RiverinePlains

Research for the Riverine Plains 2018

A selection of research relevant to agriculture in the Riverine Plains

Farmers inspiring farmers

riverineplains.org.au



Research for the
Riverine Plains 2018

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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Welcome to Research for the Riverine Plains, 2018

In 2017, Riverine Plains Inc was again involved in a number of significant and diverse research projects. As a result, the 2018 edition of *Research for the Riverine Plains* is comprised entirely of articles written by Riverine Plains Inc, or by one of our project partners. We are proud that we have been able to bring local research to the Riverine Plains region and that this local content can feature so prominently in this year's trial book. Local research findings are important to the ongoing productivity and sustainability of farmers across the Riverine Plains and we hope you find this collection of articles both interesting and relevant.

FAR Australia are our project partners for the Grains Research and Development Corporation (GRDC) investment *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project and have contributed several articles. This includes results from the large-scale trials looking at stubble management to enhance stubble breakdown, as well as small plot trials looking at stubble height and nitrogen response across in-paddock zones. FAR Australia has also contributed an article on the management of early-sown wheat as part of a GRDC investment led by LaTrobe University. We sincerely thank Nick Poole, Michael Straight and Tracey Wylie for their contributions.

Riverine Plains Inc has produced several articles that describe the results from our projects. This includes results from our work on precision agriculture and frost as part of the stubble project, the interaction between sulphur and nitrogen in canola, soil moisture monitoring, spatial soil sampling of nitrogen and harvest weed seed control.

Local trial results have also started to become available from the *Managing subsoil acidity* project, led by Charles Sturt University and NSW Department of Primary Industries (DPI), with financial support from GRDC and we are pleased to include an article from Dr Jason Condon of CSU on the 2017 project trial results.

On behalf of Riverine Plains Inc, I would like to formally thank all authors for sharing their results with our members. A special thank you to the Riverine Plains Inc staff for their contribution to this publication and to sub-editor Catriona Nicholls and graphic designer Josephine Eynaud for their work in producing a professional and easy to read publication.

We hope you enjoy reading your copy of *Research for the Riverine Plains 2018* and wish you all the best for the 2018 cropping season.

Dr Cassandra Schefe
Research and Extension Officer, Riverine Plains Inc.

Research for the Riverine Plains 2018 is supported by Murray Local Land Services through funding from the Australian Government's National Landcare Program.

Riverine Plains Inc Research & Extension Officer, Cassandra Schefe talking soils.

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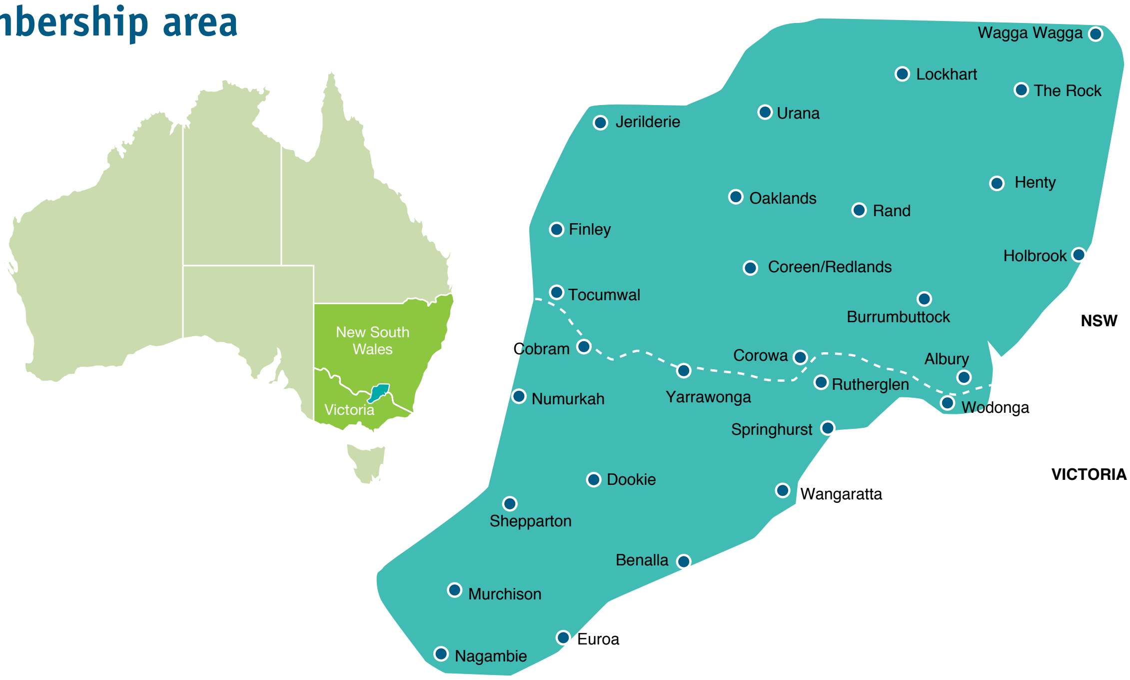
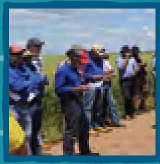
Area covered by
Riverine Plains Inc
Membership area





2018 Riverine Plains Inc Committee, support and staff

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Units of measurement

Row spacings

Some trials carried out during 2017 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

hectolitres — hL

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

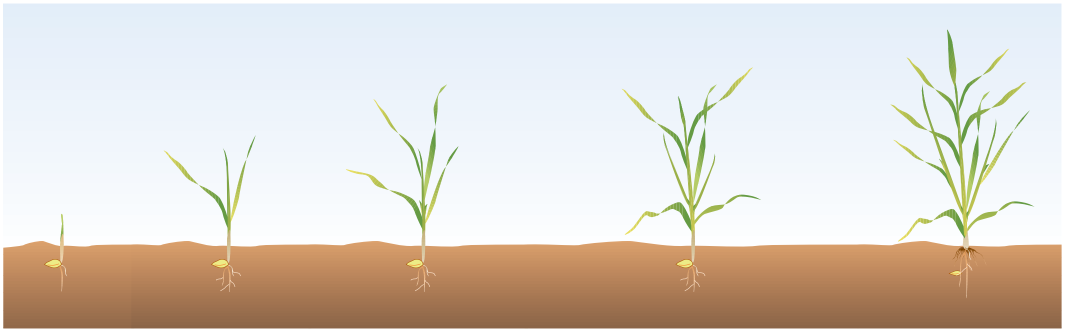
The most commonly used growth stage key for cereals is the:

- 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)

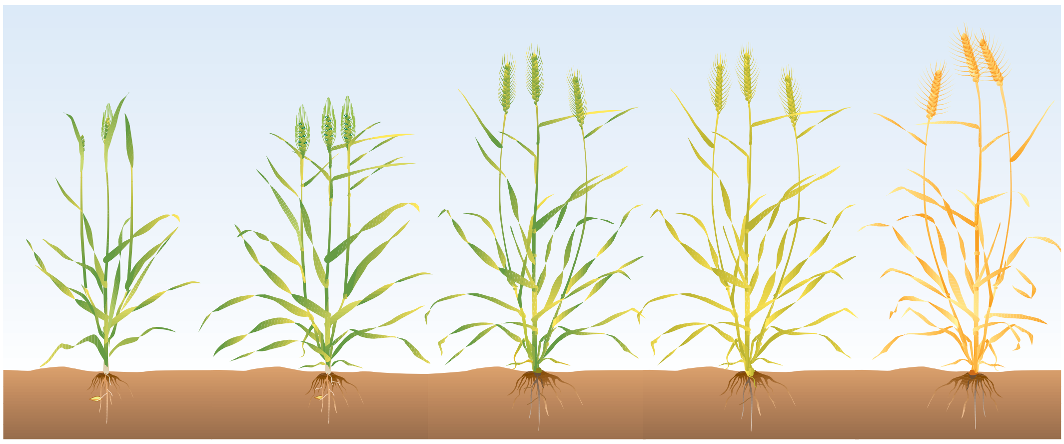
Within each of the 10 development phases there are 10 individual growth stages, for example, in the seedling stage:

- GS11 describes the first fully unfolded leaf
- GS12 describes two fully unfolded leaves
- GS13 describes three fully unfolded leaves
- GS19 describes nine 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) and, least significant difference (LSD), are used to measure the difference between the averages. 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		Average 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, take care 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.

MURRAY Local Land Services

What do we do?

Murray Local Land Services delivers services that add value to local industries, enhance natural resources, protect agriculture from pests and disease, and help communities prepare and respond to emergencies like fire and flood.

AGRICULTURAL PRODUCTION

Murray Local Land Services provides agricultural advice to assist farmers increase their productivity and profitability in an environmentally and socially sustainable way. We work closely with industry, producer groups and Landcare, to link farmers with research and practical information. Our specialisations include irrigation systems, cropping, pastures, livestock management, land capability and seasonal condition reporting.

BIOSECURITY & LIVESTOCK HEALTH

We provide biosecurity services relating to animal and plant pests and diseases including management, control and eradication; preparedness, response and recovery from animal and plant pest and disease emergencies; chemical residue prevention control and management; and movement of stock. This contributes to confidence in the safety of livestock and livestock products, international market access and environmental health.

TRAVELLING STOCK RESERVES & ROUTES

Our management of TSRs aims to balance the needs of travelling or grazing stock and the conservation of native species. Our work includes: authorising and monitoring stock movements, recreation and apiary site use; controlling noxious weeds, pest animals and insects; maintenance of fencing, watering points and holding yards.

NATURAL RESOURCE MANAGEMENT

We work with community, Landcare and industry groups to develop and deliver projects that improve the management of native vegetation, wetlands, flora and fauna habitat, water quality, and soil health, that underpin productive agricultural businesses and communities.

EMERGENCY MANAGEMENT

Murray Local Land Services works in collaboration with the Department of Primary Industries to manage livestock disease emergencies and biosecurity events involving plants, animals and pest insects such as locust plagues. We work alongside other agencies to provide vital support in emergencies where agricultural industries are impacted, such as floods and bushfire.

Australian Government | National Landcare Program

NSW GOVERNMENT

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www.lls.nsw.gov.au/murray

A word from the Chairman

Ian Trevethan
Chairman, Riverine Plains Inc

Welcome to the 2018 edition of *Research for the Riverine Plains*.

The year in review

The 2017–18 season was another unique year, with the wet season of 2016 seeing many growers head into 2017 with a full soil profile and a pocket full of optimism. The dry June, as well as the warm and dry September, saw lowest-on-record rainfall totals for many areas, which looked set to check yields significantly. Fortunately, plentiful rains across large parts of our membership area during the middle two weeks of October provided a late reprieve and turned the season for many. However, in the areas that missed out on the rain, or where the rain was too late to make a difference, particularly in the north, the season was particularly tough. Others too, were left lamenting the effect of late and severe frosts, with yields reduced and in a number of instances canola was cut for hay.

As ever, farming is a challenging game and our ability to respond to seasonal conditions depends on a number of things, not least our emotional and financial well-being. During tough times, when our stress levels are high, our decision-making ability can be compromised and we can also find ourselves feeling isolated or confused about what to do next. This is why being connected to groups such as Riverine Plains Inc is so important. Our extensive peer network and program of events and field days provide a social forum, as well as access to new ideas and quality information to help us navigate the tough seasons, as well as those curveball issues that can occur in any season. With that in mind, I encourage members to get along to as many events and field days as possible, or to make use of our great range of publications to stay informed.

Extension summary: Our 2017 extension program kicked off with several pre-sowing events, which helped focus our thoughts on the season ahead. An extension program of this size and scope requires a significant amount of support and I'd like to thank Extension subcommitttee chair Adrian Clancy, our Research and Extension Officer, Dr Cassandra Schefe, as well as all the subcommittee members for their behind the scenes efforts in running these events.

Harvest weed seed machinery tour: On 24 January 2017 a small group of growers joined a local tour looking at three different mechanical options for harvest weed control. The group saw home-made mechanical options for a) separating chaff and straw behind the header in readiness for baling and b) the collection of chaff in a chaff cart towed behind the header. The group also discussed the merits of adding a ready-made chaff deck to the header (to separate the chaff from straw) and placing the chaff in the wheel track for follow up herbicide control.

Sykesy's Buraja Meeting: The Buraja Recreation Reserve Hall was host to 100 growers and agribusiness representatives on 2 March 2017 for *Sykesy's Buraja Meeting*. This annual event continues a tradition started by the late John Sykes 'Sykesy' in providing a forum to discuss the season that was and to hear about varieties and agronomic information relevant to the year ahead. Issues relating to the 2016 season, wheat, barley, canola, pulses as well as grain marketing were discussed.

GRDC Grains Research Update: On 16 February 2017 more than 100 growers, advisers and agribusiness representatives attended the *GRDC Grains Research Update* held at Corowa. A number of high-profile speakers addressed a range topical issues for 2017, including the opportunities and challenges for continuous cropping systems, strategic tillage, Riverine Plains research in progress, living with the Russian wheat aphid, strategies to manage weed seed blowouts during 2017 and a report on the 2016 Riverine Plains Inc study tour to South America.

Soil pit day and nitrogen workshop: Boorhaman: On 23 March around 15 growers attended a soil pit day near Boorhaman. The pit was used as a backdrop to discuss the soil moisture results from nearby probes, the impact of soil type on water movement, and where the nitrogen went during 2016. This was followed by a discussion about the effects of the previous season and also how nitrogen strategies might be affected during 2017.

This event was supported by the North East Catchment Management Authority (NECMA), through funding from the Australian Government's National Landcare Program.

Nitrogen efficiency day: On 6 June 2017 around 40 people attended the nitrogen efficiency field day near Henty. The event featured FertCare calibration specialist Russell Nichol, who demonstrated how to calibrate three different fertiliser spreaders to improve the evenness of spread. Catch trays were used to collect urea spread from each machine, which was then weighed and the results graphed using specialised



computer software. After the test, the spreaders were adjusted with post-calibration testing showed all machines spread at a greater width and a more even distribution than pre-calibration.

A special presentation was made at lunchtime by Michael Straight, FAR Australia, on the results from the Australian Government's Department of Agriculture and Water Resources project *Management strategies for improved productivity and reduced nitrous oxide emissions.*

Farm safety workshops: Two farm safety workshops were held at Oaklands and Mulwala on 19 and 20 June 2017. The sessions covered a range of legislative issues regarding farm worker health and safety, with a focus on growers' primary duty of care under the *Workplace Health and Safety Act 2012*. The sessions were facilitated by Caroline Graham of Safe Ag Systems and were attended by around 50 people.

GRDC Farm Business Update: On 28 June 2017 Riverine Plains Inc hosted a *GRDC Farm Business Update* held in Yarrawonga/Mulwala. An audience of 80 heard farm business management information from a variety of industry experts. The range of topics included interest rates, enterprise risk and returns, the importance of a great team, superannuation changes and utilising depreciation offsets when buying land.

Farmer focus groups: The five-year GRDC-funded *'Stubble Project'* established four focus farms at Corowa, Henty, Yarrawonga and Dookie, with large, commercial-scale trials at each focus farm. The trials evaluated a range of stubble management options and paddock walks were held at each site during August and October 2017. The August paddock walks saw a total of 50 growers and agribusiness representatives attend across the four sites. The October paddock walks had a total of 45 participants attend across the four sites.

Soil pit workshop: On 22 September 2017 a series of soil pits were inspected in the Boorhaman/Rutherglen region. The 15 attendees looked at the 2017 season's soil moisture readings and the impact of soil type on water movement. This event was held as part of the *Soil Moisture Probe Network Project*, a partnership between Riverine Plains Inc and Boorhaman Landcare Group.

In-season Update: 75 growers and agribusiness representatives attended the *Riverine Plains Inc In-Season Update* held at Mulwala on 10 August 2017. The update provided information on the seasonal outlook, crop nutrition, pest management, canola agronomy and disease management, as well as precision agriculture. An update of the research projects conducted by Riverine Plains Inc was also presented.

Northern NSW study tour: 15 Riverine Plains Inc members went on a study tour of Northern NSW from 20–25 August 2017. The group visited the University of New England's (UNE) Smart Farm in Armidale to look at remote monitoring and virtual fencing, met with Matt Foster from GrazeAg to learn about pasture renovation and toured the BOSS Engineering Factory. The group also visited Beefwood farms to look at an autonomous Fendt tractor, Ian Gurley's farm to learn about how pooling grain with his neighbours is working to increase price, as well as the University of Sydney wheat breeding site. The group also attended the AgQuip field days and visited the DOW AgroScience site to look at chemical trials for some new broadleaf weed herbicide technology.

Powerline safety workshop: 35 people attended a powerline safety workshop on 26 September 2017. The key points of the day included farmer obligations under WHS legislation, identifying and addressing electrical safety risks, what to do in an emergency and ways to make powerlines and supporting structures more visible. The workshop was hosted by the Bourchier family in Oaklands.

Spring Field Day: On 28 September 2017 the Riverine Plains Inc Spring Field Day was held at the Riverine Research Centre (RRC) at Burramine. The Centre is a collaboration between Riverine Plains Inc and FAR Australia. A crowd of around 65 growers, sponsors, advisors and industry representatives attended the day and heard about the research being carried out at the RRC site, as well as fungicide resistance, management of early-sown wheat in terms of sowing date and grazing management as well as fertiliser use within the region.

Pulse Check Discussion Group: The first Riverine Plains Inc *Pulse Check Discussion Group* was held on 19 October 2017 at Dookie, attended by 30 growers and advisors. The group was established to have a focus on local lentil and chickpea production, with discussion about agronomic traits, fungicide and herbicide management, paddock selection, yield potential, desiccation and nitrogen fixation. Mitigating the increased fire risk associated with lentils and chickpeas was also discussed and attendees also inspected a crop of chickpeas.

The Evan Moll Gerogery Field Day: The *Evan Moll Gerogery Field Day* was held on 2 November 2017 and attended by around 70 people. Attendees were shown through the wheat and canola GRDC National Variety Trials and heard discussions on canola disease control, the importance of flowering dates and sowing windows to minimise frost

risk, new pasture grass varieties and their digestibility, as well as grain marketing. The field day was supported by Murray Local Land Services (LLS) through funding from the Australian Government's National Landcare Program.

Integrated Harrington Seed Destructor Demonstration: On 20 December 2017 35 people gathered at Culcairn to learn about the importance of harvest cutting height to achieve effective weed control at harvest. Graham Kotszur put the Integrated Harrington Seed Destructor (iHSD) through it's paces in a 5.5t/ha crop of Beckom wheat as part of the *Harvest weed seed control in the Southern Region* project — a GRDC investment led by Southern Farming Systems.

Research summary

High-quality farmer-driven research is a fundamental part of Riverine Plains Inc's mission and the Research subcommittee, along with our Research and Extension Officer Dr Cassandra Schefe, work exceptionally hard to manage our existing research and extension program, as well to as generate ideas for new projects. I'd like to thank Peter Campbell, the Chair of the research subcommittee as well as all subcommittee members for their efforts throughout the year. I'd also like to thank all of our farmer hosts for their ongoing work and support.

Riverine Plains Inc is continuing with a number of research and extension projects this year, though a number of projects are coming to an end on 30 June 2018.

During 2018, we start our trial work on the *Innovative approaches to managing subsoil acidity in the southern grain region* project, funded by NSW Department of Primary Industries with financial support from the GRDC.

We also continue with the GRDC investments; *Optimising crop nutrition in canola in the southern region of NSW* project as well as our involvement in the *Southern pulse extension project* through the *Riverine Plains Inc Pulse Check Discussion Group.*

However, 30 June 2018, sees the conclusion of a number of short and long-term projects. This includes the *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project. This GRDC investment commenced in 2013 as part of the *Maintaining Profitable Farming Systems with Retained Stubble Initiative* and has been a significant focus project for the group.

The GRDC investment *Harvest weed seed control in the Southern Region* project also ends at 30 June 2018.

So too does the *Sustainable Agriculture Victoria: Fast-tracking Ag innovation initiative* project, which has been made possible with the support of the Foundation for Rural and Regional Renewal (FRRR) together with the William Buckland Foundation. This project allowed for the production and promotion of the *Soil carbon in cropping systems* booklet to extend results from the *Increased soil carbon by accelerated humus formation from crop residues* project (2012–15). It also allowed for improved understanding of nitrogen processes, as well as the promotion of stubble management options and improving our media and print communications.

Other projects set to finish in 2018 include the *Improving fertiliser and chemical use through local, real time weather and soil information for farmers of the productive plains,* and the *Refining deep soil nitrogen testing to reduce environmental losses* projects*,* both supported by the Goulburn Broken Catchment Management Authority through funding from the Australian Government's National Landcare Program. The *Connecting fertiliser requirements with soil water storage and soil type in cropping systems* project, supported by North East Catchment Management Authority, through funding from the Australian Government's National Landcare Program, will also end.

Also concluding is the *Linking nutrient movement to soil moisture at weather stations in the Murray Region* project, supported by Murray Local Land Services and the *Linking nutrient movement to soil moisture at weather stations in the Riverina Region,* supported by Local Land Services which were both funded through the Australian Government's National Landcare Program. These projects saw the installation of several weather stations and moisture probes on farms across our NSW membership area and improved farmer understanding of local soil characteristics.

Riverine Research Centre (RRC)

During 2018, the RRC will again be hosting a range of research projects. This includes trials sown as part of the GRDC investment into the *Development of crop management packages for early sown, slow developing wheats in the southern region* project as well as trial research that forms part of the *National Frost Initiative*. The Centre will, for the first time, feature a Riverine Plains Inc variety sowing date evaluation of 10 wheat cultivars using late March–early April and late April–early May sowing dates. These trials, funded by Riverine Plains Inc working in collaboration with FAR Australia, will form the basis of a rapid results service to Riverine Plains Inc members on variety performance across the region, with results available to members within a week of harvest. The research builds on the 2017 work completed as part of the GRDC's *Development of crop management packages for early sown, slow developing wheats in the southern region* project, with a wider range of cultivars, including some that showed potential in the GRDC *Hyper-yielding cereal* project.

The RRC held a number of events and hosted numerous groups during 2017. I would like to acknowledge the efforts of our centre collaborators FAR Australia, and in particular Michael Straight and Nick Poole, for the impeccable presentation of the site during these visits and events, as well the exceptionally high quality of trial results generated from the site.

Funding partners

Riverine Plains Inc partners with a number of organisations in delivering our research and extension programs. I would like to recognise the ongoing support and investment made by our funding partners. We acknowledge the investments made by: the GRDC, the Foundation for Rural and Regional Renewal together with the William Buckland Foundation, the Australian Government's National Landcare Program, NSW DPI, as well as the support provided by Murray Local Land Services, Riverina Local Land Services, North East Catchment Management Authority and Goulburn Broken Catchment Management Authority.

Sponsors

Through their financial support, the businesses that sponsor Riverine Plains Inc play an important role in allowing us to deliver additional services to members. Our sponsors and their representatives are also tremendous supporters of our field days, seminars and other events and we sincerely value their presence and contributions at each event. Many of our sponsors have been with us for many years and I'd like to encourage our members to support the businesses that support farmers in our region.

Staff

On behalf of the committee and our members I would like to thank our staff for their work on behalf of Riverine Plains Inc. Our Executive Officer Fiona Hart, Finance Officer Kate Coffey, Research & Extension Officer Dr Cassandra Schefe and Communications Officer Michelle Pardy all work hard in their respective fields and their contributions to the organisation are greatly appreciated.

Committee

Riverine Plains Inc aims to promote excellence in farming systems by providing quality information, leading research and sharing ideas for the environmental, economic, and agricultural benefit of the Riverine Plains region. Our committee and various subcommittees provide direction for the research and extension programs, oversee all governance and financial management while also ensuring the needs and expectations of our members, sponsors and funders continue to be met. This is a huge task and I would like to thank all of the volunteer committee for their time, dedication and leadership.

Research for the Riverine Plains

This book is our flagship publication, and an enormous amount of effort goes into bringing you this research. Riverine Plains Inc is currently involved in a significant number of projects and for the first time, the 2018 edition of *Research for the Riverine Plains* solely includes articles written by Riverine Plains Inc, or by our project partners. This is significant as it represents the substantial and important local research the organisation brings to the region. The importance of these findings should not be under-rated as they will deliver improvements to our farming systems knowledge, which will benefit us in years to come.

Finally, I wish to thank Dr Cassandra Schefe for her role in writing articles and in the technical editing and also to Michelle Pardy, for her work in the collation and editing of these articles. Thanks also to Fiona Hart for her role in preparing the publication for print.

We trust you will enjoy the read and find value in the reports contained within. All the best for the 2018 season.

Ian Trevethan
Chairman

2017 — the year in review

Sue Briggs
Land Services Officer — Sustainable Agriculture
Murray Local Land Services

The 2017 season held many climate-related challenges for growers across the Riverine Plains region. Record-breaking dry conditions during June, successive frosts, higher-than-average temperatures during late September and an overall lack of rainfall combined to create a worrying set of circumstances for many.

There were 21 days with rainfall totals above 5mm, and half of those rainfall events occurred within the growing season months (April to October). Lack of rainfall at critical times, heavy rainfall during harvest and late frosts all contributed to variable crop performance.

Ideal start to the season

The wet 2016 season enabled many crops to be sown into moist soils. Season-breaking rainfall during late March, warm soil temperatures and an even germination meant most Riverine Plains region growers enjoyed a dream start to the cropping season. Timely follow-up rainfall during April contributed to the vigorous growth of early-sown crops. However, crops sown after the Anzac Day rain were slower to germinate due to the significant drop in soil temperature (Figure 1) that followed.

Nationally, June rainfall was the second lowest on record (the driest June on record was in 1940) and the lowest on record across most of the Riverine Plains region, with an average of 4mm falling for the month across Rand, Urana, Corowa and Henty (Figure 2).

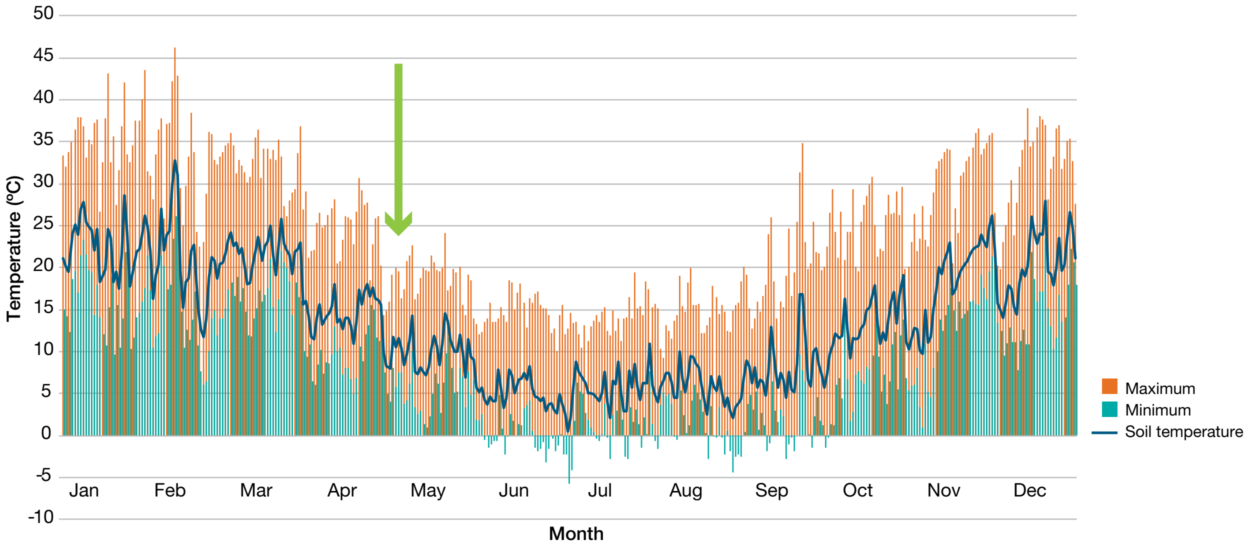

FIGURE 1 Minimum, maximum and calculated soil temperature for 2017 from the Rand on-farm weather station
Source: riverineplains.org.au

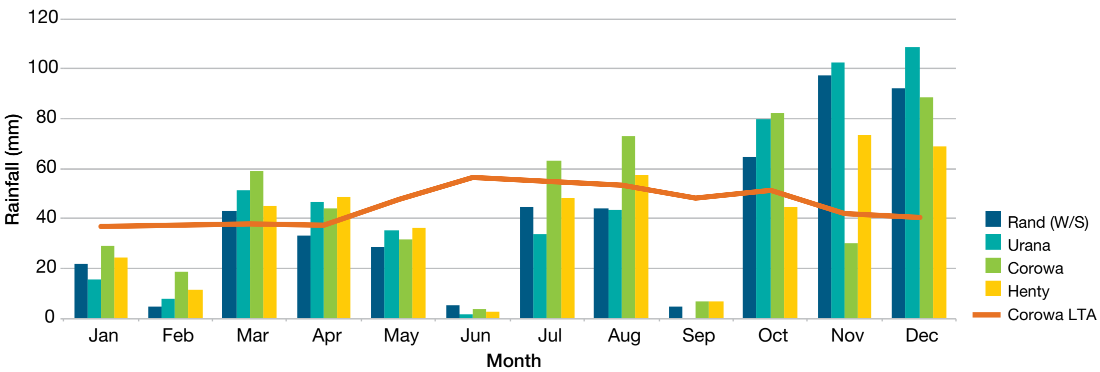

FIGURE 2 2017 monthly rainfall for Rand, Urana, Corowa and Henty, compared with the long-term rainfall average (LTA) for Corowa Airport (No. 74034)



The climatic conditions during June were influenced by higher-than-normal atmospheric pressure across southern Australia and westerly winds moving further south, leading to fewer cold fronts and low-pressure systems. These conditions initiated the record number of nights below zero, which saw the Corowa and Rand weather stations experience 25 June nights below 2°C.

The region continued to experience higher-than-average frosts per month for the rest of the year, as shown in Figure 3. Unfortunately, some parts of the region were heavily affected by frost later in the growing season, with three major frost events causing stem and head damage in cereals as well as flower and pod damage in canola.

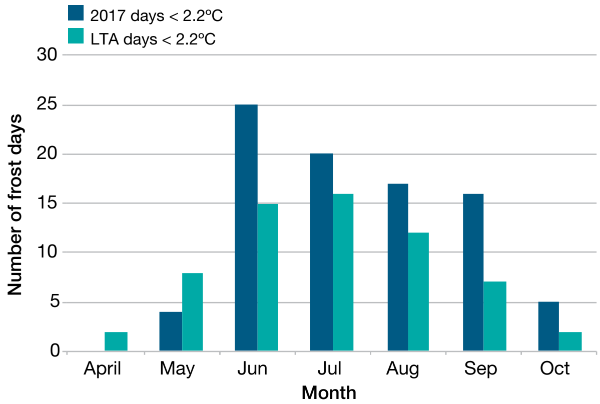

FIGURE 3 Number of frost days at Rand weather station compared with the long-term average (LTA)
Source: riverineplains.org.au

Despite the drier winter conditions, crops that started the season with full moisture profiles hung on. July and August rainfall arrived just in time to restore some confidence in the season.

"September maketh the crop" and similarly to June there was little to no rain during September, with most of the region receiving decile 1 to lowest-on-record rainfall. This, combined with high temperatures during late September, had growers wondering if the crops had enough soil moisture to get through to harvest. Figure 4 shows the crop at the site of the Rand weather station could still access and use soil moisture to a depth of around of 70cm. The dry conditions, combined with the impact of a late frost event, caused some growers to salvage their crops for hay.

Early October rainfall provided a timely boost for many crops. Late November (decile 7–8) rainfall contributed to a wet end to the year, with growers working around the clock to harvest wheat before the rain.

Wheat yields were generally higher than expected, given the dry winter and spring, and frost events. Wheat quality was generally high before the November rain, with high protein levels and minimal screenings. However, unharvested crops were impacted by the substantial rain event (up to 80mm in some parts of the region), which resulted in sprouting and downgrading of wheat to stockfeed quality.

High rainfall during December (decile 10 in some areas) refilled a much-depleted soil moisture profile and kick-started many lucerne stands. It also led to an early germination of summer weeds, such as heliotrope and hairy panic.

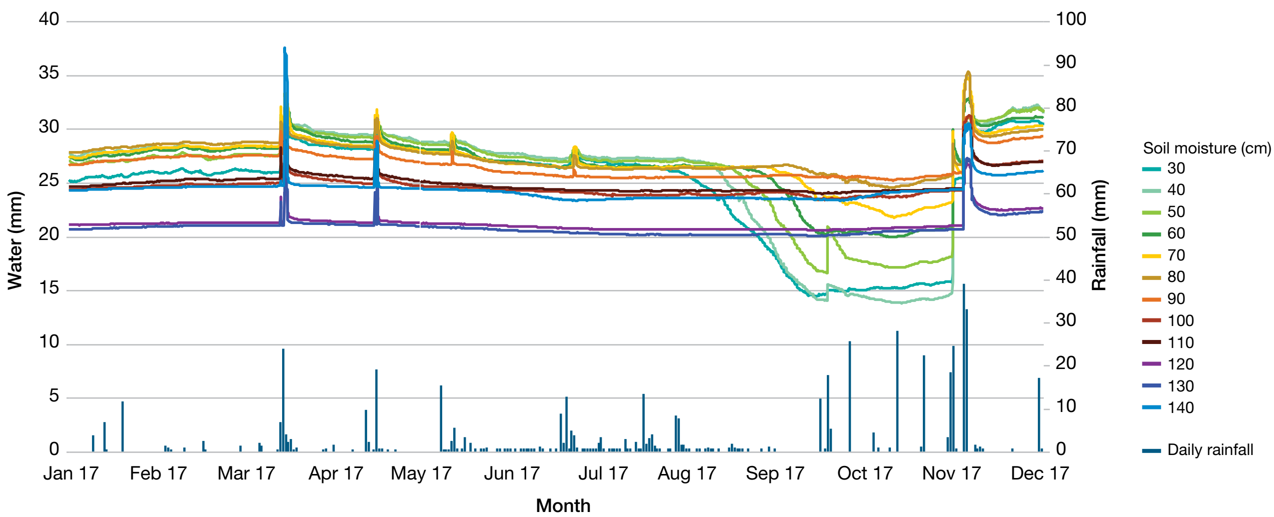

FIGURE 4 Rand soil moisture probe sensor readings showing moisture availability at different depths
Source: riverineplains.org.au

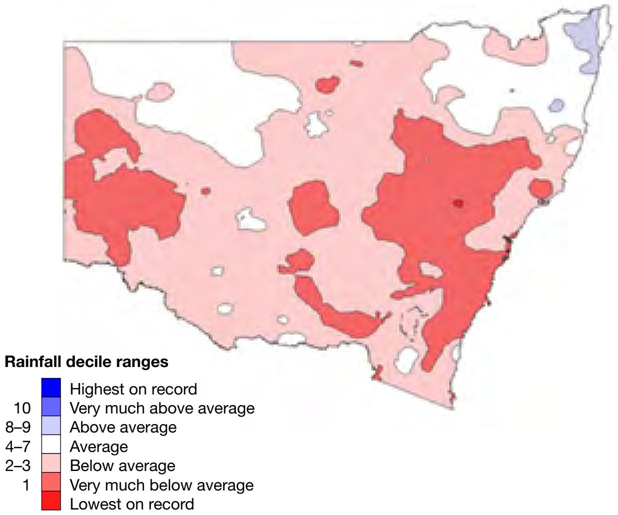

FIGURE 5 New South Wales rainfall deciles from 1 May to 31 October 2017
Distribution based on data from Australian Bureau of Meteorology

Overall, the region received average-to-below-average rainfall totals for the season, mainly as a result of the wet end to the year. However, during the six months from May to the end of October, the region received between decile 2–3 and decile 1 rainfall (Figure 5).

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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], Tracey Wylie[2]

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Introduction

The Maintaining profitable farming systems with retained stubble in the Riverine Plains region Project was managed by Riverine Plains Inc, and supported by FAR Australia, through an investment made 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 concluded in June 2018.

Objectives

The project sought to:

- investigate, demonstrate and extend cultural practices to 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 that haven't been carried out under a modern NTSR system, leaving a potential knowledge gap.

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 stubble retention practices over time, and that 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 per year 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

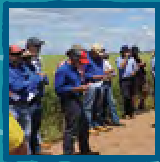
The research component of the Riverine Plains Inc *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project was comprised of a series of large and small plot trials. The first trials were established during 2014.

Using large-scale trials (focus farms) the research team evaluated the impact of a single-year, one-off change in stubble management. The result of these trials helped 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) have provided information on crop performance under a range of seasonal climatic conditions.

The focus farm trials in 2014 were located at Henty and Coreen/Redlands, New South Wales and Yarrawonga and Dookie, Victoria. In 2015, a site near Corowa was used rather than Coreen/Redlands, in order to maintain the same rotation position, moving back to Coreen in 2016. In 2017, the farm focus sites included Coreen, Yarrawonga and Dookie, with the Henty site discontinued due to variability.

As a key component of this project was to identify the long-term impact of a one-off change in management, the sites used in 2014 were returned to the farmer for commercial cropping, with new sites (in the same rotation position) established in 2015, 2016 and 2017. These are referred to as 'time replicate 1 (2014 sites)' 'time replicate 2 (2015 sites)', 'time replicate 3 (2016 sites) and 'time replicate 4 (2017 sites)'.

As 2017 was the fourth and final year of the project, the trial reports include both the experimental results from the 2017 trials, with selected yields also measured on the 2016, 2015 and 2014 sites, to understand if the change in stubble management has influenced the performance of the following commercial crop.



Locations of the 2017 large block (focus farm) trials

The range of 2017 Stubble project results from the large plot focus farm trials are presented from page 12 of this compendium and include evaluations of:

- the influence of stubble retention on in-canopy temperature and frost risk (Coreen, Yarrawonga and Dookie), (page 30);
- the interaction between stubble height and light interception in canola, (page 38); and
- nitrogen responses in different electromagnetic (EM) zones of the paddock (page 42).

The precision agriculture component of the 2017 Stubble project also evaluated in-paddock variability (page 54) as well as the economics of variable rate applications of nitrogen (page 66).

Outcomes

The overarching outcome from this project will be to increase the adoption of NTSR systems across the Riverine Plains region. Regional guidelines specific to the region have also been developed, which will aid in increasing the profitability and sustainability of NTSR cropping systems. These guidelines are available at riverineplains.org.au.

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

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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 project overview on page 10.

Method

Different methods of stubble management were trialled in four large (farm-scale) replicated trials during 2014, 2015, 2016 and 2017. 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.

As the trial sites are moved each year to reflect a one-off change in the system, each year of trials is referred to as a 'time replicate':

- 2014 trial site: time replicate 1
- 2015 trial site: time replicate 2
- 2016 trial site: time replicate 3
- 2017 trial site: time replicate 4.

After each year of field trials the site is returned to the farming co-operator and blanket-sown with a crop of their choice, as described in Table 1, Table 2, Table 3 and Table 4. At some sites the yield of the subsequent crop is also measured to determine whether a one-off strategic change has any long-term impacts through the rotation.

TABLE 1 Stubble management project trial details, 2017 (time replicate 4)

Trial details	Trial 1	Trial 2	Trial 3
	Coreen#	Yarrawonga	Dookie
NTSR* (control)	✓	✓	✓
NTSR + 40kg extra nitrogen at sowing	×	✓	×
Cultivated	One pass	One pass	One pass
Cultivated + 40kg N/ha at sowing	One pass	One pass	×
Burnt stubble	✓	✓	✓
NTSR — long stubble	×	39cm	39cm
NTSR — short stubble	×	14cm	18cm
NTSR — straw mown and removed	×	✓	✓
NTSR — stubble mulched and retained	×	×	×
NTSR — faba beans sown for forage	✓	×	×
NTSR — faba beans sown for grain	✓	×	×
Trial plot dimensions (m)	40 x 15	40 x 18	40 x 18
Farm drill used for trial	Aus seeder DBS D-300 tine seeder	Aus seeder DBS tine knife point	Simplicity seeder/knife point
Stubble loading (t/ha)	10.1	7.4	7.1
Stubble height (cm)	42	39	18
Soil type description	Loam over clay	Self-mulching red loam over grey clay	Red loam
Row spacing (cm)	30	32	33.3
Crop and rotation position	Second wheat	Second wheat	Canola

The site was relocated to a paddock near Daysdale in 2014, near Corowa in 2015 and near Coreen in 2016 and 2017 in order to maintain the required rotation position.
*No-till stubble retention (NTSR)



TABLE 2 Site details for 2017 crops sown onto 2016 stubble management trial sites (time replicate 3)

	Trial 1	Trial 2	Trial 3
Trial details	**Corowa#**	**Yarrawonga**	**Dookie**
Crop type/variety	Wheat/Whistler	Oats/Winteroo	Canola/Hyola 575
Paddock burnt	✓	✓	✓
Farmer harvested	✓	✓	✓
Plot harvester	×	×	×
Trial plot dimensions (m)	40 x 15	40 x 18	40 x 15
Farm drill used for trial	Aus seeder DBS D-300 tine seeder	Aus seeder DBS tine knife point	Simplicity seeder/knife point
Stubble loading (t/ha)	6.5	10.5	10.9
*Stubble height (cm)**	5	5	3
Soil type description	Loam over clay	Self-mulching red loam over grey clay	Red loam over clay
Row spacing (cm)	30	32	33.3
Crop and rotation position	Wheat following barley	Oaten hay following wheat	Canola following wheat

The site was relocated to a paddock near Daysdale in 2014, near Corowa in 2015 and near Coreen in 2016 and 2017 in order to maintain the required rotation position.

* Stubble height was measured in the retained stubble treatments at sowing time.

TABLE 3 Site details for 2017 crops sown onto 2015 stubble management trial sites (time replicate 2)

	Trial 1	Trial 2	Trial 3
Trial details	**Corowa#**	**Yarrawonga**	**Dookie**
Crop type/variety	Canola/Bonito	Wheat/Corack	Wheat/Trojan
Paddock burnt	×	×	×
Farmer harvested	✓	✓	✓
Plot harvester	×	×	×
Trial plot dimensions (m)	40 x 15	40 x 18	40 x 15
Farm drill used for trial	Aus seeder DBS D-300 tine seeder	Aus seeder DBS tine knife point	Simplicity seeder/knife point
Stubble loading (t/ha)	9.2	6.2	6.4
*Stubble height (cm)**	32	7	3
Soil type description	Red brown earth	Self-mulching red loam over grey clay	Red clay
Row spacing (cm)	30	32	33.3
Crop and rotation position	Canola following wheat	Wheat following canola	Wheat following canola

The site was relocated to a paddock near Daysdale in 2014, near Corowa in 2015 and near Coreen in 2016 and 2017 in order to maintain the required rotation position.

*Stubble height was measured in the retained stubble treatments at sowing time.

TABLE 4 Site details for 2017 crops sown onto 2014 stubble management trial sites (time replicate 1)

	Trial 1	Trial 2	Trial 3
Trial details	**Daysdale#**	**Yarrawonga**	**Dookie**
Crop type/variety	Wheat/Beckom	Wheat/Wedgetail	Chickpeas
Paddock burnt	×	✓	✓
Farmer harvested	✓	✓	✓
Plot harvester	×	×	×
Trial plot dimensions	40 x 15m	40 x 18m	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
Stubble loading (t/ha)	6.8	6.5	9.5
*Stubble height (cm)**	41	15	4
Soil type description	Heavy grey clay	Self-mulching red loam over grey clay	Red clay
Row spacing (cm)	30	32	33.3
Crop and rotation position	Wheat following canola	Wheat following canola	Chickpeas following Wheat

The site was relocated to a paddock near Daysdale in 2014, near Corowa in 2015 and near Coreen 2016 and 2017 in order to maintain the required rotation position.

* Stubble height was measured in the retained stubble treatments at sowing time.

Trial 1: Coreen, NSW

Sowing date: 18 May 2017
Rotation: Second wheat
Variety: Wheat cv Scepter, faba beans cv Samira
Stubble: Wheat (various treatments applied)
Stubble load at sowing: 10.1t/ha
Rainfall:
GSR: 273mm (April–October)
Summer rainfall: 107mm
Soil nitrogen at sowing: 58kg N/ha NTSR (control) (0–60cm)

Key points

- There were significant increases in dry matter (DM) accumulation, nitrogen (N) uptake and crop canopy greenness where second wheat was established following cultivation with additional nitrogen, however there was no yield benefit.
- Over four years of research (2014–17) at the Coreen focus farm there has been no benefit to either cultivating, burning or additional nitrogen at sowing with cultivation over the no-till stubble retention (NTSR) control.
- Growing a faba bean crop instead of a second wheat crop increased the yield of the following wheat by 0.34–0.47t/ha in 2016 and an average of 2t/ha in 2015, however there was no evidence that the legume benefit of the faba beans influenced canola sown two years later (in 2017).
- Burning first wheat stubbles before establishing second wheat has offered no yield benefit, despite indications of better tillering, higher DM and superior yellow leaf spot (YLS) control.

Results

i) Establishment and crop structure

There were no differences in crop establishment five weeks after sowing assessed at the three-leaf stage (GS13) (Table 5). Tiller numbers averaged less than three tillers per plant assessed at the start of stem elongation (GS30–31). Where stubbles were burnt or cultivated with extra nitrogen added, there were significantly more tillers than in the no-till stubble retention (NTSR) control and the cultivated blocks where no additional nitrogen had been added. The higher tiller number in the cultivated blocks with added nitrogen resulted in significantly more heads at harvest, however the higher head number in the burnt treatment was not significantly more than the NTSR control. Head numbers were particularly low in 2017 (mean of 298 heads/m^2) compared with 2016 (mean of 415 heads/m^2), with the 2017 results being similar to 2015 (mean of 306 heads/m^2).

TABLE 5 Plant counts 30 May 2017, one leaf stage (GS11); tiller counts 18 August 2017, start of stem elongation–first node (GS30–31) and head counts 27 November 2017, at physiological maturity (GS95)

	Crop growth stage		
	GS11	GS30–31	GS95
Treatment	Plants/m^2	Tillers/m^2	Heads/m^2
NTSR (control)	125^{a}	300^{c}	282^{ab}
Cultivated (one pass)	121^{a}	316^{bc}	269^{b}
Cultivated (one pass) + 40kg N/ha	123^{a}	364^{a}	323^{a}
Burnt	130^{a}	350^{ab}	316^{ab}
Mean	**125**	**333**	**298**
LSD	21	41	52

Figures followed by different letters are regarded as statistically significant.

ii) Dry matter production and nitrogen uptake

Plots that had been cultivated with additional nitrogen at sowing produced significantly more dry matter (DM) at first node (GS31) compared with both the NTSR (control) and burnt treatment. The cultivated stubbles with additional nitrogen and the burnt treatments also produced significantly more DM at mid-flowering (GS65) compared with the NTSR plots (Table 6). By harvest only the burnt treatment had significantly more DM production than the other treatments.

Similar trends were apparent in the nitrogen uptake figures at first node (GS31), with more nitrogen present in the cultivated plus 40kg N/ha compared with the burnt treatment and the NTSR control plots. At later assessments there was no difference in nitrogen content between the cultivated treatments and the NTSR control, however the burnt stubbles showed significantly higher nitrogen uptake (Table 7).

TABLE 6 Dry matter 9 August 2017, start of stem elongation–first node (GS30–31); 20 September 2017, flag leaf fully emerged (GS39); 9 October 2017, mid-flowering (GS65) and 27 November 2017, at physiological maturity (GS95)

	Dry matter (t/ha)			
Treatment	GS30–31	GS39	GS65	GS95
NTSR (control)	1.34^{b}	6.28^{b}	10.25^{b}	12.28^{b}
Cultivated (one pass)	1.34^{b}	6.70^{b}	9.74^{b}	11.84^{b}
Cultivated (one pass) + 40kg N/ha	1.88^{a}	8.15^{a}	11.67^{a}	12.45^{b}
Burnt	1.48^{b}	7.95^{a}	11.90^{a}	14.02^{a}
Mean	**1.51**	**7.27**	**8.27**	**12.65**
LSD	0.31	1.14	1.14	1.32

Figures followed by different letters are regarded as statistically significant.



TABLE 7 Nitrogen uptake in crop 9 August 2017, start of stem elongation–first node (GS30–31); 20 September 2017, flag leaf fully emerged (GS39); 9 October 2017, mid-flowering (GS65) and 27 November 2017, at physiological maturity (GS95)

Treatment	Nitrogen uptake in dry matter (kg N/ha)			
	GS31	GS39	GS65	GS95
NTSR (control)	65^{b}	156^{b}	120^{c}	130^{bc}
Cultivated (one pass)	60^{b}	148^{b}	141^{b}	135^{b}
Cultivated (one pass) + 40kg N/ha	89^{a}	215^{a}	167^{a}	116^{c}
Burnt	69^{b}	169^{b}	134^{bc}	151^{a}
Mean	**71**	**172**	**141**	**133**
LSD	12	23	15	14

Figures followed by different letters are regarded as statistically significant.

iii) Yellow leaf spot

Stubble management resulted in significant differences in yellow leaf spot (YLS) infection (Table 8) in the following wheat crop. Assessment at the start of stem elongation–first node stage (GS30–31) revealed that burning the stubbles gave over 90% control of YLS infection severity on flag-4 and flag-5 compared to the NTSR control. Cultivating the stubbles provided approximately 33–42% control of infection on the same leaf layers.

Disease progression was arrested by drier weather during late August and September and YLS did not move up the crop canopy onto the more important leaf layers — flag-1 and the flag itself. On 20 September at full flag leaf emergence (GS39) there were no differences in disease severity due to stubble management, with infection not exceeding 5% on the top three leaves (Table 9 and 10).

iv) Green leaf retention differences

The NTSR, burnt and cultivated plots were not as green at key assessment growth stages as where additional nitrogen had been added with cultivation; observations confirmed

TABLE 8 YLS severity and incidence assessed 9 August at start of stem elongation–first node stage (GS30–31) on flag-4 and flag-5

Treatment	YLS severity		YLS incidence	
	Flag-4	Flag-5	Flag-4	Flag-5
NTSR (control)	3.3^{a}	20.1^{a}	95.0^{a}	100.0^{a}
Cultivated (one pass)	2.2^{a}	12.7^{b}	90.0^{a}	100.0^{a}
Cultivated (one pass) + 40kg N/ha	2.2^{a}	11.4^{b}	87.5^{a}	100.0^{a}
Burnt	0.3^{b}	1.5^{c}	17.5^{b}	62.5^{b}
Mean	**2**	**11.4**	**72.5**	**90.6**
LSD	1.7	6.8	24.4	12.0

Figures followed by different letters are regarded as statistically significant.

TABLE 9 Yellow leaf spot severity assessed 20 September at full flag leaf emergence (GS39) on flag-1, flag-2 and flag-3

Treatment	YLS severity		
	Flag-1	Flag-2	Flag-3
NTSR (control)	0.45^{a}	4.7^{a}	19.6^{a}
Cultivated (one pass)	0.03^{b}	4.7^{a}	19.5^{a}
Cultivated (one pass) + 40kg N/ha	0.00^{b}	4.6^{a}	17.1^{a}
Burnt	0.00^{b}	3.1^{a}	12.9^{a}
Mean	**0.10**	**4.3**	**17.3**
LSD	0.4	3.1	9.3

Figures followed by different letters are regarded as statistically significant.

TABLE 10 Yellow leaf spot incidence assessed 20 September at full flag leaf emergence (GS39) on flag-1, flag-2 and flag-3

Treatment	YLS incidence		
	Flag-1	Flag-2	Flag-3
NTSR (control)	25.0^{a}	87.5^{a}	97.5^{a}
Cultivated (one pass)	2.5^{b}	100^{a}	100.0^{a}
Cultivated (one pass) + 40kg N/ha	0.0^{b}	100^{a}	100.0^{a}
Burnt	0.0^{b}	95.0^{a}	100.0^{a}
Mean	**6.90**	**95.6**	**99.4**
LSD	18.6	19.6	4.0

Figures followed by different letters are regarded as statistically significant.

by normalised difference vegetation index (NDVI) readings (Figure 1). The presence of stubble (brown vegetation) in the NTSR plots may have partly influenced earlier NDVI readings, compared with the burnt treatment readings. Crops established following cultivation plus additional nitrogen had higher NDVI values, which appear to be correlated to higher DM and nitrogen content up to the middle of flowering (GS65).

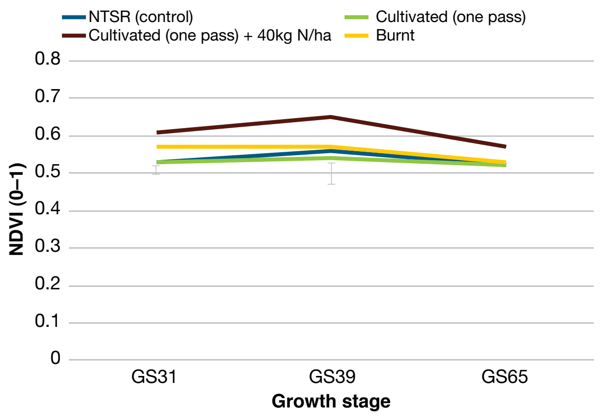


FIGURE 1 Influence of stubble management on wheat crop canopy NDVI assessed 9 August 2017, start of stem extension–first node (GS30–31); 20 September 2017, flag leaf fully emerged (GS39); 9 October 2017, mid-flowering (GS65)
Error bars presented as a measure of LSD

v) Yield and grain quality

The trial was harvested on 9 December 2017. While the cultivated plus 40kg N/ha treatment recorded greener crop canopies, higher head numbers and higher DM up to mid-flowering (GS65) this offered no significant yield benefit over the other stubble management treatments (Table 11). By way of contrast, the NTSR (control) recorded lower DM and lower head numbers but was significantly higher yielding than cultivated and burnt treatments. Therefore, for the fourth year in succession there were no significant yield advantages of any stubble treatments over the NTSR (control) at this site in the second-wheat rotation position. The only significant difference in grain quality was a lower protein level and fractionally higher screenings in NTSR control plots.

The faba beans harvested as forage and grain alongside the 2017 second wheat trial yielded 1.59t/ha.

vi) Four-year results (time replicates 1, 2, 3 and 4) — yield data 2014–17

For the past four years a replicated large block stubble management trial has been established in a different paddock on the Coreen focus farm. The trial set-up in 2014 (year one of the experiment) is referred to as the **time replicate 1** in the trial series, the trial set-up in year two is **time replicate 2**, in the third year it is **time replicate 3** and in the fourth year it is **time replicate 4**. After each trial has been completed the trial area reverts to being a commercial farm crop undergoing uniform management. The stubble management for all subsequent years has therefore been uniform across all trial plots and dictated by commercial farm operations. In each subsequent year the trial area has been revisited in order to assess any carryover yield effects of the stubble management treatments set up in year one on yields of the farm crop in the following years.

The results from this focus farm during the past four years show the rank order of stubble management treatments has been similar, with significant differences in yield only recorded during 2015 and 2017. During 2015 the cultivated stubbles plus 40kg N/ha significantly out-yielded the burnt treatment but not the NTSR control (Figure 2). In 2017 the NTSR control out-yielded all other stubble management treatments. While similar trends were observed during 2016, the yield differences were not significant. Despite the benefits of earlier DM production and early season disease control (yellow leaf spot) from burning, no yield advantage has been observed over the NTSR (control) at this trial site during the past four seasons of stubble management trials.

During the two higher-yielding seasons (2015 and 2016) there is an indication the additional nitrogen at sowing provided a benefit to the cultivation treatment, however this trend was not present during the years with lower yield potential, despite indicators of better growth. Overall, the benefit during the years of higher yield potential lead to a

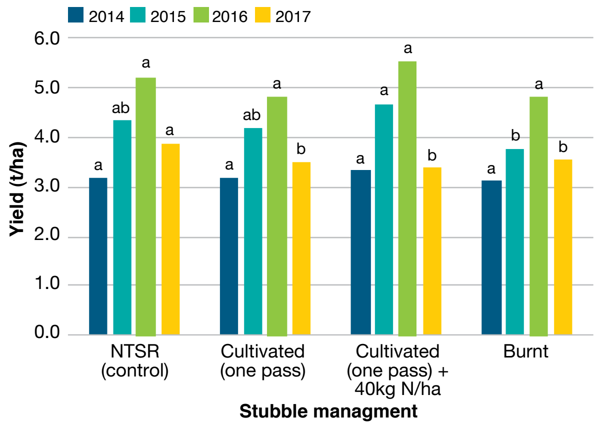


FIGURE 2 Yield data from time replicate trials 1, 2,3 and 4 — the Daysdale (red brown earth), Corowa (heavy grey clay), Coreen (loam over clay) and Coreen (loam over clay) trials for 2014, 2015, 2016 and 2017 — cv Whistler (wheat) in 2014, cv Mace (wheat) in 2015, cv Hindmarsh (barley) in 2016, cv Scepter (wheat) in 2017

Yield bars for the same year (same colour) with different letters are regarded as statistically different.

Note: The four trials were carried out on the same farm but not on the same trial site. During 2014 the cultivation treatments were established with two passes of a multidisc, while in 2015, 2016 and 2017 a single pass was used.

TABLE 11 Wheat yield, protein, test weight, screenings and thousand seed weight (TSW) 9 December 2017, at harvest (GS99)

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
NTSR (control)	3.88[a]	9.0[b]	77.9[a]	1.0[a]	43.2[b]
Cultivated (one pass)	3.50[b]	10.2[a]	78.0[a]	0.8[ab]	45.8[a]
Cultivated (one pass) + 40kg N/ha	3.37[b]	10.5[a]	77.9[a]	0.7[b]	46.1[a]
Burnt	3.54[b]	10.2[a]	77.8[a]	0.7[b]	46.3[a]
Mean	**3.57**	**10**	**77.9**	**0.8**	**45.4**
LSD	0.33	1.1	0.6	0.3	1.8

Figures followed by different letters are regarded as statistically significant.



trend for additional nitrogen to be beneficial if chopped cereal straw and stubble was incorporated, but in no single year was the difference statistically significant (Figure 3).

vii) 2015 stubble management treatments — influence on 2016 and 2017 yields

The stubble management trial has not only been set up to examine the influence of different stubble management techniques on the subsequent crop, but also to assess whether there are any rotational effects on following crops. For example, does burning or cultivating between the first and second wheat crop impact yield performance the year after the second wheat? Table 12 shows the performance of a commercial wheat crop (cv Trojan) sown during 2016 into the large block 2015 stubble management trial. As the faba bean crops sown in 2015 suffered from poor nodulation they do not represent an effective legume break crop. In 2017 the paddock was established to canola cv Bonito.

The stubble management treatments carried out during the 2015 trial (time replicate 2) did not significantly influence the following third wheat crop (cv Trojan), although there was a trend for crops established by cultivation or NTSR to yield more than crops following burning during 2016. During 2017 there was no evidence the different 2015 stubble management treatments influenced canola yields. Wheat yields following faba beans, which nodulated poorly, were 0.34–0.47t/ha higher yielding than a third continuous wheat crop, as compared with a 2t/ha advantage in the 2014 (time replicate 1) trial. These increases in wheat productivity one year after faba beans were not evident in the productivity of canola two years after faba beans.

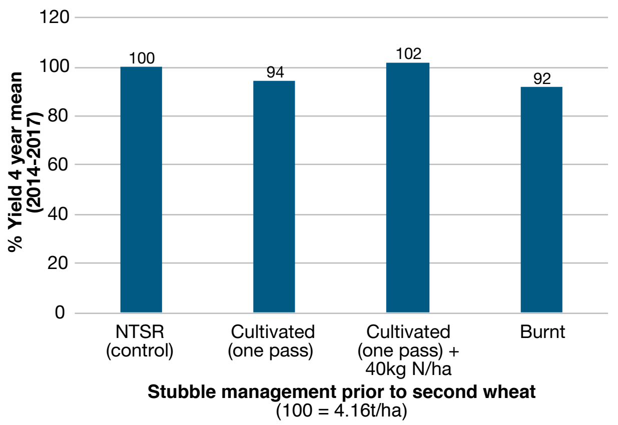


FIGURE 3 Influence of first wheat stubble management on the four-year yield mean percentage of the following wheat crop — Coreen, NSW 2014–17

TABLE 12 Effect of time replicate 2 trial on yield 2015, wheat yield 2016 cv Trojan and canola yield 2017 cv Bonito, Corowa, NSW

	2015	2016	2017
	Wheat and faba beans	Wheat	Canola
2015 stubble treatments	Yield (t/ha)	Yield (t/ha)	Yield (t/ha)
NTSR (control)	4.33[ab]	6.72[ab]	2.06[a]
Cultivated (one pass)	4.18[ab]	6.53[ab]	2.14[a]
Cultivated (one pass) + 40kg N/ha	4.69[a]	6.66[ab]	2.18[a]
Burnt	3.77[b]	5.90[b]	2.20[a]
Faba beans (green manure)	-	7.03[a]	2.09[a]
Faba beans (grain)	1.40*	6.96[a]	2.23[a]
Mean	**4.24**	**6.63**	**2.15**
LSD	0.67	0.82	0.29

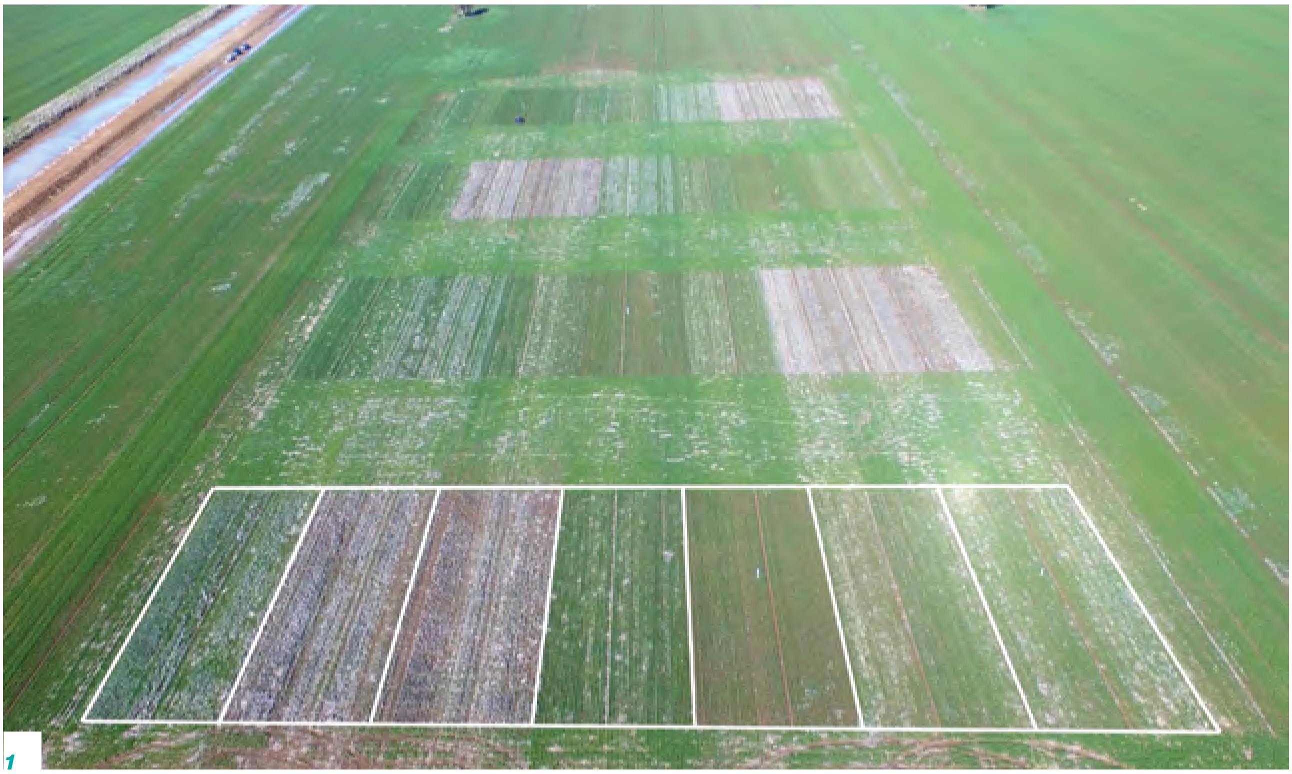
Figures followed by different letters are regarded as statistically significant.
* Beans not statistically analysed alongside wheat

The stubble management treatments carried out during the 2014 trial (time replicate 1) significantly influenced the following third wheat crop yield (cv Corack). However, the differences were relatively small in comparison to the influence of growing faba beans grown prior to wheat, which gave a 2t/ha advantage over the third wheat crop (Table 13). Unfortunately, the canola crop grown at the site in 2016 was subject to flooding, meaning that harvest was not possible.

TABLE 13 Effect of time replicate 1 trial on yield 2014 and wheat yield 2015 cv Corack, Daysdale, NSW

	2014	2015
	Wheat and faba beans	Wheat
2015 stubble treatments	Yield (t/ha)	Yield (t/ha)
NTSR (control)	3.17[a]	3.54[bc]
Cultivated (two pass)	3.18[a]	3.82[b]
Cultivated (two pass) + 40kg N/ha	3.31[a]	3.61[bc]
Burnt	3.10[a]	3.38[c]
Faba beans (forage)	6.68	5.62[a]
Faba beans (grain)	2.89	5.66[a]
Mean	**3.19**	**4.27**
LSD	0.53	0.39

Figures followed by different letters are regarded as statistically significant.
* Beans not statistically analysed alongside wheat
Note: 2016 canola crop was flooded and harvest was not possible.


1

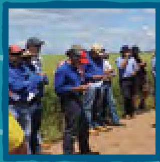

2


3

1 Coreen trial site on 9 August 2017, marked plots from left to right: NTSR (control), faba beans as grain, faba beans as mulched green manure, cultivated (one pass) + 40kg N/ha, burnt, cultivated as fire break (not analysed) and cultivated (one pass).

2 Faba beans (cv Samira) sown alongside second wheat stubble management treatments on 12 October 2017.

3 Wheat (cv Scepter) following burnt stubbles on 12 October 2017.



Trial 2: Yarrawonga, Victoria

Sowing date: 7 May 2017
Rotation: Second wheat
Variety: Corack
Stubble: Wheat (various treatments applied)
Stubble load at sowing: Long stubble 11.2t/ha, short stubble 11.1t/ha
Rainfall:
GSR: 270mm (April–October)
Summer rainfall: 88mm
Soil nitrogen at sowing: 63kg N/ha NTSR (control) (0–60cm)

Key points

- With heavy stubble loads as a result of the 2016 harvest (11t/ha) burning significantly increased second wheat DM production throughout the season and gave a 0.7t/ha yield increase over the NTSR control treatments.
- This is the first year there has been a significant yield advantage with burning. In previous years, with stubble loads of 4–8t/ha, the yield gains have been non-significant or negative (as was the case in 2015).
- The yield response to burning over the four years averaged 6% (range -6% to +20%) compared with NTSR — long stubble.
- With a higher yield potential in 2016, applying nitrogen at sowing significantly increased grain yield and protein when stubble was cultivated, but cultivation has shown no advantage at this research site unless more nitrogen was applied.
- Over the four years the average yield increase from additional nitrogen has been 6% with adding 40kg N/ha to cultivated wheat straw and 3% from adding it to standing straw in NTSR, potentially indicating more nitrogen tie up with chopped wheat stubble when it was incorporated compared with standing stubble.
- The small differential effects of stubble management in year one (time replicates 1 & 2) have not resulted in follow-on effects in commercial crops sown in the following two years at this focus farm.
- Across this project, none of the tested fungicide treatments came close to replicating the level of YLS control achieved by burning stubble.

Results

i) Establishment and crop structure

The NTSR — long stubble treatment significantly reduced plant establishment compared with treatments where stubble (straw) was removed or burnt. Reducing the stubble length in the NTSR — short stubble treatment gave significantly better establishment compared with NTSR — long stubble but establishment was still less than when stubbles were burnt (Table 14). Long stubble significantly reduced tillering recorded at the start of stem elongation (GS30) compared with where stubble height was reduced in the short stubble treatment, burnt or removed.

Overall tiller numbers were low in this trial, although there was a difference of 80 tillers/m^2 between the NTSR — long stubble treatment and the burnt treatment. This difference in tiller numbers was maintained through to harvest, with the burnt treatment having significantly more heads/m^2 than other stubble managements, with the exception of the NTSR — short stubble treatment. At harvest, although the NTSR — long stubble treatment produced the lowest head numbers (237 heads/m^2), there was no statistical difference to other treatments except burning, indicating lower levels of tiller mortality between the start of stem elongation (GS30) and harvest in this treatment.

ii) Dry matter production

The lower tiller number recorded with NTSR — long stubble (control) at the start of stem elongation (GS30) correlated to less DM accumulation at GS30 compared with the NTSR — short stubble and the burnt treatments. The burnt

TABLE 14 Plant counts, 24 May 2017, two leaves (GS12); tiller counts 19 July 2017, start of stem elongation (GS30) and head counts 17 November 2017, physiological maturity (GS95)

Treatment	Crop growth stage		
	Plants/m^2	Tillers/m^2	Heads/m^2
	GS12	GS30	GS95
NTSR — long stubble (control)	102^{c}	223^{c}	237^{b}
NTSR — long stubble + 40kg N/ha	108^{bc}	232^{bc}	249^{b}
NTSR — short stubble	115^{b}	293^{a}	271^{ab}
Straw removed	115^{b}	287^{ab}	247^{b}
Cultivated (one pass)	113^{b}	227^{c}	250^{b}
Cultivated (one pass) + 40kg N/ha	108^{bc}	266^{abc}	250^{b}
Burnt	127^{a}	303^{a}	295^{a}
Mean	**112**	**262**	**257**
LSD	11	60	33

Figures followed by different letters are regarded as statistically significant.

treatment produced significantly more DM throughout the season, however the difference between long stubble and short stubble treatments was not apparent after GS30; a result observed in previous years (Table 15). At the watery ripe grain assessment (GS71) the crop following burnt stubbles had a DM content just under 1t/ha more than the other stubble management treatments. At harvest (GS95) the burnt blocks had significantly higher DM than the NTSR and cultivated blocks. The lag in DM production in the NTSR — long stubble treatment compared with NSTR — short stubble treatment was not apparent at the harvest assessment, indicating later compensation in this treatment from flowering onwards. Cultivating the stubble significantly reduced the following crop DM at harvest compared with NTSR and burnt stubbles. The addition of 40kg N/ha significantly increased canopy DM at flag leaf emergence (GS39) in the NTSR — long stubble, though from flowering onwards there was no DM benefit to the additional nitrogen application.

The reduction in DM accumulation with NTSR — long and short stubble (controls) correlated to decreased nitrogen uptake in the crop canopy at full flag leaf emergence (GS39) compared with the burnt treatments (Table 16). The difference in nitrogen uptake between long and short stubble treatments was not significantly different at the start of stem elongation (GS30) despite there being significantly more DM following short stubble when assessed at the same growth stage. At physiological maturity (GS95) there were no differences in nitrogen uptake between the long and short stubble treatments, but the long stubble treatment had less nitrogen uptake compared with crops where straw was removed or burnt. The burnt stubble treatment had

TABLE 15 Dry matter 19 July 2017, start of stem elongation (GS30); 5 September 2017, flag leaf fully emerged (GS39); 13 October 2017, watery ripe grain (GS71) and 23 November, physiological maturity (GS95)

	Dry matter (t/ha)			
Treatment	**GS30**	**GS39**	**GS71**	**GS95**
NTSR — long stubble (control)	0.82[b]	2.57[c]	6.62[b]	7.80[b]
NTSR — long stubble + 40kg N/ha	0.82[b]	3.01[b]	6.72[b]	7.69[bc]
NTSR — short stubble	0.96[a]	2.88[bc]	6.86[b]	8.04[b]
Straw removed	0.88[ab]	3.01[b]	6.78[b]	8.03[b]
Cultivated (one pass)	0.88[ab]	2.94[bc]	6.59[b]	7.16[c]
Cultivated (one pass) + 40kg N/ha	0.89[ab]	2.76[bc]	6.65[b]	7.43[bc]
Burnt	0.98[a]	3.65[a]	7.44[a]	8.97[a]
Mean	**0.89**	**2.98**	**6.81**	**7.87**
LSD	0.12	0.43	0.45	0.62

Figures followed by different letters are regarded as statistically significant.

TABLE 16 Nitrogen uptake in biomass 19 July 2017, start of stem elongation (GS30); 5 September 2017, flag leaf fully emerged (GS39); 13 October 2017, watery ripe grain (GS71) and 23 November, physiological maturity (GS95)

	Nitrogen uptake in biomass (kg N/ha)			
Treatment	**GS30**	**GS39**	**GS71**	**GS95**
NTSR — long stubble (control)	43[bc]	72[b]	62[c]	87[c]
NTSR — long stubble + 40kg N/ha	43[bc]	79[b]	69[b]	94[ab]
NTSR — short stubble	46[abc]	70[b]	72[ab]	89[bc]
Straw removed	45[abc]	80[b]	69[ab]	94[ab]
Cultivated (one pass)	40[c]	76[b]	69[ab]	89[bc]
Cultivated (one pass) + 40kg N/ha	47[ab]	79[b]	73[a]	89[bc]
Burnt	50[a]	93[a]	68[b]	100[a]
Mean	**45**	**78**	**69**	**92**
LSD	6	12	5	7

Figures followed by different letters are regarded as statistically significant.

higher nitrogen uptake than all other stubble managements at harvest except for where straw was mown and removed. This indicates the presence of chopped straw reduced nitrogen uptake into the plant relative to those stubble management treatments where straw was mown and removed leaving just the stubble or no residue at all.

iii) Photosynthetically active radiation

During the past four seasons (2014–17) one of the most consistent effects of the stubble management treatments in NTSR systems has been the influence of stubble length on DM production. There is a consistent reduction in tillering and DM production in longer stubble. In part this appears to be linked with nitrogen availability and temperature, but as these factors could not completely explain this effect, in 2016 the research team looked, for the first time, at differences in light interception by the growing crop canopy; more accurately described as photosynthetically active radiation (PAR). The team assessed the influence of the different stubble management treatments on PAR during June 2017.

The results revealed reductions in PAR of approximately 50% in NTSR — long stubble compared with NTSR — short stubble when measurements were made at 3pm in the afternoon, however there was no difference in PAR when treatments were compared at 12pm midday (Figure 4). Although the PAR will be influenced by the Sun's zenith (high point in the sky), the results clearly show the ability to capture available sunlight is a key difference between long and short stubble treatments and could be the major factor in why there are fewer tillers and a lag in DM production with long stubble.



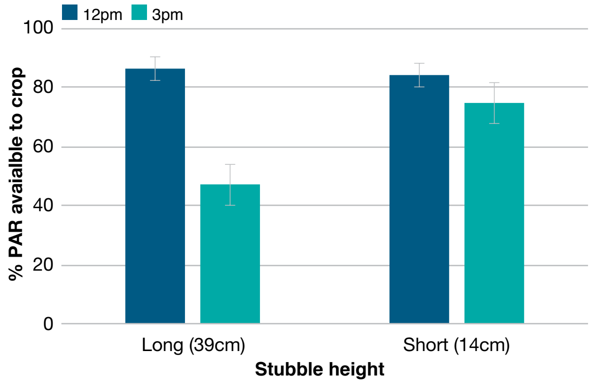


FIGURE 4 Influence of stubble treatment on availability of photosynthetically active radiation on 12pm 20 June 2017 (GS22) and 3pm on 28 June 2016 (GS23) at the Yarrawonga trial site

Error bars are a measure of LSD

Note: 20 June readings were taken at 12pm with the average above-canopy PAR measuring 865μmol/m²/s, in the 400–700nm waveband

28 June readings were taken at 3pm with the average above canopy PAR measuring 651μmol/m²/s¹, in the 400–700nm waveband

iv) Green leaf retention at the stem elongation and early grain-fill stages

At second node (GS32) and booting (GS45) the burnt and straw removed treatments resulted in higher NDVI crop canopy scores, a result that relates to higher nitrogen uptake in these treatments. The NDVI readings of the burnt plots were significantly higher than the NTSR — long stubble at early grain fill (GS71), but not if additional nitrogen was added to the NTSR treatment at sowing (Figure 5). All NDVI scores declined by the early grain fill stage (GS71) but cultivation with extra nitrogen, straw mown and removed and burnt stubble plots still gave higher NDVI readings than NTSR — short stubble and NTSR — long stubble treatments at this final assessment.

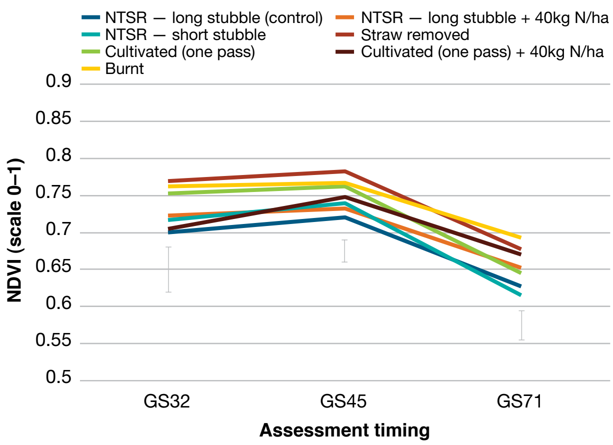


FIGURE 5 Influence of stubble management on resultant crop canopy NDVI (0–1 scale) assessed at stem elongation (GS32), booting (GS45) and early grain fill (GS71)

Error bars are a measure of LSD

v) Disease levels

With drier conditions prevailing from GS32 onwards, YLS did not progress in the crop canopy, however at the early second node assessment (GS32) burning gave significantly better YLS control on flag-3 and flag-4 than all of the other stubble management treatments. Burning stubble resulted in more than 90% control of YLS severity compared with NTSR — long stubble and NTSR — short stubble (Table 17). Removing the mown and chopped straw and leaving just stubble gave approximately 60% control, while adding 40kg N/ha to NTSR — long stubble resulted in approximately 55% control. Cultivating the soil (one pass) with or without additional nitrogen did not significantly reduce YLS infection.

At flag leaf emergence (GS39) on 6 September the influence of burning on levels of YLS was still apparent on flag-1, flag-2 and flag-3 (Table 18 and Table 19). Although the overall level of control had declined there was evidence that disease had increased on flag-3 between the two assessments. Burning the stubble before sowing was still giving 60–66% control of the disease severity on flag-3 and flag-2 at flag leaf emergence. Within this project, none of the tested fungicide treatments have come close to replicating the level of disease control achieved by burning.

These results on YLS infection are similar to results observed in previous years and in similar rotation positions at other sites.

vi) Grain yield and quality

The trial was harvested on 10 December 2017. There were statistical differences in grain yield and quality as a result of stubble management. Despite a lag in DM accumulation at early stem elongation (GS30) with the NTSR — long

TABLE 17 Yellow leaf spot severity and incidence assessed 16 August at early second node (GS32) on flag-3 and flag-4

Treatment	YLS severity		YLS incidence	
	Flag-3	Flag-4	Flag-3	Flag-4
NTSR — long stubble (control)	2.3^{a}	12.5^{ab}	72.5^{a}	97.5^{a}
NTSR — long stubble + 40kg N/ha	1.1^{c}	4.9^{bc}	85.0^{a}	97.5^{a}
NTSR — short stubble	2.1^{ab}	11.9^{ab}	87.5^{a}	100^{a}
Straw removed	1.0^{c}	5.9^{abc}	47.5^{b}	92.5^{a}
Cultivated (one pass)	1.1^{c}	13.2^{a}	70.0^{ab}	100^{a}
Cultivated (one pass) + 40kg N/ha	1.3^{bc}	10.9^{ab}	79.7^{a}	100^{a}
Burnt	0.1^{d}	0.9^{c}	7.5^{c}	52.5^{a}
Mean	**1.3**	**8.6**	**64.2**	**92.5**
LSD	**0.9**	8	**23.4**	17.3

TABLE 18 Yellow leaf spot severity assessed 6 September at flag leaf emergence (GS39) on flag-1, flag-2 and flag-3

Treatment	YLS severity		
	Flag-1	Flag-2	Flag-3
NTSR — long stubble (control)	0.9^{ab}	7.9^{a}	28.6^{ab}
NTSR — long stubble + 40kg N/ha	0.7^{abc}	9.9^{a}	30.6^{ab}
NTSR — short stubble	1.1^{a}	8.2^{a}	28.6^{ab}
Straw removed	0.4^{cd}	8.9^{a}	22.5^{b}
Cultivated (one pass)	1.1^{a}	7.4^{a}	32.5^{a}
Cultivated (one pass) + 40kg N/ha	0.6^{bc}	7.3^{a}	26.6^{ab}
Burnt	0.2^{d}	3.1^{b}	9.8^{c}
Mean	**0.7**	**7.5**	**25.6**
LSD	0.4	2.8	8.4

TABLE 19 Yellow leaf spot incidence assessed 6 September at flag-leaf emergence (GS39) on flag-1, flag-2 and flag-3

Treatment	YLS incidence		
	Flag-1	Flag-2	Flag-3
NTSR — long stubble (control)	62.5^{ab}	100.0^{a}	100.0^{a}
NTSR — long stubble + 40kg N/ha	40.0^{bc}	100.0^{a}	100.0^{a}
NTSR — short stubble	65.0^{a}	100.0^{a}	100.0^{a}
Straw removed	32.5^{cd}	97.5^{a}	100.0^{a}
Cultivated (one pass)	50.0^{abc}	100.0^{a}	100.0^{a}
Cultivated (one pass) + 40kg N/ha	45.0^{abc}	100.0^{a}	100.0^{a}
Burnt	15^{d}	77.5^{b}	100.0^{a}
Mean	44.3	96.4	100
LSD	23.7	9.9	-

stubble treatment, there was no difference in yield between long and short stubble treatments (Table 20). There was a yield advantage associated with straw removal, burning and adding 40kg N/ha additional nitrogen to the cultivated treatment, however it was the burnt treatment that significantly increased yield in this trial by 0.69–0.70t/ha compared with the NTSR — short stubble treatment. This increase in yield led to a significant decrease in grain protein (approximately 1%) in the burnt treatment compared with the other treatments. In 2016, burning the previous wheat crop residues gave a small, non-significant yield increase (4–5%) over all NTSR treatments, however in 2017 the residue burden at sowing was approximately 11t/ha compared with 4.5t/ha in 2016. Cultivation produced no yield benefits over the NTSR — long stubble (control) treatment and was the lowest yielding treatment in the trial, unless additional nitrogen was applied at sowing.

There were no significant differences in harvest index (HI — the proportion of final DM that is grain).

vii) Four-year results (time replicates 1, 2, 3 and 4) — yield data 2014–17

The stubble management trial has been established in the same crop rotation position (second wheat) on different paddocks during the past four years at the Yarrawonga focus farm. There have been only a few significant yield effects associated with stubble management over the four years of trials. In 2017, yields were significantly higher where the previous wheat residues were burnt compared with NTSR. With higher yield potential in 2016, additional nitrogen applied at sowing significantly increased the yield of crops following NTSR — long stubble and one-pass cultivation, however when the influence of additional nitrogen was removed, there were no significant differences in yield between burning, cultivating and removing straw, compared with NTSR (Figure 6).

Although burning has increased DM production in all four years, it was only in 2017 that it generated a statistical (0.7t/ha) yield advantage over NTSR, with only a small (3–5%), non-significant yield benefits in previous years. The significant yield benefit associated with burning in 2017 can be attributed to the high residue levels (approximately 11t/ha) carried over from the 2016 harvest. In 2015 the harder finish resulted in residue levels of 4.5t/ha and saw the burnt treatment yield significantly less than the NTSR — short stubble treatment, with the greater biomass of the burnt treatment possibly a disadvantage in such a dry season. In 2016 and 2014, there was no difference between the burnt and the NTSR treatments.

If the four year means were expressed as a percentage with NTSR — long stubble set at 100 for the four years, burning at this site has generated a 6.0% yield increase over those years (Figure 7), however only in 2017 were the differences statistically significant. If straw was removed, leaving just the stubble, the yield difference was only 1.5%. Over the four years the average yield increase from 40kg N/ha of additional nitrogen applied at sowing was 6.3% where chopped straw was cultivated with one pass. Yield only increased 3% where the same dose of nitrogen was applied to NTSR — long stubble, indicating potentially greater tie up of nitrogen when chopped straw is cultivated. The need for additional nitrogen was particularly noticeable during 2016 when yield potential was higher.



TABLE 20 Wheat yield, protein, test weight, screenings, harvest index (HI) and thousand seed weight (TSW) 10 December 2017, at harvest (GS99)

Treatment	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)	HI (%)
NTSR — long stubble (control)	3.39[b]	11.9[a]	76.1[a]	0.3[a]	44.7[a]	37.9[a]
NTSR — long stubble + 40kg N/ha	3.52[b]	11.6[a]	76.3[a]	0.2[a]	44.8[a]	40.5[a]
NTSR — short stubble	3.38[b]	11.5[a]	76.4[a]	0.2[a]	45.3[a]	36.3[a]
Straw removed	3.65[ab]	11.3[ab]	76.6[a]	0.2[a]	44.1[ab]	38.8[a]
Cultivated (one pass)	3.14[b]	11.3[ab]	76.3[a]	0.2[a]	45.3[a]	39.7[a]
Cultivated (one pass) + 40kg N/ha	3.56[ab]	11.4[a]	76.5[a]	0.2[a]	45.0[a]	43.2[a]
Burnt	4.08[a]	10.7[b]	76.2[a]	0.2[a]	42.4[b]	40.3[a]
Mean	**3.53**	**11.4**	**76.3**	**0.24**	**44.5**	**39.5**
LSD	0.56	0.7	0.6	0.1	2.2	7.7

Figures followed by different letters are regarded as statistically significant.

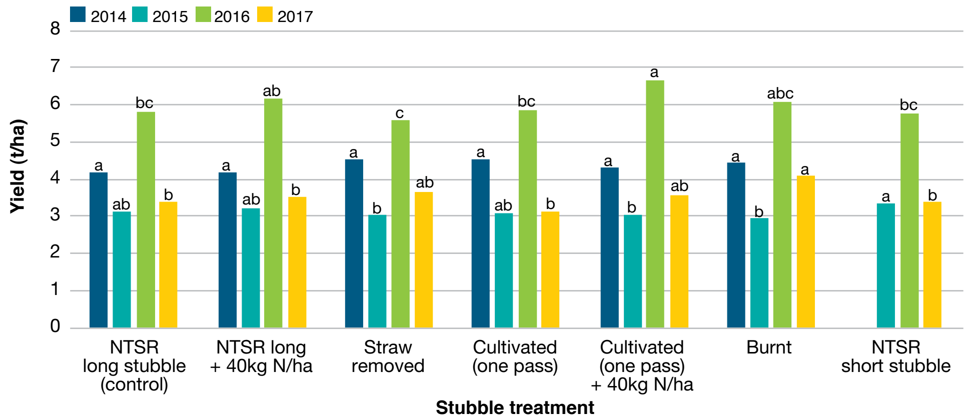


FIGURE 6 Yield data from the four Yarrawonga trials for 2014, 2015 (cv Young), 2016 and 2017 (cv Corack)

Note: The NTSR — short stubble was not part of the 2014 list of treatments.

Yield bars across treatments for the same year (same colour) with different letters are regarded as statistically different.

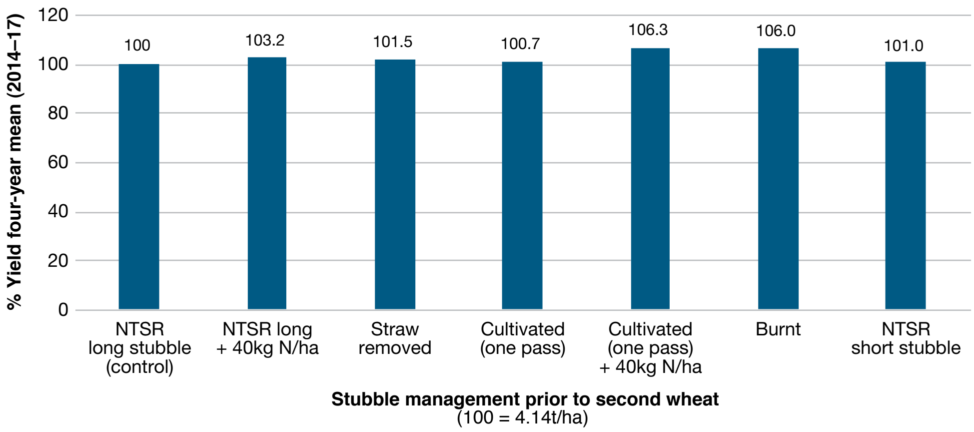


FIGURE 7 Influence of first wheat stubble management on the four-year yield mean percentage of the following second wheat crop — Yarrawonga, Victoria 2014–17

(NTSR — short stubble treatment evaluated for three years from 2015–17)

viii) 2015 stubble management treatments — influence on 2016 and 2017 yields

Different stubble management treatments established pre-sowing during 2015 resulted in significant differences in wheat yields during 2015, with the NTSR — short stubble treatment significantly increasing wheat yields compared with straw removal and burning. However, these treatment effects did not follow through to have any effect on the yield of a commercial crop of canola sown across the 2015 site during 2016 or the following wheat crop sown across the site in 2017 (Table 21).

TABLE 21 Effect of time replicate 2 trial on wheat yield 2015 cv Young, canola yield 2016 cv Bonito and wheat yield 2017 cv Trojan, Yarrawonga, Victoria

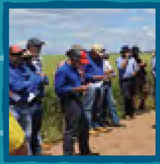
	2015	2016	2017
	Second wheat	Canola	Wheat
2015 stubble treatments	**Yield (t/ha)**	**Yield (t/ha)**	**Yield (t/ha)**
NTSR — long stubble (control)	3.13^{ab}	2.76^{a}	4.25^{a}
NTSR — long stubble + 40kg N/ha	3.20^{ab}	2.73^{a}	3.97^{a}
NTSR — short stubble	3.35^{a}	2.84^{a}	4.20^{a}
Straw removed	3.03^{b}	2.72^{a}	4.13^{a}
Cultivated (one pass)	3.10^{ab}	2.75^{a}	4.03^{a}
Cultivated (one pass) + 40kg N/ha	3.05^{b}	2.69^{a}	4.01^{a}
Burnt	2.93^{b}	2.73^{a}	4.07^{a}
Mean	**3.11**	**2.74**	**4.10**
LSD	0.29	0.42	0.36

Figures followed by different letters are regarded as statistically significant.
Note: All blocks were burnt before the 2016 crop

1 Yarrawonga trial site on 29 May 2017, marked plots in view from left to right are: NTSR — long stubble, NTSR — short stubble, NTSR — long stubble + 40N and cultivated (one pass)

2 Long stubble 13 October 2017.

3 Short stubble 13 October 2017.



Trial 3: Dookie, Victoria

Sowing date: 20 April 2017
Rotation: Canola following wheat
Variety: ATR Stingray (early-maturing triazine-tolerant variety)
Stubble: Wheat (various treatments applied)
Stubble load at sowing: 7.1t/ha
Rainfall:
GSR: 281mm (April–October)
Summer rainfall: 82mm
Soil nitrogen: 58kg N/ha control NTSR, (0–60cm)

Key points

- A growing season rainfall (GSR) of 281mm resulted in average canola yields of 3.76t/ha.
- Reducing stubble length in NTSR, burning and removing wheat straw treatments significantly increased canola DM production at the greenbud stage (GS3.3) compared with NTSR — long stubble, despite there being no differences in plant establishment due to stubble management.
- The significant reduction in DM in NTSR — long stubble was associated with a delay in the onset of flowering, which was statistically significant.
- The delay in crop development associated with longer stubble length was also observed in wheat at this site during 2015.
- Though there was a trend for the burnt and straw removed treatments to increase DM production compared with NTSR — long stubble, there was no difference in yield among any of the treatments at harvest.
- Across the four years of the trial 2014–17, NTSR — long stubble has reduced early DM production in all four years, however it has only significantly reduced final grain yield during 2014 (0.7t/ha decrease).
- The significant wheat yield reduction in 2014, due to long stubble, resulted in a significant increase in canola yields during 2015.
- The influence of stubble management treatments set up in 2015 (time replicate 2) did not affect the yield of the two subsequent commercial crops; canola in 2016, wheat in 2017.

Results

i) Establishment and crop structure

Neither burning, cultivating or removing the previous wheat straw resulted in any advantage in the following canola establishment over the NTSR control treatments. The average establishment was 52 plants/m^2 with a range in plant population of between 49–56 plants/m^2. There were no differences in crop vigour assessed at the five leaf stage of development (GS1.05) and no difference in stems/m^2 at first flower stage (GS4.1) (Table 22).

NTSR — long stubble significantly delayed the onset of flowering in canola relative to the other establishment treatments (Table 23), a feature also noted in wheat trials at this site during 2015.

i) Dry matter production and nitrogen uptake in the crop canopy

The NTSR — long stubble treatment had produced significantly less DM at the green bud stage in early stem elongation (GS3.3) compared with the NTSR — short stubble and where straw or straw and stubble had been completely removed or burnt (Table 24). At the flowering (GS4.5) and pod fill (GS5.5) stages the DM accumulation with NTSR — long stubble remained significantly lower than either the burnt treatment at flowering (GS4.5) or

TABLE 22 Plant counts and vigour 30 May 2017, five leaf stage (GS1.05) and stem counts 25 July 2017, first flowers opened (GS4.1)

	Plants/m^2	Vigour	Stems/m^2
Treatment	GS1.05	GS1.05	GS4.1
NTSR — long stubble	56^{a}	8.5^{a}	119^{a}
NTSR — short stubble	49^{a}	8.5^{a}	110^{a}
Cultivated (one pass)	49^{a}	9.0^{a}	101^{a}
Straw removed	52^{a}	8.3^{a}	115^{a}
Burnt	53^{a}	8.5^{a}	112^{a}
Mean	**52**	**8.6**	**112**
LSD	8	1.4	26

Figures followed by different letters are regarded as statistically significant.

TABLE 23 Flowering scores, percentage of plot with flowers opened 21 July 2107, first flowers opened (GS4.1)

	Flowering score
Treatment	(%)
NTSR — long stubble	2^{b}
NTSR — short stubble	13^{a}
Cultivated (one pass)	13^{a}
Straw removed	15^{a}
Burnt	17^{a}
Mean	12
LSD	6

Figures followed by different letters are regarded as statistically significant.

TABLE 24 Dry matter 4 July 2017, green bud (GS3.3); 17 August 2014, 50% of all buds on raceme flowering or flowered (GS4.5); 17 September 2017, 50% of potential pods on raceme more than 2cm long (GS5.5), and 9 November 2017, most seeds black but soft (GS6.7)

Treatment	Dry matter (t/ha)			
	GS3.3	GS4.5	GS5.5	GS6.7
NTSR — long stubble	1.40^{b}	4.09^{b}	5.36^{b}	8.10^{a}
NTSR — short stubble	1.70^{a}	4.31^{ab}	5.70^{ab}	8.11^{a}
Cultivated (one pass)	1.64^{ab}	4.33^{ab}	5.44^{ab}	8.20^{a}
Straw removed	1.78^{a}	4.59^{ab}	5.89^{a}	9.08^{a}
Burnt	1.72^{a}	4.65^{a}	5.80^{ab}	8.55^{a}
Mean	**1.65**	**4.39**	**5.64**	**8.41**
LSD	0.26	0.54	0.49	1.08

Figures followed by different letters are regarded as statistically significant.

straw removed treatment at pod fill (GS5.5). Although there was a trend for DM accumulation in the NTSR — long stubble to be lower than other treatments, the difference was not significant. While the short stubble treatment tended to produce more DM than long stubble during the flowering and pod-fill period, these differences were not statistically significant, with no difference between the two treatments at physiological harvest when most seeds are black but soft (GS6.7); a result frequently noted in previous years. There were no significant DM differences among the treatments at harvest, although the trend for DM to be higher where straw was removed was observed at the final assessment.

The lower DM production under the NTSR — long stubble treatment compared with other treatments also equated to lower nitrogen uptake in the canopy at seed ripening (GS6.7). Nitrogen uptake at seed ripening (GS6.7) was significantly greater in the cultivated and straw removed treatments, compared with the burnt and NTSR treatments (Table 25).

TABLE 25 Nitrogen uptake in dry matter 4 July 2017, green bud (GS3.3); 17 August 2014, 50% of all buds on raceme flowering or flowered (GS4.5); and 9 November 2017, most seeds black but soft (GS6.7).

Treatment	Nitrogen uptake (kg N/ha)		
	GS3.3	GS4.5	GS6.7
NTSR — long stubble	76^{ab}	111^{b}	68^{b}
NTSR — short stubble	84^{a}	101^{b}	77^{b}
Cultivated (one pass)	69^{b}	102^{b}	93^{a}
Straw removed	73^{ab}	108^{b}	91^{a}
Burnt	75^{ab}	136^{a}	77^{b}
Mean	**75**	**112**	**81**
LSD	15	14	11

Figures followed by different letters are regarded as statistically significant.
Note: DM samples taken on 17 September were damaged after weighing and it was not possible to undertake nitrogen sampling

iii) Yield and grain quality

The trial was harvested on 20 November 2017 with an average yield of 3.76t/ha and an average oil content of 46%. There were no significant differences in yield at this site, with treatments yielding between 3.70–3.85t/ha (Table 26). The significant 0.3t/ha difference in DM measured at green bud (GS3.3) between the NTSR — short stubble and NTSR — long stubble treatments resulted in a 0.05t/ha difference in yield, which was not significant (3.70 vs 3.75t/ha). There was no advantage to burning or removing straw, despite advantages in DM content at flowering and pod fill.

iv) Four-year results (time replicate 1, 2, 3 and 4) — yield data 2014–17

For the past three years a replicated large block stubble management trial has been established in a different paddock on the Dookie focus farm. The trial has on each occasion been established following a first wheat crop. The trial set up in 2014 (year one of the experiment) is referred to as **time replicate 1** in the trial series, the trial set up in year two is **time replicate 2** and in the third year it is **time replicate 3**. The 2017 trial was set up in the fourth year of the project and is referred to as **time replicate 4.**

After each trial has been completed, the trial area reverts to being a commercial farm crop undergoing uniform management. The stubble management for all subsequent years has been uniform across the trial area and dictated by commercial farm operations. In each of the subsequent years the trial area has then been remarked in order to assess any yield effects of stubble management set-up in year one on yields in year two and three farm crops.

The yield results from each time replicate trial at the Dookie focus farm have shown only one significant yield difference due to stubble management over the four years the trial has run. In the 2014 trial the NTSR — long stubble (45cm) treatment significantly reduced yield by an average of 0.7t/ha, compared with other treatments, including NTSR — short stubble treatment. This equates

TABLE 26 Canola yield, 20 November 2017, at harvest

Treatment	Yield (t/ha)
NTSR — long stubble	3.70^{a}
NTSR — short stubble	3.75^{a}
Cultivated (one pass)	3.85^{a}
Straw removed	3.74^{a}
Burnt	3.74^{a}
Mean	**3.76**
LSD	0.17

Figures followed by different letters are regarded as statistically significant.
Note: The crop in the trial area had an average oil content of 46%

to a yield reduction of 0.25t/ha for every 10cm increase in stubble height above 15cm, assuming it is a linear response between yield and stubble height (Figure 8).

Although a significant yield reduction associated with long stubble was only observed in 2014, there has been evidence in all four years that long stubble has significantly decreased DM production, resulting in slower development, reduced tillering (in wheat) and reduced crop canopy greenness. During the 2015–17 seasons, this reduction in DM accumulation has been reversed later in the season, with NTSR — long stubble treatments producing similar yields to those treatments where straw was removed before sowing.

With four year means expressed as a percentage and NTSR — long stubble set at 100, burning at this site has generated an average yield increase of 8.1% over the four years, however only in 2014 was the advantage over NTSR — long stubble statistically significant (Figure 9). In the same year burning was not statistically better than NTSR — short stubble. If straw was removed, leaving just only the stubble, the yield difference over NTSR — long stubble was an average 4.6%.

v) 2015 stubble management treatments — influence on 2016 and 2017 yields

The 2015 stubble management trial at the Dookie focus farm was sown to a commercial crop of canola during 2016 and wheat during 2017. The 2015 second wheat trial stubbles were burnt in preparation for the commercial canola crop, but for the 2017 wheat crop a uniform method of establishment was applied using NTSR with canola stubbles crunched. Despite large visual differences in crop appearance in 2015, with NTSR — long stubble plots being greener (*Research for the Riverine Plains 2016, p22*) and slightly less developed, there were no yield differences due to stubble management treatments in the 2015 trial sown to wheat. Neither were there yield differences in the following canola (2016) or wheat (2017) crops sown over the 2015 stubble treatments (Table 27).

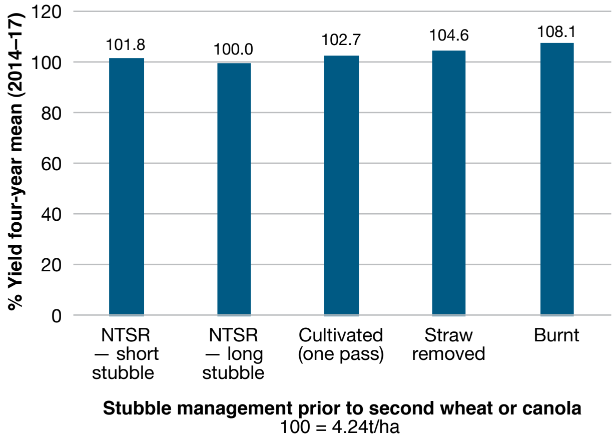


FIGURE 9 Influence of first wheat stubble management on the four year yield mean (%) of the following second wheat crop (2014–16) and canola (2017) — Dookie, Victoria 2014–17

TABLE 27 Effect of time replicate 2 trial on wheat yield 2015 cv Mace, canola yield 2016 cv Bonito and wheat yield 2017 cv Trojan, Dookie, Victoria

2015 stubble treatments	2015	2016	2017
	Second wheat	Canola	Wheat
	Yield (t/ha)	Yield (t/ha)	Yield (t/ha)
NTSR — long stubble	2.41[a]	2.6[a]	4.77[a]
NTSR — short stubble	2.52[a]	2.6[a]	5.30[a]
Cultivated (one pass)	2.39[a]	2.7[a]	5.55[a]
Straw removed	2.32[a]	2.6[a]	4.99[a]
Burn	2.49[a]	2.5[a]	5.46[a]
Mean	**2.42**	**2.6**	**5.21**
LSD	0.22	0.2	0.92

Figures followed by different letters are regarded as statistically significant.

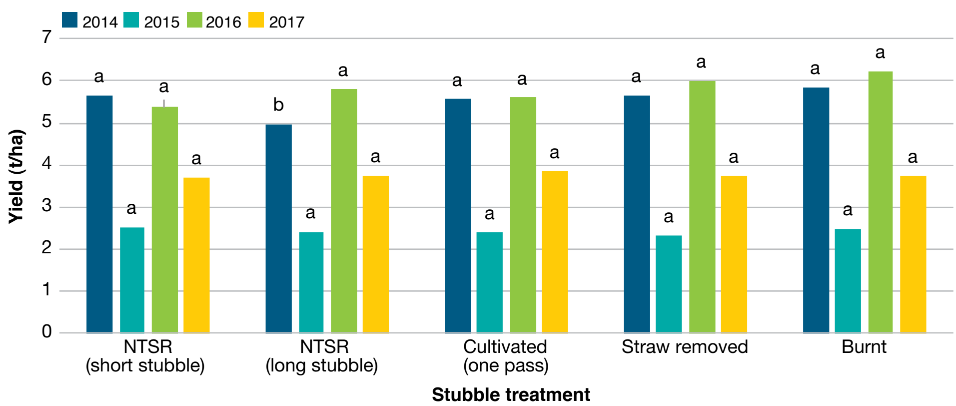


FIGURE 8 Yield data from 2014, 2015, 2016 and 2017 stubble management trials conducted in the wheat-on-wheat rotation position (time replicates 1, 2 and 3) cv Corack (2014), cv Mace (2015) and cv Corack (2016) and in cv ATR Stingray canola following wheat (time replicate 4) (2017)

Yield bars for the same year with different letters are regarded as statistically different

1 Dry matter differences observed on 28 June 2017. Burnt treatment on the left and NTSR — long stubble on the right.

2 Observed flowering differences on 25 July. Cultivated plot in foreground and NTSR — long stubble plot in the background.

3 Dookie site on 5 September 2017 NTSR — short stubble marked plot on the left and NTSR — long stubble marked plot on right. (Note small gaps in canopy where dry matter samples were taken.

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- Dookie: Ludeman Brothers

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Did stubble retention influence in-canopy temperature and frost risk during 2017?

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Key points

- The 2017 season was significantly colder than average with about 500 hours below zero.
- While stubble management may influence in-canopy temperatures, the differences between management practices were minimal during 2017.
- Differences in frost damage of grains were significant between treatments at both the Coreen and Yarrawonga sites, with the burnt treatment showing the greatest frost damage at Coreen, while the no-till stubble retained (NTSR) treatments showed the greatest damage at Yarrawonga.
- Stubble management per se did not influence frost damage in wheat during 2017, with frost damage not necessarily related to in-canopy temperatures.
- Stubble management practices can influence the rate of crop development and may lead to changes in flowering time. This change in rate of development can influence crop susceptibility to frost at different times throughout the growing season.

Background

The Grains Research and Development Corporation (GRDC) investment *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project is primarily focussed on maintaining the profitability of stubble-retained systems. However, since the establishment of the project growers have frequently asked about the influence of retained stubble on frost risk. While there is a perception retained stubble will decrease in-canopy temperatures and increase the risk and severity of frost, most frost-related research has been done in Western Australia in regions with lighter soils, where yields, and stubble loads are less than those experienced in the Riverine Plains region.

Additional funding was secured from the GRDC during 2015 to measure the impact of different stubble treatments on in-canopy temperatures at three large-plot stubble trial sites for the 2015–17 field plot trials. This funding links the project into the GRDC *National Frost Initiative*, with all results generated using protocols and analysis comparable to those being used in associated projects.

Aim

The aim of this work is to understand the impact of stubble retention on in-canopy temperatures and associated risk of frost in cropping environments with high yields and high stubble loads.

Method

The 2017 sites at Coreen, NSW and Yarrawonga and Dookie, Victoria were all established into wheat stubble. While the Coreen and Yarrawonga sites were flat and relatively uniform, the Dookie site sown to canola was located on the side of a hill. Therefore, it would be expected the Coreen and Yarrawonga sites would have a high relative frost risk, while the Dookie trial site would be subject to less frost and higher variability in temperature due to the change in altitude across the site.

Site, crop and treatment details are listed in the report *Active stubble management to enhance residue breakdown and subsequent crop management — focus farm trials*, page 12). Each treatment was replicated four times at each site. Treatments specific to each site are outlined in Table 1, along with the height placement of temperature loggers in each trial.

Tinytag temperature loggers (battery-powered temperature sensors) were installed during May in each plot, at two different heights and were removed before harvest.

The Tinytag loggers were used to record the temperature every 15 minutes for the length of the growing season (Figures 1a and 1b). The loggers faced north and were not shielded from direct sunlight. As a result, they recorded higher daytime temperatures compared with the temperatures recorded from a Stevenson screen (weather station) located at each site.

Each site weather station also included a one metre deep soil moisture probe, which measured local climatic conditions to support the temperature data. These were placed alongside trials to reduce the potential for mechanical damage, with the moisture probe recording moisture use by the commercial crop surrounding the trial site.

The temperature data was statistically analysed using Genstat, with statistical analysis determined at 5%

TABLE 1 Sites, selected treatments and temperature monitoring carried out during 2017

Site	Treatments	Measurements
Coreen, NSW (wheat)	• Stubble retained (NTSR) • Stubble burnt • Stubble incorporated	• Loggers at 300mm height • Loggers at 50mm height
Yarrawonga, Victoria (wheat)	• NTSR — long (30cm) • NTSR — short stubble (15cm) • Stubble burnt • Stubble incorporated	• Loggers at 300mm height • Loggers at 50mm height
Dookie, Victoria (canola)	• NTSR — long stubble (33cm) • NTSR — short stubble (15cm) • Stubble burnt • Stubble incorporated	• Loggers at 300mm height, moved to 600mm on 21 July, moved to 900mm on 17 August • Loggers at 50mm height • Loggers buried 50mm below the soil surface

FIGURE 1A The Yarrawonga Victoria site on 27 July 2017, showing yellow 50mm and 300mm Tinytag temperature loggers attached to the PVC tube (left foreground) and weather station (back left)

FIGURE 1B Tinytag temperature loggers and weather station at the Dookie, Victoria site, 27 July 2017. Note, the slope at the site is likely to increase the temperature variation between replicates variance. Measures of least significant difference (LSD) were used to determine which, if any, treatments were significantly different.

Results

The following results are from the temperature loggers installed at the 300mm height.

Site 1: Coreen, NSW

The temperature profile of the Coreen site is displayed in Figure 2 and shows the range and extremes of temperatures reached within the crop canopy. The amount of data presented in this graph makes it difficult to identify clear trends, however it is useful when looking at the intensity and duration of frost events throughout the season.

As the Tinytags were not shaded, the recorded maximum temperatures are higher than those measured by a weather station fitted with a Stevenson screen (which protects the temperature sensor from direct sunlight). The minimum temperatures measured in the canopy are also colder than those measured by the weather station at a height of 1.2m, more accurately reflecting the conditions the growing plant is exposed to. The coldest minimum in-canopy temperature during the 2017 season was -7.96°C at 7am on 1 July 2017. In comparison, the temperature recorded by the site weather station at the same time was -1.81°C.

Frost risk is determined by the duration and severity of frost events, with duration describing the amount of time the crop experiences sub-zero temperatures, while severity describes how cold it actually gets. The minimum temperatures were analysed to determine if the stubble treatments influenced the amount of time the crop experienced temperatures below zero (time threshold). As seen in Figure 3, the 2017 season was extremely cold, with about 500 hours below 0°C. However, there were no significant differences in the amount of time each stubble treatment spent below each threshold temperature at the Coreen site.

Wheat head samples were collected before harvest to determine the frost damage to individual florets. Based on a subsample of 90 grain heads per replicate (360 heads per treatment), the burnt treatment had significantly more frosted florets than the cultivated treatment, which in turn had more frosted florets than the stubble retained treatment (Table 2).

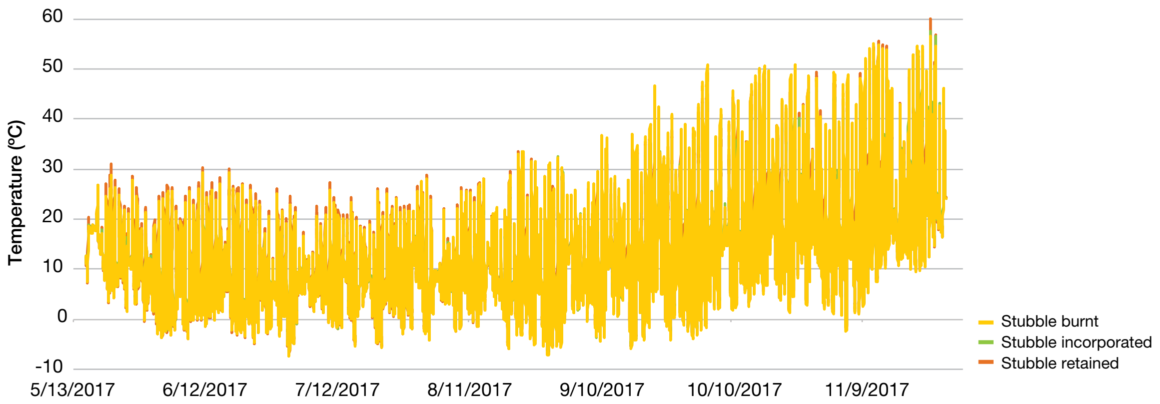

FIGURE 2 Averaged in-canopy temperatures measured by the 300mm loggers at the Coreen NSW site from 16 May – 27 November 2017

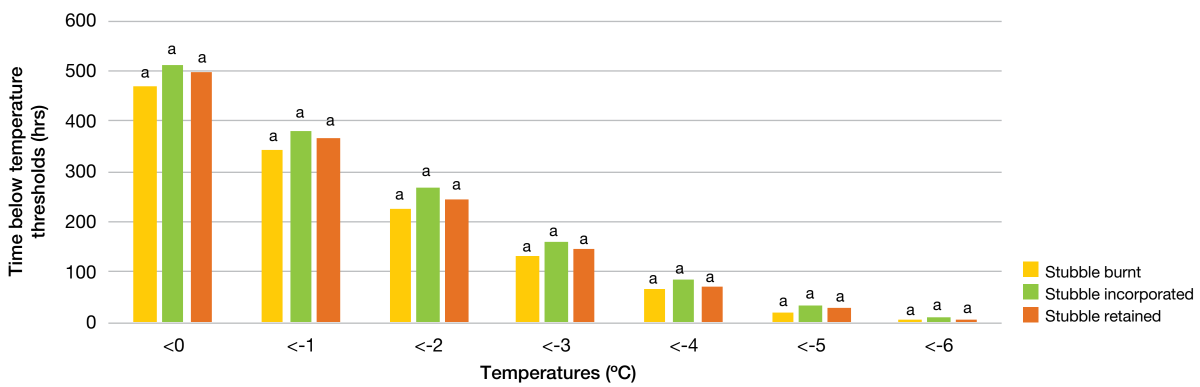

FIGURE 3 The effect of stubble treatment on the duration of in-canopy temperatures at zero degrees and each degree below, measured by the 300mm loggers at the Coreen site

Letters denote statistical significances between treatments at each temperature.

TABLE 2 Frost score at harvest (GS99) at Coreen, 2017

Treatment	Frost score (%) *
Stubble retained	3.366[a]
Stubble incorporated	5.415[b]
Stubble burnt	7.882[c]
Mean	**5.554**
LSD	1.366

*Frost score calculated as: number of frosted florets per head / total florets per head x 100

Figures followed by different numbers are regarded as statistically significant

This indicates that actual temperatures are not the only driver for differences in frost damage between treatments.

Site 2: Yarrawonga, Victoria

The Yarrawonga site experienced similar temperature ranges to the Coreen site, with the coldest minimum temperature of -7.87°C measured at 7am on 1 July 2017. At the same time the temperature recorded by the on-site weather station was -1.25°C (Figure 4).

While the Coreen site included just one NTSR treatment, the Yarrawonga site included both NTSR — long stubble and NTSR — short stubble treatments. Significant differences in canopy temperatures between treatments were observed at the Yarrawonga site, as described by the duration of time below specific temperature thresholds (Figure 5). The duration of time below the 0°C, -1°C, -2°C and -4°C thresholds was significantly less in the burnt stubble treatment compared with the incorporated and NTSR — long stubble treatments, while the NTSR — short stubble treatment was similar to all treatments.

While statistically significant differences were measured at this trial site, the actual difference in the number of hours at each threshold is still relatively small. For example, the number of hours the stubble burnt and NTSR — long stubble treatment spent below -4°C was 52 hours and 86 hours respectively, which is not a big difference when the crop spent about 500 hours below 0°C across the season.

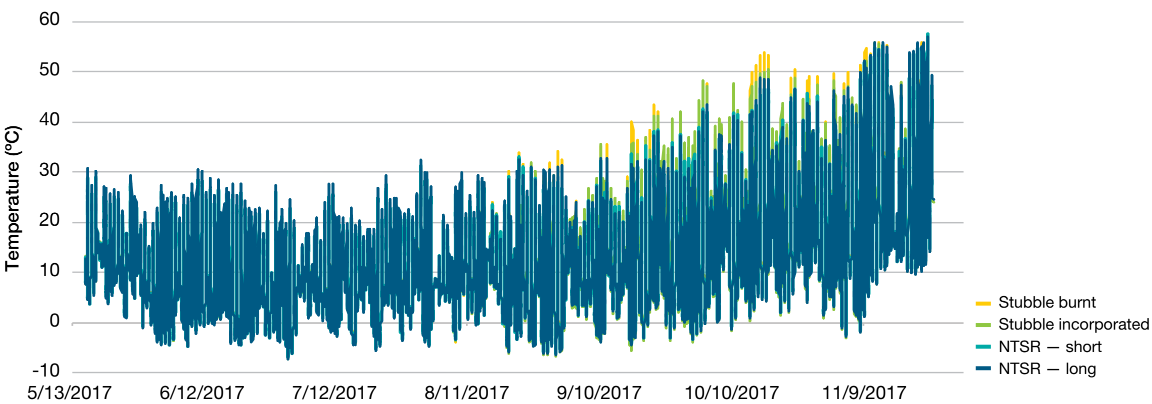

FIGURE 4 In-canopy temperatures measured at the Yarrawonga Victoria site from 16 May – 24 November 2017

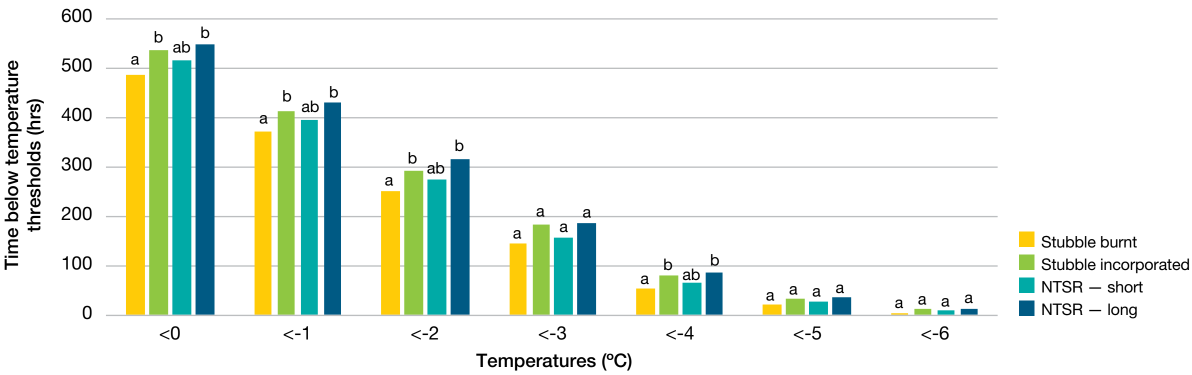

FIGURE 5 The effect of stubble treatment on the duration of in-canopy temperatures at zero and each degree below, at Yarrawonga, 2017

Letters denote statistical significance between treatments at each temperature.

TABLE 3 Frost score at harvest (GS99) at Yarrawonga, 2017

Treatment	Frost score (%) *
Stubble burnt	11.1[b]
Stubble incorporated	12.5[b]
NTSR — short stubble	17.2[a]
NTSR — long stubble	15.4[a]
Mean	**14.1**
LSD	2.78

*Frost score calculated as: number of frosted florets per head / total florets per head x 100
Figures followed by different numbers are regarded as statistically significant.

While the cumulative temperature totals can provide some indication of differences in-crop, the key element missing from this analysis is the timing of these frost events. This becomes important given actual frost damage to the wheat head (specifically the floret) requires a frost event to occur during flowering.

Physical assessment of the number of frosted florets in each head showed that the burnt and cultivated treatments had significantly less frost damage than both the NTSR — short stubble and NTSR long — stubble treatments (Table 3). Given the relatively small difference in temperatures observed between the stubble treatments, the significant difference in frost damage between treatments could be caused by differences in the timing of flowering, which may be influenced by stubble management strategy.

Site 3: Dookie, Victoria

The Dookie 2017 trial was situated on the side of a hill, with replicated blocks positioned at increasing elevation. This change in elevation between the replicates had a significant effect on the in-canopy temperatures measured. Being situated on a high point in the landscape also meant the trial site was not be subject to the same number or intensity of frost events that would be measured in a flat paddock.

The coldest temperature recorded at the Dookie site was -3.83°C at 7am on 1 July 2017. While this was a significant frost event, the Coreen and Yarrawonga sites recorded much lower temperatures at the same point in time (-7.96°C and -7.87°C respectively), which highlights the differences in micro-climate between the field sites during 2017. The in-canopy temperature data from the Dookie site show there were a number of frost events at Dookie during 2017, although this was a lot lower compared with the other sites (Figure 6).

While about 500 hours below 0°C were recorded at the Coreen and Yarrawonga sites, about 80 hours below 0°C were recorded at the Dookie site. The high and variable altitude at the Dookie site contributed towards the high data variability at the Dookie site, with no significant differences in temperatures measured between the different stubble management treatments (Figure 7). Potential frost-related damage to the canola seed pods was not assessed as canola will continue to flower to compensate for flowering stress, with the variation in altitude also meaning that any damage could not be clearly attributed to stubble management.

Comparison of temperatures recorded at different positions at Dookie

As noted in Table 1, the Dookie site was instrumented with Tinytag temperature loggers at 50mm below the soil surface in addition to the 50mm and 300mm above-surface in-canopy loggers.

An example of this data, from the NTSR — short stubble treatment, is presented in Figure 8 and clearly demonstrates the different temperatures recorded at the different logger positions. In this example, the 50mm loggers measured

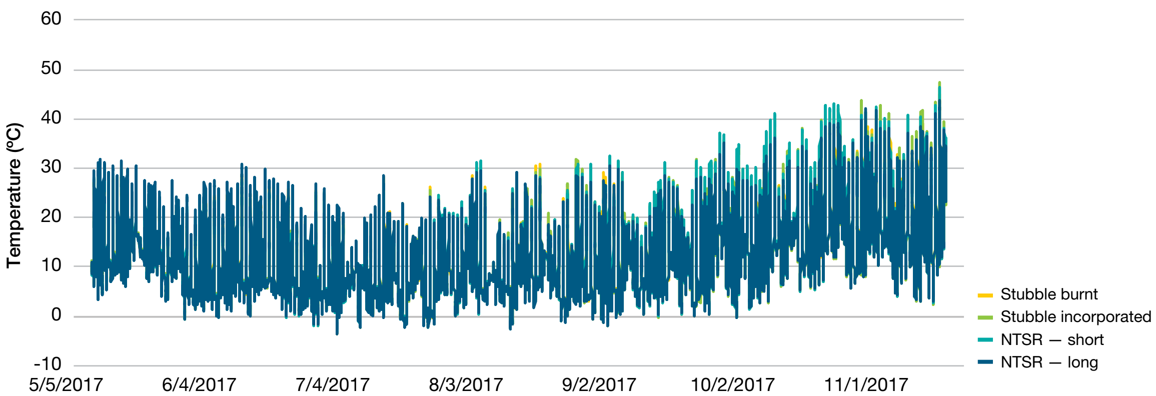

FIGURE 6 In-canopy temperatures measured at the Dookie site between 9 May – 10 November 2017

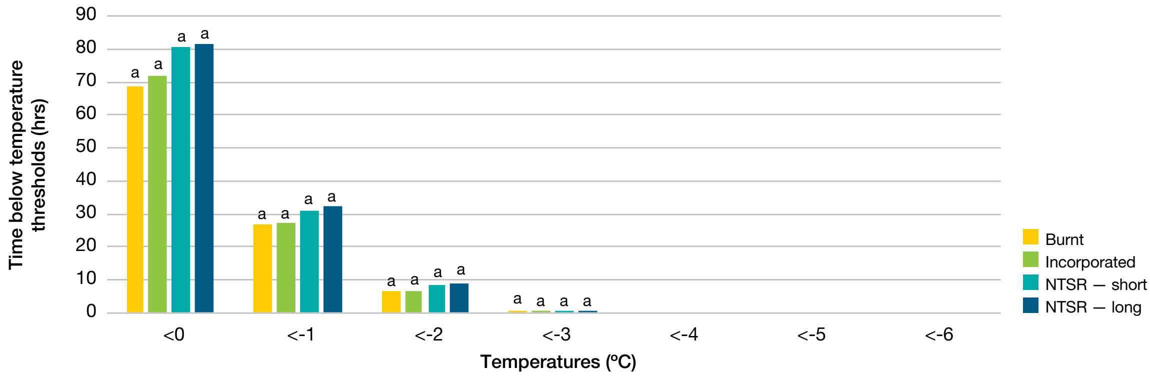

FIGURE 7 The effect of stubble treatment on the duration of in-canopy temperatures at 0°C and each degree below, at Dookie, 2017

Letters denote statistical significance between treatments at each temperature.

comparable temperatures to the 300mm loggers during the early part of the season. As the plants grew taller there were some differences between the temperatures logged at different heights, with the 50mm loggers not measuring the same extremes of cold or heat as the 300mm loggers (which were moved up to 600mm and 900mm during the season to stay in the upper part of the canopy).

The buried loggers showed even less variation in temperature throughout the season (Figure 8). While the 300mm logger measured -3.83°C on 1 July 2017, the minimum temperature recorded in the logger buried at 50mm was 4.64°C.

Observations and comments

Considering there were about 500 hours below 0°C at the Yarrawonga and Coreen sites during the 2017 season (2016 measured 160–270 hours; 2015 measured 230–270 hours), there was only a small amount of variability measured within each treatment.

Moreover, even at the Yarrawonga site, where there were statistically significant differences in temperature between treatments, these differences were not large and were unrelated to differences in measurable frost damage. If the stubble treatments were a large driver for in-canopy temperatures, this should have been clearly seen during the 2017 season, but it was not. Therefore, it appears that in particularly cold winters, stubble management has little effect on in-canopy temperature.

From the data, in-canopy temperature differences during the flowering period *per se* did not drive the difference in frost damage between burnt and stubble retained crops during the 2017 season. While differences in in-canopy temperatures were also measured during 2016, the mild temperatures measured during 2016 meant that damage attributable to frost was not detected. The 2017 season is the first in which significant differences in head damage were measured, with these results not clearly related to any trends in in-canopy temperatures.

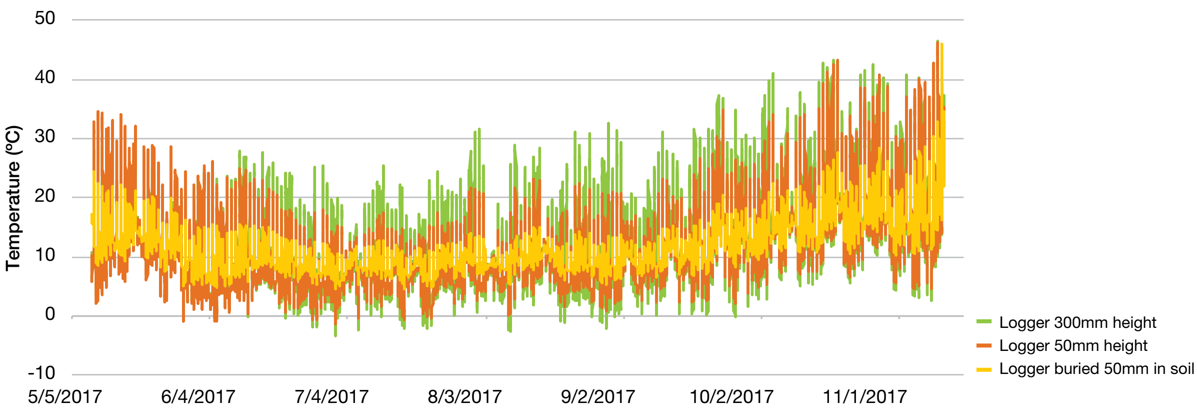

FIGURE 8 Temperatures measured at 300mm, 50mm and soil surface for NTSR — short stubble at Dookie, Victoria between 9 May – 10 November 2017

Rather, it is highly likely the early-season shading measured in crops under retained stubble, (which can cause delays in early dry matter (DM) production and crop development — see *Active stubble management to enhance residue breakdown and subsequent crop management —focus farm trials* article on page 12), resulted in differences in the timing of phenological development. The resulting delay in flowering in NTSR treatments is the most likely reason for differences in frost damage observed between treatments (i.e. whichever stubble treatment was flowering at the time of the frost event was the treatment most severely affected).

Acknowledgements

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- Dookie: Ludeman Brothers

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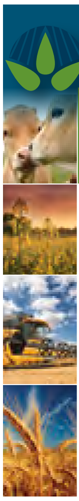



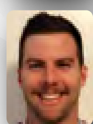

The interaction between stubble height and light interception in canola

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

Key points

- When canola was sown into wheat stubble in an east-west direction, long stubble (42cm) significantly reduced photosynthetically active radiation (PAR) and reduced true leaf number up to mid-winter.
- Although there were trends suggesting a reduction in dry matter (DM) production at the yellow bud stage (GS3.7) as a result of increasing stubble height, the differences were not statistically significant.
- The average canola yield of the trial was 1.58t/ha with no significant differences in either yield or oil content due to stubble height of the previous wheat crop.
- The results mirror a trial conducted at Dookie, where yields in long stubble were 3.70t/ha and 3.75t/ha in short stubble. At this site there were significant reductions in DM production early in the season in the long stubble treatment.

Sowing date: 2 May 2017
Rotation: Canola following wheat
Variety: Bonito
Stubble: Wheat unburnt
Rainfall:
GSR: 270mm (April–October)
Summer rainfall: 88mm
Soil mineral nitrogen:
0–10cm: 26kg N/ha (February 2017)
0–100cm: 109kg N/ha (June 2017)

Previous findings

One of the most consistent findings of the GRDC investment in the *Maintaining profitable farming systems with retained stubble in the Riverine Plains region (2013–18)* project has been the influence of long stubble in no-till stubble retention (NTSR) systems on the growth of the following crop. Longer stubbles (30–45cm) in NTSR systems have been associated with lower dry matter (DM) production and slower development through winter until spring, after which the crop invariably compensates. In some trials this delay in development and reduction in biomass (DM) has impacted yield, although in other trials it has not. This trial was established to look at the effect of stubble height on subsequent crops in more detail.

Method

A trial was established during 2017 under the Riverine Plains Inc stubble project: *Maintaining profitable farming systems with retained stubble in the Riverine Plains region (2013–18)*. The trial was carried out near Rennie, NSW.

Three different stubble height treatments were created in a commercial wheat stubble before establishing canola. The stubble rows ran in an east-west direction, with a row spacing of 25cm. The plots were 10m x 10m and each treatment was replicated three times. The trial was sown with a commercial crop of canola (cv Bonito) through the different stubble height treatments. The trial design was a randomised complete block. All paddock management was undertaken by the host farmer and was uniform for the trial site.

A ceptometer was used early in the season to measure photosynthetically active radiation (PAR) in each treatment and determine the effect of shading in each stubble length.

TinyTag temperature loggers were placed in the centre of each plot at a start height of 30cm and final height of 90cm, moving up as the canopy grew. Canopy temperatures were measured every hour to explore any differences due to stubble height.

The three lengths of stubble created ranged from 12–42cm (Table 1), with the extra residue cut to produce the shorter stubble lengths being left on the ground in the plot.

Results

i) Establishment and crop structure

When canola establishment was assessed at the four-leaf stage (GS1.04) there was no difference in crop establishment due to stubble length (Table 2).

TABLE 1 Stubble treatments

Stubble treatment	Stubble height (cm)
Short	12
Medium	21
Long	42



TABLE 2 Plant counts 29 May 2017, four-leaf stage (GS1.04)

Treatment	Plants/m² GS1.04
Short (12cm)	34[a]
Medium (21cm)	37[a]
Long (42cm)	35[a]
Mean	**35**
LSD	7

There was a significant difference in the number of true leaves produced by the canola crop under the different stubble length treatments (Figure 1). By July the crop sown into short stubble (12cm) had developed at least one extra leaf compared with the crop established in long stubble (42cm). The intermediate stubble length (21cm) had a smaller reduction in the number of true leaves produced.

ii) Temperature

Although there were small differences in accumulated temperatures across the main growing season (when recorded at 30cm at the start of the season and 90cm towards the end of the season), these differences in temperature were not statistically significant (Figure 2).

iii) Photosynthetically active radiation (PAR)

The assessments of photosynthetically active radiation (PAR) indicated that stubble height had a significant influence on the percentage of light intercepted by the crop. The long stubble (42cm) caused a significant shading effect on the young plants, more than halving the PAR available to the crop compared with the light available to the crop in short stubble (12cm) (Figure 3).

With the east-west row orientation the differences in PAR between stubble heights were similar, irrespective of whether measurements were made at 9am, 12 noon or 3pm.

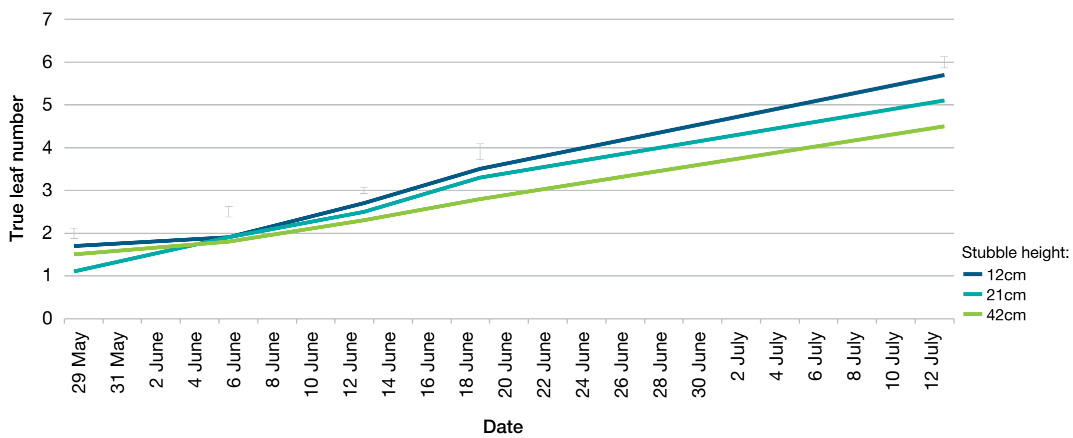

FIGURE 1 Influence of previous crop stubble length on true leaf number in canola on 29 May 2017, 6 June 2017, 13 June 2017, 19 June 2017 and 13 July 2017

*The error bars are a measure of LSD

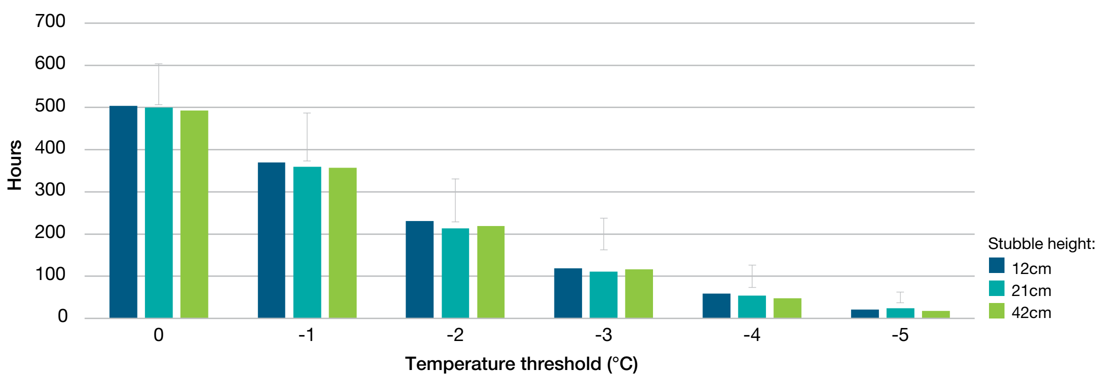

FIGURE 2 Hours spent below each temperature threshold for canola canopy in 12cm, 21cm and 42cm stubble height treatments, from 17 May 2017 until 21 November 2017

*The error bars are a measure of LSD


1


2


3


4


5


6

1 Long stubble treatment (42cm), 27 March 2017

2 Medium length stubble treatment (21cm), 27 March 2017

3 Short stubble treatment (12cm), 27 March 2017

4 Measuring PAR using a ceptometer in long stubble (42cm), 19 June 2017

5 Short stubble treatment (12cm), 18 August 2017

6 Long stubble (42cm) treatment, 18 August

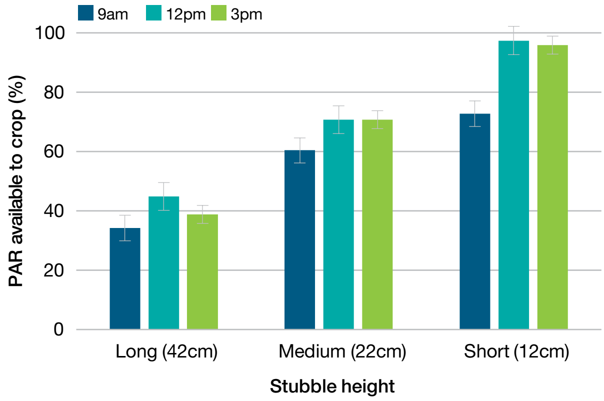

FIGURE 3 Influence of stubble height on availability of photosynthetically active radiation at 9am on 6 June 2017, 12pm on 13 June 2017 and 3pm on 19 June 2017 at Rennie, NSW

*The error bars are a measure of LSD and comparison can only be made when comparing bars of the same colour (i.e. when measurements were made at the same time on the same day)

Note:

6 June readings were taken at 9am, with the average above-canopy PAR measuring 573µmol/m^2/s in the 400–700nm waveband.

13 June readings were taken at 12pm with the average above-canopy PAR measuring 948µmol/m^2/s^1 in the 400–700nm waveband.

19 June readings were taken at 3pm, with the average above-canopy PAR measuring 583µmol/m^2/s^1 in the 400–700nm waveband.

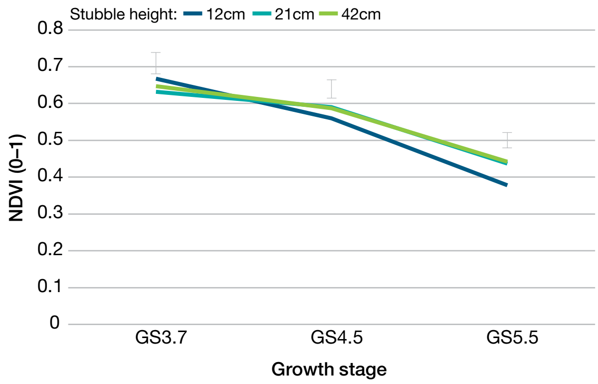

FIGURE 4 NDVI readings on 18 August 2017, yellow bud (GS3.7); 13 September 2017, 50% flowering (GS4.5) and 12 October 2017, 50 % pods on raceme more than 2cm (GS5.5)

*Error bars are a measure of LSD

iv) Dry matter production

Although there was a trend for canola in longer stubble to produce less DM compared with canola in shorter stubble at the yellow bud stage (GS3.7), the difference was not statistically significant (Table 3). At the pod maturity stage (GS6.7), when seeds were mainly black, the same non-significant trend was also apparent.

A DM assessment was conducted at full flowering, however problems with the drying oven meant results could not be used.

v) Normalised difference vegetative index (NDVI)

Measurements of crop reflectance made using a Greenseeker™ showed little difference in crop canopy NDVI (Figure 4) across stubble height treatments.

TABLE 3 Dry matter production 18 August 2017, yellow bud (GS3.7) and 21 November 2017, most seeds black but soft (GS6.7)

Treatment	Dry matter (t/ha)	
	GS3.7	GS6.7
Short (12cm)	2.17^{a}	6.95^{a}
Medium (21cm)	1.90^{a}	6.81^{a}
Long (42cm)	1.88^{a}	6.85^{a}
Mean	**1.98**	**6.87**
LSD	0.32	0.69

TABLE 4 Yield and quality at harvest (GS6.9), 21 November 2017

Treatment	Yield and quality	
	Yield (t/ha)	Oil (%)
Short (12cm)	1.57^{a}	46.1^{a}
Medium (21cm)	1.47^{a}	46.6^{a}
Long (42cm)	1.69^{a}	45.6^{a}
Mean	**1.58**	**46.1**
LSD	0.39	1.1

vi) Grain yield and oil content

The trial was harvested on 21 November 2017 with an average yield of 1.58t/ha. Stubble height had no significant influence on yield or oil content (Table 4).

Acknowledgements

This work was carried out as part of the GRDC investment *Maintaining profitable farming systems with retained stubble in the Riverine Plains region (2013–18).*

Thank you to our farmer co-operators, the Davis family of Rennie.

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Nitrogen response in different electromagnetic (EM) zones of the paddock

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

Key points

- Paddock variance was measured across two paddocks through EM (electromagnetic) surveys. Based on this variance, high and low EM zones were identified.
- Two small plot trials compared nitrogen (N) response in a high and low EM zone of two paddocks sown to Trojan wheat, one in Yarrawonga (sown 22 April) and the other in Dookie (sown 12 May).
- Both paddocks had high levels of nitrogen available in the soil (120–200kg N/ha 0–60cm) irrespective of zone.
- The largest response to nitrogen (1t/ha) was observed in the high EM zone at Dookie, where the highest levels of available soil nitrogen were recorded (200kg N/ha).
- Dry matter (DM) differences and normalised difference vegetation index (NDVI) readings at the Dookie site suggested the crop canopy was responding to applied nitrogen; this indicates the crop did not benefit from the high levels of soil nitrogen present (possibly as a result of later sowing or subsoil constraints).
- At the Yarrawonga site there were no significant indications from NDVI readings that a response to nitrogen fertiliser was likely; this was supported by high grain yields in the nil nitrogen plots (5.8t/ha and 6.4t/ha in the high and low EM zone respectively).
- At the Dookie low EM site, grain protein of 11.9% in the lowest-yielding treatment suggested there was sufficient soil nitrogen available to meet crop yield and protein requirements; this contrasts with in-crop NDVI measurements, which suggested the crop would respond to applied nitrogen.
- At Yarrawonga nitrogen application strategies based on NDVI readings meant nitrogen application was delayed until third node (GS33) in the high EM zone, which resulted in only limited uptake. A slightly earlier second node (GS32) application in the low EM zone resulted in an excellent response (0.39t/ha) to the NDVI-based approach.

Method

Four trials were established in 2017 under the Riverine Plains Inc stubble project: *Maintaining profitable farming systems with retained stubble in the Riverine Plains region (2013–18)*. The background to these trials is described on page 10. The four trials were carried out at two locations at Dookie, and Yarrawonga, Victoria.

Each location had two trials in the same paddock. Before the season commenced the paddocks were electromagnetically (EM) mapped and zoned. One of the two trials was placed in the high EM zone and one in the low EM zone. The trials were sown with a commercial crop and then marked out after crop emergence. The trial design was a randomised complete block and replicated four times. Nitrogen (N) applications were made as per the treatment lists in the following sections (Tables 1, 5, 10 and 14), with all other management inputs undertaken by the host farmer for the remainder of the season.

Site 1: Yarrawonga, Victoria

Sowing date: 22 April 2017
Rotation: First wheat after canola
Variety: Trojan
Stubble: Canola unburnt
Rainfall:
GSR: 270mm (April–October)
Summer rainfall: 88mm

Trial 1: High EM zone Yarrawonga, Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017 — so includes MAP at sowing)
0–10cm: 67.0kg N/ha
10–30cm: 38.5kg N/ha
30–60cm: 23.9kg N/ha
Total (0–60cm): 129.4kg N/ha

Results

i) Establishment and crop structure

The trial site averaged 102 plants/m^2.

The application of 120kg N/ha at early tillering (GS21) with the 120 N (N rich) treatment produced significantly more tillers (68–46 tillers/m^2) than the nil nitrogen and 20kg N/ha applied (only 50% of the 40 N dose had been applied at the tillering assessment) (Table 2).



TABLE 1 High EM zone treatment list, Yarrawonga, Victoria 2017

Treatment	22 April GS00	30 May GS21	20 June GS24/GS30	11 July GS31	25 July GS32	7 August GS33/37	17 August GS39	Total
	(kg N/ha[1])	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)
Nil N	7.5	0	0	0	0	0	0	7.5
40 N	7.5	0	20	20	0	0	0	47.5
80 N	7.5	0	40	40	0	0	0	87.5
120 N	7.5	0	60	60	0	0	0	127.5
160 N	7.5	0	80	80	0	0	0	167.5
NDVI 1*(40 N)	7.5	0	0	0	0	40	0	47.5
NDVI 2* (40 N)	7.5	0	0	0	0	0	40	47.5
120 N (N rich)	7.5	120	0	0	0	0	0	127.5

* NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots (120 N). A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 explored standard timings of nitrogen whereas NDVI 2 explored later splits of the timing of the same amount of nitrogen.

[1] GS00 nitrogen (7.5kg N/ha) was applied as 75kg MAP/ha, all other nitrogen was applied as urea (46% N)

TABLE 2 Plant counts 30 May 2017, main stem and one tiller (GS21): tiller counts 11 July 2017, first node (GS31) in the high EM zone, Yarrawonga, Victoria

Treatment	Crop growth stage	
	Plants/m^2	Tillers/m^2
	GS21	GS31
Nil N	116^{a}	328^{c}
40 N	94^{a}	350^{bc}
80 N	-	376^{ab}
120 N	-	370^{ab}
160 N	-	373^{ab}
NDVI 1 (40 N)	-	-
NDVI 2 (40 N)	-	-
120 N (N rich)	95^{a}	396^{a}
Mean	**102**	**366**
LSD	11	41

Figures followed by different letters are regarded as statistically significant.

ii) Dry matter (DM) production

Dry matter assessments were conducted at early grain fill (GS71) and physiological maturity (GS92) (Table 3). High LSD values in both assessments indicated there were only limited differences between treatments. There was a general trend for higher rates of applied nitrogen to produce higher DM, particularly at rates of 120kg N/ha and above. The nil nitrogen DM results would suggest plants could access the high levels of nitrogen coming from the soil, as indicated by the initial soil testing (129kg N/ha).

iii) Normalised difference vegetative index (NDVI)

Crop reflectance measurements taken with the Greenseeker (handheld NDVI) showed small differences in greenness in the crop canopy with none of the treatments showing any increase in NDVI compared with the untreated control (Figure 1). This result again indicates large amounts of nitrogen being supplied by the soil.

TABLE 3 Dry matter 12 October 2017 at early grain fill (GS71) and 28 November 2017, physiological maturity (GS92), high EM zone Yarrawonga, Victoria

Treatment	Dry matter (t/ha)	
	GS71	GS92
Nil N	11.48^{b}	13.18^{c}
40 N	11.74^{ab}	14.71^{abc}
80 N	12.78^{ab}	13.21^{bc}
120 N	12.82^{ab}	15.13^{ab}
160 N	14.00^{a}	16.17^{a}
NDVI 1 (40 N)	11.85^{ab}	14.16^{bc}
NDVI 2 (40 N)	12.50^{ab}	13.71^{ac}
120 N (N rich)	12.20^{ab}	13.27^{bc}
Mean	**12.42**	**14.19**
LSD	2.42	1.93

Figures followed by different letters are regarded as statistically significant.

iv) Grain yield and quality

The trial was harvested on 12 December 2017, with an average yield of 6.01t/ha and a maximum response to applied nitrogen of 0.68t/ha (Table 4).

There was a significant yield increase from applying 40kg N/ha split between tillering (GS24) and first node (GS31) (40 N treatment). There was no yield response associated with increasing nitrogen rate above 40kg N/ha, however increasing the nitrogen rate to 120kg N/ha and above significantly increased grain protein from 10.2% to 11.5%.

Applying 40kg N/ha at both third node (GS33) and flag-leaf emergence (GS39) had little or no effect, with both yield and protein results similar to the untreated control. This result is likely to be associated with the prolonged dry conditions, which would have reduced nitrogen uptake after application.

Increasing nitrogen application rates at tillering (GS21) and stem elongation (GS31) as per the 120kg N/ha and 160kg

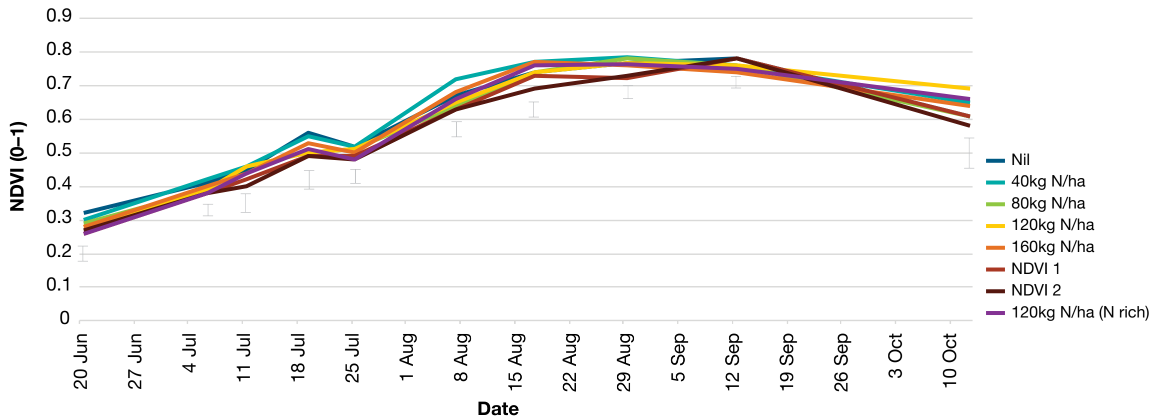


FIGURE 1 NDVI readings 20 June 2017, late tillering — start of stem elongation (GS24–30); 6 July, first node (GS31); 11 July second node (GS32); 19 July, second node (GS32); 25 July third node (GS33); 7 August third node — start of flag-leaf emergence (GS33–37); 17 August, flag leaf 75% emerged (GS37); 29 August, flag leaf fully emerged–start of booting (GS39–41); 12 September, head emergence (GS51) and 12 October, early grain fill (GS71), high EM zone, Yarrawonga, Victoria

TABLE 4 Yield, protein, test weight and screenings at harvest (GS99), 12 December 2017, high EM zone, Yarrawonga, Victoria

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	5.74[bc]	9.3[e]	75.8[a]	2.4[ab]	48.9[a]
40 N	6.42[a]	10.2[cd]	74.4[ab]	2.0[b]	45.8[ab]
80 N	5.82[abc]	10.5[c]	76.0[a]	2.1[b]	45.2[abc]
120 N	6.19[ab]	11.5[b]	75.2[ab]	2.1[b]	42.9[bc]
160 N	6.29[ab]	11.6[b]	75.1[ab]	2.3[b]	42.8[c]
NDVI 1 (40 N)	5.79[bc]	9.5[de]	75.8[a]	2.2[b]	47.5[a]
NDVI 2 (40 N)	5.52[c]	9.7[de]	75.6[a]	2.1[b]	46.2[a]
120 N (N rich)	6.29[ab]	13.4[a]	73.6[b]	2.8[a]	36.9[d]
Mean	6.01	10.7	75.2	2.2	44.2
LSD	0.61	0.8	1.7	0.5	2.9

Figures followed by different letters are regarded as statistically significant.

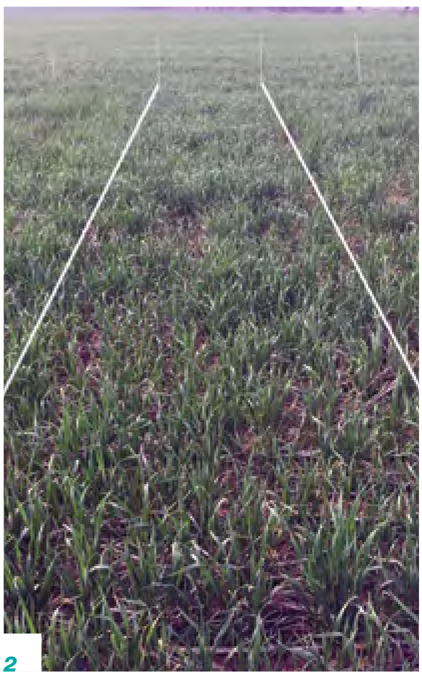
N/ha treatments significantly reduced grain size, measured as thousand seed weight (TSW), however this did not increase screening levels. If 120kg N/ha was applied at early tillering (GS21) test weight was reduced, grain size was reduced still further while screenings and protein were increased, presumably as a result of increased shoot number recorded at first node (Table 2).

The only treatment achieving the APW1 grade (both 76kg/hL and 10.5% protein) was the 80kg N/ha treatment.

1 Untreated plot at GS31, 11 July 2017

2 Nitrogen-rich (120 N) plot at GS31, 11 July 2017


1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Trial 2: Low EM zone Yarrawonga, Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017 — so includes MAP at sowing)

0–10cm: 67.1kg N/ha

10–30cm: 29.9kg N/ha

30–60cm: 23.8kg N/ha

Total **(0–60cm):** 120.8kg N/ha

Results

i) Establishment and crop structure

The low EM zone had a plant establishment of 103 plants/m^2, which was identical to the high EM zone site.

The application of 120kg N/ha at early tillering (GS21) produced more tillers than the nil nitrogen plots, but the difference was not statistically significant (Table 6). At the time of the first node tiller assessment (GS31) only 50% of the nitrogen had been applied for treatments receiving 80, 120 or 160 kg N/ha (excluding NDVI and nitrogen-rich treatments).

ii) Dry matter production

Dry matter production, assessed at early grain fill (GS71) and physiological maturity (GS92), produced no significant differences (Table 7). Overall, the DM contents of the crops in the low EM zone at physiological maturity were approximately 1.8t/ha less than those recorded in the high EM zone.

iii) Normalised difference vegetation index

Similarly to the high EM zone at Yarrawonga, there was no significant differences in the NDVI readings recorded in the low EM zone, indicating higher fertility in the untreated nil nitrogen plots (Figure 2). The lack of separation of the nil nitrogen plots from the nitrogen-rich plots fertilised with 120kg N/ha at GS21 indicated that yield at this site was not responsive to applied nitrogen.

TABLE 6 Plant counts 30 May 2017, one tiller (GS21), tiller counts 11 July 2017, first node (GS31), low EM zone Yarrawonga, Victoria

	Crop growth stage	
	Plants/m^2	Tillers/m^2
Treatment	GS21	GS31
Nil N	108^{a}	338^{a}
40 N	98^{a}	352^{a}
80 N	-	354^{a}
120 N	-	361^{a}
160 N	-	377^{a}
NDVI 1 (120 N)	-	-
NDVI 2 (120 N)	-	-
120 N (N rich)	101^{a}	375^{a}
Mean	**103**	**360**
LSD	33	47

TABLE 7 Dry matter production 12 October 2017, early grain fill (GS71) and 28 November 2017, physiological maturity (GS92) for the low EM zone, Yarrawonga, Victoria

	Dry matter (t/ha)	
Treatment	GS71	GS92
Nil N	10.76^{a}	11.95^{a}
40 N	10.55^{a}	11.84^{a}
80 N	10.70^{a}	11.88^{a}
120 N	12.09^{a}	12.04^{a}
160 N	11.26^{a}	13.82^{a}
NDVI 1 (120 N)	11.49^{a}	12.09^{a}
NDVI 2 (120 N)	11.62^{a}	12.73^{a}
120 N (N rich)	11.25^{a}	12.59^{a}
Mean	**11.21**	**12.37**
LSD	1.98	2.56

TABLE 5 Treatment list, low EM zone Yarrawonga, Victoria

	22 April GS00	30 May GS21	20 June GS24/GS30	11 July GS31	25 July GS32	7 August GS33/37	17 August GS39	Total
Treatment	(kg N/ha[1])	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)
Nil N	7.5	0	0	0	0	0	0	7.5
40 N	7.5	0	20	20	0	0	0	47.5
80 N	7.5	0	40	40	0	0	0	87.5
120 N	7.5	0	60	60	0	0	0	127.5
160 N	7.5	0	80	80	0	0	0	167.5
NDVI 1* (120 N)	7.5	0	0	60	40	20	0	127.5
NDVI 2*(120 N)	7.5	0	0	60	40	0	20	127.5
120 N (N rich)	7.5	120	0	0	0	0	0	127.5

* NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots (120 N). A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 looked at standard timings of nitrogen whereas NDVI 2 looked at later splits of the timing of the same amount of nitrogen.

[1] GS00 nitrogen (7.5kg N/ha) was applied as 75kg MAP/ha, all other nitrogen *was* applied as urea (46% N)

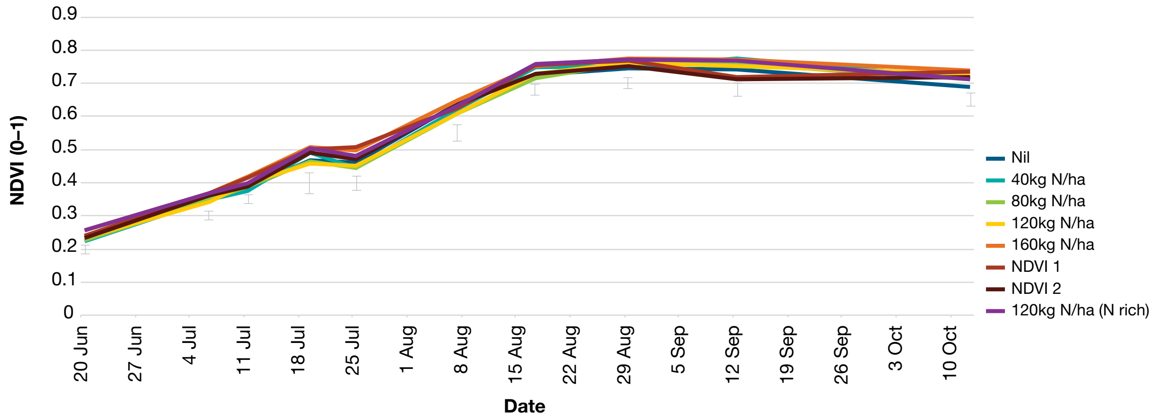


FIGURE 2 NDVI readings on 20 June, late tillering — start of stem elongation (GS24–30); 6 July, first node (GS31), 11 July second node (GS32); 19 July, second node (GS32); 25 July third node (GS33); 7 August third node–start of flag-leaf emergence (GS33–37); 17 August, flag leaf 75% emerged (GS37); 29 August, flag leaf fully emerged–start of booting (GS39–41);12 September, head emergence (GS51) and 12 October, early grain fill (GS71) for the low EM zone, Yarrawonga, Victoria

iv) Grain yield and quality

The average yield of the trial in the low EM zone was 6.74t/ha compared with 6.01t/ha in the high EM zone (Table 8). The application of 80kg N/ha and above yielded significantly higher than the nil nitrogen treatment, with a maximum yield response to nitrogen of 0.63t/ha obtained at 160kg N/ha and the economic optimum obtained at 80kg N/ha (based on $234/t and 95 cents/kg N).

The low EM zone had a similar maximum response to nitrogen as the high EM zone (0.63 vs 0.68t/ha), though yields overall were higher with a maximum of 7.01t/ha in the low EM zone compared with 6.42t/ha in the high EM zone.

The application rate of 80kg N/ha and above produced significantly higher protein than the nil nitrogen treatment.

The NDVI based treatments, which both received 120kg N/ha as 60kg N/ha at GS31, followed by 40kg N/ha at GS32, produced significantly higher proteins than the lower nitrogen rates of nil and 40kg N/ha, however the yield responses were not statistically different to the nil nitrogen plots. There were no yield, protein or quality differences between the two NDVI approaches in the low EM zone.

The high EM zone NDVI treatments received 40kg N/ha compared with 120kg N/ha in the low EM zone. The earlier application of nitrogen in the low EM zone NDVI treatments at second node (GS32 – 11 July) rather than third node (GS33 – 7 August or GS39 – 17 August) in the high EM zone was much more effective for yield and protein, presumably as a result of better uptake following application.

TABLE 8 Yield, protein, test weight and screenings at harvest (GS99), 11 December 2016, low EM zone, Yarrawonga, Victoria

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	6.38[c]	9.4[c]	75.5[a]	2.4[ab]	42.2[ab]
40 N	6.50[bc]	10.0[bc]	75.7[a]	2.9[a]	42.7[a]
80 N	6.87[ab]	10.7[ab]	75.9[a]	2.5[ab]	41.4[ab]
120 N	6.86[ab]	11.1[a]	75.9[a]	2.2[ab]	42.3[a]
160 N	7.01[a]	11.1[a]	75.7[a]	2.1[ab]	42.8[a]
NDVI 1 (120 N)	6.77[abc]	11.7[a]	75.9[a]	2.3[ab]	39.7[b]
NDVI 2 (120 N)	6.78[abc]	11.8[a]	75.6[a]	2.5[ab]	40.5[ab]
120 N (N rich)	6.73[abc]	11.1[a]	75.5[a]	1.9[b]	41.4[ab]
Mean	**6.74**	**10.8**	**75.7**	**2.2**	**41.6**
LSD	0.41	1.0	1.0	0.5	2.6

Figures followed by different letters are regarded as statistically significant.

v) Comparison of DM, yield and protein across EM zones

The slightly earlier application of nitrogen the low EM zone trial (GS32) compared with the high EM zone trial (GS33 or GS37) resulted in increased yield, presumably as a result of better uptake following application.

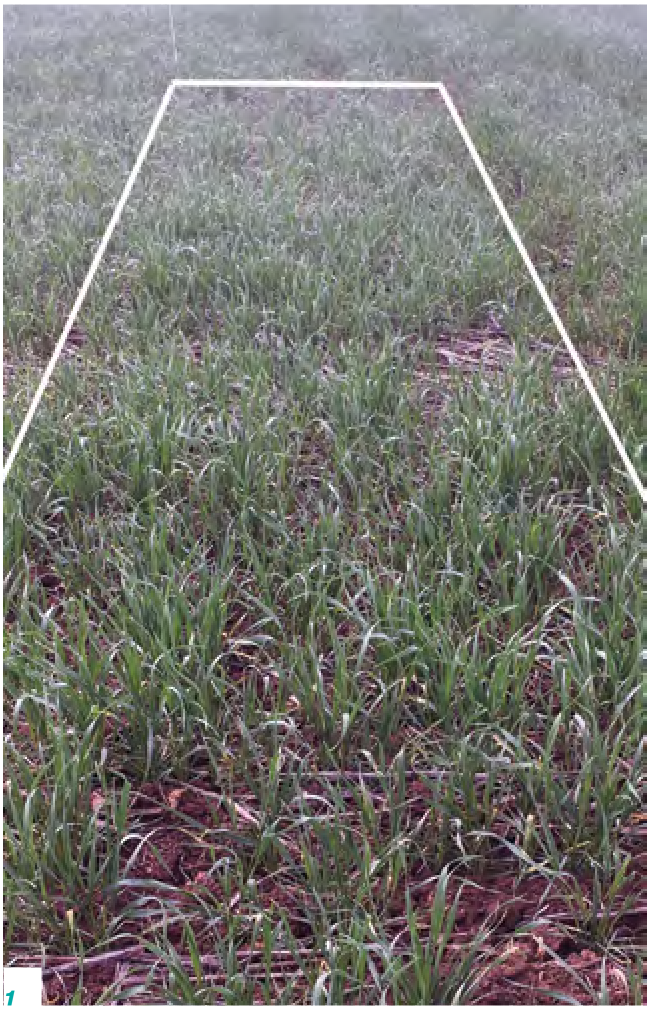
Later nitrogen applications in the low EM trial resulted in significant increases in protein, but no significant yield increases.

Crop in the low EM zone was more efficient in converting DM into yield. Harvest DM, when averaged across each zone, was 1.82t/ha greater in the high EM zone compared with the low EM zone, however average trial yields were 0.45t/ha greater in the low EM zone (Table 9).

TABLE 9 Key differences between the high and low EM zones at Yarrawonga, Victoria

	High EM zone	Low EM zone
Dry matter (t/ha)	13.2–16.2	11.9–13.8
Yield (t/ha)	5.74–6.29	6.38–7.01
Protein (%)	9.3–13.4	9.4–11.8

As the season was very dry from spring until harvest, the low EM zone can be assumed to have better water holding capacity than the high EM zone of the paddock. This can be understood by comparing yield across each zone, with higher yields in the low EM zone for the 120kg N/ha treatment (6.86t/ha) compared with the 120kg N/ha treatment yield in the high EM Zone (6.19t/ha).



1

2

***1** Nil nitrogen treatment, GS31, 11 July 2017*

***2** Nitrogen rich plot (120 N) plot, GS31, 11 July 2017*

Site 2: Dookie, Victoria

Sowing date: 12 May, 2017
Rotation: First wheat after canola
Variety: Trojan
Stubble: Canola unburnt
Rainfall:
GSR: 281mm (April–October)
Summer rainfall: 82mm

Trial 1: High EM zone Dookie, Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017)
0–10cm: 120.4kg N/ha
10–30cm: 46.0kg N/ha
30–60cm: 39.1kg N/ha
Total (0–60cm): 205.5kg N/ha

TABLE 11 Plant counts 6 June 2017, three leaf (GS13); tiller counts 25 July 2017, beginning of stem elongation (GS30)

Treatment	Crop growth stage	
	Plants/m²	Tillers/m²
	GS13	GS30
Nil N	156[a]	378[ab]
40 N	168[a]	386[ab]
80 N	-	361[b]
120 N	-	380[ab]
160 N	-	416[a]
NDVI 1 (80 N)	-	-
NDVI 2 (80 N)	-	-
120 N (N rich)	163[a]	405[ab]
Mean	**162**	**366**
LSD	20	41

Note that only 50% of the nitrogen in the 80, 120 and 160kg N/ha and NDVI treatments had been applied at the time of the tillering assessment (GS22 -28 June)
Figures followed by different letters are regarded as statistically significant.

Results

i) Establishment and crop structure

The site averaged 162 plants/m², with 120kg N/ha applied at the three-leaf stage (GS13) having no effect on plant establishment numbers over the nil or 40kg N/ha treatments. Tiller numbers were only significantly different between the 80kg N/ha treatment (361 tillers/m²) and the 160kg N/ha treatment (416 tillers/m²). Across the rest of the treatments there was no significant difference in tiller numbers, which is likely due to high levels of available soil nitrogen (Table 11).

ii) Dry matter production and nitrogen uptake

Dry matter assessments at the Dookie high EM site were lower than those recorded at the Yarrawonga site. When assessed at the mid-flowering stage (GS65) only the nitrogen-rich treatment (120 N) had significantly more DM than the nil nitrogen control. However, at physiological maturity (GS92) higher nitrogen rates in the 160 N and 120 N treatments resulted in significantly higher DM than the nil nitrogen control (Table 12).

iii) Normalised difference vegetation index

At this site, despite high levels of available soil nitrogen there was evidence the crop was taking up nitrogen and increasing crop canopy biomass as a result of fertiliser application. The NDVI value of the nil nitrogen plots at the mid-booting (GS45) and flowering stages (GS65) was significantly less than those plots that received 80kg N/ha or more. The difference in NDVI value between the NDVI 1 and NDVI 2 treatments is a result of the earlier timed second dose of nitrogen in NDVI 1 (GS32) compared with NDVI 2 (GS39). There was no increase in NDVI achieved by exceeding 80kg N/ha (Figure 3).

TABLE 10 High EM zone treatment list, Dookie, Victoria

Treatment	12 May GS00	8 June GS13	28 June GS22	25 July GS30	17 August GS32	14 September GS39	Total
	(kg N/ha¹)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)
Nil N	6	0	0	0	0	0	6
40 N	6	0	20	20	0	0	46
80 N	6	0	40	40	0	0	86
120 N	6	0	60	60	0	0	126
160 N	6	0	80	80	0	0	166
NDVI 1* (80N)	6	0	40	0	40	0	86
NDVI 2* (80 N)	6	0	40	0	0	40	86
120 N (N rich)	6	120	0	0	0	0	126

NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots (120kg N/ha). A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 looked at standard timings of nitrogen whereas NDVI 2 looked at later splits of the timing of the same amount of nitrogen.
[1] GS00 nitrogen (6kg N/ha) was applied as 60kg MAP/ha, all other nitrogen was applied as urea (46% N).

TABLE 12 Dry matter production 12 October 2017, mid-flowering (GS65) and 28 November 2017, physiological maturity (GS92) for the high EM zone, Dookie, Victoria

Treatment	Dry matter t/ha	
	GS65	GS92
Nil N	7.90^{b}	9.69^{b}
40 N	8.14^{ab}	10.24^{ab}
80 N	9.23^{ab}	10.76^{ab}
120 N	8.42^{ab}	10.72^{ab}
160 N	9.42^{ab}	11.62^{a}
NDVI 1 (80 N)	9.36^{ab}	11.16^{ab}
NDVI 2 (80 N)	9.17^{ab}	10.84^{ab}
120 N (N rich)	9.52^{a}	11.91^{a}
Mean	**8.90**	**10.78**
LSD	1.61	1.68

Figures followed by different letters are regarded as statistically significant.

iv) Grain yield and quality

The trial was harvested on 12 December 2017 and averaged 4.16t/ha (Table 13). The maximum yield response to nitrogen of 1t/ha was obtained from the split application of 120kg N/ha applied at tillering (GS22) and the start of stem elongation (GS30). Applying 120 kg N/ha in a split application of 60kg N/ha at tillering (GS22) and 60kg N/ha at the beginning of stem elongation (GS30) resulted in significantly more yield than the same dose applied at the three-leaf stage (GS13) and the 40kg N/ha treatment split into 20kg N/ha applications at GS22 and GS30. The higher yielding of the two NDVI-based treatments (NDVI 1) received 80kg N/ha split as two 40kg N/ha applications at GS22 and GS32 and produced the same yield and protein as the 120kg N/ha treatment, which received two split applications of 60kg N/ha at GS22 and GS30.

In terms of grain quality there were no differences in screenings across treatments, despite lower test weights (TSW) with higher nitrogen rates. Applying 160kg N/ha significantly reduced test weight over the nil, 40kg N/ha and NDVI treatments, however these differences were relatively small.

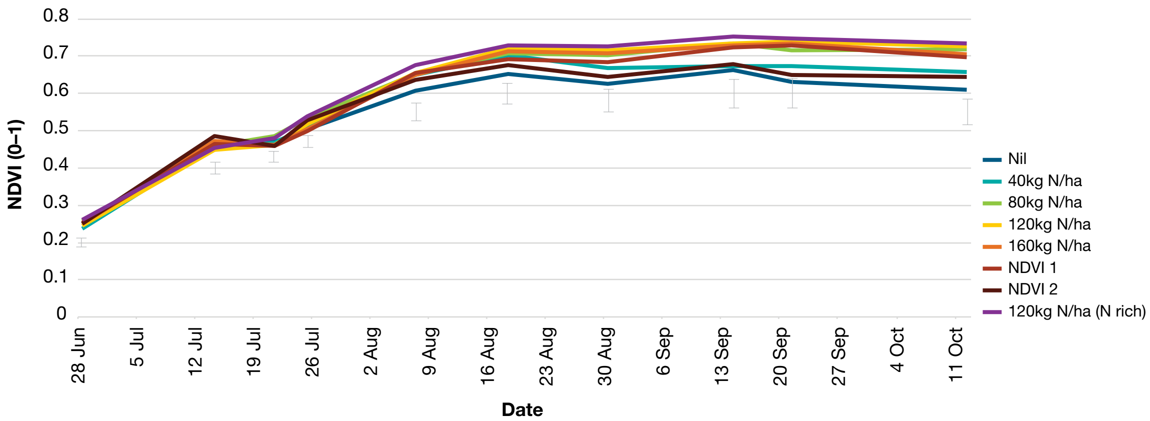


FIGURE 3 NDVI readings on 28 June, two tillers (GS22); 14 July, three tillers (GS23), 21 July, late tillering (GS24); 25 July, beginning of stem elongation (GS30); 7 August, first node (GS31); 17 August second node (GS32); 30 August, flag leaf beginning to emerge (GS37); 14 September, flag leaf fully emerged (GS39); 21 September, mid-booting (GS45) and 12 October, mid-flowering (GS65) for the high EM zone, Dookie, Victoria

TABLE 13 Yield, protein, test weight, screenings and thousand seed weight (TSW) at harvest (GS99) for the high EM zone, Dookie, 12 December 2017

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	3.59^{d}	10.2^{d}	78.6^{a}	1.5^{a}	42.2^{a}
40 N	3.77^{cd}	10.5^{cd}	78.3^{a}	1.5^{a}	41.0^{abc}
80 N	4.36^{abc}	11.6^{b}	78.2^{ab}	1.3^{a}	39.5^{bcd}
120 N	4.59^{a}	11.5^{b}	78.2^{ab}	1.2^{a}	40.0^{bcd}
160 N	4.42^{abc}	12.5^{a}	77.5^{b}	1.4^{a}	38.1^{d}
NDVI 1 (80 N)	4.47^{ab}	11.5^{b}	78.3^{a}	1.4^{a}	39.3^{cd}
NDVI 2 (80 N)	4.19^{a-d}	11.3^{bc}	78.5^{a}	1.4^{a}	41.3^{ab}
120 N (N rich)	3.91^{bcd}	10.9^{bcd}	78.1^{ab}	1.5^{a}	39.8^{bcd}
Mean	**4.16**	**11.2**	**78.2**	**1.4**	**40.2**
LSD	0.67	0.8	0.7	0.5	1.9

Figures followed by different letters are regarded as statistically significant.

1 Dookie high EM zone site 9 June 2017 (GS13)

2 Nil nitrogen treatment at GS30, 25 July, 2017

3 Nitrogen rich (120 N) treatment at GS30, 25 July, 2017



Trial 2: Low EM Zone, Dookie Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017)
0–10cm: 96.7kg N/ha
10–30cm: 43.1kg N/ha
30-60cm: 41.9kg N/ha
Total **(0–60cm):** 181.7kg N/ha

Results

i) Establishment and crop structure

The low EM zone had an average plant population of 166 plants/m^2, with nitrogen applied at the three-leaf stage (nitrogen-rich treatment) having no effect on plant population (Table 15). In this zone there was a non-significant trend for higher tiller numbers where 120kg N/ha was applied early.

ii) Dry matter production

At mid-flowering the only significant difference in DM was where no nitrogen was applied and where 120kg N/ha (N rich) was applied at the three-leaf stage (GS13) (Table 16). However, by physiological maturity (GS92) there was a clear trend suggesting plots that received nitrogen fertiliser had higher DM than those plots where no nitrogen was applied. Significantly more DM was produced where 40, 120kg N/ha (N rich) and 160kg N/ha were applied than in the nil nitrogen treatment.

For the low EM zone, as well as for the high EM zone at this site, 120kg N/ha applied at the three-leaf stage (GS13) produced significantly higher DM than the equivalent amount of nitrogen applied at tillering and the start of stem elongation (GS30) (Table 16).

TABLE 15 Plant counts 6 June 2017, three leaf (GS13); tiller counts 25 July 2017, beginning of stem elongation (GS30), low EM zone, Dookie, Victoria

	Crop growth stage	
	Plants/m^2	Tillers/m^2
Treatment	GS13	GS30
Nil N	163^{a}	377^{a}
40 N	164^{a}	398^{a}
80 N	-	402^{a}
120 N	-	404^{a}
160 N	-	422^{a}
NDVI 1 (100 N)	-	-
NDVI 2 (100 N)	-	-
120 N (N rich)	170^{a}	427^{a}
Mean	**166**	**405**
LSD	27	51

Note that only 50% of the nitrogen in 40 N, 80 N, 120 N and 160 N treatments had been applied at the time of the tillering assessment.

TABLE 16 Dry matter production 12 October 2017, mid-flowering (GS65) and 28 November 2017, physiological maturity (GS92), low EM zone, Dookie, Victoria

	Dry matter (t/ha)	
Treatment	GS65	GS92
Nil N	5.86^{b}	7.19^{d}
40 N	6.65^{ab}	8.66^{bc}
80 N	6.46^{ab}	7.61^{cd}
120 N	6.14^{ab}	8.09^{bcd}
160 N	6.72^{ab}	8.59^{bc}
NDVI 1 (100 N)	6.39^{ab}	8.53^{bc}
NDVI 2 (100 N)	6.60^{ab}	9.22^{ab}
120 N (N rich)	7.16^{a}	9.98^{a}
Mean	**6.50**	**8.48**
LSD	1.29	1.13

Figures followed by different letters are regarded as statistically significant.

TABLE 14 Treatment list low EM zone, Dookie Victoria

	12 May GS00	8 June GS13	28 June GS22	25 July GS30	17 August GS32	14 September GS39	Total
Treatment	(kg N/ha[1])	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)
Nil N	6	0	0	0	0	0	6
40 N	6	0	20	20	0	0	46
80 N	6	0	40	40	0	0	86
120 N	6	0	60	60	0	0	126
160 N	6	0	80	80	0	0	166
NDVI 1* (100 N)	6	0	40	0	60	0	106
NDVI 2* (100 N)	6	0	40	0	0	60	106
120 N (N rich)	6	120	0	0	0	0	126

* NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots. A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 looked at standard timings of nitrogen whereas NDVI 2 looked at later splits of the timing of the same amount of nitrogen.

[1]GS00 nitrogen (6kg N/ha) was applied as 60kg MAP/ha, all other nitrogen *was* applied as urea (46% N).

iii) Normalised difference vegetation index

Similarly to the high EM zone, and despite large quantities of available soil nitrogen, the crop canopy clearly responded to applied nitrogen fertiliser with significantly higher NDVI where nitrogen was applied (Figure 4). There was no significant difference in NDVI readings between the 40kg N/ha and 160kg N/ha treatments when nitrogen was applied at the same growth stages (GS22 and GS30), or the NDVI 1 treatment, which received 100 kg N/ha after sowing. The NDVI 2 (100 N) treatment received a later application of nitrogen (final 60kg N/ha dose applied at flag-leaf emergence — GS39) and gave consistently lower NDVI readings. This suggests the final dose at flag-leaf emergence (GS39) was too late, whereas the second node application (GS32) was well timed.

In the high EM zone, the nil nitrogen plots generated maximum NDVI values of 0.67 compared with the low EM zone where the nil nitrogen plots gave a maximum NDVI value of 0.61. The lower overall NDVI values measured through the growing season in the low EM zone also correspond to lower final DM in the low EM zone at harvest, with an average of 8.48t/ha DM compared with 10.38t/ha in the high EM zone.

iv) Grain yield and quality

The trial in the low EM zone at Dookie yielded an average 3.61t/ha compared with 4.16t/ha in the high EM zone. Although there was a trend to suggest applied nitrogen increased yield, the differences were not statistically significant across any treatments. The high grain protein levels from the nil nitrogen plots (11.9%) suggests there was sufficient nitrogen in the soil to satisfy both yield and protein requirements, given protein levels above 11% frequently indicate that nitrogen for yield has not been limiting (Table 17).

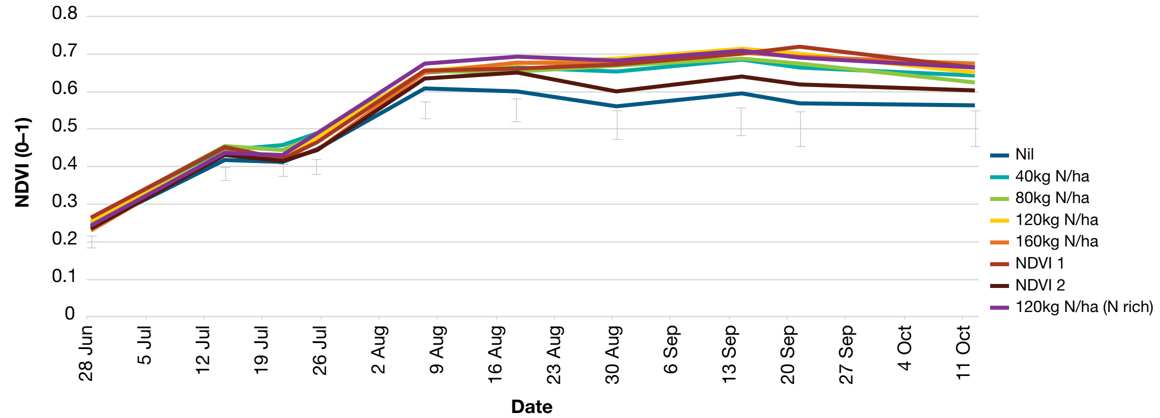


FIGURE 4 NDVI readings on 28 June, two tillers (GS22); 14 July, three tillers (GS23); 21 July, late tillering (GS24); 25 July, beginning of stem elongation (GS30); 7 August, first node (GS31); 17 August, second node (GS32); 30 August, flag leaf beginning to emerge (GS37); 14 September, flag leaf fully emerged (GS39); 21 September, mid-booting (GS45) and 12 October, mid-flowering (GS65) for the low EM zone, Dookie Victoria

TABLE 17 Yield, protein, test weight and screenings at harvest (GS99), for the low EM zone at Dookie, 12 December 2017

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	3.31^{a}	11.9^{b}	76.3^{a}	1.8^{a}	36.4^{a}
40 N	3.37^{a}	13.5^{ab}	73.9^{ab}	2.0^{a}	34.4^{ab}
80 N	3.25^{a}	14.0^{a}	75.6^{ab}	1.8^{a}	34.6^{ab}
120 N	3.80^{a}	14.7^{a}	73.4^{b}	3.4^{a}	30.9^{b}
160 N	3.74^{a}	14.1^{a}	76.2^{a}	2.1^{a}	31.5^{ab}
NDVI 1 (100 N)	3.76^{a}	14.6^{a}	75.4^{ab}	1.9^{a}	33.6^{ab}
NDVI 2 (100 N)	3.85^{a}	13.7^{a}	75.6^{ab}	1.6^{a}	35.3^{ab}
120 N (N rich)	3.82^{a}	14.5^{a}	74.8^{ab}	2.3^{a}	32.5^{ab}
Mean	**3.61**	**13.8**	**75.1**	**2.1**	**33.7**
LSD	0.77	1.6	2.8	1.9	5.0

Figures with different letters are regarded as statistically significant.
Note: Some grain may have been lost due to hail storm at this site. High grain protein in the nil plots suggests nitrogen for this site was not limiting.



1 Dookie low EM zone site, 26 June 2017

2 Nil N treatment at GS30, 25 July 2017

3 Nitrogen rich (120 N) at GS30, 25 July 2017

v) Comparison of DM, yield and protein across EM zones

At Dookie, an NDVI treatment was the highest yielding in both EM zones and also gave the best yield response to amount of nitrogen applied.

The highest yielding treatment in the high EM Zone was NDVI 1, which had 80kg N/ha applied (40kg N/ha at GS22 and 40kg N/ha at GS32) and yielded 4.47t/ha. The highest yielding treatment in the low EM zone treatment was NDVI 2, which received 100kg N/ha (40kg N/ha at GS22 and 60kg N/ha at GS39) and yielded 3.85t/ha.

The high EM zone crop was also much more efficient at turning DM into yield. Average harvest DM in the high EM zone was 10.78t/ha, while the average yield was 4.16t/ha. In the low EM zone, average harvest dry matter was 8.48t/ha while yield was 3.61t/ha (Table 18).

High protein, which was above 11.9% for all treatments in the low EM zone, showed that adequate nitrogen was available for the crop to satisfy both yields and protein requirements. The optimum treatment for protein response in the high EM zone was 160kg N/ha, which produced grain at 12% protein.

TABLE 18 Key differences between high and low EM zones at Dookie, Victoria

	High EM zone	Low EM zone
Dry matter (t/ha)	9.69–11.91	7.19-9.98
Yield (t/ha)	3.59–4.59	3.25–3.85
Protein (%)	10.2-12.5	11.9-14.7

Acknowledgements

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In-paddock variability — a snapshot and lessons learnt

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Key points

- Electromagnetic (EM) zoning was strongly related to differences in pH at 10–30cm depth in two out of three paddocks.
- All three paddocks showed variability in chemical properties, with the EM zoning showing good separation of chemical properties between zones. This provides confidence that the zoning was suitable.
- Variability in plant growth needs to be examined ‘holistically’ rather than just focussing on one variable. While a paddock may show variation in plant available water (PAW), it may be that sodicity or subsoil acidity is the key limiter in plant performance, not water availability *per se*.
- Existing precision agriculture (PA) datasets, in conjunction with selected chemistry sampling, can be used to indicate relative change in PAW across paddocks, but not the actual volume of water storage.

Background

Grain growers have readily adopted PA technologies, such as GPS-guidance, controlled-traffic and yield mapping. As such, they are the custodians of large datasets, including EM38 surveys (EM), yield maps, normalised difference vegetation index (NDVI) maps and soil analytical results. The oft-heard question from early adopters of PA technology is “I have filing cabinets and hard-drives full of data, but what can I do with it?”.

This project evolved from initial discussions with growers from the Riverine Plains region, with the aim of understanding if growers could use the existing datasets they are collecting to create something greater. This included developing predictions of in-paddock variability, with a strong focus on developing predictions for PAW variations within a paddock so growers could create meaningful zones for nutrient management (especially nitrogen).

To further this understanding, Riverine Plains Inc, through the PA component of the GRDC investment *Maintaining profitability of stubble retained systems in the Riverine Plains region* (*Stubble*) project, partnered with several organisations with a range of skills and expertise, to explore the value of this approach. Unique to this aspect of the project was the collegial approach, where all parties appreciated the value of the work, and contributed considerable in-kind support. Riverine Plains Inc supported this work by identifying the required inputs (through grower consultation), managing the data and driving the interpretation of results by connecting with organisations with specialist skills.

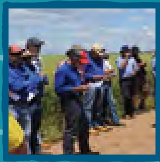
All of the field work and measurement for this work was completed during the 2017 season. While the end-goal of being able to predict in-paddock variability through utilising existing datasets is still in progress, the various datasets collected through this work tell an interesting story around in-paddock variability, as described below.

In addition to the research described in this report, the PA component of the GRDC *Stubble* project also included a series of small plot nitrogen response trials across contrasting EM zones (Report on page 42), and the economic and financial value of zoning for variable rate nitrogen, based on EM38 surveys (Report on page 66).

Aim

The aims of the PA component of the GRDC *Stubble* project were to:

- deliver a pilot project to understand how soil parameters, including PAW, vary across a paddock and understand whether current PA datasets can correlate with PAW
- connect variations in soil moisture with nitrogen supply
- demonstrate the use of NDVI to inform variable rate applications of nitrogen
- determine the economic value of variable rate nitrogen application across paddocks, based on zones



Methodology

Four Riverine Plains region paddocks were selected at Howlong (canola), Rutherglen (wheat), Telford (wheat) and Yabba South (wheat). Existing EM38 maps were used to generate three initial zones for each paddock, labelled the 'high, medium, and low EM zones'. A weather station was located in each paddock to provide local climatic data, with 1.4m depth capacitance soil moisture probes also installed into the 'high' and 'low' zones to determine the comparative depth and degree of moisture extraction by plants. Due to issues associated with the interpretation of technical data, the Telford results have been omitted from this report.

Sampling was done at common GPS-locations across each paddock. Incremental soil sampling was carried out to a depth of 0.6m for spatial soil chemistry, while intact cores were taken for PAW measurement. Incremental deep soil nitrogen (DSN) and dry matter (DM) sampling was carried out through the growing season and post-harvest.

Subsamples from all intact cores were used to measure PAW by water extraction from saturated samples at 10 and 1500kPa on ceramic pressure plates. Subsamples were also air-dried and processed through mid-infrared (MIR) spectral scanning and regression models to predict PAW directly from the spectra. The infrared spectra were recorded by diffuse reflectance for 10 seconds in a range from 8000–400cm^{-1} on <2mm, 0.5g subsamples, with the 4000–700cm^{-1} MIR region used to derive the partial least squares regression (PLSR) calibration models. This means the PAW of soils was tested directly and also predicted by MIR, which may provide a cost-effective alternative in the future.

Two sets of NDVI satellite images were taken across each paddock through the season to understand variability in plant 'greenness', which may be correlated to nitrogen supply. Where possible, yield maps were accessed from previous years, with yield map data also collected during 2017.

All these different datasets were then collated, aligned and interpolated in order to layer the data in a web-based mapping tool, and so interrogate and determine any relationships. This interrogation is still in-train, subject to ongoing funding.

Results

There is a huge dataset associated with this work, which cannot all be described in this report. As such, this report provides a snapshot of some key parameters.

The dates at which the various activities were carried out are listed in Table 1.

TABLE 1 Dates of activities at the Howlong, Rutherglen and Yabba South trial paddocks in 2017

Activity	Date
Soil chemistry sampling	16/5/17
Intact core sampling for PAW	7 and 8/6/17
End of tillering soil nitrogen, plant number, tiller number, DM cuts	29 and 30/8/17
Satellite NDVI	31/8/17
Satellite NDVI	15/10/17
Flowering DSN and DM cuts	24/10/17
Howlong harvest	7/12/17
Rutherglen harvest	15/12/17
Yabba South harvest	18/12/17

Paddock 1: Yabba South

Soil chemistry

Soil chemistry results from the Yabba South paddock show that soil pH was similar in the surface 0–10cm layer across the three zones, with values above pH$_{Ca}$ 5.0 (Figure 1). However, the low zone showed a significant drop in pH in the 10–30cm depth compared with the other zones, which maintained their values.

No real differences between zones are seen in the soil electrical conductivity (EC) and exchangeable sodium percentage (ESP) values at the 0–10cm, 10–30cm and 30–60cm depths (Figures 2 and 4).

At the 0–10cm depth, organic carbon (OC) values show a decrease in the low zone (1.38%) compared with the medium (1.99%) and high (2.24%) zones, which is a difference of 0.86% (Figure 3).

The differences in pH and organic carbon levels across zones can be largely attributed to the cation exchange

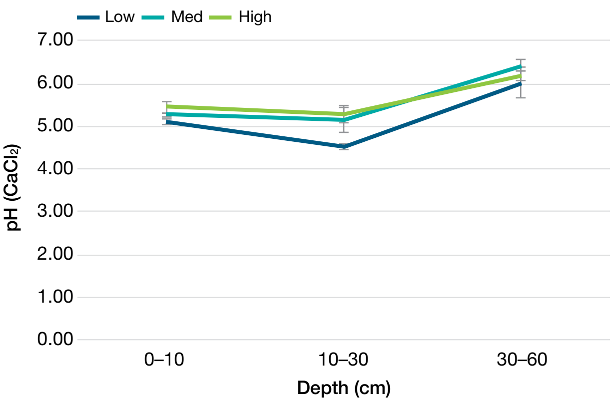


FIGURE 1 Soil pH$_{Ca}$ across three zones to depth at Yabba South

Bars are a measure of standard error.

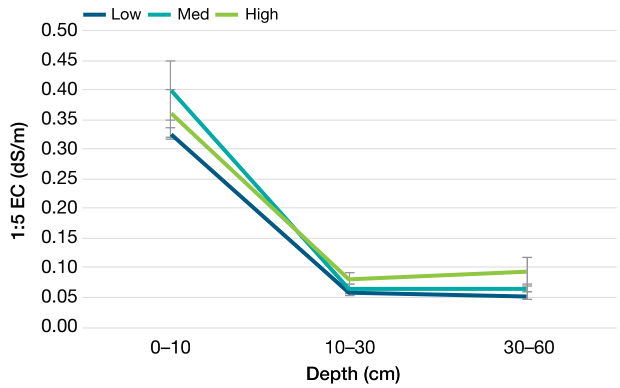


FIGURE 2 Soil EC across three zones to depth at Yabba South

Bars are measures of standard error.

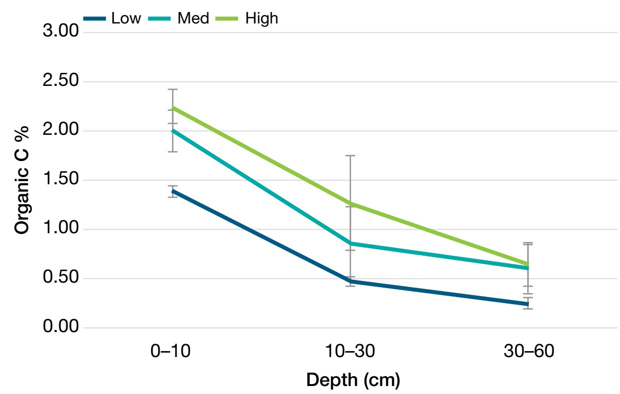


FIGURE 3 Organic carbon percentage across three zones to depth at Yabba South

Bars are measures of standard error.

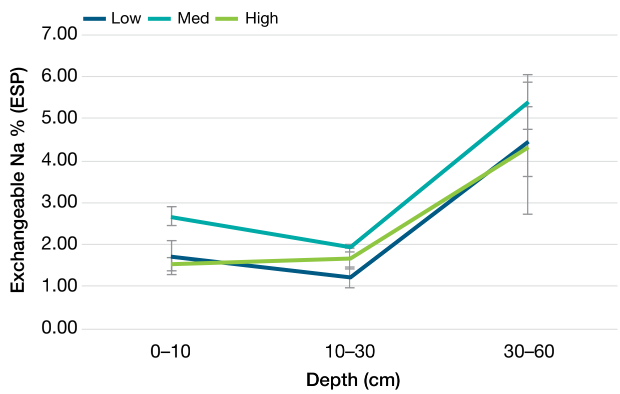


FIGURE 4 Exchangeable sodium percentage across three zones to depth at Yabba South

Bars are measures of standard error.

capacity (CEC) values across the zones (Figure 5). The CEC in the low zone is significantly less than the medium and high zones which means the low zone has less capacity to withstand chemical change, and so is likely to experience a greater rate of pH decline than higher CEC areas of the paddock. Clay content is indirectly measured by CEC, so soils with a higher clay content have a greater capacity to hold onto carbon through chemical interaction. This helps explain the differences in OC between zones.

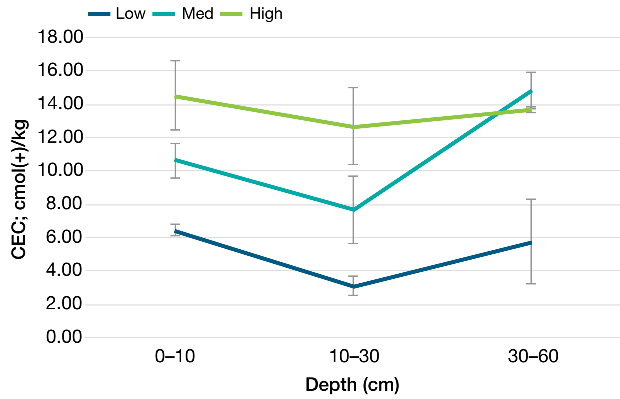


FIGURE 5 Effective cation exchange capacity across three zones to depth at Yabba South

Bars are measures of standard error

Soil PAW

The decreased CEC of the low zone (which relates to decreased clay content) correlated well with the PAW measurements (Figure 6). Increasing clay content results in less PAW (as water is strongly absorbed onto clay surfaces), so it makes sense that the low zone, which has a lower CEC and less clay, has a higher PAW content on a mm/mm basis down to 30cm. This results in a 16mm increase in stored water in the profile in the low zone compared with the high zone (Table 2).

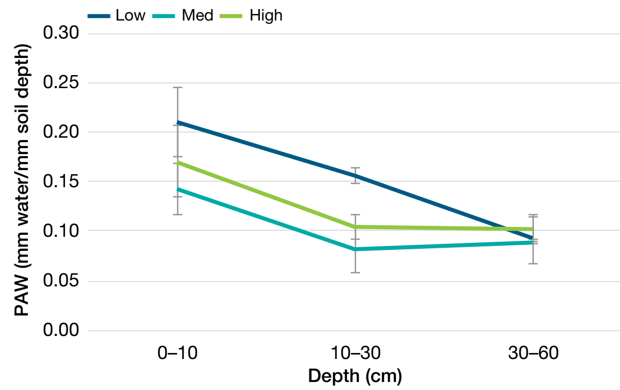


FIGURE 6 Plant available water across three zones to depth at Yabba South, measured as millimetres of water per millimetre soil depth

Note: These values increase when multiplied across the depth of sampling. For example, high zone 0–10cm depth = 0.17mm/mm x 100mm = 17.0 mm per 10cm depth.

Bars are measures of standard error

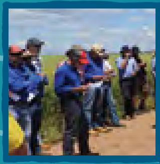


TABLE 2 Total PAW in the measured profile depth of 60cm across three zones at Yabba South, 2017

Zone	Total PAW/profile (mm)
High	68.1
Medium	65.5
Low	84.1

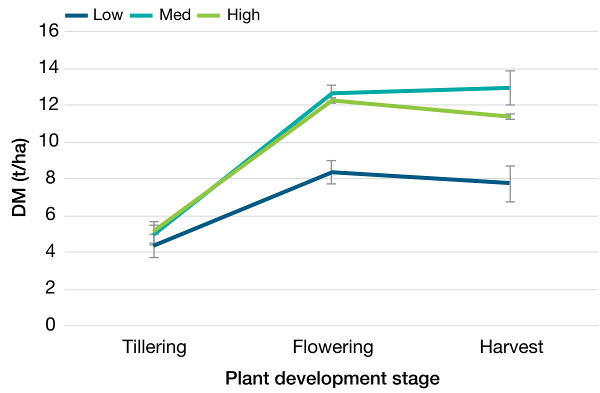


FIGURE 7 Dry matter across three zones to depth at Yabba South throughout the 2017 season

Bars are measures of standard error.

Dry matter and nitrogen

There were clear differences in DM between the low and medium–high zones (Figure 7). While the low zone has a higher PAW, and therefore a higher capacity to hold water, it will also dry out more quickly than heavier soils with a higher clay content. The dry spring conditions during 2017 likely meant the low zone 'ran out of puff' before the medium and high zones, which is reflected in the significantly lower DM results.

Comparison of measured PAW results and MIR predictions

The conventional method of measuring PAW is a slow, costly and laborious laboratory method using a series of pressure plates. The Australian Precision Ag Laboratory has been working with researchers to develop quick and cost-effective mid-infrared (MIR) predictions of PAW. The samples used for PAW analysis using pressure plate methodology were also used for MIR prediction.

Figure A and B show the strong correlation between the measured and predicted values for the Yabba South paddock. This means PAW may become a common-place parameter incorporated within a routine soil surface test, which would provide timely and highly valuable information.

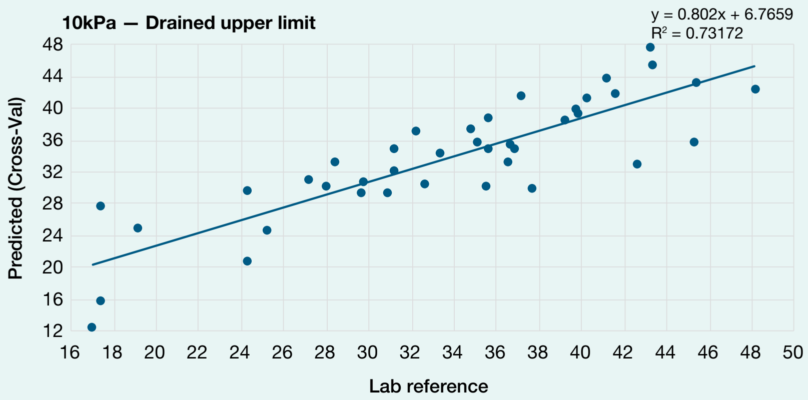


FIGURE A The relationship between the measured crop lower limit and the predicted value based on laboratory MIR analysis of the same samples

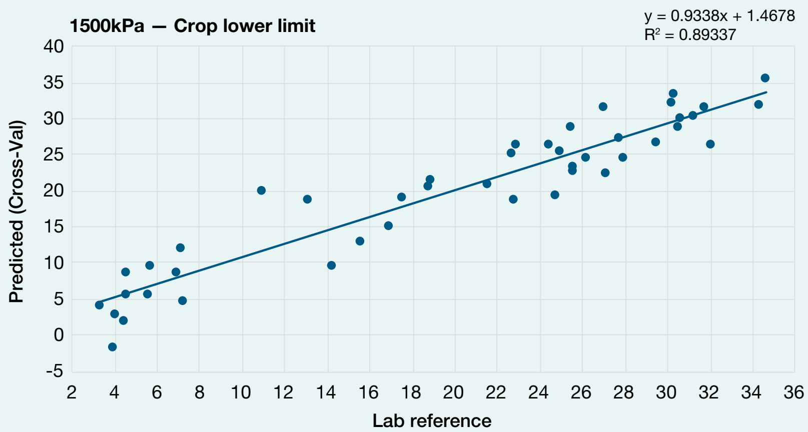


FIGURE B The relationship between the measured drained upper limit and the predicted value based on laboratory MIR analysis of the same samples

The mineral nitrogen numbers also reflect the variable production potential across the paddock (Figure 8). While all the nitrogen values at sowing are high (200–300kg N/ha) the high zone is lower, likely due to greater depletion of nitrogen from the previous crop.

The spatial data in Figure 9 shows how the EM zones created at the start of the 2017 season align with the NDVI values collected in-crop as well as the yield map. The yield map clearly shows the variation in productivity across the paddock, to the degree that assigning average yield values for each zone would be of limited value. The NDVI imagery from October 2017 clearly shows that the lighter soils of the low zone in the middle of the paddock are running out of water (indicated by the dark red colouring), which has resulted in a DM decrease and the yield penalty as seen on the yield map.

Paddock 2: Rutherglen

Soil chemistry

Soil chemistry results for the Rutherglen paddock show that while the soil pH_{Ca} values are above 5.0 in the surface 0–10cm, they decline in the 10–30cm zone to a range of pH_{Ca} 4.2–4.5 units (Figure 10). This resulted in aluminium levels of between 10–25 %Al (data not shown), which is likely to have a negative effect on plant growth. The pH drop in the 10–30cm zone corresponds to a decrease in the CEC in that zone (Figure 14), with the lower CEC (and clay content) at that depth meaning the soil has less ability to withstand chemical change and making it liable to greater rates of acidification. Although the differences are small, the high zone has a slightly higher pH_{Ca} value and associated CEC value than the low and medium zones, which also corresponds to a slightly higher organic carbon value (Figure 12).

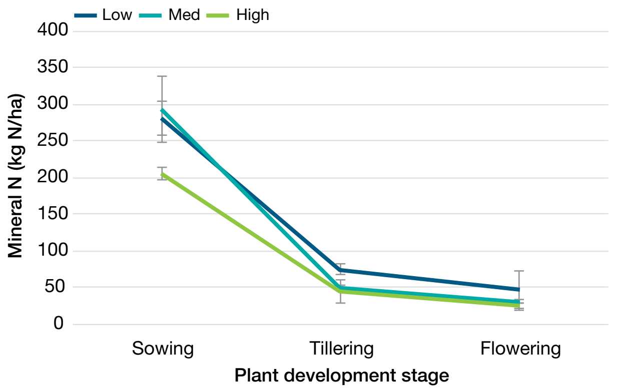


FIGURE 8 Mineral nitrogen to 60cm across three zones to depth at Yabba South throughout the 2017 season
Bars are measures of standard error

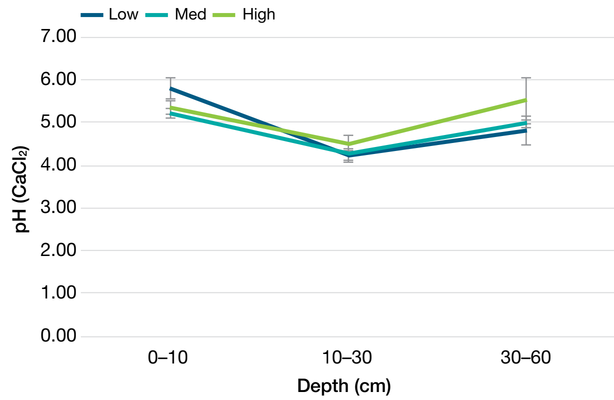


FIGURE 10 Soil pH_{Ca} across three zones to depth at Rutherglen
Bars are measures of standard error

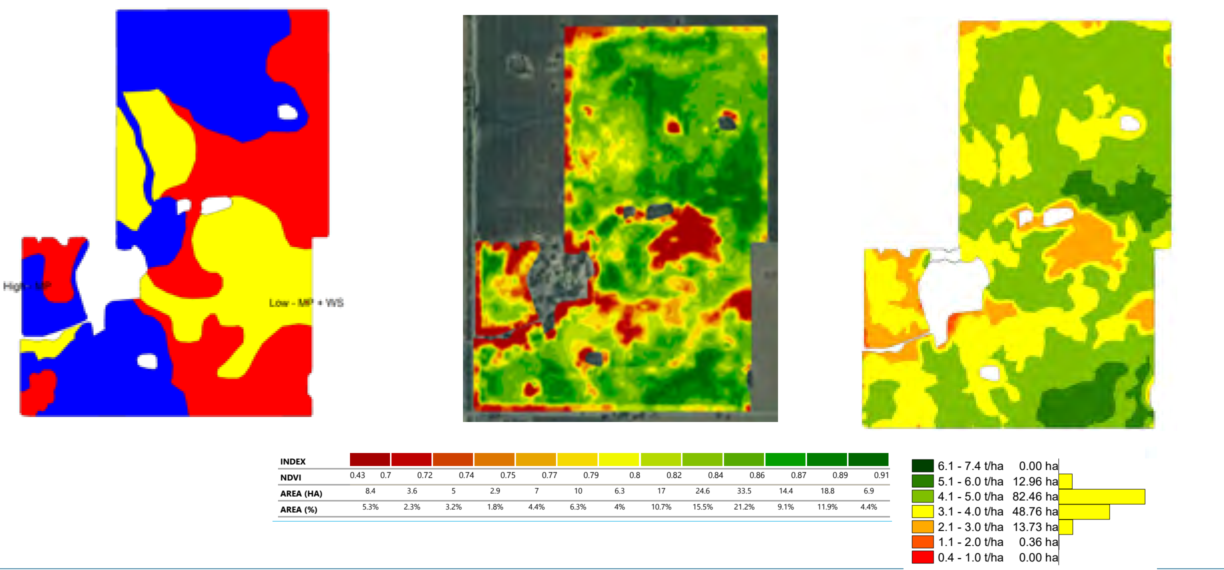


FIGURE 9 The allocation of zones and location of the weather station and soil moisture probes, NDVI satellite imagery collected 21 October 2017 and the Yabba South paddock yield map, 2017



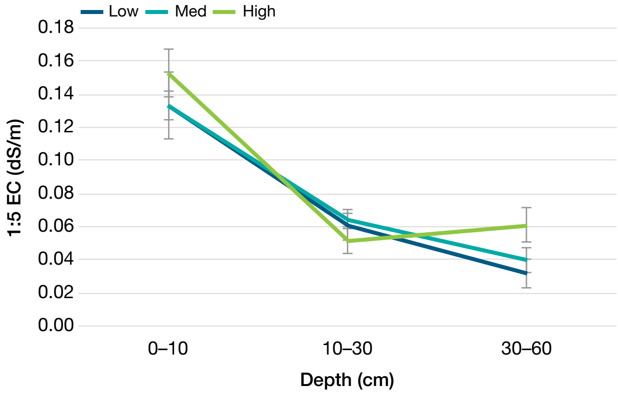


FIGURE 11 Soil EC across three zones to depth at Rutherglen
Bars are measures of standard error

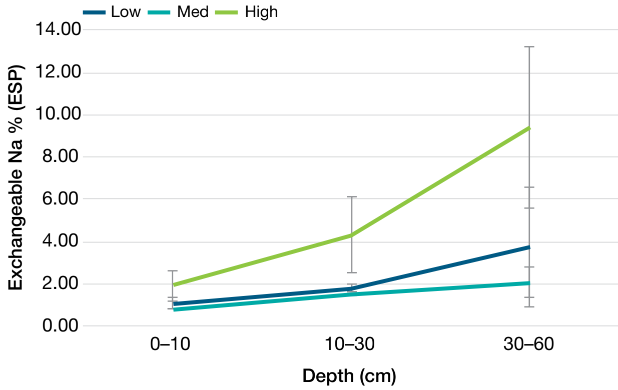


FIGURE 13 Exchangeable sodium percentage across three zones to depth at Rutherglen
Bars are measures of standard error

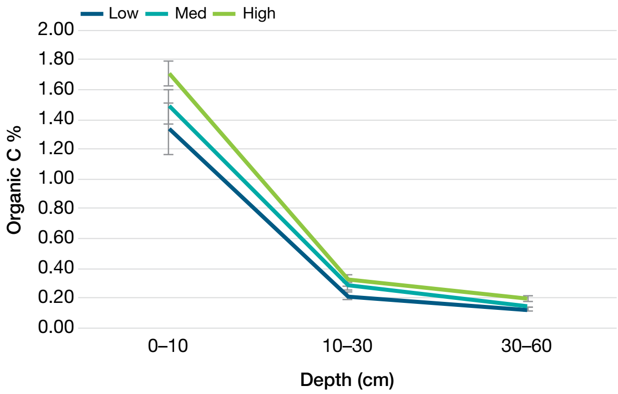


FIGURE 12 Organic carbon across three zones to depth at Rutherglen
Bars are measures of standard error

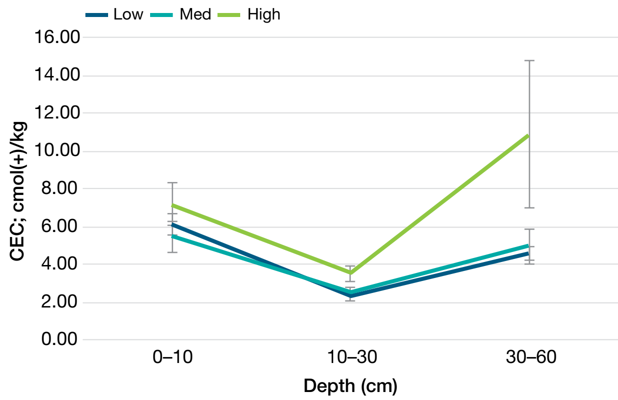


FIGURE 14 Effective cation exchange capacity across three zones at Rutherglen
Bars are measures of standard error

The soil EC values show limited differences between the zones (Figure 11), while the exchangeable sodium percentages (ESP) does show an increase in ESP (sodicity) at depth in the high zone (Figure 13).

Soil PAW

The higher CEC value of the high zone (Figure 14) correlates well with the plant available water (PAW) measures. This is based on the assumption that the high zone has a higher clay content at depth, which is supported by MIR predictions (data not shown). These PAW results show that the low and medium zones maintain a relatively constant PAW at depth, however the high zone PAW decreases significantly at depth (Figure 15), with approximately 40mm less water storage to 60cm depth compared to the low and medium zones (Table 3).

Dry matter and nitrogen

The DM cuts from the Rutherglen paddock show little variation between the zones throughout the season (Figure 16). This is aligned with the high starting mineral nitrogen values, which become relatively uniform as the season progressed (Figure 17).

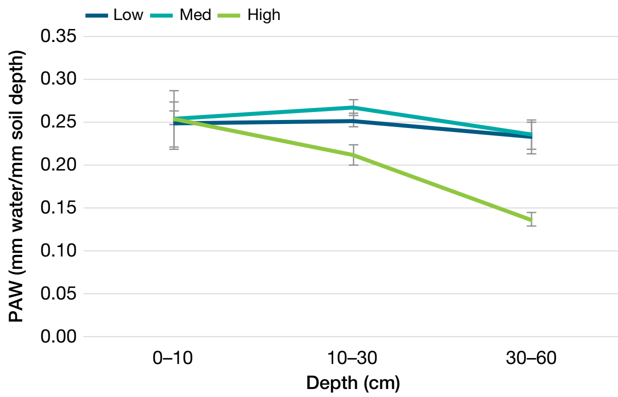


FIGURE 15 Plant available water across three zones to depth at Rutherglen, measured as millimetres of water per millimetre of soil depth
Note: These values increase when multiplied across the depth of sampling. For example, high zone 0–10cm depth = 0.17mm/mm x 100mm = 17.0mm per 10cm depth.
Bars are measures of standard error

TABLE 3 Total PAW in the measured profile depth of 60cm across the three zones in the Rutherglen paddock

Zone	Total PAW/profile (mm)
High	108.4
Medium	148.9
Low	145.0

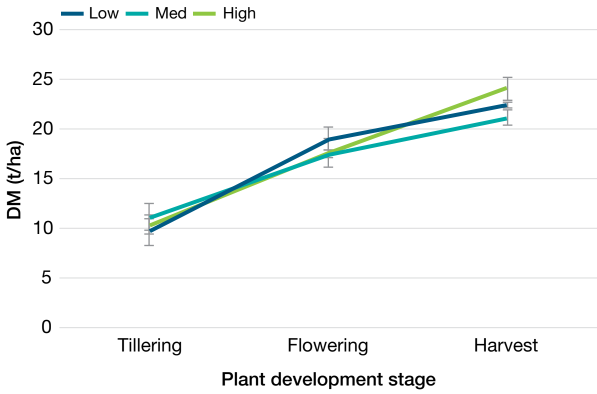


FIGURE 16 Dry matter across three zones to depth at Rutherglen throughout the 2017 season

Bars are measures of standard error

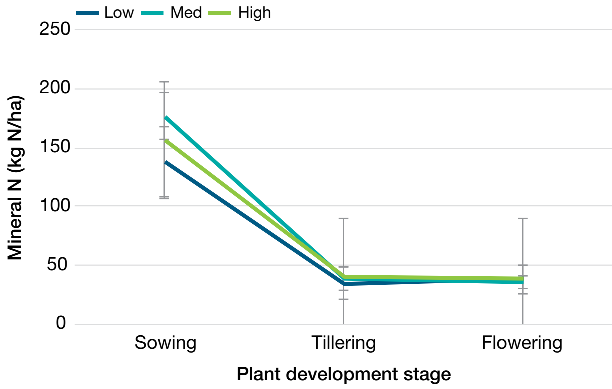


FIGURE 17 Mineral nitrogen to 60cm across three zones to depth at Rutherglen throughout the 2017 season

Zoning, NDVI and yield

The NDVI and yield maps show only limited variation in growth across the site (Figure 18), with the main variance being seen in the top half of the images. These images show that the lighter soil type in the low zone may be starting to run out of moisture, while the high zone may still have moisture available. Although the high zone has less total PAW (Table 3), the heavier clay content means that it will continue to supply PAW longer through a drying period than the low zone.

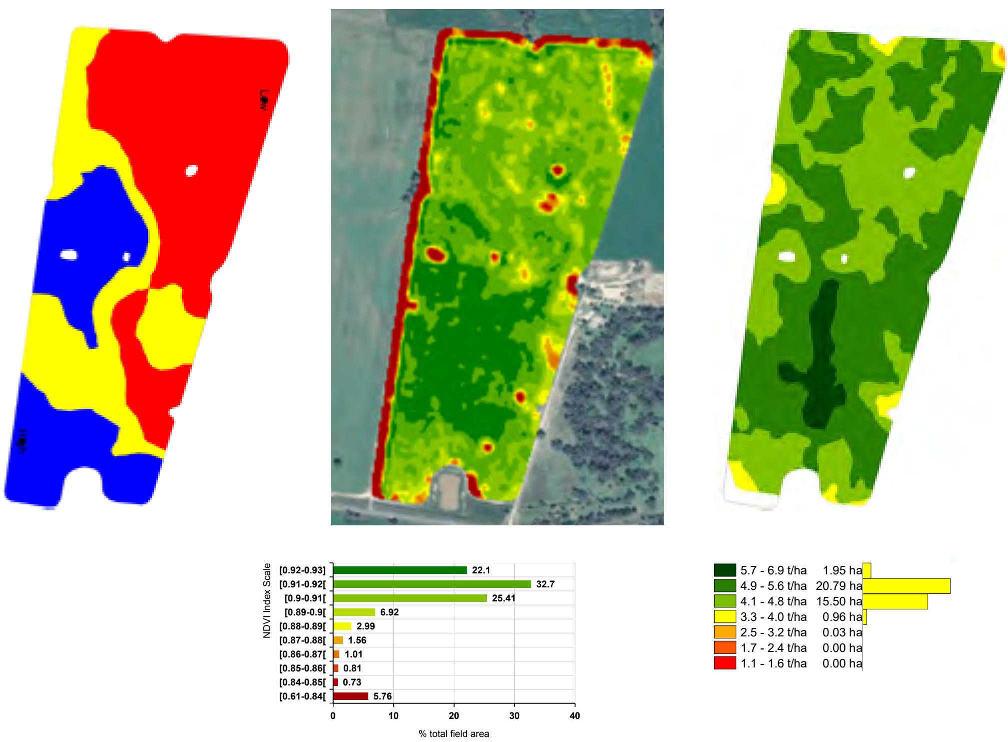


FIGURE 18 The allocation of zones and location of the weather station and soil moisture probes, NDVI satellite imagery collected 15 October 2017 and the Rutherglen paddock yield map, 2017

Paddock 3: Howlong

Soil chemistry

The Howlong paddock soil chemistry results tell a similar story to the other paddocks. The soil pH_{Ca} values are consistently lowest in the low zone, with the lowest values for all zones found at the 10–30cm depth (Figure 19). The EC and organic carbon values were also lowest in the low zone (Figures 20 and 21), as was ESP (Figure 22) and CEC (Figure 23).

Soil PAW

In conjunction with the MIR predictions of decreased clay content in the low zone (data not shown), these results indicate that the low zone has a lighter textured subsoil with a low capacity to buffer against chemical change. This means that the rate of subsoil acidification is likely to be higher in the low zone. It also means that the low zone has a slightly larger capacity to store PAW (Figure 24 and Table 4), however it is also likely to be the first zone to run out of water.

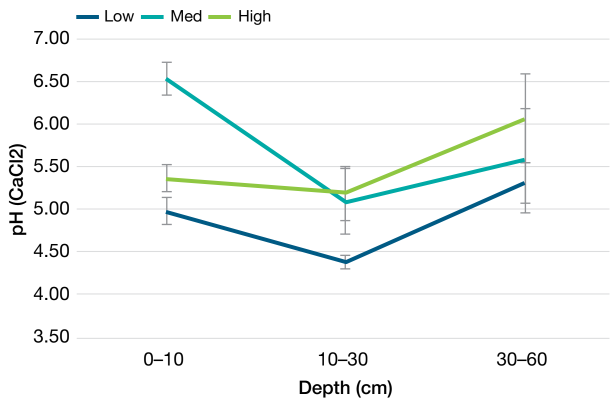


FIGURE 19 Soil pHCa across three zones to depth at Howlong
Bars are measures of standard error.

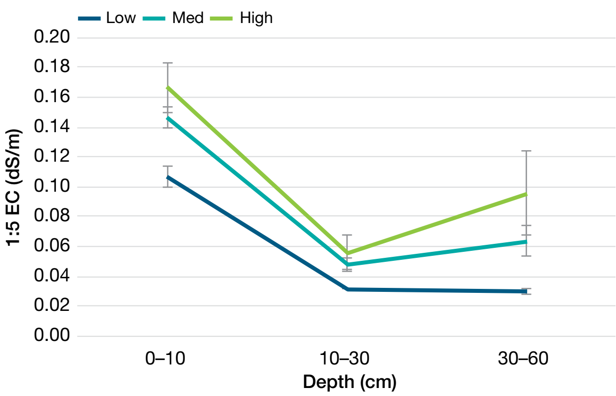


FIGURE 20 Soil EC across three zones to depth at Howlong
Bars are measures of standard error

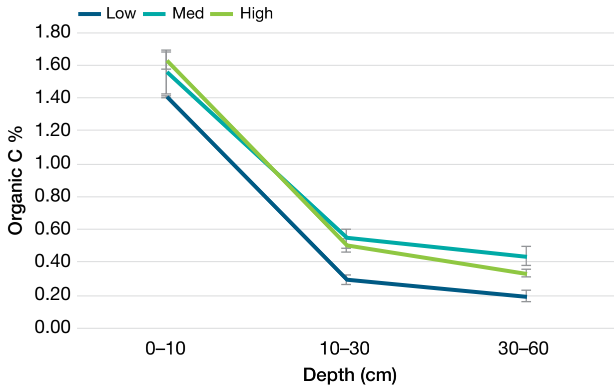


FIGURE 21 Organic carbon across three zones to depth at Howlong
Bars are measures of standard error

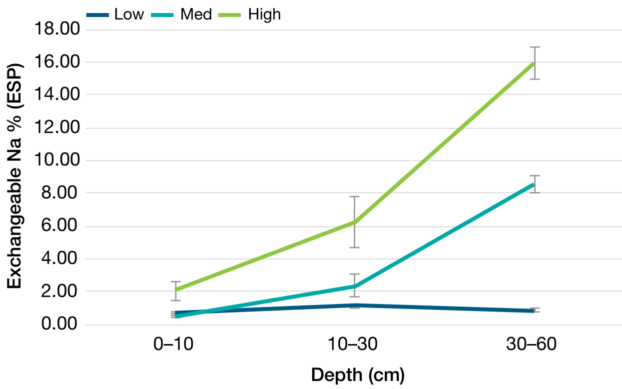


FIGURE 22 Exchangeable sodium percentage across three zones to depth at Howlong
Bars are measures of standard error

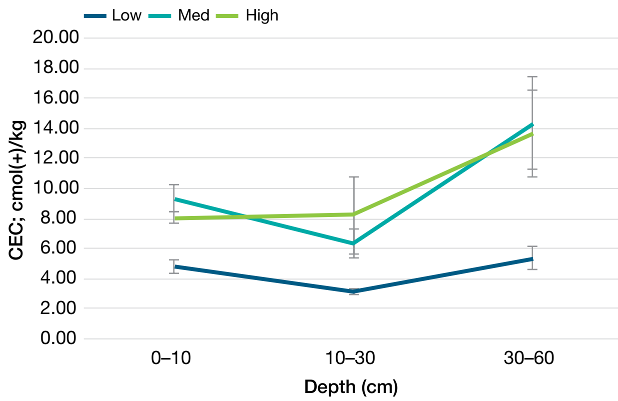


FIGURE 23 Effective cation exchange capacity across three zones to depth at Howlong
Bars are measures of standard error

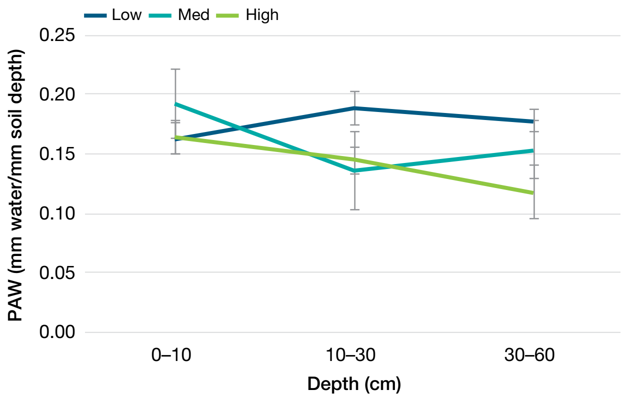


FIGURE 24 Plant available water across three zones to depth at Howlong, measured as millimetres of water per millimetre of soil depth

Note: These values increase when multiplied across the depth of sampling. For example, high zone 0–10cm depth = 0.17mm/mm x 100mm = 17.0 mm per 10cm depth.

Bars are measures of standard error

TABLE 4 Total PAW in the measured profile depth of 60cm across the three zones in the Howlong paddock

Zone	Total PAW/profile (mm)
High	80.8
Medium	92.7
Low	107.5

While the low zone has a lighter texture, with a lower clay content than the high zone, the high zone has a significantly higher ESP value at depth (Figure 22). This means that the high zone has more clay and a greater ability to hold water as the profile dries out. However, higher sodicity at depth will mean that the plant roots cannot easily extract all the water from that zone due to poor structure. As such, the actual plant-extractable water content may be relatively even across the paddock, with differences in DM between zones likely due to the slight effects of aluminium toxicity on canola roots in the low zone (Figure 25).

Nitrogen

Availability of mineral nitrogen through the season was similar across EM zones (Figure 26), with no clear zonal effects on NDVI or yield (Figure 27). This suggests that nutrition was adequate across zones, with any differences in PAW not enough to cause yield differences as a result of the dry spring conditions of 2017.

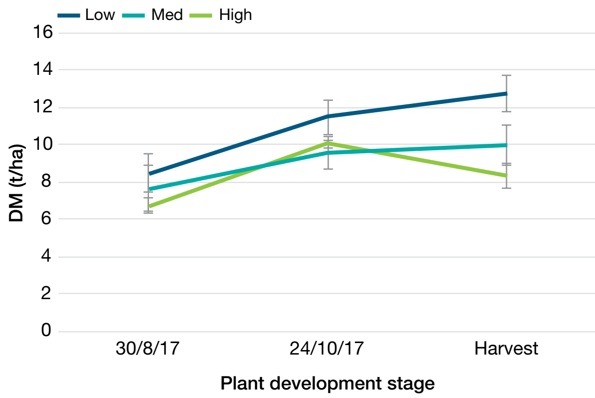


FIGURE 25 Dry matter across three zones to depth at Howlong throughout the 2017 season

Note: Dates are used rather than growth stages, as this crop was canola. While they were sampled at the same time as the wheat trials, the sampling date was not clearly aligned with crop stage; except for harvest

Bars are measures of standard error

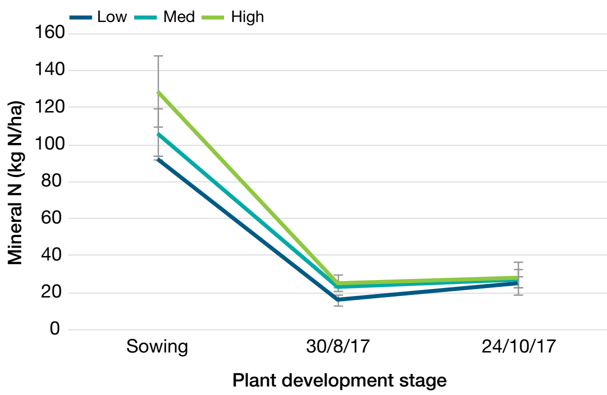


FIGURE 26 Mineral nitrogen to 60cm across three zones to depth at Howlong throughout the 2017 season

Bars are measures of standard error

Observations and comments

The field sampling from this project was intensive in order to attempt to validate the accuracy of the EM zoning for changes in soil chemical properties and to understand the relevance of that zoning for in-paddock PAW variance.

The results from this work show a clear delineation of soil chemical properties between zones, with significant differences being seen across a range of properties. The PAW measurements provided the link between these soil chemical parameters, and what that means for effective water uptake, with soil chemical parameters such as pH or sodicity sometimes acting to restrict plant uptake.

A key element of this project was the use of GPS-located sampling points, with all spatial datasets collected from the same locations within the paddock, somewhat reducing the spatial variance. The use of GPS-assisted sampling also means that these sampling points can be revisited in future to monitor change over time.

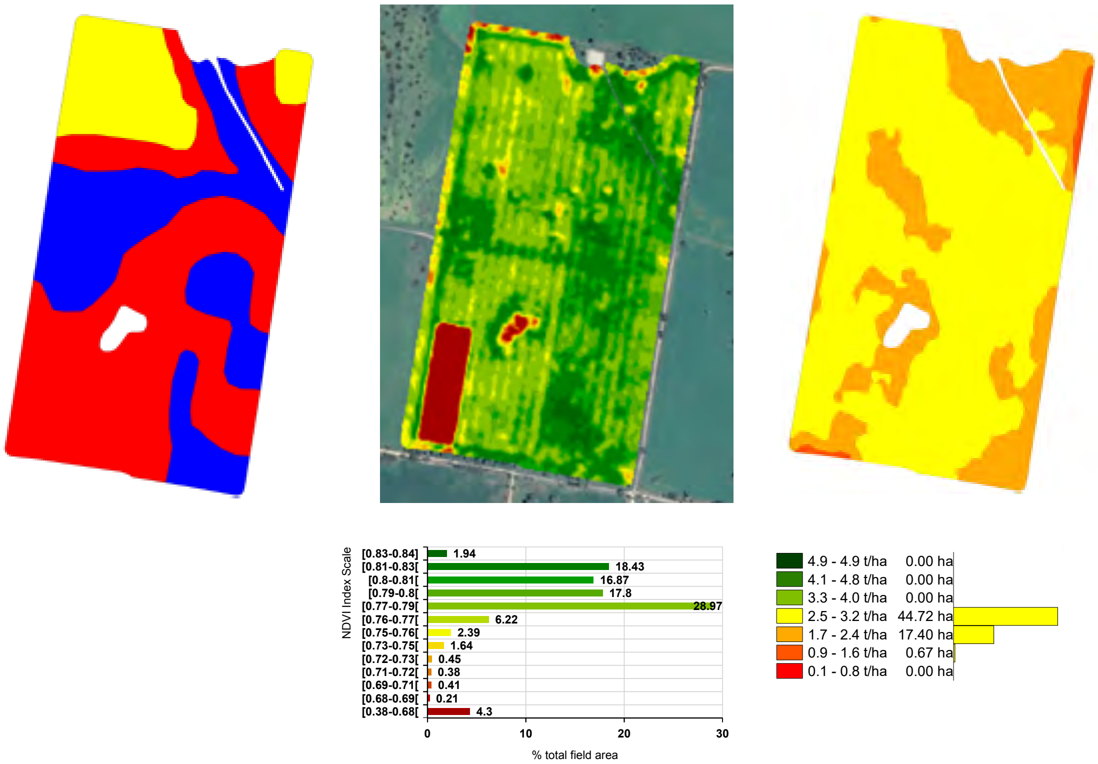


FIGURE 27 The allocation of zones and location of the weather station and soil moisture probes, NDVI satellite imagery collected 15 October 2017 and the Howlong paddock yield map, 2017

Note: The red rectangle is a small plot trial zone not related to this project, with fertiliser burn due to seeding issues also evident on the image right-hand side. Note also that canola NDVI will decrease in value with flowering due to decreased visible green area.

This research continues to evolve, on the basis that when this project commenced, the potential to use this approach to understand PAW variation in-paddock was unknown. Therefore, the methodology was designed to collect all datasets which may be of value in answering this question.

While this project has not yet achieved the end-point goal of using existing spatial datasets to predict in-paddock variation in PAW, and so inform variable rate zoning for in-crop nitrogen application, it has contributed to new knowledge around in-paddock variability as well as an understanding of the key drivers of change. Moreover, the spatial data analysis component of this work (still in development) has challenged existing approaches around management of spatial data, and how disparate datasets can be processed to enable 'cross-scale analysis'. This is likely to contribute to further learnings in future work.

Most importantly, this project has demonstrated that effective project learning can be achieved through partnerships built on a common vision of what could be, and an appreciation that sometimes you need to just make a start on a problem, in order to learn what you need to know.

Acknowledgements

This work was carried out as part of the PA component of the GRDC investment into the *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* project. Thank you to our host farmers —Trevethan Family Farms, the Inchbold family, Harmer Farms and Lilliput Ag.

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Economic and financial analysis of precision variable rate applications (VRA) of nitrogen

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Key points

- The use of variable-rate technology for nitrogen (VRT-nitrogen) application had mixed gross margin results given measured wheat yields, protein levels, calculated income and nitrogen costs in the nitrogen-rate trials undertaken at Yarrawonga and Dookie during 2017.
- Based on initial results at Yarrawonga and Dookie (using 19 and 13 years of wheat and canola yield responses to growing season rainfalls, respectively), the costs of conducting variable rate applications of nitrogen would require crop yields to increase by about 1%, or applied nitrogen costs to be reduced by at least 70%, before the approach breaks even over time.
- High overhead cost structures increase the risk of negative farm income. As VRT increases overhead costs, reviewing overall cost structures before adopting the technology is advisable.

Background

In 2017, wheat paddocks at Yarrawonga and Dookie each hosted nitrogen-rate experiments as part of the GRDC investment *Maintaining profitable farming systems in the Riverine Plains region* project. The trials were conducted on sub areas with low and high electromagnetic (EM38) conductivity. Based on results of these trials, measured wheat yields and protein content for each nitrogen-rate were available, allowing financial analysis for each experiment area to be completed. Using costs typical of the region, hypothetical farms were used to simulate financial risk for farms with high and low fixed costs.

Aims

To quantify the within-paddock variability of yields using records from paddocks in the Yarrawonga and Dookie areas and to quantify the impact of VRT-nitrogen on long-term, whole-farm financial risk.

Methods

For two farms at Yarrawonga and Dookie, farmer co-operators provided geo-referenced (harvester records) for wheat and canola yields, each from multiple paddocks over 19 and 13 crop years, respectively. The average yield of all wheat paddocks on a farm in a year was combined with growing season rainfall (GSR) data for that year, calculated from respective BOM monthly rainfall records for Yarrawonga and Dookie. In the case of wheat, 19 such data pairs could be assembled, while in case of canola 13 pairs of annual yield and GSR data were assembled, excluding two frost years. Quadratic functions were fitted to each of these data sets to show the relation of crop yield to GSR.

Using Charles Sturt University's (CSU) Spatial Data Analysis Network (SPAN), the geo-referenced yield records obtained over several years for the two paddocks were divided into grid areas of 90x90m (0.81ha). The grid areas were considered sufficiently large to serve as a basis for estimating the repeatability of yield categories (ie, highest quartile) over time and the correlations between crop yield and EM measures at different GSR levels.

In 2017, wheat paddocks at Yarrawonga and Dookie each hosted nitrogen-rate experiments in high and low electromagnetic (EM) zones. Based on these results, gross margins could be calculated for each experimental area considering local wheat and urea prices and assuming a 30% bonus for protein contents above 11.5%.

Farm financial risk can be expressed as the probability of a range of changes in cash flow measured over time. In this case, simulated 10-year cash books were prepared using locally valid variable, fixed and capital costs on two hypothetical farms. These costs included equipment replacement costs, based on typical machinery inventories and farmer-estimated timing of replacements. The additional costs of VRT equipment were estimated, with the assumption that all new machinery would be VRT-capable at the time of replacement.

Crop yields were simulated based on randomised 10-year historical sequences of GSR between 1960 and 2015, using wheat and canola responses to GSR. Annual gross income for each crop was calculated using these simulated yields, which were priced using randomised price sequences, based on recent historical weekly prices. The calculated cash flows included interest on the compounding cash balance, which included living costs



and income tax. This allowed calculation of the estimated change in the cash balance (similar to the bank balance) over each decade. @Risk software was used to record the change in this balance over 10,000 iterations (i.e. the 10-year cash balance was calculated 10,000 times using randomised price sequences), which allowed estimation of the probability of a range of these values, representing the risk profile for any scenario for a given farm. These indicate long-run probabilities of gains and losses.

Risk profiles were prepared for each farm before and after, including the cost of VRT given the assumption of 100% equity as starting positions.

Results

Calibrating VRT-nitrogen applications

Commonly-used benchmarks for calibrating VRT-nitrogen applications include EM38 measurements, long-term average yields and current normalised difference vegetation index (NDVI) measurements.

EM38 and yield

Several years of harvester yields and EM38 survey data summarised in 90x90m grid areas were available for the Yarrawonga and Dookie trial paddocks.

Overall, the highest EM38 levels were correlated with higher crop yields at low and medium GSR levels. In higher-rainfall seasons, crops can yield less in parts of the paddock with high EM38 than crops in the low EM parts of the paddock. Correspondingly, EM zoning can also indicate susceptibilities of high EM38 areas of the paddock to waterlogging in high-rainfall seasons and drought-proneness of low EM38 areas in drier seasons.

Gross margins of variable rate trials at Yarrawonga and Dookie, 2017

Gross margins for wheat yields measured in the 2017 variable rate trials at Yarrawonga and Dookie (*see Nitrogen response in different electromagnetic (EM) zones of the paddock* article, page 42) are presented in Table 1. These GM are based on wheat priced at $220/t, with a bonus of $30/t for protein above 11.5%, urea priced at $480/t and typical variable costs for these districts. The GM when nitrogen was applied at rates of 0, 40, 80, 120 and 160kg/ha and 40kg/ha as timed by NDVI are given for both the Yarrawonga (Farm 3) and Dookie (Farm 4) trials, along with results from both high and low EM38 plots on each farm.

During 2017, yield increased at both Yarrawonga (Farm 3) and Dookie (Farm 4), as total soil nitrogen (applied plus mineral nitrogen) increased (Figure 1).

The yield differences between trial paddocks are reflected in the GM (Figure 2), which is plotted against applied nitrogen rather than total soil nitrogen. There is high variability in yields between the trial sites, which makes these GM values difficult to interpret.

Yields at Yarrawonga were higher in the low EM38 zones compared with the high EM38 zones. At Dookie (Farm 4) this was reversed so the high EM38 zones yielded more than the low EM zones.

TABLE 1 Gross margins of different nitrogen application rates in high and low EM plots at Yarrawonga and Dookie

Applied nitrogen	Total nitrogen (soil + added N)	Yield	Protein*	Income#	Nitrogen cost^	Gross margin	Applied nitrogen	Total nitrogen (soil + added N)	Yield	Protein*	Income#	Nitrogen cost^	Gross margin
kg/ha	kg/ha	t/ha	%	$/ha	$/ha	$/ha	kg/ha	kg/ha	t/ha	%	$/ha	$/ha	$/ha
Yarrawonga high EM							**Dookie high EM**						
0	129	5.7	9.3	1,254	0	932	0	206	3.6	10.2	792	0	470
40	169	6.4	10.2	1,408	19	1,067	40	246	3.8	10.5	829	19	488
80	209	5.8	10.5	1,276	38	916	80	286	4.4	11.6	998	38	638
120	249	6.2	11.5	1,394	58	1,014	120	326	4.6	11.5	1,040	58	660
160	289	6.3	11.6	1,416	77	1,017	160	366	4.4	12.5	1,002	77	604
NDVI 40	169	6.0	9.6	1,309	45	942	NDVI 40	246	4.5	11.5	983	45	617
Yarrawonga low EM							**Dookie low EM**						
0	121	6.4	9.4	1,408	0	1,086	0	182	3.3	11.9	756	0	434
40	161	6.5	10.0	1,430	19	1,089	40	222	3.4	13.5	771	19	430
80	201	6.9	10.7	1,511	38	1,151	80	262	3.3	14	745	38	385
120	241	6.9	11.1	1,509	58	1,130	120	302	3.8	14.7	866	58	486
160	281	7.0	11.1	1,542	77	1,143	160	342	3.7	14.1	853	77	454
NDVI 40	161	6.8	11.8	1,485	45	1,118	NDVI 40	222	3.8	14.4	836	45	469

* Protein bonus of $30 for protein above 11.5%
# Income based on wheat price of $220/t
^ Nitrogen applied as urea at $480/t

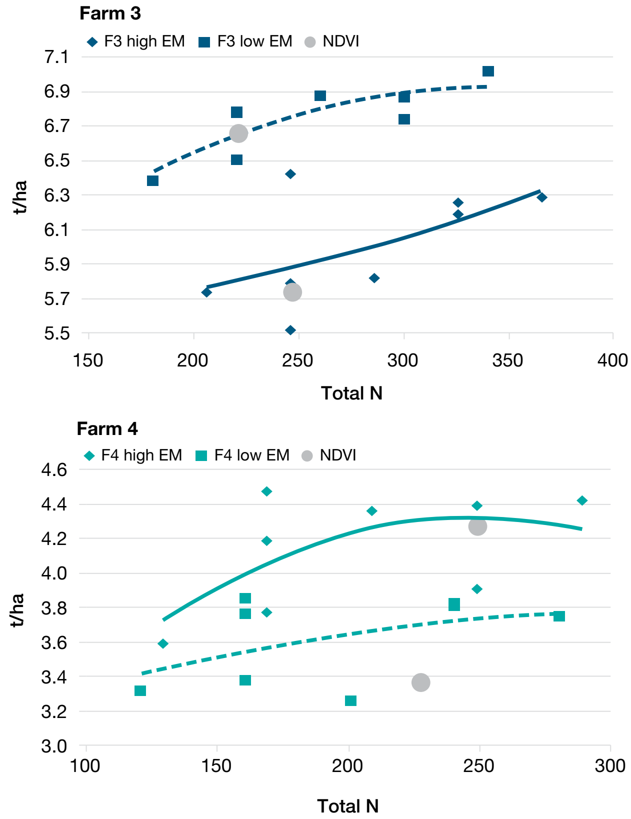


FIGURE 1 2017 trial wheat yield responses to nitrogen at the Yarrawonga (Farm 3) and Dookie (Farm 4) trial paddocks, in high and low EM plots , plotted against applied nitrogen, rather than total soil nitrogen

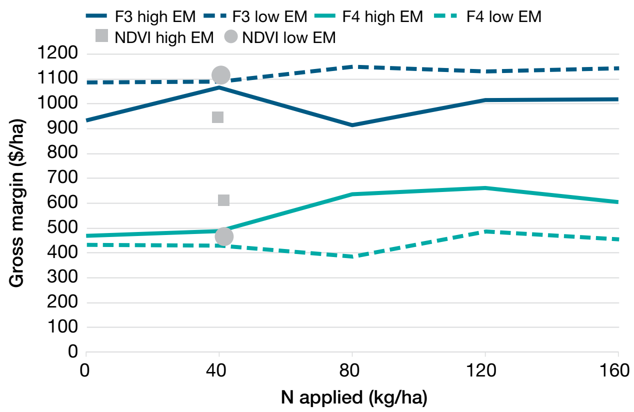


FIGURE 2 Wheat gross margins for 2017 at Yarrawonga (Farm 3) and Dookie (Farm 4)

Both EM zones at Yarrawonga had lower soil nitrogen compared with Dookie. There were yield responses to total nitrogen at Yarrawonga (Farm 3) for both EM levels, with the most economic total nitrogen rate for the high EM site 169 N (soil nitrogen — 129kg N/ha, applied nitrogen — 40kg N/ha. The most economic total nitrogen treatment for the low EM site was 201kg N/ha (soil nitrogen — 129kg N/ha, applied nitrogen — 80kg). Applying extra nitrogen to achieve protein was not economic at the high EM site.

Overall the yields at Dookie were lower than Yarrawonga, suggesting some in-season effect, which limited yields.

There were also yield responses to total nitrogen at Dookie. The most economic nitrogen rate for the high EM site was 326kg N (soil nitrogen — 206kg N/ha, applied nitrogen — 120kg N/ha), while the most economic rate for the low EM site was 302kg N (soil nitrogen — 182kg N, applied nitrogen — 120kg N/ha).

Where normalised difference vegetation index (NDVI) was used to determine nitrogen application rates, yield and GM was comparable to the other applied nitrogen treatments, with the exception of the high EM plots at Yarrawonga.

Retrospective assessments of 'most economic nitrogen rates' in a paddock in one season provide no guide to what will be 'most economic' in the future. It would be incorrect to extrapolate these particular GM results to paddocks in the district, given the extreme spatial and temporal variability of within-paddock crop yields.

Profitability — hypothetical farms with high and low fixed costs

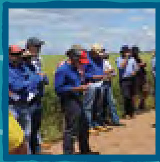
Growers looking to implement variable rate nitrogen on a whole-farm basis need to consider the financial risk over time, which requires more than a single-year GM calculation. In the following example the farms shown are hypothetical but have been developed to show the full range of likely results that may be encountered in the region.

A short list of the considerations taken into account includes: randomly drawn 10-year historical rainfall sequences, yields, livestock GM from CSIRO (GrassGro model), prices (Geelong Port), costs (high and low fixed costs), debt (standardised at 100% equity), machinery replacement costs (calculated at expected changeover year), 10-year cash flows (including living costs, tax and interest) and change in cash (bank) balance over 10 years.

The distributions of probabilities of any change in bank balances over 10 years, given price and weather variations, define the 'risk profiles' of the two hypothetical farms. One of the hypothetical farms has high fixed costs and one with low fixed costs, starting with 100% equity, with and without VRT-nitrogen (Figure 3).

Comparisons of results for the high and low-cost farms are summarised in Table 2. The low-cost farm was the most viable, with zero risk of loss. This compares with a 40% risk of loss for the high-cost farm, which suggests this farm would not be viable with any debt.

Table 2 also shows that, based on the initial results for the Yarrawonga and Dookie areas, VRT-nitrogen needs to increase crop yields by less than 1%, or reduce costs



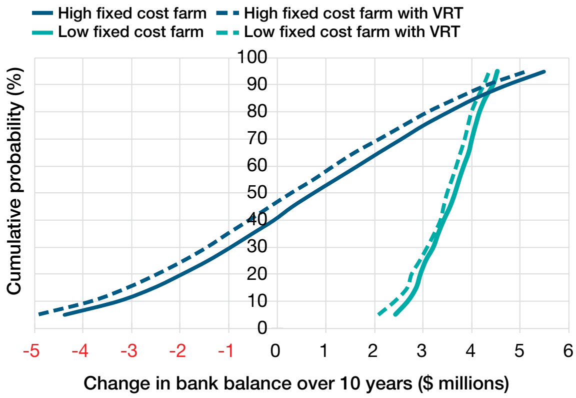


FIGURE 3 Probabilities of change in bank balances over 10 years, given price and weather variations, define the 'risk profiles' of two hypothetical farms with high and low fixed costs, starting with 100% equity with and without VRT-nitrogen application

Note: Indicated here are only the costs (without benefits) of VRT-nitrogen applications

of nitrogen applied by at least 70%, before the approach breaks-even over time.

Acknowledgements

Thank you to the cooperating farmers, who generously allowed access to their detailed header-yield estimates and who have also been generous with their time in helping us understand locally-relevant costs and equipment replacement facts.

This analysis was carried out as part of the GRDC investment *Maintaining profitable farming systems with retained stubble in the Riverine Plains* region project.

Thanks also to Brendan Torpy and Meera Dawson (Precision Agriculture), Claire Robinson (Hutcheson and Pearce) and Craig Poynter, GIS & Remote Sensing, Spatial Data Analysis Network (SPAN), Charles Sturt University.

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TABLE 2 Comparison of risk profiles

	High-cost farm		Low-cost farm	
	No VRT	With VRT	No VRT	With VRT
Initial cost of VRT		$30,963		$18,465
Cost after 10 years		$452,721		$181,744
Change in cash flow needed to cover cost of VRT				
Yield increase		0.30%		0.10%
Savings in nitrogen application cost		68%		70%
Risk of loss	41%	44%	0%	0%

The impact of stubble treatment on soil nitrogen supply to crops

Dr Cassandra Schefe
Riverine Plains Inc

Key points

- While significant differences in mineral nitrogen (N) values were measured between stubble treatments, these differences were small and unlikely to elicit a plant growth response.
- No consistent trends were observed between trial sites.
- Delayed plant growth and development under no-till stubble retained (NTSR) systems in the Riverine Plains region is unlikely to be due to decreased mineral nitrogen availability as a result of immobilisation.

Aims

The aim of this work was to determine if differences in the early growth and development of crops under different stubble management strategies were due to differences in early-season nitrogen (N) supply.

Background

Within the GRDC investment *Maintaining profitable farming systems with retained stubble in the Riverine Plains region (Stubble)* project *(2013–18)* (described on page 10), large-scale replicated trials were established from 2014–17. These trials have consistently demonstrated that no-till stubble retention (NTSR) treatments show a *biomass lag*, with slower early growth and dry matter (DM) production compared with treatments where stubble was removed.

As early crop establishment and growth is largely driven by nutrient supply, light and temperature, it is likely this biomass lag can be attributed to differences in these parameters. While differences in light interception and temperature were quantified within the *Stubble Project* (for light interception results see page 1220–21 and in-canopy temperature see page 3030–36), detailed nitrogen sampling throughout the season was outside the scope of this project.

In order to understand whether the measured *biomass lag* of NTSR crops was due to differences in nitrogen supply between stubble treatments, detailed nitrogen sampling was carried out at each of the Focus Farm trial sites established as part of the *Stubble Project* during 2016. This sampling showed that during the wet seasonal conditions of 2016, mineral nitrogen values were low and highly variable across stubble treatments, with no resulting differences between treatments. To establish if this lack of difference was due to the excessively wet conditions, or whether these results are representative of a 'normal' year, the sampling program was repeated during 2017.

This additional in-crop nitrogen sampling (2016–17) was carried out under the *Sustainable Agriculture Victoria: Fast-Tracking Innovation Initiative*, which has been made possible with the support of the Foundation for Rural and Regional Renewal (FRRR) together with the William Buckland Foundation.

Stubble impact

The presence or absence of stubble can impact nitrogen availability to the crop. When stubble is retained from the previous crop, it continues to be broken down by microbes and converted into soil organic matter (OM) throughout the following cropping season. As cereal stubbles are high in carbon compared with nitrogen (carbon:nitrogen ratio of 100:1), soil microbes need to 'borrow' nitrogen from the soil in order to balance their nutrient requirements while they break down the cereal stubble. This in turn can lead to nitrogen *immobilisation*, or *tie-up,* which reduces the total amount of soil nitrogen available to the growing crop.

This 'tie-up' effect is most evident early during the season when microbial activity accelerates with increased soil moisture following the autumn break.

As soil microbes break down the stubble during the growing season, they gradually release, or *mineralise*, nitrogen back into the soil.

However, if the stubble is burnt, microbes do not require soil nitrogen to support the stubble decomposition process and, as a result, more soil nitrogen is readily available to the early crop. While this may aid crop establishment and early growth, on the other hand there is no slow release of nitrogen throughout the season.

While the processes of nitrogen immobilisation and mineralisation under NTSR systems are significant, it is unknown if they result in measurable differences in nitrogen supply to crops when nitrogen fertiliser is applied through the season. This project aimed to quantify the impacts.

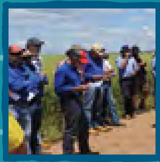


TABLE 1 Selected treatments from each Focus Farm, from which soil samples were collected on specified dates during July and August 2017

Coreen	Yarrawonga	Dookie
NTSR — control	NTSR — short stubble	NTSR — short stubble
Cultivated (one pass)	NTSR — long stubble	NTSR — long stubble
Burnt	Cultivated (one pass)	Cultivated (one pass)
	Burnt	Burnt
Soil sampling:		
July: 10/7/17	July: 11/7/17	July: 12/7/17
Aug: 15/8/17	Aug: 17/8/17	Aug: 14/8/17

Methods

The soil sampling was carried out on selected treatments at the Coreen, Yarrawonga and Dookie Focus Farm sites, established as part of the GRDC *Stubble Project* (Table 1). The Henty site was discontinued after the 2016 season due to high spatial variability and was not sampled in 2017.

After the initial stubble treatments were established, the host farmer managed the sites for the remainder of the season. The rates and timing of fertiliser applications at each site during 2017 are shown in Table 2.

The soil sampling was completed to 0–10, 10–20, 20–30cm depth increments during July and August 2017 in each of the four replicates of each treatment. A set of 10 subsamples was collected from each plot and combined into one composite sample per replicate.

When soil sampling was completed, soils were analysed for mineral nitrogen (nitrate + ammonium), with results analysed using analysis of variance (ANOVA) with Genstat® statistical software.

Results

July sampling

The mineral nitrogen levels varied at each site. Sampling during July showed the Dookie site had the lowest range of nitrogen values in the 0–10cm depth (Figure 1), with the cultivated treatment measuring the lowest (4kg N/ha) and the NTSR – short stubble measuring the highest (9kg N/ha).

There were significant differences in mineral nitrogen levels between treatments at the Dookie site, as indicated by the July sampling, however, given the low values involved, a plant response to this reduction in available nitrogen is unlikely.

The Coreen site did not show any treatment effect on mineral nitrogen supply at the July sampling.

The Yarrawonga site showed increased mineral nitrogen levels at the 10–20cm depth with the NTSR treatments compared with the cultivated and burnt treatments. However, the range of mineral nitrogen varied from 4.2–7kg N/ha, which is again unlikely to elicit any plant response.

August sampling

While there were differences in the amount of mineral nitrogen measured in the August sampling compared with the July sampling at 0–10cm depth, there were no consistent trends between sites (Figure 1).

The Coreen site showed increased mineral nitrogen values in the burnt treatment at 0–10cm depth compared with the other treatments, while the Dookie site showed the greatest 0–10cm mineral nitrogen in the NTSR — short stubble treatments and the least in the NTSR — long stubble treatment. No differences between treatments were measured at Yarrawonga at any depth, nor in the 10–30cm depths at the Coreen or Dookie sites.

Observations and comments

In-crop mineral nitrogen sampling during 2016 showed no difference between treatments. However, due to the excessively wet conditions of 2016, it was unclear if the lack of treatment response was an accurate reflection of the treatments imposed, (i.e. whether there was no effect, or if the wet conditions had confounded any response).

The 2017 mineral nitrogen measurements show that some treatment effects were measured at the 0–10cm depth at Coreen and Dookie, as well as at the 10–20cm depth at Yarrawonga. However, the low absolute mineral nitrogen values and the small relative change between treatments, means any effect would be unlikely to be great enough to cause a change in plant biomass and development.

TABLE 2 Rates and timing of nitrogen fertiliser applications at each of the *Stubble Project* Focus Farms

Location	Sowing (kg N/ha)	May 2017 (kg N/ha)	June 2017 (kg N/ha)	July 2017 (kg N/ha)	August 2017 (kg N/ha)	Total nitrogen (kg/ha)
Coreen	5		46 (17/6/17)	46 (10/7/17)		97
Yarrawonga	7.5			46 (2/7/17)	46 (11/8/17)	99.5
Dookie	10.5	41.4 (29/5/17)	41.1 (22/6/17)	41.4 (22/7/17)		134.7

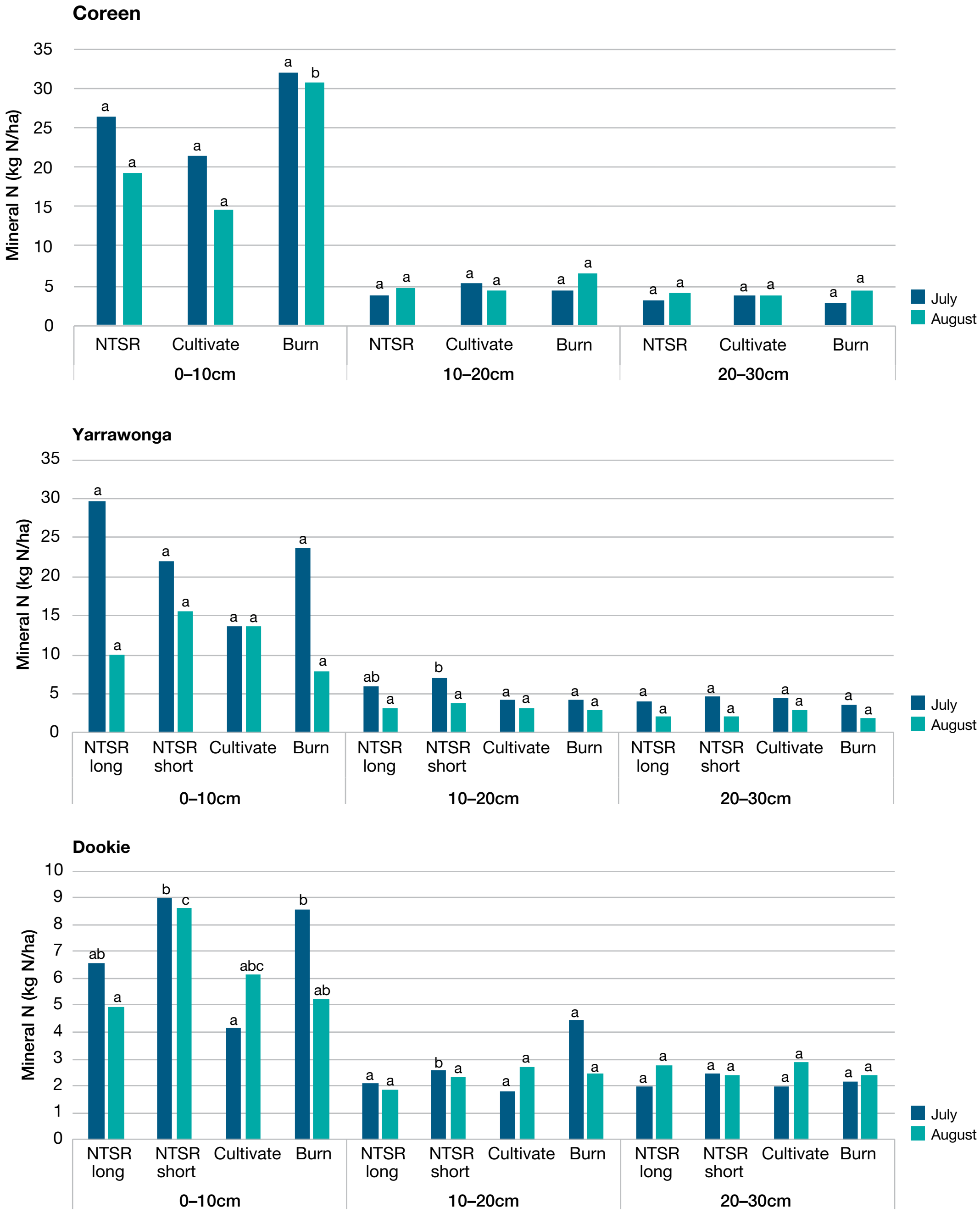
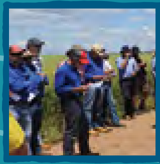


FIGURE 1 Soil nitrogen sampling at each trial site, to a depth of 0–10, 10–20, 20–30cm (July and August 2017)

Figures followed by different letters for the same sampling time, at the same depth, are regarded as statistically different.



Moreover, the aim of this work was to determine if the measured lag in early plant growth and development under NTSR systems was due to a reduction in near-surface mineral nitrogen, as a result of immobilisation of nitrogen by soil microbes as they break down stubble. For this to be the case, the mineral nitrogen measurements in the NTSR treatments would need to be consistently lower than those measured in the cultivated and burnt treatments. This was not observed, suggesting that differences in nitrogen supply was not a key driver of the measured *biomass lag* in crops sown into NTSR treatments throughout the four years of *Stubble Project* trials.

A key element of these systems is the provision of adequate fertiliser nitrogen through the season. While significant fertiliser nitrogen was applied to each trial through the season, these inputs are not reflected in the measured mineral nitrogen values, implying that uptake of applied fertiliser was relatively efficient.

Acknowledgements

This nitrogen sampling work was funded through *The Sustainable Agriculture Victoria: Fast-Tracking Innovation Initiative*, which has been made possible with the support of the Foundation for Rural and Regional Renewal (FRRR) together with the William Buckland Foundation.

Thank you to our farmer co-operators at each of the GRDC funded *Maintaining profitable farming systems with retained stubble in the Riverine Plains region* Focus Farm sites:

- Corowa/Coreen: Tomlinson Ag
- Dookie: Ludeman Brothers
- Henty: Peter Campbell
- Yarrawonga: Telewonga Pty Ltd.

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Optimising sulphur and nitrogen nutrition in canola

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Key points

- At the Howlong site, applied nitrogen gave a yield and dry matter (DM) response, however there was no sulphur response.
- The Yarrawonga site showed a clear response to applied sulphur (S) and nitrogen (N), despite high soil sulphur levels. This suggests canola roots may not be effectively exploring the soil profile to access soil sulphur.
- The Yarrawonga site had an optimum sulphur application rate of 20kg S/ha, with yield penalties measured with sulphur rates above and below this optimal rate.
- The dry finish to the season caused significant challenges during 2017. This trial will be repeated at two sites during 2018 to understand how variable the responses to sulphur are likely to be during different seasonal conditions.

Background

Following the discovery of sulphur deficiency in canola in southern NSW during the late 1980s, the application of 20–30kg S/ha was recommended when sowing canola (*GRDC Canola guide*, *2009*). Since then, the wheat–canola rotation has become established, meaning 20–30 kg S/ha is being applied as frequently as every second year. With some sulphur moving to depth, growers are questioning whether they can reduce the rate of sulphur they are applying to their canola crops.

Furthermore, a variable response to sulphur has been observed, depending on background nutrition levels, (e.g. soil nitrogen status — where nitrogen supply is sub-optimal, plant uptake of sulphur can be inhibited, leading to a confounded yield response).

The GRDC investment, *Optimising crop nutrition in canola in the southern region of NSW* is investigating the interactions between nitrogen availability and sulphur uptake, to ensure sulphur uptake is not limited by sub-optimal soil nitrogen levels.

Aims

This project aims to determine if nitrogen supply is limiting uptake of sulphur in canola crops grown in the Riverine Plains region and whether sulphur uptake and yield is increased in canola when nitrogen is available in non-limiting quantities.

The 2017 project trial assessed the response to nitrogen and sulphur in canola crops of the Riverine Plains by determining:

- the influence of nitrogen and sulphur application on canola tissue content, yield and oil
- the fluctuation in nitrogen and sulphur content and nitrogen:sulphur ratio in the plant from stem elongation (GS31) to harvest (GS99)
- the optimum available soil nitrogen level for the region's canola crops at varying sulphur application rates.

Method

Two trial sites were established at Yarrawonga, Victoria and Howlong, NSW.

A randomised block design was used with plots measuring 3m x 18m, with four replicates. The Yarrawonga trial site was sown to canola cv Roundup Ready® 44Y25 while the Howlong site was sown to canola cv Bonito.

Both sites were sown on 24 April 2017, after which combinations of nitrogen and sulphur treatments were applied.

Nitrogen (as urea) was applied in a split application at the 6–8 leaf stage (GS1.06–1.08) and green bud (GS3.3) at five rates (0, 40, 80, 120, 160 kg N/ha), with 40 kg N/ha applied at the 6–8 leaf stage, and the remainder at green bud.

Sulphur was applied as sulphate of ammonia (SOA) at four rates (0, 10, 20, 30kg S/ha), at the same time as the first application of in-crop nitrogen (GS1.06–1.08), with urea added to balance the nitrogen applied in the SOA.

Sulphur treatments were applied across the suite of nitrogen treatments to determine the interaction between nitrogen and sulphur (Table 1).

The trial site was managed as part of the surrounding commercial crop, with the exception of the sulphur and nitrogen applications.

Tissue sulphur and nitrogen testing and dry matter (DM) sampling both occurred at early flowering (GS4.1–4.2) and when seeds were black, but soft (GS6.7). Yield, oil and protein content was also measured.



TABLE 1 Sulphur and nitrogen interaction trial treatment list, 2017*

No.	Fertiliser application (kg/ha)		Total S (kg/ha)	Total N (kg/ha)
	Six-leaf stage (GS1.06)	Green bud (GS3.3)		
1	0	0	**0**	**0**
2	0	0	**0**	**0**
3	0	0	**0**	**0**
4	0	0	**0**	**0**
5	40N 0S	0	**0**	**40**
6	40N 10S	0	**10**	**40**
7	40N 20S	0	**20**	**40**
8	40N 30S	0	**30**	**40**
9	40N 0S	40N	**0**	**80**
10	40N 10S	40N	**10**	**80**
11	40N 20S	40N	**20**	**80**
12	40N 30S	40N	**30**	**80**
13	40N 0S	120N	**0**	**160**
14	40N 10S	120N	**10**	**160**
15	40N 20S	120N	**20**	**160**
16	40N 30S	120N	**30**	**160**
17	40N 0S	200N	**0**	**240**
18	40N 10S	200N	**10**	**240**
19	40N 20S	200N	**20**	**240**
20	40N 30S	200N	**30**	**240**

* Nitrogen applied as urea (46% N) and sulphur applied as ammonium sulphate (21% N and 24% S)
Treatments at six-leaf stage (GS 1.06) were applied as ammonium sulphate with residual nitrogen application applied as urea.
The first 40kg N/ha of all nitrogen treatments was applied at the six-leaf stage (GS1.06), the remainder was applied at green bud (GS3.3).
Treatment list excludes MAP applied at sowing with the commercial crop.

Trial 1: Howlong, NSW

Sowing date: 24 April 2017
Rotation: Canola after wheat
Variety: Canola, cv Bonito
Rainfall:
GSR: 272.8mm (April – October)

i) Soil sampling results

Incremented soil samples (0–30cm, 30–60cm, 60–90cm) were collected on 5 June 2017 and analysed for nitrogen and sulphur content (Table 2).

Field sites were selected based on previous cropping history and associated high levels of production and nutrient export. The soil nitrogen and sulphur levels at the Howlong site were much higher than the grower expected, with a late urea application during 2016 (to address low nitrogen availability under saturated condition) likely to have contributed to these high levels. This late application of urea would have also likely increased the movement of excess nitrogen to depth.

TABLE 2 Soil nitrogen and sulphur contents at Howlong NSW, sampled 5 June 2017

Depth (cm)	Mineral N (kg/ha)	Mineral S (kg/ha)
0–30	83.85	37.28
30–60	34.94	14.91
60–90	28.02	14.70
Total (0–90)	146.81	66.89

ii) Vigour and biomass

Due to the large number of treatments in this trial, only selected treatments (i.e. the nil sulphur and high sulphur treatments at each rate of nitrogen) received in-crop assessments.

Plant vigour assessments made at the six-leaf stage (GS1.06) showed no difference between treatments (Table 3).

The DM measurements taken at 20% flowering (GS4.2) showed the 80N:0S treatment had the greatest biomass, which was 1.49t/ha greater than the untreated controls (UTC). In comparison, measurements taken when most seeds were black but soft (GS6.7), showed that DM production aligned relatively well with the nitrogen application rate. When most seeds were black but soft (GS6.7), the greatest biomass was measured in the 240N:30S treatment, which was 4.95t/ha greater than the average of the UTC (Table 3).

iii) Plant tissue nitrogen and sulphur content

The nitrogen content of the canola at 20% flowering (GS4.2) showed uptake of nitrogen across all treatments, although the relationship was not always linear (Table 4). The greatest nitrogen uptake was measured in the 80N:0S, 160N:0S, 160N:30S and 240N:30S treatments. This suggests that at 20% flower, applications of 80N and above generally provided more nitrogen than was required.

The nitrogen response was clearer closer to maturity. When seeds were black but soft (GS6.7) there was a clear and significant trend showing increased nitrogen uptake with increased nitrogen supply (Table 4). The 80N:30S treatment showed the addition of sulphur significantly increased the uptake of nitrogen from 165kg N/ha to 207kg N/ha. Nitrogen levels at the seeds black but soft stage (GS6.7)

TABLE 3 Vigour and dry matter assessment at Howlong NSW, 2017

Treatment	21 June 2017 Vigour (1–9) Six-leaf stage (GS1.06)	18 August 2017 Dry matter (t/ha) 20% flower (GS4.2)	8 November 2017 Dry matter (t/ha) Most seed black, but soft (GS6.7)
UTC	7^{a}	3.01^{d}	13.23^{de}
UTC	7^{a}	3.00^{d}	13.12^{e}
40N:0S	7^{a}	3.06^{cd}	14.90^{b-e}
40N:30S	8^{a}	3.53^{bcd}	13.77^{cde}
80N:0S	7^{a}	4.49^{a}	15.13^{b-e}
80N:30S	7^{a}	3.93^{ab}	16.08^{abd}
160N:0S	7^{a}	3.90^{ab}	15.63^{bcd}
160N:30S	7^{a}	3.64^{bc}	16.85^{ab}
240N:0S	7^{a}	3.51^{bcd}	17.30^{ab}
240N:30S	8^{a}	3.53^{bcd}	18.12^{a}
Mean	**7**	**3.56**	**15.41**
LSD P=0.05	1	0.60	2.45
Treatment probability (F)	0.952	0.001	0.004
CV	8.37	11.37	10.68
SD	0.6	0.41	1.65

Figures followed by different letters are regarded as statistically different.

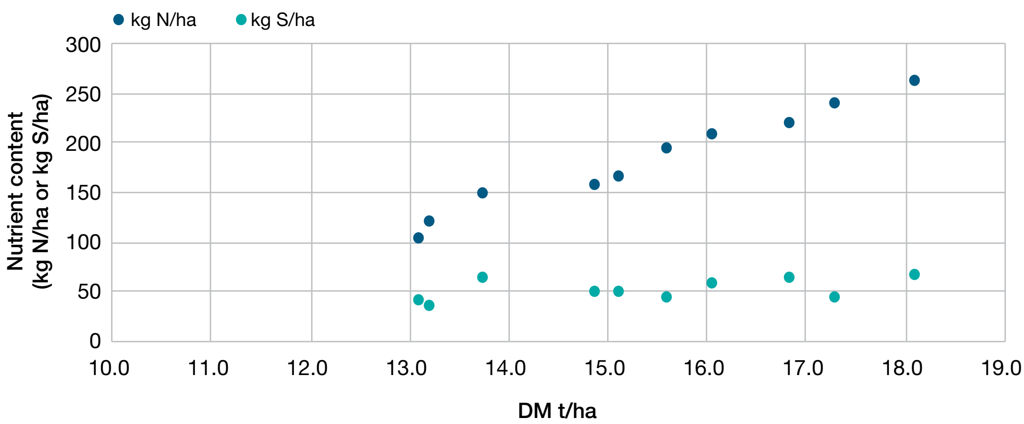


FIGURE 1 Relationship between dry matter production and nitrogen or sulphur tissue content at Howlong NSW, measured on 8 November 2017 at GS6.7

showed a strong linear relationship with the dry matter measurements taken on the same day, confirming a strong nitrogen-growth response (Figure 1).

Tissue sulphur content across treatments varied from 12–27kg S/ha at early flowering (GS4.2), with no significant differences between the nil and plus 30kg S/ha treatments. In comparison, increased tissue sulphur levels were measured at the seeds black but soft stage (GS6.7) when sulphur was added to the 40, 160 and 240kg N treatments compared with the nil treatments (Table 4). This demonstrates that added sulphur contributed to sulphur uptake by the plant. However, the lack of change in tissue sulphur levels when increasing levels of nitrogen were applied suggests that increased nitrogen supply did not facilitate increased sulphur uptake in this soil during 2017. An unclear relationship between increasing tissue sulphur levels and DM production, indicates that sulphur content was not the most limiting factor to plant growth at this site (Figure 1).



TABLE 4 Plant tissue nitrogen and sulphur contents at Howlong NSW, 2017

Treatment	Nitrogen content		Sulphur content	
	18 August 2017	8 November 2017	18 August 2017	8 November 2017
	kg N/ha	kg N/ha	kg S/ha	kg S/ha
	20% flower (GS4.2)	Most seed black, but soft (GS6.7)	20% flower (GS4.2)	Most seed black, but soft (GS6.7)
UTC	65^{d}	118^{fg}	17de	34^{d}
UTC	68^{d}	103^{g}	12^{e}	38^{cd}
40N:0S	114^{c}	156^{e}	19^{cd}	48^{bc}
40N:30S	111^{c}	148^{ef}	22$^{a\text{-}d}$	61^{a}
80N:0S	181^{a}	165de	27^{a}	47^{bc}
80N:30S	121^{c}	207^{c}	26^{a}	56^{ab}
160N:0S	167^{ab}	192^{cd}	25^{a}	42^{cd}
160N:30S	154^{ab}	219^{bc}	25^{ab}	63^{a}
240N:0S	151^{b}	239^{ab}	19^{bcd}	41^{cd}
240N:30S	155^{ab}	261^{a}	23^{abc}	65^{a}
Mean	**129**	**181**		**50**
LSD P=0.05	29	31	6	11
Treatment probability (F)	<0.001	<0.001	<0.001	<0.001
CV	15.39	13.35	17.61	14.35
SD	19.8	20.6	3.8	7.1

Figures followed by different letters are regarded as statistically different.

iv) Green leaf retention

There were significant treatment effects assessed as green leaf retention (GLR%) measured at 50% podset (GS5.5) + 15 days, however these results did not correlate to nitrogen or sulphur application rates. Moreover, the range in the UTC (nil) treatments was similar to that observed across the whole trial, further discounting the value of any differences in GLR% (Table 5). Similarly, there were no significant differences in GLR% when measured at 50% podset (GS5.5) + 32 days.

v) Normalised difference vegetation index (NDVI)

Normalised difference vegetation index was measured in each plot eight times throughout the season. The last measure, taken at 20% flowering (GS4.2), was the only one to show significant differences between treatments (Figure 2). While there were statistically significant differences between treatments, all of the treatments that received 80kg N/ha or above had comparable plant greenness.

vi) Yield, oil and protein

While there were significant differences in yield across the various treatments, the yield range at the Howlong site was only 2.46–3.04t/ha, with the UTC being the lowest yielding treatment and the 80N:20S being the highest yielding treatment (Table 6). The UTC, 40N:0S, 40N:30S, 160N:30S and 240N:30S treatments were all significantly lower yielding than the highest yielding treatment (80N:20S). When analysed as a factorial (when each group of factors are analysed together), the highest rate of sulphur (30kg S/ha) yielded significantly less than the 10 and 20kg S/ha application rates. There was no clear trend between nitrogen rate and yield response.

There were no significant differences in oil content across the treatments, and only limited differences in protein content, which ranged from 16.2% in an UTC to 17.1% in the 240N:0S treatment (Table 6).

TABLE 5 Green leaf retention at Howlong, NSW, 2017

Treatment	13 October 2017 GLR (%) GS5.5 +15 days	30 October 2017 GLR (%) GS5.5 +32 days
UTC	65^{de}	40^{a}
UTC	68^{bcd}	38^{a}
UTC	61^{e}	43^{a}
UTC	70^{abc}	40^{a}
40N:0S	68^{bcd}	40^{a}
40N:10S	73^{a}	43^{a}
40N:20S	70^{abc}	45^{a}
40N:30S	70^{abc}	40^{a}
80N:0S	71^{ab}	40^{a}
80N:10S	70^{abc}	40^{a}
80N:20S	71^{ab}	43^{a}
80N:30S	70^{abc}	43^{a}
160N:0S	71^{ab}	48^{a}
160N:10S	70^{abc}	40^{a}
160N:20S	66^{cd}	45^{a}
160N:30S	70^{abc}	38^{a}
240N:0S	70^{abc}	40^{a}
240N:10S	70^{abc}	43^{a}
240N:20S	70^{abc}	45^{a}
240N:30S	69^{a-d}	38^{a}
Mean	**69.1**	**41**
LSD P=0.05	4.9	7
Treatment probability (F)	0.013	0.373
CV	5.06	12.65
SD	3.5	5.2

Figures followed by different letters are regarded as statistically different.

TABLE 6 Harvest yield and quality at Howlong NSW, 2017

Treatment	22 November 2017 Yield (t/ha)	Oil (%)	Protein (%)
	Harvest		
UTC	2.54^{de}	48.1^{a}	16.2^{de}
UTC	2.46^{e}	47.9^{a}	16.2^{e}
UTC	2.68^{cde}	48^{a}	16.5^{b-e}
UTC	2.46^{e}	48.2^{a}	16.4^{cde}
40N:0S	2.69^{cde}	47.6^{a}	16.8^{abc}
40N:10S	2.90^{abc}	47.5^{a}	16.8^{abc}
40N:20S	2.84^{abc}	47.4^{a}	16.8^{abc}
40N:30S	2.66^{cde}	47.7^{a}	16.4^{cde}
80N:0S	2.91^{abc}	48.0^{a}	16.5^{b-e}
80N:10S	2.84^{abc}	47.6^{a}	16.9^{ab}
80N:20S	3.04^{a}	47.8^{a}	16.8^{abc}
80N:30S	2.84^{abc}	47.3^{a}	16.9^{abc}
160N:0S	2.83^{abc}	47.5^{a}	16.8^{abc}
160N:10S	3.01^{ab}	47.4^{a}	16.7^{abc}
160N:20S	2.82^{abc}	47.7^{a}	16.7^{a-d}
160N:30S	2.77^{bcd}	47.5^{a}	16.8^{abc}
240N:0S	2.77^{a-d}	47.3^{a}	17.1^{a}
240N:10S	2.90^{abc}	47.4^{a}	16.8^{abc}
240N:20S	2.99^{ab}	47.1^{a}	16.9^{ab}
240N:30S	2.75^{bcd}	47.3^{a}	16.8^{abc}
Mean	**2.79**	**47.6**	**16.67**
LSD P=0.05	0.27	0.79	0.5
Treatment probability (F)	<0.001	0.341	0.033
CV	6.81	1.17	2.13
SD	0.19	0.6	0.4

Figures followed by different letters are regarded as statistically different.

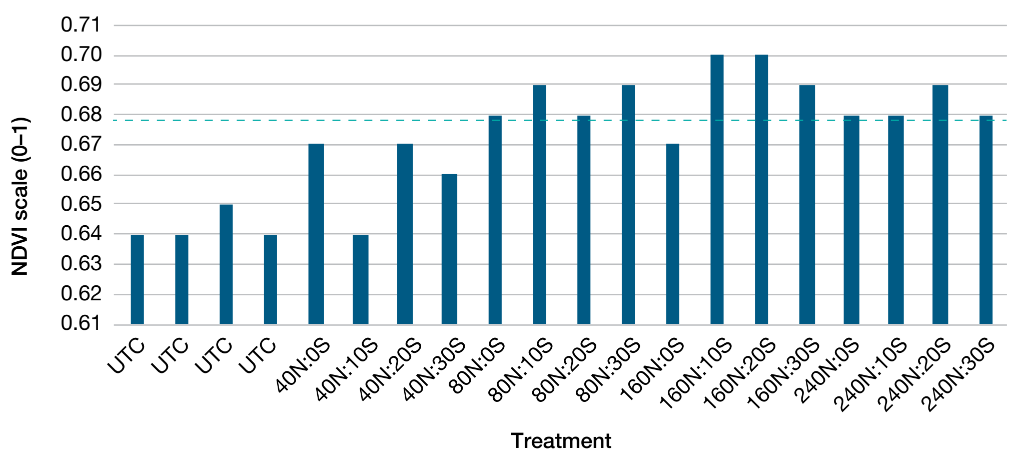


FIGURE 2 NDVI values, measured 18 August 2018, at 20% flowering (GS4.2) at Howlong, NSW

LSD = 0.02. All readings above the dotted line are statistically comparable to the highest values of 160N:10S and 160N:20S.

1 Howlong trial site, 23 May 2017

2 Canola at two-leaf stage (GS1.02), 23 May 2017

3 Howlong trial site, 24 July 2017

4 Untreated control, 13 November when most seeds black, but soft (GS6.7)

Trial 2: Yarrawonga, Victoria

Sowing date: 24 April 2017
Rotation: Canola after wheat
Variety: Canola cv 44Y25 (Round-up Ready®)
Rainfall:
GSR: 270.4mm (April – October)

i) Soil sampling results

Incremented soil samples (0–30cm, 30–60cm, 60–90cm) were collected on 5 June 2017 and analysed for nitrogen and sulphur content (Table 7).

The soil nitrogen and sulphur contents at the Yarrawonga site were almost the inverse of those measured at Howlong. The Yarrawonga site measured a mineral nitrogen value of 69.75kg N/ha and a mineral sulphur value of 140.6kg S/ha compared with 146.81kg N/ha and 66.89kg S/ha at the Howlong site. The lower nitrogen levels at depth at Yarrawonga suggest the efficient extraction of nitrogen by previous crops (Table 7). High values of sulphur were present through the profile at Yarrawonga, which is likely due to accumulation of sulphur from previous fertiliser additions and high use of gypsum as a soil ameliorant.

ii) Vigour and biomass

Similarly to the Howlong site, a large number of treatments was required at this site to understand the full interaction between nitrogen and sulphur. As such, only selected treatments received in-crop assessments (i.e. the nil-sulphur and high sulphur treatments at each rate of nitrogen).

There was no difference in plant vigour between treatments when measured at the four-leaf stage (GS1.04) (Table 8).

The DM assessment at the first flowers opened stage (GS4.1) showed a sulphur response, with the 30kg S/ha treatments showing increased biomass compared with the nil sulphur treatment (UTC) (Table 9) when 40 or 80kg N/ha was applied. The 80N:30S treatment had the highest DM production (4.68t DM/ha), which was significantly greater than the 160N:0S treatment (3.79t DM/ha).

TABLE 7 Soil nitrogen and sulphur contents at Yarrawonga, Victoria, sampled 5 June 2017

Depth (cm)	Mineral N (kg/ha)	Mineral S values (kg/ha)
0–30	57.14	42.74
30–60	8.93	66.15
60–90	3.68	31.71
Total (0-90)	69.75	140.6

TABLE 8 Vigour and dry matter assessment at Yarrawonga Victoria, 2017

	8 June 2017	23 August 2017	9 November 2017
	Vigour (1–9)	Dry matter (t/ha)	Dry matter (t/ha)
Treatment	Four leaf (GS1.04)	10% flower (GS4.1)	Most seed black, but soft (GS6. 7)
UTC	5.8[a]	3.26[cd]	6.72[e]
UTC	5.0[a]	3.16[d]	5.58[e]
40N:0S	5.5[a]	2.40[e]	8.44[d]
40N:30S	5.3[a]	4.17[ab]	10.30[bc]
80N:0S	5.3[a]	3.89[bc]	9.65[cd]
80N:30S	5.3[a]	4.68[a]	11.50[ab]
160N:0S	5.3[a]	3.79[bcd]	11.51[ab]
160N:30S	5.0[a]	4.20[ab]	11.24[abc]
240N:0S	5.3[a]	4.40[ab]	10.35[bc]
240N:30S	5.0[a]	4.37[ab]	12.45[a]
Mean	**5.3**	**3.83**	**9.77**
LSD P=0.05	1.1	0.65	1.61
Treatment probability (F)	0.950	<0.001	<0.001
CV	14.04	11.61	11.09
SD	0.7	0.45	1.08

Figures followed by different letters are regarded as statistically different.

The later assessment, made when seeds were black but soft (GS6.7), also showed that the high sulphur treatments had increased DM production compared with nil sulphur treatments (UTC) when 40 or 80kg N/ha was applied. The 80N:30S treatment had statistically comparable DM production to the 240N:30S treatment.

iii) Plant tissue nitrogen and sulphur content

When measured at the first flowers opened stage (GS4.1), there was a clear and statistically significant increase in tissue nitrogen content associated with increased nitrogen application rate (Table 9). There was also a significant increase in nitrogen tissue content with the addition of sulphur at the 40kg N/ha and 240kg N/ha rates.

Nitrogen content at the seeds black but soft stage (GS6.7) also reflected increases in nitrogen application rates. The increased nitrogen content evident at higher nitrogen application rates also related strongly to DM production (Figure 3), although the relationship isn't as clear as that seen at the Howlong site (Figure 1). This difference may be due to the more significant contribution of sulphur nutrition at the Yarrawonga site.

Tissue analysis at first flowers opened stage (GS4.1) showed that adding sulphur increased plant tissue sulphur levels, with all plus-sulphur treatments having significantly higher

TABLE 9 Plant tissue nitrogen and sulphur contents at Yarrawonga, Victoria, 2017

Assessment	23 August 2017	9 November 2017	23 August 2017	9 November 2017
	kg N/ha	kg N/ha	kg S/ha	kg S/ha
	10% flower (GS4.1)	Most seed black, but soft (GS6.7)	10% flower (GS4.1)	Most seed black, but soft (GS6.7)
UTC	61^{d}	42^{f}	16^{b}	18^{e}
UTC	53^{d}	41^{f}	12^{b}	24de
40N:0S	55^{d}	55^{ef}	11^{b}	25de
40N:30S	109^{c}	69^{e}	29^{a}	59^{a}
80N:0S	119^{c}	81de	13^{b}	41^{c}
80N:30S	131^{c}	97^{cd}	28^{a}	47^{bc}
160N:0S	179^{ab}	103^{cd}	13^{b}	30^{d}
160N:30S	167^{b}	119^{bc}	23^{a}	53^{ab}
240N:0S	175^{b}	130^{ab}	15^{b}	26^{d}
240N:30S	201^{a}	152^{a}	26^{a}	51^{b}
Mean	**125**	**89**	**19**	**37**
LSD P=0.05	22	26	5	8
Treatment probability (F)	<0.001	<0.001	<0.001	<0.001
CV	12.12	19.45	19.02	13.51
SD	15.1	17	3.5	5

Figures followed by different letters are regarded as statistically different.

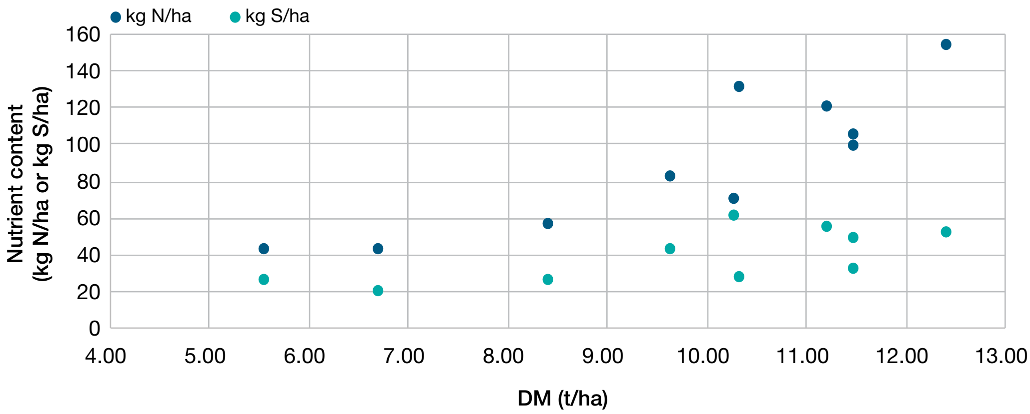


FIGURE 3 Relationship between DM production and nitrogen or sulphur tissue content at Yarrawonga, Victoria, as measured on 9 November 2017, at most seed black, but soft stage (GS6.7)

plant tissue sulphur levels compared with the nil-sulphur treatments (Table 10). There was no interaction between nitrogen supply and tissue sulphur levels at GS4.1.

A similar response was seen at the seeds black but soft stage (GS6.7) with all nitrogen treatments, except the 80kg N treatment, showing a significant increase in tissue sulphur levels compared with the nil-sulphur treatments when sulphur was added.

iv) Green leaf retention

The GLR% at the Yarrawonga site showed a nutrient response (Table 10), compared with the Howlong site, which did not show any response. When measured at both 15 and 32 days after podset (GS5.5) there was trend to increasing GLR% in all treatments from 80N:10S and above. There were no significant effects of sulphur on GLR%.

v) Normalised difference vegetation index

Of the eight NDVI measurements carried out over the life of the trial, only the last four measurements, taken during the period 27 July to 23 August 2017, showed significant differences in leaf greenness. Results from the final reading taken on 23 August are presented in Figure 4 and show a clear nutrient response, with increasing nitrogen and sulphur leading to increased NDVI measurements.

vi) Yield, oil and protein

The Yarrawonga site showed a greater yield response due to nutrition than was seen at the Howlong site, with yields ranging from 1.32t/ha in the untreated control (UTC) to 3.11t/ha in the 160N:20S treatment (Table 11). When analysed as a factorial, the addition of sulphur significantly increased yield when applied at the rate of 20kg S/ha, with

TABLE 10 Green leaf retention at Yarrawonga, Victoria, 2017

Treatment	13 October 2017 GLR (%) 50% podset (GS5.5) +15 days	6 November 2017 GLR (%) 50% podset (GS5.5) +32 days
UTC	60.0^{ef}	43.8^{cd}
UTC	57.5^{ef}	40.0^{d}
UTC	58.8^{ef}	43.8^{cd}
UTC	53.8^{f}	41.3^{cd}
40N:0S	65.0^{def}	43.8^{cd}
40N:10S	65.0^{def}	50.0^{bcd}
40N:20S	67.5^{b-e}	50.0^{bcd}
40N:30S	66.3^{cde}	43.8^{cd}
80N:0S	66.3^{cde}	42.5^{cd}
80N:10S	72.5^{a-d}	53.8^{abc}
80N:20S	73.8^{a-d}	51.3^{a-d}
80N:30S	72.5^{a-d}	47.5^{bcd}
160N:0S	81.3^{a}	60.0^{ab}
160N:10S	80.0^{a}	58.8^{ab}
160N:20S	82.5^{a}	58.8^{ab}
160N:30S	80.0^{a}	63.8^{a}
240N:0S	77.5^{abc}	57.5^{ab}
240N:10S	80.0^{a}	63.8^{a}
240N:20S	78.8^{ab}	60.0^{ab}
240N:30S	80.0^{a}	60.0^{ab}
Mean	**70.9**	**51.7**
LSD P=0.05	11.6	13.4
Treatment probability (F)	<0.001	<0.001
CV	11.59	18.25
SD	8.2	9.4

Figures followed by different letters are regarded as statistically different.

TABLE 11 Harvest yield and quality at Yarrawonga, Victoria, 2017

Treatment	22 November 2017 Yield (t/ha) Harvest	Oil (%) Harvest	Protein (%) Harvest
UTC	1.53^{gh}	47.3^{abc}	16.0^{e}
UTC	1.49^{gh}	47.1^{abc}	16.6^{cde}
UTC	1.70^{g}	47.3^{abc}	16.0^{e}
UTC	1.32^{h}	47.8^{a}	15.8^{e}
40N:0S	1.98^{f}	46.7^{a-d}	16.4^{de}
40N:10S	1.95^{f}	47.4^{ab}	16.2^{de}
40N:20S	2.16^{f}	46.1^{bcd}	16.6^{cde}
40N:30S	2.13^{f}	47.1^{abc}	16.3^{de}
80N:0S	2.45^{e}	45.5^{d}	17.9^{c}
80N:10S	2.74^{bcd}	46.1^{bcd}	17.0^{cde}
80N:20S	2.58^{de}	45.9^{cd}	17.4^{cd}
80N:30S	2.58^{de}	46.2^{bcd}	17.4^{cd}
160N:0S	2.42^{e}	42.9^{ef}	20.3^{b}
160N:10S	2.63^{cde}	43.0^{ef}	20.2^{b}
160N:20S	3.11^{a}	43.4^{e}	20.2^{b}
160N:30S	2.54^{de}	41.5^{fg}	21.2^{b}
240N:0S	2.96^{ab}	41.9^{efg}	20.8^{b}
240N:10S	2.92^{ab}	40.8^{gh}	21.4^{ab}
240N:20S	2.97^{ab}	41.7^{fg}	21.3^{b}
240N:30S	2.82^{bc}	40.0^{h}	22.6^{a}
Mean	**2.35**	**44.8**	**18.4**
LSD P=0.05	0.23	1.5	1.3
Treatment probability (F)	<0.001	<0.001	<0.001
CV	6.98	2.31	5.01
SD	0.16	1.0	0.9

Figures followed by different letters are regarded as different significant.

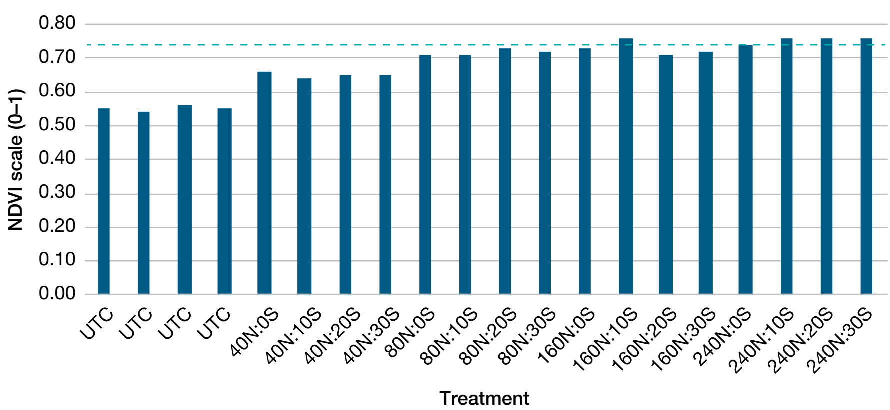


FIGURE 4 NDVI values, measured on 18 August 2018, at 20% flowering (GS4.2) at Howlong, NSW, 2017
LSD = 0.05 All the readings on and above the dotted line are statistically comparable to the highest values of 160N:10S and 240N:20S.



a yield penalty at lower and higher rates, across all nitrogen rates. There was a clear yield response to nitrogen, with an increased nitrogen application rate leading to significantly increased yield so that 240N yielded more than 80N and 160N, which yielded more than 40N.

The response of oil percentage to nitrogen was the inverse of yield so that increasing nitrogen application rate decreased oil percentage. There was no response of oil percentage to the addition of sulphur (Table 11).

Protein percentage also showed a nitrogen response, with increased nitrogen application rates causing a significant increase in protein levels. Again, protein levels showed no response to applied sulphur.

Gross margin analysis

Gross margin (GM) analyses were undertaken based on growers' input costs and included contract rates for machinery operations. Fertiliser rates were converted to combinations of urea and sulphate of ammonia, using values of $400/t for urea and $750/t for sulphate of ammonia. Grain value for the 2017–18 harvest was calculated using prices of $515/t for canola delivered Howlong and $470/t for Roundup Ready® canola delivered Yarrawonga.

A number of treatments (40N:0S, 40N:10S, 40N:20S, 80N:0S, 80N:10S, 80N:20S, 80N:30S, 160N:10S and 240N:20S) at the Howlong site were more economic than the GM of the average of the untreated control plots ($1,110/ha) (Table 12). The highest yielding treatment (80N:20S equivalent to 100kg of urea and 83kg of sulphate of ammonia) yielded 3.04t/ha and returned a GM of $1271/ha. The cost of this rate of fertiliser represented 8% of canola gross income. The second highest GM treatment (80N:0S) returned only $27/ha less and may not have been statistically different from the highest gross margin treatment. Sensitivity analysis showed that decreasing canola price by 10% or increasing fertiliser price by 10% did not change the most economic treatment outcomes.

Three of the 160kg N/ha and three of the 240kg N/ha treatments had lower GM than the untreated control plots, suggesting the higher nitrogen application rates were not economic.

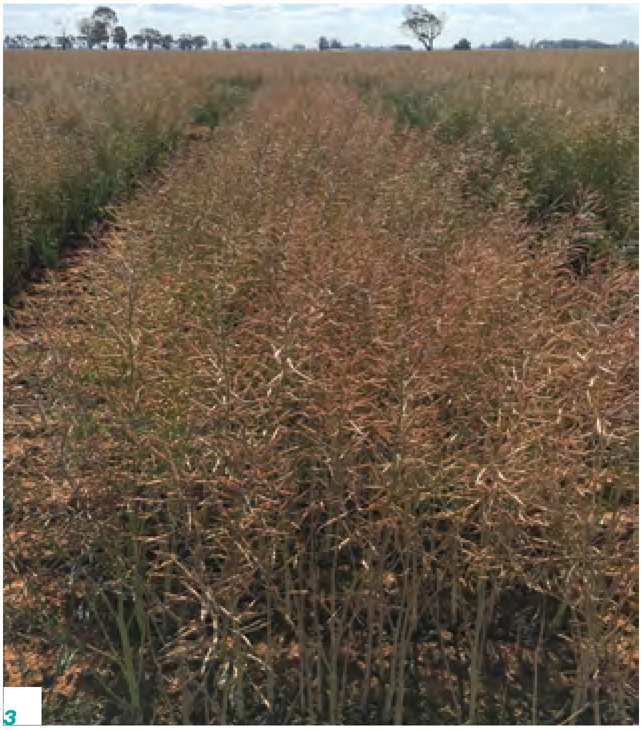
All treatments at the Yarrawonga site were more economic than the GM of the average of the untreated control plots, which returned $462/ha (Table 13). Similarly to Howlong, the highest yielding treatment (160N:20S equivalent to 200kg/ha of urea and 83kg/ha of sulphate of ammonia), which yielded 3.11t/ha, was also the most economic, returning a GM of ($1,020/ha). The cost of this rate of fertiliser represented 13.8% of canola gross income.

Sensitivity analysis showed that decreasing canola price by 10% (by $51.5/t or $164.50/ha at Howlong or by $47/t or $141/ha at Yarrawonga) had a bigger impact on canola GM than a 10% increase in fertiliser price ($40/t for urea and $75/t for sulphate of ammonia, with a combined impact of $10/ha at the Howlong site and $14 at the Yarrawonga site). Changing the canola or fertiliser price did not change which

TABLE 12 Fertiliser application rate, gross margin and sensitivity analysis for treatments at Howlong, NSW, 2017

Treatment	Urea application rate (kg/ha)	SOA application rate (kg/ha)	Gross margin ($/ha)	Gross margin# (canola price less 10%) ($/ha)	Gross margin# (fertiliser price plus 10%) ($/ha)
UTC	0	0	1110*	970	
40N:0S	87	0	1147	995	1143
40N:10S	67	42	1236	1073	1230
40N:20S	50	83	1177	1018	1169
40N:30S	30	125	1061	911	1051
80N:0S	174	0	1237	1072	1230
80N:10S	134	42	1174	1014	1165
80N:20S	100	83	1271	1099	1261
80N:30S	60	125	1134	975	1123
160N:0S	348	0	1112	953	1098
160N:10S	268	42	1209	1039	1195
160N:20S	200	83	1108	949	1094
160N:30S	120	125	1077	921	1062
240N:0S	522	0	1005	850	984
240N:10S	402	42	1095	932	1076
240N:20S	300	83	1147	980	1129
240N:30S	180	125	1037	883	1021

Gross margins not statistically analysed. The difference between the gross margins of 80N:20S and 80N:0S is therefore likely to be minimal as the yields of these treatments were not statistically different



1 *Discolouration on older leaves 20 June 2017 caused by cold and dry conditions during June 2017*

2 *Yarrawonga trial site, 21 July 2017*

3 *Untreated control, 6 November 2017 when most seed black, but soft (GS6.7)*

4 *240N:0S treatment, 6 November 2017 when most seed black, but soft (GS6.7)*



TABLE 13 Fertiliser application rate, gross margin and sensitivity analysis for treatments at Yarrawonga, Victoria, 2017

Treatment	Urea application rate (kg/ha)	SOA application rate (kg/ha)	Gross margin ($/ha)	Gross margin# (canola price less 10%) ($/ha)	Gross margin# (fertiliser price plus 10%) ($/ha)
UTC	0	0	462*	386	
40N:0S	87	0	647	548	644
40N:10S	67	42	618	519	613
40N:20S	50	83	679	572	671
40N:30S	30	125	656	548	646
80N:0S	174	0	818	697	811
80N:10S	134	42	955	818	947
80N:20S	100	83	856	728	846
80N:30S	60	125	846	717	834
160N:0S	348	0	690	575	676
160N:10S	268	42	790	665	776
160N:20S	200	83	1020	870	1005
160N:30S	120	125	718	600	704
240N:0S	522	0	851	712	830
240N:10S	402	42	827	692	807
240N:20S	300	83	878	739	860
240N:30S	180	125	792	664	776

Gross margins not statistically analysed

treatment was the most economic application of nitrogen and sulphur at either site.

The difference in optimum nitrogen fertiliser application rates for both sites highlighted the importance of understanding paddock history. Both the Yarrawonga and Howlong sites had maximum yields above 3t/ha, however, the Howlong site required 80kg/ha less nitrogen to achieve this yield. This was evidenced by yields in the Howlong UTC, which averaged 2.5t/ha compared with the untreated treatments at Yarrawonga, which averaged 1.5t/ha. This demonstrates how deep nitrogen testing and a knowledge of paddock history can be used to inform nitrogen decisions — in this example saving $167/ha.

Discussion

While the Yarrawonga site had only half the amount of mineral nitrogen than that measured at the Howlong site, soil mineral sulphur levels were approximately double at Yarrawonga compared with Howlong. Despite high background levels of sulphur (likely due to accumulation of sulphur from previous additions), the Yarrawonga site recorded clear sulphur responses, while these were not seen at the Howlong site. This suggests canola roots may not be effectively exploring the soil profile to access soil sulphur, or the accumulation of sulphur in the top 30cm may not supply adequate sulphur for the season.

There was a clear yield response to applied nitrogen and applied sulphur at the Yarrawonga site. The optimum level of applied sulphur at this site was 20kg/ha, with yield penalties above and below this level.

The movement of nitrogen to depth at this site is likely due to saturated soil conditions during 2016, which increased the movement of nitrogen to depth.

At the Howlong site applied nitrogen gave a yield and DM response, however there was no sulphur response.

Despite GSR being close to average for both sites during 2017, extremely dry conditions during June and September created challenges within these trials, although the absence of heat stress during pod fill and stored moisture from the 2016 season allowed canola to yield well. This trial will be repeated at two sites during 2018 to understand how variable the responses to sulphur are likely to be during different years.

Acknowledgements

Riverine Plains Inc acknowledges the investment made by the GRDC to the *Optimising crop nutrition in canola in the southern region of NSW (RPI00013)* project. We also thank trial contractors FAR Australia and our farmer co-operators, the Cummins family, Yarrawonga and the Trevethan family, Howlong.

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Harvest weed seed control for the southern high-rainfall zone

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Key messages

- Harvest weed seed control (HWSC) — the collection and/or destruction of weed seeds at harvest — is a non-chemical control method, which can be used to reduce the seedbank of weeds, such as annual ryegrass (*Lolium rigidium*).
- Techniques include mechanical weed destruction, or methods involving carting or baling chaff straight after harvest. Chaff can also be concentrated behind the header in a row, which is then left to mulch (chaff lining or decking) or concentrated in a narrow windrow behind the header and burnt (narrow windrow burning).
- A major premise of HWSC is that the targeted weed species retain a high proportion of their total seed production at crop maturity.
- There was no difference between a harvest height of 30cm and 15cm in terms of the number of weed seeds returned to the soil.
- In wheat crops with high annual ryegrass plant populations, a large percentage of the ryegrass seed matures and drops in the month before wheat harvest, limiting the effectiveness of HWSC in the Riverine Plains region. In 2017, approximately 30% of total ryegrass weed seeds were removed by the harvest process.
- HWSC could be used as one tool in a larger integrated weed management strategy.

Aim

The aim of this work is to understand if growers can reduce soil weed seedbanks in high-yielding high-rainfall zones by adopting harvest weed seed control (HWSC) practices.

Background

The four-year project *Harvest weed seed control for the southern high rainfall zone* (2015–18), aims to investigate the efficacy of HWSC practices across southern Australia through partnerships with Southern Farming Systems, Mackillop Farm Management Group, Riverine Plains Inc and Farmlink Inc. The project included four small plot trials and six on-farm demonstration sites across the different regions.

Riverine Plains Inc was involved in the small plot trial work undertaken to investigate the impact of harvest height on resultant weed seedbanks. The height of the seed on the weed plant in the crop determines the harvest height required to collect most weed seeds.

Method

The Riverine Plains Inc small plot trial was established at Yarrawonga, Victoria during 2016.

Soil weed seedbanks were measured before sowing in 2016. To offset the spatial variability in weed seeds across the paddock, annual ryegrass was sown at varying target densities to reflect commercial grower experiences of: nil (no ryegrass sown), 25 plants/m^2, 50 plants/m^2 and 75 plants/m^2.

In establishing the 2016 trials, the wheat (cv Corack) and ryegrass were sown in two passes on 28 April 2016 into a burnt and levelled wheat stubble, with the ryegrass sown first, followed by the wheat.

The trial was a split plot randomised design. Plots were 2m wide and 15m long. The main plot was harvest height with residue removed (15cm and 30cm) with the sub-plot being ryegrass density. Treatments were replicated five times.

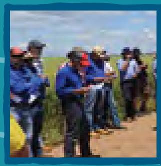
The harvest height treatment was first applied in 2016 (Table 1). The 2017 trial results are analysed based on 2016 harvest heights, with the treatments applied each year described in Table 1.

For the second year of the trial, wheat (cv Trojan) was sown on 12 May 2017, on the same site as the 2016 trial. The same trial design was applied during 2017 as in 2016, though the ryegrass treatments were not re-sown.

In 2017 the site was burnt before sowing and Sakura® was incorporated by sowing (IBS) to provide some ryegrass weed control.

TABLE 1 Wheat stubble height treatment applied from 2015–17

Year	Crop	Stubble height treatment applied at harvest (cm)
2015	Wheat	none
2016	Wheat	15, 30
2017	Wheat	15, 30



The 2017 wheat crop was sown with mono-ammonium phosphate (MAP) at a rate of 75kg/ha. Urea was applied on 4 July 2017 (100kg/ha) and also on 10 August 2017 (100kg/ha).

Soil weed seedbanks were measured on 15 May 2017 by taking five 3cm by 5cm diameter deep soil cores per plot. These cores were planted into small trays and watered regularly. Germinating weed seeds were counted and removed until 15 August 2017.

Annual ryegrass plant populations were measured in the crop when wheat was at the three-leaf stage (GS12) and again when the wheat crop had three tillers (GS23).

Ryegrass seed shedding was measured weekly from 11 November 2017, commencing when the ryegrass was at the mid-flowering (GS65) stage, and continuing until the wheat was harvested on 10 December 2017. Seed shedding was measured by placing two small trays in each plot to catch fallen seeds. Seeds collected in the trays were counted weekly.

At harvest, residue was collected by attaching a fertiliser bulk bag to the back of the plot harvester and regularly unloading straw and chaff away from the plots. The straw and chaff were burnt after harvest. The removal of residue simulates weed seed capture in a broadacre HWSC technique, such as when using a chaff cart.

Data were analysed with an analysis of variance (ANOVA), where data were log transformed for normality if needed.

Results

Harvest height in 2016 did not affect ryegrass numbers in 2017 at either the wheat three leaf (GS13), three tiller (GS23) or the hard dough stages (GS87) (Table 2).

There appeared to be a ryegrass density effect on spikelet numbers, with treatment 1 (ryegrass sown 0/m^2, harvest height 15cm) having a higher number of ryegrass spikelets than treatment 4 (ryegrass sown 75/m^2, harvest height 15cm). This was also observed in the 30cm harvest height treatment, with treatments 5 (ryegrass sown 0/m^2, harvest height 30cm) and 6 (ryegrass sown 25/m^2, harvest height 30cm) having significantly more spikelets than treatment 8 (ryegrass sown 75/m^2, harvest height 30cm). This result, while counterintuitive, may have been caused by the wet conditions experienced during 2016, which caused many of the plots to remain under water for a number of weeks.

Neither harvest height or density affected the number of ryegrass seeds shed (Table 3). Only two treatments were significantly different, with treatment 7 (ryegrass sown 50/m^2, harvest height 30cm) shedding significantly more seeds than treatment 1 (ryegrass sown 0/m^2, harvest height 15cm) and only when measured on 17 November 2017. There was no difference in the total number of seeds shed across treatments.

Harvest height or density did not affect numbers of spikelets above and below harvest height (Table 4).

The mean wheat yield across treatments was 3.10t/ha, while mean protein was 8.08%, mean screenings were 0.68% and the mean test weight was 74.05kg/hL (Table 4). Paddock flooding in 2016 caused the proliferation of ryegrass from the natural seedbank (2016 project protocols stipulated no in-crop weed control), which resulted in high ryegrass populations across all plots in 2017, even in the nil sown plots. These factors, along with the paddock being in its third year of wheat, contributed to the relatively low yield and grain protein results across treatments.

TABLE 2 Germination of ryegrass from soil cores taken 15 May 2017 and ryegrass populations measured in wheat (cv Trojan) at the three leaf (GS13), three tiller (GS23) and dough stage (GS87) stage (all data log transformed) at Yarrawonga, Victoria

	Log ryegrass plants/m^2			Log ryegrass spikelets/m^2
2016 treatment	Soil seed bank	GS13	GS23	GS87
1. Ryegrass sown 0/m^2, harvest height 15cm	1.57^{ab}	1.98	1.92^{ab}	2.31^{a}
2. Ryegrass sown 25/m^2, harvest height 15cm	1.21^{abc}	2.07	2.01^{ab}	2.32^{a}
3. Ryegrass sown 50/m^2, harvest height 15cm	0.77^{abc}	1.96	1.73^{b}	1.94^{ab}
4. Ryegrass sown 75/m^2, harvest height 15cm	0.63^{ab}	2.01	1.98^{ab}	1.45^{b}
5. Ryegrass sown 0/m^2, harvest height 30cm	1.45^{b}	2.00	1.94^{ab}	2.39^{a}
6. Ryegrass sown 25/m^2, harvest height 30cm	1.08^{bc}	2.09	2.04^{a}	2.41^{a}
7. Ryegrass sown 50/m^2, harvest height 30cm	0.65^{bc}	1.98	1.76^{ab}	2.03^{ab}
8. Ryegrass sown 75/m^2, harvest height 30cm	0.50^{c}	2.02	2.01^{ab}	1.53^{b}
Mean	**0.98**	**2.01**	**1.92**	**2.05**
LSD	0.84	n.s.	0.28	0.72

Figures followed by letters are regarded as statistically different ($P<0.05$)

Note: This data has been log transformed by a factor of 10. Log transformation is used to make highly skewed distributions less skewed in order to conduct statistical analysis. Actual data is presented in Table 5

TABLE 3 Ryegrass seed shedding measured 10 November 2017, 17 November 2017, 24 November 2017, 10 December 2017; total seeds shed and number of ryegrass spikelets above and below harvest height (24 November 2017) (all data log transformed) at Yarrawonga, Victoria

2016 treatment	Log ryegrass seed shed/m^2					Log ryegrass spikelets/m^2	
	10/11/17	17/11/17	24/11/17	10/12/17	Total	Above harvest height	Below harvest height
1. Ryegrass sown 0/m^2, harvest height 15cm	1.98	1.66[a]	2.60	2.82	3.20	1.40[ab]	0.71
2. Ryegrass sown 25/m^2, harvest height 15cm	2.23	1.98[ab]	2.74	2.67	3.24	1.78[ab]	0.28
3. Ryegrass sown 50/m^2, harvest height 15cm	2.18	2.30[ab]	2.46	2.56	3.20	1.16[a]	0.54
4. Ryegrass sown 75/m^2, harvest height 15cm	1.93	2.03[ab]	2.54	2.41	3.06	1.83[ab]	0.67
5. Ryegrass sown 0/m^2, harvest height 30cm	2.21	1.89[ab]	2.69	2.89	3.21	1.63[ab]	1.02
6. Ryegrass sown 25/m^2, harvest height 30cm	2.46	2.21[ab]	2.83	2.74	3.25	2.00[b]	0.59
7. Ryegrass sown 50/m^2, harvest height 30cm	2.41	2.54[b]	2.55	2.63	3.21	1.39[ab]	0.85
8. Ryegrass sown 75/m^2, harvest height 30cm	2.16	2.26[ab]	2.63	2.48	3.07	2.05[b]	0.98
Mean	**2.20**	**2.11**	**2.63**	**2.65**	**3.18**	**1.66**	**0.71**
LSD	n.s.	0.75	n.s.	n.s.	n.s	0.76	n.s.

Figures followed by letters are regarded as statistically different ($P<0.05$)

Note: This data has been log transformed by a factor of 10. Log transformation is used to make highly skewed distributions less skewed in order to conduct statistical analysis. Actual data is presented in Table 6

TABLE 4 Wheat (cv Trojan) plant establishment at the three-leaf stage (GS13), along with 2017 yield, protein, screenings and test weight results, Yarrawonga, Victoria

2016 treatment	Plants/m^2 (GS13)	Yield (t/ha)	Protein (%)	Screenings (%)	Test weight (kg/hL)
1. Ryegrass sown 0/m^2, harvest height 15cm	151.11[ab]	3.24	8.14	0.69	74.51
2. Ryegrass sown 25/m^2, harvest height 15cm	166.22[a]	3.08	8.36	0.76	74.34
3. Ryegrass sown 50/m^2, harvest height 15cm	157.33[ab]	3.1	8.78	0.68	74.08
4. Ryegrass sown 75/m^2, harvest height 15cm	154.67[ab]	3.19	8.34	0.73	74.05
5. Ryegrass sown 0/m^2, harvest height 30cm	138.67[b]	3.13	7.49	0.63	74.13
6. Ryegrass sown 25/m^2, harvest height 30cm	153.78[ab]	2.97	7.71	0.7	73.95
7. Ryegrass sown 50/m^2, harvest height 30cm	144.89[ab]	2.99	8.13	0.61	73.69
8. Ryegrass sown 75/m^2, harvest height 30cm	142.22[ab]	3.07	7.69	0.66	73.66
Mean	**151.11**	**3.1**	**8.08**	**0.68**	**74.05**
LSD	22.85	n.s.	n.s.	n.s.	n.s.

Plant numbers are significantly different ($P<0.05$) between treatments when followed by different letters

Wheat plant establishment was significantly lower in treatment 5 (ryegrass sown 0/m^2, harvest height 30cm) compared with treatment 2 (ryegrass sown 25/m^2, harvest height 15cm). However this did not have any bearing on yield, protein, screenings or test weight. There were no other significant differences in yield, protein, screenings or test weight across treatments.

Data were untransformed from the log format to show actual ryegrass numbers in the crop (Tables 5 and 6). Ryegrass plant densities ranged from 91–122/m^2 when wheat was at the three-leaf stage (GS13) and from 54–109/m^2 when the wheat had three tillers (GS23) (Table 5), suggesting some mortality of the ryegrass.

Seed soil bank measurements taken before sowing showed 3–38 ryegrass plants/m^2, which was lower than actual ryegrass counts (91–122 plants/m^2) when wheat was at the three-leaf stage (GS13). Ryegrass spikelet numbers at the wheat hard dough stage (GS87) ranged from 28–255/m^2, which equates to between 168 and 1530 seeds/m^2, based on an estimated average number of six seeds per spikelet.

The number of seeds shed by the ryegrass was measured weekly before harvest. Measurements taken during the second week of November showed that 85–292 seeds/m^2 were shed; this increased to 254–778 seeds/m^2 by the first week in December (Table 6). The average total numbers of seeds shed during the four weeks leading up to harvest was 1,596/m^2, with no treatment effect evident in the log transformed data (Table 3)

In 2017, 30% of ryegrass weed seeds were captured by the harvest process (Table 7). Weed seeds captured were measured as the average number of seeds above header height (15 or 30cm) divided by the total number of weed seeds. The total number of weed seeds was the sum of weed seed shed prior to harvest (Table 6) and number of



TABLE 5 Germination of ryegrass from soil cores taken on 15 May 2017, ryegrass populations measured in wheat (cv Trojan) at the three leaf (GS13), the three tiller (GS23) and the hard dough stages (GS87) and ryegrass spikelets measured at the hard dough stage (GS87) at Yarrawonga, Victoria

2016 treatment	Ryegrass plants/m²			Ryegrass spikelets/m²
	Soil seed bank	Wheat GS13	Wheat GS23	Wheat GS87
1. Ryegrass sown 0/m², harvest height 15cm	38	95	83	204
2. Ryegrass sown 25/m², harvest height 15cm	16	117	103	211
3. Ryegrass sown 50/m², harvest height 15cm	6	91	54	88
4. Ryegrass sown 75/m², harvest height 15cm	4	101	96	28
5. Ryegrass sown 0/m², harvest height 30cm	28	99	88	248
6. Ryegrass sown 25/m², harvest height 30cm	12	122	109	255
7. Ryegrass sown 50/m², harvest height 30cm	4	95	57	106
8. Ryegrass sown 75/m², harvest height 30cm	3	106	102	34

TABLE 6 Ryegrass seed shedding counts on 10 November 2017, 24 November 2017, 10 December 2017, along with total number of seeds shed at Yarrawonga, Victoria

2016 treatment	Seed shed/m²				
	10/11/17	17/11/17	24/11/17	10/12/17	Total
1. Ryegrass sown 0/m², harvest height 15cm	96	46	396	656	1596
2. Ryegrass sown 25/m², harvest height 15cm	171	94	547	465	1730
3. Ryegrass sown 50/m², harvest height 15cm	152	201	288	361	1583
4. Ryegrass sown 75/m², harvest height 15cm	85	106	343	254	1145
5. Ryegrass sown 0/m², harvest height 30cm	163	78	488	778	1636
6. Ryegrass sown 25/m², harvest height 30cm	292	162	675	551	1774
7. Ryegrass sown 50/m², harvest height 30cm	258	345	355	428	1624
8. Ryegrass sown 75/m², harvest height 30cm	144	182	424	302	1174

weed seeds above and below header cutting height, as measured on 24 November 2017.

Observations and comments

At the outset of this project it was expected that lowering harvest height from 30cm to 15cm would increase the amount of weed seed captured during the harvest process and this would reduce the number of seeds returned to the seedbank. However, 2017 plant population measurements showed no statistical evidence to indicate the 15cm harvest height applied during 2016 decreased ryegrass plant numbers compared with the 30cm harvest height.

High weed numbers in 2016, along with high rates of lodging, meant weed seeds at both harvest heights were difficult to pick up with the header front. Also, the high amount of ryegrass seed shed before the 2016 harvest (on average 4,824/m²), reduced the effectiveness of HWSC techniques.

In instances where weed numbers are low and/or there is still a significant amount of ryegrass retained in the head of the grass weed at harvest, it seems logical to harvest as low as possible to get as much seed through the header to be captured and destroyed.

During both 2016 and 2017, soil weed seed banks were measured by taking soil samples and growing them out in trays. In both years, weed germination rates in the trays were lower than the actual germination rates recorded in the paddock, indicating that this method tends to underestimate the level of the weed seedbank.

Although more ryegrass weeds germinated during 2017 compared with 2016, these ryegrass plants produced less

TABLE 7 Ryegrass spikelets and seeds captured by the harvest process at Yarrawonga, Victoria 2017

Average ryegrass spikelets above header cutting height	Average ryegrass seeds above header cutting height	Average spikelets below header cutting height	Average seeds below header cutting height	Average seeds shed prior to harvest	Total ryegrass seeds	Seeds captured by header
(spikelets/m²)	(seeds/m²)	(spikelets/m²)	(seeds/m²)	(seeds/m²)	(seeds/m²)	(%)
124	744	19	114	1596	2454	30

Note: Ryegrass seeds/m² were calculated by multiplying the number of ryegrass spikelets/m² by six.

seed overall by the soft dough stage (GS87) than during 2016 (Table 8). It appears that during 2017 some ryegrass plant mortality occurred between the three-leaf stage (GS13) in wheat and the three-tiller stage (GS23). The surviving plants produced fewer spikelets and less seed (Table 8). Lower ryegrass weed competitiveness during 2017 could be due to a number of factors including the application of HWSC during 2016 and the use of an IBS herbicide during 2017 (not used during 2016). The 2017 wheat crop was also less stressed and generally more competitive than the 2016 wheat crop, which was affected by flooding throughout the growing season.

To date, much of the data on ryegrass weed populations has been collected in the low-to-medium rainfall zones, however data collected through this project relates specifically to the medium-to- high rainfall zone.

The results from this project suggest that applying HWSC techniques will be more effective in paddocks with low-to-medium ryegrass weed densities, paddocks where the crop and weeds have not lodged and in crops with a maturity date closer to the maturity date of the ryegrass.

In wheat paddocks with high ryegrass burdens, HWSC is not recommended as a single weed control strategy and should be integrated as part of a wider weed management strategy.

TABLE 8 Comparison of 2016 and 2017 ryegrass numbers in wheat (cv Trojan) at the three leaf (GS13), three tiller (GS23) and soft dough (GS87) stages, along with total numbers of seeds shed

	2016	2017
Crop growth stage	Ryegrass density (plants/m^2)	
Ryegrass at wheat GS13	56.57	103.17
Ryegrass at wheat GS23	76.52	82.73
Spikelets at wheat GS87	803.93	147
Total numbers of seed shed	4824	1596

Acknowledgements

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Seasonal soil moisture and nitrogen availability — Rutherglen and Boorhaman regions

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Key points

- Soils in the Rutherglen region of Victoria are highly variable.
- While most soils across the region increase in clay content in the subsoil, there is a vein of sandy subsoil that runs through the Boorhaman region.
- While soil moisture probes are a valuable management tool, accurate interpretation requires an understanding of the soil type, including any physical and chemical constraints that may restrict root and/or water movement to depth.
- Sampling for deep soil nitrogen (DSN) by combining all soil from 0-60cm depth does not give a clear picture of where nitrogen is located in the profile, and how readily plants can access it.

Background

During June 2015, the North East Catchment Management Authority (NECMA) provided funds to Riverine Plains Inc to install and monitor soil moisture probes in cropping paddocks at 11 sites across the Rutherglen region of Victoria through the *Soil moisture probe network* project.

The objective of this project was for growers to understand how knowledge of stored soil moisture can inform their decisions about applying fertiliser. For example, if the soil profile has sufficient moisture, growers might decide to apply enough nitrogen (N) during spring to satisfy the full crop requirement. However, if there is limited stored soil moisture, growers might only apply a smaller amount of fertiliser, as the crop would depend entirely on in-crop rainfall events to reach maturity.

The project also involved measurements of deep soil nitrogen (DSN) post-harvest and pre-sowing to account for the amount of nitrogen mineralised over summer.

Additional funding from the *Sustainable agriculture Victoria: Fast tracking innovation initiative*, made possible with the support of the Foundation for Rural and Regional Renewal (FRRR) through the William Buckland Foundation, allowed DSN sampling (broken into incremental depth samples) at each of these sites. By connecting the results from soil nitrogen sampling to soil moisture status, growers can predict if the stored nitrogen will be available to the crop through the year, or if it will be lost through leaching (due to accumulation of nitrogen at depth under high soil moisture conditions).

The *Benchmarking soil nutrient status in connection with soil water storage and soil type in cropping systems* project is supported by NECMA through funding from the Australian Government's National Landcare Program. This project commenced in 2016 and continued throughout 2017 to extend the work undertaken during 2015.

Some of the soil moisture probe sites from the original *Soil moisture probe network* project were relocated into the Boorhaman area through a partnership with the Boorhaman Landcare Group. Soil moisture monitoring and DSN sampling continued until pre-sowing 2017, with a full soil chemistry analysis undertaken at each site during June 2017 to assist in developing a network of benchmark sites through the region.

Aim

The aim of this project was to increase the understanding of nitrogen availability and movement across and between seasons, to understand how nitrogen availability is intimately related to soil moisture status and to understand the variability in soil chemistry within the Rutherglen–Boorhaman region.

Method

Soil moisture monitoring

Soil moisture probes were installed at 11 sites across the Rutherglen region during June 2015. Probes were removed during harvest (November) and during late March 2016 in preparation for sowing. The results from this first year of soil moisture monitoring were presented in *Research for the Riverine Plains 2016* pages 66–75.

During July 2016, seven of these 11 soil moisture probes were re-installed at existing sites across the Rutherglen region and probes were installed at four new locations in the Boorhaman region. Results from this second year of soil moisture monitoring were presented in *Research for the Riverine Plains 2017,* pages 86–93.

Each probe measured up to four depth intervals (10, 30, 50 and 90cm below the soil surface), with values logged every two hours. The data was manually downloaded from each probe on a regular basis. Gaps in the dataset occurred during sowing and harvest, or if the probe was damaged.



Deep soil nitrogen sampling was carried out at each of the soil moisture probe locations during June and December 2015, April and July 2016, as well as during January, April and June 2017 (Figure 1).

The mid-season DSN sampling is timed to coincide with the typical programs of the region's growers, who use the results to identify how much nitrogen they need to apply to meet crop demand through spring. The post-harvest samplings provide a measure of post-crop residual nitrogen, while the post-sowing sampling provides information on the amount of nitrogen lost or mineralised during the summer months.

Deep soil nitrogen sampling at each of the 11 soil moisture probe sites consisted of one core sample, which was split into increments (0–10, 10–20, 20–30, 30–60 and 60–100cm) before being analysed for mineral nitrogen (nitrate + ammonium) and total nitrogen (includes organic and inorganic forms — i.e. the total nitrogen soil bank).

By measuring both mineral nitrogen and total nitrogen growers can better appreciate the role of organic forms of nitrogen in cycling and mineralisation processes.

The data from the nitrogen samples could not be statistically analysed because the collection was not replicated. While the results presented here provide an indication of nitrogen availability, they are sampled from one point in the paddock and there is the possibility the results are not representative of the rest of the paddock.

Soil chemistry benchmarking

Soil sampling for a full soil chemistry analysis (including nitrogen) was carried out during June 2017 in order to capture the key chemical constraints likely to impact on plant growth and root extraction of soil moisture. This analysis also provides key benchmarking figures on soil status in the Rutherglen-Boorhaman region, which will be of value over time.

Results

As there are now several years of data at most of the soil moisture monitoring sites, all results at each site have been compiled and evaluated *in toto* (as a whole). This has been done in order to 'step back' from the annual results to look at the soil system over several seasons.

Soil mineral nitrogen is comprised of both nitrate and ammonium, both of which are measured in standard soil tests, and when added together give a total *mineral nitrogen* value. As the ammonium fraction is sensitive to waterlogging (the value becomes elevated under anaerobic conditions), only the nitrate-nitrogen fraction is presented here. This allows comparison between wet and dry periods of sampling.

The monthly rainfall data for Rutherglen for the monitoring period is presented in Figure 2 and provides context to the soil moisture results presented. The 2015 season was characterised by high rainfall during the winter months, while the spring was dry. For the 2016 season, rainfall

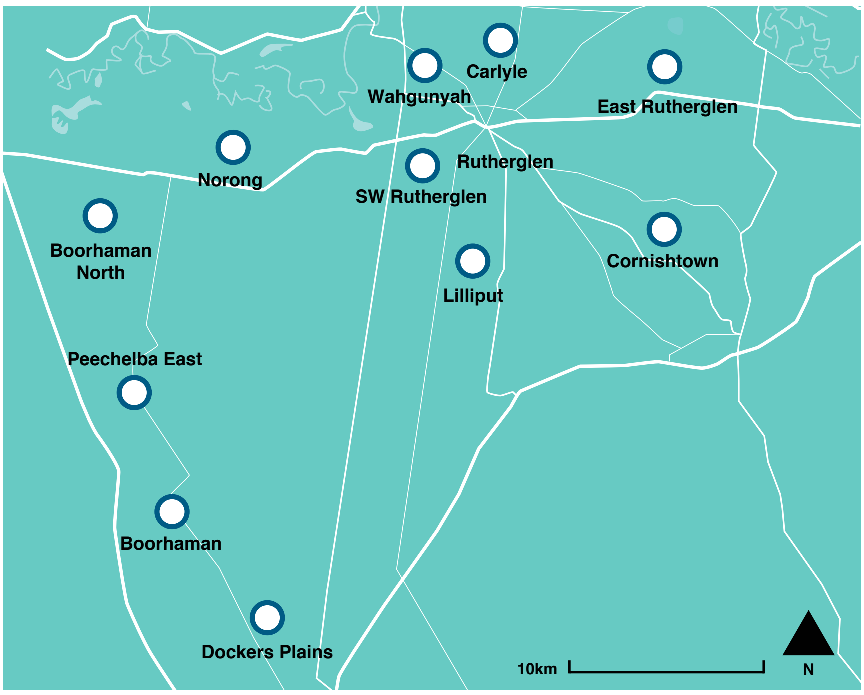


FIGURE 1 Locations of the 11 soil moisture probes installed across the Rutherglen and Boorhaman areas

during December 2015 and January 2016 helped replenish stored soil moisture reserves, however there was little follow-up rainfall during February and March 2016. The winter and spring of 2016 were extremely wet, with more than double the long-term median rainfall being received during September 2016. In comparison, the summer of 2016–17 was dry, with little soil moisture available to aid mineralisation (the microbial conversion of organic nitrogen into plant-available mineral nitrogen). High rainfall was recorded during autumn and winter 2017, while a dry spring saw crops draw heavily on soil moisture reserves. The summer of 2017–18 was characterised by intense rainfall events during harvest, followed by minimal summer and autumn rainfall.

Location: Carlyle

2015 crop and stubble practice: Wheat, cut for hay

2016 crop and yield: Triticale, cut for hay 6.9t/ha

2016 nitrogen applied: 10kg N/ha MAP, 69kg N/ha urea

Timing of 2016 in-crop nitrogen application: July

2016 stubble management (post-harvest): Multidisc

2017 crop and yield: Canola, 2.3t/ha, 43% protein (hail damage on 50%)

2017 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea

Timing of 2017 in-crop nitrogen application: July and August

2017 stubble management: Retained

The Carlyle site is a self-mulching grey clay. While the surface (0–10cm) is lighter textured and shows a clear response to rainfall and evapotranspiration, the subsurface layers do not show much response, due to the ability of heavy clay to strongly hold onto water (Figure 3).

During 2015 there was limited movement of soil moisture at depth, while the entire profile was full during the 2016 season.

All moisture probe results at depth were closely aligned and this, along with soil pit observations of soil texture, support the determination that the soil is uniformly high in clay to depth.

During the period from June 2015 to harvest 2017, the only time plant roots were observed to strongly extract water at depth was during October 2017, when a lack of rain and high plant demand combined to result in the measurable extraction of water down to 50cm. While excavation of a soil pit during spring 2017 showed roots had penetrated into the 70–80cm zone, their contribution to water extraction may have been low.

Results from the moisture probe sensors showed that this soil dried out to depth during the summer of 2018. However, given this type of heavy clay would not naturally dry out to such low levels, the drying could only be due to the development of deep cracks near the soil moisture probe sensor locations.

Nitrogen movement at the Carlyle site was mostly restricted to the 0–10 and 10–30cm layers, with only minimal nitrogen movement down to 60cm (Figure 4). As most of the nitrate-nitrogen is in the top soil layers this nitrogen, along with additional in-crop nitrogen, was likely utilised by the crop.

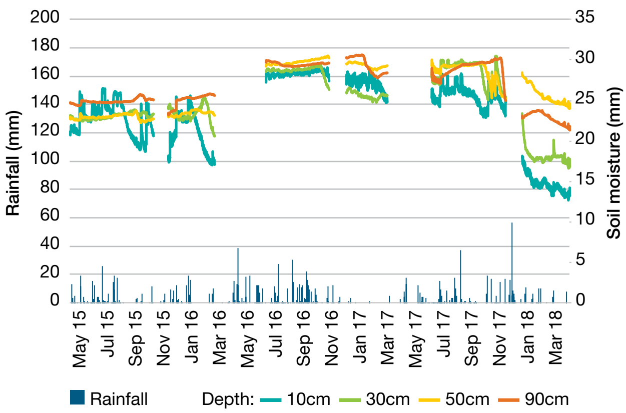


FIGURE 3 Soil moisture levels at Carlyle, Victoria May 2015 – March 2018

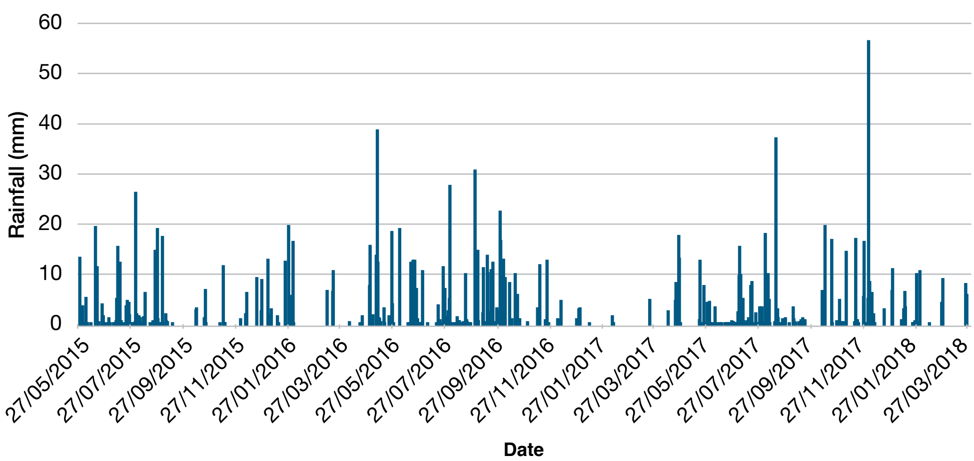


FIGURE 2 Monthly rainfall recorded at Rutherglen, 27 May 2015 – 31 March 2018

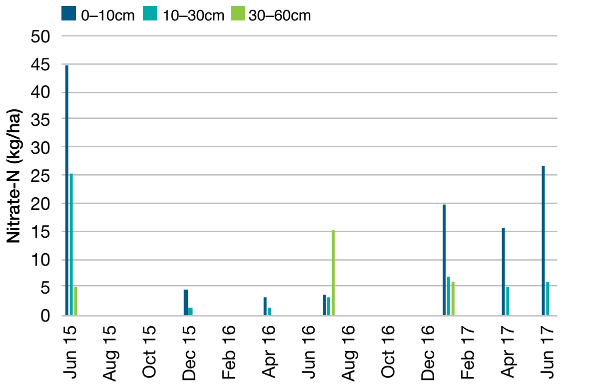


FIGURE 4 Plant-available (nitrate) soil nitrogen levels at Carlyle, Victoria June 2015 – June 2017.

The exception to this involves the July 2016 measurements, when nitrate likely leached downwards under the saturated conditions. It is also likely that significant denitrification (gaseous-nitrogen loss) occurred on this site during the 2016 winter, which probably experienced prolonged waterlogging due this soil's inability to drain water. While some mineralisation of organic nitrogen occurred before sampling in January 2017, this did not further increase in the interval to sowing, suggesting that some of this nitrogen may be left over from in-crop applications.

Soil chemistry results at Carlyle (Table 1) show a pH_{Ca} of 4.8, indicating an acidic topsoil. At this pH, aluminium (Al) toxicity becomes a risk to growing plants; if the pH value continues to decrease, aluminium availability in the soil will increase, which may limit plant growth. Sodium levels are low at this site, indicating that sodicity/dispersion is not a limiting factor. The soil organic carbon value of 1.2% should support an active microbial population.

TABLE 1 Soil chemistry results at Carlyle, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.8	5.1	6.5
EC (dS/m)	0.07	0.02	0.03
Chloride (mg/kg)	11	<10	<10
Nitrate N (kg/ha)	26.6	5.9	0
Mineral N (kg/ha)	28.8	8.4	2.7
Colwell P (mg/kg)	42	5	<5.0
PBI (Colwell)	94	40	47
CEC*	7.7	6.7	11.8
ESP#	1.5	1.1	2.8
Aluminium % of cations	3.7	<1	<1
Sulphur (KCl40)	6.2	1.6	1.7
Organic carbon (%)	1.2	0.2	<0.15
Available potassium (mg/kg)	240	120	230

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: South-west Rutherglen

2015 crop and stubble practice: Wheat, burned

2016 crop and yield: Canola, 1.7t/ha

2016 nitrogen applied: 10kg N/ha MAP, 69kg N/ha urea

Timing of 2016 in-crop nitrogen application: Mid-July

2016 stubble management (post-harvest): Burnt patches

2017 crop and yield: Wheat, 5.5t/ha

2017 nitrogen applied: 10kg N/ha MAP, 115kg N/ha

Timing of 2017 in-crop nitrogen in application: Early July, early August, late August

2017 stubble management: Burn stubble before lupins.

The soil moisture profile of the south-west (SW) Rutherglen site indicates this soil has a high capacity to store and release water for plant growth, as shown by the variance of soil moisture measured within each profile (Figure 5). Moisture probe readings show that during spring 2017 plants accessed moisture down to at least 90cm. Similarly to other soils in the region, this soil has a lighter-textured layer at 30cm depth, which has less capacity to store water than the 10cm layer.

The 2015 season moisture probe data indicated effective extraction of moisture below 50cm, with plant roots drawing down much of the available stored water during October. Several heat stress events were experienced during October, increasing the demand for moisture. Compared with the heavy clay soil of the Carlyle site, the lighter-textured soil present to 50cm depth at this site allowed the paddock to drain well during the wet winter of 2016. Data from the 2017 season showed roots accessed moisture down to 90cm during the dry spring period.

The lighter texture of this soil means nitrate-nitrogen can move easily down to 60cm, as seen in the nitrogen results (Figure 6). As such, split applications of urea during the season are of value in reducing movement of nitrogen to

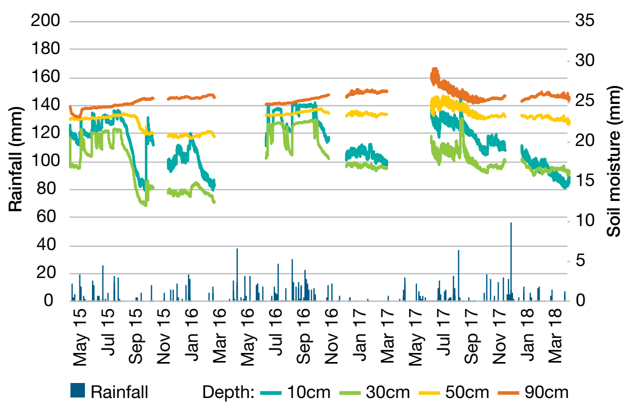


FIGURE 5 Soil moisture levels at south-west Rutherglen, Victoria May 2015 – March 2018

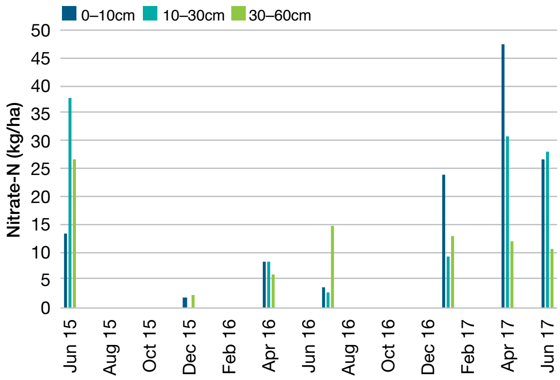


FIGURE 6 Plant-available (nitrate) soil nitrogen levels at south-west Rutherglen, Victoria June 2015 – June 2017

depth in this soil. Early summer rainfall during 2016–17 saw a large increase in mineralisation of nitrogen compared with the low mineralisation levels observed during the summer of 2015–16. Early summer rainfall during 2017–18 also saw high levels of mineralised nitrogen measured at the 10–30cm depth during summer, which moved down the profile with rainfall due to the light soil texture.

The soil chemistry results from the south-west Rutherglen site show this site is acid to depth (pH_{Ca} 4.9 at 30–60cm depth) (Table 2). The lighter texture of the soil, with its lower cation exchange capacity (CEC) and low carbon values, means it has a poor ability to withstand chemical change. High aluminium levels at the 10–30cm depth are related to the low pH values, with subsoil acidity likely to be the most limiting factor for growth of species sensitive to aluminium.

TABLE 2 Soil chemistry results at south-west Rutherglen, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.9	4.4	4.9
EC (dS/m)	0.06	0.04	0.03
Chloride (mg/kg)	<10	<10	<10
Nitrate N (kg/ha)	26.6	28.0	10.5
Mineral N (kg/ha)	28	28	10.5
Colwell P (mg/kg)	89	14	<5.0
PBI (Colwell)	61	71	120
CEC*	4.67	3.77	6.28
ESP#	0.65	0.74	4.2
Aluminium % of cations	3.3	14	3.8
Sulphur (KCl40)	6.3	5.2	9
Organic carbon (%)	0.91	0.21	<0.15
OM (%)	1.6	0.36	0.26
Available potassium (mg/kg)	200	130	150

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: Wahgunyah

2015 crop and stubble practice: Wheat, burned
2016 crop and yield: Triticale, 4.2t/ha
2016 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea
Timing of 2017 in-crop nitrogen application: Early June, late August
2016 stubble management (post-harvest): Burnt
2017 crop and yield: Canola, 3.0t/ha
2017 nitrogen applied: 10kg N/ha MAP, 16.8kg N/ha SOA, 115 kg N/ha urea
Timing of 2017 in-crop nitrogen application: SOA end May, urea end June and August
2017 stubble management: Knocked down with harrows.

The soil at the Wahgunyah site is lighter textured than many of the soils in the region, being free draining down to 50cm (Figure 7). The large range between the upper and lower soil moisture limits (field capacity and permanent wilting point respectively) at the 50cm layer also indicates a lighter soil texture. The soil moisture probe results show that water can be extracted by plants down to a depth of 90cm. Clay content increases incrementally with depth in this soil, but it lacks the strong duplex texture contrast between the 10cm and 30cm depth increments commonly found at other sites in the region.

Soil moisture probe data indicated that this site maintained high levels of soil moisture throughout the 2015 season until October, when high temperatures and high crop demand saw the crop run soil moisture levels down (Figure 7). The wet conditions experienced during 2016 meant the profile was at field capacity for most of the season, with some drying to 50cm depth from October 2016. The 2017 season began with high levels of stored soil moisture, which was again drawn upon during the subsequent dry spring.

The nitrate-nitrogen measurements at the Wahgunyah site were generally low, with the exception of the June

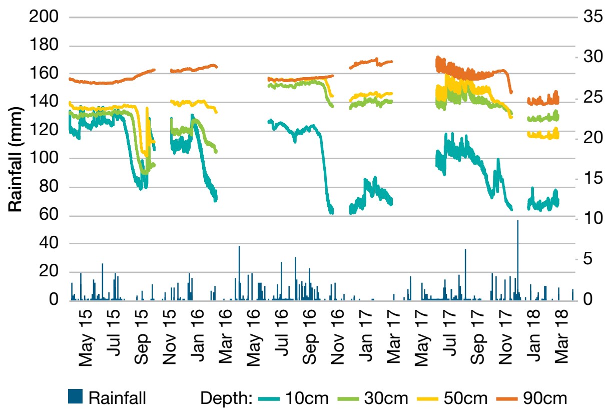


FIGURE 7 Soil moisture levels at Wahgunyah, Victoria May 2015 – March 2018

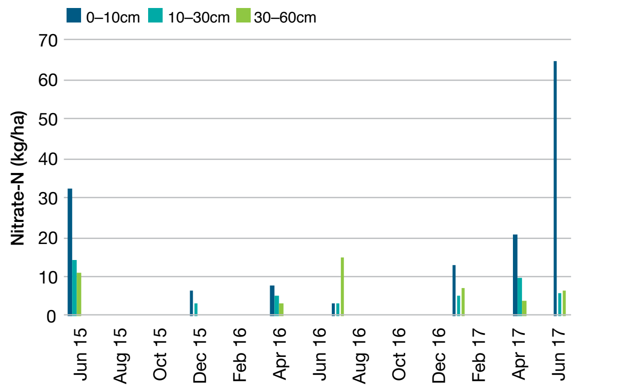


FIGURE 8 Plant-available (nitrate) soil nitrogen levels at Wahgunyah, Victoria June 2015 – June 2017

2015 and 2017 samples (Figure 8). These low numbers suggest most of the in-season fertiliser was used by the crop. As the soil moisture results show active root uptake of moisture to depth, it is likely that while some nitrogen moved to depth, this nitrogen was taken up by plant roots. Some mineralisation of nitrogen was measured between the December 2016 and April 2017 sampling. The spike in nitrogen observed during June 2017 in the 0–10cm layer would be due to in-crop nitrogen application.

The soil chemistry results for Wahgunyah show that while the 0–10cm depth is acid (pH_{Ca} 4.9), pH increases with depth and is neutral at 30–60cm depth (pH_{Ca} 7.1) (Table 3). Although there is measurable sodicity at depth (ESP 11–19%), this does not appear to limit root exploration to depth. The organic carbon value of 1.4% is good and possibly reflects a history of pasture in this paddock.

TABLE 3 Soil chemistry results at Wahgunyah, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.9	5.8	7.1
EC (dS/m)	0.13	0.05	0.15
Chloride (mg/kg)	19	<10	13
Nitrate N (kg/ha)	64.4	5.88	6.72
Nineral N (kg/ha)	81.2	5.88	9.37
Colwell P (mg/kg)	85	<5.0	<5.0
PBI (Colwell)	76	49	150
CEC*	6.14	5.53	16.1
ESP#	1.1	11	19
Aluminium % of cations	2.7	2.3	0.69
Sulphur (KCl40)	12	9.4	26
Organic carbon (%)	1.4	0.18	0.24
OM (%)	2.4	0.31	0.41
Available potassium (mg/kg)	270	110	250

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: East Rutherglen

2015 crop and stubble practice: Wheat, burnt

2016 crop and yield: Canola, 2t/ha

2016 nitrogen applied: 7.5kg N/ha MAP, 101kg N/ha urea

Timing of 2016 in-crop nitrogen application: Late May, early July

2016 stubble management (post-harvest): Retained

2017 crop and yield: Wheat, 6.5t/ha

2017 nitrogen applied: 7kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: Sowing, July

2017 stubble management: Burnt

The east Rutherglen site is characterised by increasing clay content to depth, changing from a loam texture in the surface to a medium–heavy clay beyond a depth of 60cm.

During 2015, the east Rutherglen site maintained high soil moisture levels for most of the growing season, until mid-September 2015 when the season turned dry (Figure 9). Soil pit observations showed wheat roots penetrated more than 1m during the 2015 season. The profile was re-wet by plentiful rains over the 2015–16 summer, which was followed by a wet winter and spring 2016. While the 10cm depth layer stayed wet until mid-October 2016 (when it started to drain), the 30cm layer appeared to remain in a saturated state from July onwards, due to increasing clay content to depth which slowed drainage. The 2016 pre-harvest soil moisture probe results show higher soil moisture than the post-harvest results at the 50cm sensor depth, indicating the canola crop may have actively extracted moisture down to 50cm depth before harvest. There was plenty of soil moisture available at depth during the 2017 season, with roots extracting water down to 90cm during the dry spring.

The June 2015 nitrate-nitrogen sampling results showed a large amount of nitrogen (170kg/ha) was available at 0–10cm depth (Figure 10). During late July – early August, 101kg N/ha was applied as urea, which meant the wheat crop potentially had access to 271kg N/ha during late winter. As it was quite wet at this time, it is likely some of this nitrogen was lost as gaseous-nitrogen due to denitrification, while the rest was taken up by the crop. Mineralisation over the 2015–16 summer resulted in almost 40kg N/ha becoming available to the following crop. The wet winter of 2016 saw a large amount of nitrate moving into the 30–60cm depth by July 2016 (67kg N/ha), however about two-thirds of this nitrogen was likely extracted by plant roots throughout the season.

The high clay content of this soil at depth would minimise further leaching of nitrogen, as shown by the reduced concentrations available at depth post-harvest. The 2016–2017 mineralisation results showed that about 25kg

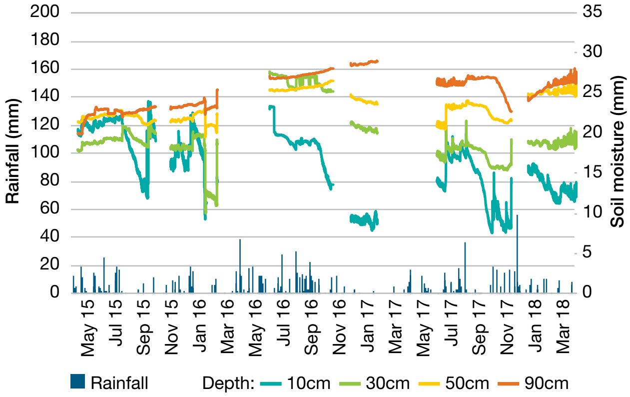


FIGURE 9 Soil moisture levels at east Rutherglen, Victoria May 2015 – March 2018

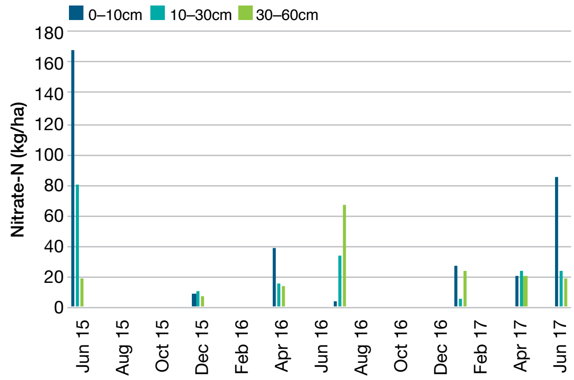


FIGURE 10 Plant-available (nitrate) soil nitrogen levels at east Rutherglen, Victoria, June 2015 – June 2017

N/ha of organic nitrogen became available post-harvest at the 0–10cm depth, which was comparable with most other sites (although it appears less due to the scale of the graph) (Figure 10). The high concentration of nitrate-nitrogen measured at the 0–10cm depth during June 2017 can be attributed to 100kg urea (46kg N/ha) applied at sowing with MAP.

The soil chemistry results for east Rutherglen show mid-range pH values due to a regular liming history (Table 4). The high Colwell phosphorus measurement (120mg P/kg) at the 0–10cm depth would be due to MAP application at sowing, as well as the accumulation of residual phosphorus as a result of stubble breakdown over many years of no-till cropping. The 10–30cm layer in this soil has been depleted due to years of prolific root growth in this zone. This includes pH (the depletion of alkali makes conditions more acidic) and CEC (cation exchange capacity). Regular monitoring and a proactive lime application will support amelioration of this layer over the long term.

TABLE 4 Soil chemistry results at east Rutherglen, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.8	5.2	5.5
EC (dS/m)	0.17	0.05	0.1
Chloride (mg/kg)	19	<10	<10
Nitrate N (kg/ha)	85.4	24.36	18.06
Mineral N (kg/ha)	88.06	26.26	21.38
Colwell P (mg/kg)	120	25	6.7
PBI (Colwell)	43	71	190
CEC*	7.27	5.8	8.85
ESP#	0.44	1.1	4.8
Aluminium % of cations	<1	<1	<1
Sulphur (KCl40)	15	14	42
Organic carbon (%)	1.1	0.36	0.2
OM (%)	1.9	0.62	0.34
Available potassium (mg/kg)	340	210	170

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: Cornishtown

2015 crop and stubble practice: Wheat, burnt
2016 crop and yield: Faba beans, 3t/ha
2016 nitrogen applied: 14kg N/ha DAP
Time of 2016 in-crop nitrogen application: None
2016 stubble management (post-harvest): Sheep grazed, then burnt
2017 crop and yield: Wheat, 6.5t/ha
2017 nitrogen applied: 10kg N/ha MAP
Time of 2017 in-crop nitrogen application: None
2017 stubble management: Burnt

The soil at the Cornishtown site gradually increases in clay content with depth, as is shown by the differences between soil moisture levels at each depth (Figure 11).

The high temperatures experienced during October 2015 saw wheat roots draw down moisture from past 50cm depth, though soil water content was replenished to saturation point by the wet winter and spring of 2016. The soil profile remained quite full during the 2017 season until the dry spring, during which moisture extraction by roots was observed down to 90cm.

The nitrate-nitrogen values were relatively low at the Cornishtown site (Figure 12). Mineralisation over the 2015–16 summer resulted in at least 40kg N/ha becoming available after the wheat crop had been harvested, while almost 60kg N/ha was mineralised after the faba bean crop of 2016 was harvested. Of particular interest is the increase in available nitrogen, which was measured

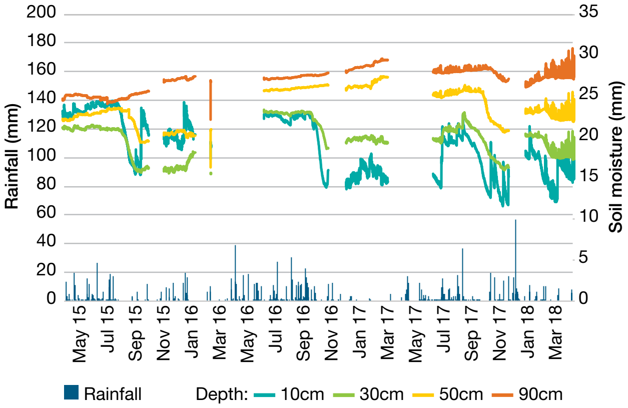


FIGURE 11 Soil moisture levels at Cornishtown, Victoria May 2015 – March 2018

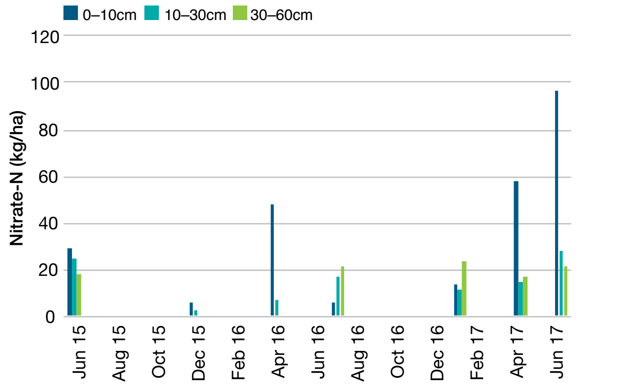


FIGURE 12 Plant-available (nitrate) soil nitrogen levels at Cornishtown, Victoria June 2015 – June 2017

mostly between January and April 2017, during a time of low rainfall. This likely coincides with the period of sheep grazing, demonstrating the potential for the combination of pulse crop production and sheep grazing of pulse stubble to increase mineral nitrogen values over summer. The high value of nitrate-nitrogen in June 2017 was due to the applied MAP in addition to the high levels of mineralised nitrogen.

The soil chemistry results for Cornishtown show that while the pH in the 0–10cm depth is acidic (pH_{Ca} 5.1), very low pH at the 10–30cm depth (pH_{Ca} 4.7) will likely be associated with an increase in aluminium availability (Table 5) and could limit plant growth of sensitive species, such as canola in the coming years. The organic carbon level of 1.4% is a good result for this soil. The 10–30cm layer shows a reduction in the phosphorus buffering index (PBI) compared with the 0–10cm layer. This suggests the 10–30cm layer has a slightly lower clay content, which also aligns with the slight drop in CEC at this depth (clay being a major provider of exchange sites as part of CEC).

TABLE 5 Soil chemistry results at Cornishtown, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.1	4.7	5.9
EC (dS/m)	0.16	0.05	0.04
Chloride (mg/kg)	19	<10	<10
Nitrate N (kg/ha)	96.6	28	21.84
Mineral N (kg/ha)	100.24	30.52	25.41
Colwell P (mg/kg)	37	6.5	<5.0
PBI (Colwell)	78	68	120
CEC*	6.88	5.16	7.83
ESP#	1.2	2	6.2
Aluminium % of cations	<1	4.9	<1
Sulphur (KCl40)	11	11	7.5
Organic carbon (%)	1.4	0.27	<0.15
OM (%)	2.4	0.46	0.26
Available potassium (mg/kg)	210	170	140

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Lilliput

2015 crop and stubble practice: Wheat, burnt
2016 crop and yield: Faba beans, 2.5t/ha
2016 nitrogen applied: None
2016 stubble management (post-harvest): Retained
2017 crop and yield: Canola, 3t/ha
2017 nitrogen applied: 8kg N/ha MAP, 16.8kg N/ha SOA, 115kg N/ha
Timing of 2017 in-crop nitrogen application: May, early July
2017 stubble management: Retained

The Lilliput site is relatively free draining, both at the surface (0–10cm) and subsurface (10–50cm) layers (Figure 13). The 30cm layer contains more clay than the surface layer, but is still readily accessed by plant roots, as seen by the range of soil water values. The 50cm depth layer is lighter again, as indicated by the 50cm probe soil water readings, which are lower than those measured at the 10cm depth. This soil is a grey-coloured material, which occurs through the landscape around Black Dog creek, before moving into a heavy clay at 90cm.

Soil moisture was non-limiting throughout most of the 2015 cropping season. During September 2015 conditions dried off and soil moisture started to be drawn down to 50cm. Rainfall during November 2015 somewhat wet the profile to a depth of 30cm, however by sowing (2016), the soil had dried out in the top 10cm. Although the soil profile was close to saturation during the wet season of 2016, the lighter-textured soil at this site meant plants could extract water

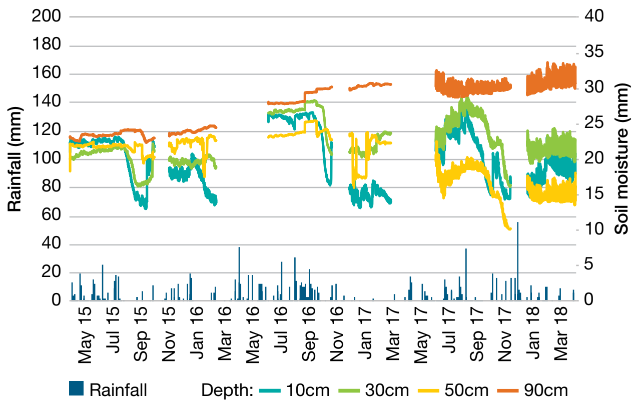


FIGURE 13 Soil moisture levels at Lilliput, Victoria May 2015 – March 2018

throughout the winter. The profile dried out quickly after the wet conditions eased during October, which highlighted the texture contrast between the 10 and 30cm layers.

Stored moisture reserves were high at the start of the 2017 season, but the dry spring period meant most of the available stored water was used to bring the crop to harvest. While rainfall over the summer of 2017–18 helped restore some soil moisture, the light texture of the 30cm and 50cm layers meant most of the moisture moved down into the 90cm zone. This stored moisture may only become accessible later in the 2018 season.

The June 2015 nitrogen sampling showed a large 'bulge' of nitrate (plant-available nitrogen) at 30–60cm depth, which is likely due to accumulation of nitrogen over time (Figure 14). This bulge had largely disappeared by the post-harvest sampling, with limited nitrogen remaining by the pre-sowing sampling. While the crop may have used some of this DSN, it is likely at least some of the nitrogen was lost to the deeper layers through leaching given soil moisture levels were high throughout the season. Low levels of nitrate-nitrogen were measured during July 2016, with the highest levels observed at 30–60cm (which is in line with other sites) due to the wet conditions. The low levels of nitrogen measured during the 2016 season were expected given there was no nitrogen applied to the 2016 faba bean crop. As with the Cornishtown results, the faba bean crop at Lilliput resulted in significant nitrogen mineralisation over the following summer – autumn (40kg N/ha), even with low summer rainfall. The higher levels of nitrogen measured in June 2017 would be partly due to the fertiliser added at sowing and partly due to further in-crop mineralisation of nitrogen.

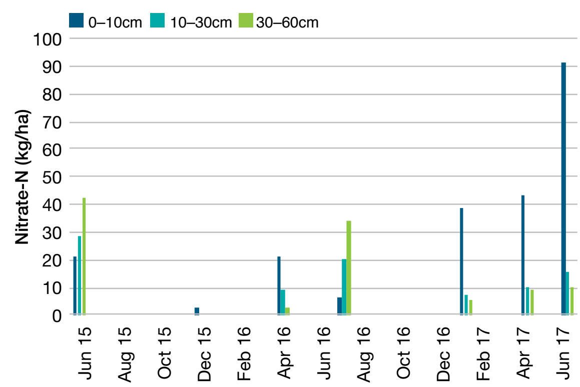


FIGURE 14 Plant-available (nitrate) soil nitrogen levels at Lilliput, Victoria June 2015 – June 2017

The soil chemistry results at Lilliput show that lime was needed to amend the low pH (pH_{Ca} 4.6) in the topsoil (Table 6). The soil carbon value of 1.3% is good for this soil and will contribute towards the ongoing sustainability of this site for cropping. The lower PBI in the 10–30cm zone (48), compared with the 0–10cm layer (72) supports the observation of a lower clay content at this site. Increases in the CEC with depth are likely due to increasing silt content (not clay). The exchangeable sodium percentage (ESP) results are only of concern at the 30–60cm depth, however at this point they are beyond the reach of management options.

TABLE 6 Soil chemistry results at Lilliput, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.6	5.5	6.7
EC (dS/m)	0.16	0.03	0.06
Chloride (mg/kg)	23	<10	<10
Nitrate N (kg/ha)	107.8	8.96	5.04
Mineral N (kg/ha)	119	11.45	8.53
Colwell P (mg/kg)	63	5.9	<5.0
PBI (Colwell)	72	48	80
CEC *	7.03	9.59	16.4
ESP#	2	3.3	8
Aluminium % of cations	3.2	<1	<1
Sulphur (KCl40)	11	3.3	2.1
Organic carbon (%)	1.3	0.22	0.16
OM (%)	2.2	0.38	0.28
Available potassium (mg/kg)	290	140	280

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: Norong

2015 crop and stubble practice: Wheat, retained
2016 crop and yield: Canola, 1.1t/ha
2016 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea
Timing of 2016 in-crop nitrogen application: Sowing, mid-July
2016 stubble management (post-harvest): Some burnt
2017 crop and yield: Wheat, 5.4t/ha
2017 nitrogen applied: 8kg N/ha MAP, 105.8kg N/ha urea
Timing of 2017 in-crop nitrogen application: Sowing, May, early July
2017 stubble management: Burnt

The soil at Norong showed a high capacity to store and release moisture from the 10cm depth, due to a light-textured topsoil (Figure 15). There is an increase in clay content below the 10cm layer, which would explain why the moisture release range of the 30cm and 50cm soil layers are similar. A further increase in clay content at 90cm resulted in higher stored soil moisture, with only a small range in results observed between wetting and drying.

Plants had access to adequate soil moisture during the 2015 season, with soil moisture drawn from at least 50cm depth during the period of heat stress during mid-October 2015. The site was wet throughout the 2016 season, however post-harvest results show some difference in moisture content between of the soil layers; this indicates that roots extracted water from the 30cm layer as well as some water from the 50cm layer in the lead-up to harvest (after the probe was removed). This soil has a large texture change into the subsoil; the large increase in clay content means water and nutrients move only slowly into the subsoil. Adequate moisture was present during the 2017 season, until the dry spring period when plant roots extracted water down to 50cm depth. While significant rainfall during the

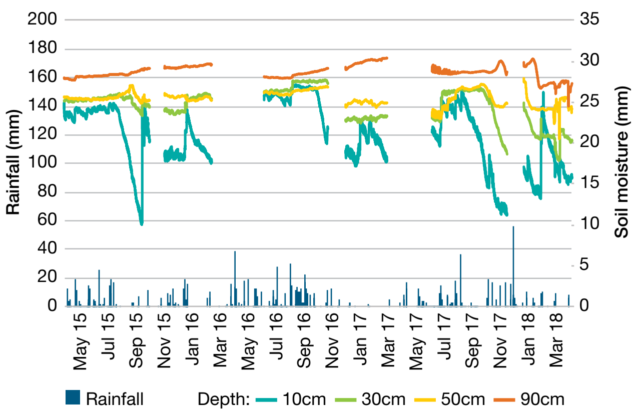


FIGURE 15 Soil moisture levels at Norong, Victoria May 2015 – March 2018

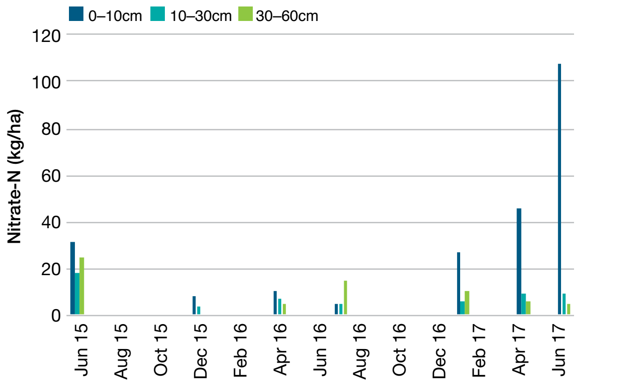


FIGURE 16 Plant-available (nitrate) soil nitrogen levels at Norong, Victoria June 2015 – June 2017

2017 harvest increased stored soil moisture levels, the 2018 season started with a soil moisture profile at less than field capacity.

A soil pit excavated during February 2018 showed wheat roots from the 2017 season had penetrated past the 50cm zone, however this was not reflected in the moisture probe data. This suggests there may not have been a high enough density of roots in this zone to change the soil moisture profile to the extent it could be detected by the soil moisture probe.

The nitrate-nitrogen results were low throughout 2016, indicating that any nitrogen not used by plants was likely lost through denitrification (Figure 16). Any leaching of nitrate-nitrogen to depth would have been detected during the January 2016 sampling as high levels within the subsurface layers. As these levels were low, this suggests leaching is not a significant issue in this soil. Some mineralisation of nitrogen occurred over the summer of 2016–17, with more than 40kg N/ha mineralised by April 2017. The increase in nitrate-nitrogen measured during June 2017 reflects the combined effect of mineralised nitrogen and urea applied during May.

The soil chemistry results for Norong showed that while the pH in the surface soil was low (pH_{Ca} 4.8), it increased rapidly with depth (Table 7). The CEC for this soil also increases with depth as does the ESP, meaning that dispersion and sodicity are issues at depth. However, as this cannot be practically ameliorated it needs to be considered in terms of future soil management (i.e. a return to deep inversion ploughing would bring dispersive sodic subsoil up to the surface, which would reduce the surface soil quality). The organic carbon content is high (1.8%) at this site and would add further value to nutrient cycling processes.

TABLE 7 Soil chemistry results at Norong, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.8	5.9	7.2
EC (dS/m)	0.16	0.06	0.1
Chloride (mg/kg)	26	<10	<10
Nitrate N (kg/ha)	91	15.96	10.08
Mineral N (kg/ha)	94.36	18.76	13.82
Colwell P (mg/kg)	44	<5.0	<5.0
PBI (Colwell)	78	66	70
CEC*	7.86	11.9	17.5
ESP#	1.2	7.4	11
Aluminium % of cations	<1	<1	<1
Sulphur (KCl40)	13	4.1	7.5
Organic carbon (%)	1.8	0.35	0.23
OM (%)	3.1	0.6	0.4
Available potassium (mg/kg)	350	220	260

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: Dockers Plains

2015 crop and stubble practice: Wheat, stubble burnt

2016 crop and yield: Wheat, 4t/ha

2016 nitrogen applied: 8kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: June, August

2016 stubble management (post-harvest): Sown to lucerne

2017 crop and yield: Lucerne

2017 nitrogen applied: 8kg N/ha MAP

2017 stubble management: Will be four years of lucerne pasture

The Dockers Plains soil moisture probe was installed during July 2016, along with the other moisture probes in the Boorhaman region. While the 2016 cropping season was extremely wet, the soil moisture probe data indicates the soil appears to be free draining down to 30cm, with the 10cm sensor showing short increases in moisture content after rainfall, before returning to a steady level (Figure 17). The soil moisture measurements for the 10cm and 30cm layers indicate they are both quite light textured (low clay content), with plants extracting water from these layers with ease after conditions started to dry out during October 2016. Plants accessed soil moisture in the 50cm layer from mid-October onwards, as seen by the decrease in soil moisture in the 50cm layer by the end of the season. The 90cm layer likely has a higher clay content, with no measurable water uptake shown by plants. The 2017 soil moisture probe data indicates the 10–30cm layer is a lighter texture than the 10cm layer, with the 30cm depth retaining

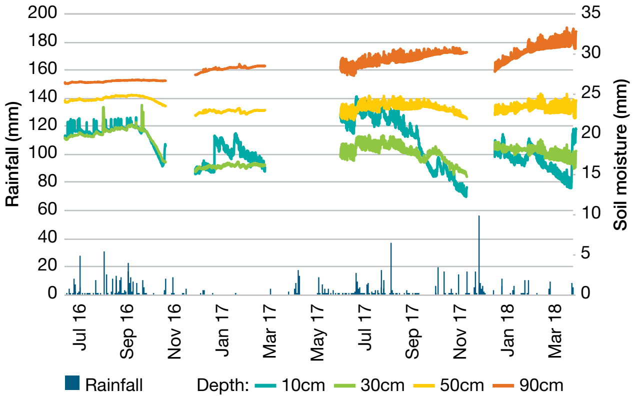


FIGURE 17 Soil moisture levels at Dockers Plains, Victoria July 2016 – March 2018

less water than the 10cm layer for most of the 2017 season. The dry spring of 2017 resulted in the drawdown of soil moisture in the 10cm and 30cm layers, with indications of root extraction of water down into the 50cm layer.

The July 2016 nitrate-nitrogen results show that nitrate moved down to 30–60cm depth with high winter rainfall (Figure 18). Subsequent post-harvest nitrogen sampling showed a reduction in nitrogen at this depth. This, when combined with higher clay content at depth (which would minimise further leaching), indicates the likely accessing of nitrogen by plant roots during the second half of the season. Mineralisation of organic nitrogen to nitrate-nitrogen was measured over summer and was particularly evident in the April 2017 sampling. The increased concentration of nitrate-nitrogen in the surface soil (observed in the absence of fertiliser) along with minimal nitrogen measured at depth, is indicative of mineralisation. The further increase in nitrate-nitrogen at all three depths during June 2017 is likely due to the contribution of MAP, which would move readily in this soil.

The soil chemistry results for Dockers Plains indicate that subsoil acidity is likely to be an ongoing issue at this site

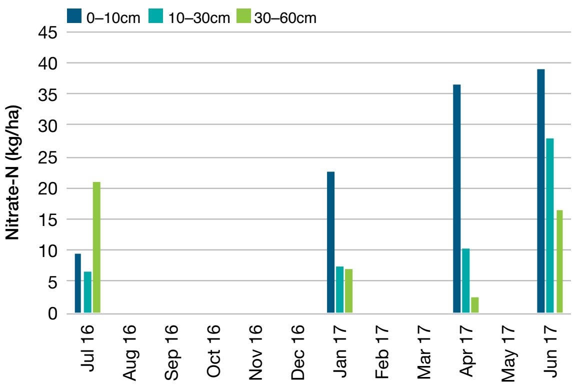


FIGURE 18 Plant-available (nitrate) soil nitrogen levels at Dockers Plains, Victoria July 2016 – June 2017

(Table 8). While the 0–10cm depth value of pH_{Ca} 5.7 is high, this drops to pH_{Ca} 4.4 in the 10–30cm layer and is associated with an increase in aluminium to 19%, which will limit the productivity of sensitive crops. Furthermore, the low CEC in this soil means it has limited capacity to resist chemical change, meaning the pH decline in the subsoil will continue if not addressed.

TABLE 8 Soil chemistry results at Dockers Plains. Sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.7	4.4	5.3
EC (dS/m)	0.09	0.05	0.03
Chloride (mg/kg)	17	10	<10
Nitrate N (kg/ha)	39.2	28	16.38
Mineral N (kg/ha)	43.4	30.07	16.38
Colwell P (mg/kg)	28	13	5.9
PBI (Colwell)	33	53	64
CEC*	5.49	3.31	5.22
ESP#	<1	<1	<1
Aluminium % of cations	2.8	19	3
Sulphur (KCl40)	6.2	8.7	10
Organic carbon (%)	1.1	0.24	<0.15
OM (%)	1.9	0.41	0.26
Available potassium (mg/kg)	220	170	130

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Boorhaman

2015 crop and stubble practice: Wheat, baled straw
2016 crop and yield: Canola, 2t/ha
2016 nitrogen applied: 8kg N/ha MAP, 115kg N/ha urea
Timing of 2016 in-crop nitrogen application: Early June, mid-July
2016 stubble management (post-harvest): Sheep grazed, harrowed, burnt
2017 crop and yield: Wheat, 4.5t/ha
2017 nitrogen applied: 9kg N/ha MAP, 115kg N/ha urea
Timing of 2017 in-crop nitrogen application: June, August
2017 stubble management: Baled straw, sown into remaining stubble

The Boorhaman site has a lighter-textured surface soil, with clay content increasing with depth.

The Boorhaman soil moisture probe was installed during July 2016, along with the other moisture probes in the Boorhaman region. The 2016 season was characterised by a high soil moisture content and the flat-lining of soil moisture probe sensor data at all depths until mid-October 2016, indicating the soil may have reached its capacity to

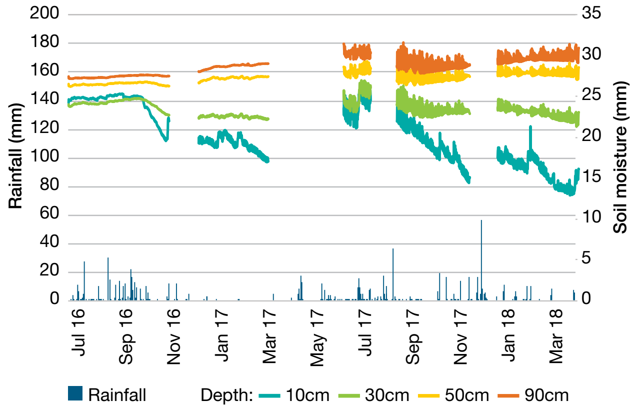


FIGURE 19 Soil moisture levels at Boorhaman, Victoria July 2016 – March 2018

store water and become waterlogged (Figure 19). The high clay content at depth would also have reduced the capacity for water to drain through the profile. The 2017 season started with a full profile of stored water and soil moisture probe data indicates water was only extracted by plant roots to a depth of 30cm (possibly to 50cm depth) during the dry spring.

The low nitrate-nitrogen values measured in the 0–10cm and 10–30cm layers during July 2016 indicate that urea applied during early June 2016 may have been largely lost through denitrification, with some also moving down the profile into the 30–60cm depth (Figure 20). This demonstrates the value of split applications, as a follow-up urea application during mid-July (after soil sampling) was needed to meet plant requirements for the rest of the season. There is some evidence of plant roots moving beyond the 30cm layer, as the bulge of nitrate-nitrogen measured in the 30–60cm depth in July 2016 had largely disappeared by January 2017, indicating it was utilised by the crop. Mineralisation of organic nitrogen to plant-available nitrogen during the 2016–17 summer was high at this site, with 95kg N/ha of nitrate-nitrogen measured in the 0–10cm depth at sowing.

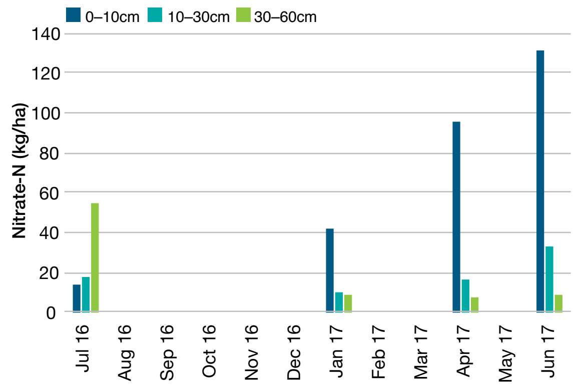


FIGURE 20 Plant-available (nitrate) soil nitrogen levels at Boorhaman, Victoria July 2016 – June 2017

The high value of nitrate-nitrogen measured during June 2017 likely resulted from the combination of mineralised nitrogen and urea applied in June 2017.

The soil chemistry results from the Boorhaman site show that subsoil acidity is an issue at this site (Table 9). The 10–30cm depth pH_{Ca} of 4.5 corresponds to 13% aluminium, which may impact on the growth of sensitive species. The drop in CEC in the 10–30cm depth (3.68cmol(+)/kg) also indicates this zone may be poorly buffered against pH change (i.e. the pH may decrease more quickly than at a higher CEC value).

TABLE 9 Soil chemistry results at Boorhaman, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5	4.5	5.4
EC (dS/m)	0.21	0.05	0.02
Chloride (mg/kg)	19	<10	<10
Nitrate N (kg/ha)	131.6	33.6	8.82
Mineral N (kg/ha)	134.82	33.6	8.82
Colwell P (mg/kg)	44	12	<5.0
PBI (Colwell)	38	45	100
CEC*	5.71	3.68	7.03
ESP#	0.41	<1	0.45
Aluminium % of cations	3.6	13	1.5
Sulphur (KCl40)	25	8.4	3.4
Organic carbon (%)	1.3	0.34	0.32
OM (%)	2.2	0.58	0.55
Available potassium (mg/kg)	270	160	170

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Peechelba East

2015 crop and stubble practice: Wheat, burnt

2016 crop and yield: Wheat, 4.5t/ha

2016 nitrogen applied: 9kg N/ha MAP, 129kg N/ha urea

Timing of 2016 in-crop nitrogen application: Sowing, end June, mid-August

2016 stubble management (post-harvest): 50% retained, 50% burnt

2017 crop and yield: Canola, 3.36t/ha

2017 nitrogen applied: 9kg N/ha MAP, 128.8kg N/ha urea

Timing of 2017 in-crop nitrogen application: Pre-sowing, June, late July

2017 stubble management: Stubble broken up with a disc chain

The surface soil at Peechelba East is lightly textured. This is seen by the large fluxes in soil moisture levels in the 0–10cm layer as well as the low base level of soil moisture measured (less than 10mm by mid-March 2017) (Figure 21). The 30cm layer is a heavier soil type, which gradually

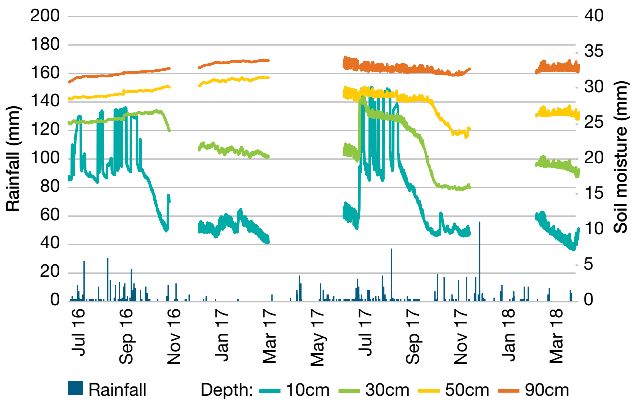


FIGURE 21 Soil moisture levels at Peechelba East, Victoria, July 2016 – March 2018

increases in clay content and dispersiveness at depth (see soil chemistry notes on following page), as shown by the increase in soil moisture content and reduced flux in soil moisture with depth. While the soil moisture probe results show limited movement of water in the 50cm and 90cm depth zones during 2016, indicating they were at capacity, there was clear extraction of water to the 30cm zone in the period leading up to harvest 2016. This suggests roots did not penetrate much past 30cm during 2016. The 2017 season results showed the extraction of water down to 50cm, especially during the dry spring conditions. The 2018 season started with approximately 50% soil water capacity, available to a depth of 50cm.

The nitrate-nitrogen levels measured during July 2016 show some of the urea applied at the end of June may have been lost by leaching or denitrification (gaseous nitrogen loss), with increased nitrogen measured in the 30–60cm depth (Figure 22). A follow-up urea application was needed during mid-August to replace the lost nitrogen and meet crop needs.

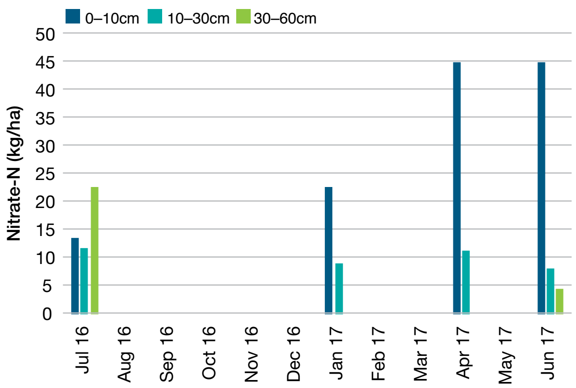


FIGURE 22 Plant-available (nitrate) soil nitrogen levels at Peechelba East, Victoria July 2016 – June 2017.

Note: An extraordinarily high nitrate reading (63kg N/ha) was measured for the 30–60cm depth during April 2017. Based on soil type, it was considered to be an analytical error and removed.

Summer mineralisation of nitrogen was also good at Peechelba East, assisted by rainfall during December 2016. While some nitrate-nitrogen was measured at depth during July 2016, this was not detected in the January 2017 sampling. The lack of change in the nitrate-nitrogen values between the April and June 2017 measurements suggest the June urea application may have been made after the soil sampling was done.

The soil chemistry results from Peechelba East indicate this soil type naturally increases in pH at depth (Table 10). This means that although the surface 0–10cm layer has a low pH (pH_{Ca} 4.7), the increased CEC value at the 10–30cm depth will assist in buffering against pH change. Ongoing lime application will be needed to increase the pH in the 0–10cm layer and maintain the higher pH values (pH_{Ca} 5.2) at the 10–30cm depth. The ESP also increases at depth, suggesting water movement to depth is compromised by dispersion as well as increased clay content.

TABLE 10 Soil chemistry results at Peechelba East, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.7	5.2	8.1
EC (dS/m)	0.09	0.06	0.37
Chloride (mg/kg)	16	<10	48
Nitrate N (kg/ha)	44.8	8.12	4.2
Mineral N (kg/ha)	48.44	9.88	6.89
Colwell P (mg/kg)	37	<5.0	<5.0
PBI (Colwell)	69	66	94
CEC*	5.73	8.48	23.5
ESP#	2.7	11	15
Aluminium % of cations	2.6	<1	<1
Sulphur (KCl40)	8.5	8.2	32
Organic carbon (%)	1.2	0.27	0.17
OM (%)	2.1	0.46	0.29
Available potassium (mg/kg)	160	90	190

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: North Boorhaman

2015 crop and stubble practice: Wheat, windrowed and baled

2016 crop and yield: Canola, 1.5t/ha

2016 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: Early June

2016 stubble management (post-harvest): Retained

2017 crop and yield: Wheat, 5t/ha

2017 nitrogen applied: 8kg N/ha MAP, 36.8kg N/ha

Timing of 2017 in-crop nitrogen application: July, August

2017 stubble management: Stubble burnt

The North Boorhaman site has a sandy loam surface soil, with a sand layer at 10–30cm depth.

The North Boorhaman soil moisture probe was installed during July 2016 and the soil moisture graph indicates good storage and extraction of water from the surface soil, but with lower soil moisture storage at 30cm depth (Figure 23). The lack of flux in the 30cm layer throughout the wet season of 2016 suggests this layer reached field capacity early during the season, with lateral drainage through the sand layer across the landscape. The soil did not dry out until late October 2016, after the 10cm layer started to be depleted.

The 2017 season results showed that while the soil moisture profile was full, the soil did not reach field capacity in the 10cm and 30cm layers as it did during 2016. The dry spring of 2017 caused the extraction of detectable amounts of water only to the 30cm depth. Further drying of these layers, measured during the summer of 2017–18, was likely caused by the capillary movement of water or by the development of cracks in the soil near the moisture probe.

Nitrate-nitrogen concentrations were very low during July 2016, likely due to high movement of nitrogen to depth and lateral movement through the sand layer (Figure 24). While some mineralisation was measured in the 0–10cm layer during January 2017, no increase in nitrate-nitrogen levels as a result of summer – autumn mineralisation was evident during April 2017. This was the only site not to show increased nitrate-nitrogen levels during April 2017 and suggests that April soil sampling at this site was either not representative of the paddock or that some of the 0–5cm soil (where most of the nitrogen is) had been accidentally removed. This is supported by the high nitrate-nitrogen results returned from June 2017, which being greater than the amount of MAP applied at sowing, indicates ongoing mineralisation.

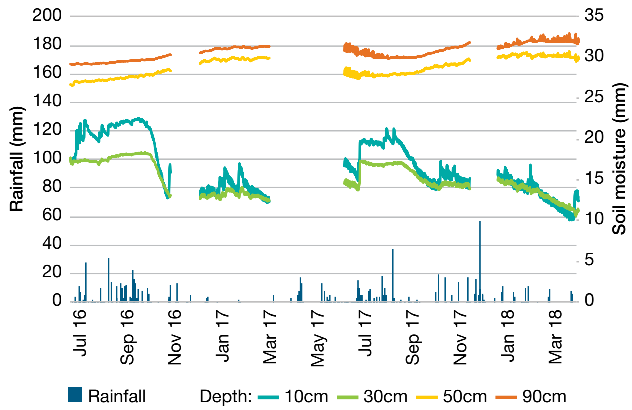


FIGURE 23 Soil moisture levels at North Boorhaman, Victoria, July 2016 – March 2018

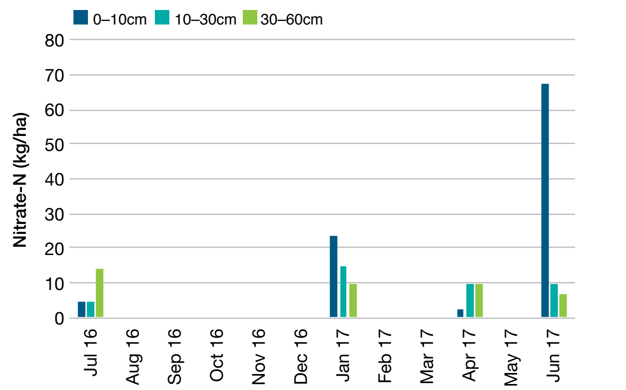


FIGURE 24 Plant-available (nitrate) soil nitrogen levels at North Boorhaman, Victoria, July 2016 – June 2017

The soil chemistry results at North Boorhaman indicate that root growth to depth would be limited by soil pH (Table 11), which is supported by an observed lack of change in the soil moisture profile at depth at this site. The low pH_{Ca} values of 4.5 (10–30cm) and 4.2 (30–60cm) also correspond to high aluminium values. Moreover, the sand layer at 10–30cm below the soil surface make it difficult to maintain high pH values at this depth due to the low CEC value in this zone (1.1cmol(+)/kg). An increase in clay content in the 30–60cm zone is reflected in the high CEC value and the associated increase in phosphate buffering index (PBI), which is related to higher phosphorus sorption with increasing clay content.

TABLE 11 Soil chemistry results at North Boorhaman, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.7	4.5	4.2
EC (dS/m)	0.12	0.02	0.06
Chloride (mg/kg)	<10	<10	<10
Nitrate N (kg/ha)	67.2	9.52	6.72
Mineral N (kg/ha)	68.6	9.52	6.72
Colwell P (mg/kg)	55	23	<5.0
PBI (Colwell)	33	21	150
CEC*	4.47	1.1	14.5
ESP#	1.1	2.6	6.9
Aluminium % of cations	2.6	27	10
Sulphur (KCl40)	12	2.1	8.5
Organic carbon (%)	0.93	0.21	<0.15
OM (%)	1.6	0.36	0.26
Available potassium (mg/kg)	120	40	250

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Observations

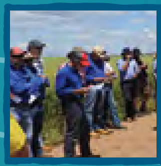
A range of soil types exist across the Rutherglen–Boorhaman region. While the typical duplex soil type with a texture contrast (i.e. a sharp increase in clay content in the subsoil) dominates, a range of features is evident through the landscape, with a new adventure in every soil pit!

Some of the key features observed during local soil pit examinations include dispersive subsoils just below the surface, sand layers at depth and dense clays just below the surface. The key message is that understanding the variability of soil types and their behaviour is key to optimising management in different paddocks in difficult years (i.e. when it is too dry or too wet).

The challenge with these variable soil types is that soil moisture probe readings could be somewhat misleading if the underlying soil is not well understood. For example, measurements of soil moisture content may be high at a site with a highly dispersive, dense clay at depth. However, if the plants cannot access this stored moisture because of either physical or chemical constraints hindering root growth at depth, the moisture is not actually *plant-available.* This means the total soil water content measured using a probe must be interpreted through the lens of that particular soil and its inherent attributes and potential constraints. This is readily achieved by digging a soil pit during late spring to see where the roots are, measuring some soil chemical parameters and by making informed decisions about the rooting depth and associated depth of water extraction (and predicted stored soil water). These actions only need to be done once, after which a soil moisture probe can provide relevant, timely information across seasons and years, given the 'context' of the readings is already well understood.

The 2015–16 measurements, taken during the term of the previous project, showed that most of the soil nitrate-nitrogen was present in the surface soil, with generally little nitrogen measured at depth. By comparison, the 2016–17 measurements, taken during and after a wet season, showed how quickly nitrogen could move to depth even in clay-based soils, with a general depletion of nitrogen in the surface soil and accumulation of nitrate-nitrogen in the 30–60cm zone by July 2016.

While these two sets of measurements show different numbers, a key point is that if a general (bulked) 0–60cm depth soil sample for nitrogen had been collected in these soils, we may have received the same answer for the two different seasons! For example, in July 2016 the bulked soil test may have indicated adequate nitrogen, but if that nitrogen was present below a clay layer in a soil subject to waterlogging, it may be months until the soil dried out enough for roots to move to that depth. Splitting the soil



sample into two increments (i.e. a 0–30cm and a 30–60cm depth sample) provides more accurate information on the availability of nitrogen as the season progresses, supporting better and more timely fertiliser decisions.

The last point to note is that the soil chemistry results, supported by soil pit observations, show that the soils of this region have different origin. This is seen by differences in clay content, CEC and pH at depth, which means one size certainly does not fit all in these systems. While some soils have increased pH at depth, others are acid at depth and will require careful management to maintain the productivity of these systems.

Acknowledgements

This project was carried out in partnership with Boorhaman Landcare, with support for the soil moisture probe monitoring from the North East Catchment Management Authority (NECMA) through funding from the Australian Government's National Landcare Program.

Many thanks to the many farmer co-operators for this project.

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Refining deep soil nitrogen testing to reduce environmental losses

Dr Cassandra Schefe
Riverine Plains Inc

Key points

- While there was some movement of nitrogen (N) to depth (60–100cm), the concentrations were low and likely to be accessed by plant roots in subsequent seasons.
- Under current agronomic practice there is low risk of nitrate leaching to groundwater in these soils.
- While pre-sowing sampling gives an idea of 'what is in the bank' at the start of the season, a late June sampling would better account for fertiliser applied at, or after, sowing, enabling a more precise determination of nitrogen required to achieve a target yield.
- Nutrient sampling within zones (as determined by electromagnetic [EM] surveys) can provide a more accurate understanding of nutrient requirements given variations in soil type also equate to variations in nutrient storage and movement.

Background

Many grain growers carry out deep soil nitrogen (DSN) testing annually to understand how much nitrogen is stored in the soil and how much additional nitrogen will be needed as in-crop fertiliser to meet the demands of the growing crop and target yields. This sampling is generally done by collecting multiple soil cores across a paddock down to a depth of 60–100cm and bulking the cores together into one sample to produce a single stored-nitrogen value for each paddock.

However, this approach does not provide an understanding of how potential nitrogen storage varies across a paddock, and where the nitrogen is stored in the soil (i.e. whether it is all accumulated in the top 10cm, or whether there is a bulge of nitrogen at, say, 90cm, beyond the reach of most roots and at risk of leaching to groundwater).

Furthermore, the actual timing of this deep soil nitrogen (DSN) testing can vary, as sampling can occur at sowing, late autumn, or during late winter-early spring. This variability can result in large variations in the final nitrogen test results from the laboratory. Given test results are used to calculate the amount of nitrogen fertiliser to be applied to the crop, there is potential for large over-supply of fertiliser, potentially resulting in nitrate leaching to groundwater or the production of nitrous oxide (N2O) — a potent greenhouse gas.

The *Refining deep soil nitrogen testing to reduce environmental losses* project, supported by Goulburn Broken Catchment Management Authority (CMA) through funding from the Australian Government's National Landcare Program, was conducted to better understand in-paddock variability of nitrogen supply through the season, as well as the impact of sampling time on soil nitrogen results.

Aim

This project aims to illustrate the value of considering paddock variation when sampling for nitrogen as well as undertaking depth-incremented sampling to understand where the nitrogen is distributed through the soil profile.

Method

The consistently wet weather during 2016 delayed the start of this project from 2016 until 2017, when two demonstration sites were established at Burramine and Yundool–St James in Victoria. Both sites were sampled at key stages throughout the season to determine DSN levels, nutrient movement to depth, and soil spatial variation to understand the variation in soil nitrogen in time and space.

Soil sampling occurred in locations across each site based on zones determined by electromagnetic (EM) mapping. High and low EM zones were identified at each site, with soil sampling occurring within these zones.

Sampling was undertaken during February, May, June, August and September 2017, with final post-harvest sampling taking place during January 2018.

Deep soil nitrogen sampling consisted of one core sample, split into increments (0–10, 10–20, 20–30, 30–60 and 60–100cm), and analysed for mineral nitrogen (nitrate + ammonium) and total nitrogen (includes organic and inorganic forms — i.e. the total nitrogen soil bank).

The mid-season DSN sampling was timed to coincide with the typical programs of the region's growers, who use the results to identify how much nitrogen they need to apply to meet crop demand through spring. The post-harvest samplings provide a measure of post-crop residual nitrogen, while the post-sowing sampling provides information on the amount of nitrogen lost or mineralised during the summer months.

Results

Burramine

Deep soil nitrogen testing

High nitrogen concentrations were retained in the surface soil (0–10cm depth) in the high EM zone at the Burramine site due to fertiliser input (Figure 1). However, there was more movement of nitrogen to depth in the low EM zone, especially during August–September 2017, due to the presence of lighter soils with more capacity for nutrient transfer (Figure 2). While total nitrogen levels were similar between the zones, nitrogen was more evenly distributed through the soil profile in the low EM zone.

Post-harvest sampling showed that similar amounts of nitrogen were mineralised during summer, with surface soil (0–10cm) values of around 20kg N/ha in both zones. While nitrogen levels at depth were slightly higher in the low EM zone, this represented a relatively low value of nitrate moving through. Based on related sampling in other projects, it is highly likely plant roots will pick up the nitrogen at the 60–100cm depth during the following season.

Yundool

Deep soil nitrogen testing

The Yundool site (near St James) showed lower nitrogen values than the Burramine site due to differences in fertiliser management (Figure 3, Figure 4). There was a trend to greater accumulation of nitrogen at depth at the Yundool site, particularly in the low EM zone. This suggests nitrogen can move more freely in this profile, likely due to a higher sand content in this zone (Figure 4).

Similarly to the Burramine site, the levels of nitrogen measured in the 60–100cm zone was not high and likely to be extracted by roots of the following crop.

Observations and comments

The use of EM zones for DSN testing was useful in understanding the range of soil nitrogen values across the paddock, with the different zones likely reflecting differences in soil texture. As the high EM zones are potentially associated with higher clay content, these

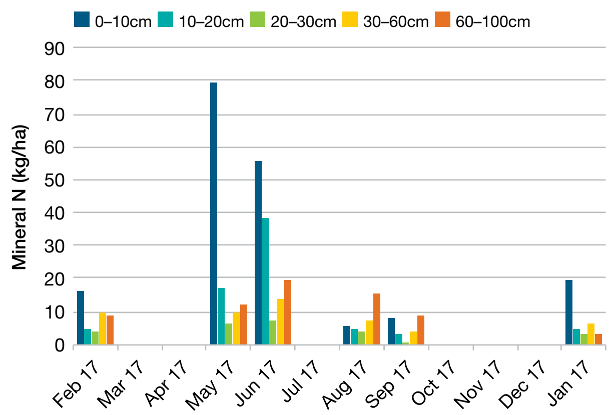

FIGURE 1 Mineral nitrogen across the season at incremented depths from the Burramine site, in the high EM zone, 2017

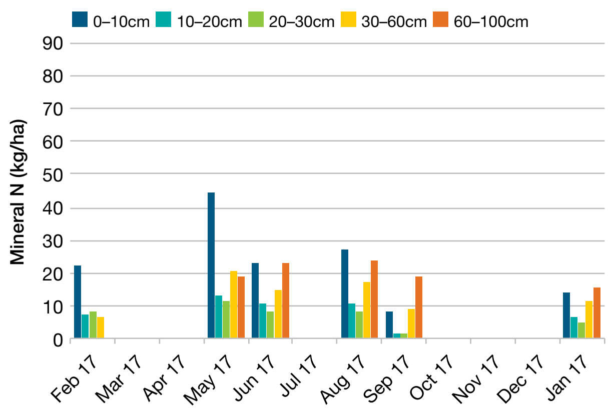

FIGURE 3 Mineral nitrogen across the season at incremented depth from the Yundool–St James site, in the high EM zone, 2017

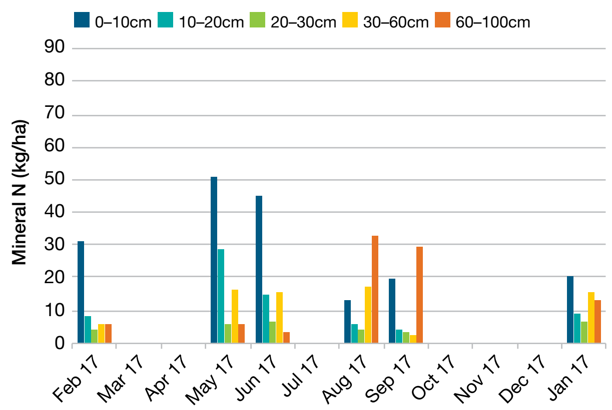

FIGURE 2 Mineral nitrogen across the season at incremented depths from the Burramine site, in the low EM zone, 2017

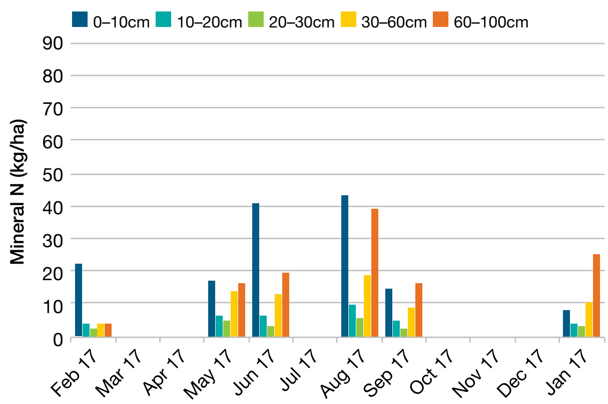

FIGURE 4 Mineral nitrogen across the season at incremented depths from the Yundool–St James site, in the high EM zone, 2017

areas will have less capacity for water and nitrate to move to depth, compared with a higher capacity for water and nitrate movement to depth in the low EM zone.

A key part of this project was to understand the likelihood of nitrate leaching to groundwater in the dryland cropping zone of the Goulburn Broken region. While only two paddocks were measured through this project, the results obtained suggest that under current agronomic practice there is low risk of nitrate leaching to groundwater in these soils.

The timing of DSN sampling has a large impact on the results obtained. While pre-sowing sampling gives an idea of 'what is in the bank' at the start of the season, a late June sampling would better account for nitrogen mineralisation through the summer and autumn, and the amount of residual fertiliser nitrogen that was applied at or after sowing; enabling a more precise determination of nitrogen required to achieve a target yield.

Acknowledgements

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Benchmark soil sampling of weather station sites across NSW

Dr Cassandra Schefe
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Key points

- These results provide some benchmarking of soil chemistry for the Riverine Plains region.
- There was a high variance in soil chemistry parameters across the seven monitor sites.
- Results showed the timing of sampling had some influence on the results obtained.
- Consistency in sampling method and timing will improve the quality of results obtained.

Background

Through a partnership with the Murray and Riverina Local Land Services (LLS), Riverine Plains Inc installed seven on-farm weather stations across southern NSW during 2016. These weather stations were installed to address the shortage of local weather information and are accessible via the Riverine Plains Inc website: riverineplains.org.au.

To develop greater value from these sites, a series of benchmark soil samples were taken at each site during May and August 2017 and January 2018. These soil samples, in conjunction with soil pit workshops held at selected sites, were used to better understand the soil profiles and properties across the region and to understand how some soil properties, such as soil pH and carbon (C), change with time.

Methodology

Soil samples were collected at three depths (0–10, 0–30, and 30–60cm). These depth increments were chosen to reflect the different analyses at different depths (i.e. phosphorus [P] is generally measured in the 0–10cm increment, while other analyses are generally carried out at the 0–30cm increment). The 30–60cm depth was sampled to determine which nutrients had moved to depth (i.e. nitrogen [N], sulphur [S]).

A selection of soil analysis results is presented in Table 1. The intent of presenting this information is to demonstrate the range of results obtained throughout the region and to understand the key indicators associated with each parameter. These results are obtained from one location in the paddock and do not consider the broader context of the farming system they came from.

Note the 0–30cm depth measurement includes the 0–10cm increment. If the 0–10cm depth result is higher than the 0–30cm depth result, this indicates the result was lower in the 10–30cm depth compared with the 0–10cm surface depth measurement. Conversely, if the 0–10cm depth result is lower than the 0–30cm depth result then the soil from 10–30cm has a higher measurement than the surface 0–10cm.

The soil test results indicate that most sites showed variation in pH measurements taken at different times (Table 1) due to both spatial and temporal variation. A soil's composition can fluctuate widely on a small scale, due to differences in the amount of plant or root material collected in the soil corer (even with sieving, small pieces of organic material will pass through with the sample). Given a soil core sample contains a relatively small amount of soil the effect of these variances is increased. Sample timing is also important and while analysis techniques adjust for seasonal variation to some degree, there will be still be some variance through the year. This means it is always advisable to be consistent with the timing of sampling for soil chemistry parameters.

Results

i) Soil pH

While the 0–10cm depth results show that most soils are considered acidic, the only site considered strongly acidic is Barooga, where a pH of 4.8 may be limiting growth of acid sensitive crops (Table 1). This is also the only site where the aluminium percentage of the cation exchange capacity (CEC) is more than 5%, and likely to show phytotoxicity (there is a direct relationship between increasing soil acidity and increased exchangeable aluminium).

Most sites show an increase in pH from the 0–10cm layer to the 0–30cm layer. This means there is generally an increase to depth, with all sites except Henty showing an increase in pH at the 30–60cm depth.

ii) Salinity

The salinity, or salt content of the soil solution, is generally considered in the context of the environmental system it is within. For example, in agriculture the EC value would be considered in respect to the salt tolerance of the plants being grown. On average, the thresholds of low (<0.24 dS/m),

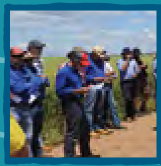

TABLE 1 Soil pH measurement at weather station and soil moisture probe sites across southern NSW*

Site	Depth (cm)	Soil pH		
		May 2017	August 2017	January 2018
		(pH)	(pH)	(pH)
Barooga	0–10	4.8	4.5	4.7
	0–30	5.5	5.5	6.3
	30-60	7.4	7.1	8.0
Berrigan	0–10	5.4	5.8	5.2
	0–30	6.3	5.6	7.3
	30–60	8.0	6.9	7.9
Culcairn	0–10	6.1	6.1	6.3
	0–30	6.0	5.2	5.6
	30–60	7.3	6.7	7.6
Henty	0–10	6.3	5.4	6.0
	0–30	6.2	5.4	5.6
	30–60	5.9	5.7	5.4
Lockhart	0–10	5.7	6.3	5.8
	0–30	6.9	5.5	6.9
	30–60	8.5	6.7	8.4
Pleasant Hills	0–10	5.7	6.7	5.8
	0–30	5.4	5.1	5.0
	30–60	6.3	6.3	6.3
Rand	0–10	5.0	4.6	4.4
	0–30	5.7	4.7	6.0
	30–60	7.1	5.9	7.3

* Measured in calcium chloride ($CaCl_2$).

TABLE 2 Salinity measurement at weather station soil moisture probe sites across southern NSW

Site	Depth (cm)	Electrical conductivity		
		May 2017	August 2017	January 2018
		(dS/m)	(dS/m)	(dS/m)
Barooga	0–10	0.14	0.07	0.20
	0–30	0.08	0.04	0.06
	30–60	0.21	0.08	0.29
Berrigan	0–10	0.64	0.26	0.31
	0–30	0.15	0.08	0.22
	30–60	0.26	0.10	0.22
Culcairn	0–10	0.31	0.13	0.14
	0–30	0.09	0.08	0.08
	30–60	0.10	0.16	0.18
Henty	0–10	0.14	0.20	0.06
	0–30	0.07	0.06	0.05
	30–60	0.05	0.09	0.10
Lockhart	0–10	0.09	0.08	0.12
	0–30	0.13	0.07	0.20
	30–60	0.54	0.13	0.55
Pleasant Hills	0–10	0.14	0.14	0.09
	0–30	0.04	0.04	0.04
	30–60	0.09	0.04	0.04
Rand	0–10	0.38	0.46	0.15
	0–30	0.12	0.43	0.10
	30–60	0.20	0.12	0.17

moderate (0.24–0.56 dS/m), and high (>0.56 dS/m) EC values can be used.

While the Berrigan, Culcairn and Rand sites measured higher EC values in the surface 0–10cm layer, the Lockhart site measured a high EC reading at the 30–60cm depth (Table 2). This indicates root growth to depth during wet seasons may be negatively affected, due to roots experiencing saline conditions, which impedes water uptake into the root and can induce a form of *physiological drought*.

iii) Sodicity

While **salinity** is a measure of the amount of sodium (salt) in the solution *between* soil particles, **sodicity** is a measure of the amount of sodium (salt) occupying the *surface* of the clay particles. So, salinity-salt floats around in the water, while sodicity-salt is stuck onto the clay, and has a chemical effect on how that clay particle behaves.

If lots of sodium sticks onto the clay, when that clay gets wet, all the particles blast apart and disperse. As the clay particles dry, they lose their order and settle into any tiny holes in the soil, blocking water movement through the profile. This is why a dispersive surface soil tends to get muddy on top quickly, while the subsurface might stay dry, as the sodium stuck on the clay has caused it to plug up biopores and limit water transfer down. As this soil dries it forms a crust on top, which may cause issues with plant emergence and water infiltration.

If the sodic, dispersive layer of soil is deeper down the profile, it will limit downwards root penetration. When that soil layer gets wet, it turns to mush, but when it dries, it sets hard.

A key measure of sodicity is the percentage of sodium on the CEC (the surface exchange sites of soil particles). When this value of the exchangeable sodium percentage (ESP), is greater than 6% the soil is likely to show characteristics of sodicity and dispersion.

Three of the monitoring sites measured an ESP above 6% in the 0–30cm layer, which indicates the problem zone is deeper than 10cm. All sites, except Barooga, had high ESP values at the 30–60cm depth, indicating root penetration to depth at most of these sites could be compromised by high sodicity.

TABLE 3 Sodicity measurement at the weather station and soil moisture probe sites across southern NSW*

Site	Depth (cm)	Exchangeable sodium		
		May 2017	August 2017	January 2018
		(%)	(%)	(%)
Barooga	0–10	1.5	0.7	1.8
	0–30	2.8	0.5	3.9
	30–60	5.3	0.7	7.1
Berrigan	0–10	2.6	1.6	3.1
	0–30	7.1	3.9	8.5
	30–60	12.0	8.0	13.0
Culcairn	0–10	3.5	2.0	2.2
	0–30	5.5	6.1	9.1
	30–60	9.7	12.0	14.0
Henty	0–10	1.2	5.3	<1
	0–30	1.2	5.9	1.6
	30–60	8.3	10.0	7.8
Lockhart	0–10	4.9	2.4	4.1
	0–30	14.0	7.5	12.0
	30–60	19.0	12.0	17.0
Pleasant Hills	0–10	2.2	0.9	0.4
	0–30	3.7	1.6	<1
	30–60	20.0	6.2	4.3
Rand	0–10	4.0	3.1	3.8
	0–30	7.7	1.7	8.5
	30–60	15.0	8.9	13.0

* Measured as exchangeable sodium percentage (ESP) on the cation exchange capacity (CEC).

TABLE 4 Soil organic carbon measurements at the weather station and soil moisture probe sites across southern NSW

Site	Depth (cm)	Soil organic carbon		
		May 2017	August 2017	January 2018
		(%)	(%)	(%)
Barooga	0–10	1.4	1.5	1.6
	0–30	1.0	0.6	0.3
	30–60	0.3	0.2	0.2
Berrigan	0–10	1.9	2.6	1.9
	0–30	0.6	0.6	0.3
	30–60	0.4	0.3	0.3
Culcairn	0–10	1.9	1.7	1.7
	0–30	0.9	0.8	0.7
	30–60	0.3	0.3	0.2
Henty	0–10	1.2	1.1	1.0
	0–30	0.7	0.5	0.5
	30–60	0.3	0.2	0.2
Lockhart	0–10	1.1	1.2	0.9
	0–30	0.7	0.6	0.6
	30–60	0.3	0.2	0.2
Pleasant Hills	0–10	1.3	2.0	1.3
	0–30	0.6	0.5	0.5
	30–60	0.2	<0.15	<0.15
Rand	0–10	1.9	2.0	1.4
	0–30	0.7	2.1	0.3
	30–60	0.4	0.4	0.3

iv) Soil organic carbon (SOC)

All sites had soil organic carbon values (SOC) of around 1% or more in the 0–10cm depth. Variation is high at some sites, potentially due to the inclusion of plant matter into the soil sample. As SOC is comprised of plant (root and shoot) residues, which have been decomposed by soil microbes, SOC values are expected to decrease with depth. As microbes require oxygen and moisture to function, most decomposition happens near the surface, where oxygen and moisture are most readily available.

v) Mineral nitrogen

The May 2017 values for mineral nitrogen indicate appreciable mineralisation of organic nitrogen during summer at some sites, as measured by the 0–10cm values, which ranged from 22–143kg N/ha (Table 5). There also appears to be some residual nitrogen stored from the 2016 season in the 0–30cm zone (this is seen at sites where the 0–10cm value is less than the 0–30cm value,), which means more nitrogen was present in the 10–30cm layer. Some nitrogen at the 30–60cm layer would also have been left over from last season; likely leached to depth.

The August 2017 samples showed depletion of nitrogen compared with the May 2017 samples for most sites, with the Henty and Rand sites likely sampled immediately after urea was spread. This depletion during late spring was generally seen with the 2017 soil samples, showing that even where adequate fertiliser was applied, crops could utilise the nitrogen quite efficiently.

The January 2018 surface samples show some nitrogen mineralisation across all sites, with some movement of nitrate to depth.

vi) Phosphorus

The two phosphorus tests commonly used are the Olsen phosphorus and Colwell phosphorus tests. The Olsen phosphorus is a measure of the readily available phosphorus in the soil, while the Colwell phosphorus test measures the total available pool, as well as some of the less available, chemically-bound phosphorus, which is likely to become available through the season. This is why the Colwell test always gives a higher value than the Olsen test.



TABLE 5 Soil mineral nitrogen measurement at the weather station and soil moisture probe sites across southern NSW

Site	Depth (cm)	Soil mineral nitrogen		
		May 2017	August 2017	January 2018
		(kg N/ha)	(kg N/ha)	(kg N/ha)
Barooga	0–10	88	31	111
	0–30	117	25	30
	30–60	13	12	20
Berrigan	0–10	47	25	23
	0–30	42	11	15
	30–60	22	7	16
Culcairn	0–10	143	48	41
	0–30	99	40	32
	30–60	24	11	15
Henty	0–10	30	67	11
	0–30	68	12	25
	30–60	15	7	24
Lockhart	0–10	22	13	47
	0–30	60	22	49
	30–60	13	12	32
Pleasant Hills	0–10	84	13	46
	0–30	61	9	39
	30–60	28	3	14
Rand	0–10	60	221	42
	0–30	32	181	31
	30–60	23	31	21

TABLE 6 Soil Colwell P measurement at the weather station and soil moisture probe sites across southern NSW

Site	Depth (cm)	Colwell P		
		May 2017	August 2017	January 2018
		(mg P/kg)	(mg P/kg)	(mg P/kg)
Barooga	0–10	100	120	170
	0–30	54	36	20
	30–60	6.5	<5.0	<5.0
Berrigan	0–10	190	240	130
	0–30	18	96	<5.0
	30–60	5	<5.0	<5.0
Culcairn	0–10	170	67	89
	0–30	56	34	21
	30–60	5	<5.0	<5.0
Henty	0–10	79	61	83
	0–30	29	11	28
	30–60	5	<5.0	<5.0
Lockhart	0–10	62	49	62
	0–30	17	25	16
	30–60	5	<5.0	<5.0
Pleasant Hills	0–10	120	83	100
	0–30	37	37	18
	30–60	5	<5.0	<5.0
Rand	0–10	51	55	51
	0–30	14	41	<5.0
	30–60	5	<5.0	<5.0

The Colwell results indicated good stores of phosphorus in the surface soil across all sites. The increase in Colwell phosphorus from August 2017 to January 2018 may be due to mineralisation of organic phosphorus to plant-available phosphorus, with spatial variability also likely to have contributed to the difference.

The Colwell phosphorus value should be taken in context of the ability of the soil to release phosphorus for plant use or bind it chemically (adsorbed phosphorus), rendering it non-available to plants. For this reason, a phosphorus buffering index (PBI) test is helpful.

vii) Phosphorus buffering index (PBI)

The PBI measurement is independent of the actual phosphorus levels measured in the soil at any time. Rather, it measures a soil's ability to chemically bind phosphorus.

While the values show some differences over time, this is largely due to the inherently high variation in clay content across small scales. Rather, it is more important that the range of results stays the same. A high PBI value means higher phosphorus application rates are needed to raise plant-available levels. A PBI value of <30 mg P/kg means the soil has a low phosphorus holding/buffering capacity, while a value of 30–60 mg P/kg is considered moderate and a value of >60 mg P/kg is considered high.

As an example, the Berrigan site had a Colwell value of 190mg P/kg for the 0–10cm depth (Table 6), which is considered quite high, however the Berrigan site's very high PBI value (150 mg P/kg for the 0–10cm depth) means that this soil holds onto phosphorus very strongly. Hence, a higher Colwell phosphorus is needed to ensure adequate phosphorus nutrition for the growing crop. This is also shown at the Rand site, with the high PBI values indicating this soil has a high proportion of clay, which will bind with the applied phosphorus fertiliser.

viii) Sulphur

The level of plant-available sulphur in the soil varies widely between sites. Historically, growers have been encouraged to apply sulphur with every canola crop, due to the higher sulphur demand of canola compared with cereals (up to 20–30 kg S/ha), however this could be revised in paddocks with a history of regular sulphur application

TABLE 7 Soil phosphorus buffering index measurement at the weather station and soil moisture probe sites across southern NSW

Site	Depth (cm)	Phosphorus buffering index		
		May 2017	August 2017	January 2018
		(mg P/kg)	(mg P/kg)	(mg P/kg)
Barooga	0–10	63	84	79
	0–30	66	84	110
	30–60	96	85	120
Berrigan	0–10	150	180	140
	0–30	140	110	140
	30–60	140	87	130
Culcairn	0–10	96	77	65
	0–30	87	81	90
	30–60	69	72	79
Henty	0–10	41	41	46
	0–30	39	65	55
	30–60	84	110	140
Lockhart	0–10	41	47	36
	0–30	64	72	91
	30–60	90	59	91
Pleasant Hills	0–10	65	95	79
	0–30	52	75	57
	30–60	76	98	72
Rand	0–10	89	81	110
	0–30	140	110	230
	30–60	180	210	230

TABLE 8 Soil sulphur measurement at the weather station and soil moisture probe sites across southern NSW*

Site	Depth (cm)	Soil sulphur		
		May 2017	August 2017	January 2018
		(kg S/ha)	(kg S/ha)	(kg S/ha)
Barooga	0–10	11	7	17
	0–30	12	6	6
	30–60	17	n.d.	32
Berrigan	0–10	392	154	140
	0–30	113	76	172
	30–60	88	71	97
Culcairn	0–10	32	22	21
	0–30	32	46	35
	30–60	27	59	42
Henty	0–10	55	18	7
	0–30	50	55	42
	30–60	42	76	97
Lockhart	0–10	10	4	8
	0–30	29	27	29
	30–60	185	50	134
Pleasant Hills	0–10	24	14	7
	0–30	21	55	21
	30–60	46	23	16
Rand	0–10	182	83	49
	0–30	130	840	80
	30–60	139	122	76

* Measured as sulphate sulphur.

(either through gypsum, ammonium sulphate or even single superphosphate).

Of interest are the high sulphur values present at the 30–60cm depth at the Berrigan, Lockhart and Rand sites, which could be utilised by crops. As sulphur is somewhat mobile, some of the sulphur present at depth may have leached through the soil profile as a result of the wet 2016 season.

Conclusions

The results shown here provide a benchmark of the soil chemistry status of the region for reference in future. However, they also demonstrate the variability across the region and highlight the risks of managing paddocks across a single farm with a blanket approach when the soil characteristics can vary significantly.

Some variability in results was seen across the three sampling times, even for parameters that would not change rapidly (e.g. pH).

To ensure the most accurate and meaningful results from soil sampling across years, always use the same sampling method, sample from the same GPS location in the paddock (while ensuring the same holes aren't sampled) and at the same time of year. Avoid sampling when conditions are wet, as this will affect the results. Send samples to the same NATA-accredited laboratory to minimise analytical variance.

Ideally, some understanding of the subsurface physical characteristics of the soil would aid in interpreting soil chemistry results. So, if possible, look at the soil moisture probe measurements from nearby weather stations, and/or dig a soil pit occasionally to see how the chemical measures interact with the physical structure of the soil.

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Thank you to our weather station and soil moisture probe host farmers.

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Management of early-sown wheat

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

The following report has been based on the first year's data from a new research project, so please exercise caution in interpreting the results.

Key points

- Eight cultivars sown at four sowing dates (15 March, 3 April, 13 April and 26 April) yielded between 2.80–4.28t/ha.
- There was a significant interaction between sowing date and cultivar yield performance in the spring wheat cultivars, with increased yield when the sowing date was moved from the 15 March to 26 April.
- In contrast, the winter wheat yields were relatively stable over the same sowing window.
- Floret sterility (mainly due to frost) was recorded at high levels in the two spring wheat cultivars when they were sown before 26 April.
- Higher grain yields were measured in wheat crops that flowered during the first 10 days of October.
- Spring wheat cultivars ranged in flowering date from 24 June – 30 September, compared with winter wheats sown on the same dates, which flowered 29 September – 14 October.

Previous findings

During the past 10 years there has been a major shift to sow broadacre crops earlier in south-eastern Australia. This earlier sowing regime has been underpinned by increases in grain yields, particularly in the low and medium rainfall zones. However, the move to early sowing has also exposed shortcomings in wheat germplasm, since earlier sowing results in earlier flowering dates, which have a higher frost risk. As a result, there has been increasing interest in new faster-developing winter wheat cultivars, which are more adapted to early sowing.

Method

Two trials were established during 2017 as part of a GRDC research investment on the management of early-sown wheat, led by La Trobe University (ULA9175069 — Development of crop management packages for early-sown, slow-developing wheats in the Southern region). The trials were carried out at the Riverine Research Centre (RRC) at Yarrawonga, Victoria.

Trial 1: Time of sowing x cultivar

Sowing date: See treatment list below (Table 1)
Rotation: Wheat following canola
Stubble: Canola unburnt
Rainfall:
GSR: 270mm (April–October)
Summer rainfall: 88mm
Soil mineral nitrogen:
0–10cm: 17kg N/ha
10–30cm: 54kg N/ha
30–60cm: 34kg N/ha

The research carried out at the RRC involved eight, developmentally different, cultivars sown across four sowing dates. Two spring wheat cultivars were also included at each time of sowing as controls. Pressure-compensating drip irrigation was used to mimic a break if there was not enough natural rainfall for establishment, applied as 10mm for time of sowing 1 and 2 (Table 1). Assessments were made to increase the understanding of early-sown wheat phenology and provide insights as to how new winter wheats can be best managed in broadacre systems.

TABLE 1 Time of sowing treatment details, 2017

TOS	Targeted time of sowing	Actual time of sowing	Date of emergence
1	15 March	15 March	20 March
2	1 April	3 April	8 April
3	15 April	13 April	17 April
4	1 May	26 April	1 May

	Cultivar	Type
1	Scepter	Fast spring
2	Cutlass	Mid spring
3	LPB14-0392	Intermediate; fast winter–slow spring
4	Longsword (RAC2341)	Fast winter
5	V09150-01	Mid–fast winter
6	Kittyhawk	Mid winter
7	ADV08.0008	Mid winter
8	ADV11.9419	Slow winter

Results

i) Establishment and crop structure

All plots were sown at 120 seeds/m^2, which resulted in 80–106 plants/m^2 (Table 2).

TABLE 2 Plant counts 3 April 2017, 27 April 2017, on 10 May 2017 and 1 June 2017

TOS*	Date of plant count	Plants/m^2
TOS 1 (15 March)	3 April	83[b]
TOS 2 (3 April)	27 April	106[a]
TOS 3 (13 April)	10 May	100[a]
TOS 4 (26 April)	1 June	80[b]
Mean		92
LSD		14
Variety		
Scepter		99[a]
Cutlass		105[a]
LPB14-0392		85[b]
Longsword		99[a]
V09150-01		100[a]
Kittyhawk		88[b]
ADV08.0008		83[b]
ADV11.9419		82[b]
LSD		11

*Time of sowing
Note: Mean is average plants/m^2 for all times of sowing
Figures followed by different letters are regarded as statistically significant.

Based on weather station data, the two spring wheat cultivars Scepter (fast spring) and Cutlass (intermediate spring) required less thermal time to reach the start of stem elongation (GS30) than the six winter wheat cultivars (Figure 1). The accumulated thermal time to reach the start of stem elongation (GS30) was greater in the winter wheat cultivars when they were sown earlier, however this was not the case with the spring wheat cultivars.

ii) Floret sterility

Floret sterility (principally due to frost) was recorded at high levels in the two spring wheat cultivars (Cutlass and Scepter) when they were sown before 26 April. This level of sterility was significantly greater than the levels of sterility recorded in the six winter wheats sown at the first two times of sowing (15 March and 3 April) (Figure 2).

iii) Grain yield and quality

There was a significant interaction between sowing date and cultivar yield performance, with yield of the spring wheat cultivars increasing from the 15 March sowing date to 26 April (Table 3 and 4).

In contrast, the winter wheat yields were relatively stable over the same sowing window, although there was some significant evidence (ADV08.0008 LPB14-0392,

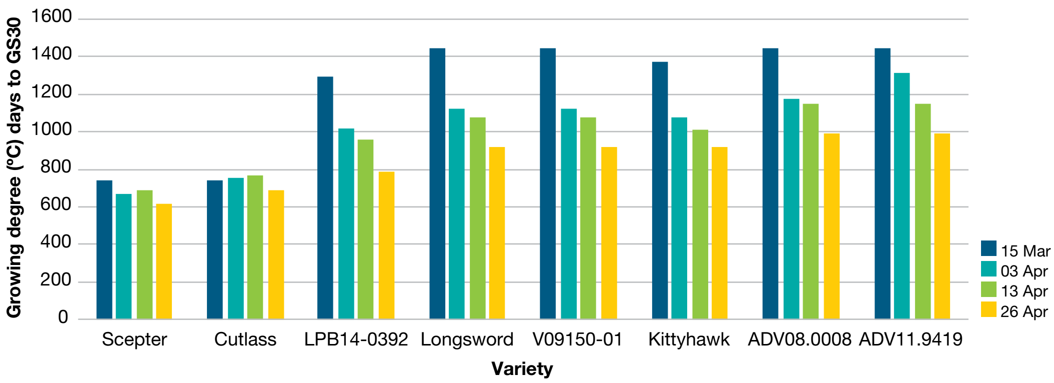


FIGURE 1 Growing degree (°C) days for each cultivar at each time of sowing to reach the start of stem elongation (GS30)

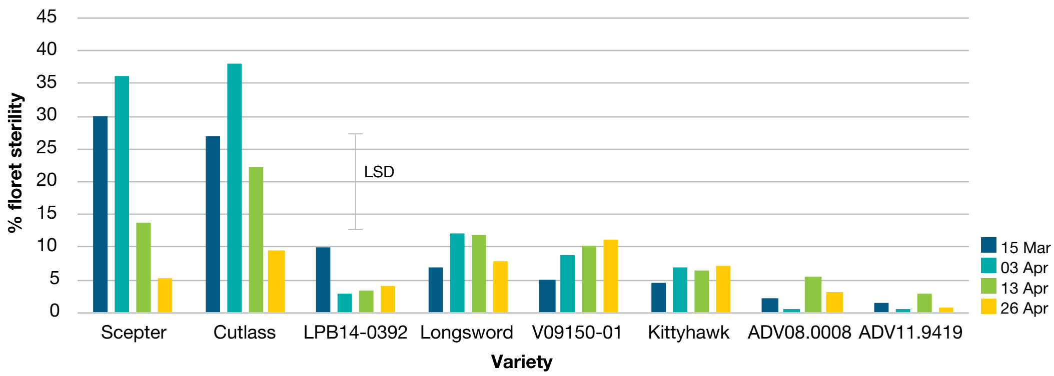


FIGURE 2 Percentage of floret sterility for each cultivar at each time of sowing
Error bar is a measure of LSD

TABLE 3 Yield, protein, test weight and screenings of time of sowing at harvest (GS99), 11 December 2017*

Time of sowing	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
15 March	3.45^{b}	10.8^{a}	73.5^{b}	1.7^{a}
3 April	3.73^{a}	10.5^{b}	75.0^{a}	1.5^{b}
13 April	3.73^{a}	10.5^{b}	75.7^{a}	1.5^{b}
26 April	3.87^{a}	10.1^{c}	76.1^{a}	1.4^{c}
Mean	**3.70**	**10.5**	**75.1**	**1.5**
LSD	0.15	0.2	1.1	0.1

* Mean of eight cultivars
Figures followed by different letters are regarded as statistically significant.

V09150-01) that the earliest sowing date of 15 March was a less favourable sowing option than the April sowing dates.

Sowing the spring wheat cultivars (Scepter and Cutlass) on 26 April produced among the highest yields and proteins in the trial, however sowing earlier than this date resulted in significant yield penalties due to frost-induced floret sterility (Figure 3). The yield of Scepter and Cutlass from the March and early-mid April sowing dates was a result of crop re-growth following frosting of the first crop during July.

TABLE 4 Yield, protein, test weight and screenings for cultivar at harvest (GS99), 11 December 2017*

Cultivar	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
Scepter	3.48^{c}	10.9^{b}	76.1^{b}	1.9^{b}
Cutlass	3.33^{d}	11.8^{a}	76.1^{b}	1.7^{c}
LPB14-0392	3.74^{b}	10.0^{c}	75.4^{bc}	1.7^{c}
Longsword	3.58^{c}	11.5^{a}	75.3^{c}	0.8^{e}
V09150-01	3.82^{ab}	10.8^{b}	72.7^{f}	0.9^{e}
Kittyhawk	3.72^{b}	9.9^{c}	77.2^{a}	1.1^{d}
ADV08.0008	**3.95^{a}**	**10.0^{c}**	**73.6^{f}**	**2.1^{a}**
ADV11.9419	3.96^{a}	8.8^{d}	74.5^{d}	2.0^{ab}
Mean	**3.70**	**10.5**	**75.1**	**1.5**
LSD	0.14	0.4	0.7	0.2

* Mean of four sowing dates
Figures followed by different letters are regarded as statistically significant.

The two spring wheat cultivars (Cutlass and Scepter) flowered during mid-July and then flowered again with re-growth during early October when they were sown at TOS1–TOS3 (Figure 4).

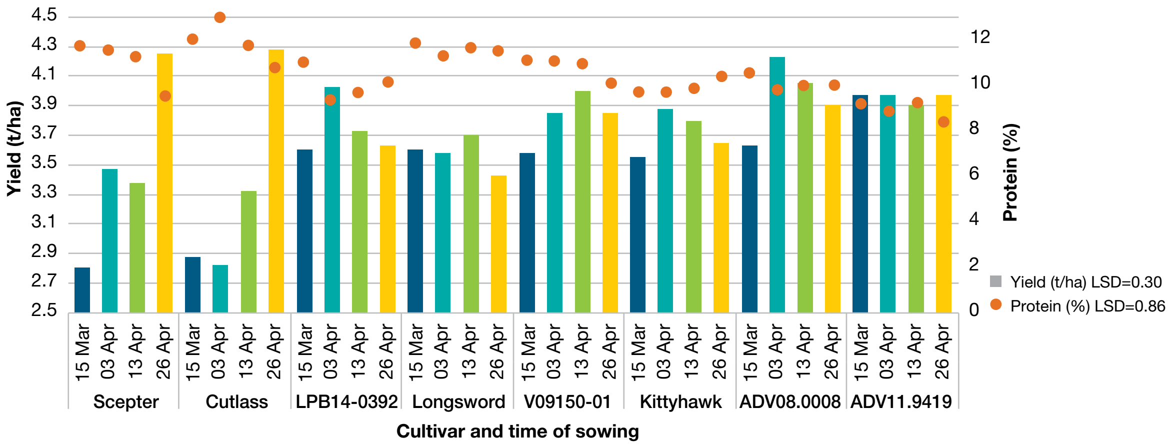


FIGURE 3 Interaction between time of sowing and cultivar on yield and protein

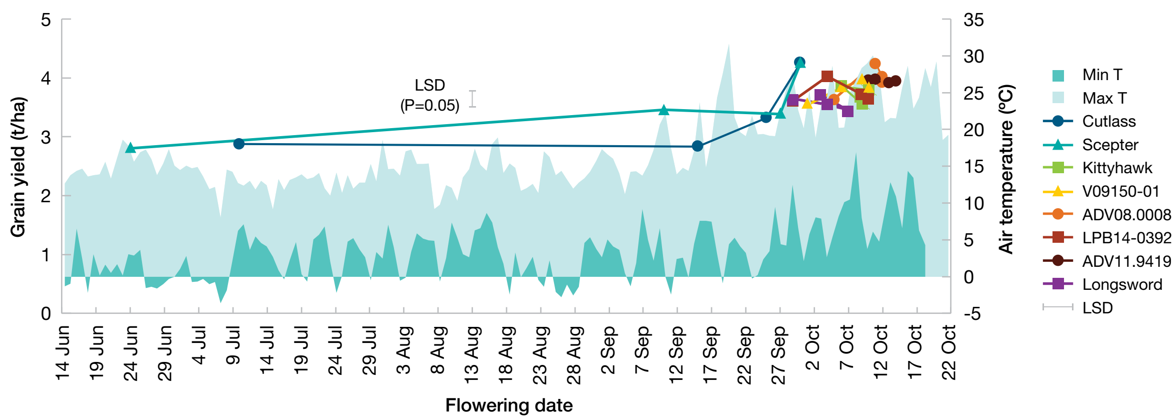
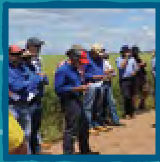
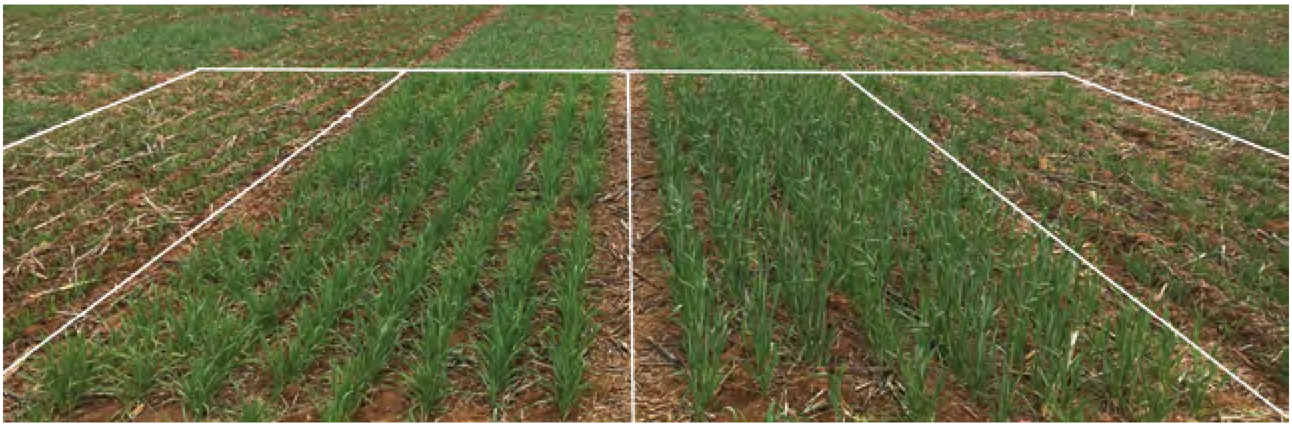


FIGURE 4 Interaction between time of sowing and cultivar on flowering date and yield
NOTE: Each cultivar is represented by four identical symbols, with the first on the left representing TOS1 and the one on the right representing TOS4.





Time of sowing (TOS) trial 24 May 2017. From left: TOS 4 (26 April) ADV11.9419, TOS 2 (April 3) Scepter, TOS 1 (March 15) Scepter and TOS 3 (April 13) Cutlass

Trial 2: Cultivar x sowing rate x nitrogen timing x grazing

Key points

- Three cultivars sown on 13 April yielded between 3.03–4.23t/ha.
- There was a significant interaction between grazing and yield performance across all cultivars, nitrogen treatments and sowing rates combined, with increased yield where the crop had not been grazed.
- Longsword suffered no yield penalty from grazing, but Kittyhawk and ADV11.9419 did.
- Floret sterility (mainly due to frost) was recorded at higher levels in certain cultivars that had been grazed.
- Higher grain yields were measured in wheat crops that had nitrogen applied at the start of stem elongation (GS30) compared with crop that had nitrogen applied at sowing.
- Larger amounts of biomass were removed from plots that had a higher sowing rate.

Sowing **date:** 13 April 2017
Rotation: Wheat following canola
Stubble: Canola unburnt
Rainfall:
GSR: 270mm (April–October)
Summer **rainfall:** 88mm
Soil **mineral nitrogen:**
0–10cm: 17kg N/ha
10–30cm: 54kg N/ha
30–60cm: 34kg N/ha

The aim of the trial was to manipulate the canopy of early-sown wheat and to understand how these interventions can affect crop management.

Manipulation of the crop canopy was achieved by cultivar selection, sowing rate, the application of nitrogen fertiliser and through grazing. The trial studied three winter wheat cultivars: ADV11.9419, Kittyhawk and Longsword, sown at two target plant populations (50 and 150 plants/m^2) on 13 April 2017 (Table 5). Plots were fertilised with nitrogen as urea at sowing (GS00) or at the start of stem elongation (GS30). Each treatment combination was either grazed mechanically or left ungrazed.

Results

i) Establishment and crop structure

Establishment plant counts taken on 10 May 2017 showed the average plant population was close to the targeted population (Table 6).

Using the averaged values for each treatment, ADV11.9419 took the longest time to reach the start of stem elongation (GS30) with Longsword and Kittyhawk being similar (Figure 5).

ii) Dry matter offtake at grazing

Dry matter (DM) removed by mechanical grazing was significantly greater where plant population averaged 136 plants/m^2 rather than 54 plants/m^2. Applying nitrogen at sowing significantly increased the amount of DM removed when grazed at the start of stem elongation (GS30) compared to when nitrogen was applied at the same time as grazing (GS30) (Table 7).

TABLE 5 Target population treatment details, 2017

Cultivar	Target plant density (plants/m²)	Nitrogen timing (200kg urea)	Grazing*
ADV11.9419	50	GS00	Nil
	50	GS00	Grazed
	50	GS30	Nil
	50	GS30	Grazed
	150	GS00	Nil
	150	GS00	Grazed
	150	GS30	Nil
	150	GS30	Grazed
Kittyhawk	50	GS00	Nil
	50	GS00	Grazed
	50	GS30	Nil
	50	GS30	Grazed
	150	GS00	Nil
	150	GS00	Grazed
	150	GS30	Nil
	150	GS30	Grazed
Longsword	50	GS00	Nil
	50	GS00	Grazed
	50	GS30	Nil
	50	GS30	Grazed
	150	GS00	Nil
	150	GS00	Grazed
	150	GS30	Nil
	150	GS30	Grazed

*Grazing was undertaken on each plot by mechanical defoliation at the four-tiller stage (GS24) and start of stem elongation (GS30)

TABLE 6 Target and actual plant emergence 10 May 2017

Target plant population (plants/m²)	Actual plant population (plants/m²)
50	54
150	136

TABLE 7 Effect of plant density and nitrogen timing on dry matter offtake when all cultivars were combined, at the start of stem elongation (GS30) 27 July 2017

Plant density	DM (t/ha)
54 plants/m²	0.44^{b}
136 plants/m²	0.71^{a}
Mean	**0.57**
LSD	0.15
Nitrogen timing	
GS00	0.73^{a}
GS30	0.41^{b}
LSD	0.15
Plant density x nitrogen timing	
54 plants/m² : GS00	0.49^{b}
54 plants/m² : GS30	0.38^{c}
136 plants/m²: GS00	0.98^{a}
136 plants/m² : GS30	0.44^{bc}
LSD	0.10

Figures followed by different letters are regarded as statistically significant.

iii) Floret sterility

Floret sterility was significantly greater in Longsword than Kittyhawk, which was significantly greater than ADV11.9419. It is unclear if frost was the sole reason for this sterility, however as levels were less than 8% in all cases, frost is unlikely to be the primary cause (Table 8). Grazed crops of Kittyhawk and Longsword had significantly higher levels of floret sterility than the ungrazed treatments (Table 9).

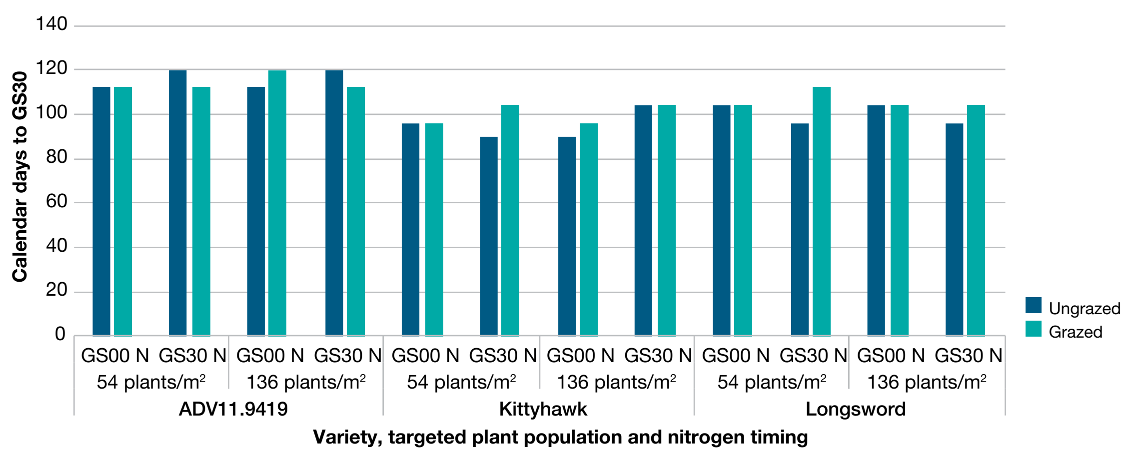


FIGURE 5 The interaction of cultivar, seed rate, nitrogen timing and grazing on averaged calendar days from sowing until start of stem elongation (GS30)

TABLE 8 Effect of cultivar on floret sterility at early dough stage (GS83), 16 November 2017

Cultivar	Floret sterility (%)
ADV11.9419	1.2^{c}
Kittyhawk	5.5^{b}
Longsword	7.3^{a}
Mean	**4.7**
LSD	1.8

Figures followed by different letters are regarded as statistically significant.

TABLE 9 Interaction of cultivar and grazing on floret sterility at early dough stage (GS83), 16 November 2017

Cultivar	Floret sterility (%)	
	Ungrazed	Grazed
ADV11.9419	1.5^{cd}	1.0^{d}
Kittyhawk	6.5^{b}	4.6^{bc}
Longsword	3.2^{c}	11.3^{a}
Mean	**4.7**	
LSD	3.2	

Figures followed by different letters are regarded as statistically significant.

TABLE 10 Effect of cultivar, plant density, nitrogen timing and grazing on grain yield and quality, 11 December 2017

Cultivar	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
ADV11.9419	3.81^{a}	9.2^{c}	76.1^{a}	1.5^{a}
Kittyhawk	3.40^{b}	10.4^{b}	78.8^{b}	0.8^{b}
Longsword	3.46^{b}	11.3^{a}	76.8^{b}	0.5^{c}
Mean	**3.56**	**10.3**	**77.2**	**0.9**
LSD	0.12	0.3	0.3	0.1
Plant density (plants/m^2)				
54	3.52^{a}	10.6^{a}	77.4^{a}	1.1^{a}
136	3.59^{a}	10.0^{b}	77.0^{b}	0.8^{b}
LSD	0.10	0.3	0.3	0.1
Nitrogen timing				
GS00	3.45^{b}	10.1^{b}	77.2^{a}	0.9^{b}
GS30	3.61^{a}	10.5^{a}	77.2^{a}	1.0^{a}
LSD	0.10	0.3	0.3	0.1
Grazing				
Nil	3.80^{a}	10.7^{a}	77.2^{a}	0.9^{b}
Grazed	3.31^{b}	9.9^{b}	77.2^{a}	1.0^{a}
LSD	0.10	0.3	0.3	0.1

Figures followed by different letters are regarded as statistically significant.

iv) Yield and quality

Influence of cultivar

ADV11.9419 was significantly higher yielding than Kittyhawk and Longsword, but had significantly lower protein, lower test weight and higher screenings (Figure 6 and Table 10).

Influence of plant population

There was no difference in grain yield due to plant population when the results from the three cultivars were averaged, although the higher plant population reduced grain protein, test weight and screenings (Table 10).

Influence of nitrogen timing and grazing

Nitrogen applied at start of stem elongation (GS30) significantly increased yield by 0.16t/ha compared with the same application applied at sowing (GS00). It also significantly increased grain protein. In contrast grazing on average significantly reduced grain yield by 0.49t/ha along with protein levels (Table 10 and Figure 7).

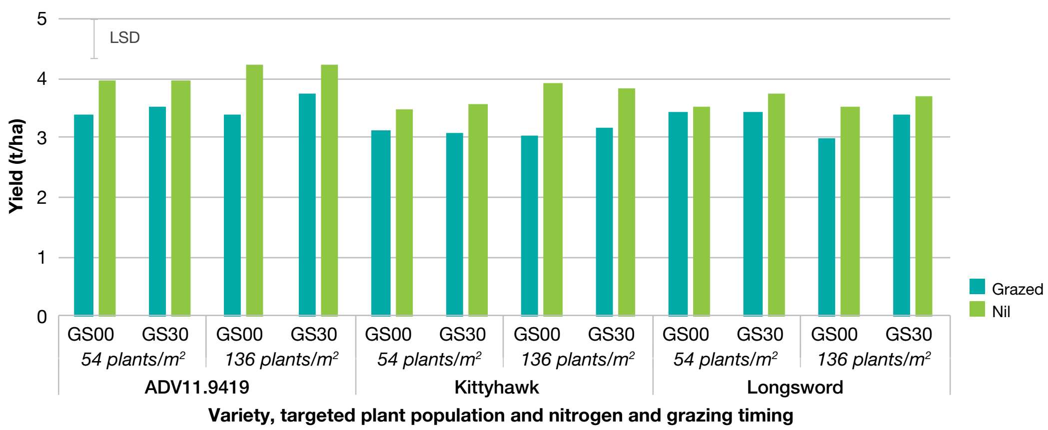


FIGURE 6 The interaction of cultivar, plant density, nitrogen timing and grazing on yield at harvest (GS99), 11 December 2017
Error bar is a measure of LSD

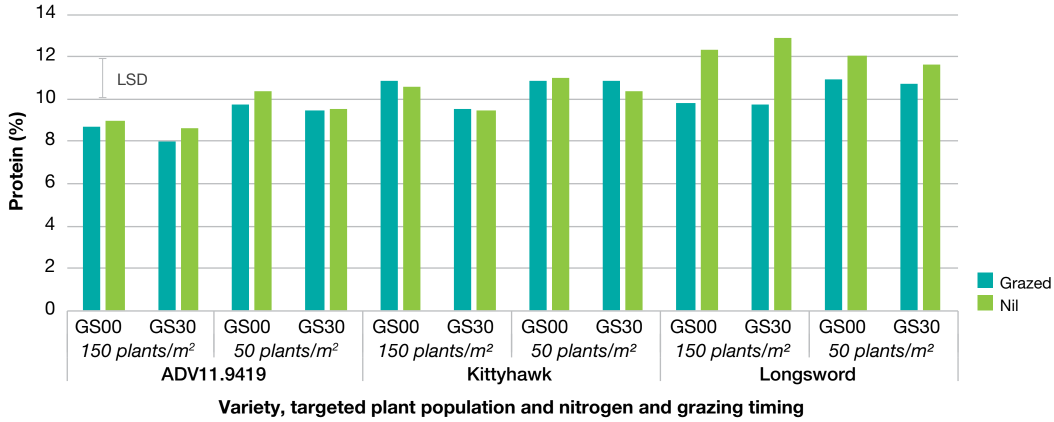


FIGURE 7 The interaction of cultivar, plant density, nitrogen timing and grazing on protein at harvest (GS99), 11 December 2017
Error bar is a measure of LSD

Cultivar x sowing rate x nitrogen timing x grazing trial on 29 July 2017 after second grazing.

Acknowledgements

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Addressing soil acidity: subsurface soil amendments increasing pH and crop yield at Rutherglen

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Graham Centre for Agricultural Innovation (alliance between Charles Sturt University and New South Wales Department of Primary Industries)

Key points

- Surface soil acidity (0–10cm) limited crop yield by about 8–12%.
- Deep placement of reactive phosphate rock or organic matter (OM) achieved yield gains of up to 18% compared with surface-applied lime.
- Deep placement of OM may induce manganese (Mn) toxicity.
- The interaction between subsurface pH increase and nutrient release needs further investigation.

Introduction

Acidity of subsurface soil (below 10cm from the soil surface) is a major constraint to crop production in the high-rainfall (500–800mm) cropping zone. While acidic surface soil (0–10cm) can be easily and effectively addressed by incorporating lime at the soil surface, amelioration of the subsurface (below 10cm) soil has not been practical.

The current GRDC-funded project *Innovative approaches to managing subsoil acidity in the southern grain region* (DAN00206) aims to identify and evaluate a range of products, which may be used to overcome adverse effects of subsurface soil acidity. These products include alkaline materials, such as lime and dolomite, and novel products such as magnesium silicate (which reacts to create alkali) or reactive phosphate rock (which can increase pH and release plant available phosphorus as it dissolves in acidic soil).

Organic amendments, such as lucerne pellets, are known to increase soil pH either by being an alkali source or by enabling alkaline reactions to occur during the decomposition of organics. The influence of these products on the conditions of subsurface acidity (soil pH and toxic aluminium) and crop yield were investigated.

Aim

To quantify the yield limitation caused by subsoil acidity and evaluate innovative soil amendments that act to ameliorate subsurface acidity.

Method

A three-year, replicated field trial was established at Rutherglen, Victoria, on a site located adjacent to the Rutherglen–Wahgunyah Road. The site has a history of more than 20 years of clover pasture, which was grazed and cut for hay. The absence of any lime applications to the site during this time, has resulted in highly acidic soil and high aluminium (Al) concentrations in both the surface (0–10cm) and subsurface soil (10–30cm) (Table 1).

Existing pasture was sprayed out and 14 amendment treatments were applied during March 2017 in a randomised block design with three replicates, with plots measuring 5m x 20m (Table 2).

The treatments include a *nil control* (no additions) while all other treatments received surface application of superfine lime (neutralising value = 98%) at 1.7t/ha to achieve a soil pH in the 0–10cm of pH 5.0 in order to ameliorate surface acidity. An additional treatment received a higher rate (2.7t/ha) of surface applied lime to achieve a target pH of 5.5 in the surface layer (*surface lime*).

Deep amendment treatments included: lime, dolomite, magnesium silicate (MgSi), lucerne pellets, reactive phosphate rock (RPR) and liquid phosphorus. The deep amendments were placed approximately 15–30cm deep in the profile at a 50cm row spacing using the 3D ripper machine engineered by NSW DPI. A deep-ripped control, which had surface lime (pH 5.0) but was deep ripped with no amendment added (*deep ripping only*), was included to contrast the deep amendment treatments. Deep

TABLE 1 Initial pH and exchangeable aluminium percentage* of the Rutherglen field trial, January 2017

Soil depth (cm)	Soil pH ($CaCl_2$)	Al%
0–10	4.55	12
10–20	4.22	30
20–30	4.32	10
30–40	5.05	3

* Exchangeable aluminium percentage is determined as the percentage of the measured cation exchange capacity, which is comprised of aluminium. A value greater than 6% generally indicates aluminium to be likely to cause plant phytotoxicity.



TABLE 2 Surface and deep amendment treatments applied to the Rutherglen, Victoria trial site during 2017

Treatment	Surface lime application rate (t/ha)	Target surface pH ($CaCl_2$)	Deep amendment (placed about 15–30cm deep)	Deep amendment application rate (t/ha)
Nil control	0	-	n/a	n/a
Limed control	1.7	5.0	n/a	n/a
Surface lime	2.7	5.5	n/a	n/a
Deep ripping only	1.7	5.0	Deep ripping only	n/a
Deep lime	1.7	5.0	Lime	2.5
Deep dolomite	1.7	5.0	Dolomite	2.3
Deep MgSi (low)	1.7	5.0	Magnesium silicate	4
Deep MgSi (high)	1.7	5.0	Magnesium silicate	8
Deep lucerne (low)	1.7	5.0	Lucerne pellets	7.5
Deep lucerne (high)	1.7	5.0	Lucerne pellets	15
Deep RPR (low)	1.7	5.0	Reactive phosphate rock	4
Deep RPR (high)	1.7	5.0	Reactive phosphate rock	8
Deep P	1.7	5.0	Liquid phosphorus	15 kg P/ha
Deep P + deep lime	1.7	5.0	Liquid phosphorus + lime	15 kg P/ha + 2.5t/ha lime

amendments were applied at rates to achieve a target pH 5.0 based on short-term laboratory incubation studies conducted at Charles Sturt University (CSU). Amendments applied at two rates (MgSi, RPR and lucerne pellets) were labelled *high* and *low*, for the targeted pH 5.0 rate and half that rate, respectively.

Canola (Hyola 559 TT) was sown on 3 May 2017 at 3kg/ha, with 75kg MAP/ha placed with the seed using a cone seeder on a 25cm row spacing. Crop growth was monitored through the season and standard agronomic metrics (establishment counts, biomass, crop height, podding height) were recorded (data not presented).

The site was harvested on 22 November 2017 using a plot harvester. Yield data were statistically analysed using ANOVA and a Student-Newman-Keuls test to determine treatment differences. The mean yield data are graphically represented here using least significant difference (LSD) for simplicity, as results for statistical analyses were analogous.

The soil from each plot was sampled after harvest by taking two 50mm diameter cores on the rip-line and two cores between rip lines to a depth of 140cm. Core samples were divided into depth increments of 0–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100, 100–120, 120–140cm with depth increments from duplicate cores bulked to produce representative soil samples for each sampling depth, on and off the rip-line.

Each soil sample was analysed for soil water content and soil pH ($CaCl_2$). Air-dried soil subsamples have been stored for future analysis of other chemical properties, such as mineral nitrogen (N), aluminium, and available phosphorus.

Results

The application of lime to the surface (0–10cm) soil increased soil pH (Figure 1) compared with the untreated control (nil). However it can be seen that where only surface application of amendments occurred (limed control, surface lime, deep ripping only) the soil pH in the subsurface remained unchanged and acidic conditions persisted at depth.

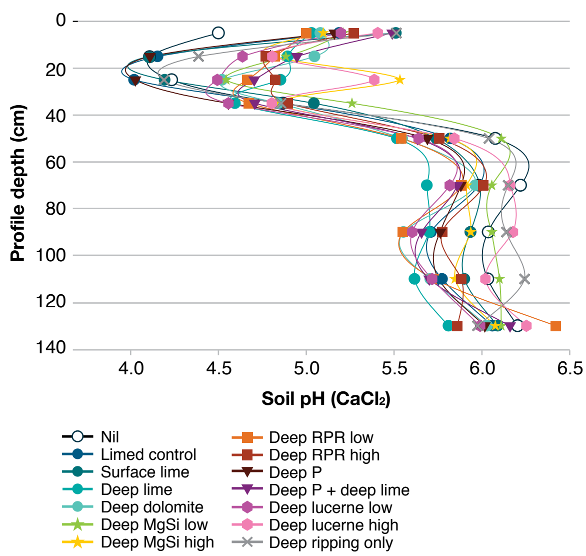

FIGURE 1 Profile soil pH ($CaCl_2$) measured post canola harvest (November 2017) of amendment treatments at Rutherglen site

Data are means of three replicates

All deep (15–30cm) amendments increased the pH of the soil at the depth of placement with the exception of the ripping only and deep phosphorus treatments, which had no alkali-producing material added.

Large increases in soil pH of the amended layer were recorded for the high rates of MgSi and lucerne pellets. The soil pH below the depth of placement was unchanged by treatments and exhibited considerable variation consistent with field sampling of subsoils.

Liming the surface (0–10cm) soil increased grain yield (Figure 2) compared with the untreated control (nil) indicating that unchecked acidity was limiting yield. However, the deep placement of amendments did not increase yield over the limed control, with the exception of the low and high RPR and high lucerne pellet treatments, which returned yield gains of about 0.5t/ha higher than the limed control.

The incorporation of lucerne pellets appeared to induce manganese toxicity during the growing season however the effect of this on yield was not able to be determined in this experiment.

Observations and comments

Deep placement of organic matter, such as lucerne pellets, may induce manganese toxicity due to enhanced oxygen consumption by microorganisms and poor aeration at depth. The increase in yield with RPR and lucerne pellets may be due to both a pH increase and improved nutrition at depth. Therefore, the interaction of these factors needs to be investigated for growers to realise efficiency gains by applying amendments at depth. A cereal crop will be sown in the experiment in 2018.

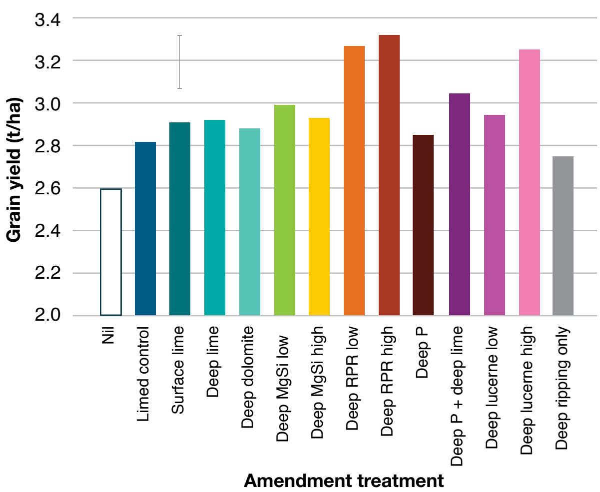

FIGURE 2 Yield of canola for amendment treatments at Rutherglen

Data are treatment means of three replicates.

Error bars indicate LSD (p=0.05).

Visual symptoms of manganese toxicity in canola plots (14 August 2017) treated with deep-placed lucerne pellets. The symptoms appear on the ripping row. Photo: Dr Sergio Moroni

Acknowledgements

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