ryegrass

Treatment			Ryegrass plants (plants/m²)	Ryegrass seed (seed/m²)	Grain yield (t/ha)
No.	IBS	POST			
1	Trifluralin (2L/ha) + Triallate	Intervix (750mL/ha) + Clethodim (500mL/ha)	632[ab]	5404[a]	1.71[abc]
2	Trifluralin (2L/ha) + Triallate	Intervix (750mL/ha) + Clethodim (500mL/ha) + Butroxydim (80g/ha)	128[a]	7915[a]	1.79[a]
3	Product A		1697[d]	54347[d]	1.41[bcd]
4	Rustler (1L/ha)		553[ab]	17270[ab]	1.65[abcd]
5	Rustler (1L/ha)	Clethodim (500mL/ha)	385[ab]	3663[a]	1.84[a]
6	Trifluralin (2L/ha)	Product D	1206[cd]	33299[a]	1.44[bcd]
7	Trifluralin (2L/ha)	Product E	589[ab]	28159[bc]	1.61[abcd]
8	Product E		1643[d]	27107[bc]	1.36[d]

Values with different letters within a column are significantly different (p=0.05)

some resistance to trifluralin. This limited the options available for controlling annual ryegrass in CLF canola. Rustler applied pre-emergent with clethodim post-emergent was one of the better treatments despite resistance to clethodim being present.

Frances trial

Method

A two-year trial was established in collaboration with the MacKillop Farm Management Group at a site to the east of Frances, SA to identify appropriate management strategies for clethodim-resistant canola in crop rotations.

During 2014, RT canola (RT-Hyola 525) was established and three levels of herbicide management (low, medium and high) were undertaken to control clethodim-resistant ryegrass (Table 4). RT canola, a new technology developed by Pacific Seeds combining dual herbicide tolerance of Roundup Ready with Plantshield® (RR) with triazine tolerance was chosen for in-crop use of both glyphosate and triazine herbicides.

The trial was established as a randomised complete block design with three replicates. A standard knifepoint press-wheel system was used to sow the trials on 22.5cm row spacings.

Sowing and fertiliser rates were undertaken as per district practice (Table 5). Pre-sowing herbicides were applied within a few hours of being incorporated by sowing (IBS), while post-emergent (POST) clethodim was applied when most ryegrass had reached three to four-leaf growth stage.

Application of glyphosate, simazine and atrazine in RT canola was undertaken following label recommendations.

TABLE 4 Herbicide management strategies for Frances, SA, 2014

Strategy	Timing and crop stage	Product
HS1 (low)	IBS (pre-sowing)	Simazine (1.1kg/ha)
	POST 2 (six true leaf stage)	Atrazine (1.1kg/ha)
		Clethodim (500mL/ha)
HS2 (medium)	IBS (pre-sowing)	Simazine (1.1kg/ha)
	POST 1 (cotyledon stage)	Roundup Ready (0.9kg/ha)
	POST 2 (six true leaf stage)	Atrazine (1.1kg/ha)
		Roundup Ready (0.9kg/ha)
HS3 (high)	IBS (pre-sowing)	Rustler (1L/ha)
		Avadex Xtra (2L/ha)
	POST 1 (cotyledon stage)	Roundup Ready (0.9kg/ha)
	POST 2 (six true leaf stage)	Atrazine (1.1kg/ha)
		Roundup Ready (0.9kg/ha)
	POST 3 (20% canola seed changed colour)	Over-the-top Weedmaster DST



TABLE 5 Crop management and herbicide application details for Frances, SA, 2014

Sowing date	12 May 2014	
Canola cultivar	Hyola 525-RT	
Sowing rate	2.5kg/ha	
Treatment type, date and weed/crop growth stage		
Treatment	**Date**	**Weed/crop growth stage**
IBS	12 May 2104	n/a
POST1	3 June 2014	1–2 leaf/cotyledon
POST2	3 July 2014	One-leaf – two-tiller/six-leaf
POST3	5 November 2014	Milky to hard-dough/20% seed colour change

Over-the-top glyphosate (Weedmaster DST) was applied when 20% of the canola seed had changed colour following label directions.

Assessments included ryegrass control (reduction in plant density, seed set and seedbank), crop yield and grain quality.

Results

In the RT canola trial at Frances, the annual ryegrass population was highly resistant to clethodim. Therefore, the TT strategy (HS1 – low) was the least effective option (Figure 2), both in terms of ryegrass control and reduction of seed set. Substituting clethodim with Roundup Ready herbicide (HS2 – medium) reduced ryegrass numbers and seed set. Including Rustler plus Avadex Xtra as a pre-emergent herbicide and crop-topping with Weedmaster DST (HS3 – high) reduced annual ryegrass numbers further. The crop-topping application should also have an additional effect on seed viability.

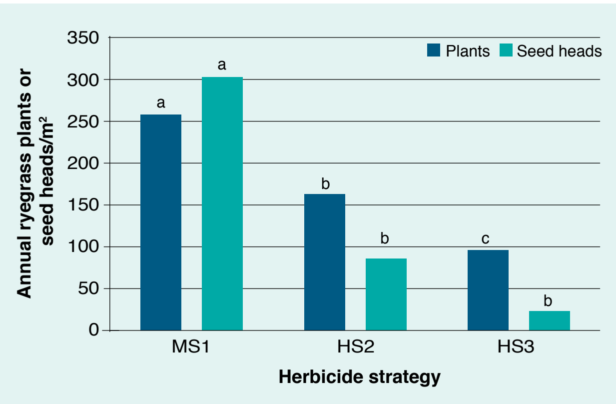

FIGURE 2 Annual ryegrass plant numbers and seed heads following three management strategies in RT canola at Frances, 2014

Bars with different letters for each measurement are significantly different (p = 0.05)

Observations and comments (both trials)

Currently there are no effective herbicides to control clethodim-resistant annual ryegrass in canola. Therefore, the most effective strategy is to start with an effective pre-emergent herbicide and then use clethodim to stunt any ryegrass present in the crop. Using a hybrid canola variety will improve the efficacy of the pre-emergent herbicides.

Alternative practices will have to be adopted in canola to manage annual ryegrass in the rotation. The most effective of these at present are crop-topping with Weedmaster DST and windrow burning. It is essential to use one of these strategies where clethodim-resistant annual ryegrass is present.

Researchers are currently working with some new chemistry to control annual ryegrass in canola. One product will be a pre-emergent herbicide, which can also be applied early post-emergent. The other product is a post-emergent herbicide. In current trials, neither of these herbicides are as effective as clethodim used to be, so additional practices will remain essential.

Acknowledgments

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Canola disease update — 2015

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Key points

- Blackleg monitoring sites indicated a slight decrease in the overall blackleg stem canker levels during 2014 compared with 2013.
- Regional monitoring results for each blackleg resistance group are available on the NVT online website. Consult the *Blackleg Management Guide* for details of resistance groups.
- Monitoring canola crops for levels of blackleg is an essential tool when making informed disease management decisions.
- Symptoms of stem injury due to blackleg were observed higher in the crop canopy during spring 2014; these symptoms caused yield loss in some instances.
- Sclerotinia stem rot occurred in those districts with a frequent history of the disease.
- Drier-than-average conditions during spring kept potential disease levels low.
- Early-sown canola crops in districts prone to sclerotinia stem rot are more likely to develop high levels of the disease.

New South Wales 2014 blackleg severity

Background: Cultivars representing each of the blackleg resistance groups were sown at 32 Grains Research and Development Corporation (GRDC)-funded National Variety Trial (NVT) sites across Australia (13 sites were located in NSW) and monitored for levels of blackleg development during 2014.

Each site contained a representative cultivar of each of the seven blackleg resistance groups: Groups A, B, C, D, E, F, and S. No fungicide was applied to seed, fertiliser or the growing plot (foliar) at these blackleg monitoring sites. These results indicate which resistance groups have higher levels of disease compared with the national average at each of the regionally-based NVT canola yield sites and serve as a monitoring tool of local blackleg pathogen populations.

Overall blackleg severity decreased in most cultivars at blackleg monitoring sites during 2014 in southern NSW (Table 1). Blackleg severity decreased from 38% average internal infection level during 2013 to 24% during 2014. This is a similar level of infection to that measured during 2012.

The blackleg severity in NSW during 2014 was similar to that measured in South Australia. The decrease in the level of blackleg incidence reflects the seasonal conditions in southern NSW. Warm autumn and early winter conditions meant canola plants grew quickly through the seedling growth stage, thereby reaching the fifth leaf stage and escaping susceptibility to stem canker.

Warnings for southern NSW

Despite the overall decrease in the level of stem infection there are some warning signs to come from the data collected. The level of stem infection in Group A and B cultivars was significantly higher than the national average. This reflects the intensity that cultivars from these groups are grown in southern NSW. Isolated reports were also received, from growers and advisors, of concerns with the level of blackleg development in some commercial crops of Group A and B cultivars.

In contrast, the level of blackleg in Group D cultivars was much reduced compared with 2013 and reflects the dynamic nature of the blackleg pathogen population. Although the level of disease in the Group D cultivar did not cause any yield loss during 2014 it should be monitored in 2015 so growers know if it has increased to a dangerous level, allowing them to change cultivars before the 2016 season if necessary.

Manage to minimise yield loss

Spores of the blackleg fungus are released from the previous year's canola stubble, so an increased area of canola results in increased disease pressure. The most effective blackleg management tool is to keep a 500m distance between this season's crop and last year's canola stubble. However, as more canola is grown this control measure is becoming more difficult to achieve, particularly in tight wheat–canola rotations.



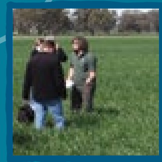

TABLE 1 Summary of all Australian blackleg monitoring sites*

	Group							Comments
NSW	**A**	**B**	**C**	**D**	**E**	**F**	**S**	
BECKOM	H	H	L	L	L	L	H	High blackleg severity in groups A,B and S.
BELLATA	L	L	L	L	L	L	L	Low blackleg severity in all groups.
COOTAMUNDRA	M	M	L	L	L	L	H	High blackleg severity in group S. Moderate in groups A and B.
CUDAL	M	H	L	L	L	L	H	High blackleg severity in groups B and S. Moderate in group A.
GEROGERY	H	H	L	L	L	L	H	High blackleg severity in groups A, B and S.
GOULBURN	M	L	L	L	L	L	L	Moderate blackleg severity in group A.
GREENETHORPE	L	L	L	L	L	L	H	High blackleg severity in group S.
GRENFELL	M	H	L	L	L	L	H	High blackleg severity in groups B and S. Moderate in group A.
LOCKHART	H	H	L	L	L	L	H	High blackleg severity in groups A, B and S.
MULLALEY	L	L	L	L	L	L	L	Low blackleg severity in all groups.
PARKES	L	H	L	L	L	L	H	High blackleg severity in groups B and S.
TAMWORTH	H	M	L	L	L	L	H	High blackleg severity in groups A and S. Moderate in group B.
WAGGA WAGGA	M	H	L	L	L	L	H	High blackleg severity in groups B and S. Moderate in group A.
SA	**A**	**B**	**C**	**D**	**E**	**F**	**S**	
ARTHURTON	L	L	L	L	L	L	H	High blackleg severity in group S.
BORDERTOWN	L	H	L	L	L	L	H	High blackleg severity in groups B and S.
CUMMINS	L	L	L	H	L	L	H	High blackleg severity in groups D and S.
FRANCES	L	M	L	M	L	L	H	High blackleg severity in group S. Moderate in groups B and D.
MT HOPE	L	H	L	M	L	L	L	High blackleg severity in group B. Moderate in group D.
RIVERTON	M	L	L	M	L	L	H	High blackleg severity in group S. Moderate in groups A and D.
SPALDING	L	M	L	L	L	L	M	Moderate blackleg severity in groups B and S.
TURRETFIELD	M	M	L	H	L	L	H	High blackleg severity in groups D and S. Moderate in groups A and B.
WANILLA	H	H	L	H	L	L	H	High blackleg severity in groups A, B, D and S.
YEELANNA	L	H	L	H	L	L	L	High blackleg severity in groups B and D.
VICTORIA	**A**	**B**	**C**	**D**	**E**	**F**	**S**	
CHARLTON	L	L	L	L	L	L	M	Moderate blackleg severity in group S.
DIGGORA	M	H	L	L	L	L	H	High blackleg severity in groups B and S. Moderate in group A.
HAMILTON	L	M	L	M	L	L	H	High blackleg severity in group S. Moderate in groups B and D.
KANIVA	L	H	L	L	L	L	H	High blackleg severity in groups B and S.
LAKE BOLAC	H	M	L	L	L	L	L	High blackleg severity in group A. Moderate in group B.
MINYIP	L	L	L	L	L	L	M	Moderate blackleg severity in group S.
WUNGHNU	L	H	L	L	L	L	H	High blackleg severity in groups B and S.
YARRAWONGA	M	H	L	L	L	L	H	High blackleg severity in groups B and S. Moderate in group A.
WA	**A**	**B**	**C**	**D**	**E**	**F**	**S**	
BADGINGARRA	L	H	L	L	L	L	L	High blackleg severity in group B.
CORRIGIN	L	H	L	L	L	L	L	High blackleg severity in group B.
GIBSON	H	H	L	L	L	L	L	High blackleg severity in groups A and B.
KATANNING	H	H	L	L	L	L	M	High blackleg severity in groups A and B. Moderate in group S.
KENDENUP	L	H	L	L	L	L	M	High blackleg severity in group B. Moderate in group S.
KOJONUP	L	H	L	L	L	L	H	High blackleg severity in groups B and S.
SOUTH STIRLING	H	L	L	L	L	L	M	High blackleg severity in group A. Moderate in group S.
WILLIAMS	L	H	L	L	L	L	H	High blackleg severity in groups B and S.

* Cultivars representing each of the resistance groups were sown adjacent to canola NVT sites across Australia and monitored for levels of blackleg. These data indicate which resistance groups have high levels of disease compared with the other groups at a particular site.

L — Low blackleg severity compared with other groups at that site — continue with current management techniques.

M — Moderate blackleg severity compared with other groups at that site — monitor crops for disease, see the *Blackleg Management Guide.*

H — High blackleg severity compared with other groups at that site — high risk of yield loss if environmental conditions are conducive to high disease severity – see the *Blackleg Management Guide.*

Blackleg can be minimised by a number of factors including the sowing of cultivars with high blackleg resistance, avoiding last year's stubble and applying the appropriate fungicides (see *2015 Blackleg Management Guide* for details — www.grdc.com.au).

An additional method to minimise disease is to rotate cultivars with different resistance genes. All canola cultivars are now classified into different resistance groups. Refer to the current *Blackleg Management Guide* (www.grdc.com.au) for individual cultivar groups.

Remember to monitor the level of blackleg development in canola crops during the growing season as a basis for selecting appropriate management strategies in the future.

Symptoms of blackleg — upper branch infection

Growers normally associate blackleg infection as lesions observed on cotyledons and leaves at the vegetative stage, and later in the season as stem cankers at the crown. In the period between early leaf infection and canker development the fungus grows from the cotyledon–leaf lesion to the crown (junction between the stem and the roots) where it causes a necrosis, blocking the vascular tissue, which can cause the plant to lodge and die prematurely.

In recent years stem infection symptoms have been observed later in the growing season. Typically these have been dark necrosis of the pith inside the stem and necrotic lesions on the outside of the stem and branches (Figure 1). During 2014 these symptoms were more widespread and more severe. In some cases these necrotic lesions have caused significant yield loss.

Causes of stem–branch cankers

It is not entirely clear why upper stem/branch infections are now being observed; however the causal fungus has been isolated and it has been confirmed it is the blackleg pathogen causing these symptoms.

Anecdotal observations

This type of symptom has been observed in southern NSW in the past, albeit at low levels. But this year the level of infection appears to have been exacerbated by particular environmental influences.

FIGURE 1 Examples of various blackleg symptoms in the upper canopy of canola plants



Southern NSW experienced some unusual growing conditions for canola during 2014, with warm autumn and winter temperatures resulting in rapid establishment and growth of crops. Several frost events also caused injury to early bolting and flowering crops during late July and August, and then drier-than-average conditions throughout late winter and spring also resulted in crops suffering moisture stress. Injured plants or plants undergoing stress can become more prone to infection by pathogens.

Some symptoms on plants were observed around injury points on the stem, including frost and hail injury, as well as branch junctions where moisture is likely to gather and allow germination and infection by spores. Many plant pathogens are opportunistic and will take advantage of any wounds or ruptures in the epidermis (outer stem) for infection. Infection by the blackleg pathogen can occur when conditions are moist and cool throughout the growing season. When established, secondary spores, spread by rainsplash, can quickly expand the disease within a crop canopy onto any plant tissue including leaves, stems and pods.

Management of stem–branch infection

- Do not be tempted to sow canola early. Follow recommended sowing times for your district and try to ensure stem elongation occurs during the normal flowering window, not during winter when blackleg intensity and risk of frost injury is at its highest.
- Cultivars with effective major gene resistance did not get stem–branch infection. Therefore blackleg resistance groups D, E and F did not get stem–branch canker, even at sites where groups A, B, C and S did get branch cankers.
- Seed dressing fungicides and foliar fungicides applied at the 4–6 leaf growth stage will not protect the stem or branches. It is unclear if later applications of foliar fungicide will protect plants.

Sclerotinia stem rot — 2015 update

How does the disease develop?

Sclerotinia stem rot has a complex lifecycle compared with many other foliar diseases. There are several key stages that must be synchronised and completed in order for plant infection to occur. Weather conditions must also be suitable for the pathogen at each stage of development. These stages of development are:

1. Soil-borne sclerotia are the main source of inoculum each year. Sclerotia soften and germinate during winter after soil has been wet at the surface. This requires continuous wet conditions for about 10 days and often not until full ground cover is reached by the developing crop. Most sclerotia will remain viable for up to 3–4 years, after which survival slowly declines.
2. Airborne spores of the fungus are released from apothecia (a small, golf-tee shaped structure, 5–10mm in diameter), which germinate from sclerotia in the soil.
3. Spores of the sclerotinia pathogen cannot infect canola leaves and stems directly. They mainly use petals as a food source to germinate, grow and colonise. While petals are the most common food source, other plant parts, such as old leaves under the canopy, are also prone to infection and colonisation. When the infected petal dies, it may become lodged onto a leaf, within a leaf axil or at branch junctions along the stem. If conditions are moist, the fungus grows out of the petal and invades healthy plant stem tissue, which will result in a stem lesion and production of further sclerotia within the stem, which will be returned to the soil after harvest. Sclerotinia is more prevalent in crops with heavy vegetative growth, where air circulation is likely to be limited.
4. Sclerotia also can germinate in the soil, produce mycelium and directly infect canola plants in close proximity, causing a basal infection.
5. Weather conditions during flowering play a major role in determining the development of sclerotinia. The presence of moisture during flowering and petal fall will determine if sclerotinia develops. Dry conditions during this time can quickly prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development.

Research findings in 2014

Commercial canola crops were monitored for the development of sclerotinia stem rot in high sclerotinia risk districts during 2014. These crops were located east of Cootamundra and south of Henty in southern NSW. Consistent with results from 2013, observations within these crops found a strong relationship between prolonged periods of leaf wetness and stem rot development.

There was potential for high levels of stem rot to develop at several of the disease monitoring sites during 2014. Rapidly-developing crops, the presence of apothecia, and high levels of petal infestation by sclerotinia, all indicated that epidemics of the disease were likely. However, drier-than-average conditions throughout August and spring kept potential stem rot levels low in many districts. Dry conditions within the crop canopy did not allow the pathogen to spread from petals into stems.

Where did the disease occur during 2014?

During 2014 sclerotinia was observed in southern NSW and northern Victoria in those districts with a history of sclerotinia and reliable spring rainfall. These included districts east of Cootamundra and Young, south of Henty, around Corowa and Howlong and districts along the Murray River. Infection levels observed in some crops were as high as 30–60%. In other districts, crop infection levels were generally low.

What are the indicators that sclerotinia stem rot could be a problem during 2015?

- **Spring rainfall:** Epidemics of sclerotinia stem rot generally occur in districts with reliable spring rainfall and long flowering periods for canola.
- **Frequency of sclerotinia outbreaks:** Use the past frequency of sclerotinia stem rot outbreaks in the district as a guide to the likelihood of a sclerotinia outbreak. Paddocks with a recent history of sclerotinia are a reliable indicator of potential risk, as well as those paddocks that are adjacent. Also consider the frequency of canola in the paddock. Canola is an attractive host for the disease and can quickly build up levels of soil-borne sclerotia.
- **Start of flowering:** The start of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. Canola crops that flower earlier during winter, when conditions are cooler and wetter, are more prone to disease development.

If I had sclerotinia in my canola crop last year, what should I do this season?

The biggest challenge in managing sclerotinia stem rot is deciding whether or not there is a risk of disease development and what will be the potential yield loss. Research in Australia and Canada has shown the relationship between the presence of the pathogen (as infected petals) and development of sclerotinia stem rot is not clear due to the strong reliance on moisture for infection and disease development.

Important management options include:

1. **Sowing canola seed free of sclerotia:** This applies to growers retaining seed on farm for sowing. Consider grading seed to remove sclerotia that would otherwise be sown with the seed and infect this season's crop.
2. **Rotate canola crops:** Continual wheat–canola rotations are excellent for building up levels of viable sclerotia in the soil. A 12-month break from canola is not effective at reducing sclerotial survival. Consider other low-risk crops, such as cereals, field peas or faba beans.
3. **Follow recommended sowing dates and rates for your district: Do not be tempted to sow crops early if you are located in a sclerotinia-prone district.** Early-flowering crops are more prone to developing sclerotinia stem rot by increasing opportunities for infected petals to lodge in a wet crop canopy. In addition, early-sown crops will most likely develop bulky crop canopies, which retain moisture and increase the likelihood of infection. Wider row spacings can also help by increasing air-flow through the crop canopy to some degree and delaying the onset of canopy closure.
4. **Consider the use of a foliar fungicide:** Weigh up yield potential, disease risk and costs of fungicide application when deciding to apply a foliar fungicide.
5. **Monitor crops for disease development and identify the type of stem infection:** Main stem infections cause the most yield loss and indicate infection events early in the growing season. Lateral branch infections cause lower levels of yield loss and indicate infection events later in the growing season.

Use of foliar fungicides

At this time there are no commercial canola cultivars available on the Australian market with resistance to sclerotinia stem rot. Management of the disease relies on the use of cultural and chemical methods of control. Consider foliar fungicides in those districts at a high risk of disease development (e.g. districts where the disease frequently occurs, long flowering period and reliable spring rainfall). There are several foliar fungicides currently registered for use in Australia to manage sclerotinia stem rot.

Points to consider when using a foliar fungicide to manage sclerotinia stem rot

1. The most yield loss from sclerotinia occurs from early infection events. Early infection is likely to result in premature ripening of plants and produce little or no yield.
2. Plants become susceptible to infection after flowering starts. Research in Australia and Canada has shown an application of foliar fungicide around the 20–30% flowering stage (20% flowering is 14–16 flowers on the main stem, 30% flowering is about 20 flowers on the main stem) can be effective in significantly reducing the level of sclerotinia stem infection. Most registered products can be applied up to the 50% flowering (full bloom) stage.



3. The objective of the fungicide application is to prevent early infection of petals while ensuring fungicide also penetrates into the lower crop canopy to protect potential infection sites (such as lower leaves, leaf axils and stems). Timing of fungicide application is critical.
4. A foliar fungicide application is most effective when applied before an infection event (e.g. before a rain event during flowering). These fungicides are best applied as protectants and have no curative activity.
5. In general, foliar fungicides offer a period of protection of up to three weeks. After this time the protectant activity of the fungicide is compromised.
6. Use high water rates and fine droplet sizes for effective canopy penetration and coverage.

During 2014 some commercial crops that received an application of foliar fungicide still developed stem rot later in the season. This is not unexpected as the fungicide has a limited period of protection during a time of rapid plant growth and the main aim of foliar fungicide applications is to prevent main stem infections, which cause the greatest yield loss. Development of lateral branch infections later in the season is not uncommon, and will result in lower yield loss.

Consult the *Sclerotinia stem rot in canola* factsheet for further information. This publication is available from the GRDC website — (www.grdc.com.au).

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Assessing legume nodulation during late winter or early spring to check inoculation success

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Key points

- Monitoring inoculation success of legumes helps guide decisions about future inoculation programs.
- Sampling is best carried out 8–12 weeks after sowing.
- Score each root sample according to the presence, pattern and appearance of the nodules.
- Nodulation can be affected by a range of management and environmental factors.

Background

The nitrogen benefits of inoculating legumes have previously been covered in *Research for the Riverine Plains 2014* pages 38–40. The following article outlines simple steps growers can take to check whether or not inoculation of legumes with rhizobia has been successful.

Why assess legume nodulation?

Checking legume nodulation provides a useful guide to decision making about future inoculation, and indicates whether there is any need to improve inoculation practices.

For inoculated legumes, it is worth checking to see if inoculation has worked well or not. If an inoculated crop has nodulated poorly, investigate the reason for lack of success.

For uninoculated legumes, it is worth checking if the level of nodulation meets minimum expectations, to help decide whether or not to inoculate in the future.

Where there is some soil nitrogen, it is possible for crops and pastures to look reasonable, but have few nodules and fix little nitrogen. In these instances, because there are no obvious above-ground symptoms, a check of nodulation can provide a useful guide to understanding legume performance.

Also, while checking the root systems, general root health can be assessed — look for any disease or herbicide damage. For example, depending on location, season and crop rotation or paddock history, there might be a lot of "spear tips" and "cut off", shortened roots caused by *Rhizoctonia*, or symptoms of other soil-borne diseases.

Assessing nodulation: what do I need and how do I do it?

Equipment: Figure 1 shows what is needed: at least three 10L buckets, a spade, water (either tap water from home or shed, or water carried to the paddock; water quality is unimportant).

When do I sample? Ideally 8–12 weeks after sowing, but a few weeks after this is still OK, especially if crop growth during winter has been slow.

FIGURE 1 Sampling gear

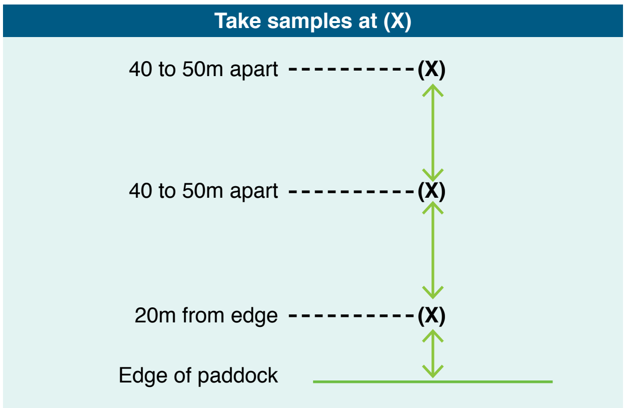

FIGURE 2 Sampling pattern

Taking samples:

1. Collect the root systems (the top 15–20cm of soil) of about 30 plants per paddock, about 10 plants at each of three sample spots using a spade, and put each 10-plant sample in a separate bucket (see sampling pattern diagram, Figure 2). Start sampling 20m from the edge of the crop to avoid headlands. Try to bring soil along and keep the root systems intact. Take particular care in heavy clay soils, where legume nodules can easily break off from the roots. In most soils, and especially in heavy soils, it is best to take samples when soils are moist to aid in collection of roots and nodules.
2. Add plenty of water to each bucket and allow to soak for up to 30 minutes to make the washing process easier. Carefully wash the soil off the roots and rinse to remove remaining soil.
3. Lay the plants out on the back of the ute or on the ground and score each 10-plant sample for "% plants adequately nodulated" (see next section for guidance on this process) and work out the average of the three scores.
4. Overall average score:

Adequate	Nodulation similar to or better than "adequate" for 70% or more of plants.
Borderline	Nodulation similar to or better than "adequate" for 50–70% of plants.
Poor	Nodulation similar to or better than "adequate" for less than 50% of plants.
None	No nodules present (= no nitrogen fixation)

NOTE: Plants scored as "adequate" should have red/pink nodules inside (check by opening a few nodules with a knife or with a thumbnail).

What does adequate nodulation look like?

Photos of "adequate nodulation" are available via www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/.

The *Nodulation assessment guide* has a range of photos of poor and adequate nodulation of each of the main grain legume crops. *Inoculating Legumes: The Back Pocket Guide and Inoculating Legumes: a practical guide* contain photos of adequate nodulation of pasture and grain legumes, and details about expected number of nodules per plant.

Adequate nodulation varies with crop and pasture legume type and also to some extent with soil type. For a particular legume, expect to see more nodules per plant on heavier soils.

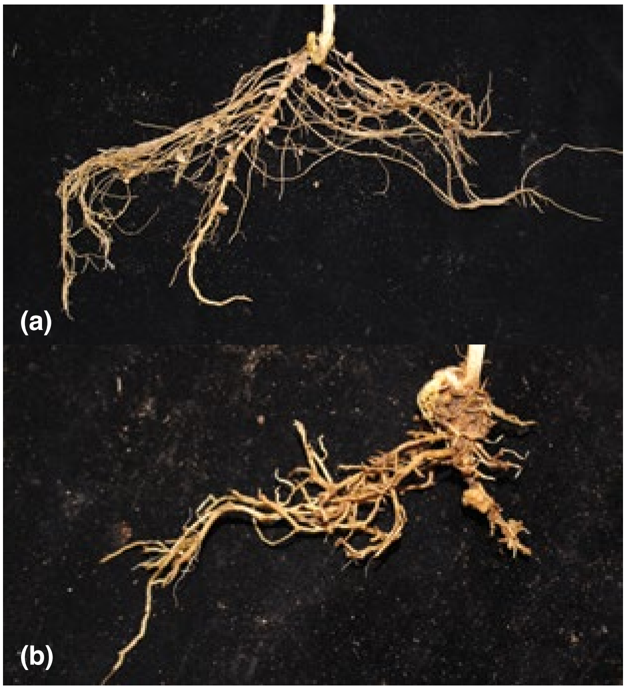

FIGURE 3 Good nodulation of a pea plant (a) and poor nodulation of a pea plant due to root disease (b)

The nodulation pattern on the root system can also give important information. If a crop has been inoculated, expect to see more and larger nodules around the 'crown' of the plant where the seed was attached (Figure 3a).

If an inoculated crop doesn't have many nodules around the crown this suggests inoculation may not have been prompt or successful. Such plants may still have nodules spread around on the lateral roots, if some of the applied rhizobia survived or the correct rhizobia were present in the soil from a previous legume crop or pasture. These crops may show early signs of nitrogen (N) deficiency, but can recover as the nodules on lateral roots begin to function in fixing nitrogen. Nodulation from "background" rhizobia already present in the soil tends to be distributed more evenly and broadly over the root system.

What if nodulation is poor?

Consider doing follow-up sampling (single 10-plant samples rather than triple) in other parts of the paddock, as nodulation may be variable. Factors that can lead to nodulation failure or poor nodulation include:

- not inoculating in a paddock where that legume (or a legume in the same inoculation group) has not been previously grown;
- adverse soil conditions, such as very low pH or sowing into dry soil, especially if it is a first time legume crop (not recommended unless higher rates of inoculant are used);

- poor storage conditions of the inoculant or inoculated seed (see handbooks for storage conditions);
- using the incorrect inoculant type, where the inoculant group/strain of rhizobia is not compatible with the legume sown;
- high soil nitrate levels due to adding a high rate of nitrogen fertiliser or from rapid mineralisation of crop residues;
- insufficient rate of inoculant application (doubling the rate of inoculant can be helpful when a legume is grown in a paddock for the first time);
- use of saline bore water or chlorinated water to prepare peat-based or freeze-dried inoculant (advisable to use rainwater or other clean potable water);
- mixing inoculant with fertiliser (especially acidic fertiliser), trace elements or pesticides;
- herbicide damage, either in-crop or from residues (especially SU herbicide residues on alkaline soils); or
- serious root disease (through reduction in root system size and health; see Figure 3b).

Nodulation failure is extremely difficult to remedy, except by adding nitrogen. Application of nitrogen fertiliser during the growing season may partly recover the crop, but production is still likely to be less than that possible with adequate nodulation. Nitrogen fixation will be low or absent, which means the nitrogen benefit of growing the legume is lost.

What is the actual rate of nitrogen fixation?

If a legume has no nodules, then it cannot fix nitrogen from the air into "fertiliser" for the plant. If a legume is well nodulated and the nodules are pink (active), this plant is likely to be fixing nitrogen when conditions (soil moisture etc) are suitable.

The actual rate of fixation can only be determined using a detailed scientific approach by analysing leaf or pod samples, which is time-consuming and costly.

A practical first step to optimising legume nitrogen fixation is to ensure adequate nodulation is occurring. This means paying careful attention to the list of factors that can cause poor nodulation. After these have been taken care of, actual rates of nitrogen fixation will depend on suitable seasonal conditions and effective crop management (temperature, soil moisture, weed control).

For further information, please refer to publications found at www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation

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Crop rotation effects on phosphorus nutrition in canola

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Key points

- Canola yield increased with 16kg/ha of applied phosphorus (P) during 2014, compared with wheat after canola, which required 24kg P/ha (2012 and 2013), and wheat after wheat which only needed 8kg P/ha (2013).
- Oil percentage was lower at the highest phosphorus rates (≥32kg P/ha).
- Canola grain phosphorus content increased to 5.4kg P/t when 40kg P/ha was applied and phosphorus offtake increased to 14.5kg P/ha when 16 kgP/ha was applied.
- Adjusting phosphorus rates at sowing, based on crop rotation, could be advantageous in a red clay loam soil type.

Location: 8km SE of Dookie, Victoria
Rainfall:
Annual: 496mm (2014), 551mm (mean all years)
GSR: 343mm (2014), 367mm (mean all years)
Stored moisture: Dry (<30mm)
Soil
Type: Red clay loam
CEC: 6.32meq/100g
pH ($CaCl_2$): 4.7
Colwell P: 41mg/kg
Phosphorus buffering index (PBI): 55
DGT# phosphorus: 36ug/L
Deep soil nitrogen (80cm): 94kg/ha
Deep soil sulphur (80cm): 426kg/ha
Organic carbon (OC): 1.8%
Zinc (DTPA extract): 0.47mg/kg
Sowing information:
Sowing date: 28 April 2014
Fertiliser: Sowing: 80kg N/ha, In crop: 80kg N/ha
Variety: Canola ATR Bonito
Sowing equipment: Cone seeder, knife point, press wheel
Row spacing: 29cm
Paddock history: 2013 — wheat; 2012 — wheat; 2011 — canola
Plot size: 10m x 1.74m
Replicates: 4

DGT — Diffuse gradients in thin film: This test is a measure of soil solution phosphorus available to plant roots.

Aim

The aims of this project were to investigate the response of canola to phosphorus (P) rate compared with trials in previous years of wheat following wheat and wheat following canola, and to assess whether higher phosphorus rates should be applied to wheat following canola and determine if phosphorus rates can be reduced in wheat following wheat and canola following wheat.

Method

A canola trial was established in the same paddock where wheat on canola (WOC) and wheat on wheat (WOW) phosphorus response trials were carried out during 2012 and 2013. Soil analysis at the trial site for 0–10cm depth indicated a Colwell P of 41mg/kg (refer to trial site summary details for other soil test information).

The wheat stubble was burnt before sowing and gypsum was spread at 2.5t/ha.

Canola (cv ATR Bonito) was sown into moisture at 2.5kg/ha on 28 April, 2014. Seven treatment rates of: nil phosphorus, 8kg, 16kg, 16kg + 20kg sulphur (S), 24kg, 32kg and 40kg of phosphorus per hectare were applied as monoammonium phosphate (MAP) at sowing. Nitrogen was balanced at sowing to supply an equivalent of 80kg N/ha, with a further 80kg N/ha (174kg/ha urea) topdressed on 12 August (bud initiation), to all plots.

Dry matter (DM) and tissue assessments were taken on 12 August 2014 (105 days after sowing [DAS]). Grain samples were collected for yield and oil assessment at harvest. The trial was harvested on 25 November, 2014. Growing season rainfall (GSR) was approximately 343mm.

The trial comprised a completely-randomised block design with four replicates. Analysis of variance (ANOVA) was undertaken using Genstat® V.16. Least significant difference (LSD) between treatments was determined at the 5% level of significance using Fisher's Protected LSD.

Results

Canola DM production (105 DAS) increased significantly with 32kg/ha of applied phosphorus and similarly, tissue phosphorus content increased with 24kg P/ha compared with the control (Figure 1).

Increased DM and tissue phosphorus levels at first flower only translated into a grain yield response to 16kg P/ha at harvest (Figure 2). While the higher phosphorus rates (≥32kg P/ha) decreased grain oil by one percentage unit, this was still above base grade.

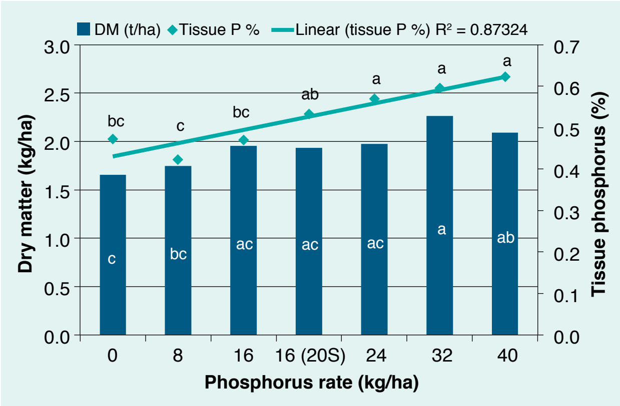

FIGURE 1 Canola dry matter and tissue phosphorus content at first flower, sampled on 12 August 2013 (105 DAS)*

* Treatments followed by the same letter are not significantly different at P=0.05.

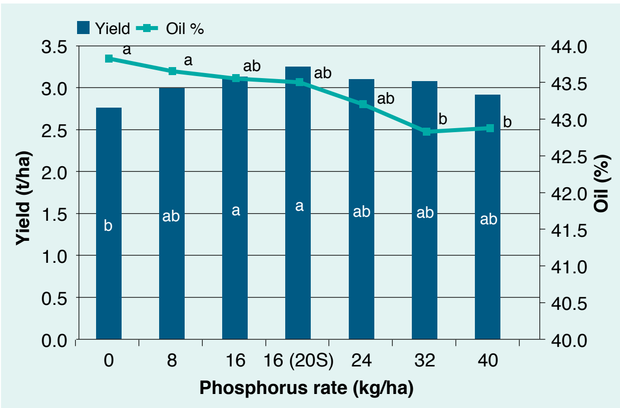

FIGURE 2 Canola yield and oil percentage in response to phosphorus rate*

* Treatments followed by the same letter are not significantly different at P=0.05.

Similar to canola yield, both grain phosphorus content and phosphorus offtake in grain were increased significantly at the 16kg P/ha rate (Figure 3a). While grain phosphorus content increased further with additional phosphorus applied, this was only significantly higher at the 40kg P/ha rate.

In contrast, phosphorus rate had no effect on grain phosphorus content in wheat following canola (2012 trial, Figure 3b). Wheat phosphorus offtake in grain was increased with increased yields in response to phosphorus rate, statistically significant at the high rates (≥32kg P/ha) compared with the control.

Observations and comments

Critical soil test values determine if a crop is likely to respond to applied fertiliser. A Colwell P value above the critical range indicates there is unlikely to be a yield response to fertiliser phosphorus. Revised critical Colwell P values for different crops and soil types have been established using phosphorus rate trial results from

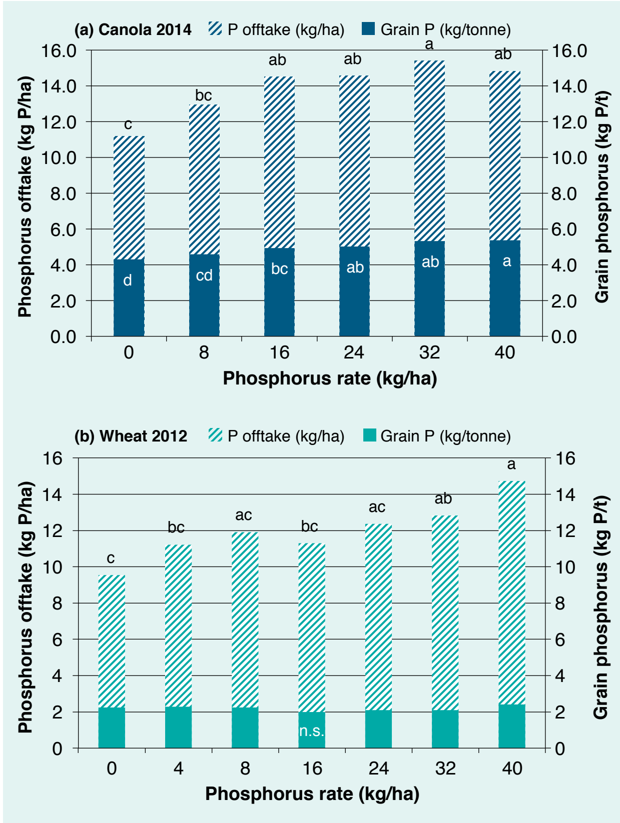

FIGURE 3 Effect of phosphorus rate on crop offtake and grain phosphorus concentration in (a) canola (2014 trial) and (b) wheat (2012 trial) from the same paddock*

* Treatments followed by the same letter are not significantly different at P=0.05.

south-eastern Australia in the *Better Fertiliser Decisions for Cropping* (BFDC) database (www.bfdc.com.au).

Interrogation of the BFDC database indicates the critical Colwell P level (90% relative yield) in wheat following wheat from 235 phosphorus rate trials across NSW, Victoria and SA is 27mg/kg (range 23–32mg/kg). However, for wheat following canola the critical Colwell P level is 40mg/kg (range 16–100mg/kg), albeit from a smaller dataset (30 phosphorus rate trials). For canola on cereal stubble (17 phosphorus rate trials) the critical Colwell P level was 19mg/kg with a range of 16–26mg/kg.

During 2013, soil samples (0–10cm depth) collected at Dookie before sowing indicated Colwell P levels of 48mg/kg for the WOW site and 60mg/kg for the WOC site, suggesting both were at or above critical phosphorus levels for wheat.

Similarly, DGT phosphorus levels of 63ug/L for the WOW and 76ug/L for the WOC site indicated soil phosphorus was in the adequate range (57–100ug/L).

During the past two seasons, fertiliser trials carried out at Dookie in WOC in neighbouring paddocks have shown a much greater rate response to applied phosphorus (Figure 4 — broken green line for 2012 and solid green line for 2013) than observed in WOW (Figure 4 — aqua line, 2013 season only).

Wheat grown after brassica crops normally yields more than wheat grown after wheat. This is largely attributed to depleted inoculum levels of soil-borne cereal pathogens following the brassica crop. Given potential root disease suppression benefits and sufficient soil phosphorus reserves, the magnitude of the phosphorus response in WOC in two consecutive years in different paddocks at Dookie continues to indicate a crop rotation effect that is not fully understood.

Whether this relates to the specific crop, herbicide system (triazine tolerant), soil biology, soil type or other factors requires further examination. Reduced mycorrhizal colonisation in WOC may be a factor. Canola does not support arbuscular mycorrhizal fungi, the symbiotic fungi that can increase the uptake of phosphorus and other nutrients in exchange for carbohydrates from the host plant. Reduced access to phosphorus for wheat at lower rates and a reduced drain on carbohydrates at higher rates may explain the steepness of this phosphorus response in WOC during both 2012 and 2013.

The canola on wheat trial in 2014 had a Colwell P level of 41mg/kg and a DGT phosphorus value of 36, so critical phosphorus levels are satisfied, which would indicate a low response to applied phosphorus. As expected the phosphorus response was flat (Figure 2). Canola can forage for nutrients and moisture and therefore phosphorus rates in rotation could potentially be decreased when soil critical levels are met. A similar approach may be possible for WOW given the flat response to applied phosphorus, however there may be a need to apply higher phosphorus rates during the WOC phase of the rotation.

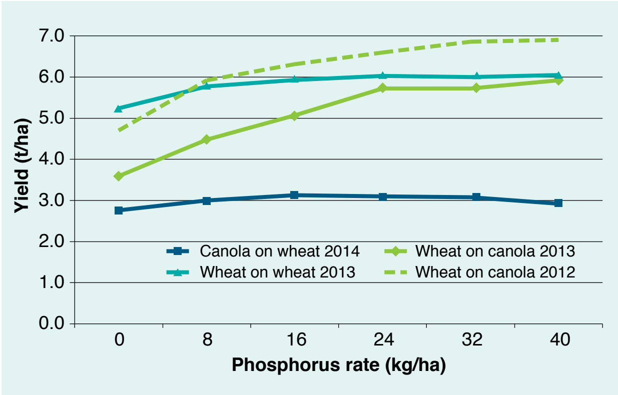

FIGURE 4 Effect of phosphorus rate on yield in wheat (2012 and 2013) and in canola (2014)*

* The wheat on canola trial in 2013 was conducted in a neighbouring paddock. All other trials were run within the one paddock over consecutive years.

While the 2012 WOC and 2013 WOW trials were grown in a similar section of the same paddock and grown under favourable seasonal conditions in both years, it is not possible to say whether yield potential was higher in the WOC situation between different years. For the 2015 season, the effect of phosphorus in cropping rotations will be investigated further with the trial site set up within a neighbouring paddock in sections sown to either wheat or canola in 2014.

Acknowledgements

This research was conducted in collaboration with Riverine Plains Inc. Special thanks to the Tallis family for provision of the trial site and assistance with field day activities in consecutive years.

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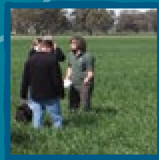

Canola response to nitrogen rate, splits and timings

Lee Menhenett, Craig Farlow and Charlie Walker
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Key points

- Canola yield responded to nitrogen (N) application, up to a rate of 80kg N/ha.
- There was no effect on yield from timing (sowing, stem elongation, early flower) or splitting of nitrogen applications.
- The oil percentage decreased with increasing nitrogen rates above 80kg N/ha.
- Apparent grain recovery of the nitrogen applied was generally low, with residual soil mineral nitrogen only accounting for a portion of the unrecovered nitrogen.

Location: 8km SE of Dookie, Victoria

Rainfall:
Annual: 496mm (2014), 551mm (mean all years)
GSR: 343mm (2014), 367mm (mean all years)
Stored moisture: 30mm (dry)

Soil: (sampled 14 April 2014)
Type: Red clay loam
CEC: 6.32 meq/100g
pH ($CaCl_2$): 4.7
Colwell P: 41mg/kg
Phosphorus buffering index (PBI): 55
DGT[#] phosphorus: 36ug/L
Deep soil nitrogen 0–80cm: 94kg/ha (sampled 9 May)
Deep soil sulphur (80cm): 426kg/ha
Organic carbon (OC): 1.8%
Zinc (DTPA extract): 0.47mg/kg

Sowing information:
Sowing date: 28 April 2014
Fertiliser: Sowing: triple super phosphate 77kg/ha (NPKS: 0-20.7-0-1.0)
Variety: Canola ATR Bonito
Sowing equipment: Cone seeder, knife point, press wheel

Row spacing: 29cm

Paddock history:
2013 — wheat

Plot size: 10m x 1.74m

Replicates: 4

[#] DGT — Diffuse gradients in thin film: This test is a measure of the soil solution phosphorus available to plant roots.

Aim

To investigate canola yield and quality response to nitrogen (N) rate, split applications and timing of application based on growth stage.

Method

Canola (cv ATR Bonito) was sown into burnt wheat stubble at 2.5kg/ha on 28 April, 2014. Sixteen treatment rates of 0, 40, 80, 160 and 240kg N/ha were applied as urea at three growth stage timings (sowing (GS0.0), stem elongation (GS2.01) and 20% flower (GS4.2)) as single or split applications (Table 1).

Deep soil analysis (0–80cm) on 9 May, 2015, indicated a mineral soil nitrogen of 94kg/ha in the soil profile (refer to trial site summary details for other soil test information).

Gypsum was spread at 2.5t/ha before sowing. Deep soil sampling was also conducted post-harvest for three depth segments (0–30cm, 30–60cm and 60–90cm), and three replicates (1–3), for selective treatments (Table 1).

Growing season rainfall (GSR) was approximately 343mm (Figure 1). The trial was harvested on 25 November, 2014.

The trial comprised a completely randomised-block design, with four replicates. Analysis of variance (ANOVA) was undertaken using Genstat® V.16. Least significant difference (LSD) between treatments was determined at the 5% level of significance using Fisher's Protected LSD.

Results

Canola yield increased at the 80kg N/ha rate, regardless of timing or split, with no further significant yield increases from extra nitrogen applied at 120, 160 or 240kg N/ha (Table 2).

Yield at the 40kg N/ha rate was not statistically different from the control (nil nitrogen). Banding all of the nitrogen at sowing at the highest rate (240kg N/ha) decreased yield, which could be attributed to the toxic amount of ammonia in the fertiliser band that visually set the canola growth back until GS2.01 (stem elongation). Splitting application rate and timing based on growth stage did not influence yield.

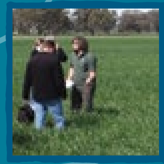

TABLE 1 Nitrogen treatment rate, splits and timings

Treatment No.	Nitrogen treatment (applied as urea) (kg N/ha)	Nitrogen banded at sowing (GS0.0), (kg N/ha)	Topdress stem elongation (GS2.01) (kg N/ha)	Topdress at 20% flower (GS4.2) (kg N/ha)	Total nitrogen applied (kg N/ha)
1*	Nil nitrogen	0	-	-	0
2	40	40	-	-	40
3	40+40	40	40	-	80
4	0+40+40	-	40	40	80
5*	80	80	-	-	80
6	0+80	-	80	-	80
7	0+0+80	-	-	80	80
8	120	120	-	-	120
9	40+40+40	40	40	40	120
10*	160	160	-	-	160
11	0+160	-	160	-	160
12*	0+0+160	-	-	160	160
13	80N+80	80	80	-	160
14*	0+80+80	-	80	80	160
15*	240	240	-	-	240
16	80+80+80	80	80	80	240

* Post-harvest deep soil sampling carried out on these six treatments only for replicates 1–3.

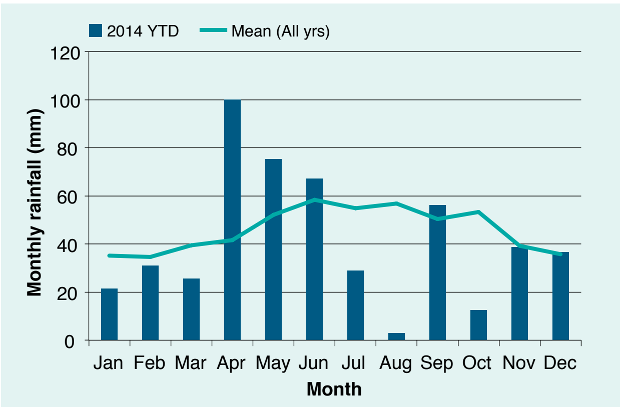

FIGURE 1 Mean and 2014 monthly rainfall at Dookie

Nitrogen rate had no significant effect on oil content up to 80kg N/ha compared with the control (Table 2). Further increases in applied nitrogen significantly reduced oil content compared with the control and 40kg N/ha. Splitting applications and the timing of applications had little effect on oil content at the same nitrogen rates. Nitrogen applied at 80kg N/ha increased oil yield per hectare over the control (nitrogen), with no further benefit from higher nitrogen rates (Table 2).

Grain test weights were increased by around one unit at the higher nitrogen rates. Overall there is little impact of nitrogen rate on oil yield per hectare, other than for the control (nil nitrogen) and 240kg N/ha where total oil yield was depressed.

The relationship between canola oil and protein content in response to nitrogen rate is shown in Figure 2. Increasing nitrogen rates reduced canola oil content while increasing protein content. The combined sum of oil and protein content remained constant at about 65% (Table 3).

Protein response to nitrogen appears to be influenced more by the total nitrogen rate rather than splits and timings.

The grain nitrogen recovery (GNR), calculated from the total yield and protein, generally showed a significant increase up to 120kg N/ha, though not statistically different from the split applications at 80kg N/ha (Table 3).

After a very dry finish to the 2014 season, deep soil sampling was carried out post-harvest to examine residual mineral nitrogen in the profile. There was little difference in profile nitrogen between the control (nil nitrogen) and where 80kg N/ha had been banded at sowing (Figure 3). An additional 27.8 to 32.2kg N/ha of mineral nitrogen was found in the soil profile over and above the control (nil nitrogen) where rates of 160kg N/ha had been applied, and an extra 74kg N/ha in the profile where 240kg N/ha had been banded at sowing.

With the exception of the 240kg N/ha rate, most of the nitrogen, (between 60–70%), was retained in the top 30cm of the soil profile. In contrast, at the high nitrogen rate about 55% had moved below 30cm.

TABLE 2 Effect of nitrogen rate, splits and timings on canola yield, oil content, oil yield and test weight*

Total nitrogen applied (kg N/ha)	Timing	Yield (t/ha)	Oil content (%)	Oil yield (kg /ha)	Test weight (kg/hL)
0	Nil nitrogen	2.78^{d}	47.0^{ab}	1308.0^{d}	64.0^{e-f}
40	BAS**	3.10^{bd}	47.3^{a}	1464.8^{ad}	63.8^{f}
80	BAS	3.30^{ac}	46.2^{ad}	1524.9^{ab}	63.7^{f}
80	BAS+TSE***	3.49^{a}	46.5^{ac}	1623.6^{a}	64.3^{cdef}
80	TSE	3.28^{ac}	46.0^{be}	1507.1^{ab}	64.1^{def}
80	TSE+TFL****	3.38^{ac}	45.9^{be}	1551.2^{ab}	64.3^{bcdef}
80	TFL	3.37^{ac}	46.5^{ac}	1565.0^{ab}	64.5^{bcdef}
120	BAS	3.43^{ab}	45.6^{ce}	1565.7^{ab}	63.9^{f}
120	BAS+TSE+TFL	3.50^{a}	45.1^{df}	1576.7^{ab}	65.0^{abcd}
160	BAS	3.37^{ac}	44.9^{df}	1514.7^{ab}	65.1^{abc}
160	BAS+TSE	3.35^{ac}	44.7^{ef}	1498.5^{ac}	65.1^{abc}
160	TSE	3.59^{a}	45.3^{ce}	1629.1^{a}	64.9^{abcde}
160	TSE+TFL	3.29^{ac}	43.3^{g}	1425.4^{bd}	65.5^{a}
160	TFL	3.38^{ac}	45.2^{de}	1524.5^{ab}	64.6^{abcdef}
240	BAS	3.09^{cd}	43.2^{g}	1333.4^{cd}	65.3^{a-b}
240	BAS+TSE+TFL	3.41^{ac}	43.9^{fg}	1499.2^{ac}	65.0^{abcd}
LSD (P = 0.05)		0.334	1.3	172.5	0.929
p value		0.005	<0.001	0.021	0.002
CV%		7.1	2.0	8.0	1.0

*Means followed by the same letter are not significantly different at P=0.05. Oil yield is calculated from grain yield (kg/ha) x oil(%).
**BAS = Banded at sowing ***TSE = Topdressed at stem elongation. ****TFL = Topdressed at 20% flower.

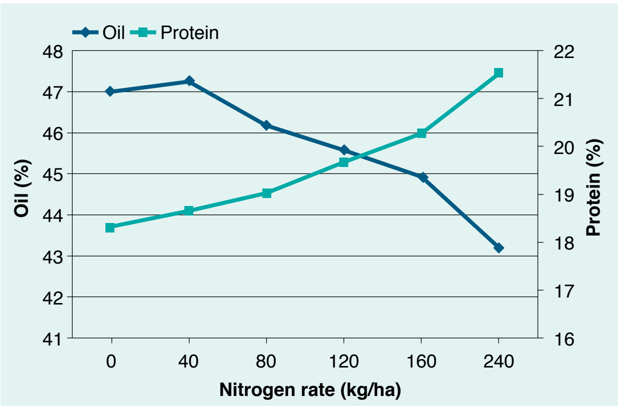

FIGURE 2 Effect of nitrogen rate (banded at sowing) on canola oil and protein content

Observations and comments

The 2014 season received well above average rainfall from April through to June, and well below rainfall during July/August and October (Figure 1). The crop experienced excellent growing conditions early on, became waterlogged during early winter, and relied heavily on subsoil moisture and September rainfall to finish.

With starting soil mineral nitrogen to 80cm depth of 94kg N/ha and an unusually warm autumn and early winter conducive to mineralisation, the optimum yield and oil response to applied nitrogen resulted from 80kg N/ha, split between sowing and stem elongation. Yield was increased by 0.71t/ha, oil content was 0.5% lower and oil yield per hectare was 318.6kg/ha greater from 80kg N/ha applied compared with the control.

A basic analysis of incremental returns from yield and oil responses over the control, less the cost of fertiliser, is provided in Table 4.

Applying 50% less nitrogen than the optimum (40kg N/ha) meant yield was not maximised and return per hectare was halved. Applying 50% above the optimum rate (120kg N/ha) produced a similar yield but with reduced oil; the return per hectare was decreased, though it was still better than the return from the 40kg N/ha rate.

With the exception of 160kg N/ha applied at stem elongation, higher rates of nitrogen application produced a poor, or even negative, rate of return due to the cost of over-applying fertiliser. The risk:reward ratio (gross return per hectare above the control divided by the cost of nitrogen) was similar for the early split at 80kg N/ha and lower nitrogen rate at 40kg N/ha (Table 4).



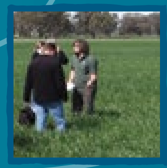

TABLE 3 Effect of nitrogen rate, splits and timings on canola protein content, combined oil and protein content, and grain nitrogen recovery*

Total nitrogen applied (kg N/ha)	Timing	Protein (%)	Oil + protein (%)	Grain nitrogen recovery (kg/ha)
0	Nil nitrogen	18.3[h]	65.3	81.6[f]
40	BAS**	18.7[gh]	65.9	92.5[ef]
80	BAS	19.0[gh]	65.2	100.7[de]
80	BAS+TSE***	19.5[eg]	65.9	108.7[ad]
80	TSE	19.2[gh]	65.2	100.7[de]
80	TSE+TFL****	19.3[fh]	65.3	104.2[bd]
80	TFL	19.0[gh]	65.5	102.6[ce]
120	BAS	19.7[dg]	65.3	108.2[ad]
120	BAS+TSE+TFL	20.4[ce]	65.5	114.2[ab]
160	BAS	20.3[df]	65.2	109.1[ad]
160	BAS+TSE	20.6[bd]	65.4	110.6[ad]
160	TSE	20.3[df]	65.6	116.4[a]
160	TSE+TFL	21.7[a]	65.0	114.1[ac]
160	TFL	20.4[cf]	65.5	110.0[ad]
240	BAS	21.5[ab]	64.7	106.3[ad]
240	BAS+TSE+TFL	21.4[ac]	65.2	116.4[a]
LSD (P = 0.05)		1.0		11.6
Treatment F Pr.		<0.001		<0.001
CV%		3.7		7.7

*Means followed by the same letter are not significantly different at P=0.05. Grain nitrogen recovery is yield (t/ha) x protein % x 1.6.
**BAS = Banded at sowing. ***TSE = Topdressed at stem elongation. ****TFL = Topdressed at 20% flower.

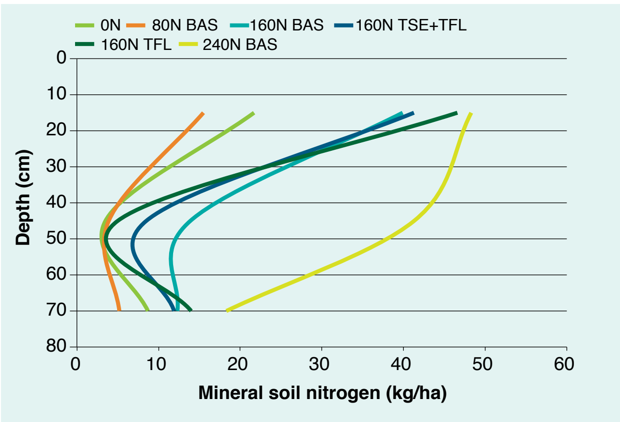

FIGURE 3 Soil mineral nitrogen recovered post-harvest (26 November 2014). LSD (P=0.05) = 18.5kgN/ha

Apparent grain nitrogen recovery (GNR) of applied nitrogen was generally low. With 80kg N/ha applied at the early split timing (BAS and TSE) the GNR was 27.1kg N/ha above the control. Further applications of nitrogen fertiliser had no significant effect on increasing the amount of grain nitrogen recovered. This represents an apparent fertiliser efficiency of 34% at best, however this does not account for nitrogen in roots and stubble, or residual nitrogen in the soil profile.

The fate of applied nitrogen not harvested in grain or recovered in mineral form in the soil is not clear. The nitrogen remaining in crop residues has not been accounted for, with most of this nitrogen present in organic forms. A portion of soil nitrogen will also be present in organic forms (not available for plant uptake) or may have been lost through leaching and gaseous losses. At higher application rates there is evidence of some movement of nitrogen down the profile, however with limited rainfall from July to October, the minimal effect of later application timings and splits, and a healthy yield of 2.78t/ha with no nitrogen applied, the extent of these losses is questionable.

In summary, while there was no direct yield benefit from the different timing or application splits in this trial, matching nitrogen inputs with water availability and crop yield potential generally requires tactical/split applications of nitrogen as the season unfolds.

TABLE 4 Incremental returns from applied nitrogen

Total nitrogen applied (kg N/ha)	Nitrogen cost ($/ha)	Application timing	Yield (t/ha)	Canola price on farm ($470/t)	Oil (%)	Oil premium ($/t)	Gross return including oil ($/ha)	Return net of nitrogen vs control ($/ha)	Risk:reward ratio ($)
0	0	Nil nitrogen	2.78	470	47.0	35.3	1,406	0	0
40	48	BAS	3.10	470	47.3	37.0	1,571	117	3.45
80	96	BAS	3.30	470	46.2	29.4	1,650	148	2.54
80	96	BAS+TSE	3.49	470	46.5	31.4	1,752	250	3.60
80	96	TSE	3.28	470	46.0	27.8	1,632	130	2.36
80	96	TSE+TFL	3.38	470	45.9	27.7	1,680	178	2.85
80	96	TFL	3.37	470	46.5	31.5	1,689	187	2.95
120	144	BAS	3.43	470	45.6	25.2	1,700	150	2.04
120	144	BAS+TSE+TFL	3.50	470	45.1	21.7	1,719	169	2.17
160	192	BAS	3.37	470	44.9	20.6	1,653	55	1.29
160	192	BAS+TSE	3.35	470	44.7	19.2	1,639	41	1.21
160	192	TSE	3.59	470	45.3	23.4	1,771	173	1.90
160	192	TSE+TFL	3.29	470	43.3	9.3	1,577	-21	0.89
160	192	TFL	3.38	470	45.2	22.4	1,663	64	1.34
240	288	BAS	3.09	470	43.2	8.5	1,477	-217	0.25
240	288	BAS+TSE+TFL	3.41	470	43.9	13.0	1,649	-45	0.84

Assumptions: $470/t canola on farm; 1.5% oil premium/1% above 42% base grade; urea $550/t on farm

Acknowledgements

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The effect of microwave soil treatment on wheat and canola growth in a pot experiment

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Key points

- Microwave soil treatment accelerates crop plant growth.
- Microwave soil treatment improves crop yield.

Introduction

A sustained research program has demonstrated that microwave treatment of in-situ soil, using a horn antenna applicator, can effectively kill weed plants and their seeds. Microwave soil treatment can also reduce populations of some pathogenic organisms in the soil, such as *Escherichia coli* and nematodes, without significantly affecting other beneficial soil organisms such as fungi and protozoa. However the effect of microwave soil treatment on subsequent crop growth has not been well studied.

Aim

The aim of this research was to assess the impact of microwave treatment of soil on subsequent growth and yield of wheat and canola.

Method

Fifty pots (15cm diameter by 20cm deep) of top soil, harvested from a weedy patch in the headland of a regularly-cropped paddock at the Dookie Campus of The University of Melbourne, were randomly subjected to varying amounts of microwave energy (0 [control – no weeding], 168, 384, and 576J/cm^2], which was applied to the soil in the pots using a horn antenna with aperture dimensions of 110mm x 55mm, fed from a 2kW, 2.45GHz microwave generator (Figure 1).

A second untreated control, with hand weeding of all non-crop plants, was included for each species, to provide optimal growth conditions without applying microwaves for comparison with the other treatments. No other treatments were weeded during this experiment.

After cooling overnight, 25 pots were each planted on 14 June with 10 seeds per pot of wheat and 25 were planted with 10 seeds per pot of canola to achieve five replicates of each treatment combination for each crop species.

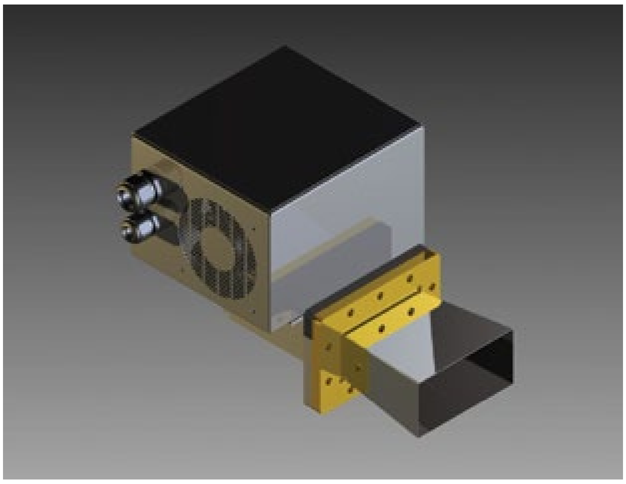

FIGURE 1 Rendering of the horn antenna and microwave feed system used in these experiments

The sown pots were placed in a glasshouse and watered three times per week. After the plants were well established the pots were thinned to a maximum of three crop plants per pot. Growth and final grain yield per pot were assessed at harvest. The glasshouse was heated at night to ensure the minimum temperature remained above 10ºC. The maximum temperature in the glasshouse during the experimental period was 28ºC.

Results

The number of non-crop plants per pot for the untreated soils varied between five and 15. There were between zero and three non-crop plants in the soils exposed to the highest microwave treatment, with most pots having no non-crop plants.

In all cases, the non-crop plants were at the edge of the pots, suggesting these seeds survived the microwave treatment because the soil around the edge of the pot cooled too fast to kill the seeds in this part of the pot.

Plant maturation rate (Figure 2), mean plant height (Figure 3), and mean yield per pot (Table 1) all increased significantly in wheat and canola as the level of applied microwave energy increased.

While hand weeding increased crop yield, there were no significant differences in yield between the hand weeded pots, the control, or the lowest microwave treatment for either species (Table 1).

FIGURE 2 Comparison of wheat and canola plant growth as a function of microwave treatment energy
(In order of microwave treatment levels from the unweeded control then weeded controls on the left to the highest treatment on the right)

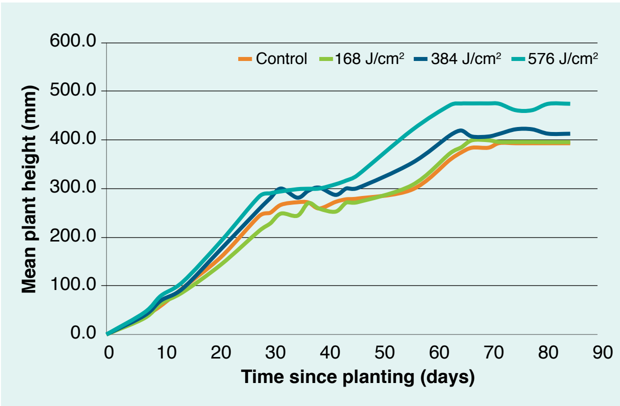

FIGURE 3 Mean wheat plant height as a function of time since planting (date of planting) and microwave soil treatment energy
Error bars represent LSD for P = 0.05

TABLE 1 Mean yield as a function of applied microwave treatment energy

Applied microwave energy (J/cm²)	Wheat grain (g/pot)	Canola pods (g/pot)	Canola days to flowering
0	0.66[a]	0.30[a]	75.2[a]
0 (hand weeded)	0.72[a]	0.56[a]	67.6[bc]
168	0.68[a]	0.36[a]	70.2[abc]
384	0.75[a]	1.25[b]	63.2[c]
576	1.25[b]	1.95[c]	61.0[c]
LSD (p<0.05)	0.30	0.55	7.1

Note: Entries with different letters in the same column are statistically different from one another

Observations and comments

This experiment was performed as a pot trial in the glasshouse under controlled conditions. In both crop species, there was faster emergence, higher emergence numbers, higher final biomass, higher yield, and faster plant growth in the soil exposed to the two highest microwave treatments compared with the two controls and the lowest microwave treatment.

The enhanced plant vigour and yield in the microwave-treated soils was not only due to decreased competition from weeds in the pots, as indicated by poorer growth in the hand-weeded treatments.

Flowering occurring at least 10 days earlier for the canola grown in the soil exposed to the highest microwave treatment (Table 1), compared with the plants grown in the untreated soil.

As yet, it is unclear what has changed in the soil to provide this additional growth and yield, with soil chemical and biological tests currently underway. The biological soil test results are reported on pages 86–87; however the results from the chemical soil tests will not be available for some time. These growth responses are yet to be verified in field conditions.

Acknowledgements

This research is supported by RIRDC (project PRJ-008765 — *A study of microwave-based weed management in the rice industry*) and GRDC (project UM00053 — *Development of new non-chemical weed control technologies — microwave weed control*).

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The effect of microwave soil treatment on soil microbes

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Key points

- Microwave soil treatment decreased bacterial populations in the surface layers of the soil.
- Bacterial populations in deeper soil were unaffected by microwave soil treatment.
- The bacteria in surface soil recovered quickly after treatment.
- Other groups of soil microbes (fungi, protozoa) were not affected by microwave treatment.

Introduction

With increasing herbicide resistance among weed species, alternative methods of management are being developed, one of which is the use of microwaves.

Microwave treatment of soil has been shown to kill weed seeds by increasing the soil temperature above 80°C. Studies have also shown the amount of microwave energy required to kill emerged broadleaf weed plants is at least an order of magnitude less than the energy needed for seed inactivation in the top layers of soil.

Although microwaves have been shown to kill weeds, the impact of microwave energy on the surrounding soil, specifically the soil microorganisms, has not been well studied. If the energy produced by microwaves was to sterilise the soil (kill all the microorganisms), this would have a severe negative impact on the ability of the soil to supply nutrients to the plant and recycle crop residues.

Aim

This study investigated the impact of microwave treatment on soil micro-organisms, with a focus on bacteria, fungi and protozoa.

Method

On 19 August, 2014, 20 soil profile samples, dominated by the Caniambo loam soil type, were randomly sampled from a paddock at Dookie Campus of the University of Melbourne. A volume of soil was carefully removed from the ground using a shovel so the soil profile in the sample experienced minimal disturbance. Samples were cut to fit into a 150mm diameter pot using a knife and the soil was carefully placed into the pot to maintain the existing soil profile. If the profile was disturbed in this process, samples were discarded. The pots were placed into the Dookie campus glasshouse and watered.

During the following day, the pots were subjected to varying levels of microwave energy (0, 150, 300 and 600J/cm^2) using a horn antenna. One day after treatment, access points were made in the sides of the pots with a scalpel. These access points were at the surface of the soil, at 5cm below the soil surface and at 10cm below the soil surface.

Soil samples were removed from the pots at these locations and assessed for active bacteria, fungi and protozoa using a fluorescence microscopy technique, which can be used to determine the proportions of living and dead micro-organisms extracted from the soil.

The pots were placed in a glasshouse, planted with wheat seeds and watered regularly for a month (31 days), at which time the soil in the pots was resampled and assessed for the same organisms.

Results

Analysis of the soil samples showed that microwave treatment significantly reduced the number of soil bacteria when exposed to the highest level of energy (Table 1), but did not sterilise the soil. However, bacterial numbers increased after a month (Table 2), to be significantly higher than at the start of the experiment. The numbers of other soil microbes (fungi, protozoa) did not change significantly upon exposure to microwaves.

TABLE 1 Soil bacterial numbers shortly after microwave treatment*

Soil depth (cm)	Soil bacterial numbers (10^3/g) Estimated microwave treatment (J/cm^2)			
	0	150	300	600
0	6.20^a	5.57^a	4.73^{ab}	1.78^c
5	3.78^{abc}	4.71^{ab}	4.23^{ab}	1.18^c
10	4.06^{ab}	2.93^{bc}	3.87^{abc}	1.74^c
LSD (P = 0.05)				2.60

* Entries in the table with different letters in the same column are significantly different to one another.



TABLE 2 Soil bacterial numbers as a function of microwave treatment, soil depth and recovery time after treatment*

Soil depth (cm)	Time since microwave treatment (days)	Soil bacterial numbers (10^3/g)			
		Estimated microwave treatment (J/cm^2)			
		0	150	300	600
0	1	6.20^{d}	5.57^{d}	4.73^{d}	1.78^{d}
	31	18.90^{c}	38.48^{a}	38.25^{a}	19.67^{c}
5	1	3.78^{d}	4.71^{d}	4.23^{d}	1.18^{d}
	31	18.73^{c}	24.28^{bc}	29.95^{b}	28.22^{b}
10	1	4.06^{d}	2.93^{d}	3.87^{d}	1.74^{d}
	31	16.93^{c}	26.13^{bc}	28.90^{b}	18.00^{c}
LSD ($P = 0.05$)					7.30

* Entries in the table with different letters in the same column are significantly different to one another.

Observations and comments

Microwave treatment decreased bacterial populations in the top layers of soil, with no impact on populations deeper in the soil. There was no response of soil fungi or protozoa to microwave treatment.

Bacterial populations in all treatments increased significantly within a month after treatment, including the control. This indicates the increase in bacterial numbers was stimulated by the optimal moisture and temperature conditions of the glasshouse, with no residual negative impact of the microwave treatment.

Acknowledgements

This research is supported by RIRDC (project PRJ-008765 — *A study of microwave-based weed management in the rice industry*) and GRDC (project UM00053 — *Development of new non-chemical weed control technologies — microwave weed control*).

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The yield response of wheat to heat shock

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Key points

- The effect of extreme heat (>33°C) on wheat yield and quality was investigated in a glasshouse trial.
- Three to five days of heat just before flowering decreased grain number by 5.2% per degree increase in temperature above 32°C, with a greater than 50% reduction in grain number measured at 42°C.
- Applying heat five days before flowering increased individual grain weight by 1.2% per degree increase in temperature above 32°C. In contrast, heat applied five days after flowering decreased grain size by 1.4% per degree increase in temperature above 32°C.
- Applying heat five days before flowering had a significant effect on grain protein, with rising grain protein observed as heat shock temperatures increased.
- The magnitude of the responses from this glasshouse trial needs to be validated in field trials.

Research goal

The glasshouse trials reported here are part of a larger research project, which aims to develop crop simulation models that incorporate the yield impacts from frost and extreme heat events.

Crop growth models provide an opportunity to investigate a range of management scenarios, which can help balance the risks and maximise the growing season and therefore production. However, current models have only a limited ability to consider extremes in climatic conditions when predicting yield under different management options.

Aim

The aim of this trial was to quantify the change in grain number, individual grain weight and grain protein in response to simulated heat shock events around flowering (anthesis).

Method

The experimental work was carried out in a naturally-lit open-air glasshouse at Horsham, Victoria. Four wheat plants (variety: Yitpi) were grown per pot, with wheat planted on 30 July 2014.

Plants reached 50% flowering on 30 October, with heat treatments applied on 25 October, 4 November and 14 November, which corresponded to five days before flowering, five and 15 days after flowering (-5DAF, 5DAF and 15DAF) respectively.

What is heat shock?

Heat shock events are short periods (1–3 days) of temperatures above 33°C, which can result in significant wheat yield losses. Wheat is most vulnerable to heat damage during the reproductive growth phase, particularly during flowering to early grain filling. Yield loss occurs through a reduction in grain number per plant (due to sterility or abortion of grains) or individual grain weight (due to the formation of shrunken, notched and split grains, resulting from cellular damage, accelerated plant death and a shortened grain-filling period).

An example of the difference between healthy wheat grains (below left) and small shrivelled grains in response to heat shock (below right).



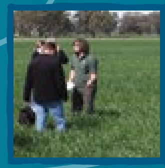

TABLE 1 Heat treatment combinations for glasshouse trials at Horsham, 2014*

		October									November																	
Date		23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Timing (DAF)				-5					Flowering					5										15				
Duration (days)	1			x										x										x				
	3		x	x	x								x	x	x								x	x	x			
	5	x	x	x	x	x						x	x	x	x	x						x	x	x	x	x		
Target temperature (°C)				~32, 35, 37, 42										~32, 35, 37, 42										~32, 35, 37, 42				

* All duration of treatments (days) and peak temperatures (°C) were applied at each timing of treatment (DAF — days after flowering)

Heat treatments were applied for one, three and five days duration with target peak temperatures of 35°C, 37°C and 42°C compared with an ambient temperature (~32°C) (Table 1). All together there were 36 treatment combinations (four temperature × three crop periods × three durations) and four replicates of each combination, with pots organised within the glasshouse in a randomised complete-block design.

Heat was applied by moving the pots from the open-air glasshouse to heat chambers for one, three or five days. Heating started at 9:00am, reaching the target peak temperature by 10:00am.

Peak temperature was maintained for a target six-hour period each day. An ambient (control) treatment was put in a heat chamber without applying heat and the temperature rarely exceeded 32°C.

After the heating period, the chambers were allowed to return to ambient temperature and the overnight temperature matched that of the open-air glasshouse. When heat treatments were completed, pots were returned to their randomised design within the open-air glasshouse. This process was staggered depending on the duration of heat exposure.

The crop was harvested on 18 December (141 days after sowing), with four plants harvested per pot for all treatments and replicates. The yield components of grain number and individual grain weight (based on 1000 grain weight) were measured for the whole plant and grain protein was measured.

Results

Grain number

Heat shock treatments applied pre-flowering (-5DAF) significantly reduced grain number (Figure 1). While one day of heat treatment did not significantly affect grain number, 3–5 days of heat treatment decreased grain number by 5.2% per degree above ambient (32°C).

At five days after flowering (5DAF) the impact of heat on grain number was much less, with only a 0.66% decrease per degree increase in temperature above the ambient temperature (32°C). There was no significant effect of heat on grain number at 15DAF.

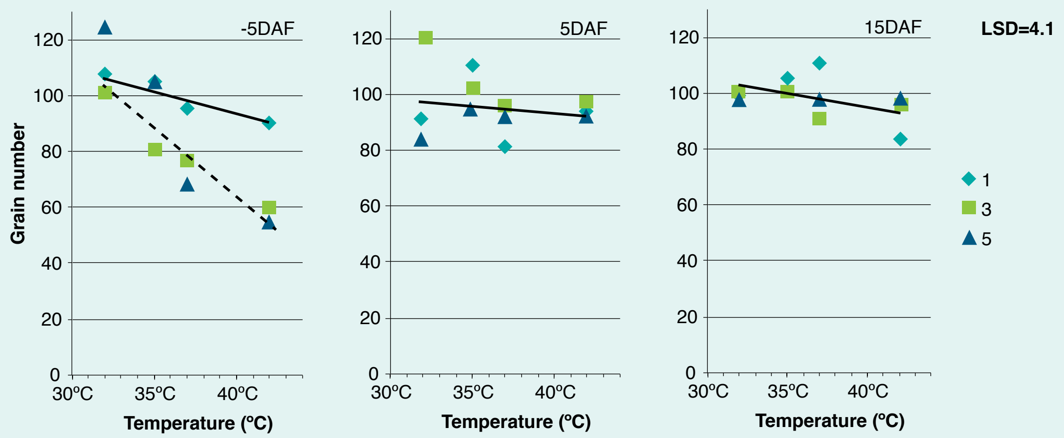

FIGURE 1 Whole plant grain number as a function of temperature treatment, with heat treatments applied for one (◆), three (■) or five (▲) days*

*For pre-flowering heat (-5DAF), the solid line is the response to one day of heat exposure and the dashed line is the average response to three and five days of heat treatment. After flowering (5DAF and 15DAF) the solid line is the average response one, three and five days of heat.

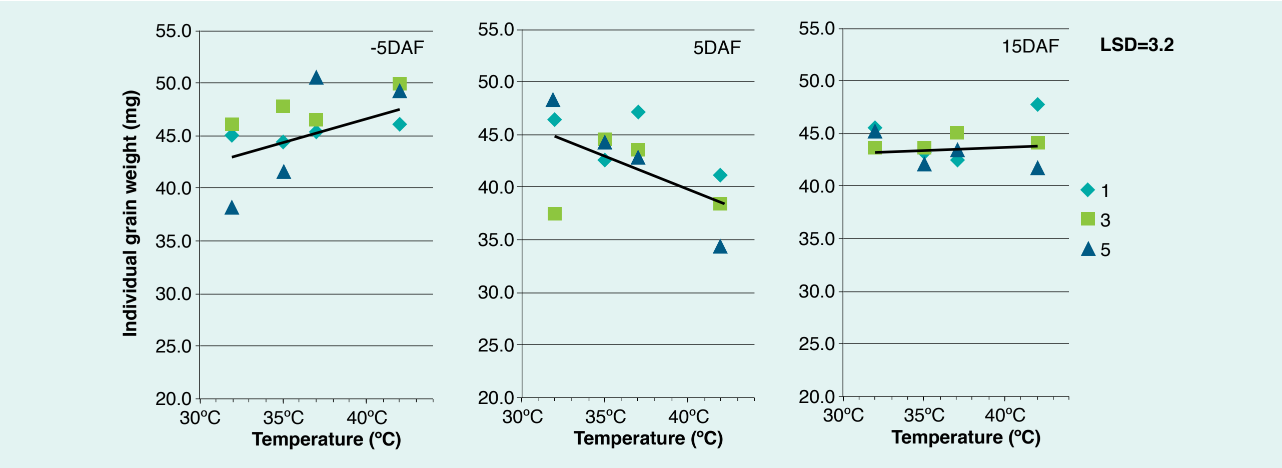

FIGURE 2 Individual grain weight as a function of temperature treatment, with heat applied for one (◆), three (■) or five (▲) days*
*The solid line is the average response to one, three and five days of heat treatment.

Grain weight

Pre-flowering (-5DAF) heat shock produced a small, but significant ($p=0.002$), increase in individual grain weight equivalent to a 1.2% increase per degree increase in temperature above 32°C (Figure 2). In contrast, heat applied at 5DAF decreased individual grain weight by 1.4% per degree increase in temperature above the ambient temperature (32°C). Heat applied at 15DAF had no effect on individual grain weight.

Grain protein

As well as its impact on the yield components, the heat shock treatments also affected grain protein concentrations. The heat treatment five days before flowering (-5DAF) had a significant effect on grain protein, with increasing grain protein observed with increasing heat shock temperatures. Average protein levels were 17.9%, 19.0%, 19.8% and 20.3% for the 32°C, 35°C, 37°C and 42°C treatments respectively.

During the post-flowering period, heat treatments at 5DAF significantly increased grain protein from 18.3% to 19.7% for the 32°C and 42°C treatments respectively. While at 15DAF grain protein was not significantly affected by heat treatments.

Previous work has shown that temperatures above 30°C during grain filling decreases the rate at which starch accumulates, while the rate of protein accumulation is largely unaffected, resulting in a higher grain protein concentration. However, despite grain protein content increasing under heat stress this is not necessarily beneficial, as the dough properties of the wheat decline.

Factors affecting these results

This research looked at how the timing, temperature and duration of heat shock influences wheat yield and protein. These results were for wheat grown in pots in an open-air glasshouse using simulated heat treatments. Further field work is needed to determine if the magnitude of the response in the glasshouse reflects field conditions, although similar responses have been observed in other field studies.

It is worth noting that field conditions vary in terms of plant density and the combination of stresses experienced by the plant, which may change the impact of heat stress. For example, the soil moisture content would be expected to interact with heat shock treatments (plants were well watered in this trial). As this research only used a single wheat variety, the final impact of wheat shock may also change, as varieties differ in their tolerance to heat.

The next steps in this research

The results from this and associated experiments will be used to identify the key crop responses to heat stress, so existing crop models can be further developed to incorporate the yield losses associated with extreme heat events. These improved models will be particularly important in evaluating the impact of extreme heat events due to current and future climates, and developing appropriate management options.

Acknowledgements

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Greenhouse gas emissions from Australian rice fields

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Key points

- Methane is the dominant greenhouse gas generated by Australian rice production.
- Addition of stable sources of carbon (C) (i.e. biochar and compost) did not increase methane production from rice crops.
- Methane emissions were greatest when rice was grown in a fully-flooded system.

Background

Agriculture is a major contributor to nitrous oxide (N_2O) and methane (CH_4) emissions derived from human activity. Nitrous oxide and methane gases have about 300 and 23 times the global warming potential than carbon dioxide (CO_2) on mass balance, respectively, and are potent greenhouse gases. As methane is formed when carbon from stubble breaks down in flooded soils, rice fields are a major agricultural contributor to global methane emissions, but emissions from Australian rice fields have not been quantified.

In 2013, the Rice Growers Association of Australia, together with NSW Department of Primary Industries, Rice Research Australia and Southern Cross University, received funding from the Australian Government through the *Carbon Farming Futures Action on the Ground* grant programme to trial water and stubble management strategies to reduce methane emissions from flooded rice fields.

Aim

The aim of this project is to determine the baseline emissions from Australian rice fields under the current practice of full flooding and stubble burning, and to evaluate alternative management practices that may reduce emissions. The two alternative management strategies evaluated were:

1. returning rice stubble as compost or biochar compared with stubble removal (baling)
2. manipulating water levels throughout the season.

Trial 1

Returning rice stubble as compost or biochar compared with stubble removal (baling)

Method

Researchers investigated whether methane emissions would increase if stubble was returned to the soil as either compost (composted with cow manure) or biochar (stubble burnt in a controlled chamber without oxygen) at the equivalent of 10 tonnes of stubble per hectare (about 5t of biochar and compost, equivalent to about 2t of carbon) compared with removing (baling) the stubble.

This approach aimed to determine if methane emissions were strongly related to the amount and type of stubble-derived carbon present under flooded conditions.

The trial was established in a randomised block design with four replicate plots per treatment. Plots were 10m x 40m. All plots received 125kg/ha MAP-Zn drilled before drill sowing of rice (cv. Sherpa).

Where stubble was baled and removed the plots received 225kg urea before flooding.

Based on available nitrogen (N) contents in the biochar, the biochar-amended plots also received 225kg/ha of urea before flooding, while the compost-amended plots only received 160kg/ha of urea.

Greenhouse gases were sampled twice per week during the growing season from specialised chambers (see Figure 1). Samples were sent to NSW DPI laboratories to measure methane and N_2O concentrations.

Results

Importantly, the addition of biochar or compost did not increase methane emissions across the season. This is probably because the carbon in the biochar and compost is only slowly available to microbes. Yields did not differ significantly among stubble treatments (11.2t/ha).

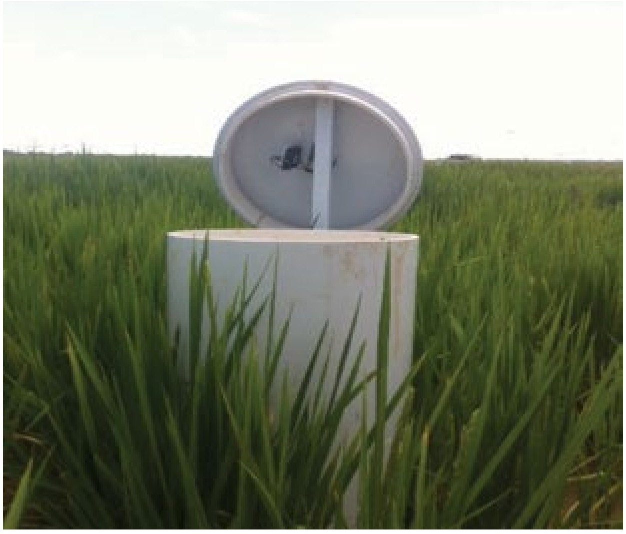

FIGURE 1 Specialised chamber for sampling greenhouse gases in rice

Note: These large chambers have a fan to circulate air while the chamber lid is in place.

Trial 2

Manipulating water levels throughout the season

Method

The second trial investigated whether manipulating water levels during the growing season would reduce methane emissions. Four treatments were tested:

- full flood (aerial sown);
- drill sown (grown aerobically for first four weeks then full flooding after);
- delayed permanent water (DPW, drill sown but grown aerobically for first 10 weeks); and
- early draining (drill sown, grown aerobically for first four weeks and again after flowering).

The trial was established in a randomised block design with four replicate plots per treatment. Plots were 10m x 40m, with nitrogen fertiliser applied as per standard recommendations for each treatment.

The trials were sown late (2 December 2013) with rice (cv. Sherpa) and harvested on 19 May 2014.

Results

The late sowing resulted in poorer growth in the drill-sown plots (drill sown, DPW and early drain treatments) compared with the aerial sown fully-flooded plots, which yielded 14t/ha compared with an average of about 9t/ha for the other treatments (Table 1).

Interestingly, only the aerially-sown full-flood treatment showed a spike in methane emissions during the first month after sowing (Figure 2).

TABLE 1 Grain yield under watering treatments with a December sowing

Treatment	Grain yield (t/ha)
Full flood (aerial sown)	14.0[a]
Full flood (drill sown)	9.0[b]
DPW (drill sown)	9.7[b]
Early drain (drill sown)	8.5[b]

DPW = delayed permanent water
Letters denote significant differences between treatments.

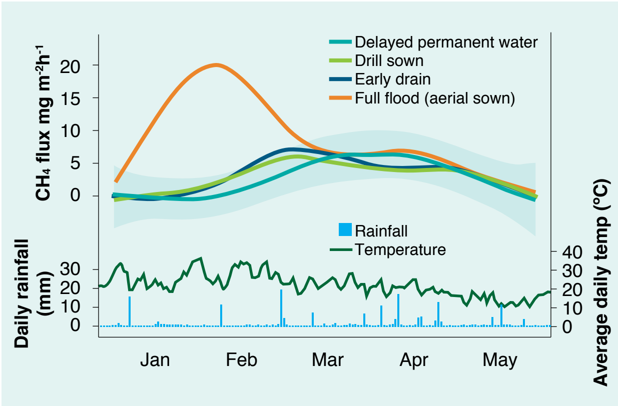

FIGURE 2 Methane (CH_4) emissions from the water management trial

Note: Lines for each treatment that fall within the pink shading are not significantly different from each other.

As stubble was burnt before sowing for all water management treatments, the main labile carbon source in the soil was the root mass of last season's crop, which may have decomposed anaerobically in the first month in the fully-flooded, aerially-sown treatment and led to emissions of methane.

Under drill sowing or DPW, the roots were likely to have broken down under aerobic conditions in the first month, which led to emissions of CO_2 rather than methane.

Throughout the 2013–14 season, the fully-flooded treatment emitted 293kg/ha of methane (i.e. 6.8t CO_2 equivalents per hectare), which was significantly higher than the other treatments (Table 2).

In comparison, there was no difference in N_2O emissions among treatments, and the average flux of 366g/ha was almost 1000 times lower than methane (equivalent to 0.1t CO_2 equivalents per hectare). These results confirm that methane is the dominant greenhouse gas emitted from Australian rice fields.

When compared with methane emissions from other rice-growing nations, the Australian methane emissions of 29g/m (6.8 t/ha CO_2 equivalents) in the full-flood treatment are towards the lower end of the reported emissions



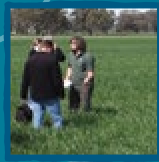

TABLE 2 Cumulative methane emissions over the season for the four water management treatments

Treatment	Methane flux per season (t/ha)	Methane emission CO_2 equivalents (t/ha)	N_2O flux per season (g/ha)
Full flood (aerial sown)	0.293[a]**	6.8[a]	
Full flood (drill sown)	0.118[b]	2.7[b]	
DPW* (drill sown)	0.097[b]	2.2[b]	
Early drain (drill sown)	0.122[b]	2.8[b]	Mean = 366 (= 0.1t CO_2 equivalents per ha)

* DPW = delayed permanent water
** Letters denote significant differences between treatments.

Conclusions

Australian methane emissions from rice fields are in line with reported values from other nations. Any watering treatments that avoid anaerobic conditions in the first month after sowing appear to reduce methane emissions, although it will be interesting to see whether this holds true in the 2014–15 trial, which has stubble incorporated into the soil.

Returning stubble to the soil as compost or biochar did not increase methane emissions, but further investigation over the next two seasons is required to confirm this.

The 2014–15 crop was sown on time (late October), and yield differences are unlikely to be as prominent as those from the 2013–14 season.

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North east Victoria National Variety Testing Trials 2014

Trials conducted by Agrisearch and NSW DPI
Data collated by Katherine Hollaway (DEDJTR Horsham), Julia Severi and Dale Grey (DEDJTR Bendigo) from data provided by the NVT website.

The 2014 Rutherglen long-season and Yarrawonga main-season wheat trials had data that is too variable to publish.

TABLE 1 Long-term predicted wheat yield (main-season) in north east Victoria for 2010–14

Variety	Predicted yield (t/ha)	% of EGA Gregory	Site years
Viking	5.05	105	3
Hydra	5.01	104	3
Trojan	4.99	104	9
Cobra	4.96	103	9
Scout	4.92	102	14
Suntop	4.90	102	14
Condo	4.85	101	9
Impala	4.83	101	13
Espada	4.83	101	11
Cosmick	4.83	101	5
EGA Gregory	4.80	100	13
Phantom	4.80	100	14
Corack	4.78	99	14
Correll	4.77	99	13
Sunmate	4.75	99	6
Mace	4.73	98	6
Orion	4.72	98	11
Elmore CL Plus	4.72	98	11
QAL2000	4.69	98	8
Gascoigne	4.68	98	11
Magenta	4.67	97	14
Harper	4.63	96	13
Bolac	4.62	96	9
Wallup	4.61	96	14
Estoc	4.61	96	13
Clearfield STL	4.58	95	8
Sentinel	4.58	95	8
Ventura	4.57	95	6
Yitpi	4.56	95	10
Gazelle	4.56	95	11
Barham	4.54	95	13
Emu Rock	4.53	94	13
Chara	4.53	94	12
Gauntlet	4.52	94	11
Kord CL Plus	4.52	94	10
Justica CL Plus	4.52	94	13
Lincoln	4.51	94	13
Sabel CL Plus	4.51	94	5
GBA Ruby	4.51	94	6
Young	4.50	94	6
Gladius	4.48	93	14
Peake	4.46	93	6
SQP Revenue	4.46	93	5
Sunguard	4.46	93	5
Dart	4.45	93	11
Merlin	4.42	92	13
Shield	4.42	92	4
Livingston	4.42	92	9
Derrimut	4.41	92	14
Lancer	4.39	91	6
Spitfire	4.38	91	14
Forrest	4.38	91	3
Axe	4.38	91	13
Grenade CL Plus	4.37	91	11
Kennedy	4.33	90	4
Clearfield JNZ	4.32	90	8
Frame	4.21	88	6



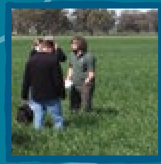

TABLE 2 Long-term predicted wheat yield (long-season) in north east Victoria for 2010–14

Variety	Predicted yield (t/ha)	% of Bolac	Site years
Beaufort	5.28	111	15
Preston	5.25	111	15
Adagio	5.24	110	6
SQP Revenue	5.24	110	15
Kiora	5.18	109	9
Trojan	5.06	107	6
Manning	5.04	106	9
QAL2000	4.94	104	13
Scout	4.88	103	12
Mackellar	4.86	102	6
Frelon	4.84	102	3
Scenario	4.80	101	6
Viking	4.78	101	6
Gazelle	4.76	100	15
Orion	4.75	100	6
Bolac	4.74	100	15
Forrest	4.70	99	12
Yenda	4.67	99	3
Phantom	4.66	98	9
Sentinel	4.66	98	12
Elmore CL Plus	4.64	98	9
Derrimut	4.58	97	6
Chara	4.58	97	15
Lincoln	4.58	97	6
EGA Gregory	4.56	96	9
Kellalac	4.49	95	15
EGA Wedgetail	4.49	95	15
Estoc	4.47	94	12
Espada	4.42	93	6
Barham	4.39	92	6
Lancer	4.37	92	6
Mansfield	4.36	92	12
Sunguard	4.31	91	6
Gascoigne	4.27	90	9
Endure	4.26	90	3
EGA Bounty	4.21	89	6
Naparoo	4.18	88	12
Bowie	4.03	85	4

TABLE 3 Yield and quality of wheat varieties (main-season) at Dookie during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings <2.2mm (%)	Seed size (g/1000 seeds)	Height (cm)	Heading year day*
LRPB Viking	4.94	84.4	9.0	0.2	40.6	103	267
LRPB Cobra	4.63	83.7	9.8	0.6	44.6	77	257
LRPB Scout	4.59	84.9	9.8	0.3	44.4	92	260
LRPB Trojan	4.59	83.6	9.2	0.6	44.9	90	260
Suntop	4.52	82.7	9.7	0.4	43.4	95	264
Mace	4.47	82.5	9.2	0.1	45.0	90	257
EGA Gregory	4.43	83.7	9.3	0.3	44.5	108	267
Cosmick	4.41	82.9	9.2	0.8	40.8	97	260
Wallup	4.40	82.6	10.0	0.2	40.1	85	257
LRPB Lancer	4.38	82.5	10.4	0.1	43.4	100	267
LRPB Phantom	4.38	81.5	9.3	0.6	45.8	90	264
Barham	4.37	79.9	9.2	0.6	38.6	90	260
Condo	4.36	83.2	10.3	0.4	44.4	87	246
QAL2000	4.31	82.2	8.6	0.3	45.4	95	267
LRPB Gauntlet	4.30	84.3	10.0	0.3	42.6	91	260
Corack	4.27	80.9	9.8	0.6	46.6	100	260
Harper	4.25	83.1	9.6	0.7	41.7	92	267
LRPB Merlin	4.23	83.4	10.7	0.3	46.1	90	250
Elmore CL Plus	4.22	83.9	9.4	0.7	40.6	91	260
Gascoigne	4.22	NA	9.8	NA	45.8	98	260
Correll	4.21	NA	9.4	NA	45.8	93	267
Impala	4.21	82.7	9.2	0.9	36.8	93	260
LRPB Spitfire	4.20	84.4	10.6	0.3	44.2	90	253
Magenta	4.20	80.8	9.2	0.3	43.8	93	264
Emu Rock	4.10	82.7	10.0	0.6	51.0	85	253
Estoc	4.09	84.7	10.4	0.8	45.3	87	264
Derrimut	4.02	84.3	9.7	1.1	38.0	80	264
Kord CL Plus	3.99	81.6	9.8	0.9	44.9	88	260
Yitpi	3.99	83.0	9.8	0.4	47.4	100	267
Axe	3.95	82.6	10.6	0.7	41.5	NA	NA
Gladius	3.95	82.1	10.2	0.7	44.4	90	257
LRPB Lincoln	3.94	82.9	9.4	1.7	40.8	95	257
Justica CL Plus	3.77	81.1	10.3	0.4	40.2	83	267
Grenade CL Plus	3.61	82.5	10.1	0.2	43.5	85	264
Sown	13 May 2014						
Harvest	10 December 2014						
Site mean (t/ha)	4.28						
CV (%)	3.83						
F prob	<0.001						
LSD (t/ha)	0.28						
pH ($CaCl_2$)	7.1						
GSR (Apr–Oct)	343mm						

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during August, September and October



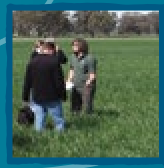

TABLE 4 Yield and quality of wheat varieties (main-season) at Wunghnu during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings <2.2mm (%)	Seed size (g/1000 seeds)	Height (cm)	Heading year day*
LRPB Viking	4.97	83.9	8.4	0.3	40.7	115	267
LRPB Trojan	4.87	83.0	9.5	0.0	45.0	90	267
LRPB Scout	4.86	83.9	8.9	0.6	43.9	95	260
Suntop	4.77	83.0	9.3	0.7	44.6	105	267
EGA Gregory	4.63	83.4	8.6	1.3	44.4	110	271
Correll	4.61	80.8	8.6	0.4	44.6	90	264
LRPB Phantom	4.57	82.0	8.7	0.3	46.1	100	267
LRPB Cobra	4.53	81.2	8.9	0.3	42.3	80	257
Cosmick	4.47	82.7	8.7	0.0	40.7	93	260
Mace	4.45	82.4	8.7	0.0	43.9	85	257
Barham	4.34	78.6	8.5	0.3	38.1	100	264
Magenta	4.34	82.5	9.2	0.2	42.3	100	260
Derrimut	4.31	83.6	8.9	0.3	40.2	90	264
Yitpi	4.31	82.4	9.3	0.0	45.7	105	267
Gascoigne	4.30	83.5	9.4	0.0	45.1	110	260
Condo	4.29	83.0	9.3	0.0	46.3	100	250
Corack	4.29	81.0	8.8	0.3	49.9	90	260
Harper	4.26	82.4	8.9	0.4	43.1	100	264
Elmore CL Plus	4.23	84.1	8.9	0.3	38.9	100	260
Impala	4.22	82.2	9.0	0.4	38.1	105	260
LRPB Lancer	4.16	83.4	9.4	0.3	45.5	75	267
Estoc	4.15	83.5	9.7	0.5	41.4	80	267
Grenade CL Plus	4.12	81.6	9.6	0.2	46.0	90	260
Kord CL Plus	4.12	81.3	9.2	0.0	49.9	85	264
Axe	4.04	82.6	9.7	0.2	41.5	85	250
Wallup	4.04	83.3	9.6	0.2	41.0	80	260
LRPB Gauntlet	4.03	83.5	9.2	0.0	45.2	95	264
Gladius	3.99	81.5	9.4	0.3	46.4	90	260
LRPB Lincoln	3.90	82.4	8.6	0.7	41.2	90	260
Justica CL Plus	3.87	80.8	9.3	0.5	39.4	85	264
LRPB Spitfire	3.86	83.6	10.2	1.3	46.6	90	255
LRPB Merlin	3.83	84.3	10.1	0.0	44.6	85	250
Emu Rock	3.81	82.2	10.3	0.4	47.8	75	257
Sown	13 May 2014						
Harvest	6 December 2014						
Site mean (t/ha)	4.33						
CV (%)	4.13						
F prob	<0.001						
LSD (t/ha)	0.32						
pH ($CaCl_2$)	4.90						
GSR (Apr–Oct)	294mm						

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during August, September and October

TABLE 5 Yield and quality of irrigated wheat varieties (main-season) at Numurkah during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)	Seed size (g/1000 seeds)	Height (cm)
Beaufort	10.36	80.4	8.5	1.1	44.3	90
LRPB Cobra	9.73	84.3	9.2	0.9	44.3	75
LRPB Scout	9.63	85.6	9.6	0.8	45.7	80
LRPB Trojan	9.49	86.4	8.8	0.6	49.3	80
LRPB Viking	9.44	87.4	9.0	1.0	44.0	85
Wallup	9.25	85.0	9.4	0.8	43.7	80
Suntop	9.11	84.6	8.6	1.6	46.3	85
LRPB Lancer	9.10	86.5	9.4	1.0	42.0	75
Chara	9.09	84.3	8.9	0.7	44.3	80
LRPB Phantom	9.06	85.2	9.0	1.3	47.3	85
Corack	9.01	86.2	9.3	0.7	53.7	80
Condo	8.99	85.7	9.0	1.3	51.0	80
Sentinel	8.87	86.4	8.8	0.5	47.3	85
Gazelle	8.72	80.2	8.2	0.7	40.7	93
EGA Wedgetail	8.67	82.8	8.8	0.6	45.3	85
Adagio	8.61	82.8	9.1	1.9	40.7	85
Bolac	8.55	83.0	9.0	1.4	37.7	90
Shield	8.42	83.4	9.5	1.4	46.0	75
Gladius	8.39	84.5	9.4	0.6	47.7	85
Magenta	8.38	84.6	8.5	1.1	50.3	80
Mace	8.32	82.8	8.7	0.6	47.7	80
Derrimut	8.29	84.6	8.9	0.9	41.3	80
Livingston	8.10	85.2	9.9	0.5	42.0	85
Scenario	7.85	79.2	9.1	2.4	38.3	80
LRPB Spitfire	7.61	87.7	9.7	0.8	48.3	75
Sown	14 May 2014					
Harvest	3 December 2014					
Site mean (t/ha)	8.8					
CV (%)	5.4					
F prob	<0.001					
LSD (t/ha)	0.9					
pH ($CaCl_2$)	6.0					
GSR (Apr–Oct)	300mm					

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during July and September



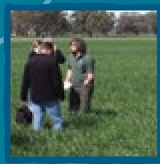

TABLE 6 Long-term predicted triticale yields in north east Victoria for 2008–14

Variety	Yield (t/ha)	% of Hawkeye	Site years
Fusion	4.82	108	10
Bison	4.78	107	4
Hawkeye	4.48	100	13
Bogong	4.45	99	13
Berkshire	4.41	99	13
Canobolas	4.38	98	13
Jaywick	4.35	97	13
Crackerjack	4.35	97	3
Chopper	4.27	95	13
Goanna	4.16	93	8
Rufus	4.11	92	13
Yowie	4.06	91	10
Tahara	4.05	90	13
Tobruk	3.77	84	3
Tuckerbox	3.70	83	11
Speedee	3.34	75	3

TABLE 7 Yield of triticale varieties at Rutherglen during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings <2.0mm (%)	Seed size (g/1000 seeds)	Height (cm)	Heading year day*
Fusion	5.00	67.8	9.6	1.9	46.7	125	265
Berkshire	4.50	70.2	9.9	0.5	52.2	125	275
Bogong	4.49	67.9	9.7	1.9	45.7	130	272
Bison	4.42	69.8	10.5	0.9	44.5	120	265
Chopper	4.38	65.0	9.7	3.2	44.0	105	265
Canobolas	4.18	70.2	9.9	1.6	43.3	140	275
Hawkeye	4.14	68.8	9.8	0.6	48.5	135	265
Jaywick	4.07	67.7	9.5	1.8	48.9	130	268
Goanna	3.87	69.6	10.3	1.3	41.9	130	272
Rufus	3.86	66.8	9.6	1.3	45.4	140	268
Tahara	3.54	65.5	10.5	2.7	45.9	135	268
Tuckerbox	3.49	66.2	9.5	2.7	39.3	115	275
Yowie	3.02	67.6	9.5	1.1	45.9	130	272
Sown	16 May 2014						
Harvest	19 December 2014						
Site mean (t/ha)	4.11						
CV (%)	12.34						
F prob	0.003						
LSD (t/ha)	0.79						
pH ($CaCl_2$)	4.30						
GSR (Apr – Oct)	353mm						

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during September and October

TABLE 8 Yield of triticale varieties at Yarrawonga during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)	Seed size (g/1000 seeds)	Height (cm)	Heading year day*
Bison	5.86	70.5	11.2	0.5	50.5	115	248
Chopper	5.17	71.8	11.3	0.8	47.6	120	248
Hawkeye	5.04	75.6	11.8	0.2	51.1	120	251
Berkshire	4.92	77.0	11.5	0.4	52.4	125	248
Canobolas	4.50	76.8	11.7	1.3	53.5	130	258
Bogong	4.45	76.0	11.6	0.7	44.7	135	251
Goanna	4.39	76.4	11.9	1.6	46.8	135	254
Jaywick	4.31	73.4	12.0	0.5	47.5	125	254
Fusion	4.23	72.8	10.5	0.9	46.7	120	248
Rufus	3.93	71.2	12.6	1.0	45.1	140	251
Tahara	3.79	71.9	12.0	1.0	46.5	129	251
Yowie	3.50	74.0	11.1	1.0	47.9	120	254
Tuckerbox	3.31	74.1	11.4	3.0	34.0	120	254
Sown	14 May 2014						
Harvest	4 December 2014						
Site mean (t/ha)	4.5						
CV (%)	6.5						
F prob	<0.001						
LSD (t/ha)	0.49						
pH ($CaCl_2$)	5.1						
GSR (Apr–Oct)	320mm						

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during August, September and October



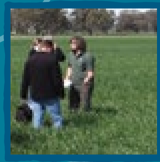

TABLE 9 Long-term predicted barley yield for north east Victoria for 2005–14

Variety	Predicted yield (t/ha)	% of Gairdner	Site years
Malting barley			
Charger	3.54	115	5
Maltstar	3.40	110	3
LaTrobe	3.39	110	4
Commander	3.38	110	9
Alestar	3.37	109	3
Henley	3.37	109	5
Granger	3.30	107	4
Navigator	3.30	107	5
Fitzroy	3.30	107	4
Fairview	3.23	105	6
Buloke	3.21	104	9
Scope	3.20	104	6
Wimmera	3.19	104	5
Westminster	3.15	102	6
Bass	3.15	102	7
Macquarie	3.15	102	8
Flinders	3.14	102	5
Vlamingh	3.13	102	4
Gairdner	3.08	100	9
Baudin	3.02	98	9
Flagship	2.91	95	9
Franklin	2.82	92	4
Schooner	2.79	91	9
Feed barley			
Lockyer	3.38	110	3
Fathom	3.36	109	5
Fleet	3.35	109	6
Oxford	3.35	109	6
Hindmarsh	3.32	108	8
Capstan	3.30	107	6
Keel	3.16	103	5
Hannan	3.12	101	3
Yarra	3.11	101	5
Finniss	2.63	85	6
Barley under malt evaluation			
Compass	3.57	116	3
SY Rattler	3.28	107	6
Skipper	3.27	106	5

TABLE 10 Yield of barley varieties at Wunghnu during 2014

Variety	Yield (t/ha)
Maltstar	6.07
LaTrobe	5.90
Charger	5.88
SY Rattler	5.81
Alestar	5.73
Compass	5.70
Macquarie	5.68
Fairview	5.65
Navigator	5.56
Commander	5.55
Fathom	5.55
Gairdner	5.55
Granger	5.53
Skipper	5.52
Oxford	5.47
Bass	5.44
Hindmarsh	5.44
Westminster	5.43
Scope	5.39
Buloke	5.25
Flagship	5.09
Flinders	5.08
Baudin	5.05
Schooner	4.83
Sown	13 May 2014
Harvest	05 December 2014
Site mean (t/ha)	5.54
CV (%)	5.83
F prob	0.0125
LSD (t/ha)	0.54
pH ($CaCl_2$)	4.9
GSR (Apr–Oct)	294mm
This trial was sprayed with fungicide during August and September.	

TABLE 11 Long-term predicted oat yield in north east Victoria for 2010–14

Variety	Predicted yield (t/ha)	% of Mitika	Site years	Type
Williams	4.14	132	10	Milling
Bannister	3.91	124	10	Milling
Wombat	3.71	118	11	Milling
Dunnart	3.50	111	11	Milling
Quoll	3.49	111	7	Feed
Euro	3.35	106	5	Milling
Possum	3.29	105	11	Milling
Yallara	3.20	101	11	Milling
Mitika	3.15	100	11	Milling
Echidna	2.99	95	4	Feed
Numbat	2.42	77	5	Hull-less

TABLE 12 Yield of oat varieties at Yarrawonga during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)	Seed size (g/1000 seeds)	Height (cm)	Heading year day*
Williams	3.65	50.8	10.1	20.5	36.3	95	267
Wombat	3.10	51.3	10.3	21.2	37.7	80	271
Dunnart	3.03	48.9	9.5	19.6	39.8	90	271
Bannister	2.97	72.0	9.7	12.2	40.9	81	269
Echidna	2.84	50.8	9.8	18.3	37.4	75	274
Yallara	2.82	50.9	9.9	19.8	41.3	95	271
Mitika	2.81	51.4	11.1	12.1	41.2	70	274
Possum	2.81	49.1	11.0	14.3	39.5	75	269
Sown	16 May 2014						
Harvest	15 December 2014						
Site mean (t/ha)	2.92						
CV (%)	13.28						
F prob	0.117						
LSD (t/ha)	0.61						
pH ($CaCl_2$)	4.3						
GSR (Apr–Oct)	320mm						

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during September.

TABLE 13 Yield of oat varieties at Dookie during 2014

Variety	Yield (t/ha)	Test weight (kg/hL)	Protein (%)	Screenings (%)	Seed size (g/1000 seeds)	Height (cm)	Heading year day*
Echidna	5.12	54.5	9.9	19.7	38.8	80	269
Bannister	5.01	57.2	11.3	18.5	38.4	89	259
Williams	4.97	54.9	9.6	26.4	36.8	95	262
Dunnart	4.73	51.4	9.3	16.0	40.0	90	265
Wombat	4.70	54.9	9.7	19.9	42.1	80	262
Mitika	4.32	55.8	9.6	11.0	45.1	65	258
Possum	4.32	52.3	9.7	15.6	40.0	70	255
Yallara	4.15	55.2	10.1	20.9	42.0	95	265
Sown	13 May 2014						
Harvest	3 December 2014						
Site mean (t/ha)	4.54						
CV (%)	3.54						
F prob	<0.001						
LSD (t/ha)	0.27						
pH ($CaCl_2$)	7.1						
GSR (Apr–Oct)	343mm						

* Heading year day is the calendar day of the year on which the crop heads emerged.
This trial was sprayed with fungicide during September.

TABLE 14 Long-term predicted yield of conventional canola varieties in north east Victoria yield for 2010–14

Variety	Predicted yield (t/ha)	% of Garnet	Site years
Hyola 50	2.68	105	4
Nuseed Diamond	2.66	104	3
Victory V3002	2.58	101	2
AV Garnet	2.56	100	4
AV Zircon	2.53	99	3
CB Agamax	2.51	98	3
CB Tango C	2.40	94	2



TABLE 15 Yield of conventional canola varieties (mid-season) at Wunghnu for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (μmol/g)
Hyola 50	3.45	43.6	19.2	5.9
Hyola 635CC	3.35	46.4	19.2	6.6
Nuseed Diamond	3.25	44.1	18.0	10.4
AV Zircon	3.20	45.7	17.0	7.4
AV Garnet	3.05	44.0	17.7	7.3
Victory V3002	2.97	43.3	18.4	9.5
Sown	7 May 2014			
Harvest	11 November 2014			
Site mean (t/ha)	3.21			
CV (%)	7.07			
F prob	0.0137			
LSD (t/ha)	0.3			
pH ($CaCl_2$)	4.6			
GSR (Apr–Oct)	293mm			

TABLE 16 Long-term predicted yield of imidazolinone-tolerant (imi) canola varieties (mid-season) in north east Victoria for 2009–14

Variety	Predicted yield (t/ha)	% of Hyola 474CL	Site years
Archer	2.69	107	6
Pioneer 45Y88 (CL)	2.68	106	6
Pioneer 45Y86 (CL)	2.67	106	9
Pioneer 46Y83 (CL)	2.63	104	3
Pioneer 44Y87 (CL)	2.63	104	4
Hyola 676CL	2.59	102	2
Pioneer 44Y89 (CL)	2.58	102	2
Hyola 577CL	2.58	102	4
Hyola 571CL	2.57	102	2
Hyola 575CL	2.57	102	9
Pioneer 44Y84 (CL)	2.56	101	7
Hyola 474CL	2.53	100	7
Pioneer 45Y82 (CL)	2.51	99	5
Carbine	2.51	99	5
Pioneer 46Y78	2.46	97	2
Pioneer 43Y85 (CL)	2.36	93	2

TABLE 17 Yield and quality of imidazolinone-tolerant (imi) canola varieties (mid-season) at Yarrawonga for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (μmol/g)
Hyola 474CL	3.11	41.4	20.1	6.4
Pioneer 45Y88 (CL)	3.10	38.6	22.1	4.9
Pioneer 45Y86 (CL)	3.08	41.5	20.7	6.3
Hyola 575CL	3.07	41.4	21.5	5.9
Pioneer 44Y87 (CL)	3.02	40.2	19.9	5.3
Archer	3.00	40.9	20.6	5.4
Hyola 577CL	2.98	42.8	22.6	5.0
Pioneer 44Y89 (CL)	2.89	39.9	20.2	6.4
Sown	05 May 2014			
Harvest	20 November 2014			
Site mean (t/ha)	3.05			
CV (%)	7.69			
F prob	0.894			
LSD (t/ha)	0.37			
pH ($CaCl_2$)	5.2			
GSR (Apr–Oct)	320mm			

TABLE 18 Yield and quality of of imidazolinone-tolerant (imi) canola varieties (mid-season) at Wunghnu for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (μmol/g)
Pioneer 45Y88 (CL)	3.29	-	-	-
Pioneer 44Y89 (CL)	3.16	42.9	17.8	6.5
Pioneer 44Y87 (CL)	3.13	42.5	18.4	4.9
Hyola 575CL	3.11	43.2	19.5	6.0
Archer	3.10	43.6	17.8	6.8
Hyola 474CL	3.07	43.2	19.2	6.0
Hyola 577CL	3.04	44.9	19.2	3.8
Pioneer 45Y86 (CL)	2.89	43.6	19.0	5.6
Sown	24 April 2014			
Harvest	11 November 2014			
Site mean (t/ha)	3.06			
CV (%)	6.83			
F prob	0.0404			
LSD (t/ha)	0.32			
pH ($CaCl_2$)	4.6			
GSR (Apr–Oct)	293mm			

TABLE 19 Long-term predicted yield of triazine tolerant (TT) canola varieties (mid-season) in north east Victoria for 2010–14

Variety	Predicted yield (t/ha)	% of Hyola 444TT	Site years
Hyola 650TT	2.44	116	3
CB Henty HT	2.42	115	5
Hyola 559TT	2.42	115	6
Hyola 751TT	2.40	114	2
Pioneer Atomic TT	2.39	113	6
Hyola 656TT	2.38	113	4
Crusher TT	2.38	113	7
Hyola 555TT	2.38	113	7
ATR Bonito	2.35	111	6
ATR Wahoo	2.34	111	6
Jackpot TT	2.31	110	2
Hyola 450TT	2.30	109	4
ATR Gem	2.29	109	7
Hyola 525RT	2.27	107	4
CB Nitro HT	2.24	106	4
CB Jardee HT	2.23	106	7
ATR Stingray	2.15	102	7
Thumper TT	2.15	102	7
CB Junee HT	2.12	100	4
Monola 515TT	2.12	100	2
Hyola 444TT	2.11	100	3
ATR Snapper	2.09	99	5
Pioneer Sturt TT	2.08	99	4
Monola 314TT	2.08	98	4
CB Tumby HT	2.08	98	2
Tawriffic TT	2.05	97	3
Monola 77TT	2.04	97	3
Fighter TT	2.03	96	2
Monola 413TT	2.03	96	4
Monola 76TT	2.01	95	3
CB Mallee HT	2.00	95	3
Monola 704TT	1.99	95	2
CB Scaddan	1.99	94	3
Monola 506TT	1.98	94	3
Monola 605TT	1.97	93	4
Monola 603TT	1.96	93	2
ATR Cobbler	1.90	90	5
Telfer	1.88	89	2
Bonanza TT	1.86	88	3
CB Tanami	1.72	82	2
CB Argyle	1.70	81	2

TABLE 20 Yield and quality of triazine tolerant (TT) canola varieties (mid-season) at Yarrawonga for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (μmol/g)
Hyola 650TT	3.25	41.7	21.1	5.1
ATR Bonito	3.09	43.8	19.4	5.8
Hyola 559TT	3.07	42.9	20.2	6.6
ATR Wahoo	3.04	41.4	21.0	5.4
ATR Gem	2.88	42.7	21.0	3.7
Hyola 525RT	2.80	43.8	19.9	5.9
Pioneer Atomic TT	2.75	40.3	22.0	5.7
Monola® 515TT	2.57	41.2	21.0	3.9
Hyola 450TT	2.52	43.6	20.3	6.9
Hyola 725RT	2.38	44.2	21.4	6.5
Monola 314TT	2.17	38.2	21.6	4.7
Sown	5 May 2014			
Harvest	20 November 2014			
Site mean (t/ha)	2.71			
CV (%)	8.64			
F prob	<0.001			
LSD (t/ha)	0.38			
pH ($CaCl_2$)	5.2			
GSR (Apr–Oct)	320mm			

TABLE 21 Yield and quality of triazine tolerant (TT) canola varieties mid-season at Wunghnu for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (μmol/g)
Hyola 650TT	3.07	44.7	18.8	5.6
Hyola 450TT	2.95	45.9	19.0	4.7
Hyola 559TT	2.93	45.0	19.3	5.1
Pioneer Atomic TT	2.89	43.6	19.1	4.9
Hyola 525RT	2.85	45.3	19.1	4.6
ATR Gem	2.70	44.7	18.3	5.3
ATR Bonito	2.66	45.2	18.5	4.8
Monola® 515TT	2.57	43.1	19.2	3.9
ATR Wahoo	2.44	43.9	18.9	5.5
Monola 314TT	2.31	41.8	19.4	3.5
Sown	24 April 2014			
Harvest	11 November 2014			
Site mean (t/ha)	2.71			
CV (%)	7.42			
F prob	<0.001			
LSD (t/ha)	0.34			
pH ($CaCl_2$)	4.60			
GSR (Apr–Oct)	294mm			



TABLE 22 Long-term predicted yield of Roundup Ready (RR) canola varieties in north east Victoria for 2010–14

Variety	Predicted yield (t/ha)	% of GT Cobra	Site years
Pioneer 45Y25 (RR)	2.86	115	3
Pioneer 43Y23 (RR)	2.81	113	4
Nuseed GT-50	2.73	110	7
Pioneer 44Y24 (RR)	2.72	110	7
Hyola 600RR	2.71	109	2
Pioneer 45Y22 (RR)	2.71	109	5
Victory V5002RR	2.69	108	6
Pioneer 44Y26 (RR)	2.69	108	2
Hyola 500RR	2.68	108	4
Hyola 400RR	2.67	108	4
Hyola 404RR	2.67	108	7
Monola G11	2.66	107	3
IH52 RR	2.63	106	3
Hyola 505RR	2.63	106	4
DG 550RR	2.60	105	3
CB Frontier RR	2.59	105	5
IH50 RR	2.59	104	7
Nuseed GT-41	2.56	103	4
IH51 RR	2.51	101	2
GT Cobra	2.48	100	5
Monola 513GT	2.47	100	6
Hyola 525RT	2.46	99	4
CB Eclipse RR	2.40	97	3
GT Viper	2.28	92	5
CB Status RR	2.21	89	2

TABLE 23 Yield of Roundup Ready (RR) canola varieties at Yarrawonga trial for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (μmol/g)
Pioneer 45Y25 (RR)	3.52	42.9	19.1	4.6
Nuseed GT-50	3.25	41.9	18.8	8.6
Hyola 500RR	3.18	45.0	18.4	5.5
Pioneer 44Y24 (RR)	3.16	40.2	21.5	6.8
IH51 RR	3.13	41.1	20.4	6.5
IH52 RR	3.09	40.7	20.7	6.3
Pioneer 44Y26 (RR)	3.09	44.6	17.9	5.7
Hyola 404RR	3.01	44.3	19.6	6.8
Victory V5002RR	3.01	42.4	20.7	11.1
Hyola 600RR	2.95	44.6	21.5	6.7
IH50 RR	2.95	41.2	19.9	5.5
DG 550RR	2.89	43.2	20.5	5.3
Hyola 400RR	2.79	44.5	19.7	7.6
Monola® G11	2.79	45.4	18.9	NA
Monola 513GT	2.65	44.7	19.6	7.8
Sown	5 May 2014			
Harvest	20 November 2014			
Site mean (t/ha)	3.04			
CV (%)	7.7			
F prob	<0.001			
LSD (t/ha)	0.36			
pH ($CaCl_2$)	5.2			
GSR (Apr–Oct)	320mm			

TABLE 24 Yield of Roundup Ready (RR) canola varieties at Wunghnu for 2014

Variety	Yield (t/ha)	Oil (%)	Seed protein (%)	Gluc (µmol/g)
IH52 RR	3.38	43.0	17.8	6.6
IH50 RR	3.26	42.8	18.2	5.8
Hyola 400RR	3.23	47.7	17.7	6.5
Pioneer 44Y24 (RR)	3.22	43.5	18.8	5.6
DG 550RR	3.15	44.7	18.6	5.4
Hyola 500RR	3.14	46.9	17.3	5.6
Monola® G11	3.13	47.4	17.8	NA
Pioneer 45Y25 (RR)	3.12	45.7	17.3	3.9
Hyola 600RR	3.10	47.1	17.9	6.0
Hyola 404RR	3.08	47.7	17.8	6.1
Nuseed GT-50	3.04	43.9	17.8	7.7
Pioneer 44Y26 (RR)	3.01	45.8	16.2	4.6
IH51 RR	2.94	42.7	19.2	6.4
IH30 RR	2.91	46.7	17.5	4.1
Monola 513GT	2.90	47.7	17.7	6.8
Victory V5002RR	2.69	45.4	17.7	8.2
Sown	24 April 2014			
Harvest	11 November 2014			
Site mean (t/ha)	3.05			
CV (%)	6.58			
F prob	<0.001			
LSD (t/ha)	0.32			
pH ($CaCl_2$)	4.6			
GSR (Apr–Oct)	294mm			

TABLE 25 Long-term predicted yield of faba bean varieties in north east Victoria for 2007–14

Variety	Predicted yield (t/ha)	Site years
Fiesta VF	2.79	7
Farah	2.76	7
PBA Rana	2.63	6
Nura	2.62	7
Doza	2.46	4
Fiord	2.40	3

TABLE 26 Yield and quality of faba bean varieties at Dookie for 2014

Variety	Yield (t/ha)	100 seed weight (g/100 seeds)
Farah	2.38	59.4
PBA Rana	2.06	67.2
Fiesta VF	1.90	59.2
PBA Samira	1.89	60.2
Nura	1.76	52.6
Sown	19 May 2014	
Harvest	24 December 2014	
Site mean (t/ha)	2	
CV (%)	12.3	
F prob	0.0508	
LSD (t/ha)	0.42	
pH ($CaCl_2$)	6.3	
GSR (Apr–Oct)	341mm	

TABLE 27 Long-term predicted yield of lupin varieties in north central Victoria for 2008–14

Variety	Predicted yield (t/ha)	% of Mandelup	Site years
Mandelup	1.97	100	7
PBA Gunyidi	1.96	99	5
Jenabillup	1.89	96	7
PBA Barlock	1.87	95	5
Coromup	1.82	93	7
Wonga	1.64	83	7

TABLE 28 Yield and quality of lupin varieties at Diggora (near Elmore) for 2014

Variety	Yield (t/ha)	100 seed weight (g/100 seeds)	Height (cm)	50% flowering (year day)*
PBA Gunyidi	2.58	13.3	65	251
PBA Barlock	2.53	14.0	70	251
Jenabillup	2.27	15.0	70	251
Coromup	2.14	14.5	72	261
Mandelup	2.08	14.5	65	258
Wonga	2.01	15.7	70	258
Sown	9 May 2014			
Harvest	28 November 2014			
Site Mean (t/ha)	2.33			
CV (%)	8.18			
F prob	<0.001			
LSD (t/ha)	0.31			
pH ($CaCl_2$)	5.1			
GSR (Apr–Oct)	336mm			

*Day of the year when 50% of the main stems had an open flower

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