GRAINS RESEARCH UPDATE

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Parkes

Wednesday 14th August

9.00am to 1.00pm

Parkes Services Club,

9 Short Street, Parkes

#GRDCUpdates

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GRDC Grains Research Update
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9:50 am	**Ameliorating sodic subsoil constraints**	***Ehsan Tavakkoli,*** *NSW DPI*
10:30 am	***Morning tea***	
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11:40 am	**Better pastures – better crops**	***Jeff McCormick,*** *Graham Centre for Agricultural Innovation*
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Central West Farming Systems Inc (CWFS)

Central West Farming Systems Inc (CWFS) was formed in 1998 as a farmer based research group with the motto of: "***Farmers Advancing Research".***

The principal aim of the organisation is:
"To be the leading regional group effectively demonstrating, extending and promoting farming innovation to assist farmers manage their businesses for long term economic, social and environmental viability"

The group is managed by an Executive Committee comprising of 10 farmers & industry representatives. CWFS currently has over 330 members. These are predominately farmers, although we are also strongly supported by private advisers, agribusiness, research organisations and universities. Core funding for our activities derive from industry and Government funding programs. Our major funding partners currently include the Grains Research and Development Corporation (GRDC), CRC for High Performance Soils, government agencies, Landcare and Local Land Services. CWFS works closely on a number of projects with universities, the Low Rainfall Collaboration Group and other farming systems groups at a national and regional level.

Our projects include:

- Maintaining profitable farming systems with retained stubble in Central West NSW
- Improving grower profits through longer season wheat crops
- Soil Acidity and pH Management for Central West Farming Districts
- Women and Youth in Agriculture
- Nitrogen Use Efficiency

CWFS' Women & Youth in Agriculture Project has been established since 2009 and aims to engage and empower women and youth to participate more fully in agriculture and increase productivity through building opportunities.

This Project incorporates workshops, conferences, field days and mentoring groups to encourage women and young people to become decision makers within their farm businesses.

CWFS has developed an AgMarketing program which supports on-farm decision makers in their substantial commodity marketing role.

Irrigation research

In 2014 CWFS officially commenced irrigation research via its Condobolin based irrigation site now known as The Fettell Centre. In 2018, a $422,890 multi-purpose, field-based laboratory was built at the Centre and officially opened in August 2018. The infrastructure investment project is a collaboration between GRDC, CWFS and Lachlan Shire Council. This facility provides CWFS an unprecedented opportunity to expand its areas of research into irrigated crop varieties, irrigation technologies & techniques, and water use efficiencies within an irrigation system.

Members receive information via a wide variety of publications and extension activities.

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Management of hard to control weeds

Christopher Preston.

School of Agriculture, Food & Wine, University of Adelaide.

GRDC project codes: UA00149, UA00158, UCS00020

Keywords

- fleabane, windmill grass, silverleaf nightshade, wild oats, glyphosate resistance.

Take home messages

- Management of hard to control weeds requires an understanding of when the weeds germinate.
- High efficacy is needed with the first herbicide mixture to achieve good double knock control of fleabane in summer.
- Windmill grass needs to be controlled as soon as it is noticed, as the old plants are much harder to control.
- Early autumn applications are better for getting glyphosate into the root system of silverleaf nightshade than summer applications.

Hard to control weeds

The main reason there are hard to control weeds in farming systems is that the current weed management practices that are used do not control them. This may be because there are no effective herbicides available for that weed, the germination pattern of the weed means it avoids current control methods or for a number of other reasons. Many of these weeds tend to be weeds that have come into prominence due to changes in farming systems, and therefore, we have limited experience with these weeds.

In order to develop better management strategies for these weeds it is necessary to understand the biology and ecology of the weeds, so that the management strategies can be better targeted. Understanding the time of emergence of the weeds can be particularly important, in order that control practices are implemented at the time of or shortly after emergence when weeds are small.

Fleabane

Fleabane has been present for a long time in Australia but it has only become a weed of cropping systems in recent years. Fleabane is a small seeded weed that requires several days of moist soil on the surface to germinate. Therefore, it is favoured by no-till, stubble-retention farming systems. It germinates primarily in spring, but if water is available, it can germinate through summer into early autumn provided temperatures are not too hot. Many fleabane populations in Australia are resistant to glyphosate, which makes them harder to control in the summer fallow period.

The best time to control fleabane is in late winter and early spring as it is germinating. Amicide® Advance and FallowBoss® Tordon® can be used in cereals. However, the latter has a 20-month plant back to pulse crops, cotton and pastures and a 12-month plant back to canola, so care needs to be taken when it is used in crop.

If control is left until after harvest, a double knock approach must be used. This is normally glyphosate plus a Group I herbicide, followed at least two weeks later by paraquat. However, the first application needs to provide at least 60% control of fleabane on its own to get effective fleabane control with the double knock (Figure 1).

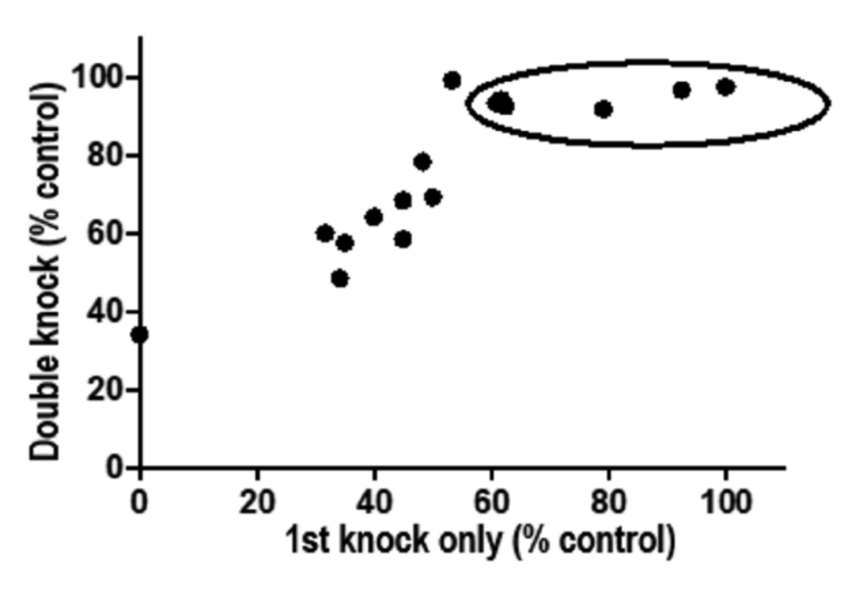

Figure 1. Fleabane control in fallow of standalone herbicide treatment (1st knock) compared with control from the double knock with paraquat for each treatment at two trial sites (Bute and Pinnaroo, SA). Data from Ben Fleet, University of Adelaide.

Crop competition can also be used to reduce establishment of fleabane. Fleabane occurs most commonly following poorly competitive cereals, pulse crops and pastures. Increasing the amount of competition in cereal crops will limit the number of fleabane plants that survive through to crop harvest.

Windmill grass

Windmill grass is another surface-germinating weed species like fleabane. Windmill grass is an Australian native and has been sown widely in areas with summer rainfall as a pasture grass. Unlike fleabane, windmill grass is a short-term perennial, with plants surviving for several years. Some windmill grass populations have evolved resistance to glyphosate, making them harder to control in the summer fallow period.

Windmill grass germinates in both spring and autumn. The optimum temperature for germination is 25°C but it has a broad range for germination from 15°C to 30°C (Figure 2). Light is required for germination, which is why windmill grass is increasing as a problem in no-till systems. Windmill grass seed fails to germinate from even as little as 0.5cm below the surface, so is unlikely to be a

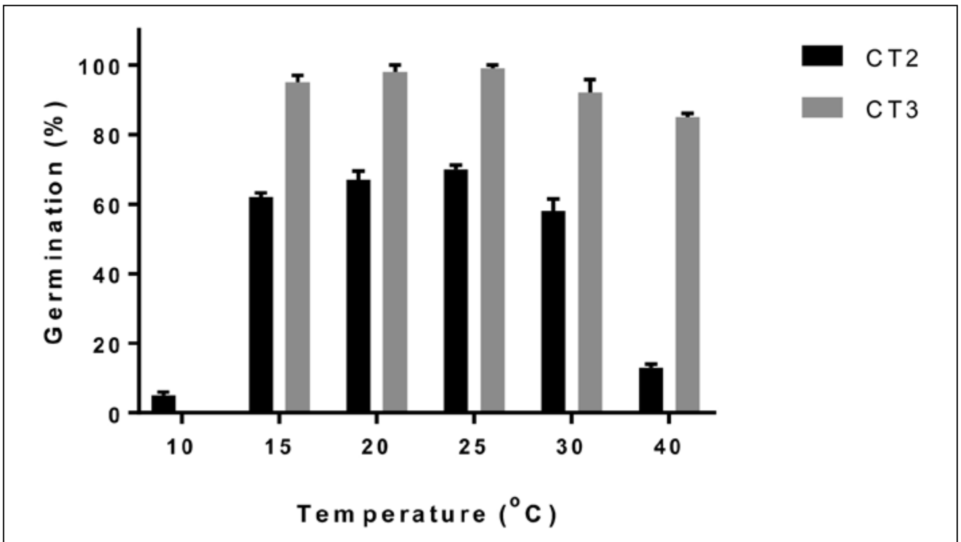

Figure 2. The effect of temperature in the light on germination of windmill grass seeds from two different populations (CT2 and CT3). Data from The Duc Ngo, University of Adelaide.

problem in cultivated cropping systems. Cultivation can also be used to control perennial plants, but a follow up treatment for new seedlings is required.

The challenge to managing windmill grass is that there are almost no herbicides registered for its control. Butroxydim in summer-growing broadleaf crops is the only registered in-crop herbicide. In summer fallows, some glyphosate products are registered for control. There is also a permit for the use of quizalofop-ethyl in fallows, provided it is double-knocked within seven days with paraquat. Particularly challenging to control are the older established plants from previous years, which often have dead leaves around the base. Getting good herbicide coverage on these older plants is challenging. Consequently it is important to control windmill grass as soon as it is noticed.

Silverleaf nightshade

Silverleaf nightshade is a summer growing perennial weed with a large root system. The root system may grow more than 3m deep and 10m or more across. Silverleaf nightshade has the ability to grow new stems from small root pieces. Controlling the shoots of silverleaf nightshade does not necessarily control the root system and control of the root system is necessary to achieve long-term control.

Silverleaf nightshade seedlings are rarely seen. Silverleaf nightshade seeds are covered by a mucilaginous coating that prevents germination. As this needs to be removed before germination can occur, germination typically only occurs after very wet conditions. Most often this will happen with wet spring and early summer conditions, such as in 2016. This is why silverleaf nightshade patches tend to appear out of nowhere. Control of seedlings is easy but finding them is difficult. This means control tends to focus on managing established plants.

Silverleaf nightshade seeds readily survive passage through stock. Sheep are the main cause of silverleaf nightshade spread in Australian agriculture. While initially stock may avoid eating the berries, sheep can get a taste for them and actively consume the berries. Birds, farm machinery and fodder are also likely vectors of spread of seed but are of much less importance than sheep. As silverleaf nightshade can grow new shoots from root fragments as small as 5cm in length, cultivation does not control silverleaf nightshade and can help to spread patches of the weed.

Work to introduce a biological control of silverleaf nightshade is underway; however, in the meantime herbicides are the only effective control practice. There are few herbicides with any efficacy against silverleaf nightshade. Some like 2,4-D simply kill the shoots without reducing root growth. With others, timing is everything in terms of getting the herbicide into the root system. Research work looking at glyphosate movement in silverleaf nightshade plants showed that application of glyphosate after flowering moved the most herbicide into the root system, whereas application at flowering tended to have little movement (Figure 3). This is because flowering plants are moving photosynthate (and glyphosate) into the developing flowers and fruits, rather than into the roots.

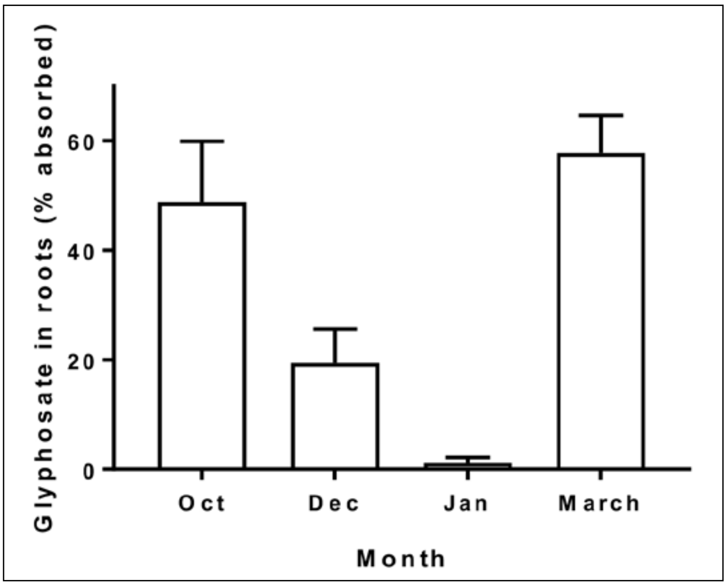

Figure 3. Translocation of glyphosate into roots of silverleaf nightshade plants at different times of the growing season. Silverleaf nightshade tends to flower in the period December to February and glyphosate translocation to the roots is reduced in this period. Data from Kerensa Greenfield, University of Adelaide.

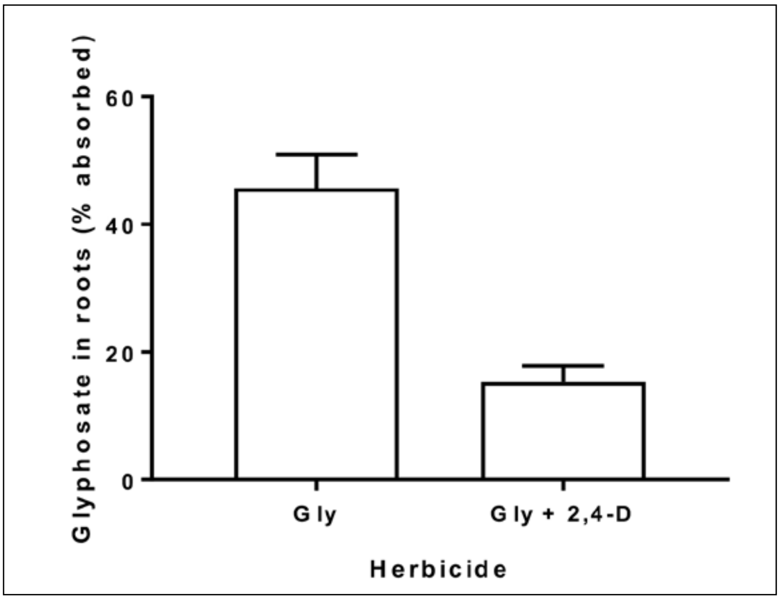

Figure 4. Effect of adding 2,4-D on translocation of glyphosate into roots of silverleaf nightshade plants. Data from Kerensa Greenfield, University of Adelaide.

Adding 2,4-D to glyphosate is counter-productive to getting glyphosate into the roots (Figure 4). This is because the addition of 2,4-D tends to kill the shoots quickly and limits the movement of glyphosate into the root system. The best approach for glyphosate application to silverleaf nightshade is to apply the herbicide immediately after harvest, but before flowering of the weed, and then to have a second application in early autumn. Due to the extensive root system, it will take five to ten years to see a noticeable decline in the density of silverleaf nightshade patches.

Wild oats

The main problem with wild oats is that it has resistance to both the Group A and Group B herbicides. What is more of a concern is the increasing resistance to Axial®, which is used for late season control of wild oat seed set. Our data suggests that resistance across the fop herbicides in wild oats can be variable, so getting a resistance test to determine whether any of the products still work can be useful.

Control of wild oats with pre-emergent herbicides has been challenging in the past, but new products and a move to no-till have offered new approaches to controlling wild oats. Data has shown that Trifluralin + Avadex®Xtra or Sakura® + Avadex® Xtra consistently provide control of wild oats in wheat. Due to the ability of seeds to bury themselves in soil and the more extended emergence of wild oats, crop competition in combination with pre-emergent herbicides is an essential component of reducing wild oat seed set of late emerging plants.

The challenge comes in the pulse phase of rotations where due to lower competition, later emerging wild oat seedlings can produce a lot of seed. Wild oat tends to mature earlier than ryegrass and seed can shed well before harvest. This makes crop topping and harvest weed seed control practices less effective on wild oats. Getting the rotation right and using all the practices that are available can keep wild oats under control.

Useful resources

https://grdc.com.au/__data/assets/pdf_file/0023/109049/grdc_fs_fleabane_low-res-pdf.pdf.pdf

http://sciences.adelaide.edu.au/agriculture-food-wine/system/files/docs/2017-wmg-biology.pdf

https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/839857/Silverleaf-nightshade-best-practice-management-manual-2018.pdf

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Notes

Understanding the amelioration processes of the subsoil application of amendments

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GRDC project code: DAV00149

Keywords

- soil constraints, sodic soils, amendments, amelioration.

Take home messages

- The early results of this project showed great potential in improving soil structure and crop productivity in sodic subsoils using deep placement of organic and inorganic amendments. The increases resulted from improvement in the physical and chemical properties of the clay soil volume around the rip line containing the organic and inorganic amendments, and from increased root growth through the subsurface soil layers adjacent to the rip lines. This improvement was possibly mediated by increased microbial activity that leads to improved soil aggregation.
- In both years of the field experiment, the greatest yield response was achieved in the pea hay + gypsum + nutrients treatment. Given multiple subsoil constraints including high pH, sodicity and poor soil structure that exist in south-east Australia, an amendment with multiple modes of action is required to improve hostile subsoils.
- It is proposed that a reduction in net dispersive charge and pH together with an enhanced microbial biomass carbon (C) resulted in improved soil aggregation. The changes in soil chemicophysical properties correlated with higher crop water uptake from the ameliorated layer.

Background

Approximately 75% of Australian soils have subsoil constraints that limit agricultural productivity. The major constraints to crop growth are poorly structured subsoils that result from high clay content and bulk density, as well as the presence of high subsoil exchangeable sodium (Na) concentrations (resulting in soils with poor subsoil structure, impeded drainage, waterlogging, and high soil strength). These constraints adversely affect soil water and plant available water content (PAWC) by impeding water entry into the soil, restricting water movement within the soil, reducing the soil's ability to store water and nutrients, and reducing the ability of plants to access and extract stored water and nutrients. Soil constraints may be multiple or singular, occurring either near the soil surface, or in the subsoil and they tend to be highly variable across any given paddock or property (McDonald et al. 2013).

A range of practices including deep ripping, subsoil manuring, clay incorporation, applying gypsum, installing underground drainage or use of 'primer-crops' have been tested to overcome subsoil constraints, usually with unreliable results and often potential financial losses to growers (Gill et al. 2008). For example, despite the fact that gypsum is widely used as the main soil amendment in improving poor structure of sodic soils, it is a sparingly soluble salt and because of this attribute it is hardly possible to deliver adequate calcium (Ca) to correct sodicity issues in the subsoil. In regards to subsoil manuring, despite the demonstrated step change in crop yields that can be achieved by this management strategy, practice change in the grains industry to date has been limited. One constraint to widespread adoption includes the local availability and high cost of suitable organic ameliorants delivered in-paddock. This factor can be significant as research to date in the higher rainfall zones suggests rates of up to 20t/ha are required — transport costs quickly become prohibitive if this material needs to be sourced off-farm (Gill et al. 2008; Sale et al. 2019). Therefore, solutions integrating complementary sources of organic matter materials, such as crop residue and cover crop biomass produced in-situ, need to be investigated, with current project DAV00149 initiating this new area of research.

A series of field and glasshouse experiments was established to understand the amelioration process when various organic and inorganic amendments are placed at depth in dispersive subsoils. This paper will provide results of a GRDC project (DAV00149) aiming to ameliorate subsoil constraints and to understand the amelioration processes of the subsoil application of amendments. It will show how deep incorporation of organic amendments into the clay subsoil provided significant improvements in grain yield, which was associated with changes in subsoil properties and improved root growth.

Method

Field trial

The two-year field experiment was established on a farm in Rand, southern NSW, in February 2017. The site was located in a paddock that had been cropped with a cereal-canola rotation for more than 50 years. Selected soil properties collected from the untreated soil are presented in Table 1. The soil is a Sodosol (Isbell, 2002), with a texture-contrast profile increasing in clay content at depth. The physical and chemical properties indicate that the subsoil condition was unfavourable for root growth. The high clay content in this subsoil layer has a bulk density of 1.55g/cm3 that restricts water movement, and consequently the saturated hydraulic conductivity value is low at 0.03cm/hr (Table 1).

The experimental plots were 2.5m wide and 20m long. There were 14 treatments comprising 1) the control, 2) surface application of gypsum, 3) surface application of chicken manure, 4) surface application of pea hay, 5) deep ripping, 6) deep placement of gypsum, 7) deep placement of manure, 8) deep placement of wheat stubble, 9) deep placement of wheat stubble + nutrients, 10) deep placement of pea hay, 11) deep placement of biochar, 12) deep placement of pea hay + nutrients, 13) deep placement of liquid nutrients, and 14) deep placement of pea hay + gypsum + nutrients. The experiment was a randomised complete block design with four replicates. Ripping and subsoil incorporation treatments were carried out with a 3-D ripping machine (NSW DPI). The machine can deliver inorganic and/or organic amendments at two depths from 10cm to 30cm. The machine is also capable of delivering liquid nutrients/fertilisers at depth. The experiment at Rand was sown to barley (cv. La Trobe⁽ᴰ⁾) on 18 May 2017 and wheat (cv. Lancer⁽ᴰ⁾) on 15 May 2018.

A Geonics EM38® instrument in vertical dipole mode was used to measure the apparent electrical conductivity (EC_a) of the soil. Based on the map of EC_a, the most uniform area of each field was selected for the experiments. The experiment was direct sown using DBS tynes spaced at 250mm. At sowing, 80kg monoammonium phosphate (MAP) (18kgphosphorus (P)/ha and 8kg nitrogen (N)/ha) was added to all plots. Pre-crop weed control was undertaken by applying Roundup® at 1.5L/ha, as well as the pre-emergents Sakura® (pyroxasulfone 850g/L) at 118g/ha and Logran® (triasulfuron 750g/L) at 35g/ha, and was incorporated at sowing. Precautionary disease control was implemented, seed was treated with Hombre ®Ultra imidacloprid (360g/L) and tebuconazole (12.5g/L)] at 200mLs/100kg and Prosaro® (prothioconazole 210g/L and tebuconazole 210g/L) was applied at 300mL/ha at DC 31. The experiment was harvested on 1 December. Grain protein and seed quality were estimated using near infrared (NIR) (Foss Infratec 1241 Grain Analyzer) and seed imaging (SeedCount SC5000R), respectively. At anthesis, about 50 youngest fully mature leaves (YML) were obtained randomly from each replicate plot of each genotype and then dried at 70°C for 48 hours. Dried plant samples were digested in an acid mixture of nitric and perchloric acid and concentrations of ions were measured on inductively coupled plasma (ICP).

Incubation experiment

To provide further insights into the dynamics of C mineralisation and the interactive effects of organic amendments and gypsum, a laboratory based incubation experiment was conducted. The soil (450g air-dried soil, equivalent to 430g oven-dried soil) was uniformly mixed with organic amendments (i.e. crop stubble) at an application rate of 6.2g C/kg soil with or without gypsum ($CaSO_4 \cdot 2H_2O$) of 7.2g/kg soil or nutrients. The soils were incubated for 90 days and the changes in soil pH, exchangeable Na%, microbial biomass C and aggregate stability were then measured.

Results and discussion

Soil constraints and weather

The depth-wise distribution of physicochemical soil constraints are shown in Figure 1. The profile is characterised by the soil pH ranges from 5.1-9.1 with increasing sodicity (ESP up to 30%) with depth. A dispersion test was performed on several aggregates and indicated significant dispersion in subsoil increasing with depth (Figure 1). A considerable amount of soil water below 60cm was found after harvest which suggests limitations to root growth reduced the ability of the crop to access subsoil water (Rengasamy et al. 2016).

The growing season rainfall in 2017 and 2018 was 329mm and 225mm, respectively. In 2017, rainfall during the April to November growing season was 62.5mm less than the long term average, whereas in 2018, it was 178mm less than the average rainfall. The average rainfall in 2018 was about 40% lower than 2017 (Figure 2).

Yield response to different amendments

This experiment established in 2017 showed consistent, significant ($P<0.05$) effects of amendment

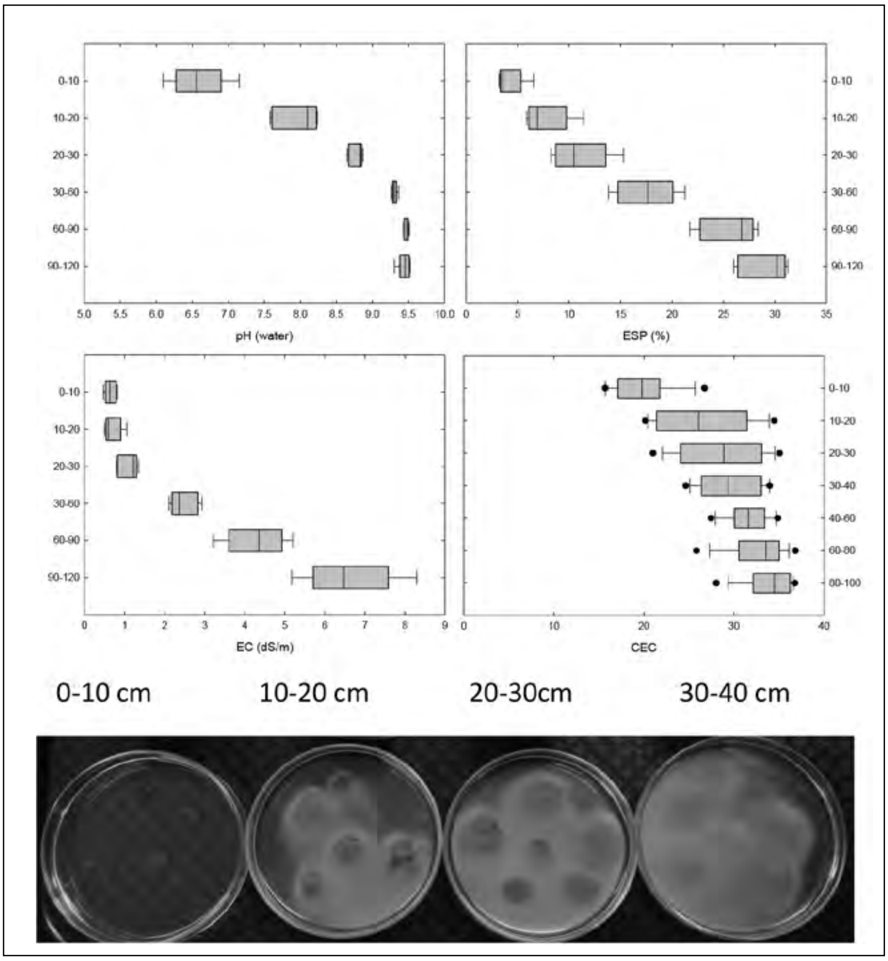

Figure 1. Soil characteristics of sodic site in Rand (southern NSW). Various lines indicate multiple locations across the trial. The picture shows the assessment of soil dispersion at four different depths. The increasing levels of exchangeable Na relative to calcium (Ca) and/or magnesium (Mg) in subsoil result in a decrease in soil structural stability and higher dispersion as shown above. When dispersion occurs, the dispersed clay particles fill up the pores between soil particles and aggregates, and when the soil dries out, the dispersed clay blocks soil pores. This can restrict seedling emergence, water and air movement, and root penetration. Dispersed soils are generally hard-setting and may form a surface crust or concrete-like lump which can also result in waterlogging.

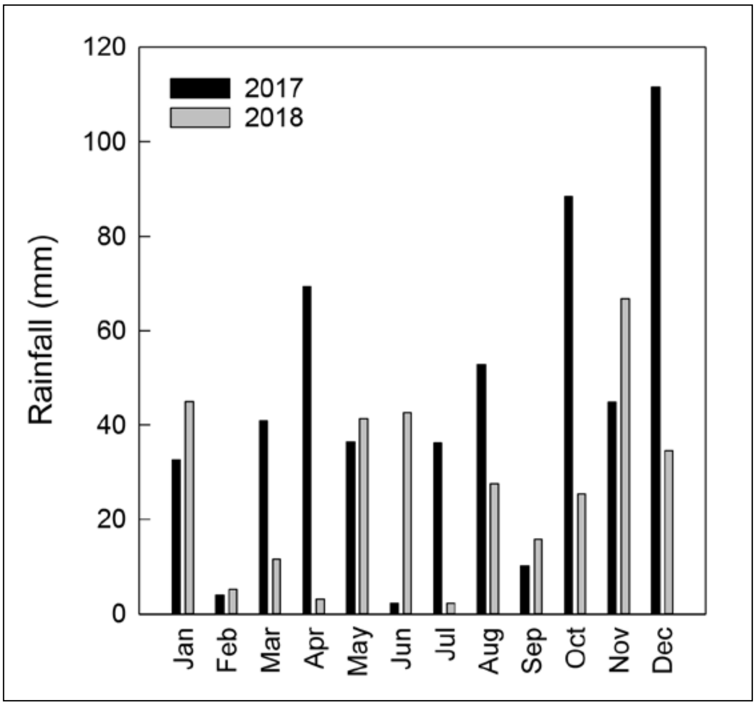

Figure 2. Mean monthly rainfall (histogram) and mean monthly air temperatures at the experimental site (Rand) in southern NSW in 2017 and 2018.

on grain yield in two consecutive years (Figures 3 and 4). In 2017, each plot with deep placement of amendments was harvested in two locations. These were on the amended rip line and off the amended rip line. This approach was undertaken based on the field observations of differential responses between crop rows on and off rip lines. While there was no significant difference (P>0.05) between the control and yield response off the amended rip line, a marked positive response was achieved for crop harvested on the amended rip line. Compared with the control treatment, the highest increase (P<0.05) in grain yield was observed for deep placement of pea hay + gypsum + nutrient (27%), followed by deep placement of manure (22%) and pea hay (20%). As a main effect, rip only, surface gypsum and surface pea hay treatments yielded 6%, 10% and 13% less than control treatments (Figure 3).

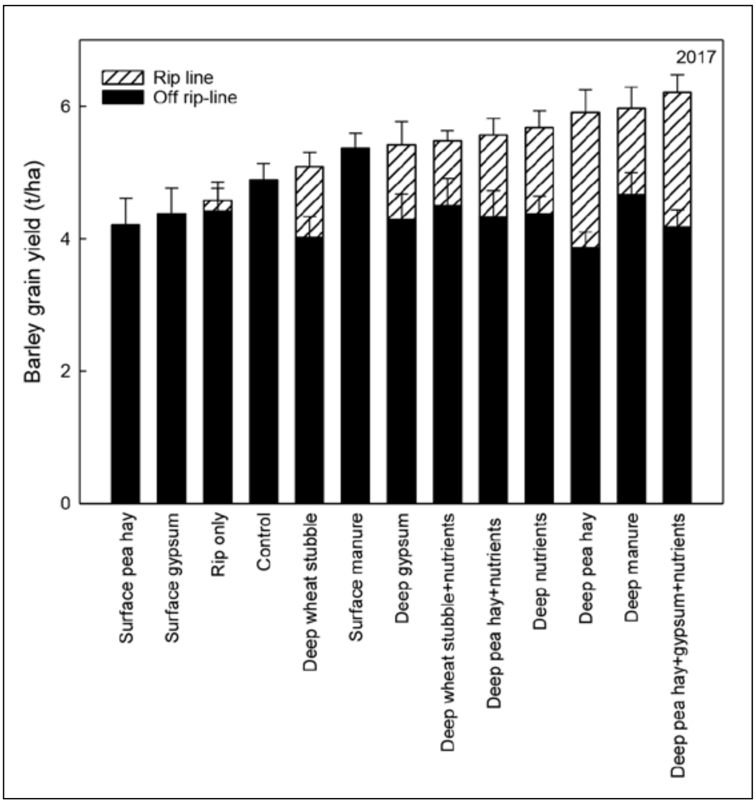

Figure 3. The effects of surface or deep placed amendments on grain yield of La Trobe⁽ᵈ⁾ barley in 2017 at Rand, southern NSW. Plots with deep placement treatments were harvested on amended rip lines (dashed bars, on rip line) and off unamended rip lines (black bars, off-rip line). Values are averages (n = 4).

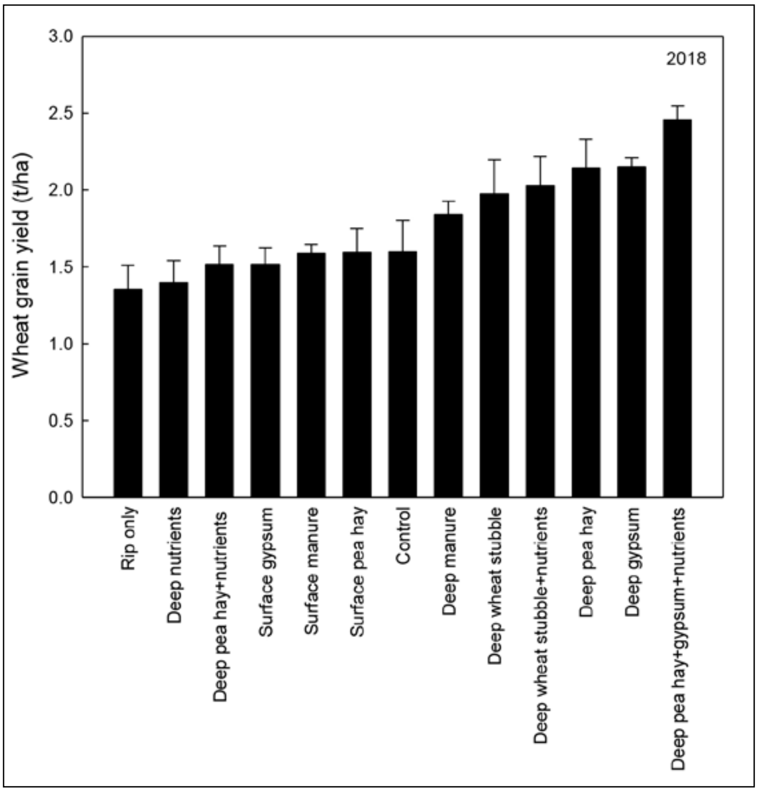

Figure 4. The effects of surface or deep placed amendments on grain yield (whole plot) of Lancer[(b)] wheat in 2018 at Rand, southern NSW. Values are averages (n = 4).

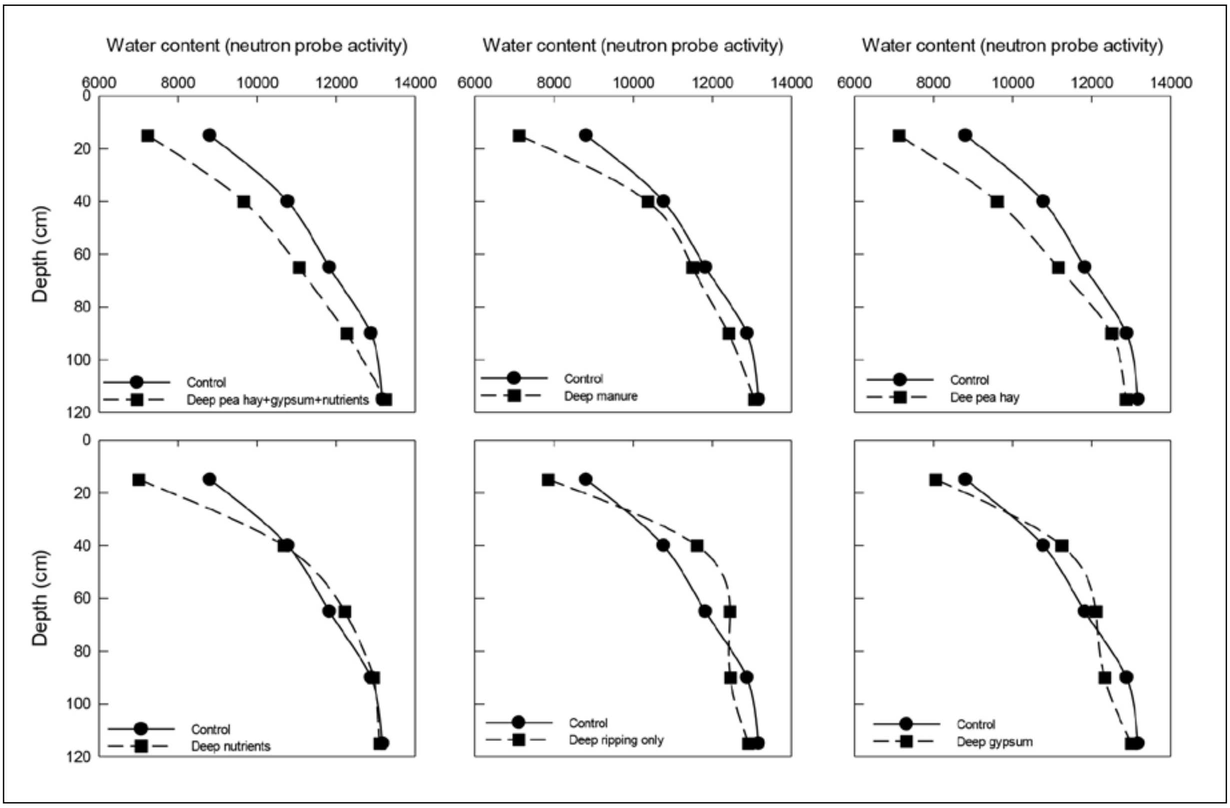

Figure 5. The changes in soil water content in various treatments compared with the control at the Rand site in 2018. Results are based on the neutron activity (raw data), where higher values represent higher water content in the soil profile. Values are averages (n = 4).

Table 1. The changes in soil exchangeable sodium percentage (ESP) and soil pH in selected treatments at the Rand site. Samples were collected in May 2018 pre-sowing. Values are means

	Control	Deep gypsum	Deep nutrients	Deep manure	Deep pea hay	Deep pea+ gyp+ nutrients	rip only
				ESP (%)			
0-10	5.89	7.00	6.43	7.89	6.09	5.13	7.23
10-20	8.47	8.18	9.11	11.41	8.33	6.01	9.69
20-30	13.35	11.70	12.59	16.24	12.91	9.68	14.09
				pH (1:5 water)			
0-10	6.61	6.96	7.04	6.37	6.87	6.89	6.86
10-20	7.98	7.77	7.99	7.66	7.76	7.69	7.91
20-30	8.99	8.13	8.96	8.60	8.87	8.38	8.94

In the 2018 season, wheat grain yield significantly ($P<0.05$) increased 27%-53% (compared with the control) following amendment application in 2017 (Figure 4). The highest increase was observed for deep placement of pea hay + gypsum + nutrient treatment (53%), followed by deep placement of gypsum (34%), pea hay (34%) and deep wheat stubble + nutrients (27%). As a main effect, surface pea hay, surface manure, surface gypsum, deep pea hay + nutrients, deep nutrients and rip only treatments yielded 0.1%-15% less than the control. These differences were not significant ($P>0.05$).

The volumetric water content in the soil declined in all layers of the profile as the wheat crop matured some 200 days after sowing (2018 growing season). A number of variations in the pattern of the decline in soil water were observed in different subsoil amelioration treatments. The most notable result occurred with the deep pea hay + gypsum + nutrients treatment followed by deep manure and deep pea hay, where there was a marked drying of the ameliorated layers as the crop matured (Figure 5). The effect was observed in the 40cm-60cm (amended layer). The neutron probe values in this layer were significantly lower ($P<0.05$) for the organic amendment treatments at crop maturity than for all other treatments including the control, the deep ripped, deep nutrients and the deep gypsum treatments (Figure 5).

Table 1 shows the effect of various amendments on soil ESP and pH at three depths. The deep placement of amendments at a depth of 15-40cm had a marked impact on the physicochemical properties in the subsoil layers. The 20-30cm deep subsoil layer in the control treatment had a pH of 9 and ESP of 13.4%. Deep placement of gypsum, pea hay + gypsum + nutrients and deep manure reduced the soil pH by 0.86, 0.61 and 0.39 unit, respectively ($P<0.05$). Compared with the control, the deep placement of gypsum and pea hay + gypsum + nutrients treatments also reduced the ESPby 12% and 27%.

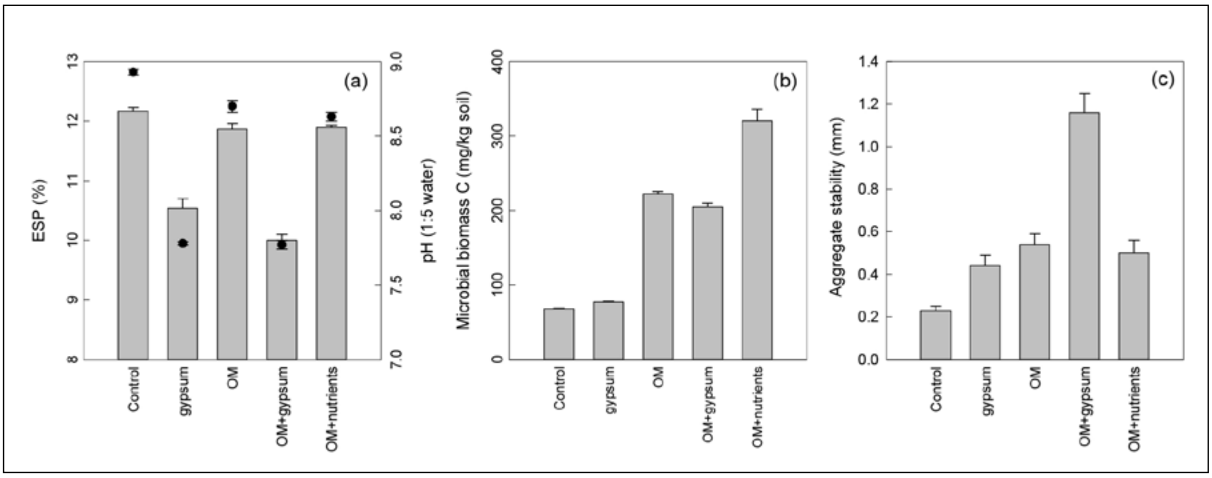

Figure 6. The effect of gypsum, OM, OM + gypsum and OM + nutrients on (a) soil ESP (bars) and pH (●), (b) microbial biomass C (mg/kg soil) and (c) aggregate stability (mm) over the 90-day incubation period. Error bars represent ± standard errors of the mean (n = 4).

To further explore the changes that organic amendments have on subsoil physical and chemical properties, primarily the effects on water-stable aggregates, an incubation experiment was conducted to investigate how the physical condition of the sodic clay soil may benefit from the addition of organic amendments that are able to benefit biological activity in the soil. Figure 6 shows the effects of gypsum, organic matter (crop stubble), organic matter + gypsum and organic matter + nutrients after an incubation of 90 days on the formation of water-stable aggregates. Similar to data from field trials, gypsum had a significant effect ($P<0.05$) on reducing soil pH (1.15 unit) and ESP (13%-17%) compared with the control. The addition of organic matter with or without nutrients had no influence on soil pH or ESP. However, the input of organic matter and organic matter + nutrient increased total microbial biomass C by 3-fold and 4.7-fold, respectively ($P<0.05$). Combined application of organic matter (OM) and gypsum had the greatest influence on the proportion of stable aggregates in the poorly structured sodic alkaline subsoil used in this study. While separate application of gypsum and OM increased the aggregate stability, the much greater improvement in soil aggregation in OM + gypsum treatment suggests that their co-application has an additive and/or interactive effect.

Discussion

This study provides early but significant indications that soil amelioration of alkaline-sodic subsoils with organic and inorganic amendments can provide significant grain yield increases that are associated with both improved soil chemicophysical properties and water use.

The extent of the changes in soil chemical and physical properties in the 15cm-40cm layers of this alkaline sodic soil, with the deep incorporation of organic and inorganic amendments, was remarkable. The changes occurred over the 14-month period between the incorporation of the amendments in late February 2017, and the taking of soil samples in May 2018. The key changes were a reduction in subsoil pH and ESP (Table 1) and an increase in soil porosity (data not shown) and higher water uptake by the crop (Figure 5). While the soil analysis is still in progress, it is suggested that this is resulted from improved soil aggregation, as incubation studies using this clay subsoil and similar organic amendments, led to a rapid improved aggregation in the clay matrix over three months (Figure 6).

The results demonstrated that amelioration of multiple soil constraints (high pH, sodicity and poorly structured aggregates) requires amendments and strategies with various modes of action and independent mechanisms. The suggested improvement in subsoil aggregation with OM + gypsum and the resulting significant increases in grain yield in this study can be attributed to several causes. The first was that application of gypsum resulted in a reduction in pH of 0.86-1.15 unit (Table 1, Figure 5). Tavakkoli et al. (2015) showed that carbonate salts of Na and potassium (K) dominate above pH 8.5 of many sodic subsoils in south-east Australia and a reduction in pH below 8.5 can decrease the net dispersive charge and ESP by changing the speciation of carbonate salts (Rengasamy et al. 2016). The second reason for the suggested improvement in subsoil aggregation was that the organic amendments provide a substrate for greatly enhanced microbial activity in and around the rip lines. The incubation study discussed above also found that the addition of OM to alkaline sodic, clay subsoil increased microbial biomass C over the 90 day of incubation period which in turn led to rapid improvement in aggregation (Clark et al. 2007; Gill et al. 2008; Fang et al. 2018).

Conclusions

The findings from this study demonstrate early results for amelioration of alkaline sodic subsoils in southern NSW. Deep application of organic and inorganic amendments resulted in significant yield increases in 2017 and 2018. The increases resulted from the improvement in the chemical and physical properties of the subsoil around the rip line containing the organic and inorganic amendments. This improvement was mediated by a reduction in soil pH and ESP and an increased microbial activity that leads to improved soil aggregation. This led to considerable water extraction from the deeper clay layers.

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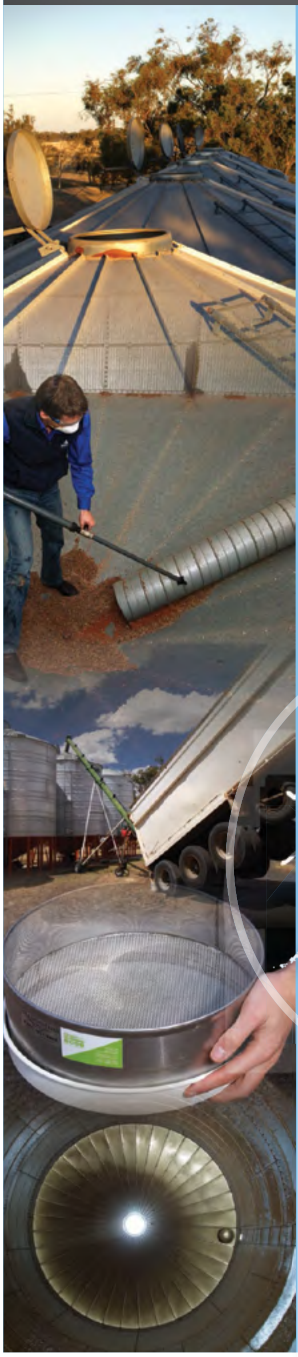

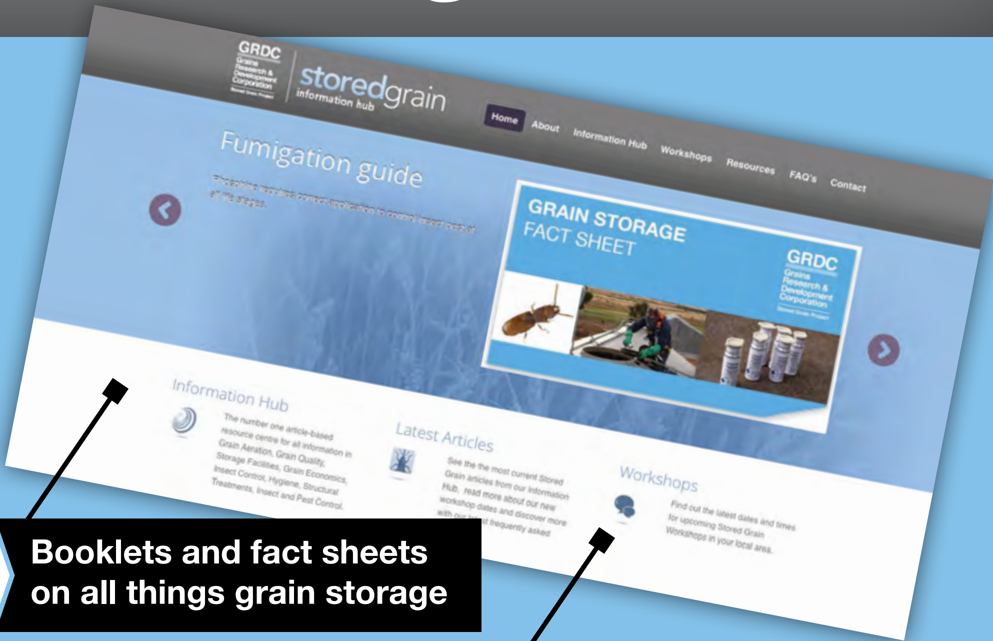

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How did barley fare in a dry season?

Felicity Harris[1], David Burch[2], Kenton Porker[3], Hugh Kanaley[1], Hayden Petty[4] and Nick Moody[2].

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GRDC project code: DAN00213

Keywords

- phasic development, sowing time, flowering time, photoperiod, vernalisation.

Take home messages

- Barley is capable of maintaining a yield advantage over wheat in southern NSW across yield environments.
- New barley varieties such as RGT Planet⁽ᵈ⁾ and Banks⁽ᵈ⁾ offer alternative phenology patterns compared to the benchmark fast spring type La Trobe⁽ᵈ⁾.
- In southern NSW, most spring barley types are still suited to traditional May sowing dates, and earlier sowing options are limited by suitable winter varieties.

Background

Compared to wheat, barley is considered to be more widely adapted, has superior frost tolerance, and offers higher yield potential across environments of southern Australia. A comparative analysis of the best performing barley and wheat genotypes (defined as highest yielding treatment), where experiments were co-located in southern NSW from 2015-2018, indicated that barley maintained a constant yield advantage over wheat at all yield levels, including in low yield potential seasons such as 2018 (Figure 1).

Matching varietal phenology and sowing date to achieve an optimal flowering time for each growing environment is the most effective management strategy in minimising effects of abiotic stresses, whilst maximising grain yield in all seasons. Recent yield improvements in barley varieties have been achieved through direct selection of yield based on traditional May sowing dates and suitable flowering dates, achieved through indirect selection of phenology types with photoperiod sensitivity and without vernalisation responses (Porker et al. 2017). However, a recent trend towards the earlier sowing of cereals (and canola), as well as European long-season spring barley introductions such as RGT Planet⁽ᵈ⁾ has highlighted differences in barley phenology in southern NSW. This paper presents phenology and grain yield responses of some diverse barley genotypes with respect to sowing date across three environments in southern NSW in 2018, and discusses options for early sowing opportunities.

Phenology and grain yield responses to sowing date – Condobolin and Wagga Wagga, 2018

Field experiments were conducted at Condobolin and Wagga Wagga to determine optimal sowing date and phenology to maximise grain yield. A range of genotypes with varied development (through different responses to vernalisation and photoperiod) were sown across sowing dates from mid-April to late May. In 2018, grain yield and

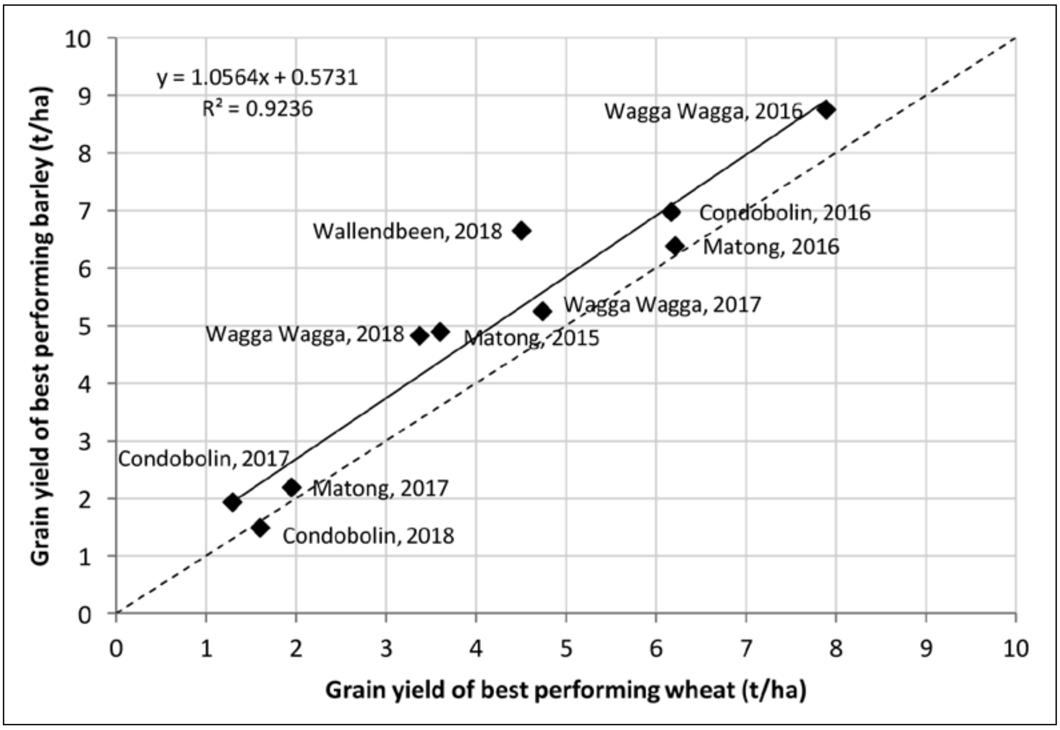

Figure 1. The relationship between the best performing wheat variety and the best performing barley variety across a range of sowing dates (mid-April to late-May) at co-located field experiments at Condobolin (2016-2018), Matong (2015-2017), Wagga Wagga (2016-2018) and Wallendbeen (2018). Dotted line indicates 1:1 relationship.

phenology responses were significantly influenced by below average rainfall and frost at both sites, with growing season rainfall (April to October) recording of 91 mm at Condobolin (long term average – 246 mm) and 135 mm at Wagga Wagga (long term average – 355 mm). Eleven extreme frost events (<-2°C) were recorded at both sites, including -4.9°C (28 August), -6.3°C (29 August), -5.4°C (30 August) and -3.9°C (17 September) at Wagga Wagga. Sowing dates were achieved by supplementary irrigation to ensure establishment due to lack of reliable autumn rainfall. The Condobolin site received 30 mm prior to all sowing dates and a final irrigation of 20 mm in early September, whilst at the Wagga Wagga site, the first two sowing dates were established with 15 mm via drippers at sowing, and the site was rainfed thereafter.

Generally, flowering date is a strong predictor of yield, with genotype and sowing date combinations that flower in early-mid September at Condobolin, and in late September- early October in Wagga Wagga capable of achieving the highest yields. In 2018, there was significant variation in grain yields for genotype x sowing date combinations which flowered within the optimal period at both sites. (Figure 2 and 3). At both sites, optimal flowering time and similar grain yields were achieved by both fast winter type Urambie⦶ sown mid-late April and the best performing spring type sown mid-May, whilst novel French winter genotypes, characterised as having a strong vernalisation and photoperiod response flowered too late and suffered a significant yield penalty as grain filling occurred under terminal drought conditions (Table 1).

Differences in phasic development – Wagga Wagga, 2018

Genotypes varied significantly in phasic development in addition to flowering time as shown for the Wagga Wagga site in Figure 4. Experiments conducted from 2014-2018 indicate many spring varieties achieve optimal flowering times and greatest grain yields when sown mid-May in southern NSW. Faster developing spring types (with minimal responses to vernalisation), sown early (when temperatures are warmer and days longer), progressed quickly and had a shorter vegetative phase, and flowered earlier in comparison to slower spring and winter types. For example, La Trobe⦶ sown 16 April 2018 at Wagga Wagga, started stem elongation (GS30) on 2 June. However, winter type Urambie⦶ sown on the same day (16 April), had a prolonged vegetative phase, due to its vernalisation requirement and reached GS30 four weeks later

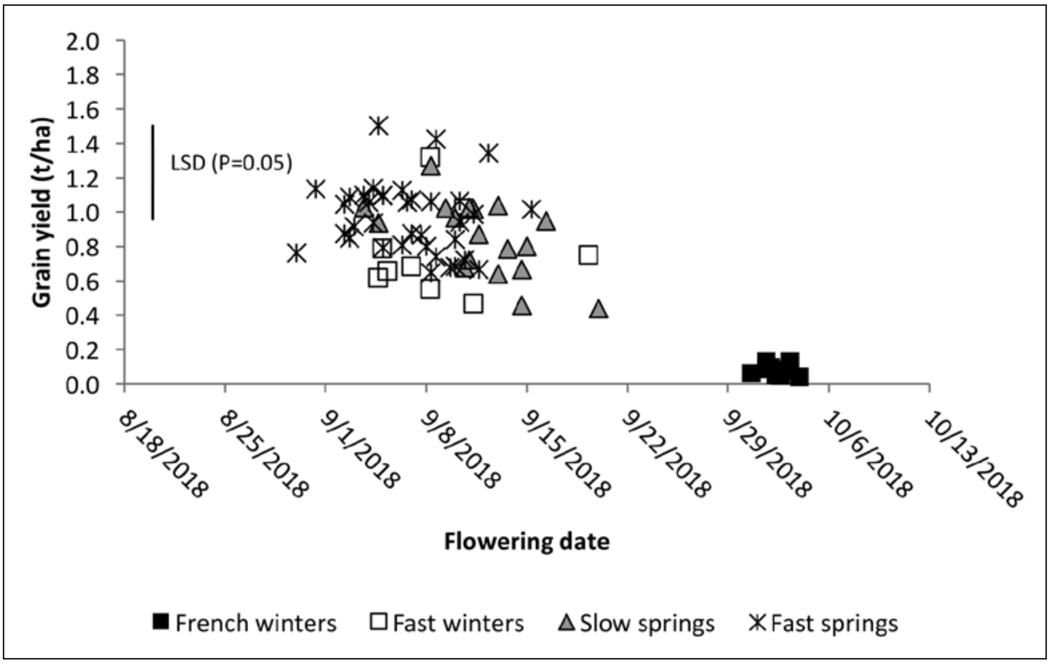

Figure 2. The relationship between flowering date and grain yield of genotypes with varied phenology patterns sown 23 April, 5 May and 28 May at Condobolin in 2018.

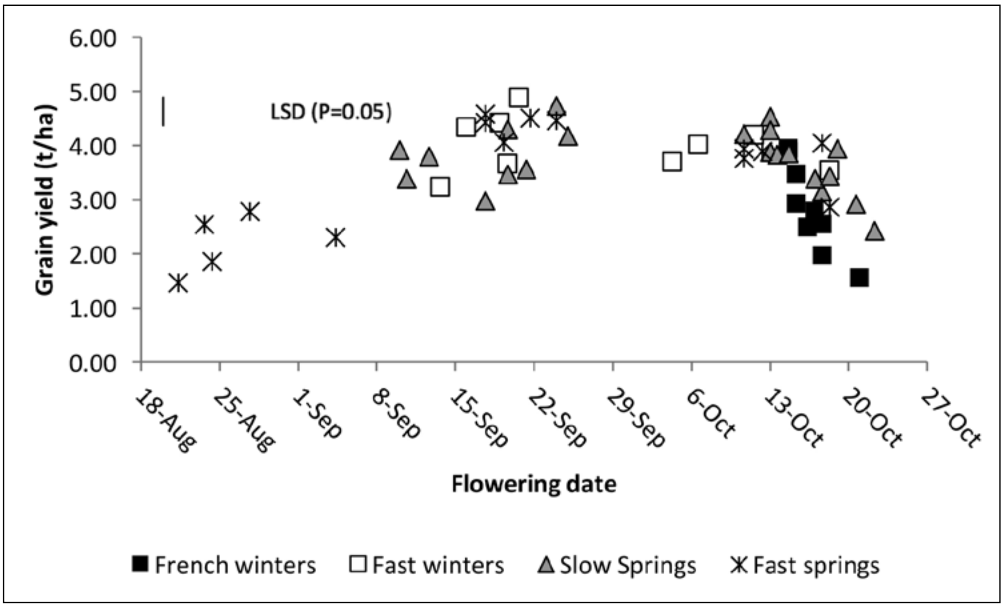

Figure 3. The relationship between flowering date and grain yield of genotypes with varied phenology patterns sown 16 April, 8 May and 28 May at Wagga Wagga in 2018.

on 6 July. It also had a relatively stable flowering response across sowing dates.

Increased photoperiod requirements of Commander⏀ and Banks⏀ resulted in slightly slower development comparative to La Trobe⏀, however, despite this they still achieved greatest grain yields from the mid-May sowing (Table 1). RGT Planet⏀ is also a longer- season spring genotype, though via a different phenology pattern (minimal vernalisation response coupled with weak photoperiod response), and is characterised as having only a slightly longer vegetative phase than La Trobe⏀, with an extended reproductive phase. RGT Planet⏀ has shown some flexibility across sowing dates, and is capable of being sown earlier in May than La Trobe⏀, however, in frost prone environments, due to its lack of vernalisation response, it is not suited to April sowing dates.

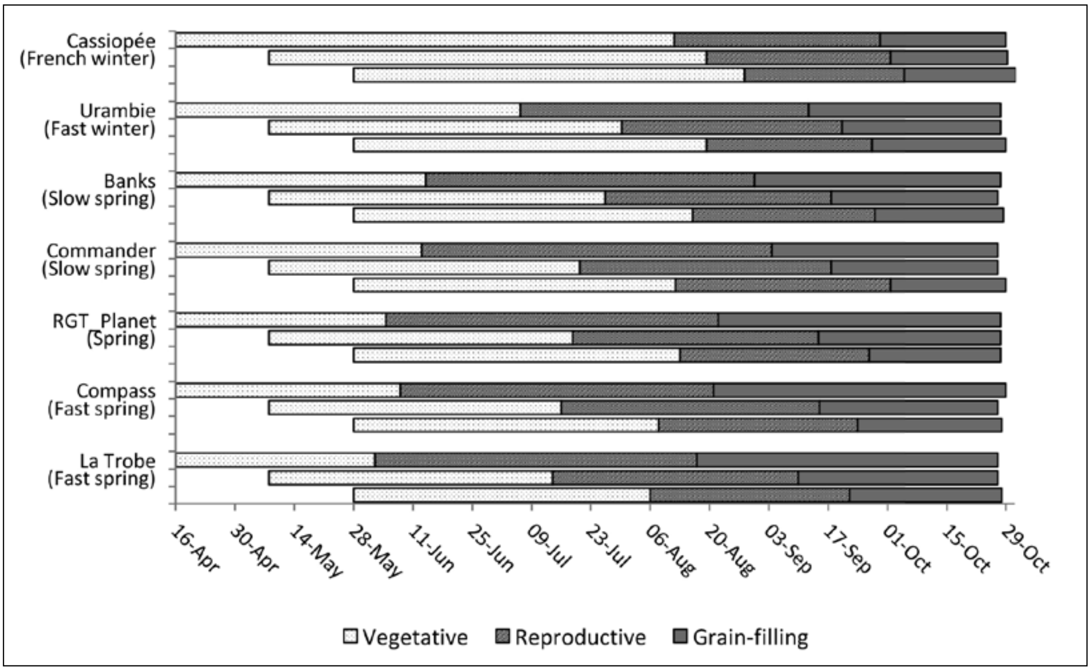

Figure 4. Influence of sowing date on phasic development of selected genotypes sown 16 April (SD1), 8 May (SD2) and 28 May (SD3) at Wagga Wagga, 2018. Vegetative phase (sowing to GS30); reproductive phase (GS30 to flowering); grain-filling stage (flowering to maturity).

Table 1. Grain yield of genotypes across three sowing dates (SD) at Condobolin and Wagga Wagga in 2018.

Genotype	Condobolin			Wagga Wagga		
	SD1: 23-Apr	SD2: 5-May	SD3: 28-May	SD1: 16-Apr	SD2: 8-May	SD3: 28-May
Banks⦸ (Slow spring)	1.27	0.87	0.95	3.57	4.53	3.94
Biere⦸ (Fast spring)	0.76	1.14	0.88			
Bottler⦸ (Fast spring)	0.81	0.87	0.99			
Cassiopée (French winter)	0.06	0.13	0.08	3.47	2.93	2.49
Commander⦸ (Spring)	0.97	0.67	0.46	3.81	4.21	3.38
Compass⦸ (Fast spring)	0.94	1.42	1.34	2.31	4.47	4.05
CSIROB1 (Fast winter)	0.66	0.62	0.47	3.24	3.66	3.7
CSIROB10 (Spring)	0.79	1.13	0.74	2.79	4.58	3.89
CSIROB2 (Fast winter)	0.78	0.68	0.55	4.33	4.42	4.01
CSIROB5 (Spring)	1.06	0.65	0.68	2.55	4.51	3.95
Fathom⦸ (Fast spring)	1.5	1.06	0.72	3.39	4.18	3.86
La Trobe⦸ (Fast spring)	0.85	0.92	0.68	1.86	4.43	3.77
Maltesse (French winter)	0.05	0.09	0.04	3.89	2.55	1.57
Oxford⦸ (Slow spring)	0.68	0.64	0.44	4.3	3.16	2.43
RGT Planet⦸ (Spring)	1.03	0.94	1.03	3.92	4.73	3.83
Rosalind⦸ (Fast spring)	1.1	1.05	0.8	1.48	4.06	2.87
Salamandre (French winter)	0.09	0.05	0.13	3.94	2.79	1.98
Scope CL⦸ (Fast spring)	0.87	1.07	1.06			
Spartacus CL⦸ (Fast spring)	1.09	1.14	0.84			
Traveler (Slow spring)	1.02	1.02	0.79	2.99	4.29	3.44
Urambie⦸ (Fast winter)	1.32	1.02	0.75	4.88	4.19	3.54
Westminster⦸ (Slow spring)	0.72	1.04	0.8	3.47	3.88	2.93
Mean	*0.96*	*0.94*	*0.79*	*3.34*	*3.98*	*3.31*
LSD (Genotype)	*0.31*			*0.06*		
LSD (SD)	*0.11*			*0.12*		
LSD (Genotype x SD)	*0.54*			*0.51*		

Opportunities for early sown barley – Wallendbeen, 2018

A third field experiment was conducted at Wallendbeen to determine suitability of novel winter genotypes to early sowing in a higher rainfall environment. Genotypes including Australian winter barley - Urambie⁽ᵇ⁾ (fast winter), European winter types (strong vernalisation and photoperiod responses), and some spring types with varied development patterns were sown on 13 April 2018. In 2018, the Wallendbeen site also recorded below average rainfall, with growing season rainfall (April to October) recording 219 mm (long term average – 460 mm). Wallendbeen recorded considerably less frost (number and severity), with three frost events <-2°C, including -2.4°C (14 July), -2.3°C (16 July), and -2.1°C (17 September), which influenced phenology and grain yield responses. Following sowing (13 April), the site received 6mm rain, though additional 7mm irrigation via drippers was applied 2 May to assist establishment.

Highest yields were achieved by genotypes which flowered late September-early October, with a yield penalty associated with the delayed flowering of European winter types beyond the optimal window (Figure 5). The yield penalty commonly experienced for early sowing of fast developing types (resulting in flowering earlier than optimal) was not as severe as for Condobolin (Figure 2) and Wagga Wagga (Figure 3) at Wallendbeen (Figure 5) in 2018. This is likely due to reduced early frost risk, and timely grain filling prior to significant moisture stress experienced by slower winter types.

An analysis comparing the best performing spring types (sown at optimal time for each environment, typically traditional May dates), with the best performing fast winter and slow winter types was conducted across nine experiments in southern NSW and SA in 2017-2018. This indicated that the fast winter types (typically Urambie⁽ᵇ⁾) were capable of comparable high yields when sown early, and both offered a constant significant yield advantage over slow winter types at seven out of nine sites (Figure 6). This suggests that a fast winter genotype is capable of achieving high yields when sown earlier than traditional May sowing dates. The strong vernalisation requirements of the European winter types consistently resulted in later flowering than optimal at all sites and were not able to maintain grain yield even in high rainfall environments. Further research investigating options for early sowing in southern NSW, requires suitable germplasm which combines a vernalisation requirement capable of early sowing.

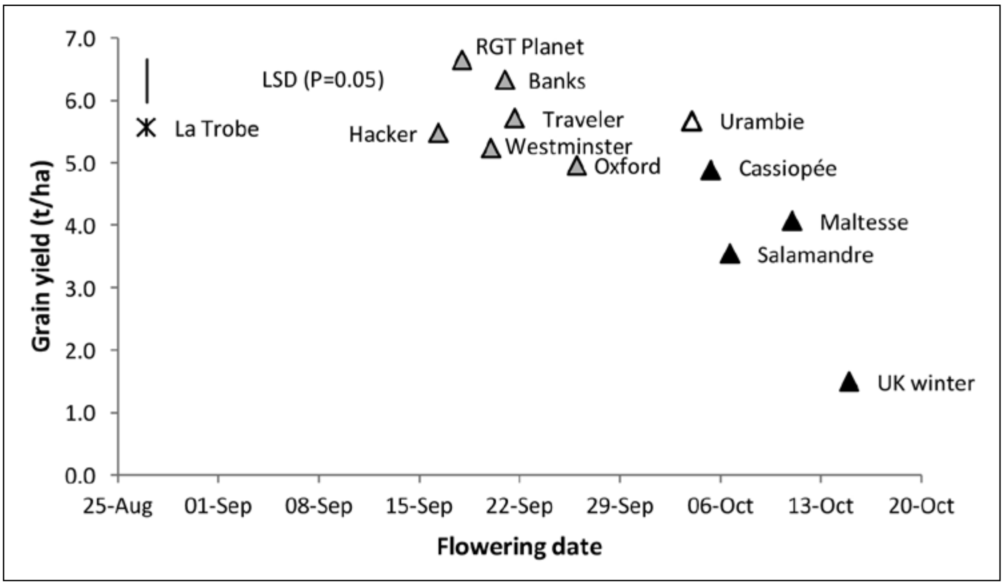

Figure 5. The relationship between flowering date and grain yield of barley genotypes sown 13 April at Wallendbeen in 2018.

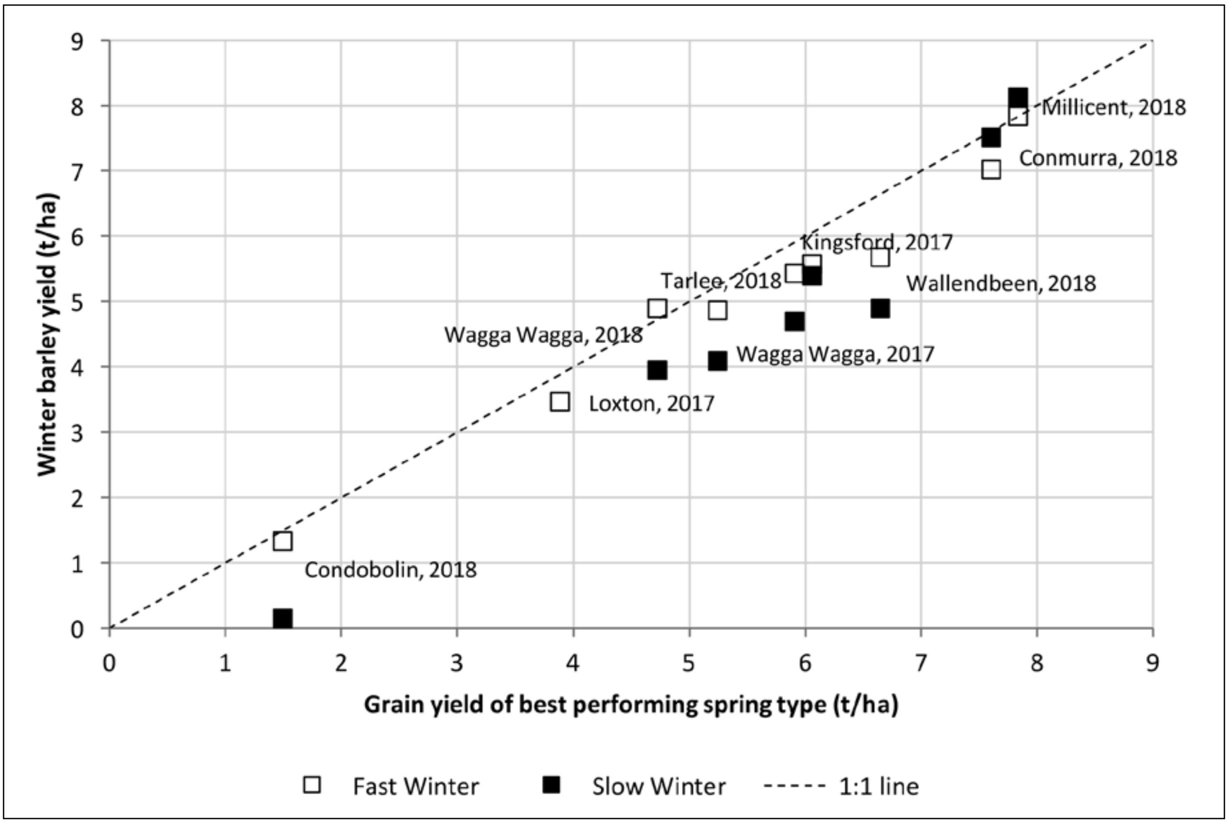

Figure 6. The relationship between the best performing spring barley types (sown at optimal time) with fast winter and slow winter genotypes (sown mid-late April) at field experiments in NSW: Condobolin, 2018; Wagga Wagga 2017, 2018; Wallendbeen, 2018; and South Australia: Conmurra, 2018; Kingsford, 2017; Loxton, 2017; Millicent, 2018 and Tarlee, 2018.

Summary

Despite the seasonal conditions experienced in 2018, barley was able to achieve stable grain yields across a range of yield environments comparative to wheat. High yields were achieved through varied genotype x sowing time combinations, however in southern NSW, many barley varieties are still suited to traditional May sowing dates. Recent European introductions of longer season spring types such as RGT Planet$^{\phi}$ offer opportunities for slightly earlier sowing (early May) and slower spring types such as Banks$^{\phi}$ and Commander$^{\phi}$ have alternative phenology patterns compared with benchmark fast spring types such as La Trobe$^{\phi}$. Recent research has evaluated novel European winter types to provide options for early sowing; however these did not offer a yield advantage over Australian fast winter types such as Urambie$^{\phi}$. Whilst new spring types have displayed some alternative phenology patterns, early sowing options in frost prone environments of southern NSW are currently limited by suitable winter genotypes.

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We also acknowledge the support of NSW DPI and their cooperation at the Wagga Wagga Agricultural Institute and Condobolin Agricultural Research and Advisory Station.

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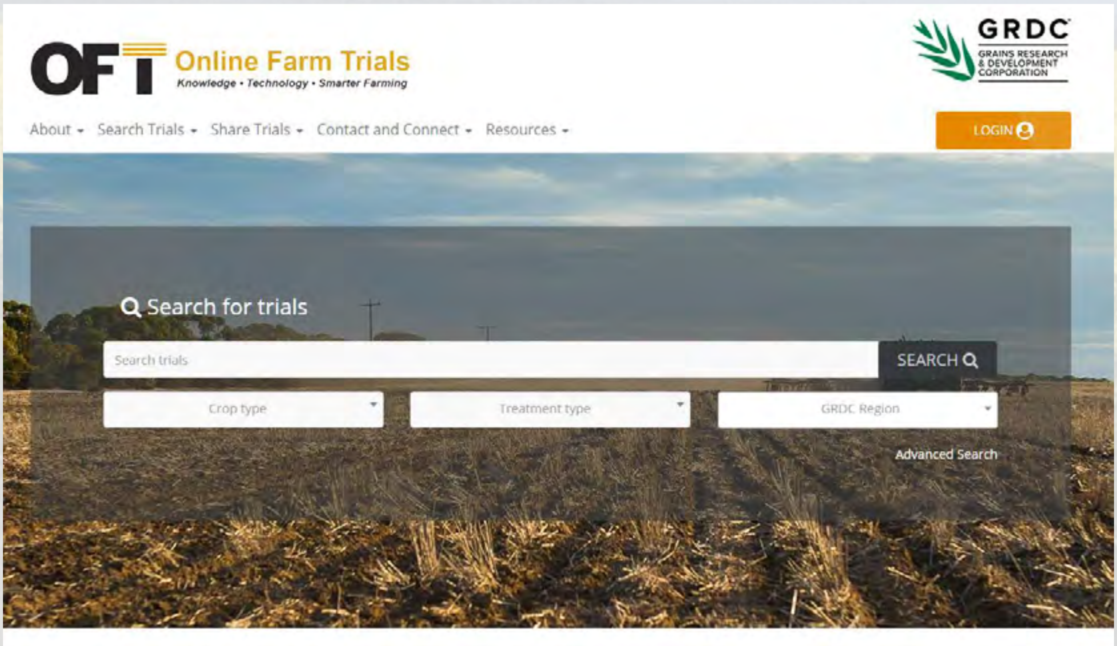

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Emerging management tips for early sown winter wheats

Kenton Porker, Dylan Bruce, Brenton Spriggs and Sue Buderick[1]; James Hunt[2]; Felicity Harris and Greg Brooke[3]; Sarah Noack[4]; Michael Moodie, Mick Brady and Todd McDonald[5]; Michael Straight[6]; Neil Fettell, Helen McMillan and Barry Haskins[7]; Genevieve Clarke and Kelly Angel[8].

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GRDC project code: : (GRDC Management of Early Sown Wheat 9175069)

Keywords

- winter wheat, crop development, frost, dual purpose, vernalisation.

Take home messages

- Highest yields for winter wheats come from early to late April establishment.
- Highest yields of winter wheats sown early are similar to Scepter⦵ sown in its optimal window.
- Slower developing spring varieties are not suited to pre-April 20 sowing.
- Different winter wheats are required for different environments.
- Flowering time cannot be manipulated with sowing date in winter wheats such as spring wheat.
- 10mm of rainfall was needed for establishment on sands, 25mm on clays - more was not better.

Background

Winter wheat varieties allow wheat growers in the Southern Region to sow much earlier than currently practised, meaning a greater proportion of farm can be sown on time. The previous GRDC Early Sowing Project (2013-2016) highlighted the yield penalty from delayed sowing. Wheat yield declined at 35kg/ha for each day sowing was delayed beyond the end of the first week of May using a fast-developing spring variety.

Sowing earlier requires varieties that are slower developing. For sowing prior to April 20, winter varieties are required, particularly in regions of high frost risk. Winter wheats will not progress to flower until their vernalisation requirement is met (cold accumulation), whereas spring varieties will flower too early when sown early. The longer vegetative period of winter varieties also allows dual-purpose grazing.

The aim of this series of experiments is to determine which of the new generation of winter varieties have the best yield and adaptation in different environments and what is their optimal sowing window. Prior to the start of the project in 2017, the low to medium rainfall environments of SA and Victoria had little exposure to winter varieties, particularly at really early sowing dates (mid-March). Three different experiments have been conducted in the Southern Region in low to medium rainfall environments during 2017 and 2018, and one of these has been matched by collaborators in NSW for additional datasets presented in this paper.

Method

Experiment 1

Which wheat variety performs best in which environment and when should they be sown?

- Target sowing dates: 15 March, 1 April, 15 April and 1 May (10mm supplementary irrigation to ensure establishment).
- Locations: SA - Minnipa, Booleroo Centre, Loxton, Hart. Victoria - Mildura, Horsham, Birchip, Yarrawonga. NSW - Condobolin, Wongarbon, Wallendbeen.
- Up to 10 wheat varieties:- The new winter wheats differ in quality classification, development speed and disease rankings (Table 1).

Experiment 2

How much stored soil water and breaking rain are required for successful establishment of early sown wheat without yield penalty?

- Sowing dates: 15 March, 1 April, 15 April and 1 May.
- Varieties: Longsword(b, Kittyhawk(b and DS Bennett(b.
- Irrigation: 10mm, 25mm and 50mm applied at sowing.
- Locations: SA - Loxton. Victoria Horsham, Birchip.

Experiment 3

What management factors other than sowing time are required to maximise yields of winter wheats?

- Sowing date: 15 April.
- Varieties: Longsword(b, Kittyhawk(b and DS Bennett(b.
- Management factors examined: Nitrogen (N) at sowing vs. N at early stem elongation, defoliation to simulate grazing, plant density 50 plants/m^2 vs. plant density 150 plants/m^2.
- Locations: SA - Loxton. Victoria - Yarrawonga.

Results and discussion

Experiment 1

Development speeds

Flowering time is a key determinant of wheat yield. Winter varieties have stable flowering dates across a broad range of sowing dates. This has implications for variety choice as flowering time cannot be manipulated with sowing date in winter wheats like spring wheat. This means different winter varieties are required to target the different optimum flowering windows that exist in different environments. The flowering time difference between winter varieties is characterised based on their relative development speed into four broad groups — fast, mid-fast, mid and mid-slow for medium to low rainfall environments (Table 1 and Figure 1).

Table 1. Summary of winter varieties, including Wheat Australia quality classification and disease rankings based on the 2019 SA Crop Sowing Guide.

Variety	Release Year	Company	Development	Quality	Disease Rankings#			
					Stripe Rust	Leaf Rust	Stem Rust	YLS
Kittyhawk(b	2016	LRPB	Mid winter	AH	MR	MR	R	MRMS
Longsword(b	2017	AGT	Fast winter	Feed	RMR	MSS	MR	MRMS
Illabo(b	2018	AGT	Mid-fast winter	AH/APH*	RMR	S	MRMS	MRMS
DS Bennett(b	2018	Dow	Mid-slow winter	ASW	R	S	MRMS	MRMS
ADV08.0008	?	Dow	Mid winter	?	-	-	-	-
ADV15.9001	?	Dow	Fast winter	?	-	-	-	-
LPB14-0392	?	LRPB	Very slow spring	?	-	-	-	-
Cutlass(b	2015	AGT	Mid spring	APW/AH*	MS	RMR	R	MSS
Trojan(b	2013	LRPB	Mid-fast spring	APW	MR	MRMS	MRMS	MSS
Scepter(b	2015	AGT	Fast spring	AH	MSS	MSS	MR	MRMS

**SNSW only*

AH=Australian Hard, APH=Australian Prime Hard, ASW=Australian Standard White, APW=Australian Premium White

R=resistant, MR=moderately resistant, MS=moderately susceptible

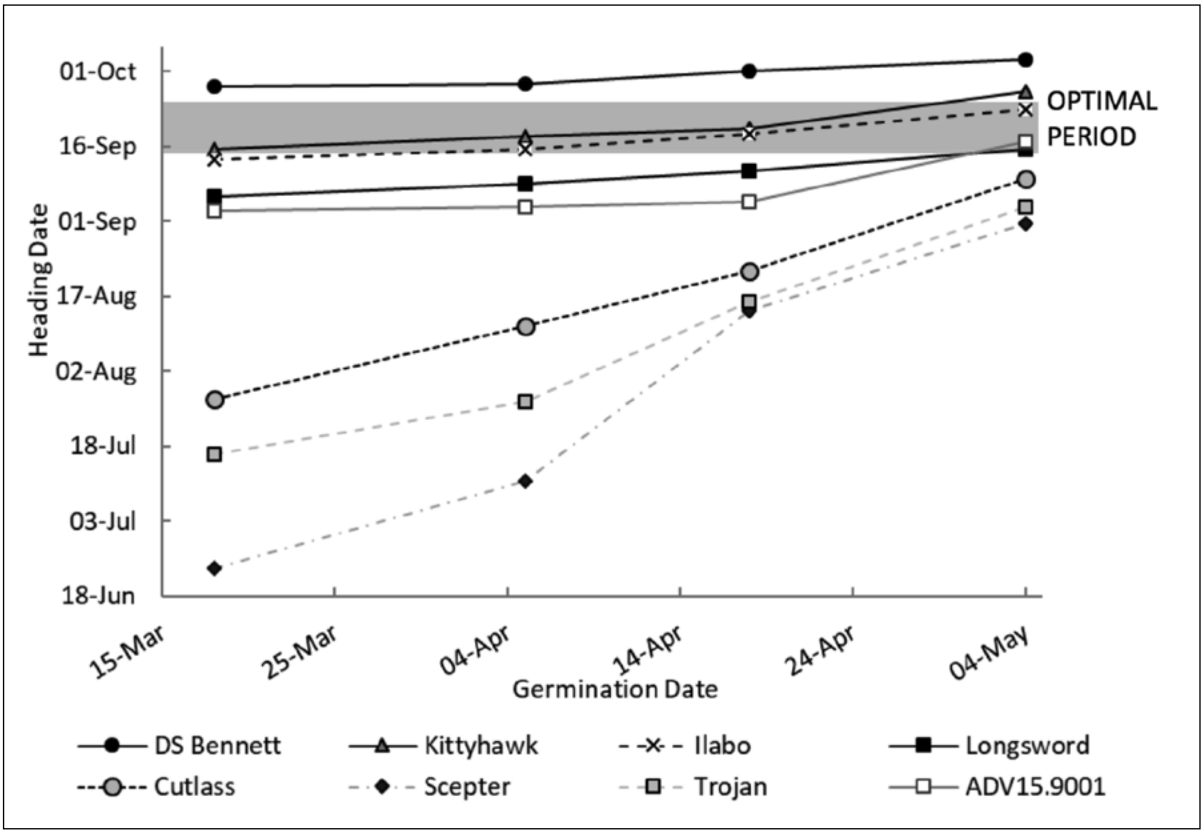

Figure 1. Mean heading date responses from winter and spring varieties at Hart in 2017 and 2018 across all sowing times — grey box indicates the optimal period for heading at Hart.

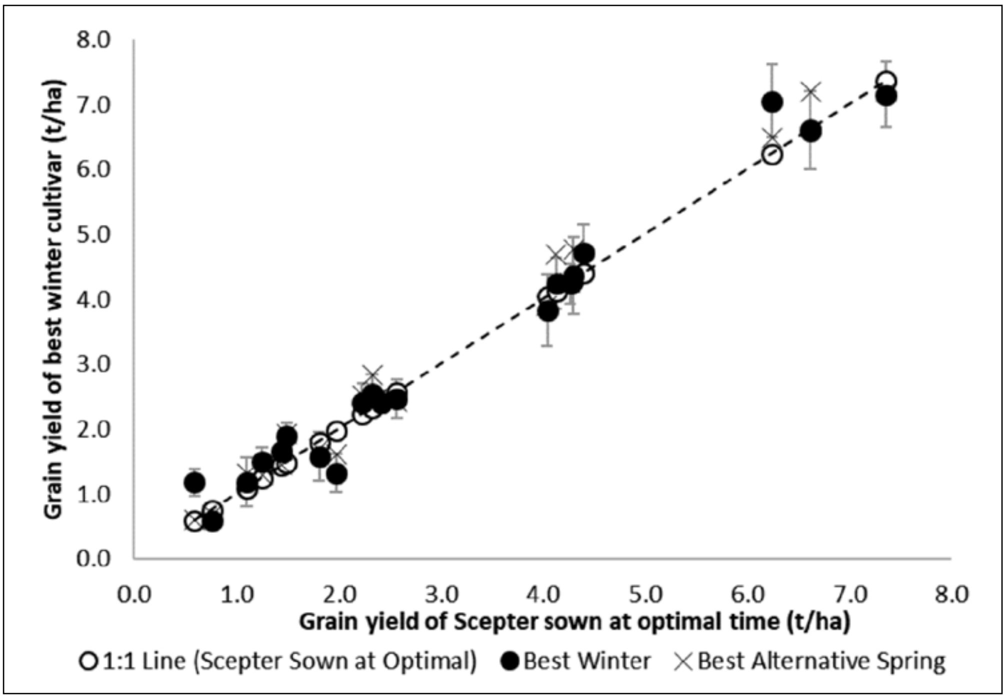

Figure 2. Grain yield performance of Scepter⁽ᴰ⁾ wheat sown at its optimal time (late April-early May) in 20 environments compared to the best performing winter wheat and best alternative spring wheat. Error bars indicate LSD ($P<0.05$).

For example, at Hart in the Mid North of SA, each winter variety flowered within a period of 7-10 days across all sowing dates, whereas spring varieties were unstable and ranged in flowering dates over one month apart (Figure 1). In this Hart example, the mid developing winter wheats such as Illabo(b and Kittyhawk(b were best suited to achieve the optimum flowering period of September 15-25 for Hart. In other lower yielding environments such as Loxton, Minnipa and Mildura, the faster developing winter variety Longsword(b was better suited to achieve flowering times required for the first 10 days in September.

Winter versus spring wheat grain yield

- Across all experiments, the best performing winter wheat yielded similar to the fast developing spring variety Scepter(b sown at the optimal time (last few days of April or first few days of May, used as a best practice control) in 16 out of 20 sites, greater in three and less than in one environment (Figure 2).
- The best performing winter wheat yielded similar to the best performing slow developing spring variety (alternative development pattern) at 14 sites, greater at four and less than at two sites.

Sowing time responses

- Across all environments, the highest yields for winter wheats generally came from early to late April establishment. The results suggested that yields may decline from sowing earlier than April and these dates may be too early to maximise winter wheat performance (Table 2).
- Slower developing spring wheats performed best from sowing dates after April 20, and yielded less than the best performing winter varieties when sown prior to April 20. This reiterates slow developing spring varieties are not suited to pre-April 20 sowing in low to medium frost prone environments.

Table 2. Summary of grain yield performance of the best performing winter and alternate spring variety in comparison to Scepter(b sown at the optimum time (late April-early May). Different letters within a site indicate significant differences in grain yield.

Site		Year	Scepter(b sown at optimum Grain Yield (t/ha)	Best Winter Performance			Best alternate Spring Performance		
				Grain Yield (t/ha)	Variety	Germ Date	Grain Yield (t/ha)	Variety	Germ Date
Yarrawonga*	Vic	2018	0.59 a	1.18 b	DS Bennett(b	16-Apr	0.61 a	Cutlass(b	16-Apr
Booleroo	SA	2018	0.77 a	0.59 a	Longsword(b	4-Apr	0.69 a	Trojan(b	2-May
Loxton	SA	2018	1.10 a	1.19 a	Longsword(b	19-Mar	1.32 a	Cutlass(b	3-May
Minnipa	SA	2018	1.25 a	1.50 b	Longsword(b	3-May	1.29 a	Trojan(b	3-May
Mildura*	Vic	2018	1.44 a	1.66 b	DS Bennett(b	1-May	1.46 a	LPB14-0293	1-May
Mildura	Vic	2017	1.49 a	1.90 b	Longsword(b	13-Apr	1.93 b	Cutlass(b	28-Apr
Horsham*	Vic	2018	1.81 a	1.58 a	DS Bennett(b	6-Apr	1.70 a	Trojan(b	2-May
Booleroo	SA	2017	1.98 a	1.33 b	DS Bennett(b	4-May	1.61 b	Cutlass(b	4-May
Minnipa	SA	2017	2.23 a	2.42 a	Longsword(b	18-Apr	2.52 a	Cutlass(b	5-May
Loxton	SA	2017	2.33 a	2.55 a	Longsword(b	3-Apr	2.83 b	LPB14-0293	3-Apr
Hart	SA	2018	2.41 a	2.42 a	Illabo(b	17-Apr	2.52 a	LPB14-0293	17-Apr
Rankins Springs	NSW	2018	2.57 a	2.47 a	DS Bennett(b	19-Apr	2.42 a	Trojan(b	7-May
Birchip	Vic	2018	4.04 a	3.83 a	Longsword(b	30-Apr	3.90 a	Trojan(b	30-Apr
Hart	SA	2017	4.13 a	4.25 a	Illabo(b	18-Apr	4.70 b	LPB14-0293	18-Apr
Yarrawonga	Vic	2017	4.27 a	4.24 a	DS Bennett(b	3-Apr	4.26 a	Cutlass(b	26-Apr
Wongarbon	NSW	2017	4.30 a	4.37 a	DS Bennett(b	28-Apr	4.77 a	Trojan(b	13-Apr
Tarlee	SA	2018	4.40 a	4.71 a	Illabo(b	17-Apr	4.62 a	LPB14-0293	17-Apr
Wallendbeen	NSW	2017	6.24 a	7.05 b	DS Bennett(b	28-Mar	6.49 a	Cutlass(b	1-May
Birchip	Vic	2017	6.62 a	6.60 a	DS Bennett(b	15-Apr	7.20 a	Trojan(b	15-Apr
Horsham	Vic	2017	7.36 a	7.15 a	DS Bennett(b	16-Mar	7.19 a	Trojan(b	28-Apr

repeated frost during September followed by October rain.

Which winter variety performed best?

The best performing winter wheat varieties depended on yield environment, development speed and the severity and timing of frost (Table 2). The rules generally held up that winter varieties well-adjusted to a region yielded similar to Scepter⍉ sown in its optimal window. These results demonstrate that different winter wheats are required for different environments and there is genetic by yield environment interaction.

- In environments less than 2.5t/ha, the faster developing winter wheat Longsword⍉ was generally favoured (Table 2, Figure 3).
- In environments greater than 2.5t/ha the mid to slow developing varieties were favoured — Illabo⍉ in the Mid North of SA, and DS Bennett⍉ at the Victorian and NSW sites (Table 2, Figure 4).

The poor relative performance of Longsword⍉ in the higher yielding environments was explained by a combination of flowering too early and having inherently greater floret sterility than other varieties, irrespective of flowering date.

Sites defined by severe September frost and October rain included Yarrawonga, Mildura and Horsham in 2018. In these situations, the slow developing variety DS Bennett⍉ was the highest yielding winter wheat and had the least amount of frost induced sterility. The October rains also favoured this variety in 2018 and mitigated some of the typical yield loss from terminal drought. Nonetheless, the ability to yield well outside the optimal flowering period may be a useful strategy for extremely high frost prone areas for growers wanting to sow early.

Experiment 2

2018 had one of the hottest and driest autumns on record and provided a good opportunity to test how much stored soil water and/or breaking rain is required to successfully establish winter wheats and carry them through until winter. The 10mm of irrigation applied at sowing in the sowing furrow was sufficient to establish crops and keep them alive (albeit highly water stressed in most cases) until rains finally came in late May or early June at seven of the eight sites at which Experiment 1 was conducted in 2018. The one exception was Horsham, which had very little stored soil water and a heavy, dark clay soil. At this site, plants that emerged following the first time of sowing in mid-March died after establishment and prior to the arrival of winter rains. Plants at all other times of sowing were able to survive. Experiment 2 was also located at this site, and 25mm of irrigation was sufficient to keep plants alive at the first time of sowing. A minimum value of 25mm for sowing in March on heavier soil types is supported by results from Minnipa in 2017, which

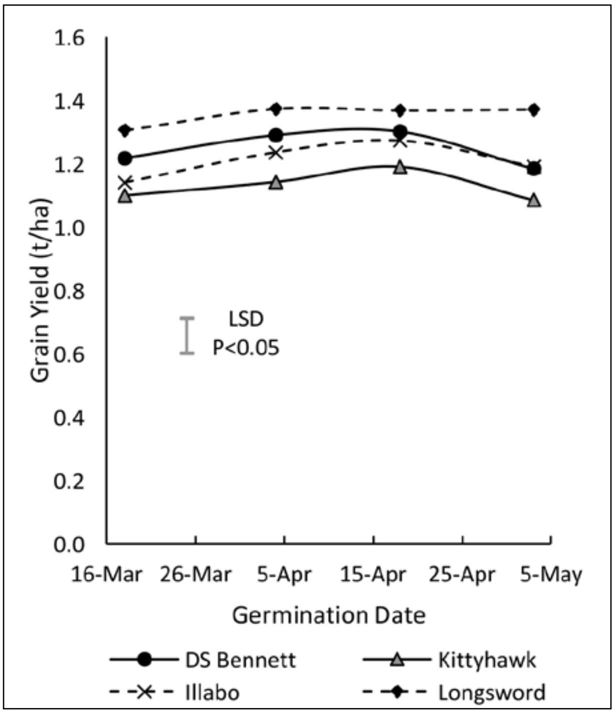

Figure 3. Mean yield performance of winter wheat in yield environments less than 2.5t/ha (11 sites in SA/Victoria)

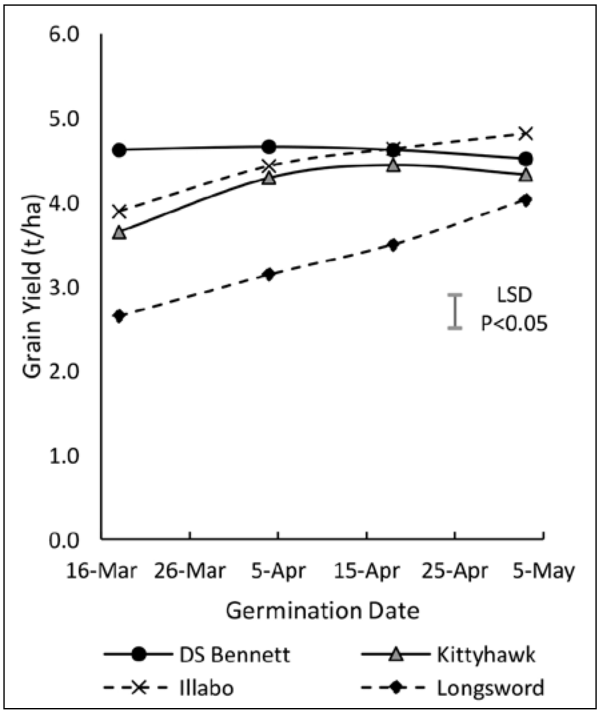

Figure 4. Mean yield performance of winter wheat in yield environments greater than 2.5t/ha (five sites in SA/Victoria)

also experienced a very dry autumn. In this case, approx. 30mm of combined irrigation, rainfall and stored soil water was sufficient to keep the first time of sowing alive. On lighter soil types, less water was needed and 10mm irrigation at sowing with 8mm of stored water plus an accumulated total of 13mm of rain until June allowed crops to survive on a sandy soil type at Loxton in 2018.

Based on these observations, it is concluded that when planting in March on clay soils, at least 25mm of rainfall and/or accessible soil water are required for successful establishment. Once sowing moves to April, only 10mm (or enough to germinate seed and allow plants to emerge) is sufficient.

Experiment 3

Yield responses to changes in plant density, N timing and defoliation have been small (Table 3). There have been limited interactions between management factors and varieties. The results from Experiments 1 and 3 confirm selecting the correct winter variety for the target environment and sowing winter varieties on time (before April 20) increase the chances of high yields. The target density of 50 plants/m^2 is sufficient to allow maximum yields to be achieved, and there is no yield benefit from having higher densities in winter varieties. Deferring N until stem elongation had a small positive benefit at Yarrawonga, and a negative effect at Loxton. Grazing typically has a small negative effect in all varieties, however the mean percentage grain yield recovery from grazing has been higher in Longsword$^{\phi}$ (95%) compared to DS Bennett$^{\phi}$ (87%) and Kittyhawk$^{\phi}$ (82%), respectively.

Conclusion

Growers in the low to medium rainfall zones of the Southern Region now have winter wheat varieties that can be sown over the entire month of April and are capable of achieving similar yields to Scepter$^{\phi}$ sown at its optimum time. However, grain quality of the best performing varieties leaves something to be desired (Longsword$^{\phi}$=feed, DS Bennett$^{\phi}$=ASW). Sowing some wheat area early allows a greater proportion of farm area to be sown on time. Growers will need to select winter wheats suited to their flowering environment (fast winter in low rainfall, mid and mid-slow winter in medium rainfall) and maximum yields are likely to come from early to mid-April planting dates. If planting in April, enough rainfall to allow germination and emergence will also be enough to keep plants alive until winter. If planting in March, at least 25mm is required on heavy soils. Reducing plant density from 150 to 50 plants/m^2 gives a small yield increase, while grazing tends to reduce yield slightly.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC — the authors would like to thank them for their continued support. The project is led by La Trobe University in partnership with SARDI, Hart Field-Site Group, Moodie Agronomy, Birchip Cropping Group, Agriculture Victoria, FAR Australia and Mallee Sustainable Farming. Collaboration is with NSW DPI, Central West Farming Systems and AgGrow Agronomy & Research.

Table 3. Mean main effects on grain yield (t/ha) from management factors at Loxton and Yarrawonga (2017 and 2018 = 4 sites).

Management Factor (Grain Yield t/ha)						Mean Management Effect (t/ha)
Variety choice	DS Bennett$^{\phi}$ (2.21) & Kittyhawk $^{\phi}$	(2.10)	Vs.	Longsword$^{\phi}$	(2.40)	+0.30***
Seeding Rate (target density)	150 Plants/m^2	(2.14)	Vs.	50 Plants/m^2	(2.35)	+0.21***
Nitrogen Timing	Seedbed applied N	(2.32)	Vs.	N Delayed to Stem Elongation	(2.21)	-0.11 ns
Grazing^	Ungrazed	(2.38)	Vs.	Grazed	(2.11)	-0.27***
Sowing Date#	Early May Germination	(1.70)	Vs.	Mid-April Germination	(2.19)	+0.49***

*^grazing was simulated by using mechanical defoliation at Z15 and Z30, # Sowing date effect derived from Experiment 1 at Loxton and Yarrawonga. Level of significance of main effect indicated by ns=not significant, *** = P<0.001.*

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Notes

Notes

Dual-purpose crops, forage crops or oversowing pastures – how to manage feed supply post drought

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Keywords

- Dual-purpose crops, forage crops, pasture lucerne, subterranean clover, density, post drought.

Take home messages

- Using dual purpose crops increases management options to allow post drought recovery.
- Assess pastures on density before the start of season.
- Determine the area of pasture and crops required.

Introduction

Grain producers have become more proficient alt is critical that a whole farm feed budget be created to determine the requirement of feed for the year. This should include dual-purpose crops as they can supply livestock requirements from May to mid-August depending on the season. Environmental stresses such as drought can significantly decrease the density and forage production from existing pasture stands. Assessing a pastures density and its ability to recover from drought is essential for the forage production and long-term viability of the pasture stand. If pastures are degraded dual-purpose crops can provide a good source of feed allowing the existing pastures to recover post drought.

The primary species used in pastures in the mixed farming zone is lucerne and subterranean clover. Lucerne is a perennial legume species that does not recruit seedlings in the field and the population tends to decline over time. Persistence of a lucerne pasture is related to the density of lucerne plants. Environmental stresses such as drought can significantly decrease the density of a lucerne stand. Therefore, a critical density measurement of lucerne can be used to determine if management is required.

In comparison, annual legume species such as subterranean clover rely on the development of a seed bank. As part of the annual cycle, seeds are set each year and the maintenance of the seed bank is essential for maintaining the productivity of the pasture. Determining seed bank levels is difficult but it is likely that following two dry springs that there will have been a severe reduction in the pasture legume seed bank.

Determining a benchmark for lucerne density.

When sufficient soil water is available, lucerne production is limited by the amount of light that is intercepted. These conditions can occur in many dryland areas in spring and it is lucerne density that will limit the amount of light intercepted by the crop, and therefore, limit production. Maximum production under irrigation can be achieved with a lucerne density of 30 plants/m^2 (Palmer and Wynn-Williams 1976). Within the mixed farming zone densities between 20-40 plants/m^2 are sufficient for maximum production (Dear et al 2007; Dolling et al

2011). This may seem low particularly in comparison to the number of plants sown but the population of lucerne declines over time and does not recruit seedlings. When lower lucerne densities occur a companion species such as subterranean clover can intercept light thereby increasing pasture production during periods of adequate soil water. Wolfe and Southwood (1980) suggested that at Wagga Wagga, NSW that 10 lucerne plants/m^2 was adequate when lucerne was sown with a companion species such as subterranean clover.

Under low rainfall conditions the plant density required for maximum production is likely to be lower. Virgona (2003) demonstrated that lucerne density of 12 plants/m^2 could deplete the soil water to equivalent levels as higher densities. Presuming that water use is strongly related to lucerne growth that may indicate that 12 plants/m^2 could produce similar levels of biomass under water limited conditions as that produced with sufficient water. Similarly, at a low rainfall site at Trangie and Condobolin, Bowman et al (2002) demonstrated that 8 plants/m^2 was the critical value for maximum production below which lucerne biomass production decreased.

Mccormick (2017) conducted a paddock survey in the Temora region and measured species' frequency. This was conducted using a 50cm x 50cm quad across a paddock 50 times and a species was observed to be present or absent. This quick assessment demonstrated that a species frequency of 50% limited that species to producing a maximum of 20% of the pasture biomass. The species frequency would need to be at 80% to be able to produce 50% of the biomass. Converting frequency data to density is problematic but if it was assumed there was 1-2 plants at a frequency of 80% (50cm x 50cm quad) that would lead to densities of approximately 3 plants/m^2 to 6.5 plants/m^2. Under this situation companion species would be required to contribute to biomass to meet livestock feed requirements but in degraded pastures it is likely to be weeds.

Companion species in lucerne pastures

Subterranean clover or other annual clovers are the most useful companion species due to the quality of feed produced and their nitrogen fixation ability. Research has indicated that 1000 seedlings/m^2 is sufficient for maximum pasture production from subterranean clover (Silsbury and Fukai, 1977). Environmental conditions and perennial density influence seed production. Drought can lower the seed bank level of companion species. Other species can also be important in lucerne pastures. For example, barley grass can provide important feed early in the season but in spring quality will decrease and animals may be injured due to grass seeds. Consequently, barley grass should be controlled in the winter which will reduce its contribution to pasture production. Annual ryegrass can also be a very useful pasture species in a lucerne stand due to high growth rate and high quality. If the pasture is likely to be returned to annual crops in the next two years, the annual ryegrass should be spray-topped in the spring time to reduce seed set.

Utilising dual-purpose crops in the farming system

Dual-purpose crops are a critical component for feed supply on mixed farms. Dual-purpose crops can support approximately 20-30 dry sheep equivalent (DSE)/ha during the winter period provided there is sufficient soil water. Dove et al (2015) demonstrated in a trial near Canberra that deferred grazing of pasture due to the grazing of dual-purpose crops led to increased pasture production. Not using dual-purpose crops will increase grazing pressure on degraded pastures increasing the requirement for supplementary feed. To offset the requirements for pastures during autumn and winter and also to maximise growth for dual-purpose crops it is essential to follow the best management practices including:

1. Select a paddock with a history of low weed pressure.
2. Ensure paddock has had strict weed control during the fallow period as to ensure greatest soil water storage.
3. Plan to sow early. Earlier sowing increases biomass accumulation. Canola can be sown from late February to April. Wheat can be sown from March to May. Early sowing does increase risk of moisture stress.
4. Select a true winter type cultivar to enable early sowing.
5. Provide sufficient nitrogen.
6. Provide mineral supplements with dual-purpose wheat. Not for canola

Decision making for the year ahead

As sowing time approaches growers will be trying to determine how much pasture to sow as well as what management strategies can be used in existing pastures. Pasture removal should be for those pastures that have degraded over the last season and that are unlikely to be productive in the year ahead. Firstly all pastures should be assessed for lucerne density. This can be done by using a 50cm x 50cm quad randomly placed 30 times across the paddock. Determining actual plant numbers can be difficult in higher density stands as individual plants that are close together cannot be distinguished other than by digging up and counting tap roots. Paddocks should be ranked depending on density.

Companion species can also be assessed. This could be done using residue from last year i.e. grass seed heads or sub clover burrs. Very small areas (<1m^2) could also be wet up from March to determine the number of seedlings that emerge. It is difficult to determine a critical value for subterranean clover seedling density. After the previous two dry springs it is unlikely that any paddocks will reach the critical number of 1000 plants/m^2. Comparing a density to that achieved after a low sowing rate of subterranean clover would result in a critical value of 75 plants/m^2. There would be no point re-sowing subterranean clover if the existing density was already greater than that which could be achieved by re-sowing.

In discussion with the grower determine the area of pasture required. At the most basic level discuss with the manager how many hectares of pasture they normally have to supply sufficient feed for livestock. McCormick et al (2012) calculated an average stocking rate for pasture areas on mixed farms from a survey to be 11 DSE/ha. A simple feed budget could be constructed to determine the livestock requirement for different periods in the season. This could be done with simple online tools such as the Evergraze Feed Calculator (https://www.evergraze.com.au/library-content/feedbase-planning-and-budgeting-tool/) or simple estimation using 3-4% of body weight for growing/lactating animals. Ascertaining the time of season when pasture growth will be most limiting will aid in choosing the most appropriate management strategy. If dual-purpose crops are used extensively on-farm, then animal requirement could be met by these crops from May to mid-August depending on the break of season. Calculate the area required to be sown for dual-purpose crops using the number of ewes on farm and an estimated stocking rate of 20 DSE/ha. Be aware that the DSE rating of a pregnant or lactating ewe can vary from 1.5 – 4 DSE depending on breed and weight of animal. The area required for dual-purpose crops also depends on the timing of the break. An early rainfall event with early sowing accumulates more biomass, and therefore, less area is needed. In comparison a late break would require larger areas of dual-purpose crops to be sown to have the same effect. With the use of dual-purpose crops, it is likely that degraded pastures will be limiting production immediately after the break in season (late autumn) and from August to September after grazing has ceased on the dual-purpose crops. Identifying production limitations will help with selection of the best management option.

The decision tree (Figure 1) outlines different options that are available for paddocks depending on the density of lucerne determined.

Options for pasture renovation

There are a number of options in response to pastures that have a low density of lucerne. It is recommended not to re-sow lucerne back into old lucerne stands due to disease and autotoxicity (Kehr 1983). Pastures could be over sown with subterranean clover or a cereal to increase forage production. Alternatively the pasture could be removed to sow an annual crop.

Using the decision support tree (Figure 1) will lead to the following various options:

- Option 1 - Remove pasture and sow crop for current year.

  If there is no requirement for the pasture, or forage can be supplemented elsewhere with sown cereals (Option 2) then this paddock should be brought back into the cropping phase.

  Opportunities – Moves the paddock into the cropping phase.

  Limitations – If pasture is still present in autumn it is likely that the soil has not stored summer rainfall and the lucerne will be difficult to remove. Crop yield maybe reduced. Does not provide any extra pasture.

- Option 2 - Keep pasture and sow cereal for grazing, hay or grain.

  Cereals can be successfully direct drilled into lucerne stands. Dry sowing can be an option but should not be undertaken too early as lucerne will compete strongly for moisture in

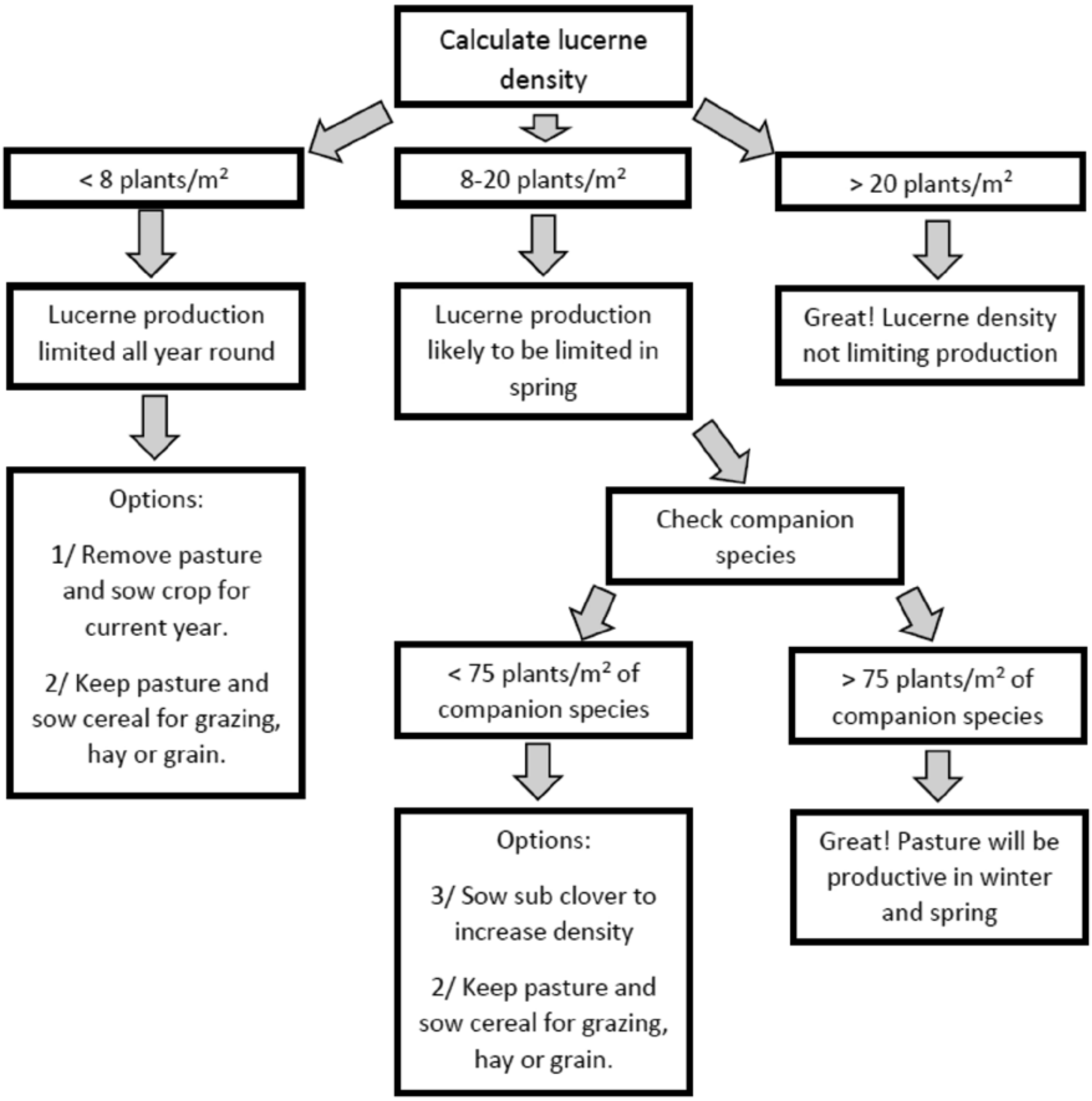

Figure 1. Pasture decision support tree.

the autumn. Cereal species used will depend on what is required. Oats is vigorous and will provide early feed. Barley could be late sown and yet is still vigorous. Winter wheat could be suitable for early sowing with the potential for grain although late grazing may limit significant grain recovery. The opportunity for hay or silage could be high and would enable refilling of haysheds. Decision on cereal species will also depend on seed cost and availability.

Opportunities – High quality forage for autumn, winter and early spring. Potential for hay, silage or grain from dual purpose crops.

Limitations – Cost of sowing operation and seed. One year only. If lucerne density is low, then there is still limited production from the lucerne.

- Option 3 - Oversow sub clover to increase density.

Ideally high sowing rates will ensure a fast establishment for grazing. Seed should be sown rather than broadcast on the soil as broadcasting success rate is low. Pre-sowing herbicides should be used.

Opportunities – Should increase the productivity of the pasture for the next few years.

Limitations – Can be an expensive option. Number of seeds sown is much less than that from an established seed bank, and therefore, growth will be slower.

Conclusion

Pastures on mixed farms will have likely degraded following the drought last year. It is crucial that pastures are assessed to determine their productive potential. Management options can be used to increase forage supply this year to ensure that livestock enterprises are not impacted by poor pastures. Dual-purpose crops can play an important role in filling early season feed gaps giving pastures time to recover and or new pastures to establish.

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Nutrition decisions following a dry season

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GRDC project code: UQ82

Keywords

- crop nutrition, drought, nitrogen recovery.

Take home messages

- Fertiliser savings after drought or failed crop are possible with phosphorus (P) where there has been an extensive P fertiliser history and Colwell P values are at or above crop critical requirements. As a guide, one third of average crop P replacement can be applied down to a base level of 3-4kg P/ha.
- Savings in nitrogen (N) are likely to be less substantial than savings in P. Nitrogen savings are likely a result of higher spared N (mineral N carryover from last season), lower immobilisation due to lower crop residues and higher mineralisation rates assuming adequate late summer and early autumn rains.
- To better assess spared and mineralised N, deep soil cores should be taken to 60cm and split at 30cm to determine the amount and timing of mineral N availability.

Background

Fertiliser costs represent 20-25% of variable costs for growing grain crops. This proportion is likely to increase with the continued decline of soil organic matter and corresponding reduction in annual soil mineralisation of N (e.g. Angus and Grace 2017). In approximate terms, the N mineralisation potential in cropping soils is declining by 50% every 25 to 30 years (Helyar et al. 1997, Heenan et al. 2004). Soil mineralisation of N is not enough to meet crop demand, consequently N fertiliser is typically applied pre and/or post sowing. The in-crop efficiencies of fertiliser N retrieval in the year of application vary greatly, with approximately 44% in above-ground plant parts, 34% in soil and 22% not recovered, which is presumably lost (Angus and Grace 2017).

Soil mineral N at the start of the growing season still has a large impact on fertiliser N budgeting. Soil mineral N is a function of a number of variables including: [(spared N) + (total N mineralised)] – [(N immobilised) + (weed N uptake) + (N lost)]. On the plus side of the equation; **spared N** is the carryover of mineral N from the previous year and **total N mineralised** is N from mineralised plant residues and mineralisation of the soil organic N pool by microbes. On the negative side of the equation; **N immobilisation** is the N used by microbes to break down crop residues, **weed N uptake** represents another means of N tie up, and **N lost** considers leaching, denitrification (nitric and nitrous oxide and nitrogen gas), erosion and other gaseous losses (ammonia). After drought it is possible that spared N is higher due to lower exports of N in grain. Other considerations after drought include lower immobilisation rates due to lower quantities of crop residues and higher rates of mineralisation after the drought breaks.

Phosphorus is the other substantial annual fertiliser input for crop production in southern NSW. The extensive history of P application and mostly adequate to high soil Colwell P values in this region allow many growers some flexibility in managing P inputs, particularly where cash flow maybe limited following a dry season. The flexibility in P management is also made possible as crop uptake of P is primarily from the soil reserve with a smaller but important component coming from starter P applied at sowing.

In this paper we discuss both P and N considerations after drought. In the N section we consider an experiment examining the recovery of spared N in a 2018 canola crop where the N was applied to a wheat crop in 2017.

Nitrogen with an emphasis on spared nitrogen

Methods

2017 nitrogen experiment

This experiment was sown at Wagga Wagga Agricultural Institute, NSW on 14 May and included one wheat variety (cv. Beckom⁽ᵇ⁾), nine N rates and four N application methods with N applied as mono-ammonium phosphate (MAP) and/or urea (Table 1) in a fully randomised complete block design with four replicates.

The soil at the experimental site was a Red Kandosol with a starting mineral N content of 42kg/ha to a depth of 1.5m (May 4). The previous crop was barley which was burnt late prior to sowing. Soil pH ($CaCl_2$) was 5.8 (0–10cm), 4.7 (10-20cm) and 5.5 (20-30cm) and Colwell P was 57mg P/kg soil (0-10cm). The experiment was direct sown using Ausplow DBS tynes spaced at 250mm. At sowing, 100kg MAP (22kg P/ha and 10kg N/ha) was added to all treatments except the nil N treatment which received triple superphosphate at 22kg P/ha to balance all treatments for P. In plots receiving MAP, various amounts of urea were added to provide the N rates 35kg N/ha through to 185kg N/ha. Mean plant density at DC14 was 127 plants/m^2 and was not significantly different between treatments. In crop weed control was undertaken by applying the pre-emergents Sakura® (pyroxasulfone 850g/L) at 118g/ha and Logran® (triasulfuron 750g/L) at 35 g/ha on 14 May and was incorporated at sowing. Precautionary disease control was implemented, seed was treated with Hombre ® Ultra [Imidacloprid (360g/L) and Tebuconazole (12.5g/L)] at 200mLs/100kg and Prosaro® (Prothioconazole 210g/L and Tebuconazole 210g/L) was applied at 300mL/ha at DC 31.

The experiment was harvested on 30 November. Grain protein and seed quality were estimated using near infrared (NIR) (Foss Infratec 1241 Grain Analyzer) and Seed Imaging (SeedCount SC5000R), respectively. Nitrogen offtake was estimated by protein (%)/5.7 (conversion constant) x grain yield (t/ha). The proportion of apparent fertiliser N recovery in grain was calculated by (GrainN+N – GrainN-N)/N rate where GrainN+N is the grain yield with fertiliser N, GrainN-N is grain yield with no fertiliser N and N rate is the amount of fertiliser N applied. Economic returns after N costs were determined on 2017 prices (e.g. Junee 11th Dec) were calculated by multiplying grain yield (t/ha) by $210 for AUH2, AUH2, AGP1, $250 for AWP1, $265 for H2 and $280 for H1. Pre- and post-rain grain price was only influenced by test weight, protein and falling numbers. Grain discolouration was not significant enough to impact on price.

2018 nitrogen experiment

This experiment was sown into last year's wheat stubble on 5 May over the exact location of the 2017 wheat by N and N application method experiment described above using canola variety 43Y92 sown

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

Variety	x	N rate (kg/ha)	x	Application method
Beckom⁽ᵇ⁾		0		Mid-row banding at sowing (May 14) [**MRB**]
		10		Spread and incorporated by sowing (May 14) [**IBS**]
		35		Deep placement under each row at sowing[**DP**]
		60		Broadcast at DC30 (July 28) [**BSE**]
		85		
		110		
		135		
		160		
		185		

at 4.5kg/ha. The aim of the experiment was to determine grain yield and N recovery (recovery of spared N) in 2018 from N applications made in 2017. The experiment received 20mm of irrigation immediately after sowing (5 May) and had 32mm of stored soil water as well as growing season rainfall (May to October) of 154mm providing a total of 196mm.

At sowing 100kg MAP (22kg P/ha and 10kg N/ha) was added to all treatments except the nil N treatment which received triple superphosphate at 22kg P/ha to balance all treatments for P. In-crop weed control was undertaken by applying the pre-emergent herbicide Treflan at 2.0L/ha prior to sowing. Precautionary disease control was implemented with Prosaro® (375mls/ha) at 20% flowering.

The experiment was harvested on 15 November (hand harvest by cutting 2/m^2) to determine 2018 seed yield, protein and oil response to 2017 N rates and application methods. Seed protein and oil content were estimated using NIR (Foss Infratec 1241 Grain Analyzer). Nitrogen offtake was estimated by protein (%)/6.25 (conversion constant) x seed yield (t/ha). The proportion of apparent fertiliser N recovery (spared N) in seed was calculated by (SeedN+N – SeedN-N)/N rate where SeedN+N is the seed yield with fertiliser N, SeedN-N is seed yield with no fertiliser N and N rate is the amount of fertiliser N applied. Economic returns after N costs were determined on 2018 canola prices (e.g. $600/t) and adjusted for oil premiums using a 1.5% increase or decrease in price for every 1% increase or decrease in oil content above or below 42%.

Results

Seed yield and protein measured in 2018 from 2017 N application

Seed yield and protein of canola harvested in 2018 increased with increasing rates of N applied in 2017 (Figure 1). All rates of N application increased seed yield although yield increases were more responsive above 85kg N/ha. The highest 2018 seed yield was achieved by the highest 2017 N rate using the MRB application method. No yield plateau occurred in any treatment, except for 2017 in the BSE treatment for the 160 and 185kg N/ha rates (Figure 1A). As with seed yield response, seed protein increased with increasing N rate however the protein levels were lower for the IBS method of application at the three highest 2017 N rates (Figure 1B).

Recovery of spared N and oil content measured in 2018 from 2017 N application

Recovery of spared N in 2018 increased with increasing rates of N applied in 2017, particularly at rates above 85kg N. The recovery of spared N was higher in MRB and DP compared with IBS for the highest three rates. Mid-row banding returned the highest recovery rate of spared N at the highest N rate (Figure 2A). Oil content of seed measured in 2018 declined with increasing 2017 N rate and MRB, DP and DC30 methods of application declined further than the IBS method (Figure 2B).

The percentage of spared N recovery in 2018 from 2017 N application ranges from 1% to 18% and increased with increasing N rate (Figure 3A). When

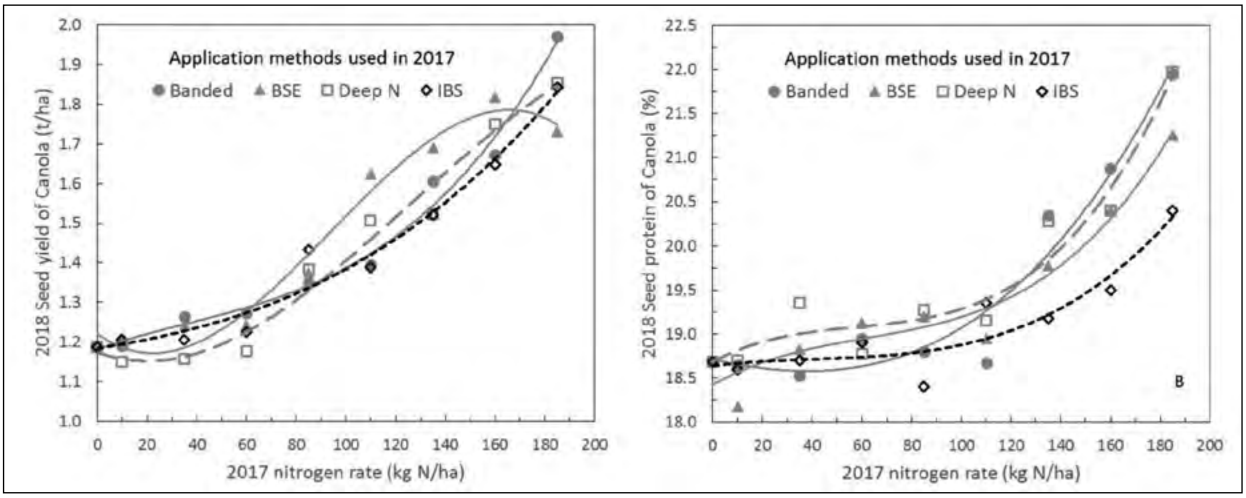

Figure 1. Responses of seed yield (t/ha) (1A) and seed protein (%) (1B) in 2018 to N applied in 2017 using four different methods of N application. Methods of application included (i) surface broadcast and incorporated by sowing (IBS), (ii) mid-row banding (MRB) at sowing (8cm deep) between every second row, (iii) deep placement (DP) at sowing under each wheat row (16cm), and (iv) broadcasting at stem elongation (BSE).

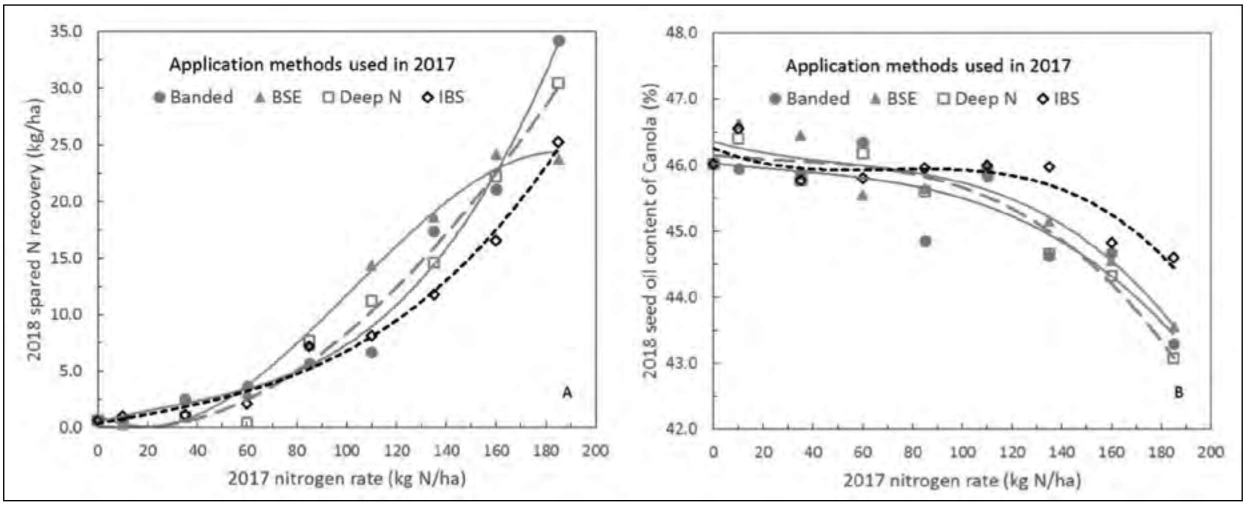

Figure 2. The recovery of spared N (kg/ha) (2A) and oil content (%) (2B) in 2018 from the N applied in 2017 using four different methods of N application.

the percentage of apparent fertiliser recovery and spared N recovery was summed over 2017 and 2018, there was a common rate of recovery of between 55% and 60% recovery across all methods of application when applied at 110kg N/ha (Figure 3B). At rates lower than 110kg N/ha, N recovery rates varied between methods of application although MRB tended to show higher and more stable results. Recovery rates above 110kg N/ha showed a consistent decline, although MRB had higher recovery rates than IBS while the other methods (BP and DC30) were intermediate (Figure 3B).

Net returns after fertiliser costs

Figure 4A indicates that 110kg N/ha produced 95% of maximum return on fertiliser N investment when considered on a single year response using Beckom⦸ wheat (2017). However, Figure 4B indicates that when considering returns over two years, the optimal N rate increases to 135kg N/ha.

Discussion

Spared N

In this experiment, spared N recovery in grain the year after N application was found to be low (1-18%) and for commercially used rates of N it is estimated at 6% (±5%) of the previous year's application rate (Figure 3A). This approach used the difference method to estimate spared N captured in grain and agrees with 15N studies that show spared N in the following crop from N fertiliser is 5.4% (±4.5%) (Smith and Chalk 2018). Spared N measured in soil the year after fertiliser N application is estimated at 24%

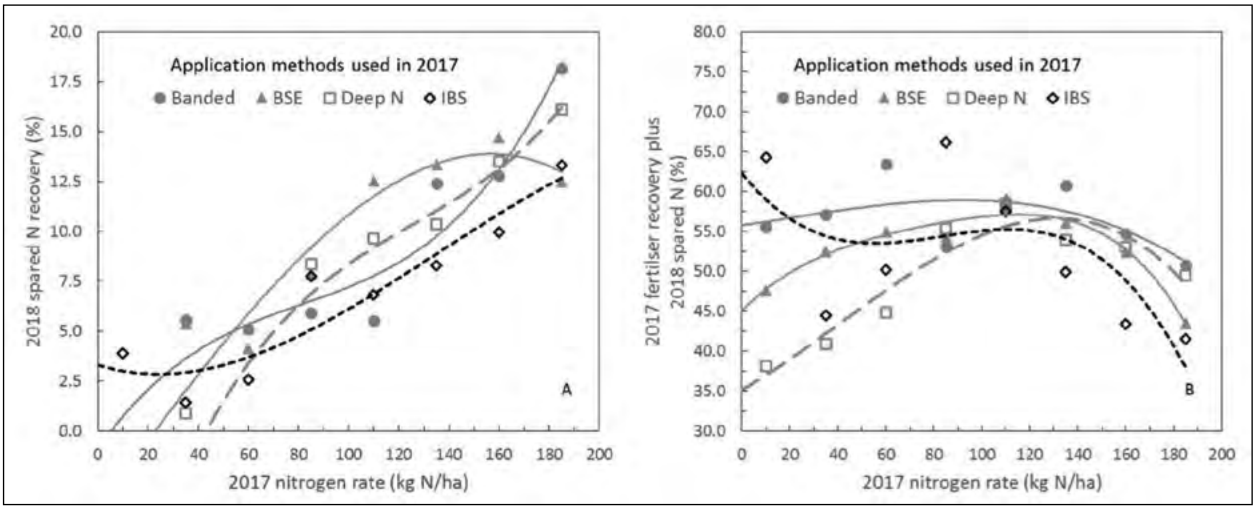

Figure 3A. The percentage of spared N recovery in 2017, and Figure 3B total recovery of fertiliser N and spared N over the years 2017 and 2018.

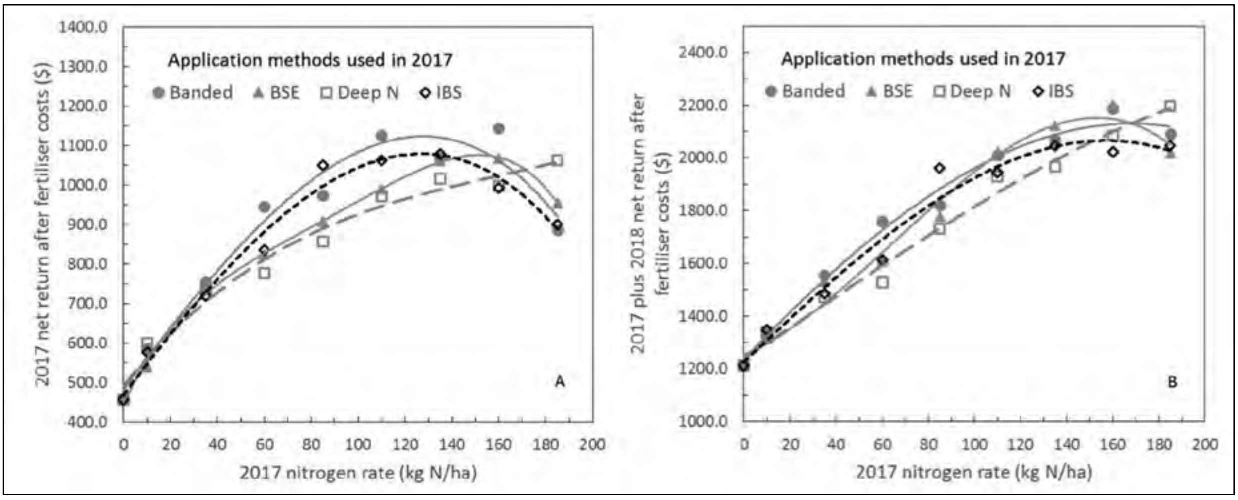

Figure 4. Net return after fertiliser costs for 2017 (Figure 4A) and combined values for 2017 and 2018 (Figure 4B).

(±15%) (Smith and Chalk 2018) suggesting a soil recovery for spared N of 25%. These results suggest N savings for 2019 sowings from spared N may be limited.

N immobilisation

Other considerations apart from spared N will be more important when N budgeting for example N immobilisation in stubble residues from the previous season. Microbes break the stubble down and to grow, these microbes use about 12 units of carbon (C) to 1 unit of N while wheat straw contains about 80 to 120 units of C for every unit of N. Consequently, the bacteria utilise soil N to break down the stubble residue. As an estimate, 1000 kg/ha of wheat grain produces about 1660 kg/ha of stubble. This stubble is made up of approximately 40 to 45% C (747kg/ha assuming 45% carbon) and has approximately 6.2kg N/ha, assuming a 120:1, C:N ratio in wheat stubble. As an estimate, 30% of the stubble is used by microbes for growth while approximately 70% is respired as carbon dioxide. Therefore, the microbes would consume 224kg C/ha (i.e. 30% of 747kg/ha) for growth and at a C:N ratio of 12:1 that would mean they require 18.6kg N/ha of which 6.2kg N/ha is already contained in the stubble. This suggests that for every tonne of last year's grain yield, 12.4kg N/ha (18.6kg N/ha – 6.2kg N/ha) is required to break down last year's stubble residue. Where this N is not supplied, the grain yield loss from immobilisation in wheat would be 250kg/ha/t of last year's wheat yield or 250kg/ha/1.66 t of residual stubble. With high stubble loads and low C:N ratios, N immobilisation can be substantial. For example, a 4t/ha wheat crop that was broken down (approximately 50% only) over the following year would immobilise an estimated 25kg N/ha or approximately55kg/ha of urea (note wheat stubble usually takes more than one year to break down in southern NSW). In a drought year assuming the stubble residue is halved so will be the immobilisation of N providing a calculated potential saving in this example of 12.5kg N/ha.

Pre-sowing mineralisation

Mineral N prior to sowing is best estimated by deep cores to 60cm. These can be split into 30cm sections to identify if the mineral N will be available early in the season or later in the growing season. In droughts mineralisation is slow due to low soil moisture and rapidly increases after the drought breaks. It's possible increased mineral N will be evident after the 2018 drought and this will be more likely expressed in paddocks with an extensive and recent pasture history.

Phosphorus budgeting after drought

P budgeting and take-off in grain

Starter P, often applied as MAP, is very important for; (i) early root development which assists the plant in exploring the greater soil P reserve and (ii) early head development when potential grain number is set (e.g. at or just prior to DC30).

Many phosphorus experiments have shown responses to starter P however, P savings can be made after drought especially where (a) December P export in grain is lower than P inputs at sowing and (b) soil Colwell P values are equal to or greater than soil critical values for the target species. In these circumstances one third of historical average annual P inputs can be applied down to a base level of 3-4kg P/ha. As an example, if our wheat target yield for 2019 is estimated at 3t/ha and the P budget is estimated to be 3.6-5.5kg P/t of grain production then we have a P budget of 10.8-16.5kg P/ha or 49-75kg/ha MAP. If a medium value of 62kg / ha MAP (13.5kg P/ha) was assumed as our standard P budget, we would reduce this by two thirds down to 18.6kg /ha of MAP or 4.1kg P/ha. At this rate the MAP granules are placed in-row at approximately 3.5-4.5cm spacings when using 25cm tyne spacing. Wheat sowing rates (50-65kg/ha) are likely to place seed at every 2-2.5cm in-row while the full MAP rate of 62kg/ha provides an in-row granule spacing of approximately 1.0-1.2cm.

The more detailed approximations used for P budgeting in wheat include grain P export (2.7-3.6kg P/t) plus stubble P not accessible to the following crop (0.4-0.8kg P/t) plus soil losses (0.3-0.7kg P/t grain production) which provides an estimated 3.6-5.5kg P required/t of grain production. Similarly, for canola seed P export (4.0-6.5kg P/t) plus stubble P not accessible (0.6-1.0kg P/t) plus soil losses (0.3-0.7kg P/t grain production) provides an estimated 6.1-10.2kg P required per tonne of seed production. On a per hectare basis the export of P for wheat and canola is approximately the same assuming canola has half the water use efficiency for grain production as wheat.

In the longer-term, P inputs should be adjusted by tracking soil P values to determine if soil test values are increasing (over estimate of P budget), decreasing (under estimate of P budgeting) or remaining within the critical 90 and 95% range (P budget balance). After several year of soil testing and adjusting P inputs it is possible to ensure relatively stable soil P test values for optimising economic returns.

Figure 5 shows the average Colwell P decline between P applied and measured in 2017 and measured again in 2018 when no P was applied in 2018. The Colwell P decline is estimated by regression analysis that included soil samples taken from plots growing four different crop species (wheat, lupin, field pea and lentil). Crop species were sown in a P deficient soil that was fertilised prior to being sown in 2017 with 11 P rates. The decline shown here, is an average over the different crop species and highlights that Colwell P decline is larger in higher P soils. This represents a greater reduction in soil P which is likely due to stronger bonding of P in the soil reserve and higher P removal in grain and stubble. The take home message from this is to ensure Colwell P values are within the 90 to 95% of maximum grain yield but not above these values as the high P levels will not increase grain yield and will decrease P use efficiency. For another supporting perspective on this point see Simpson et al (2014).

The exception to the above reduction in P budgets after drought applies to calcareous soils with high pH. Phosphorus savings in this example are not possible as the excess lime (calcium or magnesium carbonate) will not readily dissolve at high pH and it serves as a P sink for surface adsorbed calcium phosphate precipitation. In

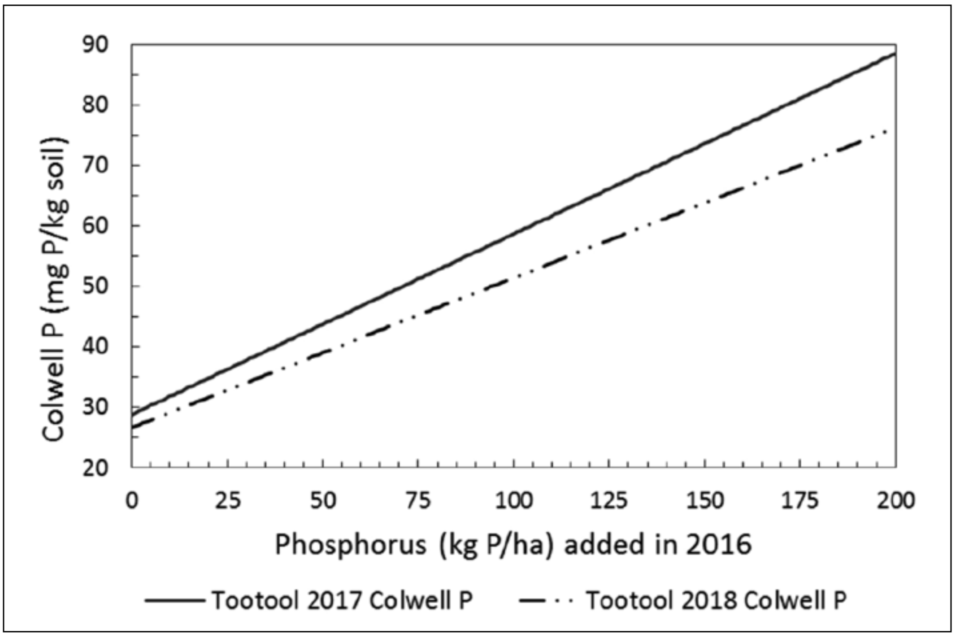

Figure 5. Average Colwell P decline between P applied in 2017 (solid line) and 2018 (dashed and dotted line) where no P was added in 2018.

addition, the lime in calcareous soil reacts with P in soil solution to form calcium phosphate at the surface of the lime. The first process of P bonding occurs in dry conditions and consequently P availability is low even in circumstance where P take-off has also been low. In these soils, advantages in P supply are achieved with application via highly concentrated P bands with minimal soil mixing.

P budgeting and take-off in hay

Phosphorus off-take in hay per ha is higher than for grain production. Previously it was estimated that a 1t/ha wheat crop would remove 2.7-3.6kg P/ha while a hay crop is estimated to remove 1.0-2.0kg P/ha/t. The same comparison for canola indicates a 1t/ha grain crop exports 4.0-6.5kg P/ha in seed while the hay exports an estimated 3.0-4.0kg P/ha/t. In some circumstance where substantial hay yields are achieved large amounts of P are removed. Large variations in P off-take in hay are also likely due to hay quality as well as the proportion of unbaled straw and leaf remaining in the paddock. Note the unbaled leaf component for canola can be large and rain on cut hay can leach plant available P into the soil.

Hence, P savings in 2019 after hay cut in 2018 needs to be considered in a more conservative light. With higher P off-take, Colwell P values will decline more substantially and consequently slightly different P saving rules apply. These include (a) soil Colwell P values greater than 95% of critical for the target species and (b) half of historical average P inputs can be used down to a base level of 5 kg P/ha.

Cash flow approach to P budgeting

One-off P savings after drought or failed crop production are made possible because most P for crop production is drawn from the soil reserve. Because of this P budgeting can be somewhat retrospective. As an example this 'somewhat retrospective' approach firstly estimates the P budget based on long term rainfall and water use efficiency to produce likely average grain yield for wheat and the subsequent P budget (e.g. stored soil water = 30mm, in season rainfall = 230mm, plant available soil water = 260mm, soil evaporation = 110mm, water use efficiency of grain production = 20kg grain production per mm of crop transpired water, grain yield therefore = 3 t/ha, P budget = approximately 16.5kg P/ha is the long term average). The second component of the budgeting exercise requires the same approach as described but applied to the season just passed. In this case let's assume last year's grain yield was 1.5t/ha and a retrospective P budget of 8.25kg P/ha is estimated (e.g. half the long-term average). The final step is to average the two estimates for the unsown crop and in this example that is estimated at approximately 12.4kg P/ha. The advantage of this approach is it considers both long term P budgeting to maintain soil P reserves and last year's retrospective P budget which is most likely to reflect cash flow. This simple model adds more P after higher yielding years and less P after low yielding years. The underlying assumption is that the soil Colwell P starting point is between 90 and 95% of crop critical P. Phosphorus inputs should always be assessed against soil test values to ensure input assumptions are maintaining Colwell P values in the critical range.

Conclusions

Fertiliser savings after drought are possible with P and less likely with N. This is because the extensive history of P application in southern cropping systems of NSW combined with low soil phosphorus buffering indexes ensures that P can be supplied to crops from the greater soil reserve. In addition, the soil reserve supplies most of the P requirements of crops while fertiliser P only directly supplies a much smaller proportion (<30%).

Drought is likely to cause slightly higher rates of mineralisation and lower rates of immobilisation compared to an average season. Spared N from the following crop is likely to be higher however, its recovery in the following crop is low. The combination of higher spared N and higher potential rates of mineralisation (assumes average or above average March and April rain) may result in lower 2019 N budgets, although this is best measured with deep soil cores.

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Useful resources

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/a-test-of-nitrogen-fertiliser-use-efficiency-in-wheat-using-mid-row-banding

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/08/improving-nitrogen-use-efficiency-of-cropping-systems-of-southern-australia-by-mid-row-banding-nitrogen-fertiliser-in-season

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Notes

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- Common root rot
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- White grain disorder
- Sclerotinia stem rot

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Phosphorus and phosphorus stratification

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GRDC project codes: UQ00082, UQ00063, 9175108

Keywords

- phosphorus, stratification, deep phosphorus, critical soil phosphorus.

Take home messages

- Phosphorus (P) stratification can impact on the critical P requirements of grain crops. In northern NSW and Queensland placing P at 20cm below the soil surface resulted in significant grain yield responses (~13% increase in wheat) (Bell et al., 2016). These findings are worth further consideration in other regions of the Australian grain belt particularly where soil P values in the 10 - 30cm layer are very low (Colwell P < 5mg/kg soil) and surface soils (> 10cm) experience extended periods of low soil moisture that limits P uptake by roots.
- Testing the extent of P stratification on-farm (surface 0–10cm and subsoil 10–30cm) can assist in P budgeting as the lack of subsoil P can be offset by higher concentrations of surface P in most soils provided soil moisture conditions are adequate for P uptake.
- The extent to which P stratification impacts grain yield is influenced by; (i) the Colwell P values for 0–10cm and 10–30cm layers, (ii) the probability of poor crop P uptake due to low soil moisture at 0–10cm, and (iii) the crop type. The current understanding of these components for southern cropping systems is inadequate to provide any precise recommendations.

Background

In the grains-growing areas of south-east Australia, the bulk of plant nutrients in labile form usually occurs in the topsoil, with much lower amounts present in the subsoil. It is becoming increasingly evident that in environments where the nutrient-rich topsoil is prone to drying, nutrient uptake by crops is likely to be adversely affected despite the availability of water in the subsoil. This is likely due to impeded root growth in the dry topsoil or reduced diffusion of immobile nutrients to plant roots or both. Despite the numerous studies on vertical nutrient stratification, there is still limited information on the effectiveness of subsoil nutrition on yield productivity and also the efficiency of nutrient use. This paper reviews P cycling and budgeting in grain production systems with an emphasis on P stratification and the resulting consequences it has on crop P demand.

Phosphorus cycling

Soils of Australia in their native state are deficient in P with some exceptions through northern NSW and Queensland (e.g. Vertisols) which have only been depleted in more recent times through cropping. Consequently, advisers aim to ensure P fertiliser has been added in amounts that are approximately equivalent to the amount of P exported in grain plus other losses such as unrecovered P in stubble and soil. Phosphorus

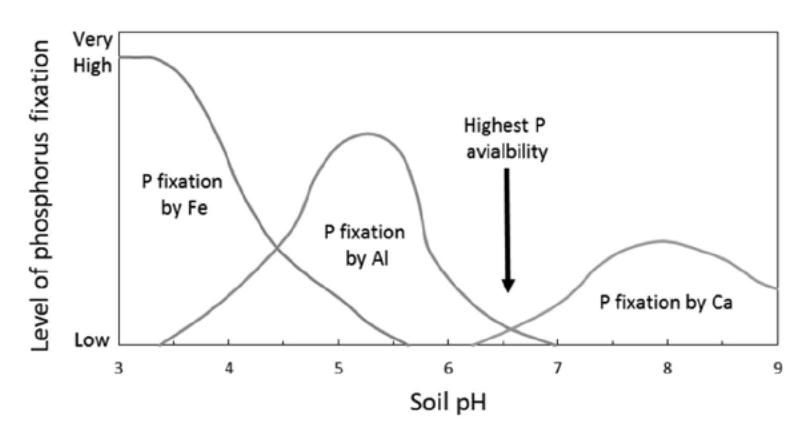

Figure 1. The effect of soil pH on phosphorus availability.

fertiliser that is added to the soil primarily goes into the 'soil reserve' where the P binds to soil, a process referred to as P sorption or fixation. Fixation occurs when P reacts with other minerals to form insoluble compounds and becomes unavailable to crops. An important factor controlling P fixation is soil pH as shown in Figure 1. There are three peaks of P fixation. The two highest peaks occur in the acid range of pH 4 and 5.5, where P precipitates with iron (Fe) and aluminium (Al). It is very difficult to supply sufficient P for crop needs when P solubility is being controlled by Fe and Al. The third peak occurs in alkaline soils around pH 8.0 when P is precipitated primarily by calcium (Ca). This fixation is relatively weak, and it is generally more economical to apply more P fertiliser than adding amendments to acidify the soil (Figure 1).

Plant available P in soil solution is predominantly present as dihydrogen phosphate ($H_2PO_4^-$) or as hydrogen phosphate (HPO_4^{-2}) in more neutral and alkaline soils. Various estimates indicate approximately 70–80% of P fertiliser added in the crop year becomes part of the soil reserve (Price 2006). The soil P reserve can be described further however for the purpose of this paper it's important to simply acknowledge that within the soil P reserve there is different bonding of P that influences the short- and long-term plant available P (Figure 2). For example the soil reserve is made up of (1) sorbed P (P held on the surface of fine clay particles), (2) secondary P minerals (freshly bounded Fe, Al and manganese (Mn) phosphates [acid soils] and Ca and magnesium (Mg) phosphates [alkaline soils]) and (3) primary P minerals (age and crystallised Fe, Al, Mn,

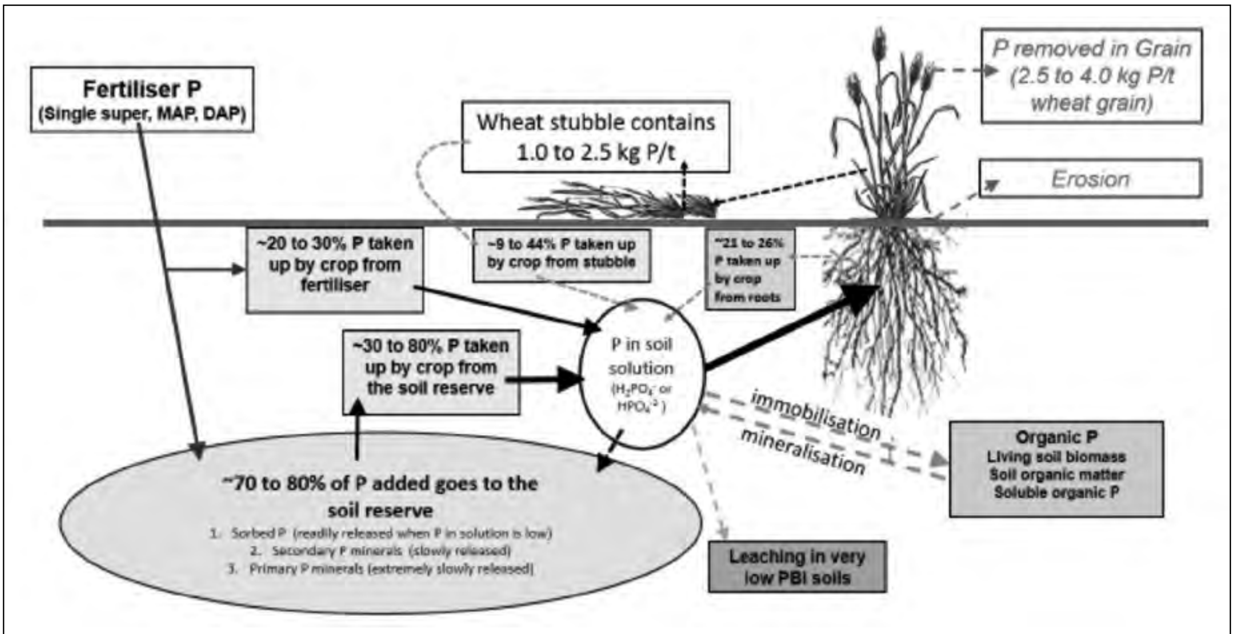

Figure 2. Soil phosphorus cycling in winter cropping systems.

Table 1. Colwell P (mg /kg soil) values for 90 and 95% of maximum grain yield for various crop and soil type combinations extracted from the BFDC database.									
Species	Soil	90%	95%	Location	Species	Soil	90%	95%	Locations
Feed barley	All soils	20	25	National	Wheat	Calcarosol calcic	24	29	SA, Vic, WA
Field Pea	All soils	27	34	National	Wheat	Dermosol	27	35	NSW
Narrow leaf Lupin	All soils	22	26	National	Wheat	Kandosol red	24	30	NSW
Canola	All soils	20	25	National	Wheat	Tenosol	16	20	WA, SA, Tas
Wheat	All soils	24	32	National	Wheat	Sodosol brown	27	32	NSW, Vic, SA
Wheat	Chromosol red	30	38	NSW, QLD, Vic	Wheat	Vertosol black	25	33	NSW, QLD
Wheat	Chromosol brown	17	19	WA, SA	Wheat	Vertosol brown	24	32	NSW, SA
Wheat	Chromosol grey	18	21	WA	Wheat	Vertosol grey	18	21	Vic, NSW, QLD

n.b. Estimated Colwell P critical values for chickpea, faba bean, lentil and broadleaf lupins are not available from the BFDC database due to no or insufficient data. Similarly, not enough data exists for feed barley, field pea, canola and narrow leaf lupin to provide specific soil type estimates of Colwell P critical values. Where states are nominated under 'Location' this refers to the state where most of the experiments (not necessarily all) were conducted.

Ca and Mg phosphates). The soil P reserve (Figure 2) in P adequate soils (Table 1) provides the largest percentage of crop nutrient requirements in any one year which is estimated at approximately 30–80% (Price 2006, Mcbeath et al 2012). Phosphorus fertiliser can directly provide approximately 20–30% of crop requirements (Price 2006) with available P from stubble making up approximately 9–44% (Noack et al 2012) and roots approximately 21–26% (Foyjunnessa et al 2016).

Phosphorus Buffering Index (PBI)

The PBI test measures the P sorption of the soil. This is the process by which soluble P becomes adsorbed to clay minerals and/or precipitated in soil and it determines the partitioning of P between the solid and solution phases of the soil. A high PBI therefore results in a greater tendency for P sorption compared with a low PBI. Consequently, P sorption capacity of soil influences the availability of P to plants and can be useful for determining Colwell P critical values. Figure 3 shows the relationship between PBI and Colwell P critical for wheat. Usually large changes in PBI values are required to change crop critical P values. Examples of this are provided in Table 2 calculated from Moody (2007). In addition, estimates are also provided from Bell et al (2013) which are quantified from a large data set in the Better Fertiliser Decisions Cropping database (BFDC; http://www.bfdc.com.au/interrogator/frontpage.vm).

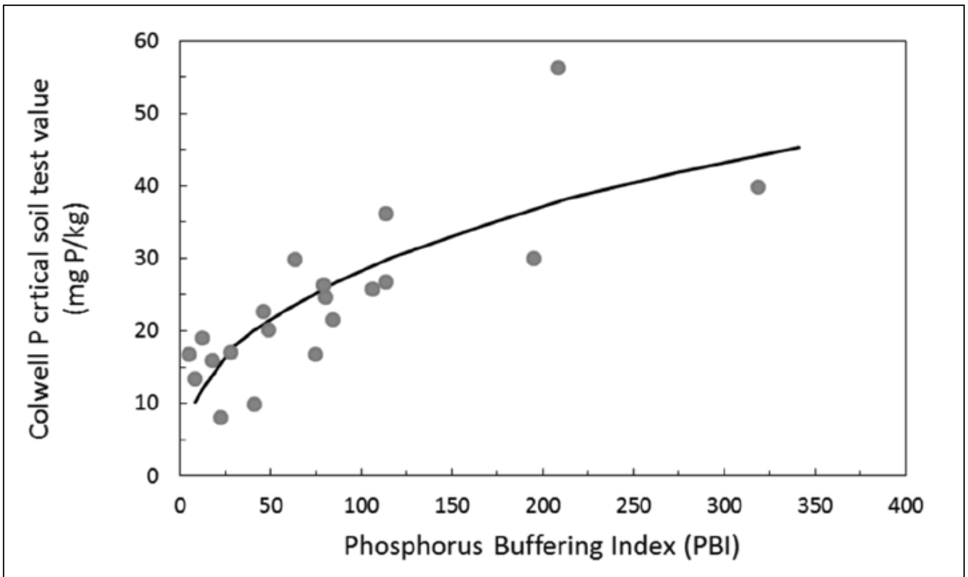

Figure 3. Effect of phosphorus buffering index on critical Colwell-P (0–0.10 m) required for 90% maximum grain yield of wheat. Critical Colwell P = 4.6 x PBI$^{0.393}$ (Moody 2007).

Table 2. Estimated 90% critical Colwell P soil values (mg P/kg soil) for wheat grown in soils with differing PBI (Moody 2007 and Bell et al 2013).

P Buffering	PBI	Estimated 90% critical P	P Buffering	PBI	Estimated 90% critical P
Extremely low	10	11.4	Low	80	25.7
Very very low	20	14.9	Moderate	180	35.4
Very low	40	19.6	High	350	46.0

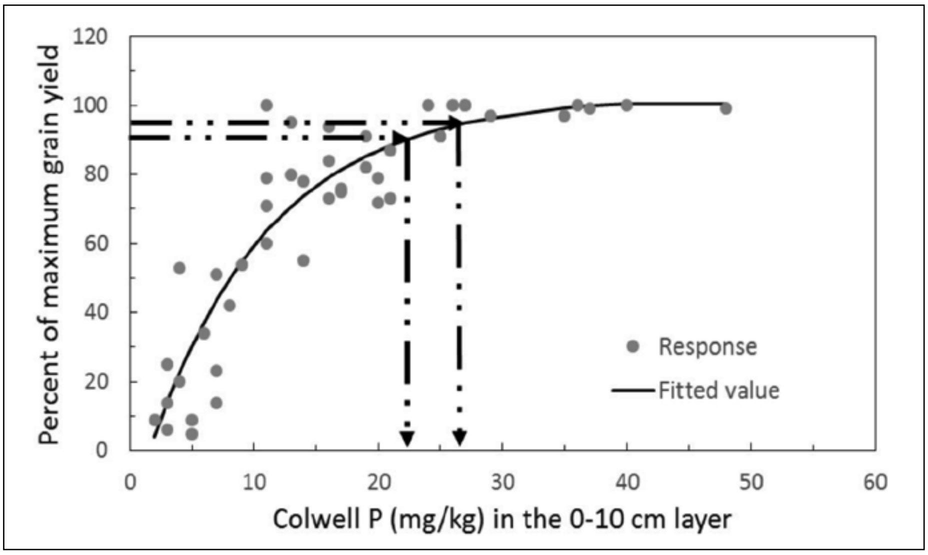

Figure 4. Grain yield response of canola across a range of soil types. Data taken from the BFDC.

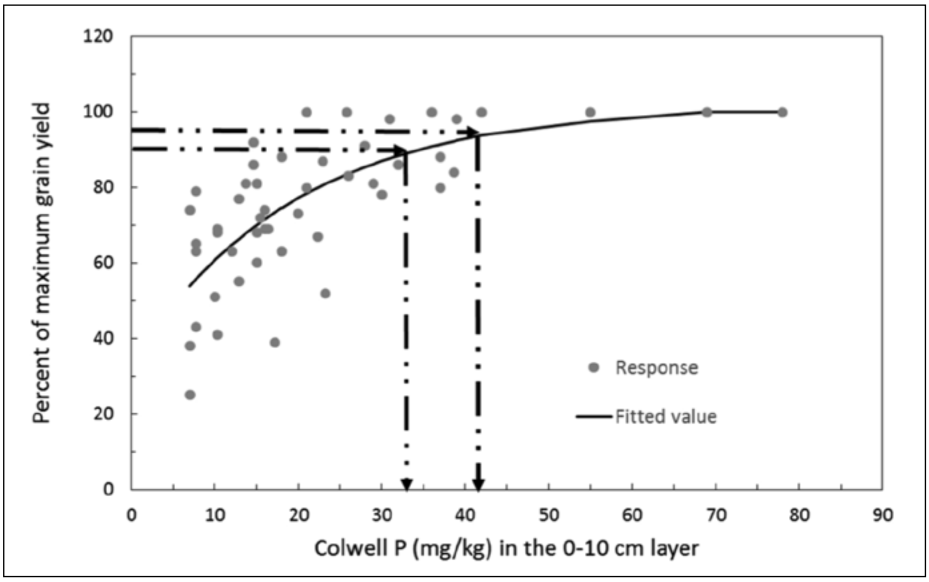

Figure 5. Grain yield response of wheat on Red Chomosol soils of NSW. Data taken from the BFDC.

Critical Colwell P soil test values

The critical soil test range is the soil P status, often measured as Colwell P, that will ensure 90-95% maximum crop production. This range may differ for different crop species and soil types that have a different PBI value or the level of soil moisture and degree of surface P stratification. The latter two factors are likely explanations for differences in critical values between years where species and PBI are fixed. Additional factors may include the type of equations used, as small changes in slope near the asymptote (e.g. maximum yield) can make large changes to soil critical values on the x axis.

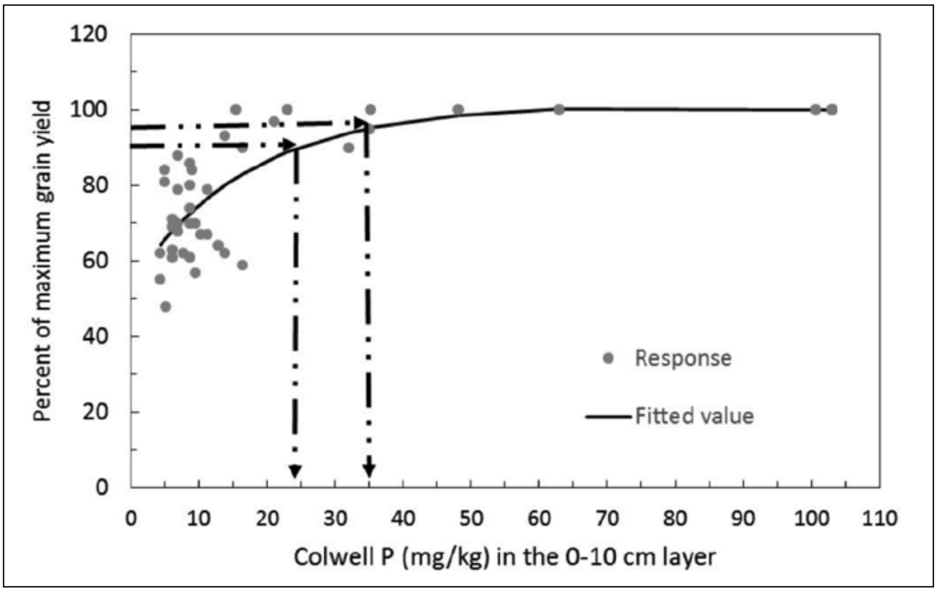

Figure 6. Grain yield response of wheat on Vertisol soils of NSW. Data taken from the BFDC.

An analysis of data from the BFDC database using Mitscherlich equations indicates 90 and 95% critical values for canola across soil types are estimated at 22 and 27mg P/kg soil using Colwell P at 0-10cm soil depth (Figure 4). The same comparisons for wheat on Red Chromosol indicates a Colwell P critical value of 35 and 42mg P/kg soil (Figure 5) and for wheat on Vertisol a Colwell P critical value of 25 and 35mg P/Kg soil (Figure 6). Using the Mitscherlich equation provides a slightly higher estimate of critical value than those estimated directly from the BFDC database (Table 1) that use quadratic equations to estimate critical P, however there is sound general agreement between the values calculated with different equations.

The sampling depth of P has a significant effect on its critical value. For example, data from the BFDC national wheat data set showed that across soil types, sampling at 0-5cm, 0–10cm and 0–15cm resulted in Colwell P critical value variation from 31 and 36, 24 and 32 and 15 and 20mg/kg for 90% and 95% of maximum grain yield, respectively.

Industry standard practice is to sample at 0–10cm however, knowledge of P concentration in the 10–30cm layer can be very informative in P budgeting. The differences in critical Colwell P for sampling depth may have resulted from (i) differing soil P status at deeper un-sampled depths, (ii) dilution and P stratification effects with greater soil sampling depth and (iii) different crop recovery of P from different depths of soil. The point raised here which will be examined in more detail later in this paper, is that P status at un-sampled depths can contribute to a reduction in wheat critical values as shown above.

Phosphorus budgeting

Phosphorus is exported in grain and recycled in stubble and roots provided the stubble component is retained. Phosphorus in wheat grain ranges from 2.7–3.9kg P/t while in canola seed the range is 3.9–7.8kg P/t (Table 3). Phosphorus in stubble for wheat and canola ranges from 1.0-3.0kg P/t and 2.0–4.0kg P/ha, respectively. Root P concentrations in wheat and canola ranges from 1.5–3.0 and 2.0–2.5kg P/t, respectively.

Approximations of P used for P budgeting in wheat include grain P export (2.7–3.6kg P/t) plus stubble P not accessible to the following crop (0.4–0.8kg P/t) plus soil losses (0.3–0.7kg P/t grain

Table 3. Concentration of phosphorus (kg/t) for wheat and canola grain samples selected from NVT sites. Values are expressed on a dry weight basis (Norton 2012; 2014).

State	NSW min	NSW max	NSW mean	SA min	SA max	SA mean	Vic min	Vic max	Vic mean
Wheat									
P in grain (mg/kg)	2.7	3.6	3.1	3.1	3.9	3.4	2.9	3.6	3.2
Canola									
P in grain (mg/kg)	3.9	6.6	5.2	5.1	7.8	6.2	5.2	6.5	5.7

production) which provides an estimated 3.6–5.5kg P required/t of grain production. Similarly, for canola seed P export (4.0–6.5kg P/t) plus stubble P not accessible (0.6–1.0kg P/t) plus soil losses (0.3–0.7kg P/t grain production) which provides an estimated 6.1–10.2kg P required/t of grain production. On a per hectare basis the export of P for wheat and canola is approximately the same assuming canola has half the water use efficiency for grain production as wheat. These budgets are estimates, and therefore, must be assessed and adjusted by tracking soil P values to determine if soil test values are increasing (over estimate of P budget), decreasing (under estimate of P budgeting) or remaining within the critical 90 and 95% range (P budget balance). After several years of soil testing and adjusting P inputs it is possible to ensure relatively stable soil P test values.

Phosphorus savings after drought

A recent meta-analysis (He and Dijkstra 2014) demonstrated that drought stress decreases the concentration of P in plant tissue, and several studies have shown that drought can decrease nutrient uptake from soil. Decreases in nutrient uptake during drought may occur for several reasons, including the reduction of nutrient diffusion and mass flow in the soil. Drought can also decrease nutrient uptake by affecting the kinetics of nutrient uptake by roots, however this effect is less well studied.

In cropping systems starter P is important for (i) early root development which assists the plant in exploring the greater soil P reserve and (ii) early head development when potential grain number is set (e.g. at or just prior to DC30).

Many P experiments have shown responses to starter P however, P savings can be made after drought especially where (i) December P export in grain is lower than P inputs at sowing and (ii) soil Colwell P values are equal to or greater than soil critical values. In these circumstances one third of historical average P inputs can be used down to a base level of 3–4kg P/ha. As an example, if wheat target yield for 2019 is estimated at 3t/ha and the P budget is estimated to be 3.6–5.5kg P/t of grain production then we have a P budget of 10.8–16.5kg P/ha or 49–75kg/ha mono-ammonium phosphate (MAP) fertiliser. If a medium value of 62kg/ha MAP (13.5kg P/ha) was assumed as our standard P budget this could be reduced by two thirds down to 18.6kg / ha of MAP or 4.1kg P/ha following the dry 2018. At this rate, the MAP granules are placed in-row at approximately 3.5–4.5cm spacings when using 25cm tyne spacing. Wheat sowing rates of 50–65kg/ha are likely to place seed at approximately every 2–2.5cm in-row while a full MAP rate of 62kg/ha provides an in-row granule spacing of approximately 1.0–1.2cm.

Phosphorus stratification

There are several reasons why P is often highly stratified near the soil surface, including; (i) 'native' Australian soils were deficient in P and farming systems, have for the most part, applied P in the top 0–10cm of soil, (ii) P is highly reactive in soils binding with Fe, Al and Mn at low pH and Ca at high pH as well as bonding with small clay particles, consequently P is not readily leached in most soils, (iii) farming systems have shifted from intensive cultivation prior to sowing to no-till or minimum-till systems and this has reduced soil mixing, and (iv) P in stubble retained systems is recycled to the soil surface.

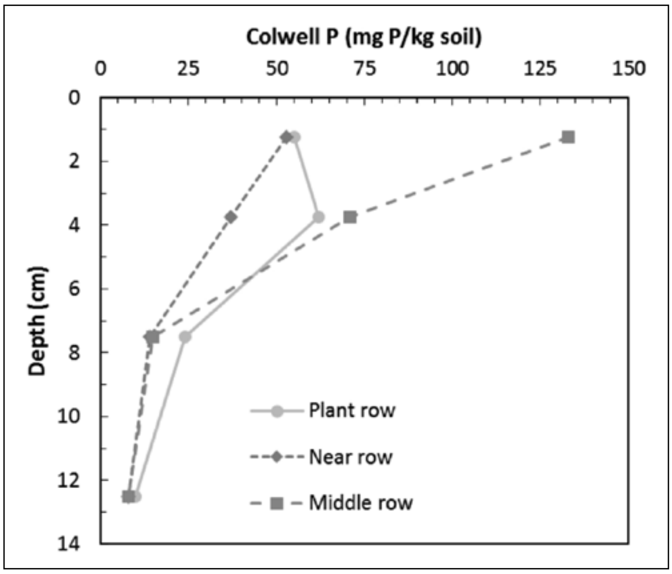

Figure 7. Vertical and horizontal stratification of P measured as Colwell P at the long-term Hart experiment. Samples taken in 2017 (Armstrong et al 2017).

An example of a stratified soil sampled in July 2017 is provided in Figure 7 (Armstrong et al 2017). In this example the 'plant row' has a Colwell P of approximately 55mg P/kg soil in the 0–2.5cm section and increases to approximately 62mg P/kg soil in the 2.5–5cm section, which reflects the fertiliser drilled at sowing. At 5–10cm the Colwell P value drop to approximately 24mg P/kg soil and declines to approximately 10mg P/kg in the 10–15cm layer. The sampling 'near row' has no fertiliser spike in the 2.5–5cm section (e.g. approximately 37mg P/kg 'near row' compared to approximately 62mg P/kg 'plant row' in the 2.5–5cm section). The 'middle row' (inter-row) section shows very high Colwell P at the soil surface (approximately 133mg P/kg soil on the 0–2.5cm section). This is most probably because the tyne on the 'plant row' has thrown P rich surface soil into the inter-row space (e.g. middle row).

The calculated Colwell P at 0 - 10cm on the plant row is approximately 40.5mg P/kg (Figure 7). The question is; how much of this does the plant root access given sowing depth of around 5cm and frequent drying of surface soil. In this scenario, let's assume the plant does not access P in the top 0–2.5cm, and therefore, the estimated Colwell P at 0–10cm reduces to 27.4mg P/kg soil. In most cases, this is still adequate P for 90% of maximum yield (Table 2) however, it highlights a number of very important issues including what is the relative efficiency of P access at different depths and soil moisture. In the above example (Figure 7) if we assume a 0–10cm Colwell P was 30mg P/kg instead of 40.5mg P/kg and the same proportion of P stratification is applied with no access to P in the 0–2.5cm layer then the Colwell P value becomes approximately 20mg P/kg soil. In this contrived scenario, crop yield may be limited.

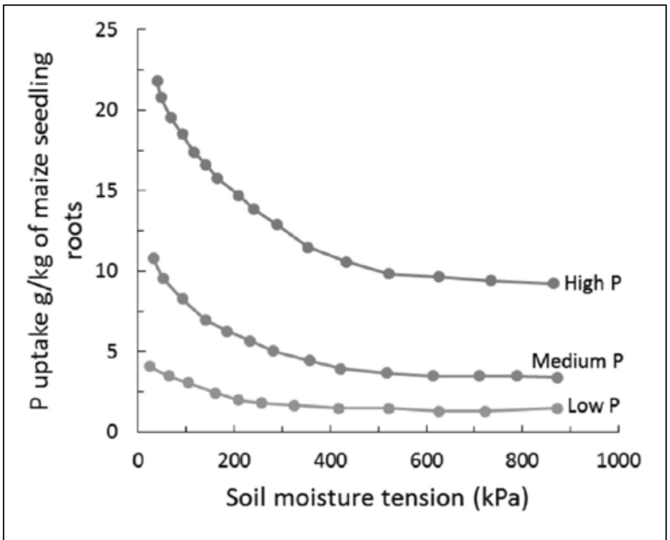

Figure 8. Phosphorus uptake in roots of maize to different soil moisture and soil phosphorus levels.

While the above scenarios are simplistic (e.g. zero P access in the 0–2.5cm section whereas low uptake efficiency is more likely in the 0-2.5 cm section), the point is clear that highly P stratified soils have the potential to limit yield particularly where P is high stratified in the 0–2.5cm layer and this layer is subject to frequent drying. Figure 8 demonstrates the principle that P uptake can be limited by soil moisture and soil P status. This evidence supports the theory that a frequently drying surface soil with adequate subsoil moisture may respond to deeper placement of P. However, this needs to be tested with wheat in southern NSW soil and climatic conditions before any conclusive statements can be made.

Phosphorus placement at sowing

Compared with broadcasting or banding fertiliser P with seed, the placement of P at 2–6cm below seed has shown significant yield increases in 14 scientific studies (**wheat**: Alston 1976; Nable and McConnell et al 1986; Webb 1993; Sander and Eghball 1999; Singh et al 2005; Wilhelm 2005; **canola**: Grewal et al 1997; Hocking et al 2003; Wilhelm 2005; **lupin**: Jarvis and Bolland 1990, 1991; Crabtree et al 1998; Brennan 1999; Crabtree 1999; Scott et al 2003) and no significant increase in five scientific studies (Hudak et al 1989; Reeves and Mullins 1995; Bolland and Jarvis 1996; McCutcheon and Rzewnicki 2001; Vyn and Janovicek 2001). All of these studies placed P at depths less than 15cm and some of these studies had starting soil P values below crop critical values.

In at Nebraska a P placement study determined the optimum P placement depth as 11.9cm (Figure 9). Research in WA by Bolland and Jarvis (1990) found wheat yield was increased by approximately 20% when the fertiliser was placed at 9cm below the soil surface compared to 3cm in the first year of sowing single superphosphate. In the second year, superphosphate placed at 13cm depth in the previous year increased grain yield by approximately 60% in lupins compared with freshly drilled fertiliser at 3cm deep.

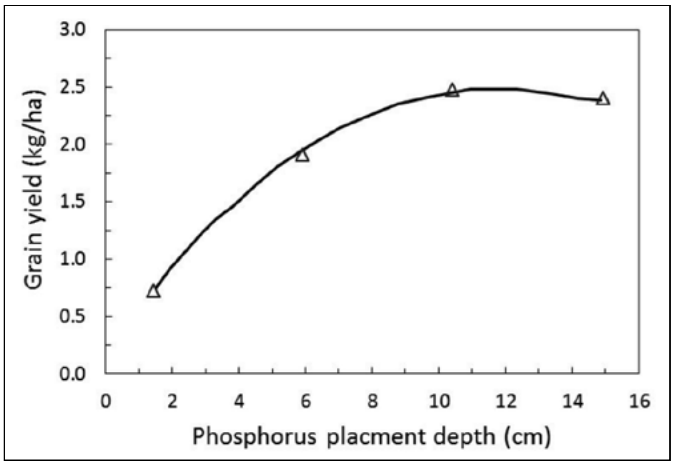

Figure 9. Effect of different depths of P placement at sowing on winter wheat yield in Nebraska (McConnell et al 1986).

Deep P

More recent research has focused on deeper placement (20cm) of P as MAP at 50cm row spacing in northern NSW and QLD. Figure 10 (Bell et al

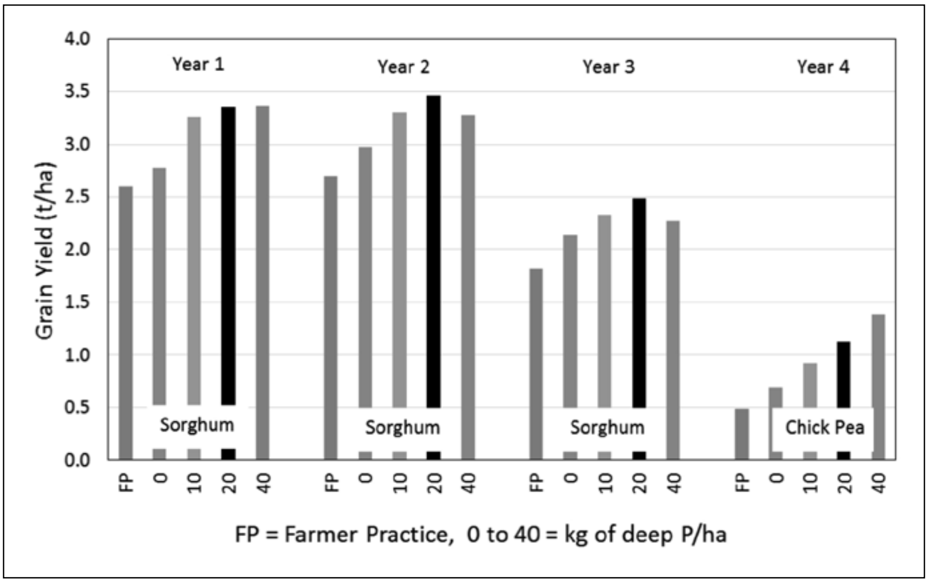

Figure 10. Deep P drill in Year 1 (2013) at a depth of 20cm and row spacing of 50cm and the subsequent grain yield response over four consecutive years at Dysart QLD for sorghum and chick pea. No additional deep P was applied in subsequent years and annual P at sowing was 6kg/ha.

2016) shows results from Dysart in Queensland where deep P was drilled in 2013. The zero deep P rate represents deep drilling at 20cm with no deep P applied (i.e. ripping effect) while the farmer practise represents no deep drilling and no deep P. The percent increase from the zero deep P rate to the best deep P response in each consecutive year was 17% (Year 1), 11% (Year 2), 7% (Year 3) and 59% (Year 4). In Year 2 (11% increase) and Year 3 (7% increase) nitrogen limited maximum yield production (Figure 10). Consequently, the P responses for Year 2 and Year 3 may be considered conservative. In each treatment 6kg/ha of P was applied at sowing and this plus the soil reserve P was not expected to limit potential yield (Figure 10). A summary of deep P results (data not shown) indicates deep P applied as MAP at 20kg P/ha provided an average of 13% yield increase in wheat yield, 11% increase in chickpea grain yield based on 10 and 4 crop years of research, respectively.

Future research

It is often assumed that because P requirements for crops have been extensively studied both in and outside Australia that all required knowledge for crop production is known. This is certainly not the case for modern cropping practices where subsoil P (0–30cm) is being exported in grain and redistributed on the soil surface via stubble. This process increases the degree of P stratification where soil P is very low in the 10–30cm layer (< 5mg P/kg soil) and high in the 0–5cm layer (e.g. 35mg P/kg soil). Other factors that contribute to P stratification include shallow placement of P at sowing, and for tyned implements, soil throw into the inter-row. In these circumstances surface drying events in the 0–5cm layer may limit grain production. Exceptions to this stratification process occur where P is leached in low PBI soils or where deep cultivation occurs which mixes the soil.

Conclusion

Phosphorus placement below seed at sowing is most likely to provide yield benefits compared to P placed with seed.

Testing the extent of P stratification on-farm (surface 0–10cm and subsoil 10–30cm) can assist in P budgeting as the lack of subsoil P can be offset by higher concentrations of surface P in most soils provided soil moisture conditions are adequate for P uptake.

Deep P placement (20cm) in northern NSW and QLD in winter dry and summer wet conditions are providing more insights into deep P responses however, these findings cannot be directly applied to cropping zones where rainfall is non-seasonal or Mediterranean in distribution because the frequency and duration of soil drying in the P rich 0–5cm layer is different and will impact on responses to deep P placement.

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Notes

THE 2017-2020 GRDC NORTHERN REGIONAL PANEL

JANUARY 2019

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John Minogue runs a mixed broadacre farming business and an agricultural consultancy, Agriculture and General Consulting, at Barmedman in south-west NSW. John is chair of the district council of the NSW Farmers' Association, sits on the grains committee of NSW Farmers' Assn and is a winner of the Central West Conservation Farmer of the Year award. His vast agricultural experience in central west NSW has given him a valuable insight into the long-term grains industry challenges.

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DEPUTY CHAIR - ARTHUR GEARON

Arthur is a grain, cotton and beef producer near Chinchilla, Queensland. He has a business degree from the Queensland University of Technology in international business and management and has completed the Australian Institute of Company Directors course. He is a previous vice-president of AgForce Grains and has an extensive industry network throughout Queensland. Arthur believes technology and the ability to apply it across industry will be the key driver for economic growth in the grains industry.

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ROGER BOLTE

Roger Bolte is a fourth-generation farmer from the West Wyalong area in NSW, operating a 6500 ha winter cropping program with his wife and family focussing on cereals, legumes and hay. During his 35-years in the industry, Roger has been involved in R&D in various capacities and has had the opportunity to travel abroad and observe a variety of farming systems. He believes that R&D and education are the cornerstones of the industry and feels privileged to be afforded the opportunity to share his experiences.

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ROY HAMILTON

Roy Hamilton operates a 4400 ha mixed family farming enterprise near Rand in NSW's Riverina. He was an early adopter of minimum till practices and direct drill and press wheel technology and is currently migrating to CTF. The majority of the property is cropped while the remainder runs ewes and trade lambs. He has held roles on the south east NSW Regional Advisory Committee, the GRDC's southern region Regional Cropping Solutions Network and was a founding committee member of the Riverine Plains farming systems group.

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DR TONY HAMILTON

Tony is a grower from Forbes, NSW and managing director of an integrated cropping and livestock business. He is a director of the Rural Industries Research and Development Corporation. He has worked as an agricultural consultant in WA and southern NSW. With a Bachelor of Agricultural Science and a PhD in agronomy, Tony advocates agricultural RD&E and evidence based agriculture.

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ANDREW MCFADYEN

Andrew is a grower and private agricultural consultant near Lake Cargelligo NSW with more than 17 years agronomy and practical farm management experience. He is an active member of the grains industry with former roles on the Central East Research Advisory Committee, NSW Farmers Coolah branch and has served on the GRDC northern panel since 2015. He is also a board member and the chair of Grain Orana Alliance.

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PETER MCKENZIE

Peter operates a private agronomy consulting business based in Quirindi NSW. Prior to this he was facilitator/agronomist for AgVance Farming group, a communications conduit between industry and growers. He is a passionate supporter of research and has been active in extending weed management research information to industry, particularly in central west NSW, is a former director of Conservation Farmers Inc., a former member of the North East Regional Advisory Committee and a participant in Northern Growers Alliance local research group on the Liverpool Plains.

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GRAHAM SPACKMAN

Graham has been Managing Director of a private agricultural consultancy at Emerald, Queensland, for the past 28 years, providing advice on the agronomy and management of summer and winter, dryland and irrigated crops in grain and mixed farming systems. He has extensive involvement in RD&E having participated in two decades of GRDC and DPI-funded farming systems research, particularly in weed management, soil fertility and adaption of agronomic practices in CQ farming systems. Graham was a member of the CQ Research Advisory Committee for over 10 years and Chairman for five years.

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BRUCE WATSON

Bruce and his family operate a 3400 ha family grain growing business near Parkes NSW, which produces a mixture of dryland winter cereals, pulses and oilseeds as well as summer dryland cereals, pulses and cotton grown on a 12m zero till CTF platform with full stubble retention. Bruce holds a Bachelor of Agricultural Economics from the University of Sydney and previously worked with PricewaterhouseCoopers in its Transfer Pricing practice. He is an active member of the grains industry and was awarded a Nuffield Scholarship in 2009.

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DR JO WHITE

Dr Jo White is an experienced researcher with over 15 years' experience in agricultural research programs based at the Department of Agriculture and Fisheries in Queensland (DAFQ) and the University of Southern Queensland (USQ), including 10 years' experience in the field of plant pathology of broad acre summer crops. Jo has a keen interest in developing and delivering on-ground practical research solutions to growers which improve productivity and profitability of their farms and is now working as a private consultant based in Queensland.

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DR NICOLE JENSEN

Nicole Jensen is GRDC General Manager for the newly created Genetics and Enabling Technologies business group. Nicole brings a wealth of experience in plant breeding and related activities arising from several roles she has held in Australia and internationally in the seed industry including positions as Supply Innovation Lead with the Climate Corporation - Monsanto's digital agricultural flagship, Global Trait Integration Breeding Lead for Monsanto.

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NORTHERN REGION GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK

JANUARY 2019

The Northern Region of the Grains Research and Development Corporation (GRDC) encompasses some of the most diverse cropping environments in Australia, ranging from temperate to tropical climates – it has the greatest diversity of crop and farming systems of the three GRDC regions.

Implemented, to provide structured grower engagement, the GRDC Grower Solutions Group projects and the RCSN project have become an important component of GRDC's investment process in the northern region. The Northern Region Grower Solutions Group and the RCSN have the function of identifying and, in the case of Grower Solutions Groups managing short-term projects that address ideas and opportunities raised at a local level which can be researched demonstrated and outcomes extended for immediate adoption by farmers in their own paddocks.

GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK CONTACT DETAILS:

NORTHERN GROWER ALLIANCE (NGA)

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Northern Grower Alliance (NGA) was established in 2005 to provide a regional capacity for industry-driven, applied agronomic grains research. NGA is currently working on a five year Grower Solutions project, fully funded by the GRDC, focussing on cropping areas from the Liverpool Plains to the Darling Downs and from Tamworth and Toowoomba in the east to Walgett, Mungindi and St George in the west. A network of six Local Research Groups, comprised of advisers and growers, raise and prioritise issues of local management concern to set the direction of research or extension activity. Areas of focus range from weed, disease and pest management through to nutrition and farming system issues.

GRAIN ORANA ALLIANCE (GOA)

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Grain Orana Alliance (GOA) is a not for profit organisation formed in 2009 to help meet growers research and extension needs in the Central West of NSW to support their enduring profitability. Currently operating under the GRDC Grower Solutions Group - Central NSW project, one of the key priorities is to identify and prioritise R,D and E needs within the region through engagement with local growers and advisers. This grower engagement helps direct both the GRDC investments in research projects and GOA's own successful research programs. GOA's research covers a wide range of relevant topics such as crop nutrition, disease management and weed control. The structure of the project allows for a rapid turnaround in research objectives to return solutions to growers in a timely and cost effective manner whilst applying scientific rigour in the trial work it undertakes. Trials are designed to seek readily adoptable solutions for growers which in turn are extended back through GOA's extensive grower and adviser network.

CENTRAL QUEENSLAND GROWER SOLUTIONS GROUP

ROD COLLINS

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The Central Queensland Grower Solutions project, is a GRDC and DAF Queensland investment in fast-tracking the adoption of relevant R,D & E outcomes to increase grower productivity and profitability across central Queensland. Covering approximately 550,000 ha and representing 450 grain producing businesses, the central Queensland region includes areas from Taroom and Theodore in the south to Mt McLaren and Kilcummin in the north, all of which are serviced by the project staff, located in Biloela and Emerald. Team leader Rod Collins is an experienced facilitator and extension officer with an extensive background in the central Queensland grains industry. He was part of the initial farming systems project team in the region throughout the late 90's and early 2000's which led the successful adoption of ley legumes to limit nutrient decline and wide row configurations in sorghum to improve yield reliability across central Queensland. He has more recently led the development and delivery of the Grains Best Management Practices program.

COASTAL HINTERLAND QUEENSLAND AND NORTH COAST NEW SOUTH WALES GROWER SOLUTIONS GROUP

The Coastal Hinterland Queensland and North Coast New South Wales Grower Solutions project was established to address the development and extension needs of grains in coastal and hinterland farming systems. This project has nodes in the Burdekin managed by Dr Steven Yeates from CSIRO; Grafton managed by Dr Natalie Moore from NSW DPI; Kingaroy managed by Nick Christodolou (QDAF) and Bundaberg managed by Neil Halpin.

BUNDABERG QUEENSLAND:

NEIL HALPIN

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Neil Halpin is a principal farming systems agronomist with the Queensland Department of Agriculture and Fisheries. He has over 30 year's field trail experience in conservation cropping systems, particularly in the sugar-based farming systems of the coastal Burnett. His passion is for the integration of grain legume break crops, reduced tillage, controlled traffic and organic matter retention in coastal farming systems. Maximising the productivity and profitability of grain legumes (peanuts, soybeans and mung beans) is a common theme throughout the various production areas and systems covered by this project.

KINGAROY QUEENSLAND:

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Nick Christodoulou is a principal agronomist with the Department of Agriculture & Fisheries (QDAF) on Qld's Darling Downs and brings over 25 years of field experience in grains, pastures & soil research, with skills in extension application specifically in supporting and implementing practice change. Nick has led the highly successful sustainable western farming systems project in Queensland. Nick was also project leader for Grain & Graze 1 Maranoa-Balonne and DAF leader for Grain & Graze 1 Border Rivers project, project leader for Grain and Graze 2 and was also Project leader for the Western QLD Grower Solutions project. Currently he is the coordinator for the Grower Solutions Southern Burnett program.

BURDEKIN QUEENSLAND:

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The Burdekin & tropical regional node of the Coastal and Hinterland Growers Solution Project is led by CSIRO research agronomist Dr Stephen Yeates and technical officer Paul McLennan, who are based at the Australian Tropical Science and Innovation Precinct at James Cook University, Townsville. The Burdekin & tropical Grower Solutions node has a committed and expanding advisory group of farmers and agribusiness professionals. Due to the rapid increase in farmers producing mungbean in the region an open door policy has been adopted to advisory group membership to ensure a balance in priorities between experienced and new growers. The node is focused on integrating grain crops into sugar farming systems in the lower Burdekin irrigation area in NQ and more recently contributing to other regions in the semi-arid tropics that are expanding or diversifying into grain cropping. Information and training requests for information and training from the Ord River WA, Gilbert River NQ, Mackay and Ingham areas necessitated this expansion. Recent work has focussed on the introduction of mungbeans in the northern Queensland farming systems in collaboration with the GRDC supported entomologists Liz Williams and Hugh Brier, Col Douglas from the mungbean breeding team, the Australian Mungbean Association and Pulse Australia. Both Stephen and Paul have many decades of experience with crop research and development in tropical Australia.

GRAFTON NEW SOUTH WALES:

NATALIE MOORE

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The NSW North Coast regional node of the Coastal and Hinterland Grower Solutions Project is led by NSW DPI research agronomist Dr Natalie Moore and technical officer Mr Nathan Ensbey, who are based at the Grafton Primary Industries Institute. The NSW North Coast Grower Solutions node prioritises and addresses issues constraining grain production via an enthusiastic advisory group comprised of leading grain growers, commercial agronomists from across the region and NSW DPI technical staff. In this high rainfall production zone (800-1400mm pa), winter and summer grain production is an important component of farming systems that also includes sugar cane, beef and dairy grazing pastures, and rice. The region extends east of the Great Dividing Range from Taree in the south to the Tweed in the north. Both Natalie and Nathan have many years experience with research and development for coastal farming systems and are also currently involved with the Australian Soybean Breeding Program (GRDC/CSIRO/NSW DPI) and the Summer Pulse Agronomy Initiative (GRDC/NSW DPI).

REGIONAL CROPPING SYSTEMS NETWORK (RCSN) SOUTHERN NSW

CHRIS MINEHAN

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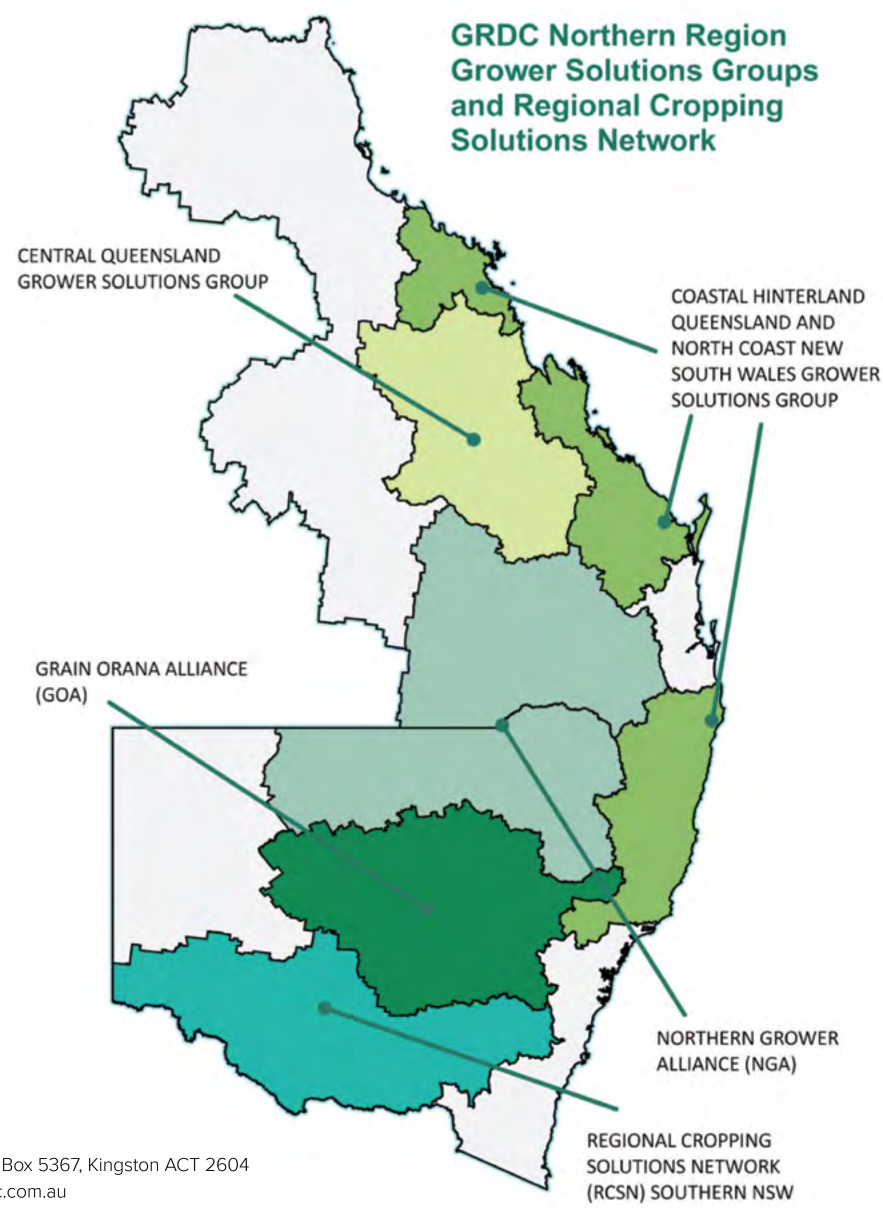
The Southern New South Wales Regional Cropping Solutions Network (RCSN) was established in 2017 to capture production ideas and opportunities identified by growers and advisers in the southern and western regions of New South Wales and ensure they translate into direct GRDC investments in local R, D & E priorities. The SNSW RCSN region covers a diverse area from the southern slopes and tablelands, through the Riverina and MIA, to the Mallee region of western NSW and the South Australian border. The region is diverse in terms of rainfall and climatic zones, encompassing rangelands, low, medium and high rainfall zones, plus irrigation. The SNSW RCSN is facilitated by Chris Minehan. Chris is an experienced farm business consultant and a director of Rural Management Strategies Pty Limited, based in Wagga Wagga, NSW. The process involves a series of Open Forum meetings which provide an opportunity for those involved in the grains industry to bring forward ideas, constraints and opportunities affecting grain grower profitability in their area. These ideas are reviewed by an RCSN committee comprises 12 members, including grain growers, advisers and researchers from across the region that meet twice per year to assist GRDC in understanding and prioritising issues relevant to southern NSW.



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- The local GRDC Grains Research Update planning committee that includes both government and private consultants and GRDC representatives.

- Partnering organisation: CWFS

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Prefer to provide your feedback electronically or 'as you go'? The electronic evaluation form can be accessed by typing the URL address below into your internet browsers:

www.surveymonkey.com/r/Parkes-GRU

To make the process as easy as possible, please follow these points:

- Complete the survey on one device
- One person per device
- You can start and stop the survey whenever you choose, **just click 'Next' to save responses before exiting the survey**. For example, after a session you can complete the relevant questions and then re-access the survey following other sessions.

2019 Parkes GRDC Grains Research Update Evaluation

1. Name [ ]

ORM has permisssion to follow me up in regards to post event outcomes.

2. How would you describe your main role? *(choose one only)*

- ❑ Grower
- ❑ Agronomic adviser
- ❑ Farm business adviser
- ❑ Financial adviser
- ❑ Communications/extension
- ❑ Grain marketing
- ❑ Farm input/service provider
- ❑ Banking
- ❑ Accountant
- ❑ Researcher
- ❑ Student
- ❑ Other* (please specify)

Your feedback on the presentations

For each presentation you attended, please rate the content relevance and presentation quality on a scale of 0 to 10 by placing a number in the box (**10 = totally satisfactory, 0 = totally unsatisfactory**).

3. Managing those hard to kill weeds: *Chris Preston*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

4. Ameliorating sodic subsoil constraints: *Ehsan Tavakkoli*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

5. Refining the management of cereals: *Peter Matthews*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

6. Better pastures – better crops: *Jeff McCormick*

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

7. Phosphorus & nitrogen nutrition – getting it right on your farm this season: *Col McMaster*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

Your next steps

8. Please describe at least one new strategy you will undertake as a result of attending this Update event

9. What are the first steps you will take?

e.g. seek further information from a presenter, consider a new resource, talk to my network, start a trial in my business

Your feedback on the Update

10. This Update has increased my awareness and knowledge of the latest in grains research

Strongly agree	Agree	Neither agree nor Disagree	Disagree	Strongly disagree
❑	❑	❑	❑	❑

11. Overall, how did the Update event meet your expectations?

Very much exceeded	Exceeded	Met	Partially met	Did not meet
❑	❑	❑	❑	❑

Comments

12. Do you have any comments or suggestions to improve the GRDC Update events?

13. Are there any subjects you would like covered in the next Update?

Thank you for your feedback.