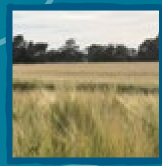
RiverinePlains

Research for the Riverine Plains 2020

A selection of research relevant to agriculture in the Riverine Plains

Farmers inspiring farmers





Research for the Riverine Plains 2020

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

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Membership area

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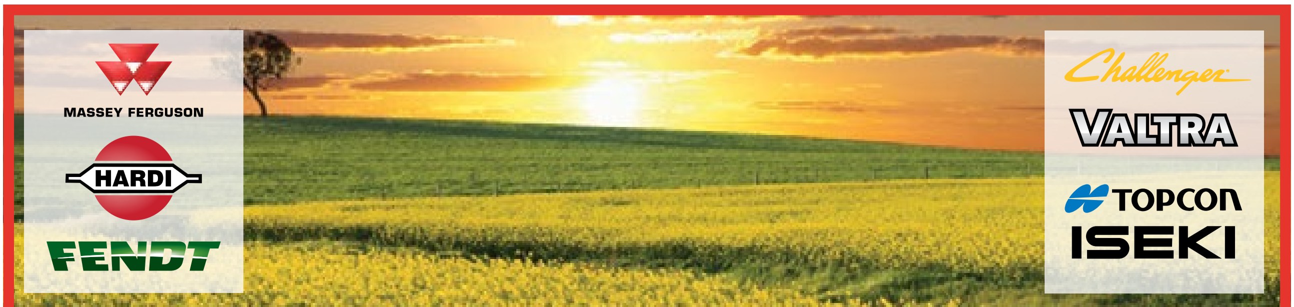

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Units of measurement

Riverine Plains Inc recognises that while the research sector has moved toward metric representation, many 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

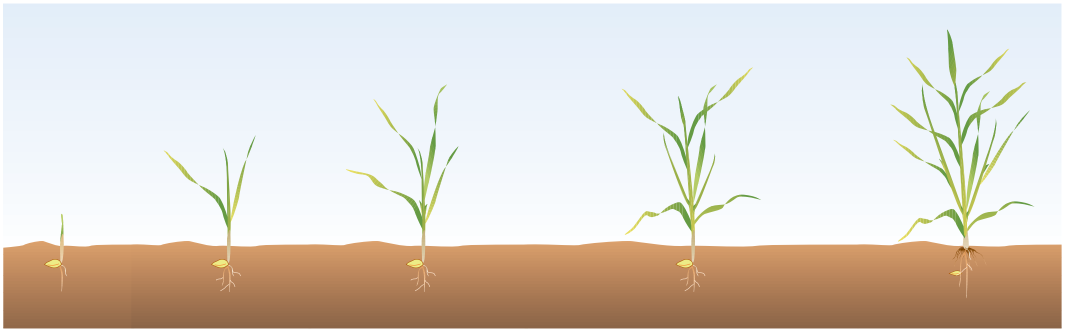
The most commonly used growth stage key for cereals is the:

- 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)

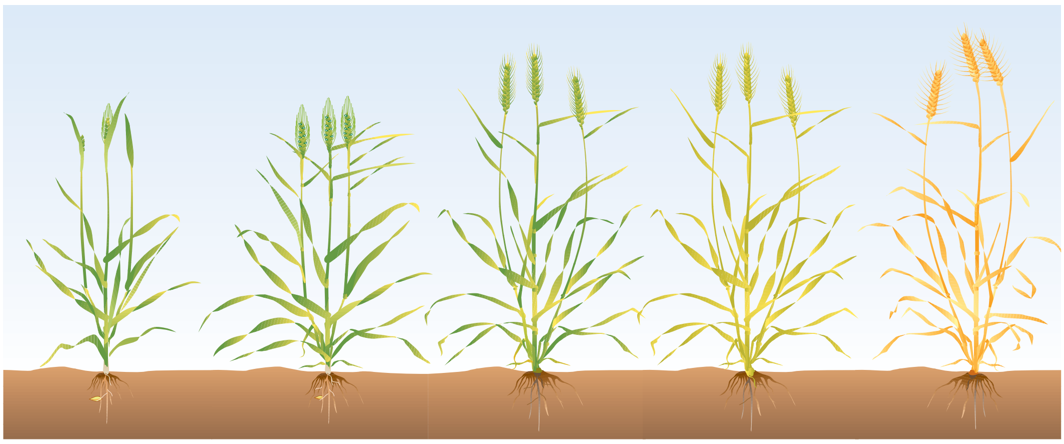
Within each of the 10 development phases there are 10 individual growth stages, for example, in the seedling stage:

- 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.



A word from the Chairman

Ian Trevethan
Chairman, Riverine Plains Inc

Welcome to the 2020 edition of *Research for the Riverine Plains*.

The year in review 2019–20

All in all, 2019 was another challenging year for farming across much of the Riverine Plains region. The autumn break was fairly elusive for most, with some areas seeing a reasonable April and crop sown into moisture, while others had to dry sow much (or all) their cropping program.

Some extraordinarily heavy rains during May brought mixed blessings for many, with the event causing widespread erosion and crusting, affecting the germination of canola crops in particular. However, the rain also helped crops along, placing them in a good position heading into winter, though poor late-winter and spring rainfall had many crops on a knife's edge throughout spring. Fortunately, relatively cool spring conditions helped many crops finish, with some yielding surprisingly well despite the lack of spring rainfall. The cool conditions did hinder the hay-making process somewhat though.

2019 was a particularly important year for Riverine Plains Inc as it marked 20 years since the group's establishment. The group celebrated this significant milestone at the *Celebration of Agriculture* dinner held during early March, with past chair, Andrew Russell, sharing the history of the group as well as highlights from the past two decades. The dinner also saw Mitchell Priestly, from Shepparton, Victoria announced as the recipient of the inaugural John Hanrahan Scholarship. The Scholarship presentation was the culmination of many years, and countless hours, of effort by members of the committee, staff and our supporters, which also saw us become a registered charity in the process. As a group, we are dedicated to improving the productivity of broadacre farming systems in north-east Victoria and southern New South Wales and there is no better way to do this than to support the next generation of passionate agriculturists from our area. We again thank the Hanrahan family and all those who have contributed to the Scholarship fund during the past few years.

Inaugural John Hanrahan Scholarship recipient, Mitchell Priestly (L) with scholarship fund trustee, Barry Membrey.

Farming systems groups, like Riverine Plains Inc, play a vital role in validating cutting-edge research at a local level, so growers can continue to evolve and adapt their businesses with confidence. Our group takes pride in the quality of our research and extension programs, and I would especially like to thank members, sponsors and supporters for their continued support of our events. The extension events and discussion groups we host add value to farming businesses, but importantly, what we do also adds to the social cohesion of the rural communities in our area. In some ways, Riverine Plains Inc has become its own community, where passionate growers and agribusiness can learn from each other and experts in the field. This is a great achievement and something I hope continues for another 20 years.

As well as marking the 20th Anniversary of Riverine Plains, 2019 was another big year for the Riverine Plains Inc research and extension program. Last year, our program comprised more than 24 individual events and we are proud to have delivered so many meaningful events to our members. Hosting such a large extension program also speaks volumes about the way Riverine Plains Inc has developed and evolved since our first few meetings, 20 or so years ago.

Farmers inspiring farmers

2019 extension summary

Sykesy's Buraja Meeting, Buraja — On 7 February 2019, more than 100 people attended the annual *Sykesy's Buraja Meeting* at Buraja Recreational Ground Hall. The audience participated in the traditional harvest debrief, facilitated by Chris Minehan (Rural Management Strategies), before hearing about local performances of wheat varieties with Michael Straight (FAR Australia), barley varieties with David Burch (NSW DPI) and canola varieties with Chris Toohey (Elders). Richard Hall (Market Check) also spoke about the outlook for grain commodity markets.

GRDC Grains Research Update, Corowa — Riverine Plains Inc hosted the annual *GRDC Grains Research Update* on 22 February, with about 95 people attending. Harm Van Rees (Cropfacts) presented key findings from the *National Paddock Survey* and spoke about the yield gap. Canadian farmers Jorden and Jennifer Lindgren (2018 Saskatchewan Young Farmers of the Year), described their grain operation, while Graeme Sandral (NSW DPI) spoke about crop nutrition. Rohan Brill (NSW DPI) spoke about canola agronomy, with James Hunt (La Trobe University) discussing the management of early-sown winter wheats. Cassandra Schefe (Riverine Plains Inc) presented findings from local GRDC research projects currently underway.

Australian Cool Farm Initiative Meeting, Mulwala — On 12 March, Elizabeth Reaves (Sustainable Food Lab, Vermont, USA), Juliette Caulkins (Mars Petcare, Amsterdam, Netherlands) and Sarah Heazlewood (Mars Petcare, Wodonga) met with farmers participating in the *Australian Cool Farm Initiative*. The meeting offered a chance to discuss project results to date and key messages, such as the importance of soil carbon in continuously growing healthy crops, the role of grazing within a cropping rotation, the benefits of including a pulse in your rotation (if possible) and the importance of getting to know your soils.

The 2019 Sykesy's Buraja Meeting was again well supported by the local farming community.

GRDC Mixed Farming Masterclass, Rutherglen — *The Mixed Farming Forum* was held on 13 March, with 40 people exploring topics related to sheep in cropping systems. Dr Kristy Howard (Inspiring Excellence) spoke about feeding to ensure ewe and lamb survival, while Matt Mahoney (AgriDome) and Josh Buerckner (IK Caldwell) addressed sown fodders within mixed enterprises. Alison Frishke (BCG) presented the Grain and Graze research on the value to livestock of grazing stubble and Danielle England (AgInnovate) briefly presented Grain and Graze work around managing business risk on a mixed farm.

GRDC Northern Pulse Check Discussion Group, Rand — About 30 growers attended a pre-sowing meeting at the Hamilton family property, near Rand, on March 14. Chris Toohey (Elders), spoke about pre-emergent herbicide use and Dan Zinga (New Edge Microbials) spoke about rhizobial formulations and biological markets. Participants also heard from Brad Chant (Warakirri Cropping) on different inoculant systems.

GRDC Southern Pulse Check Discussion Group Meeting, Dookie — About 20 participants attended a pre-sowing meeting held at the Ludeman family farm at Waggarandall on 15 March. The meeting started with a debrief of the difficult 2018 season, followed by Bruce Larcombe (Larcombe Agronomy) discussing the pre-emergent herbicide options in pulses. Wimmera farmer and entrepreneur, David Matthews, spoke on his experiences growing and marketing pulses while Anthony Cutter (AGT Foods) provided a pulse-market update.

Agribusiness Dinner and Presentation of the John Hanrahan Scholarship, Corowa — *The Celebration of Agriculture Dinner* on 22 March was an opportunity to celebrate food, farming and fellowship. More than 110 people saw the inaugural John Hanrahan Scholarship awarded to University of Melbourne Bachelor of Agricultural Science student, Mitchell Priestly. An auction was held to raise funds for the scholarship, with products generously donated by a range of individuals and organisations. The keynote speaker, Dennis Hoiberg (Lessons Learnt Consulting), spoke about aspects of resilience. The dinner also celebrated Riverine Plains Inc's 20th Anniversary, with past Chair (2010–12) and long-serving committee member, Andrew Russell, speaking on the evolution of the group since its establishment during 1999.

GRDC Insects in Canola Workshop, Corowa — A group of 11 farmers and advisors attended the *GRDC Managing Early Season Canola Pests* workshop in Corowa on 27 March. Presenters Phil Bowden (AOF/Pulse Australia) and Don McCaffery (NSW DPI) spoke about insect identification, early-season pest management options, monitoring techniques and paddock risk assessments.



Farm Cash Flow and Budgeting Workshop, Yarrawonga — A group of 18 farmers attended the *Farm Cash Flow and Budgeting* worskhop on 12 June at Yarrawonga. Topics of conversation included financial fitness, planning, cash flow, forecasting and budgeting. The workshop was presented by Wodonga TAFE and facilitated by Jan Barnard from AgBiz Assist.

GRDC Northern Pulse Check Discussion Group, The Rock — On 18 June about 30 farmers met at The Rock to view the GRDC and NSW DPI *Updating nutrient response curves trials* at the Kingston family farm. Graeme Sandral (NSW DPI) discussed early results from the trial, while Ian Menz (NSW DPI) explained the effect of temperature and rainfall. John Stevenson and Brad Chant (Warrakirri Cropping) hosted a paddock walk through a crop of chickpeas.

GRDC Southern Pulse Check Discussion Group, Dookie — The Dookie Pulse Check group met on 21 June, with a focus on nutrition. Lee Menhenett (Incitec Pivot) spoke about using grain-sample analysis to understand nutrient removal in pulse crops and Scott Palmer (SLTech) discussed how to apply micronutrients in liquid form to pulses. Other discussions included targeting soil testing to better understand the location of low-pH areas by breaking up the sampling intervals.

GRDC Farm to Profit Business Update, Mulwala — About 60 people attended the *GRDC Farm to Profit Farm Business Update* held on 25 June at Mulwala. The event included presentations on storing grain on farm, buying, leasing or investing off farm, taking a profit-first approach to precision agriculture and farm business resilience.

GRDC Canola Paddock Walk, Boorhaman — About 30 farmers attended a canola crop walk in north Boorhaman on 9 July. Phil Bowden (Bowden Rural Services) and Don McCaffery (NSW DPI) spoke about insects in canola and animal health issues in grazing crops, as well as discussing suitable canola varieties for grazing. The crop walk was part of the GRDC *Managing early-season canola establishment pests in NSW* project.

Farm Business Management Essentials, Mulwala — A group of 18 farmers attended the *Farm Business Management Essentials* workshop in Mulwala on 29 July, facilitated by Tony Hudson (Hudson Facilitations). Topics included; understanding your annual tax return, using financial ratios to understand business performance, understanding profit in your business, identifying ways to improve financial and overall business performance and how to positively influence bank's opinions. The Rotary Club of Yarrawonga and the Yarrawonga Mulwala Golf Club Resort kindly funded the workshop.

Riverine Plains Inc In-Season Update, Mulwala — About 60 people attended the Riverine Plains Inc *In-Season Update* on 8 August at Mulwala. James Manson (Southern Farming Systems), spoke on harvest weed-seed control in the southern region, addressing the effectiveness, practicality and profitability of a range of techniques. Nick Ennis (Lawson Grains), spoke on using precision agriculture to identify different production zones, while Kate Coffey (Riverine Plains Inc) presented the outcomes from the GRDC investment *Optimising crop nutrition in canola* project into sulphur and nitrogen nutrition. Dale Grey (Agriculture Victoria), presented a seasonal climate update via videolink, while Jane McInnes and Cassandra Schefe (Riverine Plains Inc) gave an update on current research being undertaken by the group. Cassandra also gave an overview of her travel to Canada and the USA as part of the GRDC *Recognising and Rewarding Excellence Award,* 2019.

Soil Health Workshop, Mulwala — A group of about 12 farmers participated in a soil CRC workshop for the project *Understanding adoptability of techniques and practices for improved soil management*. The workshop, led by researcher Catherine Allen (CSU), followed the *In-Season Update* on 8 August and provided farmers with the opportunity to discuss and prioritise their soil issues, the adoption of new practices and information sources.

GRDC Southern Pulse Check Discussion Group, Dookie — Around 20 farmers attended the pre-canopy closure *Pulse Check* meeting at Dookie on 13 August. The meeting focussed on nitrogen fixation and disease management. Results from the nitrogen fixation demonstrations sown at Bungeet and St James were discussed, as were the different treatments and cost-effective ways of increasing the amount of inoculant applied.

Irrigated Discussion Group Meeting, Mulwala — A group of 15 farmers and advisers attended the inaugural *Irrigation Discussion Group* meeting on 30 August. The Dye family volunteered to host an irrigation focus paddock trial for the group, looking at sub-soil manuring to improve soil structure and water-holding capacity, with treatments including: deep ripping, sub-soil poultry manure, surface-spread poultry manure, surface-spread gypsum and a sub-soil mixture of gypsum and poultry manure.

Riverine Plains Spring Tour, Walla Walla, Lockhart and The Rock — 26 people participated in the *Spring Tour* held on 10 September. The tag-along tour was organised by committee members John Bruce and Ian Trevethan and included visits to Garry Mickan's Walla Walla property (mixed farming lamb feed-lotting) and Di and Warrick Holding's property at The Rock (disc-seeding systems, transitioning from tyne to disc systems). There were also

The Irrigation Discussion Group was established in 2019 and is generating considerable interest.

A pre-harvest GRDC northern Pulse check meeting was held at Rand, October, 2019

visits to John Stevenson at Warakirri Ag Trusts, Lockhart (corporate agriculture, safflower trials) and Sandy Day, Lockhart (weed-seed destructor).

Riverine Research Centre Open Day, Yarrawonga — Cereal agronomy was the focus of the Riverine Plains Inc and FAR Australia Riverine Research Centre (RRC) open day on 24 September. About 130 people attended, including around 50 University of Melbourne agriculture students. Kat Fuhrmann (FAR Australia) spoke about fungal diseases, while Kenton Porker (SARDI) and Michael Straight (FAR Australia) outlined the major findings from the past three years of work on the GRDC *Managing early sown wheat project* trials. Kenton also spoke on dual-purpose and longer-season barleys for the Riverine Plains region. Michael Straight described the Riverine Plains Inc evaluation of 17 different wheat varieties sown from late March – early April and late April – early May. A panel session, which featured Michael Straight, Kenton Porker, Jamie Cummins (Yarrawonga) and Matt Coffey (Elders), also contemplated issues of hay versus grain.

GRDC southern Pulse Check Discussion Group, Dookie — Around 25 people attended the ninth *Pulse Check* discussion group meeting on 21 October, focussing on pre-harvest issues. The group visited John Alexander's faba bean crop, as well as a nitrogen-fixation demonstration in the same paddock, which compared faba beans sown with and without inoculant. The Binnie family also hosted a walk through a paddock of Luxor albus lupins. Scott Barlett (Agpro Consulting) discussed spray topping for late weed control, while Chris Warrick (Primary Business) talked about insect control in silos, the use of phosphine in sealed silos for insect control and how to use a pressure test to establish if a silo is sealed. Ben McClusky (Market Check) talked about pulse markets and there were discussions around setting up headers for harvesting pulses and the importance of calibrating headers for accurate yield mapping of different crop types.

GRDC northern Pulse Check Discussion Group, Rand — About 33 people attended the pre-harvest meeting on 21 October. Topics included: bean and chickpea agronomy, grain marketing and grain storage. In the paddock, farmers and advisors saw beans, chickpeas and lentils sown side by side. There was discussion around



phosphorus placement and its impact on pulse growth as well as liming and incorporation. Chris Toohey (Elders), spoke on crop-topping in pulses, while Mark Richards (NSW DPI), spoke about new pulse varieties for the region and Allan Peake (CSIRO), described the new GRDC *Pulse Adaptation* project. Chris Warrick (Primary Business), spoke on preventing insects in silos as part of a GRDC investment in grain storage and Ben McClusky (Market Check), gave an update on forecasted pulse production.

The Evan Moll Gerogery Field Day, Gerogery — About 80 people attended the annual *Evan Moll Gerogery Field Day* on 7 November. The day started with a walk through the pasture trials at the Leah family property before moving to the Moll family farm for the crop agronomy session. Adrian Clancy (Grain Brokers Australia) and Lachy Herbert (Riverina Oils) discussed grain markets while Andrew Millgate (NSW DPI) informed the crowd about new stripe rust strains. The GRDC *National Variety Trials* (NVT) were also inspected, with Peter Matthews (NSW DPI) leading the cereals session and Don McCaffery (NSW DPI) leading the canola session. Daniel Moll also unveiled the new dual-purpose triticale variety, Kokoda, for Waratah Seed Company Limited.

GRDC Irrigation Discussion Group Meeting, Corowa — Around 35 people attended a field walk in the Corowa district on Wednesday 18 December, 2019. The group met at *Buraja Station* to view Alistair Robb's irrigated sorghum seed crop and heard about pivot maintenance and managing wheel tracks from Paul Upton (Uptons Engineering), improving water-use efficiency (WUE) in pivots from Paul Lavis (IK Caldwell) and calculating pumping costs from Dennis Watson (DEDJTR). The group then moved to the Dye family's irrigated maize crop and heard about strip tillage and phosphorus placement from Rosie Dye (IK Caldwell), and soil amelioration demonstrations from John Fowler (Murray LLS) and Dr Ehsan Tavakkoli (NSW DPI).

Research and extension project summary

During 2019, Riverine Plains Inc was again involved in a number of research and extension projects, with some projects starting and others finishing up as part of the natural project cycle.

Riverine Plains Inc completed several research and extension projects during 2019.

This included the National Landcare Program project From the Ground Up: *Understanding subsoil acidity in cropping enterprises of the Riverine Plains*, which involved soil sampling to determine the pervasiveness of soil acidity across the Riverine Plains, led by the Goulburn Broken Catchment Management Authority.

The GRDC investment *Optimising crop nutrition in canola in the southern region of NSW* into sulphur and canola nutrition was also completed after two seasons of trial work.

Following the official completion of the GRDC investment *Maintaining profitable farming systems with retained stubble in the Riverine Plains (Stubble Project) during 2018*, Riverine Plains Inc published a summary report *Stubble retention for cropping systems of the Riverine Plains*. We thank our project partner FAR Australia and the GRDC for their contribution and support of this five-year landmark project.

A number of longer-term projects also continued during 2019.

This included our delivery of the *Australian Cool Farm Initiative* in partnership with the Sustainable Food Lab and Mars Petcare. This project aims to promote the long-term productivity and quality of broadacre cropping systems using practices that reduce on-farm greenhouse gas emissions and increase organic soil carbon values. During 2019, 30 Riverine Plains region farmers were involved in soil testing, monitoring farm inputs and meetings.

The southern region *Riverine Plains Inc GRDC Pulse Check Discussion Group*, also continued through the *Southern pulse extension* project. The group, based in the Dookie region, met four times during 2019 to discuss pulse-related research, production and marketing issues.

Similarly, the northern *GRDC Pulse Check – local extension and communication for profitable pulse production in south-east NSW* project continued. During 2019, the group met three times for pre-season, in-crop and pre-harvest discussions.

Demonstration trials for the GRDC investment *Increasing the effectiveness of nitrogen fixation in pulse crops through extension and communication of improved inoculation and crop management practices in the southern region* project were also established at Bungeet and St James, with results reported on page 36 of this publication.

Trial work also commenced for the *Innovative approaches to managing subsoil acidity in the southern grain region* project, funded by NSW DPI, with financial support from the GRDC, with the report on page 24. This work is in addition to the project sites established at Rutherglen by NSW DPI and is reported on page 46.

Excitingly, 2019 also saw the commencement of number of new research and extension projects.

Farmers inspiring farmers

As part of the Cooperative Research Centre for High Performance Soils (Soil CRC) suite of projects, trials were established at Burramine as part of the five-year project *Plant-based solutions to improve soil performance through rhizosphere modification*. The site was sown to a range of cover crop species, with the first-year preliminary results available on page 30.

Other Soil CRC projects commencing during 2019 included; *Improving the representation of soil productivity/constraints in existing decision support systems and modelling platforms, Understanding adoptability of techniques and practices for improved soil management* and the *Mechanistic understanding of the mode to action of novel soil re-engineering methods for complex chemical and physical constraints*. Three additional projects, *Visualising Australasia's Soils: A Soil CRC Interoperable spatial knowledge system, 'Smart' soil sensors* and *Addressing barriers to adoption: Building farmer innovation capability* also began.

The GRDC Irrigation Discussion Group investment, *Facilitated Action Learning Groups to support profitable irrigated farming*, led by the Irrigated Cropping Council, also commenced during 2019. The group held its first two meetings during late 2019 and established an irrigation-focus paddock trial looking at sub-soil manuring to improve soil structure and water-holding capacity.

The GRDC investment *Extension of best practice principles for identifying and managing soil limitations in southern and central NSW* also commenced during 2019. This project, led by Farmlink, involves soil sampling and delivery of a soil pit and workshop on soil characteristics in NSW.

A new *From the Ground Up* project funded by the Australian Government's National Landcare Program, led by the Goulburn Broken Catchment Management Authority, was also established. The project, *Evaluating plant-based opportunities to increase soil carbon in cropping systems*, will involve a number of demonstrations, which will be established alongside the Soil CRC site in north east Victoria. A sub-project *Quantifying the carbon gains from mixed cropping systems* will commence during 2020.

After a few relatively lean years in terms of research and extension project involvement, Riverine Plains Inc is once again involved in a large and diverse range of projects. Our involvement in these projects has been driven by Dr Cassandra Schefe, in her capacity as Research Coordinator, along with Riverine Plains Inc staff and the Research sub-committee, chaired by John Bruce, and I'd like to thank them for their work in continuing to bring high-quality research and extension to our region. I'd also like to thank all of our farmer co-operators and event hosts for their ongoing work and support of our programs. The Extension subcommittee, chaired by Adrian Clancy, as well as Riverine Plains Inc Project Officers Kate Coffey and Jane McInnes, also deserve acknowledgement given the significant expansion of our extension program over the past few years.

Riverine Research Centre (RRC)

During 2019 the RRC featured, for the second time, a Riverine Plains Inc variety by sowing date evaluation based on early April and late April sowing dates, incorporating 10 wheat cultivars for each time of sowing. These Riverine Plains Inc funded trials were sown in collaboration with FAR Australia and formed the basis of a rapid results service to Riverine Plains Inc members on variety performance in the region. The research builds on the 2017 and 2018 work completed as part of GRDC's *Management of early sown wheat* project, with a wider range of cultivars, some drawn from the GRDC's *Hyper yielding cereal* project. Results are published on page 14 of this trial book.

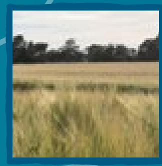
The centre also hosted trials from the GRDC investment *Development of crop management packages for early-sown, slow-developing wheats in the Southern region*, led by Latrobe University. FAR Australia managed the trials and the results are presented on page 50.

The RRC held a number of events and hosted numerous group tours through the site during 2019. 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 for events, as well the exceptionally high-quality of trial results generated from the site.

Unfortunately, with the recent end to a number of funded projects hosted at the RRC, we have been unable to continue with Centre in 2020. The RRC, established during 2016 as a partnership between Riverine Plains Inc and FAR Australia, has absolutely succeeded in its aim of being a focal point for local and national research. We sincerely thank FAR Australia, particularly Nick Poole and Michael Straight, for managing the site to the highest standard and for the exceptional quality of trial results across a diverse range of projects. We also thank the Cummins family for hosting the site during the past three years.

The two organisations will continue to look for opportunities in broadacre research that allow the RRC to continue during the 2021 season.





Funding partners

Riverine Plains Inc partners with a number of organisations in delivering our research and extension programs. We recognise the ongoing support and investment made by our funding partners; the GRDC, NSW DPI, the Sustainable Food Lab/Mars Petcare, the Soil CRC and the Australian Government's National Landcare Program, as well as the support provided by Goulburn Broken Catchment Management Authority.

Riverine Plains is also involved in projects led by Birchip Cropping Group, Farmlink, the Irrigated Cropping Council and Mallee Sustainable Farming and we thank these organisations for their support. We also recognise the support received by the large number of organisations collaborating on these projects, and who are individually acknowledged in each of the trial reports.

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 terrific supporters of our field days, seminars and other events and we sincerely value their presence and contributions. Many of our sponsors have been with us for many years and we thank them for their continued support.

Staff

On behalf of the committee and our members I would also like to recognise the contributions made by Riverine Plains Inc staff to our group's operation. Our Executive Officer Fiona Hart, Finance and Project Officer Kate Coffey, Research Coordinator Dr Cassandra Schefe, Communications Officer Michelle Pardy, Project Officer Jane McInnes and Casual Field Assistant Sue Campbell 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. The volunteer committee provides direction for the research and extension programs, oversees governance and financial management matters while also ensuring the needs and expectations of our members, sponsors and funders continue to be met. This is an important role and I would like to thank all committee members for their time, dedication and leadership.

Research for the Riverine Plains

Finally, I wish to thank Michelle Pardy, for her work in collating and editing these articles and also Cassandra Schefe for her technical and editorial contributions and to Jane Mcinnes and Kate Coffey for contributing articles for this publication.

We trust you will enjoy the read and find value in the reports contained within. All the best for the remainder of the 2020 season.

Ian Trevethan
Chairman

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2019 — the year in review

Adrian Smith
Senior Land Services Officer, Murray Local Land Services, Deniliquin

Undoubtedly, 2019 was another challenging year for growers across the Riverine Plains region, with drought, fire, heat and frost all combining to demonstrate how volatile mother nature can be. The contrast between 2019 and the autumn of 2020 we have just experienced could not be more stark!

Rainfall (or the lack thereof) was the dominant feature of 2019.

Across the Riverine Plain region there was generally around one-third to one-half of the annual long-term average rainfall. For the calendar year, the rain gauges recorded 261mm at Yabba South , 227mm at Rand and 316mm at Culcairn. This compares with a long-term average rainfall at Corowa of 543mm (Figure 1).

After what was a hot and dry summer (2018–19), the late autumn and early winter rainfall was most welcome. This, coupled with warmer-than-average temperatures, meant crops and pastures had plenty of early biomass and dry matter (DM) production and looked to be all set for a great spring. May–July rainfall at Yabba South was 132mm, Rand was 140mm and Culcairn was 156mm, so thoughts of a great season were at the forefront of producers' minds. As it happened though, May–June rainfall accounted for 50–60 per cent of the total yearly rainfall recorded at each location.

The lack of spring rainfall, particularly across the western part of the Riverine Plains, combined with warmer-than-average daytime temperatures and a higher-than-normal number of frost events, resulted in poor spring growth for many. This caused crops and pastures to hay-off early and consequently limited DM production.

Livestock producers had low reserves heading into what proved to be a hot, dry and particularly challenging 2019–20 summer.

The other challenge was the number of frosts recorded. Clear skies and drier-than-average soils, coupled with the prevailing weather conditions (i.e. above-average atmospheric pressure levels and a lack of cold-front events), saw both August and September record a higher-than-average number of nights experiencing less than 2°C (Figure 2).

The long-term average number of frost days recorded at Rand for July is 16, August is 12 and September is seven. Figure 2 highlights the significant number of frost events experienced during the 2019 winter and spring, with a total of 10 frosts recorded for July, 26 recorded for August and 20 frost events recorded for September. A significant number of frost events were also recorded into October.

Frost damage, coupled with a lack of rainfall and soil moisture, again saw numerous crops salvaged for hay or silage. Early decisions to cut affected crops resulted in good hay and silage yields, with quality (measured via protein levels and digestibility) being generally quite high.

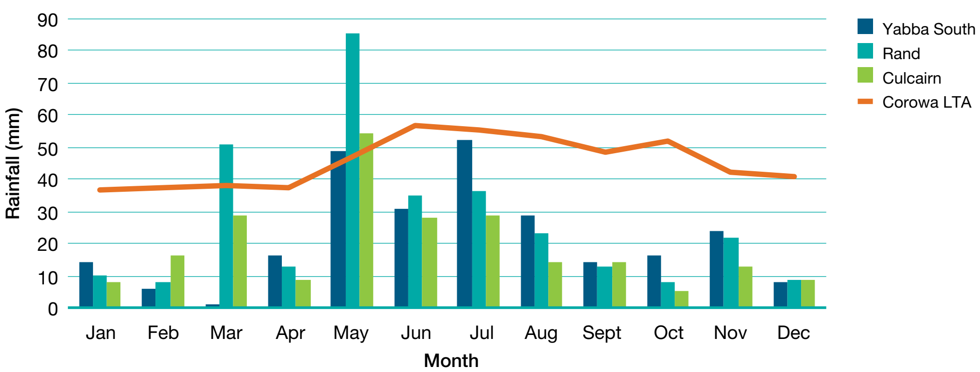

FIGURE 1 2019 monthly rainfall for Yabba South, Rand and Culcairn compared with the long-term average (LTA) for the Corowa Airport weather station (No. 74034)

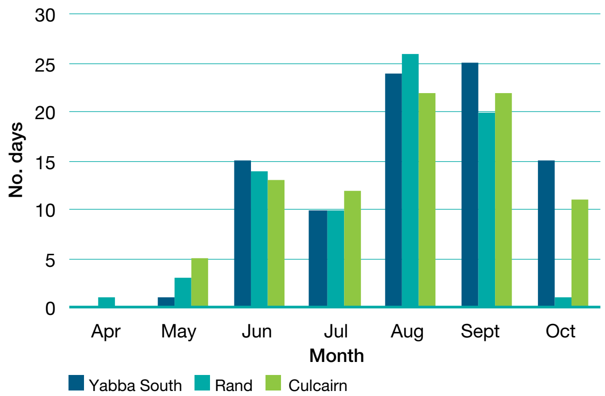

FIGURE 2 Number of frost days at Yabba South, Rand and Culcairn during the 2019 growing season (April–October).
Source: www.riverineplains.org.au (Note: the absence of data from the Rand weather station site during October)

Overall, Australia experienced its warmest year on record during 2019 (1.5ºC above the long-term average), and its driest year on record (rainfall was 40 per cent below the long-term average) (BoM, 2020).

Across New South Wales, 2019 was the warmest year on record, with temperatures nearly 2ºC above the long-term average (Figure 3). The year was dominated by dry conditions, with NSW experiencing its lowest annual rainfall on record (Figure 4), at 55 per cent below the long-term average.

Figures 5 and 6 show how 2019 NSW annual rainfall fared against the long-term average. For much of NSW, rainfall was at decile 1 (in the lowest 10 per cent of rainfall recorded) levels, with much of the north-east quarter recording lowest yearly rainfall on record.

For most of the Riverine Plain area, rainfall was also in the decile 1 range. From a rainfall perspective, 2019 was a year we hope not to be repeated.

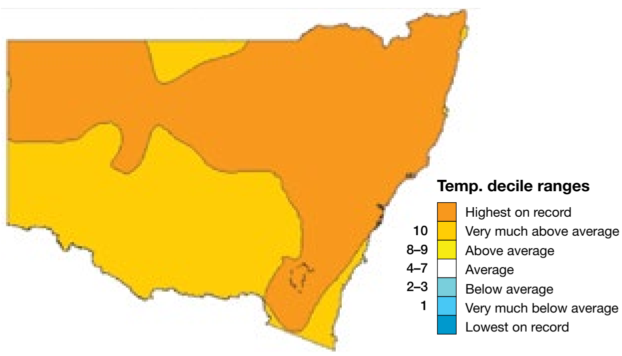

FIGURE 3 Mean temperature deciles across NSW during 2019
Source: BoM, 2020

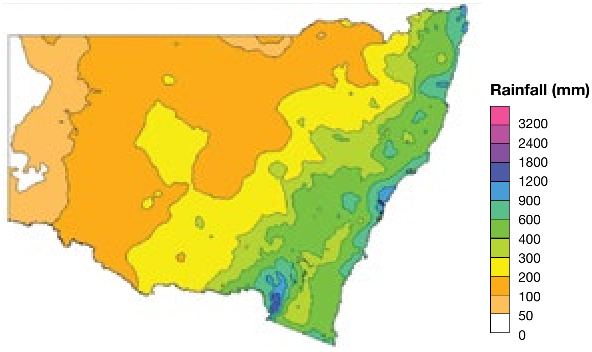

FIGURE 4 Total rainfall across NSW during 2019
Source: BoM, 2020

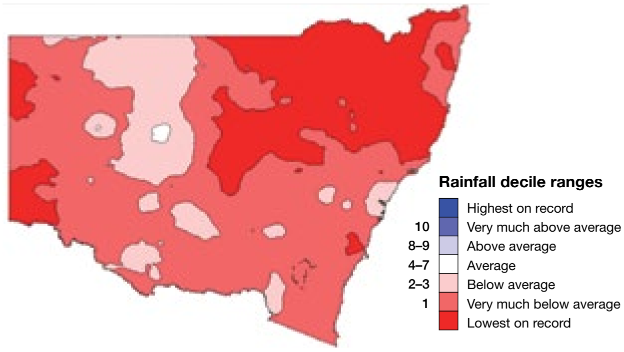

FIGURE 5 Rainfall deciles across NSW during 2019
Source: BoM, 2020

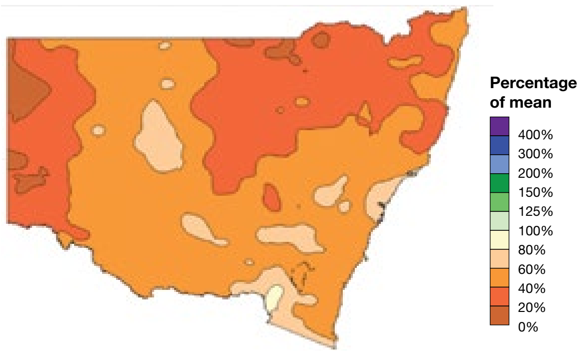

FIGURE 6 Rainfall (percentage of annual mean) across NSW during 2019
Source: BoM, 2020

Summary

In hindsight, the dry summer of 2018–19 was a sign of what was to come during the 2019 growing season.

A reasonably damp late autumn and early winter meant producers had high hopes for a return to more ‘normal’ growing conditions. However, poor late winter and spring rainfall, coupled with above-average daytime temperatures and a high number of frost events, left many growers facing difficult decisions about what to do with crops and livestock.

Growers who made early decisions, based around the best possible information at the time, were best placed to salvage some good results, despite the extenuating circumstances. Some growers in the more southern areas of the Riverine Plains observed better-than-expected yields at harvest given the dry winter and spring conditions.

The extremely hot and dry conditions during early summer unfortunately led to catastrophic fire conditions, with large areas of neighbouring regions being badly affected. The Riverine Plains region was fortunate to largely avoid the physical damage caused by the fire storms, although like many other regions, endured smoke and poor air quality for an extended period of time.

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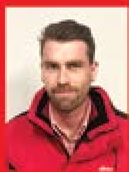

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Elders

Wheat germplasm — April sowing performance

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

Key points

- Two small plot trials sown at the Riverine Research Centre compared wheat cultivar performance at two sowing dates: 3 April 2019 and 30 April 2019.
- Comparisons were made between winter and spring wheat cultivars, with the trials including commercially available cultivars as well as novel cultivars not previously tested in the region.
- The trials were affected by drought stress, with the site only receiving 198mm rainfall from April to October; 73.8mm below the long-term average.
- For both trials, winter cultivars produced more tillers/m^2 than spring wheat cultivars, however this did not always relate to winter cultivars having more heads/m^2.
- Dry matter (DM) differences at first node stage (GS31) suggested winter cultivars produced more biomass up until second node stage (GS32), however water stress later during the season meant earlier maturing spring cultivars had higher DM production at harvest.
- Normalised difference vegetative index (NDVI) assessments showed a clear distinction in growth habits between most winter and spring cultivars at both times of sowing. This was because winter cultivars had a more prostrate growth habit and provided greater ground cover.
- The spring feed wheat LRPB Beaufort had the highest yield (4.91t/ha) when sown on 3 April 2019.
- The mid-maturing spring-type wheat Beckom was the highest yielding variety (4.15t/ha) when sown on 30 April 2019.

Method

Two small plot trials were established during 2019 at the Riverine Research Centre (RRC), Burramine (near Yarrawonga), Victoria as part of a collaboration between FAR Australia and Riverine Plains Inc.

Each trial assessed the performance of 10 wheat cultivars, sown either on 3 April (time of sowing 1) or 30 April (time of sowing 2). The earlier-sown trial was primarily focused on winter wheat germplasm, while the later-sown trial focused more on spring wheat germplasm. The trial design was a randomised complete block, replicated four times.

Due to the dry start to the season, the trial sown on 3 April (time of sowing 1) was irrigated with 10mm of water after sowing to support emergence. The trial sown on 30 April (time of sowing 2) was not irrigated as there was sufficient rainfall after sowing to ensure emergence during early May. Overall, management applications were made as per the seasonal conditions to maximise yield potential.

The trial was funded by Riverine Plains Inc, with yield results distributed to Riverine Plains Inc members via the *Rapid Results* service on 9 December 2019.

Trial 1: time of sowing 1 (3 April)

Sowing date: 3 April, 2019 (irrigated with 10mm on 4 April, emerged 7 April)

Harvested: 29 November 2019

Rotation position: First cereal after canola

Rainfall:

GSR: 198mm (April – October)

Soil mineral nitrogen: (Sampled 14 May 2019, from buffer areas of trial site)

0–10cm: 23.0kg N/ha

10–20cm: 9.8kg N/ha

20–30cm: 7.8kg N/ha

30–60cm: 16.8kg N/ha

Total (0–60cm): 57.3kg N/ha

The time of sowing 1 trial included a range of winter and spring wheat cultivars (Table 1) and focussed more on winter wheat varieties than the time of sowing 2 trial sown on 30 April.

Results

1.1 Establishment and crop structure

The trial site had an average plant establishment of 156 plants/m^2, with RGT Calabro having the highest establishment (190 plants/m^2) at the three-leaf stage (GS13). The European winter variety, Oakley, had the lowest establishment (121 plants/m^2) at the same stage (GS13).



TABLE 1 Cultivar, type and maturity of wheat sown 3 April 2019, as part of the time of sowing 1 trial at Burramine, near Yarrawonga, Victoria

Cultivar/Line	Type	Maturity
Oakley	Winter	Long-season
Tabasco	Winter	Long-season
Manning	Winter	Long-season
RGT Calabro	Winter	Long-season
RGT Accroc	Winter	Intermediate – long season
Annapurna	Winter	Intermediate – long season
EGA Wedgetail	Winter	Intermediate season
RGT Zanzibar	Spring	Intermediate – long season
Beaufort	Spring	Intermediate season
DS Pascal	Spring	Intermediate – long season

At first node (GS31) there was a significant difference in tillering between winter and spring cultivars, with spring wheats producing significantly fewer tillers than the winter wheat cultivars, with the exception of EGA Wedgetail. The winter wheat, RGT Calabro, produced the most tillers (898 tillers/m^2), while the spring wheat, DS Pascal, produced the fewest tillers (405 tillers/m^2). EGA Wedgetail was the winter wheat variety with the fewest tillers (472 tillers/m^2), which was not significantly different to DS Pascal.

Head counts at harvest revealed that tiller mortality was much higher in the winter wheats than the spring wheats. DS Pascal produced more heads (47 heads/m^2) than the other spring varieties, though this was not significantly different to the other spring wheats. Of the winter wheats, RGT Accroc produced the most heads (445 heads/m^2), which was significantly more (58 heads/m^2) than Manning (387 heads/m^2) and Oakley (389 heads/m^2) (Table 2), although these trends in head numbers did not correlate to yield.

1.2 Phenology and floret sterility

Phenology data from the trial was collected at least once a week for the life of the trial. Of the winter wheat types, EGA Wedgetail reached first-node stage (GS31) the earliest (1 August) (Table 3). The other winter wheats reached GS31 in the five days between 15 – 19 August. Severe heat (35°C) on 24 October is likely to have increased floret sterility (as assessed at early grain fill — GS71) in the winter wheat varieties Manning, RGT Calabro and RGT Accroc, as this coincided with flowering in these varieties. The remaining spring and early winter wheat varieties flowered earlier, avoiding this event (Figure 1).

There was a trend for spring wheats to have a longer period (calendar days) between first node (GS31) and the start of flowering (GS61) (Figure 2). The earliest cultivar to flower was DS Pascal, flowering on 17 September, while Oakley and Manning flowered latest, on 23 October (Oakley is the current world record holder for wheat yield (16.79t/ha) set in New Zealand).

TABLE 2 Time of sowing 1 (April 3) plant counts assessed at the three-leaf stage (GS13), 9 May 2019; tiller counts assessed at first node (GS31)* and head counts assessed at hard dough (GS89), 22 November 2019

	Plants/m^2	Tillers/m^2	Heads/m^2
Cultivar/Line	GS13	GS31	GS89
Oakley	121^{d}	787^{abc}	389^{b}
Tabasco	154^{bc}	709^{bc}	391^{ab}
Manning	149^{bcd}	671^{c}	387^{b}
RGT Calabro	190^{a}	898^{a}	436^{ab}
RGT Accroc	165^{abc}	819^{ab}	445^{a}
Annapurna	147^{cd}	774^{abc}	415^{ab}
EGA Wedgetail	162^{abc}	472^{d}	402^{ab}
RGT Zanzibar	149^{bcd}	407^{d}	393^{ab}
Beaufort	179^{ab}	427^{d}	399^{ab}
DS Pascal	148^{bcd}	405^{d}	440^{ab}
Mean	**156.3**	**636.7**	**409.6**
LSD	31.7	131.1	55.0

* Tiller counts were taken when each cultivar reached first-node stage (GS31).
Figures followed by different letters are regarded as statistically significant.

1.3 Dry matter (DM) production

Dry matter assessments were conducted on selected cultivars at second node (GS32), early – mid flowering (GS65) and at hard dough (GS89) (Table 4). At the second-node (GS32) assessment, the European winter cultivar, RGT Accroc, produced more DM (4.18t/ha DM) than any other cultivar, though this was not significant. The spring type, DS Pascal, produced 0.24t/ha DM more (at 4.00t/ha DM) than the winter type, EGA Wedgetail (3.76t/ha DM), at this assessment.

TABLE 3 Time of sowing 1 trial (3 April, 2019); dates when crops reached first node (GS31) and the start of flowering (GS61)

Cultivar/Line	GS31	GS61
Oakley	19 August	23 October
Tabasco	15 August	21 October
Manning	15 August	23 October
RGT Calabro	15 August	17 October
RGT Accroc	19 August	11 October
Annapurna	15 August	8 October
EGA Wedgetail	1 August	8 October
RGT Zanzibar	1 July	26 September
Beaufort	8 July	26 September
DS Pascal	11 June	17 September

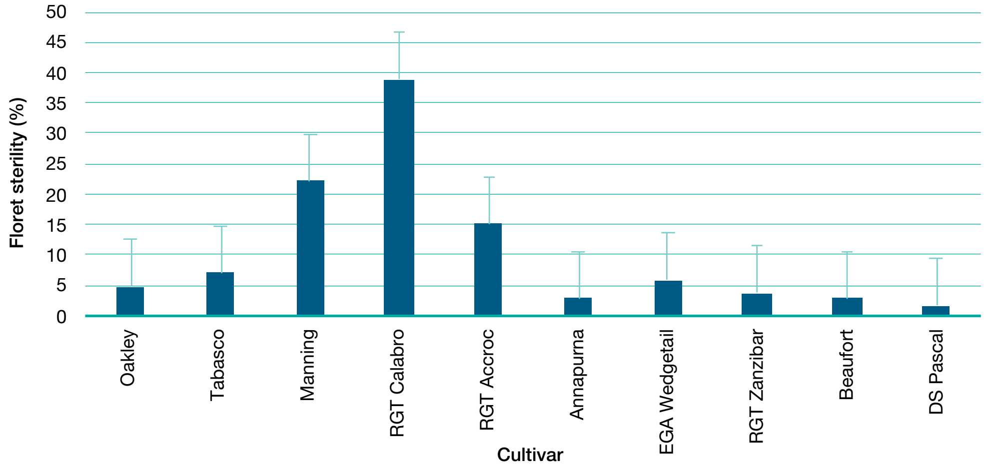

FIGURE 1 Floret sterility for time of sowing 1 cultivars assessed at early dough – hard dough stage (GS82–87), 12 November 2019

Error bars are a measure of LSD (LSD = 15.41).

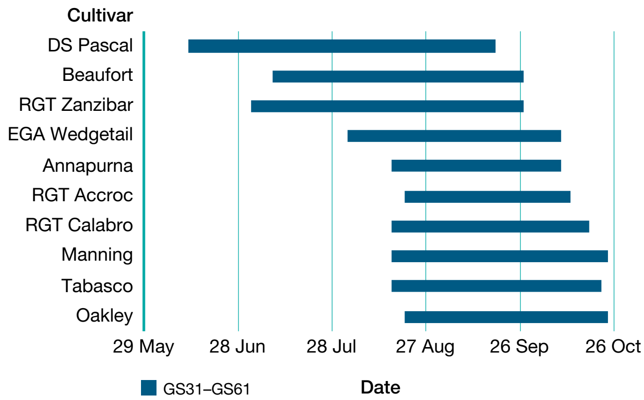

FIGURE 2 Duration of the development period between first node (GS31) and flowering (GS61) (calendar days) for time of sowing 1 cultivars

TABLE 4 Time of sowing 1 (April 3) dry matter production at second node (GS32), mid-flowering (GS65) and 22 November at hard dough (GS89)

Cultivar/Line		Dry matter (t/ha)		
		GS32	GS65	GS89
Oakley	Winter	4.07^{a}	8.71^{a}	7.34^{b}
RGT Accroc	Winter	4.18^{a}	8.52^{a}	8.39^{ab}
EGA Wedgetail	Winter	3.76^{a}	10.05^{a}	9.32^{a}
DS Pascal	Spring	4.00^{a}	9.39^{a}	10.08^{a}
Mean		**4.00**	**9.12**	**8.78**
LSD		0.61	2.09	1.74

*DM at GS32 and GS65 were taken when each cultivar was at the appropriate growth stage.
Figures followed by different letters are regarded as statistically significant.

By flowering (GS65), EGA Wedgetail (10.05t/ha) had accumulated more DM than the other varieties, however the differences were not statistically significant. The earlier stem elongation in the quicker-maturing variety, DS Pascal, resulted in good DM accumulation (10.08t/ha) at the GS89 assessment, though again, this was not significantly different to the other cultivars. The later-developing winter wheat, Oakley (7.34t/ha), produced significantly less DM than both EGA Wedgetail (9.32t/ha DM) and DS Pascal (10.08t/ha DM) by the hard-dough-stage assessment.

1.4 Normalised difference vegetative index (NDVI)

Crop reflectance measurements taken with the Greenseeker™ and recorded as NDVI showed differences in the crop canopy due growth habit (Figure 3). Normalised difference vegetative index readings for the spring cultivars peaked on 7 August, whereas NDVI readings peaked on August 15 for the winter types. Of the spring cultivars assessed on 7 August, RGT Zanzibar was significantly greener than the other two spring types, Beaufort and DS Pascal. The significantly greener canopy of RGT Zanzibar compared with DS Pascal and Beaufort continued through to the November assessment; a result likely linked to its more prostrate growth habit and greater ground cover. From September through to November, the winter types, Manning, Oakley, RGT Calabro and Annapurna, were significantly greener than the other varieties.

1.5 Grain yield and quality

The trial was harvested on 29 November 2019 with an average yield of 3.31t/ha (Table 5). The dry conditions impacted on yield and grain quality, with large variability in yield between cultivars. Beaufort (4.91t/ha) yielded significantly more (0.45t/ha) than all other cultivars, while Manning (2.1t/ha), RGT Calabro (2.09t/ha) and Oakley

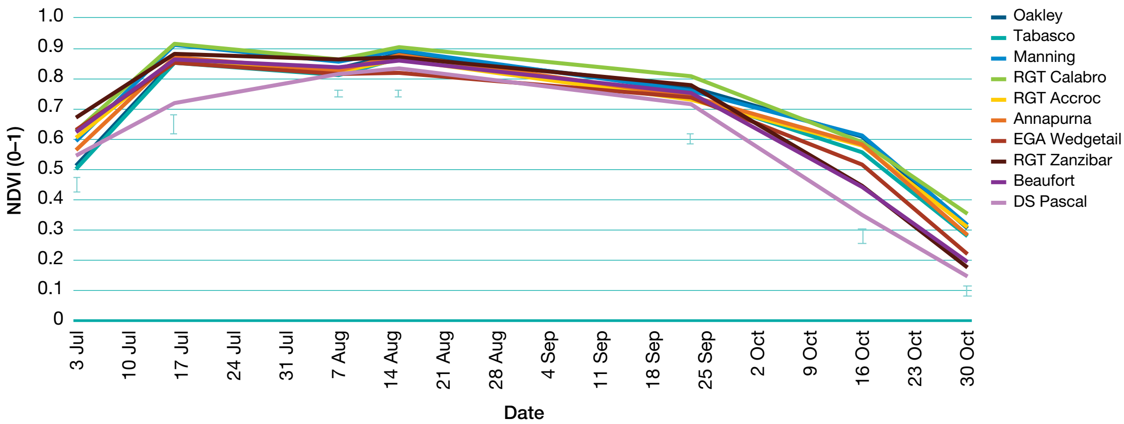

FIGURE 3 NDVI readings (0–1 scale) on 3 July, 16 July, 7 August, 15 August, 23 September, 16 October, and 30 October 2019 for time of sowing 1 trial

Error bars are a measure of LSD.

(2.03t/ha) yielded significantly less (0.62–0.69t/ha) than the other cultivars.

Protein was not as variable between cultivars as yield, however RGT Calabro produced significantly higher grain protein (14.1%) than the other cultivars; this was 3.6% higher than RGT Zanzibar, the cultivar with the lowest protein (10.5%).

Test weights were relatively low across all varieties (mean 78.8kg/hL). DS Pascal had the highest test weight (82kg/hL), while Oakley had a significantly lower test weight (71.6kg/hL) than all other varieties. Manning had the lowest screenings (1%), which were significantly lower than Oakley, Annapurna, RGT Zanzibar and DS Pascal. RGT Calabro had significantly higher (43.1g) thousand seed weight than any other cultivar tested; this was likely linked to the variety having higher floret sterility and having fewer grain sites to fill.

TABLE 5 Time of sowing 1 (April 3) yield, protein, test weight, screenings and thousand seed weight at harvest (GS99), 29 November 2019

Cultivar/Line	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW* (g)
Oakley	2.03^{f}	12.8^{b}	71.6^{e}	2.4^{ab}	36.7^{de}
Tabasco	2.72^{e}	12.3^{bc}	76.0^{d}	1.4^{cde}	37.0^{cd}
Manning	2.10^{f}	12.4^{bc}	76.2^{d}	1.0^{e}	34.9^{efg}
RGT Calabro	2.09^{f}	14.1^{a}	80.7^{abc}	1.1^{de}	43.1^{a}
RGT Accroc	2.99^{e}	12.2^{bc}	80.5^{abc}	1.5^{cde}	38.8^{bc}
Annapurna	4.28^{bc}	12.0^{bc}	80.9^{ab}	2.0^{bc}	35.6^{def}
EGA Wedgetail	3.59^{d}	12.4^{b}	80.3^{bc}	1.2^{de}	33.7^{fg}
RGT Zanzibar	4.46^{b}	10.5^{d}	80.5^{abc}	1.8^{cd}	40.5^{b}
Beaufort	4.91^{a}	10.6^{d}	79.4^{c}	1.4^{cde}	33.6^{g}
DS Pascal	3.95^{cd}	11.1^{cd}	82.0^{a}	2.8^{a}	29.6^{h}
Mean	**3.31**	**12.0**	**78.8**	**1.7**	**36.4**
LSD	0.45	1.3	1.5	0.6	2.0
CV	9.18	7.3	1.3	26.8	3.8

* Thousand seed weight.

Figures followed by different letters are regarded as statistically significant.

Trial 2: time of sowing 2 (30 April)

Sowing date: 30 April 2019 (emerged 7 May)
Harvested: 29 November 2019
Rotation position: First cereal after canola
Rainfall:
GSR: 198mm (April – October)
Soil mineral nitrogen: (Sampled 14 May 2019 from buffer areas of trial site)
0–10cm: 23.0kg N/ha
10–20cm: 9.8kg N/ha
20–30cm: 7.8kg N/ha
30–60cm: 16.8kg N/ha
Total (0–60cm): 57.3kg N/ha

The time of sowing 2 trial, sown on 30 April, included a range of winter and spring wheat cultivars (Table 6). This trial had a greater focus on spring wheat cultivars compared with the time of sowing 1 trial sown on April 3.

Results

2.1 Establishment and crop structure

Plant establishment rates for the second time of sowing (30 April) were low and averaged only 128 plants/m^2. Heavy rain post sowing (37.6mm on May 3) caused 'crusting' of the soil and contributed to uneven emergence across the trial. DS Pascal had the highest establishment at the two-leaf stage (GS12) (154 plants/m^2) while the winter type, Longsword, had the lowest establishment (106 plants/m^2), 9 plants/m^2 lower than any of the spring types (average of spring types was 132 plants/m^2) (Table 7).

At first node (GS31) there was a significant split between winter and spring cultivars. The three winter cultivars (RGT Accroc, EGA Wedgetail and Longsword) produced more average tillers (445 tillers/m^2) than the spring cultivars (307 tillers/m^2). RGT Accroc produced the most tillers per plant (4.7), followed by Longsword (4.2), while the shorter-season spring cultivar DS Pascal produced the least number of tillers per plant (1.7).

TABLE 6 Cultivar, type and maturity of wheat cultivars sown 30 April 2019 as part of time of sowing trial 2 at Burramine, near Yarrawonga, Victoria

Cultivar/Line	Type	Maturity
RGT Accroc	Winter	Intermediate – long season
EGA Wedgetail	Winter	Intermediate season
Longsword	Winter	Short season
DS Pascal	Spring	Intermediate – long season
RGT Zanzibar	Spring	Intermediate – long season
Coolah	Spring	Intermediate – long season
Cobra	Spring	Intermediate season
Chief	Spring	Intermediate season
Beckom	Spring	Intermediate season
Corack	Spring	Short – intermediate season

TABLE 7 Time of sowing 2 (April 30) plant counts assessed at the three-leaf stage (GS13), 20 May 2019; tiller counts assessed at first node (GS31)* and head counts assessed at physiological maturity (GS89), 22 November, 2019

	Plants/m^2	Tillers/m^2	Heads/m^2
Cultivar/Line	GS13	GS31	GS89
RGT Accroc	113^{c}	528^{a}	339^{a}
EGA Wedgetail	140^{ab}	368^{c}	300^{abc}
Longsword	106^{c}	440^{b}	317^{abc}
DS Pascal	154^{a}	262^{e}	307^{abc}
RGT Zanzibar	137^{ab}	345^{cd}	276^{c}
Coolah	128^{bc}	270^{e}	288^{bc}
Cobra	121^{bc}	336^{cd}	327^{ab}
Chief	140^{ab}	343^{cd}	341^{a}
Beckom	128^{bc}	292^{de}	283^{bc}
Corack	115^{c}	305^{cde}	301^{abc}
Mean	**128.1**	**348.8**	**307.8**
LSD	22.3	64.4	47.1

* Tiller counts were taken when each cultivar reached first node stage GS31. Figures followed by different letters are regarded as statistically significant.

Head counts averaged 308 heads/m^2 and were affected by drought and low plant populations caused by crusting. Chief had the highest head count (341 heads/m^2), while RGT Zanzibar produced the lowest head count (276 heads/m^2). The highest tiller mortality rates were in RGT Accroc and Longsword, which respectively lost 36% and 28% of the tillers assessed at the three-leaf stage (GS13).

2.2 Phenology and floret sterility

Phenology data was collected on a weekly basis over the life of the trial. Spring cultivars reached first node (GS31) over a wide range of dates, with Corack reaching GS31 the earliest (1 July), while Accroc reached GS31 the latest (2 September). Of the winter wheats, Longsword reached GS31 the earliest (22 July) while RGT Accroc was the slowest to develop, reaching GS31 on 2 September (Table 8).

While the spring wheats tended to reach GS31 more quickly than the winter types, there was a trend for spring wheats to spend a longer period developing from first node (GS31) to flowering (GS61). This can be largely, but not completely, attributed to the spring wheats reaching GS31 sooner than the winter wheats (Figure 4).

Corack started flowering (GS61) the earliest (24 September), while RGT Accroc and EGA Wedgetail were the last to reach GS61 (8 October).

TABLE 8 Time of sowing 2 trial (30 April); dates when crop reached first node (GS31) and the start of flowering (GS61)

Cultivar/Line	Type	GS31	GS61
RGT Accroc	Winter	2 September	8 October
EGA Wedgetail	Winter	15 August	8 October
Longsword	Winter	22 July	4 October
DS Pascal	Spring	1 August	4 October
RGT Zanzibar	Spring	1 August	4 October
Coolah	Spring	1 August	4 October
Cobra	Spring	8 July	1 October
Chief	Spring	22 July	1 October
Beckom	Spring	22 July	27 September
Corack	Spring	1 July	24 September

TABLE 9 Time of sowing 2 dry matter production at second node (GS32), mid-flowering (GS65) and 22 November at hard dough (GS89)

	Dry matter (t/ha)		
Cultivar/Line	GS32	GS65	GS89
RGT Accroc	3.18[a]	8.81[a]	7.80[a]
EGA Wedgetail	3.60[a]	7.72[a]	6.70[a]
DS Pascal	1.60[b]	8.22[a]	8.68[a]
Chief	2.17[b]	8.39[a]	8.78[a]
Mean	**2.64**	**8.28**	**7.99**
LSD	0.87	1.11	2.55

*DM at GS32 and GS65 were taken when each cultivar was at the appropriate growth stage.
Figures followed by different letters are regarded as statistically significant.

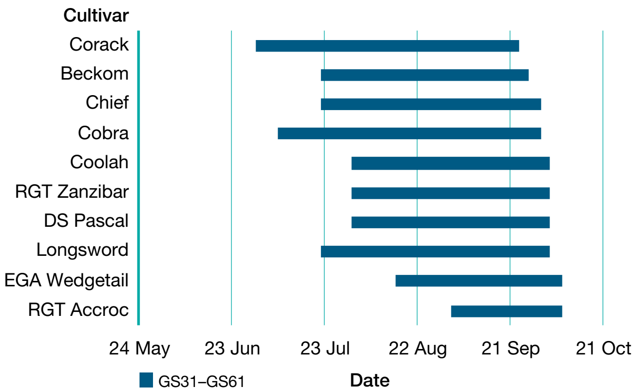

FIGURE 4 Duration of the development period between first node (GS31) and the start of flowering (GS61) (calendar days) for time of sowing trial 2

The longer-maturing winter types, RGT Accroc and Longsword, had significantly more floret sterility (at least 12%) than all other cultivars in the trial when assessed at early grain fill (GS82–87) (Figure 5). This was most likely due to the effects of moisture stress around flowering.

RGT Accroc had the shortest duration (36 days) between first node (GS31) and the start of flowering (GS61), however it was still one of the last two cultivars to flower. At the other end of the scale, Corack and Cobra both spent 85 days between GS31 and GS61, however, Corack reached GS31 seven days before Cobra. Coolah, RGT Zanzibar and DS Pascal had exactly the same duration between GS31 and GS61 (64 days).

2.3 Dry matter (DM) production

Dry matter assessments were conducted at second node (GS32), at mid-flowering (GS65) and at physiological maturity (GS89) for selected cultivars RGT Accroc, EGA Wedgetail, DS Pascal and Chief (Table 9).

At the second-node (GS32) assessment there were significant differences between winter and spring types, with the winter types, RGT Accroc and Wedgetail, producing significantly more DM than the spring types, DS Pascal and Chief. At this assessment, the winter cultivar EGA

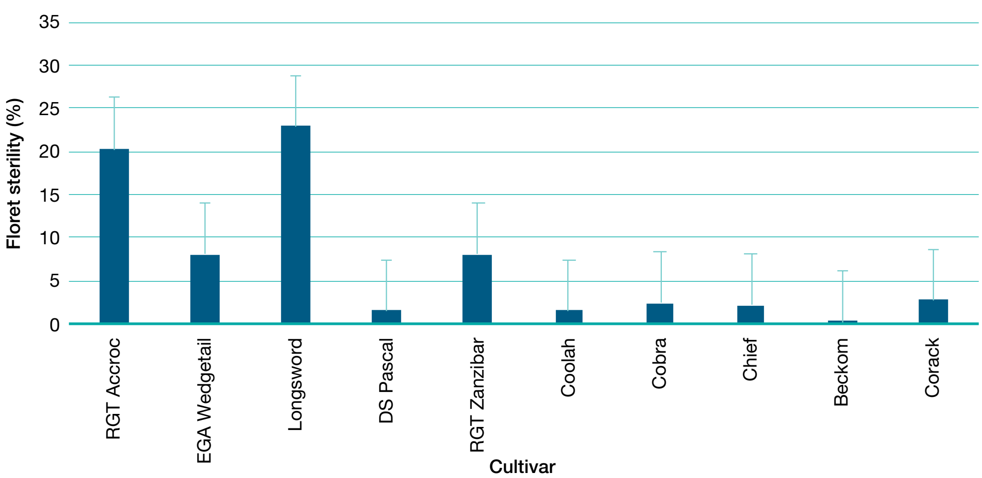

FIGURE 5 Floret sterility of cultivar assessed at early dough – hard dough stage (GS82–87), 12 November 2019
Error bars are a measure of LSD (LSD = 11.96).

Wedgetail (3.60t/ha DM) produced 0.42t/ha DM more than any other cultivar. The higher DM production at GS31 of the winter types compared with the spring types was a result of a longer period of growth to this development stage.

By mid-flowering (GS65), RGT Accroc had produced the most DM (8.81t/ha DM) of all cultivars, though this was not significant. At this assessment, EGA Wedgetail produced lower DM (7.72t/ha DM) than the spring cultivars DS Pascal (8.22t/ha DM) and Chief (8.39t/ha DM).

At the grain maturity assessment (GS89), higher DM production was evident in the earlier-maturing cultivars DS Pascal and Chief, although this was not significant. Chief produced the highest DM at maturity (8.78t/ha DM).

2.4 Normalised difference vegetative index (NDVI)

Crop reflectance measurements taken with the Greenseeker™, and recorded as NDVI, showed differences in the crop canopy due to growth habit (Figure 6). On 7 August, the cultivars DS Pascal and Longsword gave significantly lower NDVI readings than the other spring cultivars. The winter types, EGA Wedgetail and RGT Accroc, as well as the spring type, RGT Zanzibar, gave the highest NDVI scores from 16 October until harvest.

2.5 Grain yield and quality

The trial was harvested on 29 December, 2019 with an average yield of 3.50t/ha across all cultivars. Below-average rainfall for the growing season (April to October)

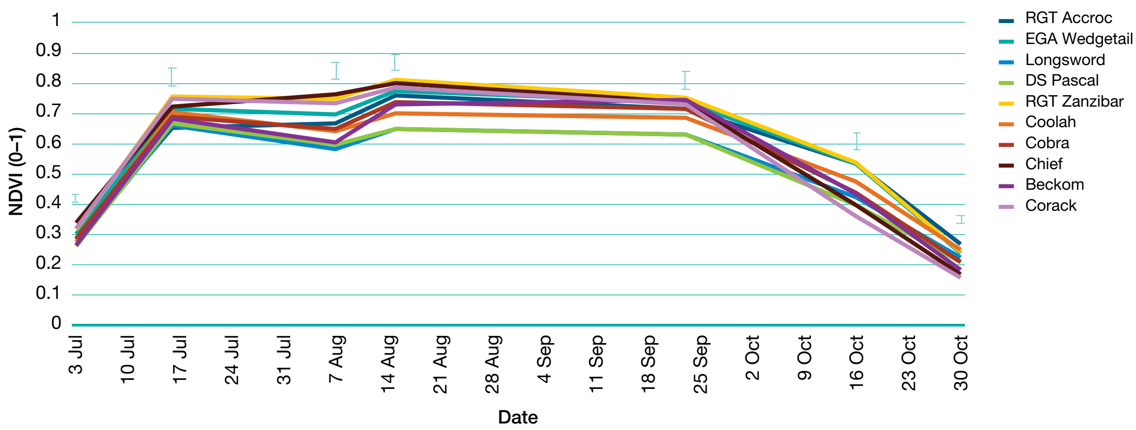

FIGURE 6 NDVI readings (0–1 scale) on 3 July, 16 July, 7 August, 15 August, 23 September, 16 October, and 30 October 2019 for time of sowing 2 trial

Error bars are a measure of LSD.

TABLE 10 Time of sowing 2 (April 30) yield, protein, test weight, screenings and thousand seed weight at harvest (GS99), 29 November 2019.

Cultivar/Line		Yield and quality				
		Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW* (g)
RGT Accroc	Winter	3.16^{c}	11.7^{bcd}	80.6^{ef}	2.0^{b}	39.8^{b}
EGA Wedgetail	Winter	2.89^{c}	13.4^{a}	80.1^{f}	0.9^{c}	35.3^{c}
Longsword	Winter	3.13^{c}	12.5^{b}	81.3^{cde}	0.5^{c}	36.5^{c}
DS Pascal	Spring	3.03^{c}	12.2^{b}	81.6^{cd}	3.2^{a}	29.6^{e}
RGT Zanzibar	Spring	3.62^{b}	11.7^{bcd}	80.7^{def}	1.6^{b}	41.6^{a}
Coolah	Spring	3.79^{ab}	10.9^{de}	83.2^{a}	2.0^{b}	35.4^{c}
Cobra	Spring	3.78^{ab}	11.9^{bc}	83.0^{a}	1.9^{b}	36.6^{c}
Chief	Spring	3.65^{b}	11.2^{cde}	82.0^{bc}	0.9^{c}	39.6^{b}
Beckom	Spring	4.15^{a}	11.0^{cde}	83.5^{a}	1.7^{b}	32.8^{d}
Corack	Spring	3.78^{ab}	10.4^{e}	82.8^{ab}	0.9^{c}	42.6^{a}
Mean		**3.50**	**11.7**	**81.9**	**1.6**	**37.0**
LSD		0.39	0.9	0.9	0.7	1.6
CV		7.77	5.34	0.75	29.2	3.1

* Thousand seed weight.

of 198mm significantly affected the establishment phase of the selected varieties.

Of the 10 cultivars, the intermediate-season, spring type, Beckom was the highest yielding variety (4.15t/ha), producing 0.65t/ha more than the mean yield of the trial (Table 10). Of the winter types, RGT Accroc (3.16t/ha) yielded more, although not significantly, than EGA Wedgetail (2.89t/ha) and Longsword (3.13t/ha) despite its later development and short stem elongation phase.

Protein levels were variable. Corack had the lowest protein (10.4%), while the lowest-yielding variety, EGA Wedgetail, had the highest protein (13.4%).

Test weights were consistently high, with all cultivars above 80kg/hL and the spring types, Cobra, Coolah and Beckom, all exceeding 83kg/hL.

DS Pascal had significantly higher screenings (3.2%) and significantly lower thousand seed weight (29.6g) than all other cultivars tested in time of sowing 2 trial.

Conclusion

The 2019 season was characterised by average rainfall throughout winter, followed by no significant rainfall from August until harvest, with a severe heat event recorded during late October.

1. Outline of trials 24 September 2019: white outline sown 3 April, red outline sown 30 April. White stars denote the first plot in each trial.

2. Time of sowing 1: Pascal at mid-booting stage (GS45), 19 August 2019, at RRC, Yarrawonga, Victoria.

3. Time of sowing 2: Pascal at second node (GS32), 19 August 2019, at RRC, Yarrawonga, Victoria (Note patchy emergence due to crusting visible in the plot).

Under these conditions, intermediate – long season, spring cultivars, sown in early April (3 April) produced the best average grain yields. Faster-maturing winter wheat sown in early April proved to be the highest yielding winter types across both trials, with Annapurna (feed wheat) yielding the highest of any winter type at 4.28t/ha.

The best-performing wheats for the second time of sowing (30 April) were the short – intermediate season, spring types.

Dry matter production is also important for mixed farmers looking to produce early livestock feed, especially from an early sowing date. Dry matter production at second node (GS32) was maximised by early sowing (3 April) compared with the later sowing (30 April). For the later sowing, winter wheats produced more DM to GS32 compared with the spring wheats.

The average yield for the wheat trial sown on 3 April was 3.31t/ha, while the average for the wheat trial sown on 30 April was 3.50t/ha. Considering there was only 198mm of growing season rainfall (GSR), the yields from both times of sowing were much better than expected in a dry finish.

Contact

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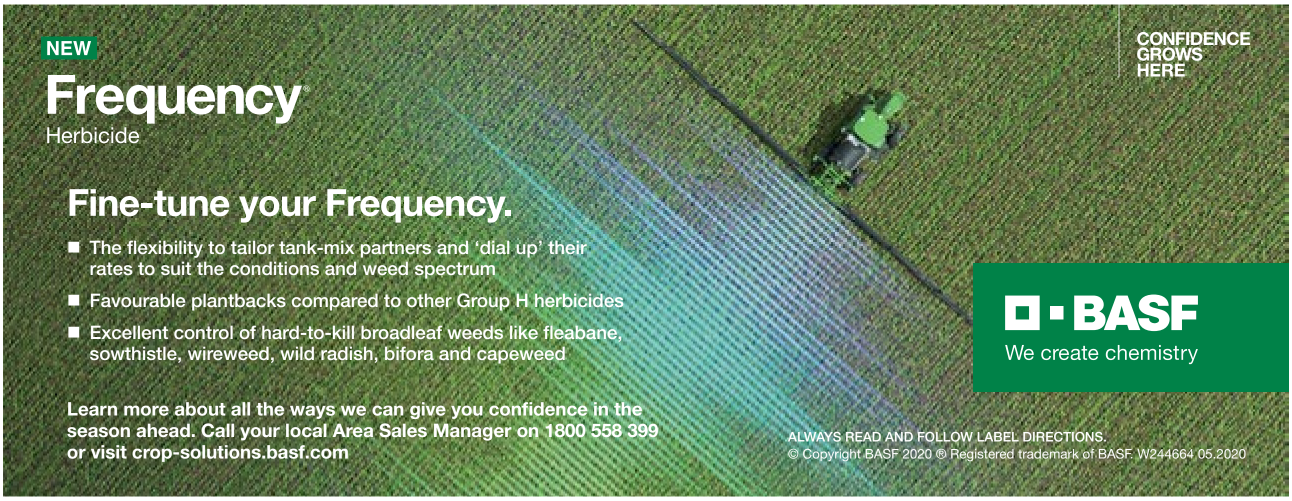
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Amelioration of subsoil acidity by subsurface placement of amendments in large-scale farm trials at Rutherglen and Bungeet

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Riverine Plains Inc

Key points

- Large farm-scale trials provided useful practical information about applying soil amendments to relate back to small-scale and glasshouse-based experiments.
- Triticale showed a limited response to lime application at the Rutherglen site during 2019, most likely due to its tolerance to acid soils.
- During 2019, canola establishment at the Bungeet site was compromised by a lack of rainfall between deep ripping and sowing, followed by an intense rainfall event, leading to uneven germination.
- Assessment of subsoil amelioration techniques is difficult due to confounding factors, with several years of data collection required to allow for the physical effects of deep ripping to subside.

Introduction

As discussed in the article *Addressing soil acidity: subsurface amendments increasing pH and crop yield at Rutherglen* (page 46), acidity of subsurface soil is a major constraint to crop production in the high-rainfall cropping zone. The GRDC investment *Innovative approaches to managing subsoil acidity in the southern grain region* (DAN00206), led by NSW DPI, has evaluated a range of ameliorant options across a number of sites and years.

As part of this project, Riverine Plains Inc is conducting two large-scale field trials at Rutherglen and Bungeet to evaluate the effect of deep placement of lime, lucerne pellets and other products, compared with the surface application of lime.

The first site was established near Rutherglen during February 2018, while a site near Bungeet was established during February 2019. Baseline soil sampling was carried out before each site was established to confirm that pH values in the 0–30cm depth were highly acidic, with follow-up soil sampling to occur after the 2020 harvest.

A range of measurements have been undertaken for these large-scale field trials, focussing on the effect of the soil amendments on crop growth and yield.

After each site was established, the area reverted to farmer management with a commercial crop sown over the trial site. Plot boundaries were marked out using GPS to allow crop monitoring to occur for the remainder of the project term.

Both the Rutherglen and Bungeet sites will be monitored until after harvest 2020, at which time detailed deep soil cores will be taken to understand the effect of each amendment on subsoil pH and aluminium (Al) levels.

Aims

The aim of this research was to quantify the yield limitation caused by subsoil acidity and evaluate innovative soil amendments which act to ameliorate subsurface acidity.

Methods

The Rutherglen site was established during February 2018, while the Bungeet site was established during February 2019. The treatments for both sites are described in Table 1.

TABLE 1 Soil amendment treatments and rate of application for the trials established at Rutherglen during 2018 and Bungeet during 2019.

Location	Rutherglen treatments*	Bungeet treatments
Year trial established	2018	2019
Treatment	Surface lime (applied at 4t/ha)	Surface lime (applied at 0.8t/ha)
	Deep ripped (to approximately 30cm depth) + surface lime (applied at 2.5t/ha)	Deep ripped
	Deep placed lime (applied at 2.9t/ha) + surface lime (applied at 2.5t/ha)	Deep placed lime (applied at 2.8t/ha)
	Deep placed lucerne pellets (applied at 15t/ha) + surface lime (applied at 2.5t/ha)	Deep lucerne pellets (applied 15t/ha)
	Deep placed reactive rock phosphate (applied at 4t/ha) + surface lime (applied at 2.5t/ha)	-

* The Rutherglen site received an additional surface lime application (2t/ha) during 2019 as part of a whole-paddock amelioration program

At Rutherglen, the paddock received a blanket application of surface lime with all plot areas included in this application. This means the surface-lime-only treatment is considered the 'standard practice' control for this trial. All lime applications were calculated based on the lime requirement to raise the pH_{Ca} to 5.5 in the 0–10cm depth (for the surface lime treatment) and to pH 5.0 in the 10–30cm depth.

At the Bungeet site, the higher pH in the surface soil meant that only the 'surface lime treatment' received a surface lime application (to increase pH to 5.5), with no surface lime applied to any other treatments.

All deep ripping was done perpendicular to the sowing row, so the tynes did not run into the furrows. The deep amendments were placed approximately 10–30cm deep in the profile on a 50cm row spacing using the 3D ripper machine engineered by NSW DPI. A deep-ripped control, which had no deep amendments added, was included to determine if any plant growth benefit could be attributed to the deep ripping process itself. Plots were 100m long by 10m wide, with each treatment replicated three times.

Results

Rutherglen site, 2018

The site was sown to triticale (cv Astute) on 22 May 2018.

Establishment counts taken on the 19 June, 2018, showed significant differences in the number of plants/m² between treatments, with the surface applied lime treatment having significantly greater plants/m² compared with the deep ripped, deep lime, and deep rock phosphate treatments (Figure 1).

Visual differences were evident at the site during the season, with plants in the deep lucerne pellet treatment observed to be a deeper green for most of the season compared with the other treatments. Growth differences were also evident, with plants in the deep lucerne pellet treatment being visibly taller (Figure 2).

FIGURE 2 Drone footage taken 31 August, 2018, showing a section of the field site at Rutherglen, Victoria. (Image courtesy Jason Condon)

Note: The plots that received the deep lucerne pellet treatments are marked with a red outline. Treatments run perpendicular to the direction of sowing, with treatments running up the image (not all plots shown).

While there were visual differences in plant growth between the deep lucerne pellet treatments and the other plots, there were no significant differences in biomass production between treatments either at flowering or at harvest. Harvest dry matter (DM) results are shown in Figure 3.

The deep lucerne pellet treatment plots were observed to be more vigorous and a deeper green than all other plots during the season and were also visibly darker at harvest compared with the other plots (Figure 4). Plant samples were collected and assessed by a pathologist, who detected a higher presence of disease in the lucerne pellet plots compared with the other plots, none of which showed any disease-related blackening. The increased incidence of disease in the lucerne pellet treatment may be related to the earlier maturity and senescence of these plots compared with the other treatments. This, combined with a significant rain event prior to harvest, may have stimulated the onset of visible disease symptoms in the deep lucerne pellet treatment.

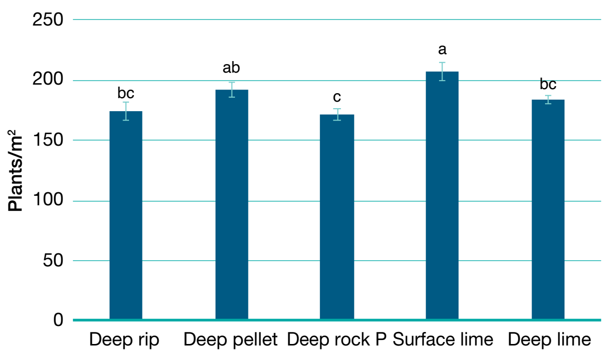

FIGURE 1 Establishment counts at the Rutherglen site, 19 June 2018

Bars are measures of standard error. Different letters denote significant differences between treatments.

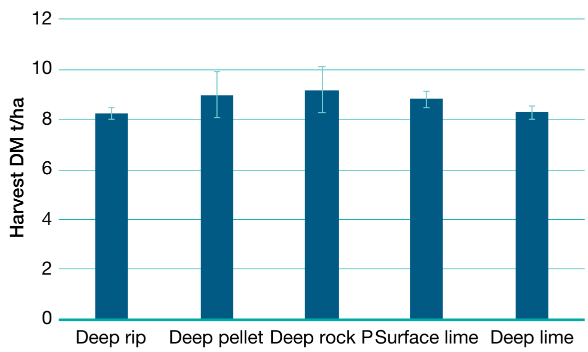

FIGURE 3 Harvest dry matter results for the Rutherglen site, 4 December, 2018

Bars are measures of standard error, with no significant differences between treatments.

FIGURE 4 Visual differences in plant colour at maturity observed in the deep lucerne pellet treatment Rutherglen, Victoria, 2018

The trial was harvested on 9 December 2018, with harvest yield data captured by the grain grower's yield monitor (Figure 5). The yield data showed a significant yield penalty for the lucerne pellet treatment compared with the other treatments, which was likely the combined result of early senescence, rain damage and an extended period from maturity until harvest (while waiting for the other plots to mature). There were no other differences between treatments.

Rutherglen site, 2019

During March 2019, a second 2t/ha application of lime was broadcast across the trial site as part of a whole-paddock amelioration program.

The site was again sown to triticale (cv Astute) on 31 May 2019. Plant counts taken on 26 June showed no differences in triticale emergence between any of the treatment plots (data not shown).

As was the case for the 2018 trial, visual differences in plant growth and greenness were again evident in the 2019 deep lucerne pellet treatment compared with the other plots (Figure 6). While this visual effect did not translate to any DM production differences at the flowering biomass assessment, there was a significant increase in harvest biomass for the deep lucerne pellet treatment ($p<0.05$), compared with all other treatments (Figure 7).

The trial was harvested on 17 December, 2019. Harvest yield data was again captured by the grower's yield monitor, with no significant differences in yield observed between any of the treatments (Figure 8).

As a legume, lucerne contains a high amount of nitrogen (N) and the deep placement of lucerne pellets (at a depth of 20–30cm) is likely to result in increased nitrogen supply to the crop throughout the season. While this is probably the reason for the increased early vigour and visual improvements in plant greenness observed in the lucerne pellet treatments, it is also likely to have caused haying off and early maturity in these plots. As the trial was harvested when all plots had reached maturity, the delay to harvest for the earlier-maturing lucerne-pellet plots likely resulted in a yield penalty for this treatment.

FIGURE 6 Drone footage taken 25 August, 2019 showing visual differences in plant growth for the deep lucerne pellet treatment at Bungeet, Victoria. (Image courtesy Jason Condon)

Note: The deep lucerne treatments are marked with a red outline. Not all plots are shown.

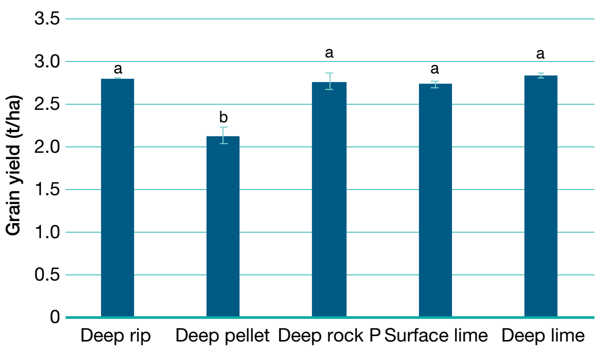

FIGURE 5 Rutherglen header yield data, 9 December 2018. Bars are measures of standard error

Different letters denote significant differences between treatments.

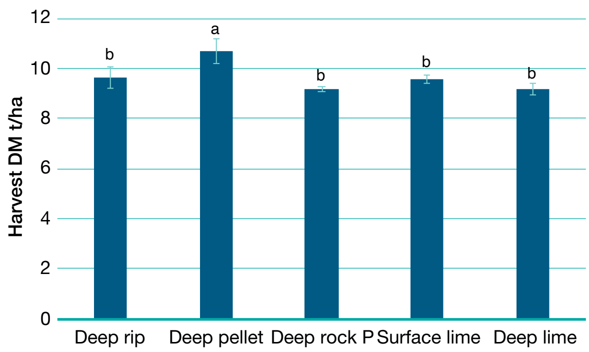

FIGURE 7 2019 Triticale harvest dry matter at the Rutherglen site. Bars are measures of standard error

Different letters denote significant differences between treatments.

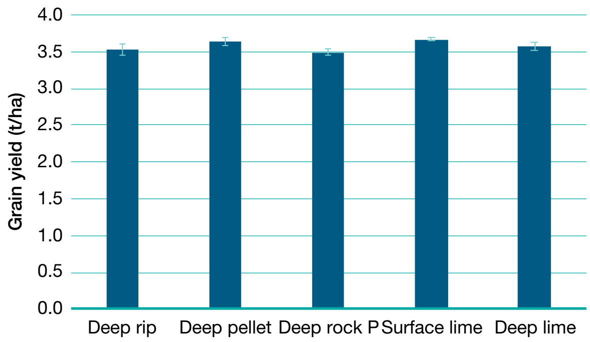

FIGURE 8 Header yield data at the Rutherglen site, harvested 17 December 2019

Bars are measures of standard error.

As a crop, triticale tolerates acid soils well and this might explain why there were no responses due to applied lime at depth compared with the surface-applied lime-only treatment. The lack of a nil-lime control means it is not possible to determine any specific plant growth response due to surface-applied lime.

Bungeet, 2019

The Bungeet site was established on 26 February 2019, with a range of soil amendments applied (Table 1). No significant rain events were received between the establishment of the trial and sowing on the 13 April, 2019, when the site was dry-sown to canola. The lack of rainfall, combined with the relatively short time frame between applying the soil amendments and sowing, meant the canola in the deep-ripped treatments was sown into a poor seedbed of highly fractured, cloddy soil. An intense rain event on 3 May, 2019, washed seed into the fractures and/or washed soil into the furrow and over the seeding row, which may have also caused some crusting. These actions meant the seed was buried at uneven depths, resulting in poor and variable germination. This can be clearly seen in Figure 9, where the most even canola growth can be observed in the surface-applied lime treatments, in the buffer strips between treatments, and in the surrounding crop.

FIGURE 9 Drone image taken 25 August 2019, at the Bungeet site, Victoria. (Image courtesy Jason Condon)

Note the visual differences in plant growth across the trial site (not all plots shown). The surface-applied lime treatments are marked with a red outline.

Given the challenging start to the season, plant establishment counts were low and variable. The surface-applied lime treatment showed a trend towards increased plant numbers, but this was not significant (Figure 10).

Variation in plant growth was evident throughout the season and flowering DM cuts also varied, however, there were no significant differences between treatments (Figure 11). A desiccant product was applied to the paddock before the harvest DM cuts could be scheduled, which meant these cuts could not proceed (walking through the crop would result in significant pod-shatter losses).

As was the case at the Rutherglen site during 2019, the canola in the deep placed lucerne pellet treatment was visually darker at harvest.

The canola plots were harvested on 30 November, 2019, with yield for each plot collected using field bins before being weighed in the paddock. There were no yield differences between treatments (Figure 12).

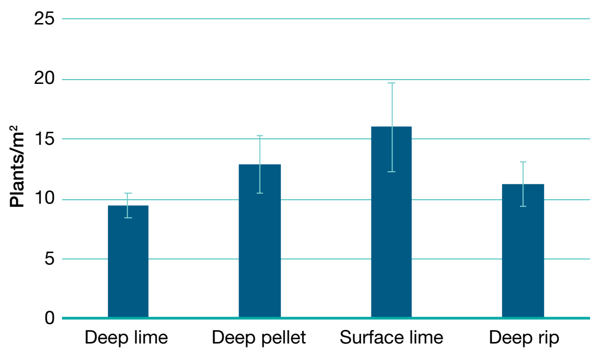

FIGURE 10 Plant establishment counts taken 18 June, 2019 at the Bungeet trial site, Victoria

Bars are measures of standard error.

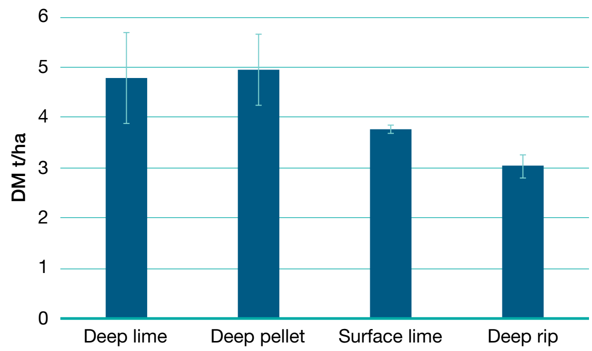

FIGURE 11 Flowering biomass cuts taken 30 August 2019, at the Bungeet site, Victoria

Bars are measures of standard error.

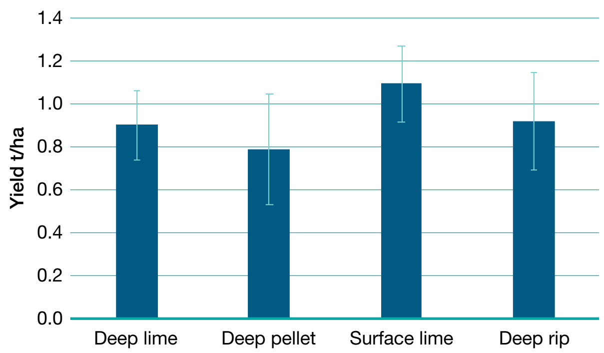

FIGURE 12 Canola harvest yields, 30 November, 2019, Bungeet, Victoria

Bars are measures of standard error.

The lack of plant response to any of the treatments applied at the Bungeet site is likely due to poor establishment caused when canola was sown into fractured, cloddy soil, which was then followed by an intense rainfall event.

The site has now received substantial rainfall, improving the condition of the soil, and it is hoped that treatment effects might be more clearly seen during the 2020 season.

The Rutherglen and Bungeet field sites will both continue to be monitored until the end of the 2020 season, when the project ends. Intensive soil sampling will be completed for each plot after the 2020 harvest; this will help identify how applying soil amendments may have altered soil pH values during the past two years at Bungeet and over three years at the Rutherglen site.

Observations and comments

The aggressive nature of the deep-ripping operation means both time and rainfall are required to resettle the soil and reduce the effect of deep ripping on crop establishment. If time and budget were not limiting, these sites would have benefited from being established one full year before monitoring commenced. This would have provided enough time for the confounding effects of soil disturbance on crop performance to be reduced. Moreover, the effect of soil disturbance has meant the yield limitation, or penalty, due to subsoil acidity could not be clearly defined. It is hoped any treatment effects become clearer after the 2020 season.

This project aimed to understand the effect of deep placement of amendments on subsoil acidity and crop performance. It did not aim to quantify the efficacy and practicality of this method on a large scale, due to its high cost. The learnings from this work will be used to further inform subsequent research, which would ideally move towards methods and practices more amenable to farmer adoption.

Further results will be available after the 2020 harvest is completed and when the post-2020 harvest soil testing results have been collated.

Acknowledgements

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Increasing plant species diversity in cropping systems

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Key points

- During 2019, a range of winter crops, including wheat and field peas, were planted at a trial site in Burramine, Victoria, as part of a larger, long-term project looking at increased diversity in cropping systems.
- The 2019 winter crop trial provided results for biomass accumulation, crop yield and soil water use for the wheat and wheat undersown with sub-clover treatments.
- Undersowing wheat with sub-clover at a rate of 4kg/ha did not affect wheat yields, probably due to the small amount of DM the sub-clover produced (60kg/ha).
- Summer cover crops were established during January 2020, with the multispecies mix (sorghum, millet, forage rape, tillage radish) producing more biomass and depleting more soil water than the buckwheat and medic mix before being terminated after eight weeks of growth.

Background

Cropping systems in Australia can have limited species diversity, which has been exacerbated by declining legume use over the past decade. The diversification of crop rotations and/or the integration of green manures (including cover crops) can have positive benefits for soil health compared to monocultures, or where break crops are used minimally. Increasing plant diversity is more likely to enhance the species richness of soil biota through providing more diverse litter deposition, exudates, rooting patterns and plant associations.

To help address a lack of species diversity in the region, Riverine Plains Inc has established a long-term (five-year) trial site at Burramine as part of a national Cooperative Research Centre for High Performance Soils (Soil CRC) project, led by Southern Cross University.

The trial is assessing the viability of integrating diverse species into the farming system, as either winter rotation crops (or green/brown manures) or as summer cover crops, within the constraints of soil water and weed pressures. These trials will investigate a range of rotation options for improving soil function and, ultimately, grain yields and farm profitability. Soil function will be assessed by measuring soil microbial communities, their structure and enzyme activities, as well as mineralisation rates of nutrients (nitrogen [N], carbon [C], phosphorus [P]), through the decomposition of litters, root debris and soil organic matter over time.

Further, the Burramine trial evaluates how green manure crops, cover crops (crops grown over summer primarily for the benefit of the soil rather than for yield), intercrops (where multiple crops are sown but only one is taken to harvest) and companion crops (where multiple species of crop are grown at the same time and are all taken through to harvest) can affect soil functionality.

Aim

Although the cereal–oilseed–legume rotation offers advantages in terms of disease control, microbial abundance and nutrient transformation, there is little incentive for growers in southern cropping systems to increase plant diversity by growing alternative winter crops. This project aims to investigate other options to increase plant diversity, such as summer cover cropping, intercropping or companion cropping, and to examine their impacts on soil function and winter crop yields.

Method

A field trial spanning three growing seasons (winter-summer-winter) was established at Burramine, Victoria, during autumn 2019. A total of 9 different rotational treatments were established based around the core wheat–canola rotation growers in the area typically employ.

The 2019 winter treatments included wheat, an intercropping treatment with wheat undersown with sub-clover, field peas for grain, a pulse brown manure treatment (field peas) and a brown manure mix (field peas + tillage radish) (Table 1). All plots were sown on 21 May 2019 using a randomised block design, with plots measuring 8m x 18m.

The wheat undersown with sub-clover treatment aimed to investigate potential root interactions between the species and the diversity of soil microbes surrounding the wheat roots by the sub-clover, with the wheat and sub-clover both sown in the same row. The sub-clover was sown at a rate

Drone image of site, taken on 15 August, 2019. Photo courtesy Jason Condon.

TABLE 1 Full list of treatments, crop rotation and 2019 yield results

Treatments	2019 winter crop	2019 winter crop yield (t/ha)	2020 summer cover crop	2020 winter crop
Control (wheat–canola)	Wheat (cv Trojan)	1.36	-	Canola
Pulse–canola–wheat	Field peas (cv Morgan)	0.85	-	Canola
Brown manure (pulse)	Field peas (cv Morgan)	n/a	-	Canola
Brown manure (mix)	Field peas (cv Morgan + tillage radish (cv Tillage Radish)	n/a	-	Canola
Companion crop	Wheat (cv Trojan)	1.38	-	Canola + peas (peola)
Intercropping (undersown)	Wheat (cv Trojan) + sub-clover (cv Riverina)	1.29	-	Canola
Cover crop mix 1	Wheat (cv Trojan)	1.42	Medic and buckwheat	Canola
Cover crop mix 2	Wheat (cv Trojan)	1.28	Sorghum (cv Crown), millet (cv Shirohie), forage rape (cv Greenland) and tillage radish (cv Tillage Radish)	Canola
Maximum diversity	Wheat (cv Trojan)	1.39	Sorghum (cv Crown), millet (cv Shirohie), forage rape (cv Greenland) and tillage radish (cv Tillage Radish)	Canola + peas (peola)

of 4kg/ha and was not intended to produce large quantities of fixed nitrogen.

The sub-clover was terminated via herbicide application on 25 September, 2019, to allow the wheat to develop without competition for nutrients and water.

The winter crop trial was harvested on 13 December, 2019 using a plot harvester, with yields measured using a weigh cell. Because the wheat plots were harvested before the sowing of the 2020 summer cover crops, the wheat-only treatments (to be planted to summer crops) were effectively the same as the control treatment during the 2019 season.

Water use by the wheat plots (controls) and the wheat under-sown with sub-clover treatment was calculated using the equation:

$$\text{Water use (mm)} = P + I + SWD$$

Where, P is precipitation (mm), I is irrigation (mm) and SWD is soil water depletion (mm) in the 90cm profile (SWD was measured as the difference between the gravimetric soil water content at sowing and at harvest). Soil samples were taken in increments of 10cm and 20cm up to 30cm and thereafter in 30cm increments to a depth of 90cm

using a hydraulically operated soil sampler. Deep drainage and runoff were considered negligible and were assumed zero. Due to a deep ground water table, capillary rise was also considered zero.

Following a significant rainfall event, three of the wheat-only treatment plots sown during 2019 were sown to one of two summer cover-crop mixes on 16 January, 2020, as outlined in Table 1. The plots were sown to either; Cover crop mix 1 (buckwheat and medic) or Cover crop mix 2 (fodder rape, tillage radish, sorghum and millet) (Table 1). The site did not receive significant rainfall between the 2019 trial harvest until just prior to 2020 summer crop sowing, which meant the site was free of weeds and did not require further preparation. Crops were sown into the previous years' crop rows (to allow for inter-row sowing of the 2020 winter crop). The summer cover crops were sprayed out with glyphosate on 18 March 2020 to prevent seed set and to allow time for any chemical residues to breakdown before sowing the 2020 winter crop.

Soil testing was carried out throughout the 2019 cropping season, as well as post-harvest, to determine whether the presence of sub-clover had any impact on soil biological function or on soil disease levels (data not presented).

During autumn 2020, the entire trial site was sown to either canola or 'peola' (a canola and pea companion crop), representing the second (canola) phase of the wheat–canola rotation. A range of measurements will be taken during 2020 to determine the effect of treatments on the yield of the canola and 'peola'. Additional measurements will also investigate whether summer cover crops provide more benefit if the summer cover crop species are from different plant families than the winter crops grown in the rotation (although it may be that the water use by the summer cover crop species is actually the key determinant of subsequent winter crop yield, rather than the plant family). Results from 2020 will be reported in next year's edition of *Research for the Riverine Plains*.

During 2021, the site will revert back to the cereal phase of the rotation, with selected plots sown to treatments having greater diversity. Actual species determination for the remaining years of the trial will be subject to crop performance during 2020 and with consideration to the specific range of weeds, pests or diseases that will require active management.

The limited range of data from the first year of the trial means this report mainly compares the results from the wheat treatments sown during 2019 with the wheat undersown with sub-clover treatment.

Results and comments

Biomass at flowering and water use at harvest

Biomass accumulation was measured as dry matter (DM) at flowering for the wheat-only (control) and wheat undersown with sub-clover treatments. The wheat-only (control) treatment produced 1.76t/ha DM, compared with 1.95t/ha DM where wheat was undersown with sub-clover (Figure 1a), where the sub-clover accounted for about 0.06t/ha DM. Although the biomass in the wheat undersown with sub-clover treatment was 10 per cent higher than the control, this was not statistically significant. Similarly, crop water use (measured by soil coring at harvest) differed between the two treatments (Figure 1b).

Grain yields for wheat and wheat undersown with sub-clover

Wheat-only (control) yields were about 1.3t/ha, which is not significantly different to the yield of wheat undersown with sub-clover treatment (Figure 2). However, at higher sowing rates sub-clover could compete with wheat for water, nutrients or light, which would be expected to have a greater yield impact on the wheat.

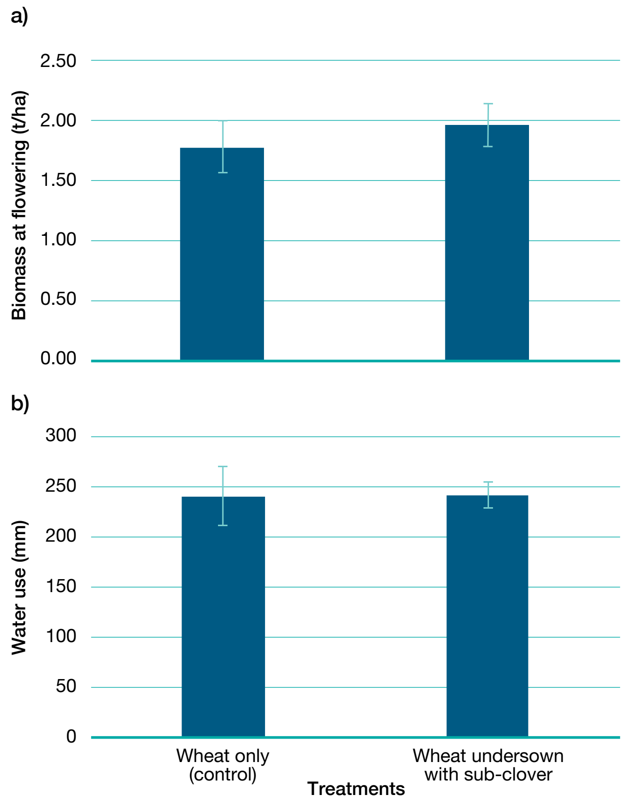

FIGURE 1 Biomass at flowering (a) and water use at harvest (b) including evaporation and transpiration for wheat-only (control) and wheat under-sown with sub-clover at Burramine, Victoria, 2019

Note: The sub-clover was terminated on 25 September 2019

Error bars depict the standard error of the mean of three replicate plots.

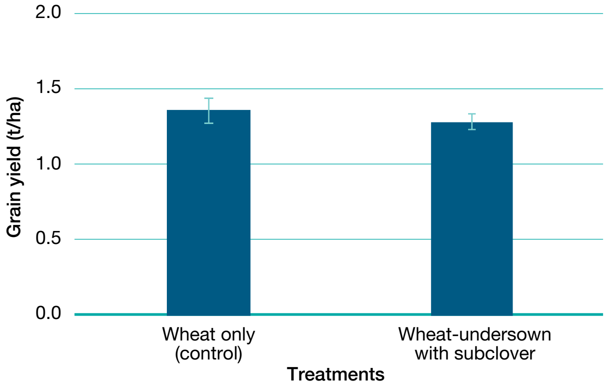

FIGURE 2 Grain yields for wheat only (control) and wheat under-sown with sub-clover at Burramine, Victoria, 2019

Error bars depict the standard error of the mean of three replicate plots.

Sub-clover seedlings growing in the seeding row, before being terminated on 25 September 2019.

Summer cover crop treatments

Summer cover crops emerged following rainfall during January 2020 and produced 0.6–0.7t/ha DM biomass before being sprayed out with glyphosate on 18 March 2020 (Figure 3).

Soil water was measured by soil coring at a depth of up to 1m when the winter crop (canola) was sown on 13 May, 2020. Compared with the fallow/control treatment, the medic and buckwheat summer cover crop (cover crop mix 1) depleted 6 per cent of soil moisture and the sorghum, millet, forage rape and tillage radish cover crop (cover crop mix 2) depleted 13 per cent of soil water (Figure 4a). The effect on total soil water was not statistically significant between these treatments.

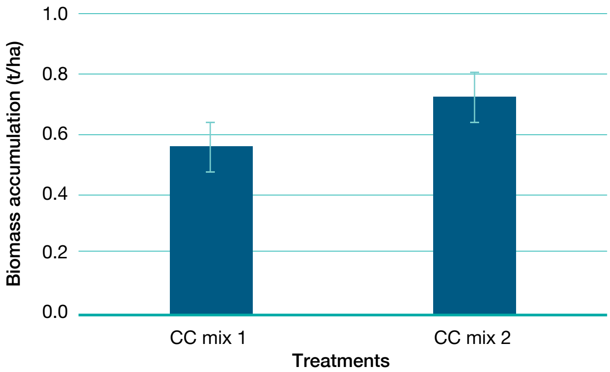

FIGURE 3 Biomass accumulation of summer cover crop treatments (CC mix 1: medic and buckwheat and CC mix 2: sorghum, millet, forage rape and tillage radish) after eight weeks of growth before being sprayed out with glyphosate on 16 March 2020 at Burramine, Victoria

Cover crop treatments prior to being sprayed out with glyphosate on 18 March 2020.

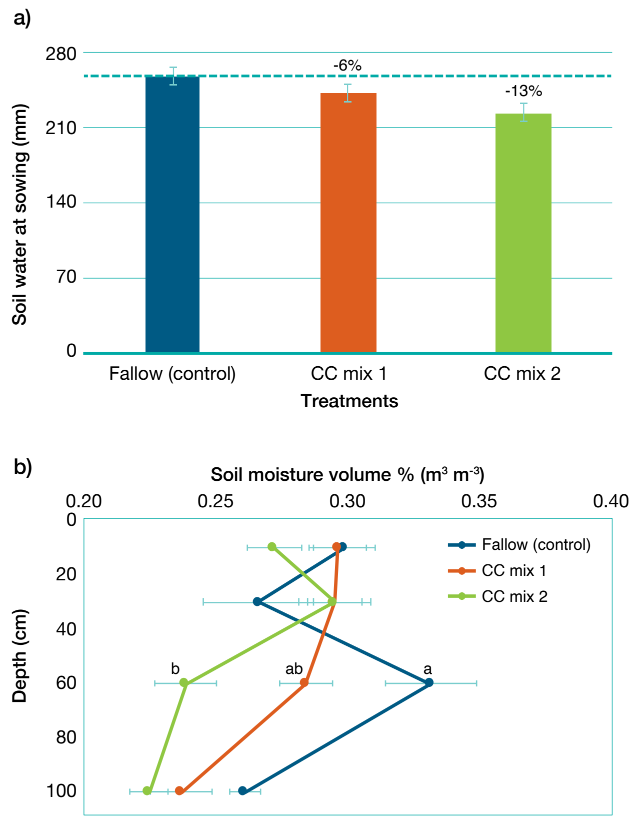

FIGURE 4 Effect of summer cover crop (cover crop mix 1: medic and buckwheat and cover crop mix 2: sorghum, millet, forage rape and tillage radish on total soil water (a) and soil water content up to 1m depth (b) at sowing of the winter canola crop, 13 May 2020 at Burramine, Victoria

When compared with the soil water content at different depths, cover crop mix 2 used significantly more soil water than the fallow (control), but only at 60cm depth (Figure 4b). The increase in soil water use at 60cm depth may be related to the rooting depth and rooting patterns of the different species in cover crop mix 2.

The full effect of the 2020 summer crop treatments on soil water and changes in soil biological function under the 2020 winter canola crop will be determined after the canola is harvested and yields are analysed.

Acknowledgements

This trial is part of the *Plant-based solutions to improve soil performance through rhizosphere modification* project, funded by the Cooperative Research Centre for High Performance Soils (Soil CRC), grant number PJA4.1.002, led by Southern Cross University.

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Demonstrating opportunities for improved pulse nodulation

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Key points

- Where there was no paddock history of chickpea and an absence of suitable rhizobia, doubling the inoculation rate resulted in the highest level of nodulation.
- A lentil crop sown in a paddock (pH 4.8–5.2) with a low background level of lentil rhizobia had good nodulation, demonstrating that not all paddocks are responsive to inoculation.
- At St James, the combination of seed inoculation and Calciprill® (granulated calcium carbonate) at depth resulted in the greatest yield in chickpeas grown on an acid soil, however multiple factors may need to be addressed to capture yield benefits.

Background and aim

As well as generating useful income, pulses provide significant benefits to following crops, with nitrogen (N) fixation boosting the supply of this critical nutrient to subsequent crops. However, not all pulses produce nitrogen-fixing nodules, rendering them unable to reach their nitrogen-producing potential, especially on acidic soils.

The demonstration trials in this report were sown as part of a GRDC investment aiming to improve the nitrogen fixation of winter pulse crops and to promote their wider adaptation and adoption. The project involves promoting effective inoculation and pulse management practices, raising awareness and knowledge around pulse nodulation and nitrogen fixation as well as the impact of soil acidity on crop yields.

A number of organisations across the GRDC Southern Region are involved in the project including: Mallee Sustainable Farming (lead organisation), the South Australian Research and Development Institute (SARDI), AgCommunicators, Bates Ag, Rural Directions, Southern Farming Systems, Birchip Cropping Group, Ryder Ryan Research Pty Ltd, Moodie Agronomy, Riverine Plains Inc, Southern Pulse Extension, and Trengove Consulting.

In order to demonstrate best practice inoculation in pulse crops on acid soils in northern Victoria, two demonstration sites at St James were sown to lentils and chickpeas while a third site was sown to faba beans at Bungeet. Inoculant treatments varied by site and crop type and were decided in consultation with the host farmer and the nitrogen-fixation project research team. At the host farmer's suggestion, Calciprill® (granulated calcium carbonate) was included as an additional treatment at the St James chickpea site to investigate its potential to address a suspected acid subsoil issue.

Farmer co-operators hosted the GRDC Riverine Plains Inc *Dookie Pulse Check Discussion Group* at the sites during 2019.

Method

The 2019 pulse inoculation demonstrations were sown at three sites in the St James and Bungeet areas using the host farmers' sowing equipment. Sites were sown to either lentils, chickpeas or faba beans as described in Table 1. All sites were soil sampled on 4 March, 2019, with 0–10cm depth samples sent to SARDI for pH and background rhizobia level testing. Background rhizobia level tests were carried out using a plant trap method in pots and also using DNA testing to estimate rhizobia number.

Nodulation was assessed at all sites on 23 July 2020. Six plants per treatment were dug out, soaked and rinsed and all effective nodules counted and scored as per Table 2.

Lentil demonstration site, St James

The lentil demonstration at St James included nil inoculum, a commercial inoculant (WSM-1455) and two acid-tolerant inoculant (SRDI-969 and SRDI-970) treatments (Table 1). Demonstration site treatments and areas are also given in Table 1. The nil inoculum treatment was 370m long and one seeder width (12m) wide, giving a total demonstration area of 0.44ha. The commercial inoculum treatment was two seeder widths (24m) wide, giving a total demonstration site area of 0.88ha. The two acid-tolerant rhizobia treatments were three seeder widths (36m) wide, giving a total demonstration site area of 1.33ha.

The lentils were sown on 6 May, 2019, and were harvested on 20 November, 2019, with yields measured using the farmer's grain yield monitor.



TABLE 1 Nitrogen-fixation demonstration site information, soil type, pH, background rhizobia levels and treatment

	Demonstration 1		Demonstration 2		Demonstration 3	
Pulse crop	**Lentils**		**Chickpeas**		**Faba beans**	
Location	**St James**		**St James**		**Bungeet**	
Cultivar	PBA Ace		Genesis 090		Samira	
Soil type	Mixed		Brown clay loam		Brown clay	
Soil pH ($CaCl_2$) 0–10cm	4.8–5.2		5.6		5.5	
Background rhizobia levels	Low levels lentil/faba* bean rhizobia		No chickpea rhizobia detected		Medium levels lentil/faba* bean rhizobia.	
	Treatment	**Plot size**	**Treatment**	**Plot size**	**Treatment**	**Plot size**
	Nil inoculation	12m x 370m (0.44ha)	Nil inoculation	12m x 240m (0.29ha)	Nil inoculation	33m x 200m (0.66 ha)
	Commercial peat inoculant (strain WSM-1455)	24m x 370m (0.88ha)	Single rate (3.5kg/ha) Tag Team® granules	36m x 240m (0.86ha)	Single rate Tag Team granules (3.3kg/ha)	33m x 200m (0.66 ha)
	Peat inoculant (acid-tolerant strain SRDI-969)	36m x 370m (1.33ha)	Double rate (7kg/ha) Tag Team granules	36m x 240m (0.86ha)	-	-
	Peat inoculant (acid-tolerant strain SRDI-970)	36m x 370m (1.33ha)	Single rate (3.5kg/ha) Tag Team granules + Calciprill (100kg/ha)	36m x 240m (0.86ha)	-	-

* The same strain of rhizobia (Group F) inoculates both lentils and faba beans

TABLE 2 Nodulation scorecard used to assess the number and distribution of nodules from plants collected across the demonstration treatments

Nodule score	Distribution of effective nodules: Crown (top 5cm)	Distribution of effective nodules: >5cm root
0	0	0
0.5	0	1–4
1	0	5–9
1.5	0	>10
2	<10	0
2.5	<10	<10
2.75	<10	>10
3	>10	0
4	>10	<10
5	>10	>10

Source: Brockwell and Gault (1977) in AGrow, Final technical report, 2018, southern NSW Trials, Improving nitrogen fixation in lentils.

Chickpea demonstration site, St James

The chickpea demonstration included nil inoculum, a single and a double rate of Tag Team granular inoculant and a single rate of Tag Team granular inoculant + Calciprill treatment (Table 1). All demonstration plots were 240m long. The nil-inoculum treatment was one seeder width (12m) wide giving a total demonstration site area of 0.29ha, while all other treatments were three seeder widths wide (36m) giving a total demonstration site area of 0.86ha.

The chickpeas were sown on 6 May, 2019. The Tag Team plus Calciprill treatment was applied at sowing through a DBS airseeder and placed below the seed at approximately 15cm deep. The chickpeas were harvested on 19 December, 2019 and yields were measured using the farmer's yield monitor.

Faba bean demonstrations site, Bungeet

The faba bean demonstration site compared the nil-inoculum treatment to a Tag Team granular treatment. The treatments, sown on 7 May 2019, were each three seeder widths wide (33m) and 200m long giving a total demonstration site area of 0.66 ha (Table 1). Technical issues meant the faba beans were hand-harvested on 6 December 2019, with 6 x 2m rows sampled in both treatment strips. Samples were then weighed and averaged.

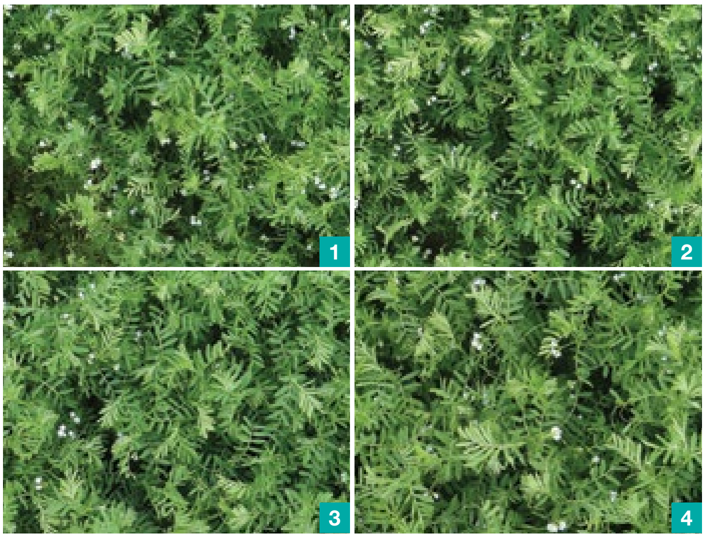
Results

Lentil trial, St James

The acid-tolerant inoculant strains SRDI-969 and SRDI-970 had nodulation scores >4.5, while the commercial inoculant treatment had a nodulation score of 2.9 (Table 3). Nodulation was not correlated with grain yields. Yields in this trial ranged from 0.75t/ha for the acid-tolerant SRDI-969 rhizobia treatment to 1.07t/ha for the nil treatment, while the rest of the farmer's paddock averaged 1.0t/ha (range of 0–3.7t/ha).

TABLE 3 Lentil nodulation scores and grain yields, St James, 2019

Treatment	Nodulation score (1–5)	Yield (t/ha)
Nil inoculum	3.9	1.07
Commercial WSM-1455	2.9	1.06
Acid tolerant SRDI-969	4.6	0.75
Acid tolerant SRDI-970	5.0	0.86



*Lentil demonstration treatments at St James, September 2019; **1.** Nil inoculation, **2.** Commercial peat inoculant (strain WSM-1455), **3.** Peat inoculant (acid-tolerant strain SRDI-969), **4.** Peat inoculant (acid-tolerant strain SRDI-970).*

Dry conditions and late frost likely limited yield potential at this site. Growing season rainfall was Decile 1 (209mm), as measured by the Yabba South Riverine Plains Inc network weather station and there were 11 days below 3°C during October and 4 days below 3°C during November.

Chickpea trial, St James

All inoculated treatments at St James had higher nodulation scores compared with the nil treatment, with the greatest nodulation score in the double-rate inoculation treatment (Table 4). Yields were low at this site and ranged between 0.33–0.73t/ha. The only treatment that had a higher yield than the nil treatment (0.40t/ha) was the single rate Tag Team + 100kg/ha Calciprill drilled below the seed treatment

TABLE 4 Chickpea nodulation scores and yields, St James

Treatment	Nodulation score (1–5)	Yield (t/ha)
Nil inoculum	0.8	0.40
Single rate Tag Team granules (3.5kg/ha)	3.0	0.33
Double rate Tag team granules (7.0kg/ha)	4.2	0.33
Single rate Tag Team granules (3.5kg/ha) + Calciprill (100kg/ha)	3.1	0.73

TABLE 5 Faba bean nodulation scores and yields, Bungeet

Treatment	Nodulation score (1–5)	Yield (t/ha)
Nil	5	2.76
Single rate Tag Team granules (3.5 kg/ha)	5	3.13

(0.73t/ha). The rest of the farmer's paddock averaged 0.37t/ha, with yield ranging between 0–1.8t/ha.

The dry season and late frost also may have limited yield potential at this site. Growing season rainfall was Decile 1, as measured by the nearby Yabba South Riverine Plains Inc network weather station, with late frosts also recorded in the area. At the Southern Pulse Agronomy site at Dookie, researchers also observed the poor performance of chickpeas relative to other pulses and suggested that cool conditions at flowering and pod-fill may have also adversely affected grain yield.

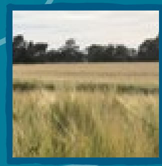
Faba bean trial, Bungeet

The paddock at Bungeet has a history (more than 10 years) of faba bean production and had previously been limed (pH_{Ca} 5.5), with pre-sowing tests indicating a substantial background level of rhizobia in the soil (Table 1). The nil treatment was well nodulated (Table 5), which validated the pre-sowing background rhizobia test results. No visual difference in crop growth was observed between the two treatments, which yielded 3.13t/ha for the inoculated treatment and 2.76t/ha for the nil treatment.

The Riverine Plains Inc network weather station data at Bungeet recorded 21mm more growing season rainfall than received at the Yabba South weather station, though it also a showed greater number of days with minimum temperatures below 3°C. Beans have a higher frost tolerance compared to lentils and this, combined with the increased rainfall and higher overall yield potential, may have resulted in higher relative yields at this site.

Observations and comments

Background soil testing for rhizobia is being trialled as a potential service for growers and will likely require soil sampling to occur in mid-February (researchers are investigating methods for sampling earlier in the year, or the year prior, to give growers more time to make inoculant decisions). In these demonstrations, background soil testing corresponded well to actual nodulation results observed in the field and this indicates background rhizobia testing could provide farmers and their advisors with accurate information regarding the requirement for inoculation.



The chickpea site benefited from the use of inoculum, while inoculation was probably not required for the paddock sown to faba beans, as indicated by the background rhizobia tests. For the faba bean paddock, the trend for increased yield with inoculant may have been due to the phosphorus solubiliser in the Tag-Team inoculant.

Acid-tolerant rhizobia (Group F for faba bean and lentil) are being trialled to verify their performance across a range of environments before they are released for pulse growers. Although the acid-tolerant rhizobia used in the lentil trial resulted in good nodulation, they did not increase yield, but have done so in other trials not limited by seasonal conditions.

For chickpeas grown on an acid soil at St James, applying 100kg/ha Calciprill at depth in combination with a standard rate of granular inoculant resulted in the highest yield. A response to this rate of Calciprill (100kg/ha) was not expected (usually lime is applied at 10–25 times that rate (i.e. 1–2.5t/ha), however the Calciprill was applied to a suspected acid layer, at 15–20cm, which may explain the results. Further investigation into Calciprill may be warranted for this area. There was no background level of chickpea inoculum detected at this site and doubling the rate of inoculation resulted in the highest nodulation scores.

Acknowledgements

Increasing the effectiveness of nitrogen fixation in pulse crops through extension and communication of improved inoculation and crop management practices in the southern region is a GRDC investment led by Mallee Sustainable Farming Systems. The author also wishes to acknowledge the technical assistance provided by Ross Ballard and Liz Farquharson (SARDI). Thank you to our farmer co-operators, the Gall family (St James) and the Alexander family (Bungeet).

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Australian Cool Farm Initiative results and learnings from the Riverine Plains

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Key points

- Analysis of soil samples from 199 paddocks participating in the *Australian Cool Farm Initiative* project showed soil organic carbon (SOC) levels ranging from 0.74–4.77 per cent.
- Analysis of 199 surface (0–10cm) soil samples taken as part of the project showed that pH ranged from 4.3–7.3 ($CaCl_2$).
- There was a slight relationship between SOC and total rainfall for paddocks sampled in this project.

Aim

The *Australian Cool Farm Initiative* aims to increase the long-term sustainability and yield stability of the grain-producing regions of southern New South Wales and north-east Victoria, through the adoption of innovative agronomic strategies to increase soil health and related function.

Background

Mars Petcare (a subsidiary of Mars Incorporated) has committed to supporting the global wheat industry through the reduction of supply chain greenhouse gas emissions.

Mars Incorporated has acknowledged that greenhouse gas emissions impact the climate and the company recognises their responsibility to address the environmental and social impacts of the business. As a result, Mars Incorporated has adopted climate-change targets to reduce greenhouse gas emissions across their full value supply chain by 27 per cent by 2025 and 67 per cent by 2050, from 2015 levels.

Mars Petcare purchases a significant amount of grain from NSW. As a result, Mars Incorporated has initiated a local project, which aims to engage NSW growers by supporting innovative agronomic management with a focus on increasing soil carbon, novel crop integration and more efficient management of nutrients, especially nitrogen (N).

To achieve this, Mars Petcare has engaged The Sustainable Food Lab (SFL), an independent international organisation based in the United States of America, along with an Australian Coordinator, to administer the *Australian Cool Farm Initiative*. Riverine Plains Inc and Central West Farming Systems are delivering the project across southern and Central NSW in partnership with SFL.

A key part of the project involves the Cool Farm Tool (CFT) (https://coolfarmtool.org/), an online calculator and accounting tool, which enables growers to measure their greenhouse gas emissions and understand mitigation options for agricultural production. The Cool Farm Tool provides growers with the ability to enter their farm data and practices to understand the impact of their farming practices on greenhouse gas emissions and other outputs. The Cool Farm Tool also can provide real-time feedback on "what-if" farm management scenarios.

To ensure accuracy of reporting for Australian conditions, the greenhouse gas emission data produced as a result of this project continues to undergo review and is therefore not presented in this report. This report summarises the results of some of the soil data collected from Riverine Plains region growers participating in the *Australian Cool Farm Initiative* project during 2018–19.

Method

During 2018, 15 growers in the Riverine Plains region and 15 growers in the Central West Farming Systems region participated in the first year of the project, with a further 15 growers engaged in each region during 2019. Only results from the Riverine Plains region are described in this report.

All participating growers identified up to five wheat paddocks each season for inclusion in the project, with GPS-located soil tests (0–10cm) taken for each paddock. Figure 1 shows the locations of all samples taken from across the Riverine Plains during 2018 and 2019.

Each soil sample was air-dried and analysed for a range of soil properties, including soil pH ($CaCl_2$), soil organic carbon (SOC) percentage, cation exchange capacity (CEC) and nutrients. Soil samples were taken from specific locations in each paddock based on ease of access and the known location of representative soil types.

Anonymised soil test results, farm input data and yields were captured in a simple database and processed through the Cool Farm Tool, which generated predictions of greenhouse gas emissions for each paddock. Results were communicated to growers as they became available.



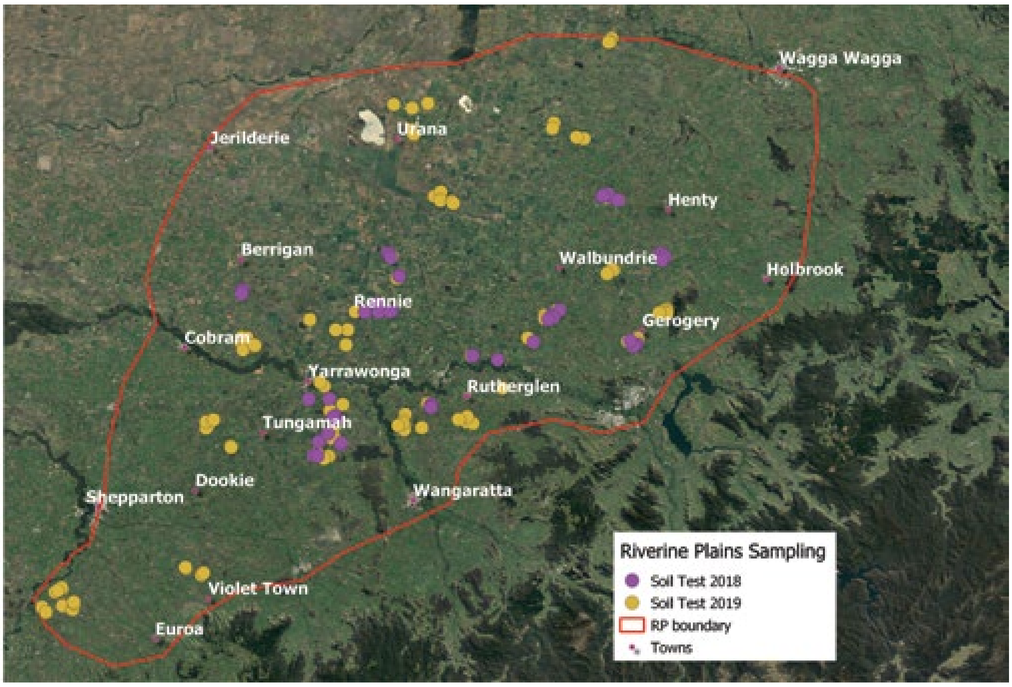

FIGURE 1 Location of paddocks across the Riverine Plains area participating in the ACFI project, incorporating the use of the Cool Farm Tool (CFT), during 2018–19

All contributing growers were encouraged to test an innovative farming practice, with additional soil sampling available to follow specific paddocks through the rotation. Additional technical support was also available to support innovative practices, such as novel intercropping strategies in grazed winter wheat, growing new pulse crops, brown manuring and summer cover cropping.

The project will continue with existing participants during 2020, with a further expansion of participant numbers.

Results

Rainfall

The 2018 and 2019 growing seasons varied greatly across the Riverine Plains region. During 2018, annual rainfall across the region ranged from 245–487mm, while growing season rainfall (GSR) from April to October, ranged from 122–239mm. During 2019, annual rainfall ranged from 214–409mm, while GSR ranged from 156–266mm (Figure 2).

Soil organic carbon

From November 2018 – February 2019, 67 GPS-referenced soil samples were taken from participating wheat paddocks. During 2019, an additional 132 soil samples were taken from July – September, including 16 samples taken from paddocks already sampled during the 2018–19 summer.

Analysis of the 2018–19 summer soil-sampling results show SOC values ranged from 0.9–2.9 per cent in the paddocks tested (Figure 3). The highest value (2.9 per cent) was recorded in a paddock that for many years had been managed using best management practice to maintain or increase soil carbon through disc seeding, stubble retention, lime application and the use of pasture rotations in the system.

Analysis of the 2019 winter sampling results showed a greater range of values, with SOC values ranging from 0.74–4.77 per cent (Figure 3). The lowest value (0.74 per cent) was recorded in a recently purchased paddock with a history of low inputs and high stocking rates.

Figure 4 shows no clear relationship between SOC levels and grain yield for those paddocks sampled, with yields below 1t/ha indicating crops that were cut for hay. During 2019, poor winter rainfall meant many wheat crops didn't have enough stored water to finish, which resulted in many of these crops being cut for hay. As a result, yields across the Riverine Plains region during 2019 were mainly limited by GSR and not influenced by SOC levels.

Previous research across Victoria and NSW has demonstrated a strong relationship between rainfall and SOC (Soil Carbon Research Program). This work showed rainfall to be the single largest factor governing soil carbon accrual when comparing between regions and soil types. However within regions, soil management strategies became more important.

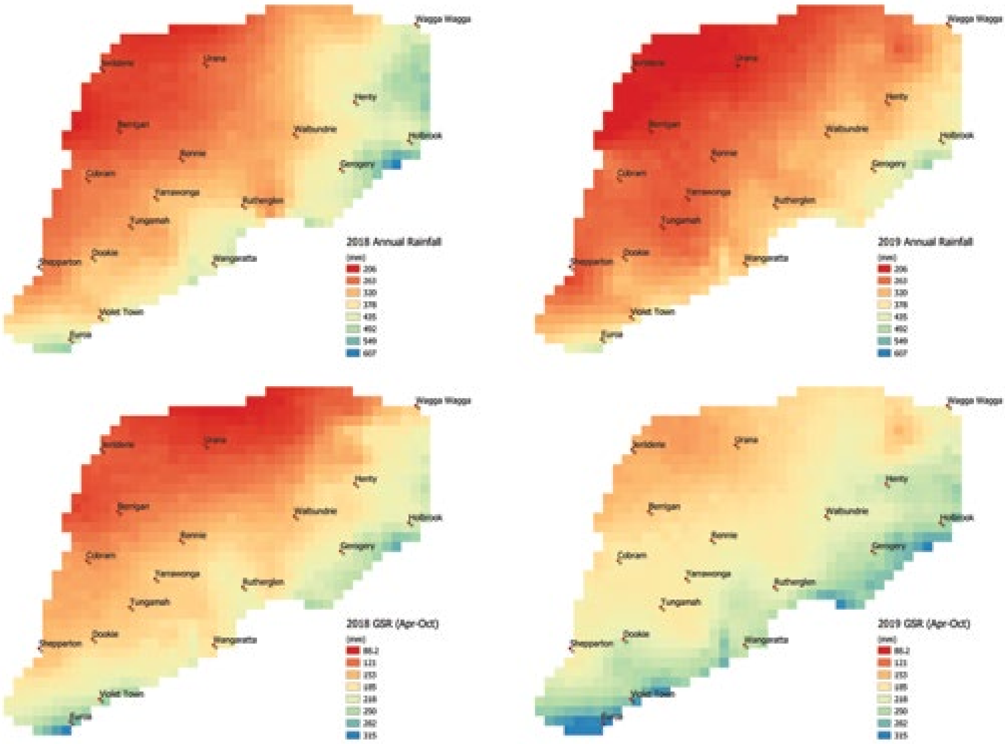

FIGURE 2 Annual rainfall and growing season rainfall 2018–19 for the Riverine Plains

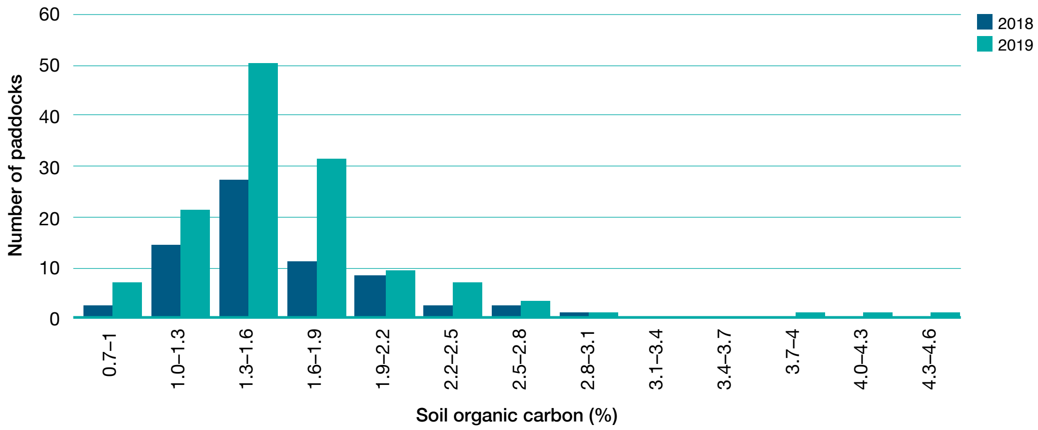

FIGURE 3 Soil organic carbon distribution across paddocks sampled as part of the ACFI 2018–19 summer sampling program and the 2019 winter–spring sampling program for the Riverine Plains region

While the 2018 and 2019 data show a slight trend for increased SOC when total rainfall increased (Figure 5) there was no such trend for GSR (Figure 6). Further comparisons will be carried out in the future to see if more 'normal' rainfall years show a different result.

Figures 5 and 6 also show there was higher total rainfall received across the project paddocks during 2018 compared with 2019, but there was less GSR received during 2018 compared with 2019.

pH ($CaCl_2$)

The Riverine Plains region has a vast range of soil types, which is reflected in the pH values seen across the area, with soils ranging from naturally acid to alkaline. Soil pH values of greater than pH 5.2 are ideal to ensure nutrient availability is not limited, while being high enough to ensure aluminium (Al) toxicity is not an issue.

The soil pH in the surface (0–10cm) soil samples taken during the 2018–19 summer ranged from pH 4.5–7.4, while the 2019 winter pH sampling results ranged from 4.3–7.3 (Figure 7). While both sets of results show a similar distribution of soil pH, analysis of paddock history and management data collected as part of the project (data not presented) suggests the range of pH values also reflects the use of amendment practices, such as applying lime, which can take a long time to show a response in the soil profile.

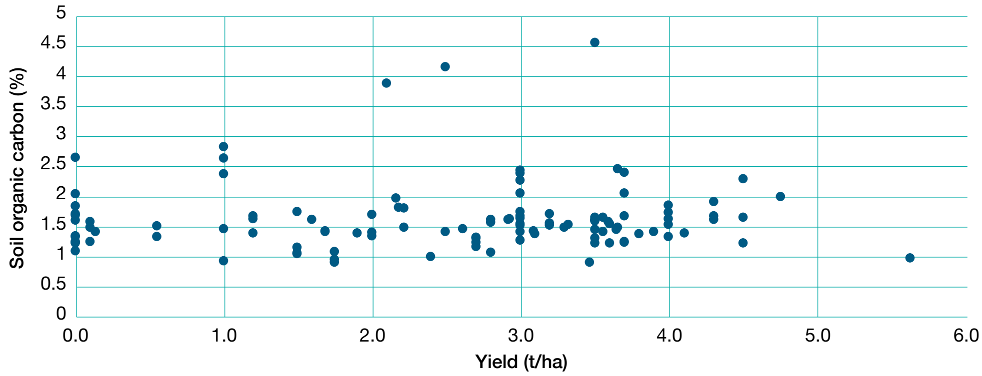

FIGURE 4 Relationship between soil organic carbon percentage and yield across paddocks sampled as part of the ACFI project during 2019

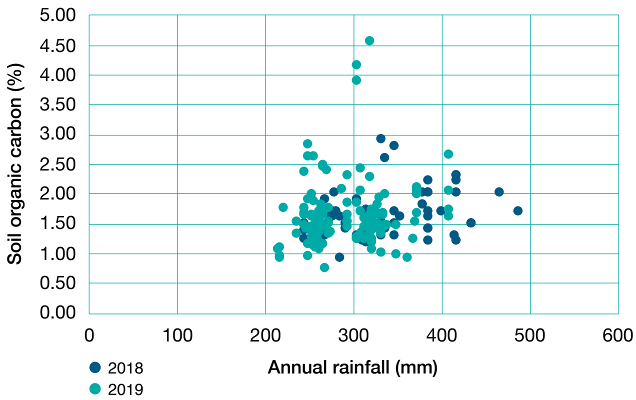

FIGURE 5 Relationship between soil organic carbon percentage and annual rainfall during 2018 and 2019

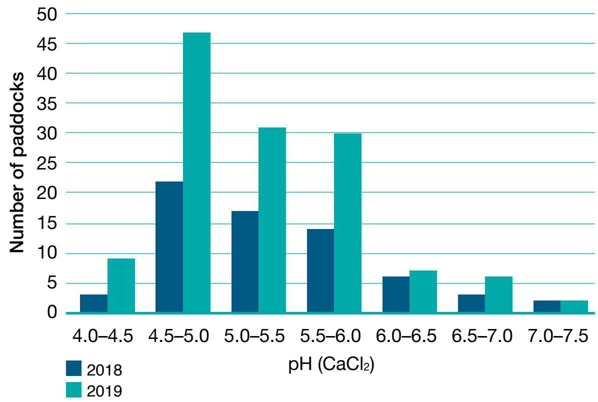

FIGURE 7 pH ($CaCl_2$) distribution across paddocks sampled as part of the ACFI project 2018–19 summer and 2019 winter-spring sampling programs

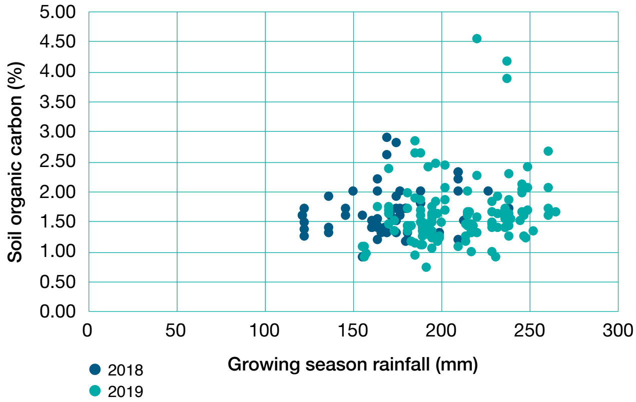

FIGURE 6 Relationship between soil organic carbon percentage and growing season rainfall (April – October) during 2018 and 2019

Aluminium toxicity

Figure 8 shows that as soil pH values decrease, aluminium solubility increased for the soil samples collected as part of the project, with an increasing contribution of aluminium into the CEC. This response is highly predictable within each soil type, with the exact relationship being dependent on clay mineralogy. Plant toxicity effects due to increased aluminium solubility are generally seen when the aluminium saturation of cation exchange sites exceeds six per cent, although different plant species have differing tolerance to aluminium. Only a relatively small proportion of paddocks sampled as part of this project showed aluminium saturation above six per cent.

Cation exchange capacity

Cation exchange capacity (CEC) is the estimate of the soil's ability to attract, retain and exchange cation elements, with a higher CEC tending to be indicative of higher clay content

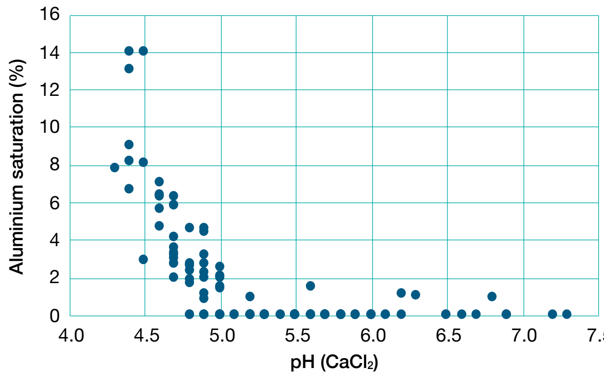

FIGURE 8 Relationship between aluminium saturation and soil pH ($CaCl_2$) for samples taken as part of the ACFI program in the Riverine Plains region during 2019

within a soil. Figure 9 shows the relationship between SOC percentage and CEC for the soil samples analysed as part of the project, with a non-significant trend for carbon values to increase with CEC. This is due to the fact that SOC (through organic matter) binds to clay particles because clay has a greater ability to attract cations than sandy soils (due to their high negative charge). Clay soils therefore tend to have higher CEC values than sandy soils and have a higher capacity to retain SOC. This explains why it is easier to build carbon levels on clay soils than sandy soils.

Greenhouse gas emissions

Data from each paddock was also analysed to determine the greenhouse gas emissions per hectare as well as greenhouse emissions per tonne of grain produced. Results from this analysis has highlighted that further work is required to validate the emission calculations made by the tool for Australian conditions, and as such, emission results are not presented in this report. It is expected that emissions results will be reported in future editions of the trial book.

Observations and comments

During 2019, the *Australian Cool Farm Initiative* project in the Riverine Plains area involved 30 participants, who collectively managed an area of 93,000 hectares.

Increasing SOC has been globally recognised as is a key driver in reducing emissions, through sequestration of atmospheric carbon dioxide (CO_2) while increasing system resilience through increased water storage and nutrient cycling, potentially contributing to increased sustainability and yield stability. Therefore, this project focuses on the adoption of on-farm practices that may increase soil carbon while maintaining production and profitability.

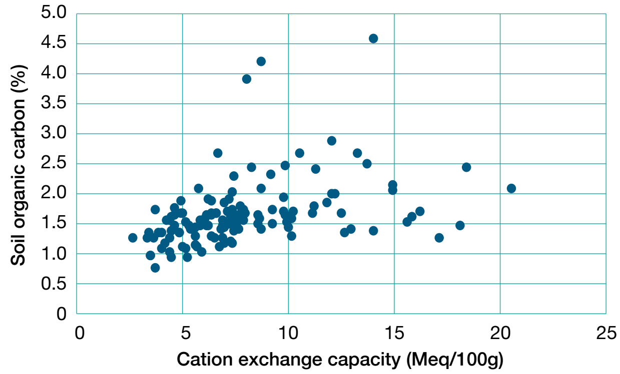

FIGURE 9 The relationship between soil organic carbon percentage and the cation exchange capacity for the paddocks sampled as part of the ACFI project in the Riverine Plains during 2019

The ACFI is an evolving project, with some value-add projects currently underway. One such project is looking at the effects of a pasture phase on SOC values over time within a mixed farming system. A selection of paddocks going from pasture into crop have been intensively sampled for soil carbon stocks in 10cm depth increments down to 30cm depth, as per the Australian Government Carbon Farming Initiative (CFI) methodology 2018. Results from this work will be presented once completed, in 2021.

Acknowledgements

Riverine Plains acknowledges the investment by Mars Petcare and the project support from Sustainable Food Lab (SFL). Thanks to all farmer co-operators, whose support for this project is greatly appreciated.

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Addressing soil acidity: subsurface soil amendments increasing pH and crop yield at Rutherglen

Dr Jason Condon, Dr Guangdi Li, Dr Sergio Moroni and Dr Alek Zander

Graham Centre for Agricultural Innovation (alliance between Charles Sturt University and New South Wales Department of Primary Industries)

Key points

- Deep placement of soil ameliorants applied during 2017 continued to improve soil pH and decreased aluminium (Al) concentrations in the subsurface soil layer during 2019.
- The benefits of soil amendments to soil pH and aluminium concentration remain for future seasons.
- Grain protein increased in treatments that ameliorated acidity and increased soil nutrition.

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 conditions) or reactive phosphate rock (which can increase pH and release plant-available phosphorus (P) 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 levels) and crop yield were investigated within a field trial established during 2017.

Aim

To quantify the yield limitation caused by subsoil acidity and evaluate innovative soil amendments that act to ameliorate subsurface acidity.

Method

During 2017, a three-year, replicated field trial was established at Rutherglen, Victoria, on a site located adjacent to the Rutherglen–Wahgunyah Road. The site has more than 20 year history 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).

The 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). Canola was grown during 2017, wheat during 2018 and canola was sown again during 2019.

There were 14 treatments, including 11 deep amendment treatments, to contrast with a nil control (no additions), lime control and surface lime treatments. Apart from the nil control, 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. The surface lime treatment received a higher rate (2.7t/ha) of surface-applied lime to achieve a target pH of 5.5 in the surface layer.

Deep amendment treatments included: lime, dolomite, magnesium silicate (MgSi), lucerne pellets, reactive phosphate rock (RPR) and liquid phosphorus (P). The deep amendments were placed approximately 10–30cm 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 amendments were applied at rates to achieve a target pH 5.0 based on short-term laboratory incubation studies conducted at Charles Sturt University. Amendments applied at two rates (MgSi,

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 (CEC), which is comprised of aluminium. A value greater than 6 per cent generally indicates aluminium to be likely to cause plant phytotoxicity.



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 12 April 2019 at 3kg/ha, with 75kg MAP/ha placed with the seed using a cone seeder on a 25cm row spacing. The site was harvested on 31 November 2019 using a plot harvester. Yield, protein and oil data were statistically analysed using ANOVA and a Student-Newman-Keuls test to determine treatment differences.

The soil from each plot was sampled on 4 December 2019 by taking two 44mm 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 air-dried and analysed for soil water content, soil pH ($CaCl_2$), exchangeable cations (including aluminium) and available phosphorus. Data for each depth increment were statistically analysed using ANOVA at the 95 per cent confidence interval. Weather data were collected at the experimental site via a data logged weather station.

Results

The experimental site received 263mm rainfall during the growing season (long-term average growing season rainfall is 400mm) and an annual rainfall of 389mm for 2019 (Figure 1). The site experienced 32 nights of negative temperatures.

Soil measurements taken after harvest (December 2019) showed soil pH in the surface (0–10cm) soil ranged from pH 4.4–5.4. A pH of 4.4 was recorded where no lime was applied during 2017, while the pH was approximately 5 where surface lime was applied at 1.7t/ha during 2017. Where lime was applied to the surface at the higher rate of 2.7t/ha (Figure 2) a pH of 5.4 was recorded.

On the treatment row in the 10–20 and 20–30cm layers, large increases in soil pH were recorded relative to the control in the deep-placed lime treatment, resulting in soil pH higher than 6.5 in those layers. Within the 20–30cm layer, the deep lime treatment with phosphorus, magnesium silicate treatment and high rate of reactive phosphate rock treatment were all effective in maintaining a soil pH between 5 and 5.5. These treatments also decreased the aluminium percentage to less than 5 per cent in the 10–20cm layer, which was significantly less than treatments not receiving alkaline amendments in the subsurface soil (i.e. control, deep ripping only, deep phosphorus and surface lime treatments). In the 10–20cm layer, both the deep dolomite and deep lime with phosphorus treatment significantly increased pH compared with the control, however neither of these treatments kept the aluminium percentage below 10 per cent in the 10–20cm layer (Figure 2).

During this third year of the experiment, soil pH in the lucerne pellet treatments were not significantly different to the untreated control in layers below the surface 10cm. For the 10–20cm layer, the aluminium percentage of the lucerne-pellet-treated soil was not significantly different to the control. However, in the 20–30cm layer, the high rate of lucerne pellets created a significantly lower aluminium percentage than treatments that received no added amendments to that layer, despite not increasing soil pH. This may indicate that components of the organic matter can tie up aluminium cations making them unavailable to

TABLE 2 Surface and deep amendment treatments applied at Rutherglen, 2017

Treatment	Surface lime application rate (t/ha)	Target surface pH ($CaCl_2$)	Deep amendment (placed about 10–30cm 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	15kg P/ha
Deep P + deep lime	1.7	5.0	Liquid phosphorus + lime	15kg P/ha + 2.5t/ha Lime

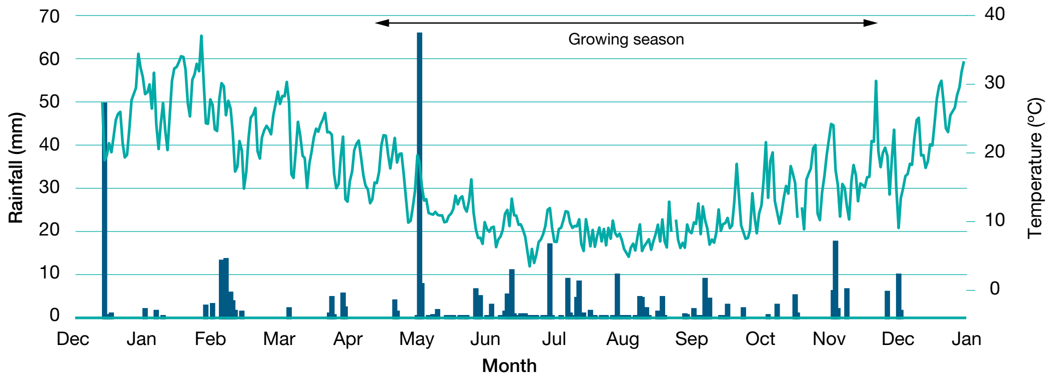

FIGURE 1 Rainfall and average air temperature during the 2019 season at Rutherglen

Note: The growing season (sowing to harvest) is indicated by horizontal arrow at top of figure.

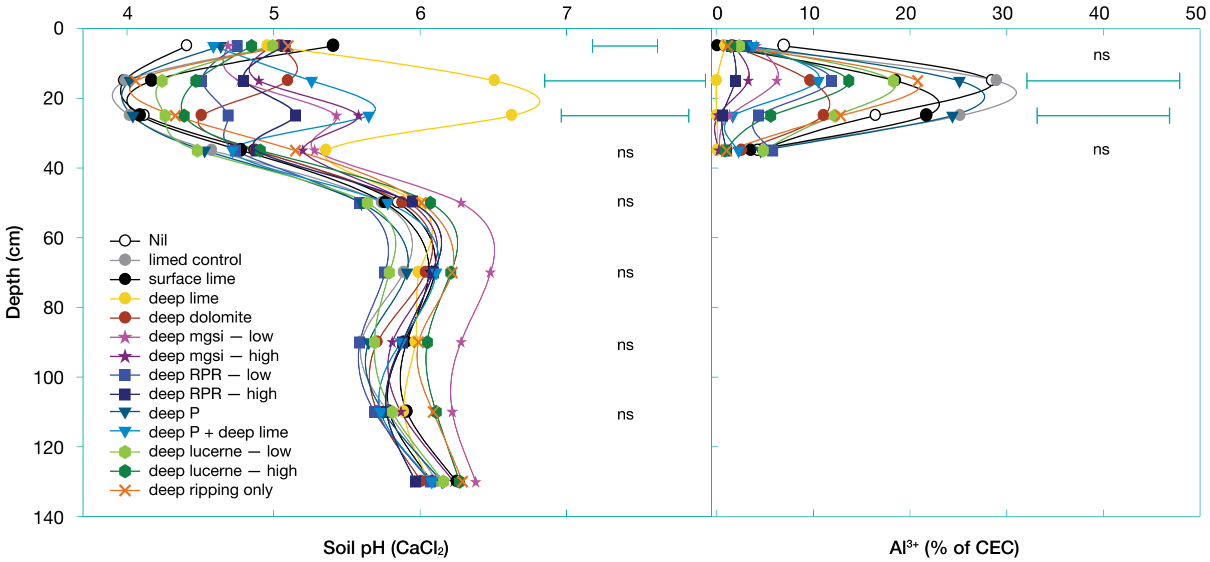

FIGURE 2 Post-harvest soil pH ($CaCl_2$) and exchangeable aluminium percentage (% of CEC) of amendment treatments as sampled from the treatment row at Rutherglen, 2019

Data are means of three replicates of each treatment. Bar represents LSD for pH data at p=0.05, ns = not significant.

plants, even at low pH (<5). This may also indicate that lucerne-derived organic compounds are binding with plant-toxic aluminium cations in a way that removes it from solution.

There were no treatment differences in the soil pH of any layer based on soil samples taken between the amendment rows (Figure 3). This provides evidence that lateral movement of amendment alkali, regardless of the form, is negligible.

There were no significant differences between treatments at P=0.05.

A strong relationship existed between soil pH and aluminium percentage across all soil layers at this trial site (Figure 4). As soil pH values decreased below pH 5.0, the amount of aluminium in solution increased exponentially, a response which is common in soils of south-east Australia. Some variation from the relationship may exist due to organic

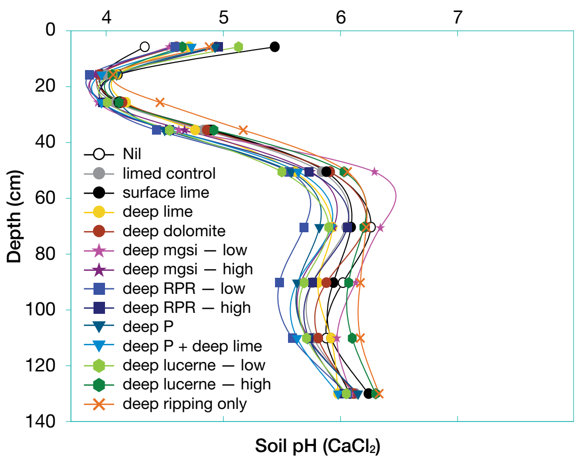

FIGURE 3 Post-harvest soil pH ($CaCl_2$) of amendment treatments as sampled from the mid-row between treatment rows at Rutherglen, 2019

Data are means of three replicates of each treatment.



complexation of Al^{3+}, however based on Figure 4 the effect is minor and the relevance to field conditions over longer periods of time is unknown.

There were no significant differences in yield between treatments in 2019 (Table 3). Yield of all treatments was low relative to yields of more than 2t/ha observed commercially across the region. The poor performance of the 2019 crop was largely due to poor seedling survival following a storm event during early May, two weeks after sowing (Figure 1). This intense rainfall event destroyed surface soil structure and inundated the seed rows, resulting in poor establishment.

Image analysis of drone footage taken on 5 August 2019 showed no treatment difference in the percentage green area of each plot.

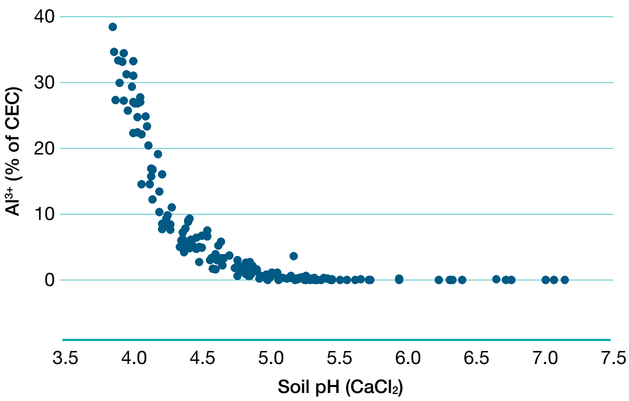

FIGURE 4 The relationship between soil pH and percentage of the cation exchange sites occupied by aluminium cations in soil samples taken at Rutherglen, December 2019

TABLE 3 Harvested yield, protein and oil content of canola grown at Rutherglen, 2019

Treatment	Yield (t/ha)	Protein (%)	Oil (%)
Nil control	1.40 (0.10)	46.6^{a}	42.40^{b}
Limed control	1.21 (0.03)	46.3^{a}	42.57^{b}
Surface lime	1.32 (0.10)	46.4^{a}	41.87^{ab}
Deep ripping only	1.13 (0.04)	46.3^{a}	42.33^{b}
Deep lime	1.14 (0.16)	46.3^{a}	41.73^{ab}
Deep dolomite	1.26 (0.05)	46.8^{a}	41.90^{ab}
Deep MgSi (low)	1.17 (0.06)	47.7^{ab}	42.33^{b}
Deep MgSi (high)	1.22 (0.04)	48.2^{b}	41.97^{ab}
Deep lucerne (low)	1.31 (0.08)	47.3^{ab}	42.47^{b}
Deep lucerne (high)	1.18 (0.10)	47.2^{ab}	41.37^{ab}
Deep RPR (low)	1.19 (0.03)	47.2^{ab}	41.63^{ab}
Deep RPR (high)	1.11 (0.05)	47.3^{ab}	40.53^{a}
Deep P	1.15 (0.23)	46.7^{a}	42.80^{b}
Deep P + deep lime	1.38 (0.08)	46.9^{ab}	42.07^{b}

Note: Within each column means marked with different letters are significantly different ($p<0.05$). There was no significant difference between treatments for grain yield; values in parentheses are standard error of means.

While there were no significant differences in yield between the treatments, grain protein and oil content were significantly influenced by treatment (Table 3). Protein ranged from 46.3–48.2 per cent, with the highest protein observed in the treatments that increased soil pH and provided additional nutrients (including the reactive phosphate rock, lucerne pellet, magnesium silicate and lime-with-phosphorus treatments).

While significant differences in oil content occurred due to treatment, no clear causation pattern was apparent, with oil content ranging from 40.5 per cent in the high rate of deep reactive rock phosphate treatment to 42.8 per cent in the deep phosphorus treatment. There were no significant differences in glucosinolate concentrations of grain due to treatment.

Conclusion

The inorganic soil amendments applied during 2017 continued to influence soil pH during 2019 and, via a strongly defined relationship, aluminium percentage. The lucerne pellet organic amendment appears to no longer be increasing soil pH, however still seems to be moderately effective at decreasing aluminium percentage at a given pH.

While no yield differences were recorded across treatments in the 2019 canola crop, perhaps due to poor crop establishment caused by a storm event soon after sowing, differences in grain quality still existed. Increased grain protein was observed in treatments that ameliorated the acidic conditions in the subsurface soil and also provided additional nutrition.

Although seasonal effects may impact yield, the soil improvements from inorganic amendments persist, and may be seen as a long-term benefit of the financial expense of the amelioration. Monitoring of future yield is required to capture this long-term benefit.

Acknowledgements

This project is funded by NSW DPI with financial support from the GRDC through the *Innovative approaches to managing subsoil acidity in the southern grain region (DAN00206) project*. The project is supported by Riverine Plains Inc, Farmlink Research, Southern Farming Systems and the Holbrook Landcare Network. Thanks to farmer co-operator Stephen Chambers. Technical staff: Richard Lowrie, Alek Zander, Adam Lowrie and Andrew Price.

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Management of early-sown wheat

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

The following report has been based on a single year's data from a research project. Please exercise caution when interpreting the results.

Key points

- Eight wheat cultivars were sown across four sowing dates (15 March, 3 April, 12 April and 30 April) and yielded between 2.5–4.6t/ha.
- There was a significant interaction between sowing date and variety yield performance, with yields decreasing when the sowing date was delayed from 16 April to 30 April.
- Considering seasonal conditions, wheat yields were high and stable across all times of sowing.
- Floret sterility (mainly due to drought stress) was recorded at moderate levels (trial average of 12 per cent) across all wheat cultivars and all times of sowing.
- The winter wheat varieties Longsword and DS Bennett had the highest levels of floret sterility across the trial.

Background

During the past 10 years there has been a major shift to sow broadacre crops earlier across south-eastern Australia. This early-sowing regime has been underpinned by increased grain yields, particularly across the low-rainfall and medium-rainfall zones. However, the move to early sowing has also exposed shortcomings in wheat germplasm, with earlier sowing resulting in earlier flowering and a subsequent increase in the risk of frost damage. Consequently, there has been increasing interest in new shorter-season winter wheat cultivars, which are better adapted to early sowing.

Method

Two trials were established during 2019 as part of a LaTrobe University research project for the Grains Research and Development Corporation (GRDC) investment *Development of crop management packages for early-sown, slow-developing wheats in the Southern region* (MESW). The first trial investigated new winter wheat germplasm at four times of sowing from 15 March to 30 April. The second trial sought to understand how changing the canopy structure (through sowing rate, nitrogen timing and grazing) affected the management and yield of winter wheats. The trials were carried out at the Riverine Research Centre (RRC) at Yarrawonga, Victoria.

Seasonal conditions

Both trials were affected by the dry start to the season and a very dry spring (decile 2). Growing season rainfall (GSR) for the site during 2019 was 198mm, with 141mm of the GSR falling throughout May, June and July. Frost events were at a minimum, with the last significant frost event recorded on 25 September, when the temperature reached -1°C.

Trial 1

Time of sowing and cultivar

Sowing date: See Table 1
Rotation: Wheat following canola
Stubble: Canola unburnt
Rainfall:
GSR: 198mm (April–October)
Summer rainfall: 24mm
Soil mineral nitrogen:
0–10cm: 10kg N/ha
10–30cm: 43kg N/ha
30–60cm: 7kg N/ha

The research carried out at the RRC involved eight developmentally different cultivars sown across four sowing dates (Tables 1 and 2). Two spring wheats cultivars were also included as controls for each time of sowing.

Trickle tape irrigation was used to mimic an autumn break if there was not enough natural rainfall for establishment, applied as 10mm for times of sowing 1, 2 and 3 (Table 1). In-crop assessments were made to increase the understanding of early-sown wheat phenology and provide insights as to how best manage new winter wheats in broadacre systems.

TABLE 1 Time of sowing treatment details, for MESW trial 1, Yarrawonga, Victoria, 2019

Times of sowing (TOS) 2019			
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	12 April	20 April
4	1 May	30 April	8 May

TABLE 2 Variety and season length details for MESW trial 1, Yarrawonga, Victoria, 2019

	Variety	Type
1	Scepter	Fast spring
2	Cutlass	Mid spring
3	Nighthawk (LPB14-0392)	Intermediate; fast winter–slow spring
4	ADV15.9001	Intermediate; fast winter–slow spring
5	Longsword	Fast winter
6	Illabo (V09150-01)	Mid–fast winter
7	Kittyhawk	Mid-winter
8	DS Bennett (ADV11.9419)	Slow winter

TABLE 3 Plant counts 8 April 2019, 20 April 2019, on 8 May 2019 and 20 May 2019 from MESW trial 1, Yarrawonga, Victoria, 2018

Time of sowing (TOS)	Date of plant count	Plants/m^2
TOS 1 (15 March)	8 April	57^{c}
TOS 2 (3 April)	20 April	80^{b}
TOS 3 (12 April)	8 May	97^{ab}
TOS 4 (30 April)	20 May	101^{a}
Mean		84
LSD		17
Variety		
Scepter		94^{a}
Cutlass		92^{ab}
Nighthawk (LPB14-0392)		86^{abc}
ADV15.9001		70^{d}
Longsword		78^{bcd}
Illabo		77^{cd}
Kittyhawk		99^{a}
DS Bennett		74^{cd}
LSD		14

Note: Mean is average plants/m^2 for all times of sowing
Figures followed by different letters are regarded as statistically significant

Results

1.1 Establishment and crop structure

All plots were sown at 120 seeds/m^2, resulting in establishment of 57–101 plants/m^2 (Table 3). The earliest sown plots had the poorest average establishment due to dry conditions at sowing (57 plants/m^2). Establishment rates increased as time of sowing was delayed, with the best establishment recorded for the latest sowing on 30 April (101 plants/m^2). The cultivar ADV15.9001 had the poorest overall establishment, with an average of only 70 plants/m^2 across all times of sowing.

1.2 Floret sterility

Floret sterility (principally due to drought stress) was recorded at high levels for the three cultivars DS Bennett, Longsword and Cutlass (Figure 1). The higher average floret sterility seen in Cutlass (13 per cent) can be explained by its being a spring variety, which when sown early, was affected by frost events during July, leading to sterility at flowering. DS Bennett and Longsword are winter types, which both tillered well and produced high levels of biomass as a result of favourable conditions during winter. As conditions dried out during spring, both varieties experienced moisture stress at flowering and this was expressed through higher levels of floret sterility (DS Bennet, 24 per cent; Longsword, 18 per cent). All other varieties expressed floret sterility levels below 10 per cent, with ADV 15.9001 having the lowest sterility at 5 per cent.

1.3 Grain yield and quality

Wheat yields were stable across the first three times of sowing, ranging from an average yield of 3.62t/ha for the trial sown on the 15 March, to 3.68t/ha for the trial sown on 12 April. The poorer establishment observed in the trial

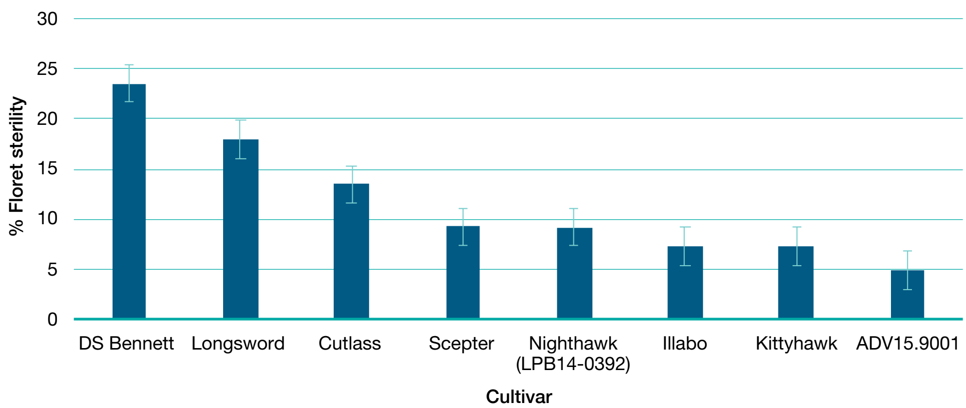

FIGURE 1 Percentage of floret sterility for each variety, averaged across all times of sowing, for MESW Trial 1, Yarrawonga, Victoria, 2019
Error bar is a measure of LSD.

sown on 15 March did not affect yield, with average yields from this trial (3.62t/ha) being similar to yields from the trials sown on 3 April (3.66t/ha) and 12 April (3.68t/ha). The trial sown on 30 April had a significantly lower average trial yield than the other times of sowing (2.95t/ha) (Table 4).

When all times of sowing were averaged, Illabo was the best performing winter-type cultivar, yielding significantly higher (3.56t/ha) than Longsword (2.90t/ha), Kittyhawk (3.38t/ha) and DS Bennett (3.26t/ha). The intermediate type ADV15.9001 had a significantly higher average yield (4.04t/ha) compared to the other cultivars (Table 5). Longsword was the lowest yielding variety, however its average protein (13.6%) was significantly higher than any other variety.

The cultivar Scepter, sown on 12 April, produced the highest yield across all sowing dates (4.6t/ha), while Illabo produced the highest yield from a winter-type cultivar (4.3t/ha) when sown on 3 April. The intermediate type, ADV15.9001, consistently yielded higher than 4t/ha across the first three times of sowing. The variety with the lowest average yield across all times of sowing was the fast-winter type, Longsword, but this variety also had the highest average grain protein. Illabo, sown on 30 April, had the highest grain protein (14%) (Figure 2).

MESW time of sowing trial on 12 June 2019. Note the poor establishment for time of sowing 1 at the front left of the picture.

TABLE 4 Average yield, protein, test weight and screenings at harvest (GS99) for MESW trial 1, at Yarrawonga, Victoria, 29 November 2019*

Time of sowing	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
15 March	3.62^{a}	11.9^{b}	82.2^{a}	1.9^{a}
3 April	3.66^{a}	11.8^{b}	82.4^{a}	1.6^{a}
12 April	3.68^{a}	11.7^{b}	82.4^{a}	1.7^{a}
30 April	2.95^{b}	12.6^{a}	81.7^{b}	2.0^{a}
Mean	**3.48**	**12.01**	**82.2**	**1.8**
LSD	0.11	0.4	0.4	0.5

*Mean of eight cultivars
Figures followed by different letters are regarded as statistically significant.

TABLE 5 Yield, protein, test weight and screenings at harvest (GS99) for cultivars sown in the MESW trial 1, Yarrawonga, Victoria, 29 November 2019*

Variety	Yield (t/ha)	Protein (%)	Test weight (kg/hl)	Screenings (%)
Scepter	3.80^{b}	11.0^{d}	82.8^{bc}	1.7^{cd}
Cutlass	3.23^{d}	12.2^{bc}	82.0^{d}	1.2^{de}
Nighthawk (LPB14-0392)	3.66^{bc}	11.8^{c}	83.0^{ab}	3.3^{a}
ADV15.9001	4.04^{a}	10.6^{d}	83.3^{ab}	2.3^{bc}
Longsword	2.90^{e}	13.6^{a}	80.5^{e}	0.5^{f}
Illabo	3.56^{c}	12.5^{b}	80.1^{e}	1.0^{ef}
Kittyhawk	3.38^{d}	12.0^{bc}	83.6^{a}	2.2^{bc}
DS Bennett	3.26^{d}	12.3^{bc}	82.2^{cd}	2.4^{b}
Mean	**3.48**	**12.0**	**82.2**	**1.8**
LSD	0.15	0.6	0.7	0.6

*Mean of four sowing dates
Figures followed by different letters are regarded as statistically significant.

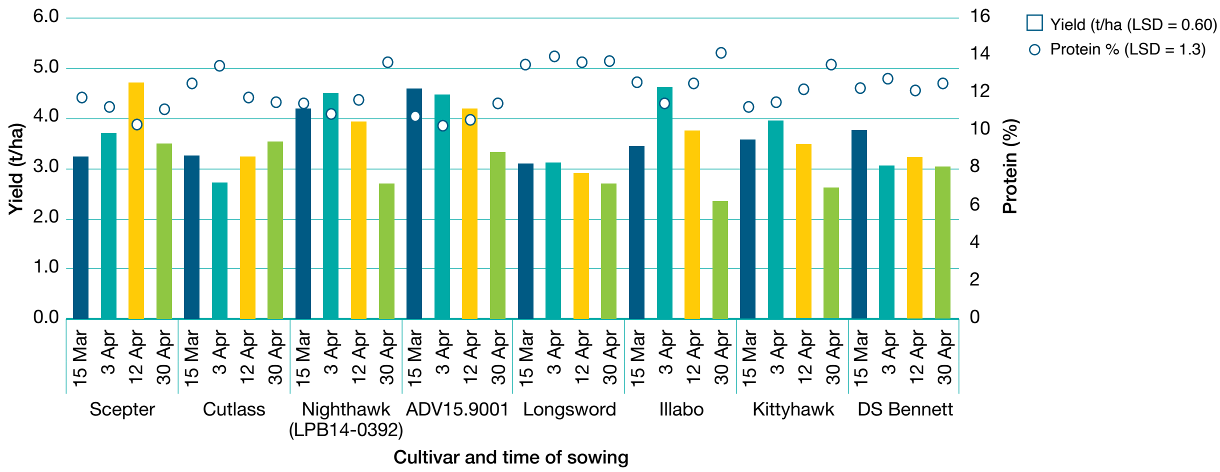

FIGURE 2 Interaction between time of sowing and variety on yield and protein for MESW Trial 1, Yarrawonga, Victoria, 2019

Trial 2

Variety x sowing rate x nitrogen timing x grazing

Key points

- Three varieties sown on 15 April yielded between 2.5–3.6t/ha.
- When all parameters were considered together (variety, nitrogen treatment and sowing rate), there was significant interaction between grazing and yield; grazed crops incurred a yield penalty.
- Floret sterility (mainly due to drought stress) was recorded at higher levels in all ungrazed varieties.
- Larger amounts of biomass were removed from plots with nitrogen (N) applied at sowing.

Sowing date: 15 April 2019
Rotation: Wheat following canola
Stubble: Canola unburnt
Rainfall:
GSR: 198mm (April–October)
Summer rainfall: 24mm
Soil mineral nitrogen:
0–10cm: 10kg N/ha
10–30cm: 43kg N/ha
30–60cm: 7kg N/ha

The aim of the trial was to manipulate the canopy of early-sown wheat and understand how these interventions affect crop management.

The crop canopy was manipulated through variety selection, sowing rate, nitrogen (N) fertiliser application and grazing. The trial studied three winter wheat varieties DS Bennett, Kittyhawk and Longsword, sown at two target plant populations (50 and 150 plants/m^2) on 15 April 2019 (Table 6). 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

2.1 Establishment and crop structure

Establishment was below target, with the low-density treatment (target 50 plants/m^2) establishing at 28 plants/m^2 and the high-density treatment (target 150 plants/m^2) establishing at 74 plants/m^2 (Table 7). There was no variety effect on establishment.

2.2 Dry matter offtake at grazing

Cumulative dry matter (DM) availability from grazing at the three-tiller stage (GS23) and at the start of stem elongation (GS30) was driven by applied nitrogen. Where nitrogen was applied at sowing (GS00), treatments produced an average 1.4t DM/ha and where nitrogen was applied at the start of stem elongation (GS30) treatments produced an average 0.8t DM/ha. There was also a significant effect of variety, with Longsword producing significantly more DM (0.6t DM/ha) than the lowest-producing variety, DS Bennett (Table 8).

TABLE 6 Target population treatment details for MESW trial 2, Yarrawonga, Victoria, 2019

Variety	Target plant density (plants/m²)	Nitrogen timing (200kg urea)	Grazing*
DS Bennett	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 7 Target and actual plant emergence 8 May for MESW trial 2, Yarrawonga, Victoria, 2019

Target plant population (plants/m²)	Actual plant population (plants/m²)
50	28
150	74

MESW grazing trial on 1 August 2019, for the second time of grazing at the start of stem elongation (GS30), Yarrawonga Victoria.

TABLE 8 Effect of variety and nitrogen timing on combined grazing and dry matter offtake at the three-tiller stage (GS23) and the start of stem elongation (GS30) when all cultivars were combined, MESW Trial 2, Yarrawonga, Victoria, 2019

Plant density	DM (t/ha)
DS Bennett	0.8^{b}
Kittyhawk	1.1^{ab}
Longsword	1.4^{a}
Mean	**1.1**
LSD	0.4
Nitrogen timing	
GS00	1.4^{a}
GS30	0.8^{b}
LSD	0.3

Figures followed by different letters are regarded as statistically significant.

2.3 Floret sterility

Grazing reduced floret sterility across all varieties during 2020. Grazing decreased floret sterility by 17 per cent for the variety Longsword (Table 9), by 15 per cent for DS Bennett and 10 per cent for Kittyhawk. Floret sterility was mainly caused by drought conditions during spring when crops with large canopies experienced moisture stress and could not convert their biomass into grain yield. The slow winter type, DS Bennett, was the most significantly affected by floret sterility when left ungrazed, with 27% of florets being sterile. DS Bennett also had the highest floret sterility in the grazed plots (12%), with grazing causing it to flower far too late for the conditions and reducing its ability to recover to fulfil its potential.

2.4 Yield and quality

The timing of nitrogen application had no major effect on yield, however both variety and grazing affected yield by at least 0.4t/ha. DS Bennett (3.4t/ha) yielded significantly more than both Kittyhawk (2.9t/ha) and Longsword (3.0t/ha) (Table 10). There was a significant interaction between variety and grazing with the highest-yielding treatment

TABLE 9 Interaction of variety and grazing on floret sterility at early dough stage (GS83), 3 November 2019 for MESW trial 2, Yarrawonga, Victoria, 2019

Variety and treatment	Floret sterility (%)
DS Bennett ungrazed	27^{a}
DS Bennett grazed	12^{bc}
Kittyhawk ungrazed	13^{b}
Kittyhawk grazed	3^{d}
Longsword ungrazed	19^{b}
Longsword grazed	2^{d}
Mean	**13**
LSD	7

Figures followed by different letters are regarded as statistically significant.

TABLE 10 Effect of variety, nitrogen timing and grazing on grain yield 29 November for MESW Trial 2, Yarrawonga, Victoria, 2019*

	Yield (t/ha)
Variety	
DS Bennett	3.4[a]
Kittyhawk	2.9[b]
Longsword	3.0[b]
Mean	**3.1**
LSD	0.2
Nitrogen timing	
GS00	3.1[a]
GS30	3.2[a]
LSD	0.2
Grazing	
Ungrazed	3.3[a]
Grazed	2.9[b]
LSD	0.2

Figures followed by different letters are regarded as statistically significant.
*Mean of both two seed rates

being the ungrazed DS Bennett treatment (Figure 3). Grain protein was moderate across the trial, with ungrazed Longsword (13.6%) having the highest protein and the grazed Longsword having the lowest protein (11.0%).

Three years of data from the FAR/Riverine Plains trials along with data from across south-eastern Australia MESW trials has been compiled into a GRDC-published booklet; *Management of flowering time and early-sown* slow-developing *wheats (January 2020).*

Acknowledgements

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Thank you also to our farmer co-operator at the Riverine Research Centre, Telewonga Pty Ltd.

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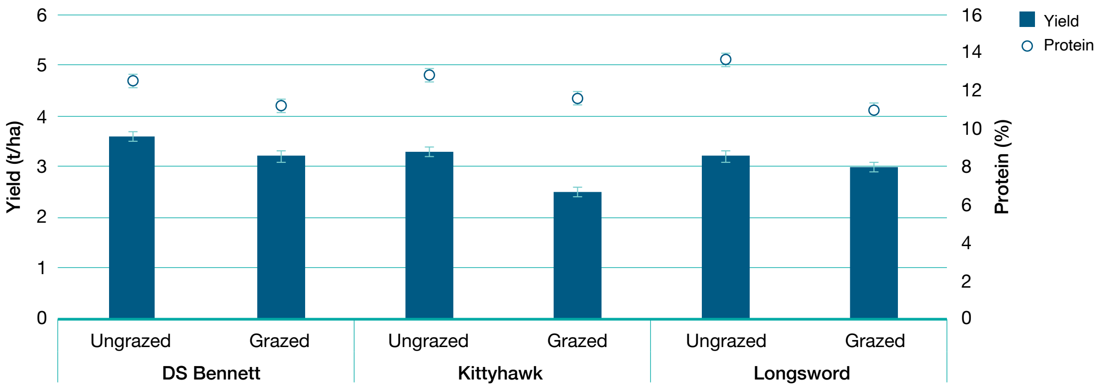

FIGURE 3 The interaction of variety and grazing on yield and protein at harvest (GS99), 29 November for MESW trial 2 Yarrawonga, Victoria, 2019*
Error bars are a measure of LSD
*Mean of both the high and low sowing rates

Understanding soil pH through dual-depth grid soil mapping

Lisa Castleman[1] and Kirsten Barlow[2]

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Key points

- Dual-depth (0–10cm, 10–20cm) grid soil sampling was used to map surface and subsoil pH across 45 properties and 2210ha of farmland in the eastern Riverina area of southern NSW.
- Soil sampling showed an average variation in pH of 0.8–1.0 pH units across a paddock in both the surface and sub-surface layers, with marked differences in soil pH between the two sampling depths.
- Exchangeable aluminium (Al) levels increased rapidly in the soil sample where pH was lower than 4.6, with minimal amounts of exchangeable aluminium detected where soil pH was greater than 4.6.

Aim

This project aimed to reduce the erodibility of high-risk landscapes through an increase in the area of land planted to perennial pasture species, which are both more productive and more persistent when not constrained by acidity and aluminium toxicity.

To achieve this, the project aimed to increase awareness, knowledge and understanding of soil acidification and management options for topsoil and subsoil acidity. Traditional blanket-rate lime practices do not address the issue of increasing subsoil acidity, nor target areas where acidity is most severe, and the project explored dual-depth grid soil mapping in combination with variable rate lime application for more effective and longer-term management of soil acidification.

The project aims to increase the area of land planted to perennial pasture species, as well as increase the area of soil limed to at least pH 5.2 in the topsoil (0–10cm). Grass and legume-based pastures limed using tailored rates will be more productive as a result, with pasture legumes and their rhizobia able to supply more fixed nitrogen (N) for the benefit of the mixed sward.

Based on intensive soil sampling, the project aimed to develop property soil nutrient and liming plans that identify the constraints, including soil acidity, that can influence the establishment and maintenance of perennial pasture systems. By ensuring that soil fertility and plant nutrition are understood and managed by the landholder, the focus can be on the prevention of soil erosion and the management of acidification.

Background

Soil acidity affects 50 per cent of Australia's agricultural land and is a major constraint to pasture and crop productivity in areas of southern NSW with an annual rainfall of 550–800mm. Soil acidification is a natural process, which is driven by rainfall and accelerated by the removal of agricultural products, which are generally alkaline. Acidity is also affected by the balance of nitrogen in the system and influenced by the leaching of nitrates and the loss of nitrogen due to volatilisation or denitrification under waterlogged conditions.

Standard soil tests, taken at a depth of 0–10cm, provide a measure of soil pH in the surface root zone of crops and pastures. In these surface soils, the developing root systems of newly established pasture or crop species, as well any soil rhizobia present, are exposed to soil pH and any associated toxicities, including aluminium toxicity. Soil pH can be inherently variable, both horizontally and vertically, in the profile and there has been a recent focus on the stratification of pH in the upper 20cm of the soil profile by soil scientists.

Farming Smarter – a soils project for the next generation is a five-year project. This project is supported by Riverina Local Land Services, through funding from the Australian Government's National Landcare Program. The project utilises precision agriculture (PA) techniques to identify the severity of soil acidity in a paddock and the range of in-paddock variation in soil pH.

This data will be used to provide guidance around the liming rates required to establish and maintain perennial pastures, as soil acidity can diminish nitrogen fixation by pasture legumes and acid-sensitive rhizobia. Soil acidity can also impact the root volume and rooting depth of pastures when constrained by aluminium and manganese toxicity, as well as affect plant nutrition when soil micronutrients, such as boron or zinc, become deficient at low pH. The dual-depth sampling process used in this project enables variable-rate lime application to be explored for managing the amelioration of acidity in both the top and sub-soil layers.



This article summarises the results of dual-depth soil sampling undertaken in the eastern Riverina area of southern NSW during autumn 2019 (year one of the project). Soil sampling was conducted across a range of paddocks used for mixed farming and selected for future perennial pasture establishment by the landholders.

This project recognises the value in having a better understanding of pH stratification in soils and focuses on understanding the variation in pH across the paddock, especially between the topsoil, which receives a surface application of lime, and the subsurface layer, which cannot be ameliorated until the acidity in the topsoil is saturated. By monitoring surface and subsurface acidity through dual-depth grid soil mapping, the project has taken a step towards increasing the knowledge and understanding of farmers and researchers in southern NSW, as well as improving the way acidification and re-acidification are managed. This will lead to increases in the efficiency in which we apply inputs of lime and fertiliser.

Method

Dual-depth grid soil mapping was undertaken during autumn 2019 (year one of the five-year project). Samples were collected from 87 paddocks (across 45 farms), representing a total area of 2210 hectares of southern NSW farmland (Figure 1).

The grid soil sampling involved dividing each of the 87 paddocks into two-hectare grids, which were treated as individual units for soil sampling. The sampling process consisted of (a) creating digitised paddock boundaries and sampling plans; (b) the collection of GPS referenced samples (0–10cm, 10–20cm) by manual sampling, with eight sub-samples collected on a diagonal across each sampling grid; (c) sending of samples to an accredited laboratory to analyse pH ($CaCl_2$) and exchangeable cations (calcium [Ca], magnesium [Mg], potassium [K] and sodium [Na]).

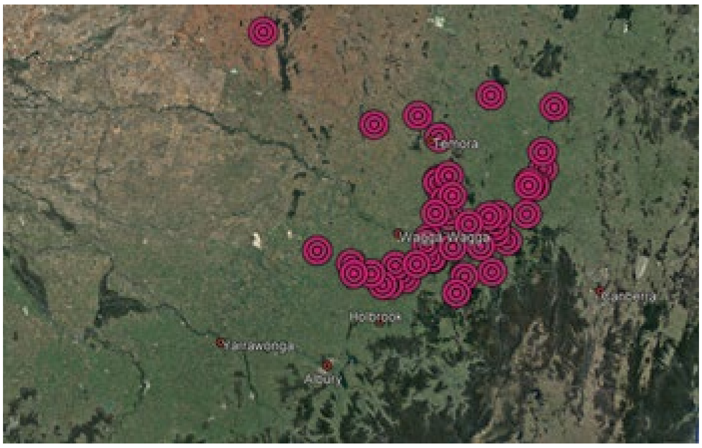

FIGURE 1 Distribution of the project sampling sites across southern NSW

After initial results were received, further analysis was conducted for each property, with the two most acidic points selected for further analysis of exchangeable acidity (aluminium and hydrogen) in both the 0–10cm and 10–20cm layers.

Results

Soil pH was highly variable across the 87 sampled paddocks. In the surface soil (depth 0–10cm), the average pH ranged from 4.1–6.2 (Figure 2). While 75 per cent of the sampled paddocks had an average surface soil pH of less than 5.2, 50 per cent of the paddocks had an average pH of below 4.8, placing them in the 'highly acidic' category.

There was significant variation between paddocks and within paddocks. The range in soil pH across a single paddock varied by 0.2–2.6 pH units, with an average range of 0.84 pH units.

In the sub-surface (10–20cm depth), average soil pH across the 87 paddocks ranged from pH 4.1–6.0, with individual paddocks measuring ranges from 0.2–2.9 pH units (average range of 0.99). Based on these average

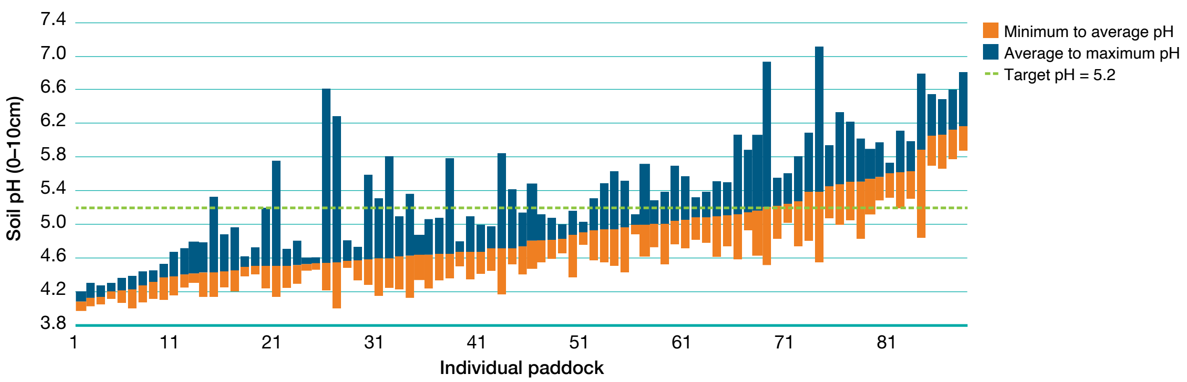

FIGURE 2 Soil pH at 0–10cm depth for 87 individual paddocks, shown as individual bars and ranked according to their average pH (intersection of the orange and blue lines)

figures, the range and variability of the surface and sub-surface soils are reasonably consistent. However, soil pH data for the 10–20cm depth in Figure 3 (ranked according to surface soil pH) indicates there wasn't a consistent trend in the pH distribution between the surface and sub-surface layers. The exception to this was for the 15 most acidic surface soils (0–10cm), which were also consistently acidic in the sub-surface (10–20cm).

Paddock sampling occurred across a range of soil types and included a mix of cropping, pasture and mixed farming systems, however there were no obvious differences in soil acidity between soils with different land-uses. While the majority of paddocks sampled as part of this project had a history of lime application (at a rate of 2t/ha or greater), the combined effects of farming system, soil type, long-term rainfall patterns and long-term management practices is likely to be driving results.

One of the additional management challenges for acidic soils is the potential for increasing levels of exchangeable aluminium to amounts that are toxic for plant growth. The results from the 45 properties where exchangeable aluminium was measured (for the two most acidic points in each property), show a strong relationship between soil pH and exchangeable aluminium levels (Figure 4). This relationship is strong for both the surface and sub-surface layers, which is consistent with previous studies. These results show that minimal exchangeable aluminium was detected where soil pH was above 4.6, however where soil pH decreased below 4.6, exchangeable aluminium levels increased rapidly.

Based on the grid soil mapping results, three variable rate lime application scenarios were calculated to optimise lime inputs and ameliorate the soil profile. The first scenario involved ameliorating the 0–10cm layer to a target pH of 5.2, while the second involved ameliorating both the topsoil (0–10cm) and subsurface layer (10–20cm) to a target pH of 5.2. The third scenario was designed to achieve a longer-term aspirational goal and involved ameliorating the top 0–20cm to a target pH of 5.8 and maintaining pH above a benchmark figure of 5.5.

In order to ameliorate the top 0–10cm of the profile to the target pH of 5.2 using variable rate applications (scenario 1), an average lime rate of 1.3t/ha was required,

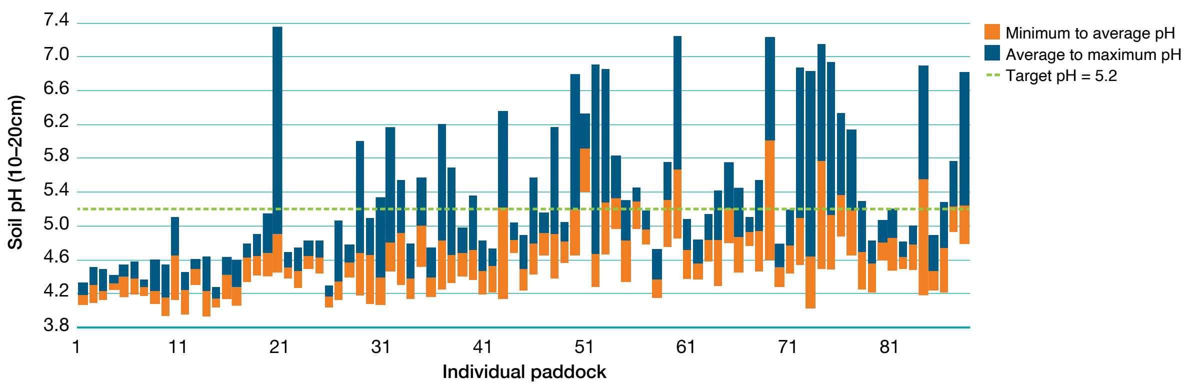

FIGURE 3 10–20cm soil pH across 87 paddocks shown as individual bars ranked in the same order as Figure 2 (average pH is the intersection of the orange and blue lines)

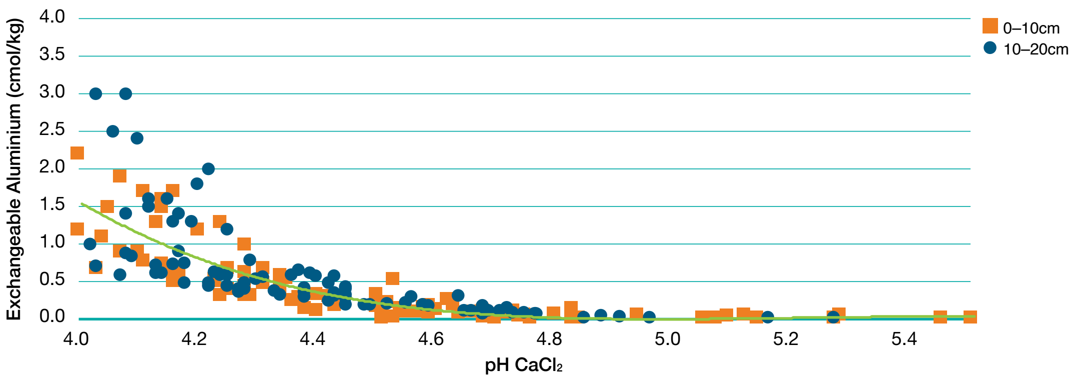

FIGURE 4 The relationship between pH and exchangeable aluminium as measured at the two most acidic points on each property at 0–10cm depth and 10–20cm depth

with 10 per cent of paddocks receiving no lime and 10 per cent of paddocks requiring an average lime application rate in excess of the industry standard (2.5t/ha). Where the aim was to ameliorate to a depth of 20cm (scenario 2), higher rates of lime were required with an average paddock rate of 2.4t/ha and 40 per cent of paddocks requiring an application rate greater than 2.5t/ha. No analysis was conducted for scenario 3, as this is a longer-term goal which is unlikely to be achieved by a single application.

Observations and comments

Soil pH was observed to be highly variable, both horizontally and vertically, within all paddocks tested as part of this project. The range in surface pH across paddocks averaged 0.8 pH units, while the range in sub-surface pH across paddocks and all two-hectare grids averaged one pH unit.

There was not a consistent correlation between the surface and sub-surface pH, due in part to the management and liming history of individual paddocks, as well as the history of product removed from each paddock. This highlights the value of dual-depth sampling when planning management actions such as amelioration (liming) or when considering acid-tolerant species for planting in an acidic topsoil (acid-tolerant species are still vulnerable to toxicities and deficiencies present in the more acidic 0–20cm layer).

When pH drops below 4.6, the levels of exchangeable aluminium were observed to increase. Low soil pH, accompanied by aluminium toxicity, creates a less favourable environment for pasture growth and rhizobial survival, which will reduce the amount of nitrogen fixed by legume pasture species. Pastures grown on acidic soils often also have a diminished root volume, will be more prone to weed invasion, more likely to encounter nutritional deficiencies and have a shorter life-span than pastures grown on higher pH soils.

There are economic and soil health benefits from placing lime more strategically in areas of highest need within the paddock. Tailoring the rate to achieve target pH values will reduce the severity of aluminium toxicity and arrest the re-acidification of the 0–10cm topsoil, as well as the ongoing acidification of the sub-surface 10–20cm layer.

Dual-depth grid soil mapping allows for more strategic use of lime in the short-term and long-term by targeting those areas that need it the most, allowing for the lime resource to be allocated more efficiently. Variable rate lime application strategies were developed for each paddock as a part of individual property management plans and delivered to landholders at workshops during June, 2019.

It is anticipated the property management plans, combined with variable rate lime strategies, will enable the successful establishment of perennial pastures to improve the quality and quantity of feed-on-offer and which will persist beyond the period it takes to recoup the establishment costs.

Acknowledgements

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Companion cropping to utilise rainfall for profit

Dr Meredith Mitchell, Brendan Christy and Dr Garry O'Leary
Agriculture Victoria

Key points

- Four companion mixes (field pea/canola, faba bean/canola, faba bean/wheat and barley/canola) were sown at different ratios at Rutherglen during 2019.
- Six out of eight companion mixes evaluated had a small, but positive, yield advantage over the monoculture treatments.
- Hot, dry conditions during September–October and frost at early flowering affected the yield of canola more than other crops.

Introduction

Companion cropping involves planting and growing two (or more) species of crop in the same paddock at the same time. Companion cropping has the potential to increase the use of total available solar radiation and water per unit of land, offers an opportunity to intensify and diversify grain production, as well as increase yields and profits. In Australia, companion cropping is not widely practiced due to additional labour requirements and the added complexity of management (e.g. harvesting and handling of mixed species).

Aim

To determine if two crop species sown together (companion cropping) could provide an opportunity to intensify and diversify grain production and increase yield and profit.

Method

Four dual-species mixtures (field pea/canola, faba bean/wheat, faba bean/canola and barley/canola) were sown to compare the performance of cereals, legumes and oilseeds when grown as companion crops.

The dual-species mixtures were sown at different species ratio targets of 25:75 per cent, 75:25 per cent and each species was also grown as a monoculture.

On 4 June 2019, a field trial was sown at Rutherglen (Figure 1). Cultivar selection was based on crops with a similar phenology and, except for field pea, herbicide tolerance including imidazoline tolerance (CL) or triazine and imidazoline tolerance (CT). Cultivars were obtained commercially, with seed treated to protect against pests and disease (Table 1).

Seed was sown on 15cm row spacings and plot size was 4.8 x 20m, giving a total plot area of 96m^2. There were four replicates of each treatment.

The pea/canola plots were sprayed with 40g/ha Raptor® herbicide on 5 August, 2019, with the pea/canola and faba bean/canola plots sprayed with 500ml/ha Clethodim 240 and 75ml/ha Verdict on 12 August, 2019. The faba bean/canola, faba bean/wheat and barley/canola

FIGURE 1 Experimental layout at Rutherglen, showing the blocked design of the companion cropping experiment on the right



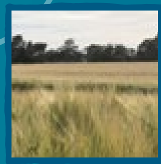

TABLE 1 Crops, cultivars and herbicide treatments for the companion cropping experiment at Rutherglen, 2019

Sowing fertiliser:	100kg/ha of MAP	
Pre-sowing herbicides:	Terbyne® (0.86kg/ha), trifluralin (1.5L/ha), Nail® (55mL/ha), and glyphosate (1.4L/ha)	
In-crop insecticides:	Veritas, Aviator X	
Crop	**Cultivar**	**Herbicide tolerance**
Barley	Spartacus CL	Imidazolinone
Canola	Hyola® 580 CT	Triazine and imidazolinone
Faba bean	PBA Bendoc	Imidazolinone
Field pea	PBA Butler	Nil
Wheat	Sheriff CL	Imidazolinone

plots were sprayed with 600ml/ha Intercept (Intervix) on 23 August. The main weeds being targeted at the site were wireweed (*Polygonum aviculare*), shepherd's purse (*Capsella bursa-pastoris*) and ryegrass (*Lolium rigidum*). Ryegrass in the barley/canola treatments was effectively suppressed by crop competition, so was not problematic. The herbicide weed control strategies were successful in all but the faba bean/wheat treatment, as Clethodium was not able to be applied to this treatment combination.

Plant establishment was recorded as plants per square metre, from random areas within the plots seven weeks after sowing, with establishment rates generally lower than the target populations. Flowering biomass was measured on 1 October 2019. Both species in each dual-species mixture were harvested together with a header, with grain separated post-harvest using a small-scale seed grader.

Rainfall at Rutherglen during 2019 was below average (Table 2). However timely, above-average rainfall during May, combined with good rainfall totals during June and July, helped to maintain yield potential above what would be expected given the dry spring conditions. Regular frosts during September and October coincided with key flowering and early grain filling periods for most crops, although the later time of sowing for this trial reduced its exposure to most of the severe frosts.

Results

Assessing the growth of companion crops is more complex than assessing monocultures, with several approaches available. The most commonly used approach is the land equivalent ratio (LER), which describes the additional land needed to grow the same quantity of both species if they were grown as monocultures, rather than as companion crops. The LER calculation is as follows;

TABLE 2 Rainfall at Rutherglen during 2019 compared with the long-term average

Month	Rainfall (mm)	Long-term average rainfall (mm)
January	10.0	37
February	36.4	39
March	24.6	39
April	0.8	42
May	85.0	50
June	45.0	56
July	41.4	63
August	20.6	60
September	19.8	54
October	8.8	57
November	41.0	46
December	16 .0	45
2019 total	**349.4**	**588**
2019 GSR (April – October)	**221.4**	**382**

$$LER = (Y1_c \div Y1_m) + (Y2_c \div Y2_m)$$

Where $Y1_c$ or $Y2_c$ = yield of crop 1 or 2 as a companion crop

$Y1_m$ or $Y2_m$ = Yield of crop 1 or 2 as a monoculture

The LER values for this trial were calculated using biomass at flowering and grain yield at harvest. An LER value of 1.0 means the productivity of the companion crop mix is equal to the monoculture components. An LER value greater than 1.0 means the companion crop is more productive than the monoculture components and is referred to as over-yielding.

i. Barley/canola companions

Total biomass at flowering (LER) was 7 per cent lower in both companion treatments compared with their monoculture biomass yield (Table 3, Figure 2).

Canola biomass at flowering indicated a higher yield potential than was achieved at harvest, likely due to the impact of frost at the start of canola flowering as well as hot and dry conditions during late October.

Total grain yield (LER) was 4–5 per cent higher in the barley/canola companion crop mix compared with their monoculture yields. For both the 25:75 and 75:25 barley/canola companion crop ratios, the canola yield was lower on an area basis compared with its monoculture, however the barley yielded well, leading to a high yield overall (Table 3, Figure 3).

TABLE 3 Barley/canola companion treatment results for flowering biomass, grain yield and land equivalent ratios (LER), Rutherglen, 2019

Planting ratio	Monoculture	75:25		25:75		Monoculture
Species mix	Barley (100%)	Barley (75%)	Canola (25%)	Barley (25%)	Canola (75%)	Canola (100%)
Flowering biomass (t DM/ha)	7.9	6.1	0.9	2.8	3.1	5.4
Flowering (LER*)	-	**0.93**		**0.93**		-
Grain yield (t/ha)	5.8	4.5	0.2	2.0	0.4	0.7
Grain (LER*)	-	**1.04**		**1.05**		-

* LER is a measure of crop yield when grown as a companion compared with that same crop grown as a monoculture.

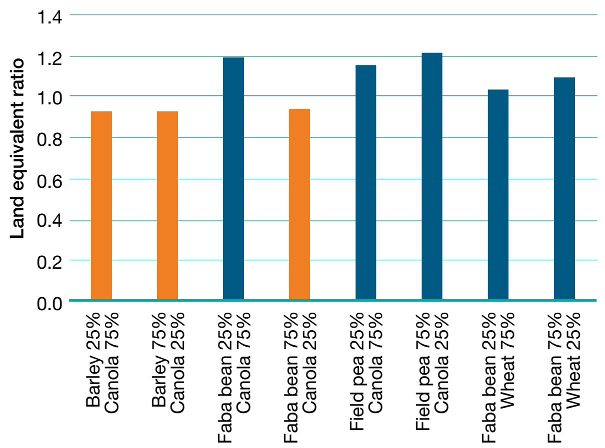

FIGURE 2 Land equivalent ratio (LER) of biomass at flowering for the four companion crop combinations at Rutherglen, 2019
Standard error of difference is 0.013.

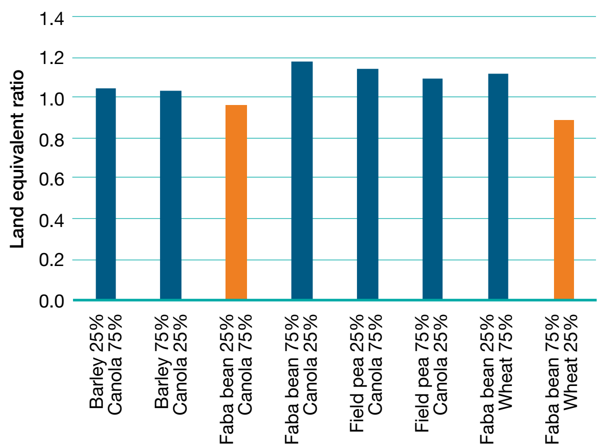

FIGURE 3 Land equivalent ratio (LER) of harvest biomass for the four companion crop combinations at Rutherglen, 2019
Standard error of difference is 0.019.

ii. Faba bean/canola companions

Total biomass at flowering (LER) was 15–21 per cent higher in both companion treatments compared with their monoculture (Table 4, Figure 2). Canola biomass at flowering indicated a higher yield potential than was achieved at harvest due to the impacts of frost at the start of flowering and hot and dry conditions during late October.

Total grain yield (LER) was -4 per cent for the faba bean:canola ratio of 25:75 per cent and +18 per cent for the faba bean:canola ratio of 75:25 per cent in crops grown as companions (Table 4, Figure 3).

25

iii. Field pea/canola companions

Canola and field pea biomass results at flowering indicated a higher yield potential than was achieved at harvest, with canola flowering impacted by frost and pod set by hot and dry conditions during late October (Table 5, Figure 2).

Total grain yield (LER) was 9–14 per cent higher in crops grown as a companion. In each of the companion crops, the field pea yield was lower on an area basis compared with its monoculture, however the extra yield achieved in the canola companion lead to a high yield overall (Table 5, Figure 3).

iv. Faba bean/wheat companions

Total biomass at flowering (LER) was 4–10% higher in both companion treatments compared to their monoculture (Table 6, Figure 2).

TABLE 4 Faba bean/canola companion treatment results for flowering biomass, yield and land equivalent ratios (LER), Rutherglen, 2019

Planting ratio	Monoculture	75:25		25:75		Monoculture
Species mix	Faba bean (100%)	Faba bean (75%)	Canola (25%)	Faba bean (25%)	Canola (75%)	Canola (100%)
Flowering biomass (t DM/ha)	4.1	2.4	2.9	1.0	4.8	5.2
Flowering (LER*)		**0.94**		**1.19**		
Grain yield (t/ha)	1.8	0.6	0.6	0.2	0.6	0.7
Grain (LER*)		**1.18**		**0.96**		

* LER is a measure of crop yield when grown as a companion compared with that same crop grown as a monoculture.

TABLE 5 Field pea/canola companion treatment results for flowering biomass, yield and land equivalent ratios (LER), Rutherglen, 2019

Planting ratio	Monoculture	75:25		25:75		Monoculture
Species mix	**Field pea (100%)**	**Field pea (75%)**	**Canola (25%)**	**Field pea (25%)**	**Canola (75%)**	**Canola (100%)**
Flowering biomass (t DM/ha)	3.9	3.0	2.2	0.8	4.3	5.9
Flowering (LER*)		**1.21**		**1.15**		
Grain yield (t/ha)	1.0	0.6	0.4	0.2	0.8	0.9
Grain (LER*)		**1.09**		**1.14**		

* LER is a measure of crop yield when grown as a companion compared with that same crop grown as a monoculture.

TABLE 6 Faba bean and wheat companion treatment results for flowering DM, yield and land equivalent ratios (LER), Rutherglen, 2019

Planting ratio	Monoculture	75:25		25:75		Monoculture
Species mix	**Faba bean (100 %)**	**Faba bean (75%)**	**Wheat (25%)**	**Faba bean (25%)**	**Wheat (75%)**	**Wheat (100%)**
Flowering biomass (t DM/ha)	4.2	2.9	2.5	1.2	5.8	7.2
Flowering (LER)		**1.04**		**1.10**		
Grain yield (t/ha)	1.4	0.4	2.6	0.1	4.1	4.2
Grain (LER*)		**0.89**		**1.12**		

* LER is a measure of crop yield when grown as a companion compared to that same crop grown as a monoculture.

%

Total grain yield (LER) was -11 per cent for the faba bean:wheat ratio of 75:25 per cent and +12 per cent for the faba bean:wheat ratio of 75:25 per cent in crops grown as a companion (Figure 3).

Observations and comments

This research demonstrates that companion cropping has the potential to increase yield in the cropping regions of southern Australia. Further work is being undertaken to determine the economic profitability and risk of companion cropping in a whole-farm context.

There are also different herbicide options available for use in these companion systems, which may provide alternative management options for grain growers.

This research is part of a project that had field experiments sown at core experimental sites at Rutherglen, Hamilton and Horsham during 2019. During 2020, additional satellite sites were sown in north-east Victoria at Burramine South and Caniambo.

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Estimating leaf nitrogen and grain protein content in wheat from hyperspectral remote sensing data

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Key points

- Airborne hyperspectral remote sensing of wheat to diagnose leaf nitrogen (N) status is new to Australia.
- By suppling in-season information on crop nitrogen status, hyperspectral and thermal remote sensing could improve fertiliser efficiency and reduce input costs.
- The chlorophyll content of leaves collected from small plots at Yarrawonga was correlated with some vegetation indices and solar-induced fluorescence collected using hyperspectral remote sensing.
- Reasonably accurate predictions of canopy nitrogen can be made by applying machine learning (ML) computer algorithms, which have been 'trained' using plots where canopy nitrogen is known.

Introduction

This study aims to estimate leaf and canopy nitrogen (N) content from airborne remote sensing imagery in both plot trials and commercial wheat crops. The study will also investigate links between canopy nitrogen content and grain protein at harvest. This is a new application of both hyperspectral remote sensing and machine learning (ML) methods to crop performance in Australia.

Leaf nitrogen content gives an indication of crop nitrogen status via estimates of chlorophyll concentration. By using remote sensing to 'see' chlorophyll fluorescence (the energy given off by photosynthesising leaves), it is possible to map the rate of photosynthesis across plots or paddocks, giving insight into the effect of, or need for, nitrogen fertiliser. Having a detailed knowledge of crop photosynthesis provides a more comprehensive understanding of crop nitrogen status, allowing grain growers to use strategic fertiliser applications to improve yield, grain quality and overall profitability.

Several approaches are currently available to estimate plant performance using remote sensing technology. Spectral indices, such as the normalised difference vegetation index (NDVI), combine a small number of bands of light reflected from the crop canopy. This 'broadband' sensing is used by portable instruments such as Crop Circle® and GreenSeeker® and can show a limited range of crop properties. However, NDVI and other broadband indices are not sensitive enough to account for normal agronomic variability; for example, changes in row spacing or soil colour can make a large difference, rendering comparisons across seasons or regions impossible. These technologies cannot provide detailed information on specific traits, such as chlorophyll or leaf nitrogen content.

In contrast, hyperspectral sensors record canopy radiance at a high resolution. In the area of visible light, where most broadband sensors (e.g. a phone camera) can 'see' only three broad bands (red, green and blue), hyperspectral sensors can detect hundreds of bands of reflectance. These images can be analysed to map plant performance across and between paddocks. The methods are still being developed but can already achieve near-real time diagnosis of nitrogen status without any ground-level contact with crops or use of nitrogen-rich strips.

While this study focuses on the nitrogen status of leaves and grain, other applications of the same methods include pathogen or weed detection and detection of disease-resistant cultivars in breeding trials.

In a world first, this study combines airborne hyperspectral remote sensing and real-world grain quality information to investigate these links at commercial paddock level.

The study also applies machine learning algorithms to estimate canopy and grain traits from large streams of data. Machine learning algorithms are already used in areas as diverse as medicine, finance and automated text recognition and they involve a computer that 'learns' to recognise patterns in data and to associate these with information provided by humans. In effect, a mathematical algorithm is applied to a large collection of numbers, such as those obtained from remote-sensing images, and the algorithm is 'trained' to recognise that a given quantity (i.e. leaf nitrogen) is related to that particular pattern of numbers. After the algorithm is 'trained' it can estimate the value of leaf nitrogen.

This study analysed hyperspectral remote-sensing data collected from plot trials sown by Riverine Plains Inc, FAR Australia and Birchip Cropping Group. Additional yield and protein data were collected from on-the-go monitors supplied by growers.

Aim

This project aims to advance methods of estimating leaf nitrogen and grain protein content in wheat from hyperspectral and thermal remote-sensing data by:

- applying machine learning to crop image data to retrieve leaf nitrogen status at different crop stages
- investigating relationships between canopy nitrogen obtained from hyperspectral data, heat and water stress at different crop stages with grain quality at harvest in order to predict grain quality
- investigating spatial relationships between information from remote-sensing sources with data from on-the-go harvest grain protein monitors.

Methods

Riverine Plains Inc and FAR Australia provided access to 20 experimental wheat plots (cv. Scepter) at Burramine, near Yarrawonga, Victoria. The trial comprised plots sown under various agronomic treatments across a range of leaf nitrogen concentrations.

The trial plots were sown with 50 kg/ha MAP, followed by in-season nitrogen applications of urea at early tillering (GS21) and at first node (GS31). Another 140 plots, from three separate trials, received a range of variety, fertiliser and other treatments and were included in airborne data analysis, with a subset of ground-level data collection added. University of Melbourne researchers collected in-crop measurements and samples during early October 2019 to ground truth airborne estimations of specific crop traits. Photosynthetic rate was measured using a gas exchange instrument, while three different hand-held devices were used to estimate leaf chlorophyll, other leaf pigments and leaf-level fluorescence. Leaf samples were also taken for laboratory analysis of chlorophyll nitrogen content.

A similar plot experiment was conducted at Birchip, with plus and minus nitrogen fertiliser applications targeting modelled yield predictions and ground-level measurements. Approximately 360 additional plots were added to the trials at Birchip and Yarrawonga during the growing season, with hyperspectral images captured and correlated to the collected yield and grain protein data. Flights were also undertaken to capture images across 800 hectares of commercial wheat near Kaniva in the Wimmera region of western Victoria, where the farmer co-operator provided yield and grain protein data from the 2019 harvest (data not presented in this report). Data collection from plots and crops will continue during 2020.

Hyperspectral data was collected by sensors mounted on a Cessna 162 light aircraft during early October 2019, on clear days and during the hours of maximum daily plant activity. Radiance (the light coming from the crop canopy) was captured in the visible and near infrared (VNIR), with passes at different heights giving pixels of 30–50cm on the ground. The on-ground activities described above were timed to coincide with the flights and targeted the uppermost, fully-expanded sun-adapted leaves. Meteorological, atmospheric and radiation data were also recorded. Grain samples were collected after harvest and analysed for both grain protein and total nitrogen by mass (data not presented).

Radiance is measured in watts per square metre and differs according to both plant traits and the colour of the light (also known as its wavelength or band). *Reflectance* is calculated from *radiance* and is the proportion of total sunlight striking the canopy reflected per wavelength. Much of the green light in sunlight is reflected (which is why we see plants as green), while plants use blue and red light for photosynthesis (meaning little of this is reflected for us to see).

In calculating indices for this study, wavelengths chosen for their relevance to chlorophyll were combined mathematically with other wavelengths. This process generates a relative number, which like radiance and reflectance, is specific for each wavelength or band (NDVI is just such a number). For this study, more than 80 hyperspectral indices were calculated for each plot.

Chlorophyll fluorescence was also retrieved from the hyperspectral data. In addition to hyperspectral images, thermal images were also captured and included for analyses (data not presented in this report). Canopy temperature may act as a further indicator of both yield and grain protein because water-stressed plants heat up more than non-water stressed plants and their performance is reduced because they close their stomata. If plants are consistently water stressed through the season, they are unable to take up nitrogen effectively. Water stress in the post-flowering period is also related to higher grain protein levels, because grain filling is limited.

Interim results

Figure 1 shows an example of a hyperspectral images taken of the plots at Yarrawonga during October 2019, with variations in reflectance clearly seen across the plots.

Selected vegetation indices demonstrated moderately strong relationships between ground and airborne observations. An example of this is the triangular greenness index (determined using hyperspectral remote sensing), which showed a moderately strong and statistically significant relationship with chlorophyll (determined through leaf sampling) (Figure 2). These results identify the areas

FIGURE 1 Airborne false-colour hyperspectral image of Yarrawonga plots, 10 October 2019

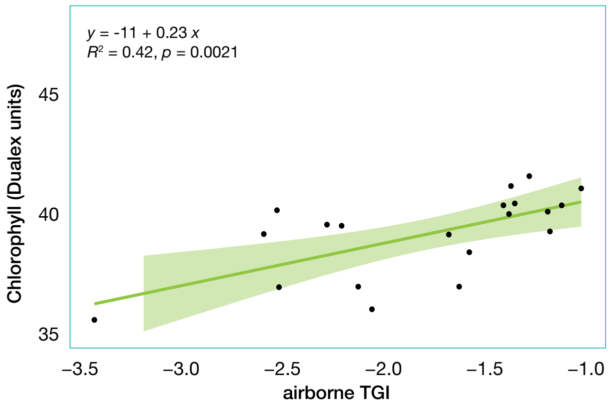

FIGURE 2 Chlorophyll content as a function of triangular greenness index calculated from airborne data for 20 plots at Yarrawonga, 10 October 2019

Note: Shaded area is standard error.

of the light spectrum and the indices most relevant to chlorophyll and nitrogen at leaf level, and which may also be associated with grain protein content.

Chlorophyll fluorescence was also measured by remote sensing. This also showed a moderately strong and statistically significant relationship with chlorophyll measurements collected in the field at Birchip and Yarrawonga (Figure 3). This is important because chlorophyll fluorescence is a proxy for the actual instantaneous rate of photosynthesis and so can be used to identify variability in plant performance due to crop nitrogen or water status associated with soil variability. This result supports the case for fluorescence to be added to other remotely sensed information to improve estimates of leaf and grain nitrogen in future analyses.

Results at Birchip were broadly similar to those at Yarrawonga, with somewhat stronger relationships shown between fluorescence and both chlorophyll from leaf clip measurements and total leaf nitrogen from leaf material analysis. The generally closer relationships between the airborne data and ground-truth data at Birchip are likely related to greater soil water availability following heavy rainfall during late 2018. The plots at Birchip showed lower water stress than the Yarrawonga plots.

Observations and comments

Early crop senescence, brought on by limited soil water availability during October 2019, meant observations at Yarrawonga were taken later than was ideal. Despite this, the results showed a strong relationship between the triangular greenness index and chlorophyll fluorescence calculated from airborne data and ground-truthed using physical measurements.

The next steps are to complete grain quality determinations, then complete a statistical analysis and machine learning to improve predictions of both leaf and grain nitrogen. Several methods of extracting crop information from the available data will be combined and their ability to predict crop qualities tested.

Acknowledgements

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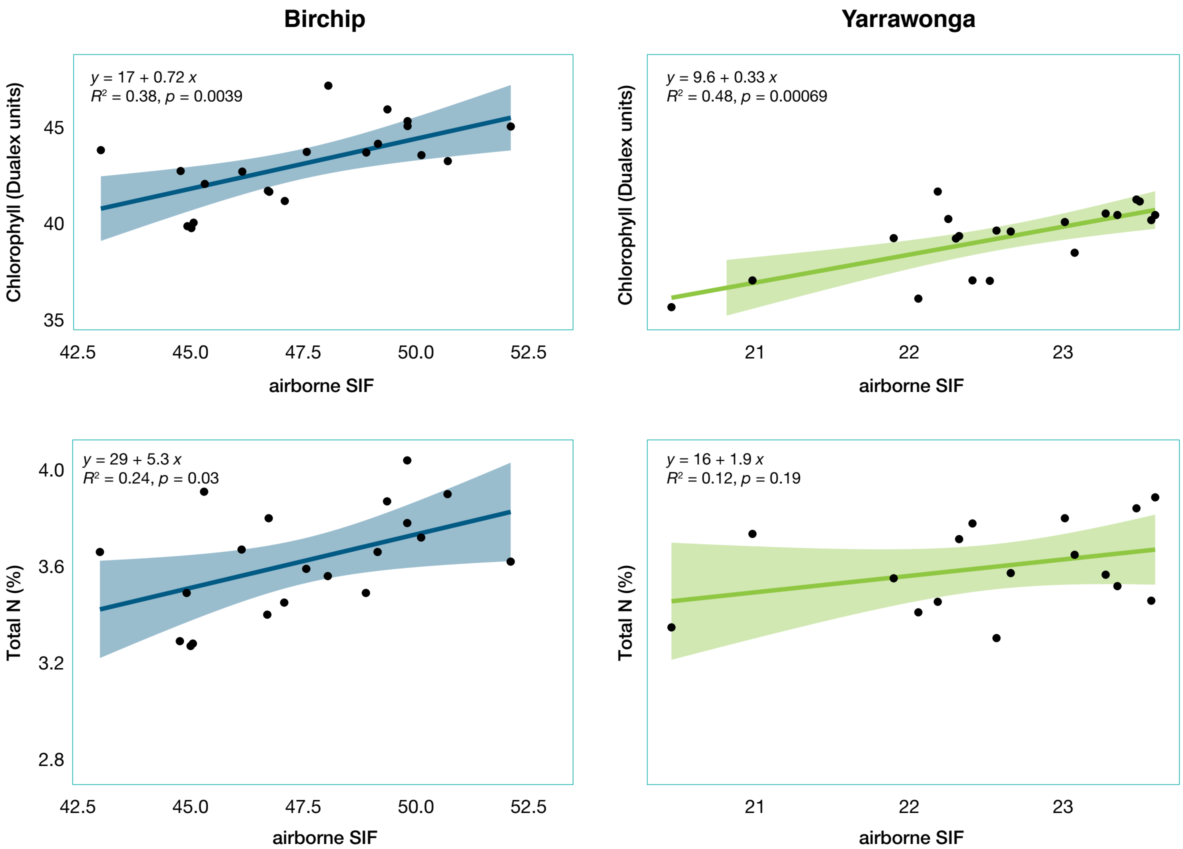

FIGURE 3 Chlorophyll content and total nitrogen as a function of solar-induced chlorophyll fluorescence (SIF; relative units) retrieved from airborne data for 20 plots at each of Birchip and Yarrawonga, 10 October 2019

Note: Shaded area is standard error.

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