LAKE CARGELLIGO
NEW SOUTH WALES
WEDNESDAY 11
MARCH 2020

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Lake Cargelligo Bowling Club

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GRDC 2020 Grains Research Update Welcome

If you are reading this, then chances are you have taken time out from an extraordinarily tough season in our very sunburnt country to hear the latest grains research, development and extension (RD&E) information.

Welcome.

We at the GRDC understand how very challenging the current situation is for growers, advisers, agronomists, researchers and those associated with the grains industry across New South Wales and Queensland.

Drought takes an enormous toll financially, emotionally and physically on those working and living through it daily. We trust that these GRDC Grains Research Updates will offer you new research information to help guide your on-farm decisions this season and to be best placed to take advantage of future seasons. We also hope the Updates provide a chance to connect with your peers and temporarily escape work pressures.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above in recent years to keep trials alive in rain-deprived environments.

Challenging seasons reinforce the importance of rigorous, innovative research that delivers genuine gains on-farm. For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual Updates, which are the premier event on the northern grains industry calendar and bring together some of Australia's leading grains research scientists and expert consultants.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers.

For the past four years we have been doing that from regional offices across the country. Through the northern region offices in Wagga Wagga and Toowoomba and a team of staff committed to connecting with industry, we are now more closely linked to industry than ever.

Today, GRDC staff and GRDC Northern Panel members are at this Update to listen and engage with you. This is a vital forum for learning, sharing ideas and networking, all of which are critical to effect successful change and progress on-farm.

Regards,
Gillian Meppem
Senior Regional Manager North

GRDC Grains Research Update
LAKE CARGELLIGO

Wednesday 11 March 2020

Lake Cargelligo Bowling Club, 1 Prior Street, Lake Cargelligo

Registration: 8:30am for a 9am start, finish 2:50pm

AGENDA Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	
9:10 AM	**New frontiers in cereal breeding for a changing climate** - long coleoptile wheat, crop competitive varieties, new wheat types for late sowing windows and adaptation to high temperature stress during grain fill	Greg Rebetzke (CSIRO)
9:40 AM	**Drivers of yield stability in wheat and barley** - picking a winner in variable seasons	David Burch (NSW DPI)
10:20 AM	**Morning tea**	
10:45 AM	**Pulses in Lake Cargelligo farming systems**.	Tony Swan (CSIRO)
11:15 AM	**Fixing more N by improving inoculant performance in suboptimal / acid soil conditions.**	Belinda Hackney (NSW DPI)
11:40 AM	**Measuring, using and budgeting P in lower rainfall zones** - are there options to spend less after a dry year?	Graeme Sandral (NSW DPI) and Jim Laycock (Incitec Pivot)
12:20 PM	**Lasers, machine learning, weed recognition and new innovations in weed management**	Guy Coleman (University of Sydney)
12:45 PM	**Lunch**	
1:40 PM	**Risks and rewards of cover cropping** - how effective are cover crops at increasing fallow efficiency and influencing soil health? What about the water they consume - how much do they use and is this offset by increased fallow efficiency?	Col McMaster (NSW DPI)
2:10 PM	**Decisions for a profitable 2020** - picking the right variety for the situation, managing P fertiliser cost, weed planning and cereal disease after the drought	Andrew McFadyen (McFadyen Ag. Consulting), Col McMaster (NSW DPI), Graeme Sandral (NSW DPI) and Helen McMillan (CWFS)
2:50 PM	**Close**	

Contents

New genetics to improve wheat establishment and weed competitiveness 5
Greg Rebetzke, C. Ingvordsen, W. Spielmeyer, B. French, C. Zaicou-Kunesch and N. Fettell

Yield stability across sowing dates: how to pick a winner in variable seasons?..11
Felicity Harris, Hongtao Xing, David Burch, Greg Brooke, Darren Aisthorpe, Peter Matthews and Rick Graham

How does phenology influence yield responses in barley? 17
Felicity Harris, Hugh Kanaley, David Burch, Nick Moody and Kenton Porker

Pulses in the Lake Cargelligo farming systems 25
Tony Swan

Fixing more N by improving inoculant performance in sub-optimal conditions 26
Belinda Hackney, Jessica Rigg, Francesca Galea, Simon Flinn, Ewan Leighton, Daryl Reardon, Barry Haskins, Rachael Whitworth, Colin McMaster and Alan Stevenson

Biserrula: its fit in the system 32
Belinda Hackney, Simon Flinn, Jeff McCormick

Budgeting phosphorus in medium and lower rainfall zones of southern NSW...37
Graeme Sandral, Ehsan Tavakkoli, Therese McBeath, Roger Armstrong, Sean Mason, Nigel Wilhelm, Rebecca Hailing, Russell Pumpa, Kelly Fiske, Maryam Barati and David Armstromg

What N is in profile - 3 dry years with minimal mineralisation. What are the results showing? Also, insights from a long-term nutrition site running since 2007 in CNSW 51
Jim Laycock

Lasers, machine learning, weed recognition and new innovations in weed management 58
Guy Coleman, Caleb Squires and Michael Walsh

Summer cover crops in short fallow - do they have a place in central NSW? 63
Colin McMaster, Allan Stevenson and Stuart Strahorn

Decisions for a profitable 2020 74
Discussion session

Managing chickpea diseases after the drought..75
Kevin Moore, Steve Harden, Kristy Hobson and Sean Bithell

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New genetics to improve wheat establishment and weed competitiveness

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Key words

wheat, breeding, genetics, dwarfing genes, coleoptile length, establishment

GRDC code

CSP00182, CSP00199, CSP00200

Take home messages

- Current Australian wheat cultivars contain dwarfing genes that reduce coleoptile length by 40%. New dwarfing genes are available that reduce plant height but don't reduce coleoptile length
- A gene increasing coleoptile length was identified and tagged with DNA markers. Breeding lines and DNA markers for new dwarfing and coleoptile length genes have been delivered to Australian breeders for efficient selection of improved crop establishment
- Deep-sowing studies in WA and NSW Managed Environment Facilities show benefit with new dwarfing and coleoptile length promoting genes in increasing emergence at sowing depths of up to 120mm but without changing plant height
- Moisture-seeking points coupled with new genetics should reliably allow seed placement and emergence from sowing depths of 100mm or greater, and/or with warmer soils
- Genetic variability exists with potential to suppress weeds through greater shoot and/or root competitiveness.

Background

In rainfed environments typical of the eastern and southern wheatbelts, crops are typically sown on the first breaking rains but sometimes moisture accumulated through summer is too deep for sowing with conventional variety × drilling systems. Key to good leaf area development for tillering, growth and weed competitiveness is good crop establishment. An ability to establish wheat crops from seed placed 80mm or deeper in the soil would be useful in situations where the subsoil is moist but the surface dry. Seeding onto moisture at depth can assist to extend the opportunities for a greater portion of the cropping program to be sown in the traditional sowing months of May and June or earlier in April following summer rain. A separate but concerning issue is the influence of increasingly warmer soil temperatures on reductions in coleoptile (the shoot that grows from the seed and allows seedling emergence through the soil) length. Earlier sowing into warmer soils will reduce coleoptile length by as much as 60% so that a variety such as Mace with a 75mm coleoptile at 15°C will likely have a 40mm coleoptile at 25°C soil temperature. Some seed dressings and pre-emergent herbicides can further reduce this coleoptile length and affect establishment.

The green revolution *Rht-B1b (syn. Rht1)* and *Rht-D1b (syn. Rht2)* dwarfing genes reduced plant heights to reduce lodging and increase grain yields and so are present in most wheat varieties worldwide. Their presence also reduces the length of the coleoptile by as much as 40%. This reduces crop emergence when sown at depths greater than 50mm, tiller number and leaf size to reduce water-use efficiency and weed competitiveness.

New dwarfing genes

A range of alternative dwarfing genes have been identified in overseas wheats with potential to reduce plant height and increase yields, while maintaining longer coleoptiles and greater early vigour. Some of these genes (e.g. *Rht8* and *Rht18*) have been used commercially overseas but have not been assessed for use here in Australia. We reduced the larger global set of alternative dwarfing genes to *Rht4, Rht5, Rht8, Rht12, Rht13* and *Rht18*, and then developed linked DNA-markers to assist with breeding of these genes in a commercial breeding program. Separately, we then bred these genes using conventional and DNA-based methods into the old, tall wheat variety Halberd for testing and disseminating to Australian wheat breeders.

Genes that promote coleoptile growth

While switching to new dwarfing genes will remove the growth inhibition on early growth, there is a need to promote coleoptile growth, particularly in the presence of conventional dwarfing genes. A gene with major effect on coleoptile length was identified in current wheat cultivars. Through a GRDC funded project, we demonstrated that the gene not only increased coleoptile length but also emergence with deep sowing in field trials conducted over three years at Yanco NSW (Figure 1). The gene was tagged with molecular markers and tested in a wide range of Australian wheat germplasm. We estimated that only 10% of recently released cultivars carry the coleoptile growth promoting gene. The markers were distributed to Australian breeding companies to assist with the selection and the expected increase of gene frequency in future cultivars. Additional genetic variation for coleoptile length and early growth exists in elite germplasm. For breeders to take full advantage of this variation, additional genes controlling this trait need to be identified and tagged with markers for efficient selection and combining growth promoting genes for even better performance.

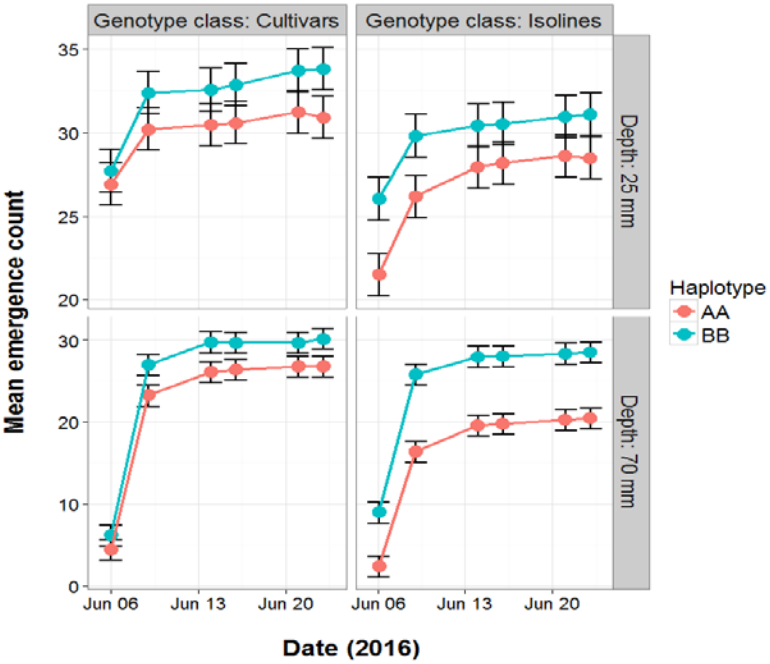

Figure 1. Emergence of wheat commercial cultivars carrying conventional dwarfing genes and tall isolines in Young background in the NSW MEF at Yanco in 2016. Sowing depth treatments were 25 mm and 70 mm depth. 12 cultivars and 12 isolines were grouped according to the presence of the coleoptile length promoting gene (BB, long coleoptiles) and the lack of the gene (AA short coleoptiles)

Preliminary sowing depth field studies

Field studies have commenced on the Halberd-based dwarfing gene lines and show that lines containing these new dwarfing genes produced coleoptiles of equivalent length to Halberd (up to 135mm in length; Figure 2) and established well when sown at 100mm depth in deep sowing experiments conducted at Mullewa and Merredin in 2016 (Figure. 3). Grain yields of lines containing the new dwarfing genes were equivalent to the yields of lines containing the commonly used *Rht-B1b* and *Rht-D1b* dwarfing genes while previous studies have shown the new dwarfing genes were linked to greater grain yields when sown deep, owing to greater plant number with improved establishment.

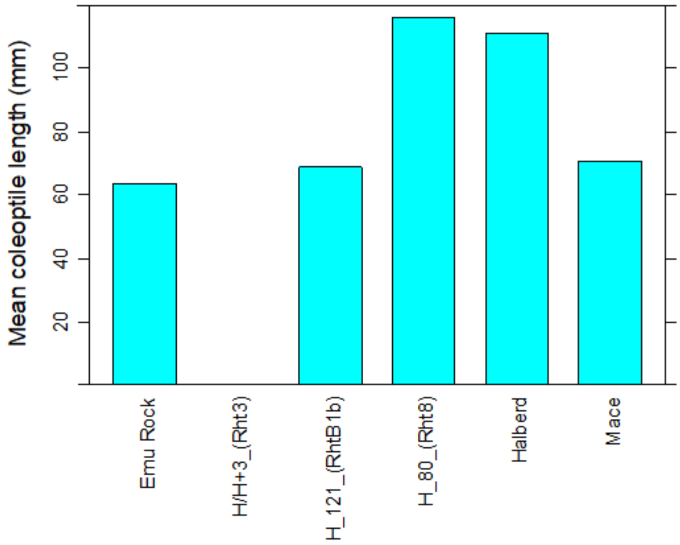

Figure 2. Coleoptile lengths of a tall wheat genotype (Halberd) and genotypes with dwarfing genes *Rht-B1b (syn. Rht1)* and *Rht8* emerging in the field in a Halberd background. Emu Rockᶲ and Maceᶲ are current commercial cultivars with *Rht-B1b* and *Rht-D1b*, respectively

The most likely useful new dwarfing genes, *Rht13* and *Rht18*, have been bred into a range of current commercial wheats (Figures 4 and 5). Long coleoptile wheat breeding lines in Maceᶲ, Scoutᶲ, Espadaᶲ, EGA Gregoryᶲ and Magentaᶲ have been delivered to Australian breeders for testing and use in breeding. If there are no problems with these new dwarfing genes, we may see the first of the long coleoptile wheat varieties in 3-4 years in NVT testing!

Agronomic opportunities

Although there is real promise in the new genetics, there is significant opportunity in coupling new genetics with new existing seeding technologies. Deep sowing is an issue overseas and in the eastern Australian states. The availability of moisture-seeking points commonly used elsewhere should allow the reliable placement of seed at depths of 100mm or greater. These points produce a slot deep into the soil at the base of which a seed is sown at 10-50mm depth. That said, further research is required aimed at tools and methods assessing across different moisture-seeking points to optimise seed placement at depth across a wide range of soil types.

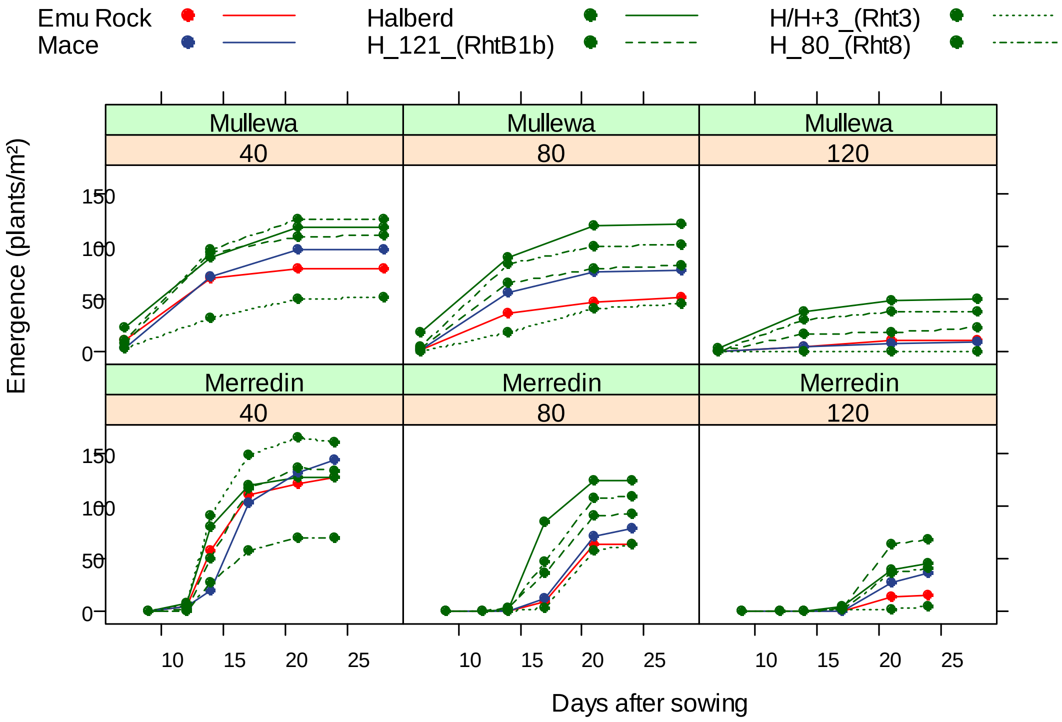

Figure 3. Patterns of emergence of wheat genotypes with different dwarfing genes sown at target depths of 40, 80, or 120 mm at Mullewa and Merredin in 2016 (after French *et al.* 2017)

Weed competitiveness

Weeds cost Australian grain growers an estimated $4B annually through lost production, reductions in crop quality, and herbicide use. These costs are unlikely to reduce with pressure on new actives in the widespread development of herbicide resistance in multiple weed species. Observed differences across cereal species and wheat varietal differences in crop competitiveness with weeds, provides impetus to use breeding and genetic improvement to aid in-crop weed control. In wheat, comparisons across a historic 100-year set of varieties highlighted that older varieties were more competitive with weeds. Presumably, this reflects selection for improved performance in the absence of in-crop herbicides. Overseas studies have demonstrated a reduction in herbicide use of up to 50% when using weed-competitive wheats, while a broader benefit is in integrating competitive varieties with cultural management (e.g. weed seed harvest and tillage) to slow herbicide resistance and reduce herbicide use.

Competitiveness can be thought of as the partial to complete suppression of competing weeds to increase crop yield, or the ability of a variety to tolerate a competitor to maintain higher yields. Selection for greater tolerance is a breeding strategy for many crop insects and diseases but is of less value in weed management as low numbers of weed survivors replenish the seed bank for the next season. In turn, breeding of competitive crops has focussed on selection of genotypes that can better access light, water and nutrients to suppress the growth of weeds. Greater early vigour, as rapid leaf area development and biomass at stem elongation and altered root architecture are mechanisms that contribute to the ability to out compete weeds.   Root exudates used in plant defence (allelopathy) may also slow the growth of neighbouring competitors.

In cereals, greater leaf size and rapid early leaf area development are associated with larger seed embryos, higher leaf area, and new dwarfing genes for reducing stem height. Unfortunately, commercial wheat varieties selected for increased yield potential often exhibit poor early growth. A global survey identified 30 wide-leafed, wheat donors which were subsequently used in a CSIRO long-term breeding activity to accumulate favourable genes to increase early vigour. High vigour lines derived from this program have been used to develop wheats with capacity to suppress the growth of ryegrass by up to 50% (Zerner et al. 2016). Field comparisons between current semi-dwarf wheat varieties and weed-competitive wheat breeding lines indicate wheat yield loss and weed suppression is greater in the weed-competitive lines (Figure 4).

Breeding companies are limited in their ability to develop and deliver new traits. The identification of new opportunities that will deliver greater grower profitability together with development of a clear value proposition will allow for pre-breeders to identify those traits and their underlying genetics and methods in selection for uptake by commercial breeders. In the case of weed competitiveness, the genes for weed suppression have come from outside existing breeding programs and include old Australian varieties and overseas landraces. Parental germplasm has been developed over many years and intercrossed into modern Australian varieties. Together with high-throughput selection methods, these populations have been delivered to Australian breeders for use in their commercial breeding efforts toward new weed competitive wheat varieties.

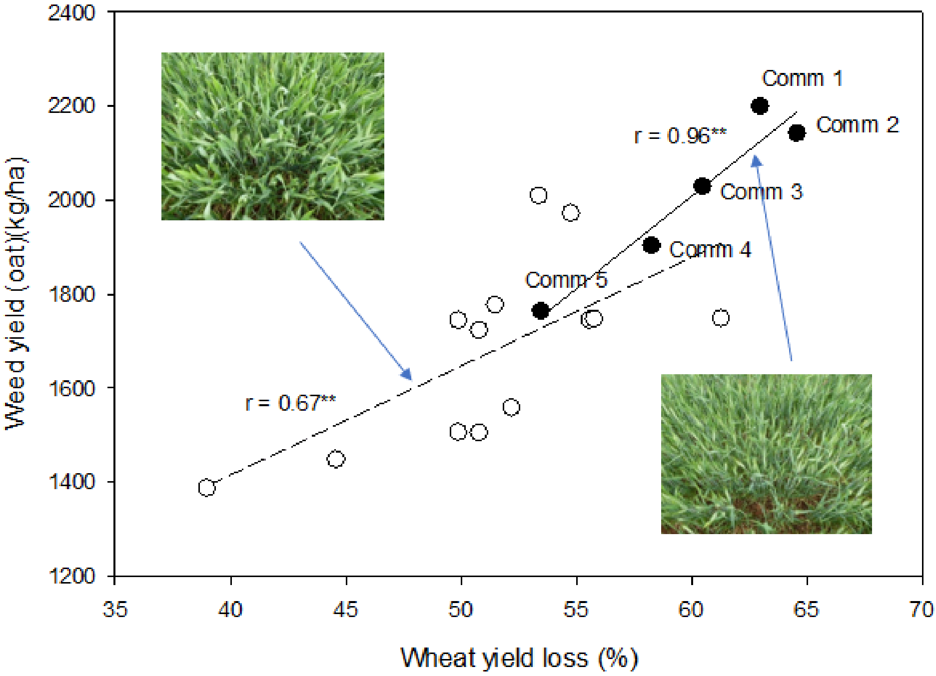

Figure 4. Relationship for yield loss in wheat and growth (as yield) of a weed mimic (oats) for breeding lines (○) and commercial wheat varieties (●) in field plots

Summary

Wheat breeders now have the new dwarfing genes to breed longer coleoptile wheat varieties. Genes that increase coleoptile length have also been identified and tagged with markers. These genes are expected to play an important role in improving emergence from depth in the presence of conventional dwarfing genes. Matching new genetics with appropriate agronomy and technologies should ensure the emergence and establishment of deep-sown wheats, particularly when sown early to make use of summer rains sitting deep in the soil profile or to increase sowing opportunities in the traditional months of May and June.

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Acknowledgements

We would like to acknowledge the support of the GRDC in funding much of the research reported herein. We'd also like to acknowledge the support of the managers of the GRDC's Managed Environment Facilities for their assistance.

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Yield stability across sowing dates: how to pick a winner in variable seasons?

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Keywords

flowering time, adaptation, sowing opportunity

GRDC code

DAN00213 (Grains Agronomy and Pathology Partnership, GRDC and NSW DPI)

Take home messages

- Match optimal flowering period to growing environment to maximise grain yield potential
- One variety doesn't fit all; there are no commercially available varieties that are broadly adapted across a wide range of sowing times or growing environments
- Optimising variety phenology and sowing time combinations achieves grain yield stability across a wide sowing window
- Probability of sowing opportunities will influence variety choice and sowing time decisions.

Background

Across the northern grains region (NGR), wheat is sown across a window from early to late autumn (April–May). There are a range of commercial cultivars which vary in their phenology from slow developing winter types to fast developing spring types, providing growers with flexibility in their sowing window. Field experiments were sown at ten locations in the NGR to determine phenology and yield responses across different environments. The experiments were conducted from 2017 to 2019, and annual rainfall at the ten locations ranged from 184mm to 620mm. The aim of these experiments is to provide growers with regional information about variety adaptation and recommended sowing times.

Aim to target optimal flowering period (OFP) for your growing environment

Across the environments of the NGR, one of the primary drivers of yield and grain quality is flowering time. When considering variety options at sowing, growers should aim to synchronise crop development with seasonal patterns so that flowering occurs at an optimal time. This period is a trade-off between increasing drought and heat threat, and declining frost risk. Across the NGR, the optimal flowering period (OFP) varies from late July in central Queensland to mid-late October in southern NSW. There is no 'perfect' time to flower when there is no risk, rather there is an optimal period based on minimising risks, and maximising grain yield based on probabilities from previous seasons.

Previously, we proposed OFPs from simulations using the APSIM cropping systems for locations across the NGR, based on historical climatic records (1961–2018) according to the parameters outlined by Flohr et al. (2017) for a fast spring genotype (Harris et al., 2019). These OFPs have now been validated using recorded flowering dates and grain yield from field experiments conducted across the NGR from 2017 to 2019. It was determined that the OFP varies significantly in timing and duration, as well as for different yield levels across environments (Figure 1). As flowering time is a function of the interaction between variety, management and environment; the variety x sowing time combinations capable of achieving OFP and maximum grain yield also varied across environments of the NGR (Figure 1).

In very dry seasons, such as 2019, yields are often higher when the crops flower earlier than the OFP; while in wetter seasons, such as 2016, flowering later does not induce the same yield penalties. Despite this, our field data supports the idea that growers should target the OFP for their growing environment to achieve maximum grain yield potential.

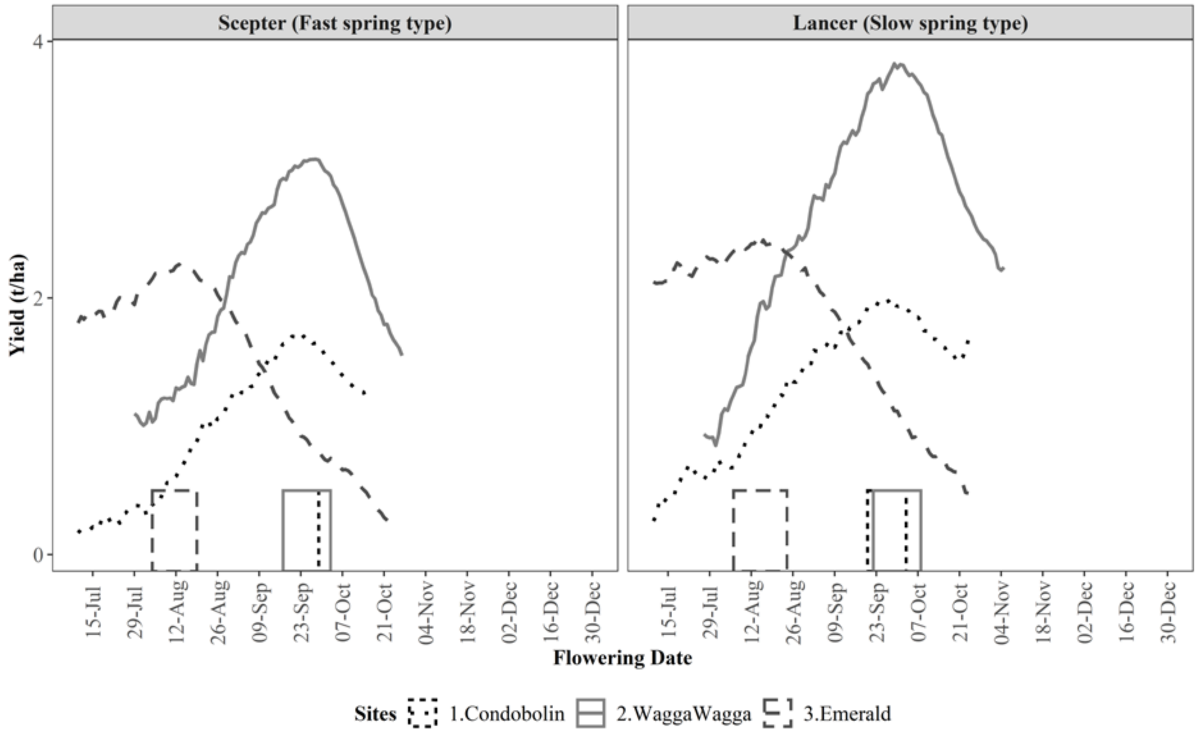

Figure 1. The optimal flowering period (OFP) for a fast spring variety (Scepterⓓ) and a slow spring variety (Lancerⓓ) determined by combining field data from experiments (2017-2019) and APSIM simulation using methods of Flohr et al. (2017) for Condobolin, Wagga Wagga and Emerald. The lines represent frost and heat limited yield (kg/ha), while the boxes on the x-axis represent the predicted OFP defined as ≥ 95% of the maximum mean yield

One cultivar doesn’t fit all - need to match variety and sowing time

Timing of flowering is influenced by phenology (genotype (G)), location and season (environment (E)) and sowing time (management (M)). Significant G × E × M interactions influencing grain yield responses across environments have been identified. The implication of these findings is that there are no commercially available varieties that are broadly adapted across a wide range of sowing times or growing environments. Differences in seasonal rainfall and temperature extremes imposed during the critical flowering period, which could have been influenced by sowing time, indicated that variety performance is also highly dependent on season. Despite this, there is evidence to suggest that variety choice can be exploited by growers to achieve OFPs and relatively stable yields across a wide sowing window. For example, in Wagga Wagga, southern NSW, winter wheat (for example; LongReachⓓ, Kittyhawkⓓ and Longswordⓓ) require earlier sowing to flower within the optimal period, due to their extended phase duration and slower development pattern. Slower developing spring types (for example; Lancerⓓ) are suited to late-April, early-May sowing dates, while mid to fast spring types (for example; BeckomΦ, CondoΦ) are sown mid-late May to synchronise development and target the OFP (Figure 2).

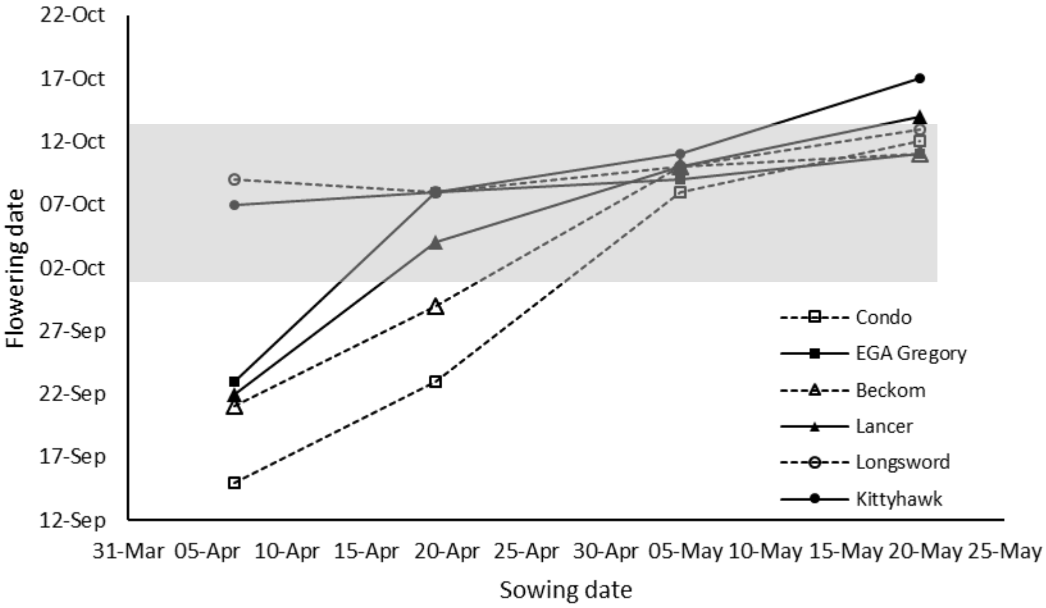

Figure 2. Mean heading date responses from selected winter and spring cultivars at Wagga Wagga (2017-18) and Marrar (2019) across all sowing times. Shaded area represents the optimal flowering period

In southern NSW, when slower developing varieties (for example; winter type EGA WedgetailΦ) are sown early and achieve OFP, they are capable of higher water-limited yields compared with faster developing spring varieties sown later. However, faster developing varieties (for example; ScepterΦ) are better adapted to regions with shorter growing seasons, and in environments or later sowing scenarios where frost and heat stresses occur in close proximity to each other (Figure 3).

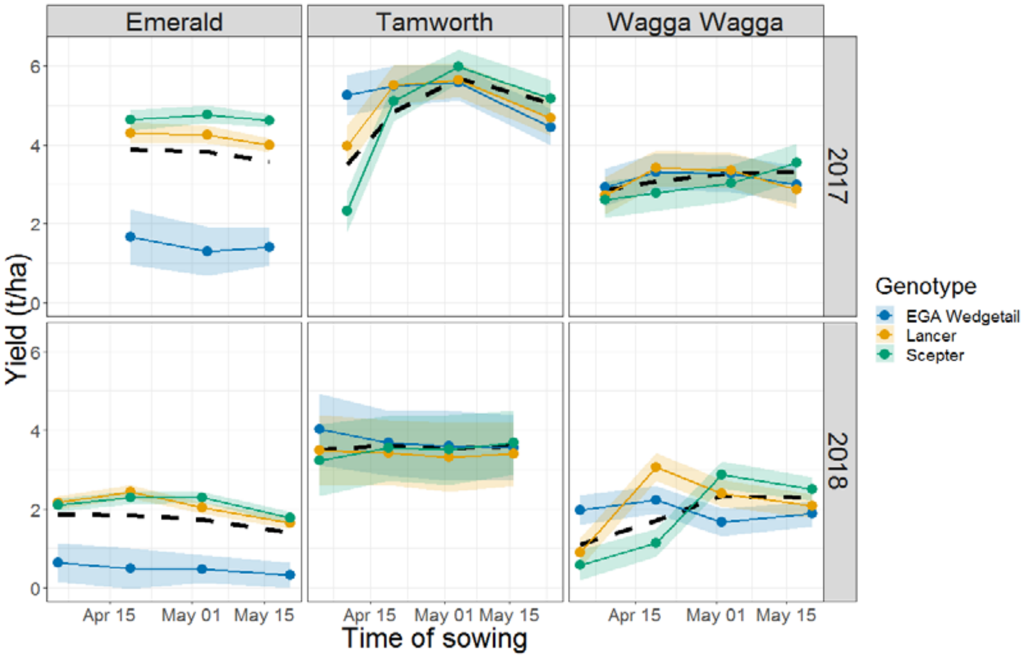

Figure 3. Predicted grain yield responses across sowing dates from early-April to late-May at Emerald, Tamworth and Wagga Wagga sites in 2017 and 2018 for selected genotypes; EGA Wedgetailⓓ (winter type), Lancerⓓ (mid spring type), Scepterⓓ (fast spring type)

Likelihood and timing of sowing opportunities varies across growing environments

Matching flowering date to a growing environment can be a challenge, as the timing of the seasonal break is highly variable. A simulation was conducted to determine the probability of a sowing opportunity occurring across locations of the NGR using methods described in Unkovich (2010). According to this sowing rule, the timing of a sowing opportunity whereby there is sufficient seedbed moisture to establish a wheat crop, differs across environments. Therefore, sowing opportunities will influence variety choice and sowing time decisions also. For example, the probability of a sowing opportunity prior to 25 April was 38% at Condobolin, compared to 65% of years at Yarrawonga (Figure 4). As such, there are limited opportunities to sow a winter wheat at Condobolin, however probability increases to approximately 70% by early-May and the opportunities increase for mid-fast developing varieties. In contrast, growers in Yarrawonga have more flexibility in their sowing window and could consider incorporating slower developing or winter types for earlier sowing in their program.

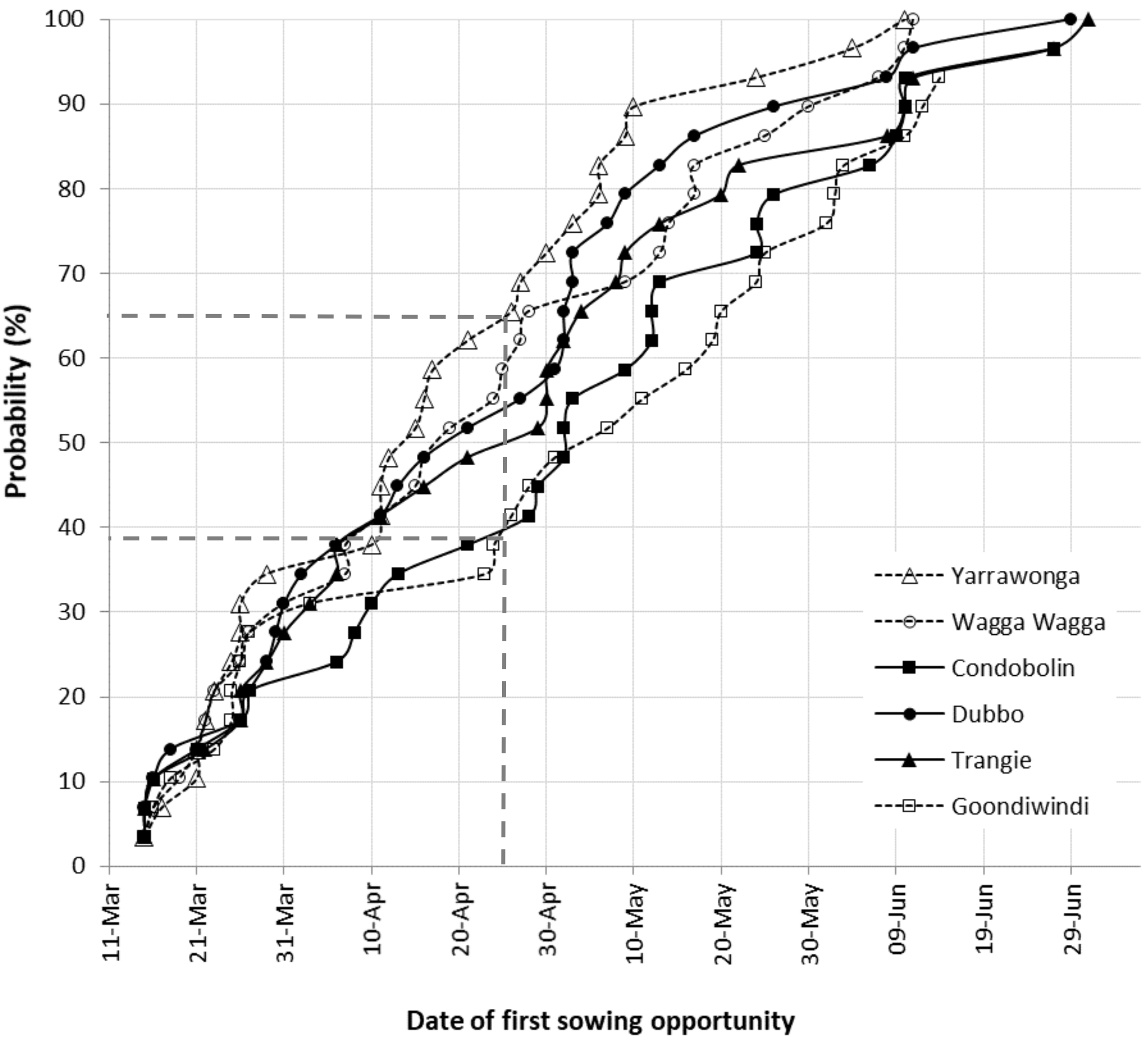

Figure 4. Probability distribution of first sowing opportunity for sites across the Northern grains region from 2000-2018 using the methods of Unkovich (2010). The dashed grey line pinpoints the probability of the sowing opportunity prior to 25 April for Condobolin and Yarrawonga

Conclusion

There were significant interactions between G × E × M, whereby genotypic responses to sowing date varied across sites in the NGR, and within seasons for varieties with varied phenology patterns. These findings indicate that the varieties tested are not broadly adapted to environment or management, and as such there is scope for growers to optimise grain yield through variety selection and management of sowing date by considering phenology responses and target OFPs.

Acknowledgements

This research was a co-investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP) project in collaboration with Department of Agriculture and Fisheries, Queensland. The research presented in this paper was made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Sincere thank you for the technical assistance of Hugh Kanaley, Cameron Copeland, Dean MacCallum, Mary Matthews, Jessica Simpson, Ian Menz, Bren Wilson and Javier Atayde at the Wagga Wagga, Marrar and Wallendbeen sites; Nick Moody, Braden Donnelly and Daryl Reardon at the Condobolin site; Peter Roberts and Jess Perry at the Cargo site; Jayne Jenkins and Paddy Steele at the Trangie and Wongarbon sites; Stephen Morphett, Michael Dal Santo, Jim Perfrement, Jan Hosking and Bruce Haig at the Tamworth, Breeza and Narrabri sites; John Lehane at the Wellcamp and Pampas sites; Ellie McCosker and Jane Auer at the Emerald site.

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How does phenology influence yield responses in barley?

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

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Keywords

optimal flowering period, frost, sowing date, adaptation

Take home messages

- The optimal flowering period (OFP) to maximise grain yield potential and minimise effects of abiotic stresses in barley is earlier than for wheat and varies across growing environments
- Flowering time and grain yield is optimised with different variety x sowing date combinations, and varietal suitability varies across growing environments
- Relative frost risk of barley is lower than for wheat, and commercial barley varieties differ in frost tolerance.

Background

Maximum grain yield potential is achieved when crop development is synchronised with growing environment. Typically, barley is sown in a window from early–late autumn (April–May), to ensure flowering occurs at an optimal time in spring. This optimal flowering period (OFP) is defined early, by the risk of reproductive frost damage, and later, by high temperatures and terminal water stress during grain filling. Barley is considered to be more widely adapted, have superior frost tolerance, and has a yield advantage compared to wheat across environments of southern Australia (Harris et al., 2019), despite this, OFPs for barley have not been adequately defined which has implications for variety choice and sowing dates for growers.

Field experiments – Condobolin and Marrar, 2019

In 2019, field experiments were conducted at Condobolin and Marrar to investigate interactions between phenology, sowing date and growing environment. Cultivar responses were significantly influenced by seasonal conditions, with both sites recording below average growing season rainfall (April to October) and severe heat stress events which coincided with the late flowering to early grain filling period (Table 1).

Table 1. Growing season rainfall (GSR) April to October, frost and heat events at Condobolin and Marrar, 2019

Site	GSR (mm)^	Frost events (days <0°C)	Heat events (days >30°C)	Comments
Condobolin	144 (246)	5	9	• Minimal frost, no days <-2°C • Heat events coincided with late grain-filling phases: 1 day >30°C early October, 4 days >30°C late October-early November • 60 mm supplementary irrigation prior to sowing, additional 110 mm irrigation in-crop (May-September) to target Decile 5-6 yield potential.
Marrar	194 (272)	3	8	• Minimal frost, no days <-2°C • Heat events coincided with early grain-filling phases: 2 days >30°C early October, including 31.1°C (3 Oct) and 34.1°C (6 Oct); 7 days >30°C (23 Oct-2 Nov) • SD1 (18 April) established with 10 mm supplementary irrigation via drippers; site rain fed thereafter.

^Long term average (LTA) in parentheses

Phenology and yield responses to sowing date, 2019

Variety and sowing date combinations which flowered in early-mid September at Condobolin, and in mid-late September at Marrar achieved the highest yields in 2019. This indicates that OFPs vary in timing and duration across different yield environments, as described for wheat (Flohr et al., 2017). As flowering time is a function of the interaction between variety, management and environment, the variety x sowing time combinations capable of achieving OFP and maximum grain yield also vary across environments (Figure 1). At both sites, optimal flowering time were achieved by fast winter type Urambie⌽ sown mid-late April, spring cultivars sown mid-May, and some faster finishing spring types (e.g. La Trobe⌽ and Fathom ⌽) capable of flowering within the optimal window when sown late-May. However in 2019, which was characterised by minimal frost risk, significant heat stress and terminal drought (Table 1), earlier flowering resulted in higher grain yields at both sites (Table 2).

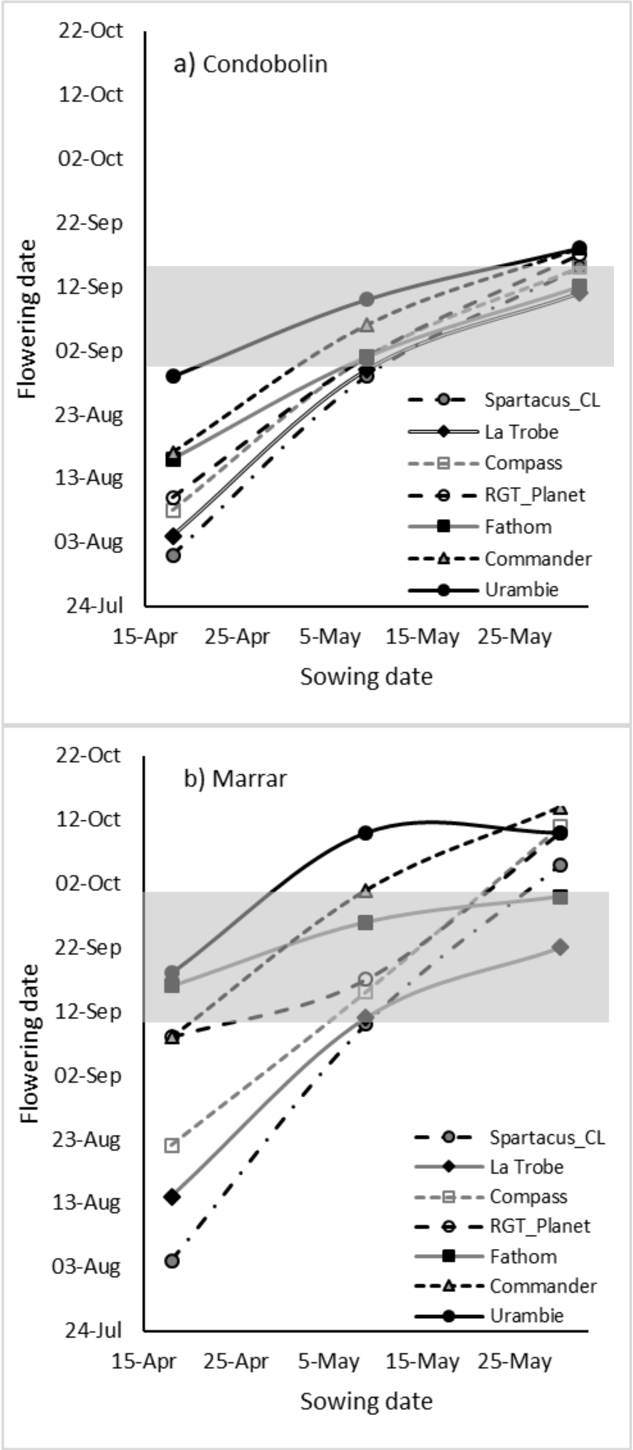

Figure 1. Flowering date responses to sowing date for selected varieties at a) Condobolin and b) Marrar field experiments in 2019. Shaded area indicates proposed optimal flowering period (OFP) at each location

Table 2. Grain yield responses to sowing date for barley varieties at Condobolin and Marrar, 2019

Variety	**Condobolin**			**Marrar**		
	18 April	**9 May**	**1 June**	**18 April**	**9 May**	**30 May**
Banksᶲ *(Mid spring)*	3.54	3.13	2.14	3.53	3.35	2.80
Biereᶲ *(Fast spring)*	2.64	2.65	2.00	3.67	2.66	2.59
Cassiopée *(French winter)*	1.59	1.17	0.79	1.80	1.64	1.17
Commanderᶲ *(Mid spring)*	3.73	2.35	1.86	3.62	3.00	2.43
Compassᶲ *(Fast spring)*	4.00	2.99	2.56	3.96	3.09	3.03
Fathomᶲ *(Mid-fast spring)*	3.80	3.07	2.54	4.57	3.58	3.00
La Trobeᶲ *(Fast spring)*	4.05	2.90	2.54	4.28	3.42	2.69
RGT Planetᶲ *(Mid-fast spring)*	4.02	2.38	1.90	3.07	2.87	2.60
Rosalindᶲ *(Fast spring)*	3.54	2.71	2.93	4.06	3.76	3.07
Spartacus CLᶲ *(Fast spring)*	3.64	3.44	2.42	4.06	3.95	2.97
Travelerᶲ *(Slow spring)*	3.41	2.69	1.83	3.21	3.39	2.52
Urambie ᶲ *(Fast winter)*	3.49	2.41	1.96	3.54	2.74	2.51
Mean	**3.45**	**2.66**	**2.12**	**3.61**	**3.12**	**2.62**
LSD (Variety)	**0.54**			**0.31**		
LSD (SD)	**0.27**			**0.15**		
LSD (Variety x SD)	**0.93**			**0.53**		

How does barley optimal flowering period (OFP) compare to wheat?

A preliminary comparison of co-located wheat and barley field experiments conducted in two contrasting seasons (Wagga Wagga, 2018 and Marrar, 2019) suggests that the OFP, whereby grain yield was maximised, for barley is significantly earlier, and relative frost risk lower than wheat, which has implications for variety choice in relation to sowing time for growers (Figure 2).

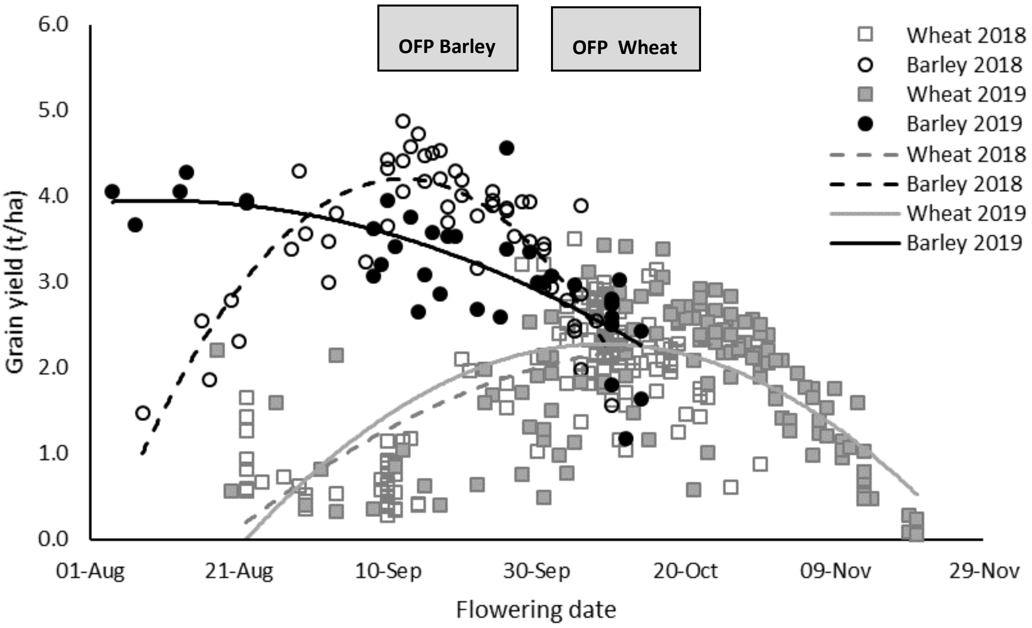

Figure 2. Grain yield responses to flowering date for a range of wheat and barley varieties sown from early April-late May in co-located experiments conducted at Wagga Wagga (2018) and Marrar (2019)

Cultivar adaptation to growing environment

A comparative analysis between yields of RGT Planet⦹ and La Trobe⦹ from field experiments conducted at Condobolin (2017-19), Matong (2017), Wagga Wagga (2016-18), Marrar (2019) and Wallendbeen (2018-19) showed that these cultivars often achieved similar grain yields (Figure 3). Generally, in environments where grain yields were less than 2.5-3 t/ha, or in seasons such as 2019, with severe heat and terminal drought stress, La Trobe⦹ or faster finishing types were favoured; whilst when grain yields were greater than 2.5-3 t/ha, RGT Planet⦹ was capable of a yield advantage. Differences in comparable yields were also apparent in relation to management, whereby RGT Planet⦹ offers an opportunity for slightly earlier sowing (early May) compared to benchmark fast spring type La Trobe⦹ which is better suited to traditional mid-late May sowing dates.

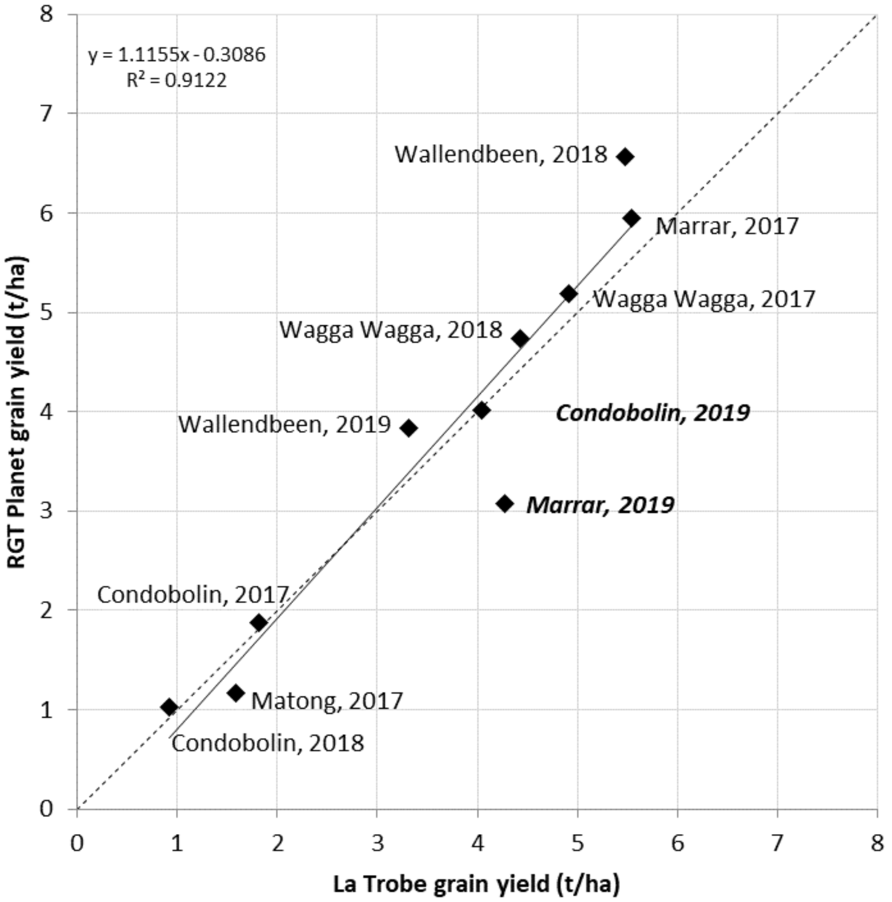

Figure 3. The relationship between highest yields of RGT Planet⟮ and La Trobe⟮ from field experiments at Condobolin (2017-19), Matong (2017), Wagga Wagga (2016-18), Marrar (2019) and Wallendbeen (2018-19). Dotted line indicates 1:1 relationship

Varietal differences have been observed under high frost risk seasons, such as those experienced at Wagga Wagga in 2018, whereby RGT Planet⟮ was better able to maintain yield under frost conditions (SD1) compared to La Trobe⟮ (Figure 4). This aligns with the National Frost Initiative (NFI) barley variety rankings (Figure 5) which is a useful resource for both barley and wheat.

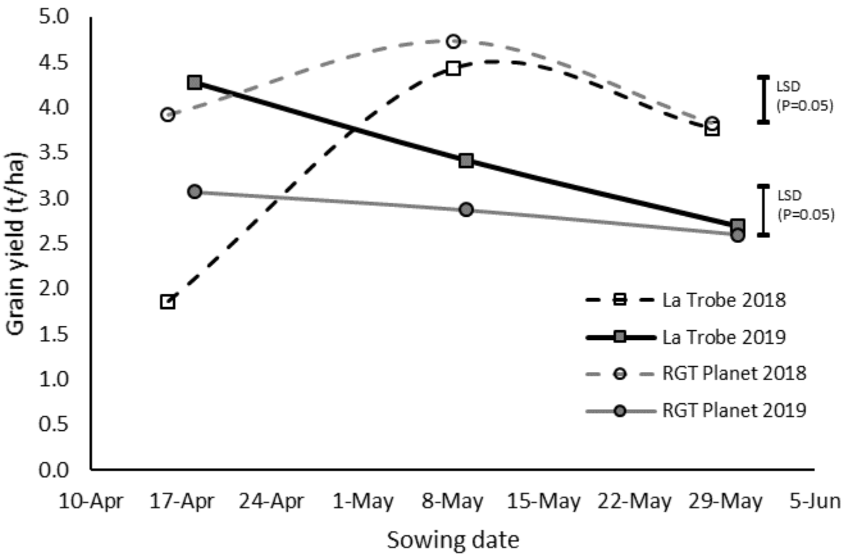

Figure 4. Grain yield responses to sowing date for RGT Planet⌽ and La Trobe⌽ at Wagga Wagga (2018) and Marrar (2019)

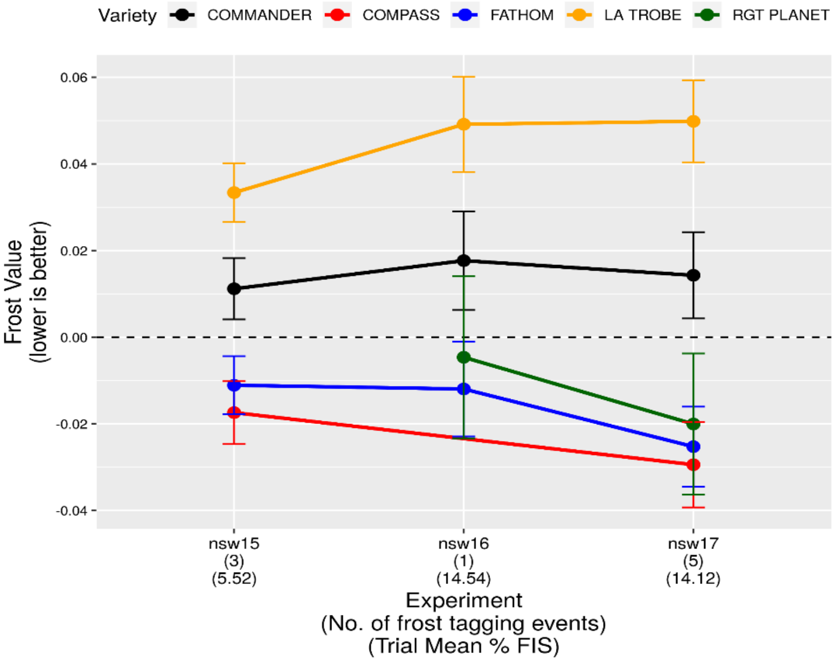

Figure 5. National Frost Initiative (NFI) variety rankings for selected barley varieties in northern region, based on experiments conducted in NSW (2015-2017).
Source: https://www.nvtonline.com.au/frost/

Conclusion

Initial comparisons indicate that the optimal flowering time (OFP) for barley is earlier than for wheat, and timing and duration of barley OFPs varies with environment. Timing of flowering and grain yield is optimised with different variety x sowing date combinations, and variety responses and suitability differ across growing environments. Most spring barley varieties are still suited to traditional May sowing dates, however some longer season spring types such as RGT Planet⌽ offer opportunities for slightly earlier sowing (early May) compared with benchmark fast spring types such as La Trobeⓓ. Whilst early sowing options in frost prone environments of southern NSW are currently limited by suitable winter varieties, there are differences in relative frost susceptibility within current commercially available varieties in NSW.

Useful resources

https://www.nvtonline.com.au/frost/

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Acknowledgements

Sincere thank you for the technical assistance of Cameron Copeland, Dean Maccallum, Mary Matthews, Jessica Simpson, Ian Menz, Bren Wilson and Javier Atayde at the Marrar site and Braden Donnelly and Daryl Reardon at the Condobolin site.

We also acknowledge the support and cooperation of the Pattison family at Marrar and NSW DPI at the Condobolin Agricultural Research and Advisory Station.

This research was a co-investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP) project.

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ⓓ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Pulses in the Lake Cargelligo farming systems

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Notes

Fixing more N by improving inoculant performance in sub-optimal conditions

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Key words

rhizobia, nodulation, lentil, field pea, vetch, faba bean

GRDC code

DAN1901 002 RTX

Take home messages

- Rhizobia strains selected from soils with pH similar to those encountered across large areas of central and southern NSW have increased nodulation in lentil, field pea and vetch compared to the current Group F strain
- > 40% of paddocks surveyed in the GRDC northern region covering central and southern NSW had a $\text{pH}_{\text{Ca}} < 5.0$
- While acid tolerant rhizobia may improve nodulation in acidic soils, consideration to amelioration acidity should be given where pHCa <5.0 as nodulation is likely to still be inadequate at this pH.

Background

There are three key considerations in achieving successful nodulation of legumes. Firstly, the host plant needs to be suited to the conditions in which it is grown. Secondly, there needs to be a sufficient number of a compatible strain of rhizobia for the host plant. Thirdly, there needs to be capacity for communication (signalling) between the host plant and the rhizobia for root infection and nodulation to occur. Suboptimal conditions including soil acidity, aridity, low clay content of soil, inadequate nutrient availability (for the host plant and the rhizobia) and/or the presence of herbicide residues can impact the host plant, the rhizobia and/or the interaction of plant and rhizobia thus reducing the formation of an effective symbiosis and reducing potential nitrogen fixation. Nodulation and nitrogen fixation are not a given when growing legumes. Legumes that don’t form an effective symbiosis use nitrogen (N) from the soil pool rather than contributing to building soil N.

So what is the current situation and probable impediments to achieving higher nitrogen fixation in legumes and what options are there to improve the situation? In the remainder of this paper we will discuss current research underway to deliver more resilient rhizobia strains for lentil, faba bean, field pea and vetch to the marketplace along with other facets of management that need to be considered to improve legume performance.

The search for more resilient, robust rhizobia strains

Current recommendations suggest lentil and faba bean are inoculated with Group F (containing the rhizobia strain WSM1455) while field pea and vetch are inoculated with Group E (SU303). However, the current Group E is difficult to manufacture and as a result, field pea and vetch are in fact inoculated with Group F inoculant. Fortunately, the current rhizobia strain (WSM1455) used in Group F inoculant has good compatibility across all of these host legumes. However, the current Group F which was isolated from soil in Greece (pH_{Ca} 8.0) and released in 2002, exhibits a rapid decline in capacity to nodulate plants where $pH_{Ca} < 6.0$, with plants generally inadequately nodulated where $pH_{Ca} <5.0$ (Yates et al. 2016; Ballard et al. 2019).

Large areas of cropping land in central and southern NSW have soils where the capacity of the current Group F to effectively nodulate host plants is restricted. A recent survey of 150 commercial paddocks in the GRDC northern region found that soil pH in the top 20 cm of the soil profile would likely restrict the performance of the current Group F in ≥ 40% of paddocks sampled (Table 1). Rhizobia with greater acid soil tolerance would likely increase capacity for nitrogen fixation throughout the regions sampled in this survey.

Table 1. The average soil pHCa of 150 commercial paddocks in the central east, central west, south east or south west regions of the GRDC northern region as sampled in 2019 and the percentage of paddocks where soil pH was less than 5.0

Depth	**Average soil pH_{Ca}**	**Percentage of paddocks $pH_{Ca}<5.0$**
0-5 cm	5.3	39
5-10 cm	5.0	84
10-20 cm	5.6	40
20-30 cm	6.1	15

Both Murdoch University (Centre for Rhizobium Studies) and SARDI have been isolating rhizobia suitable for consideration as a Group F replacement from acidic soils (pH_{Ca} 4.5-5.5); Murdoch University accessions have been sourced from Italy and SARDI accessions from commercial paddocks in South Australia. Preliminary glasshouse and field studies in Western Australia identified two acid-tolerant Italian strains (WSM1455, WSM4643) which produced improved nodulation, nitrogen fixation and grain yield in field pea (Yates et al. 2017). Similar studies in South Australia reported improved performance in lentil and faba bean where acid tolerant Australian strains (SRDI969, SRDI970) were used compared to the current Group F (WSM1455) strain (Ballard et al. 2019). These results are encouraging. However, to be considered for commercial release, it is important that any potential strain has capacity to improve nodulation across the entire Group F host range which also includes vetch. In addition, any elite strain has to be able to be manufactured easily and to remain stable up until the point of use at sowing.

In 2019, field testing of the four elite acid-tolerant strains commenced in the Northern GRDC region with sites sown at Griffith, Condobolin and Canowindra. The objective of the three sites was to evaluate the performance of the elite strains in differing soils (Table 2) and under varying climatic conditions. Griffith was the most challenging of the sites due to lower soil pH, low clay content and high summer temperatures. Canowindra with a higher soil pH, higher clay content and lower temperatures potentially increased survival capacity of the rhizobia, although such conditions also increase the potential for higher background rhizobia levels that compete with introduced strains.

Table 2. The location, soil pH and texture of three sites used for evaluation of elite rhizobia strains for lentil, faba bean, field pea and vetch in the GRDC Northern Region in 2019

Location	Soil pH_{Ca} (0-10 cm)	Soil texture
Griffith	4.6	Light sandy loam
Condobolin	4.8	Sandy loam (red chromosol)
Canowindra	5.1	Loam (dermosol)

For lentils, there was a significant difference in nodulation across sites and due to rhizobia strain (Figure 1). The most acidic site, Griffith, had lower nodulation than all other sites and only WSM4643 produced a significantly higher nodulation score than the current Group F strain. At Condobolin and Canowindra, both WSM1483 and WSM4643 produced significantly higher nodulation scores than the current Group F, while SRDI969 was also significantly higher than the current Group F at Canowindra. None of the strains at any site gave an overall nodulation score that is considered adequate (score ≥ 4; Yates et al. 2016).

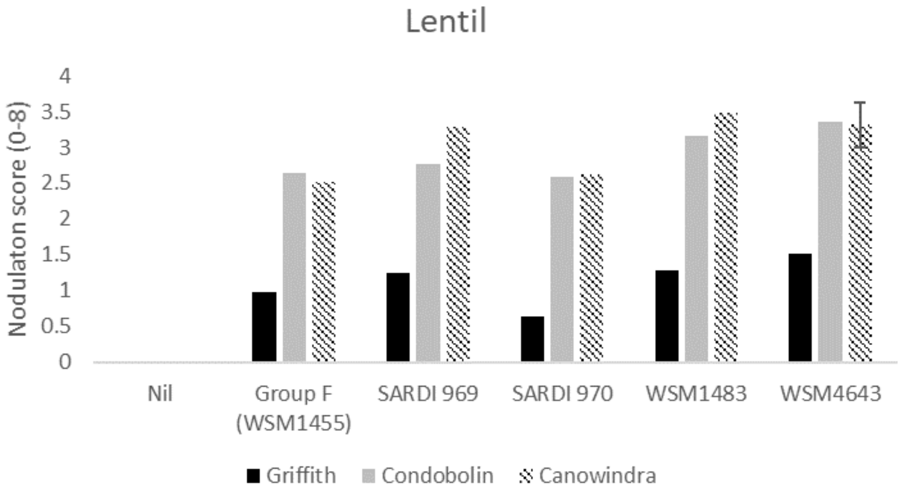

Figure 1. The average nodulation score of 15 lentil plants at Griffith, Condobolin and Canowindra where seed was inoculated with peat slurry containing a no rhizobia (nil), the current Group F strain, or one of four experimental strains. A score of 4 is considered adequate under the system developed by Yates et al. (2016)

For field pea, all experimental strains produced significantly greater nodulation than the current Group F at Griffith (Figure 2). At Condobolin and Canowindra, WSM4643 produced significantly higher nodulation score than the current Group F, with WSM1483 also significantly higher at Condobolin.

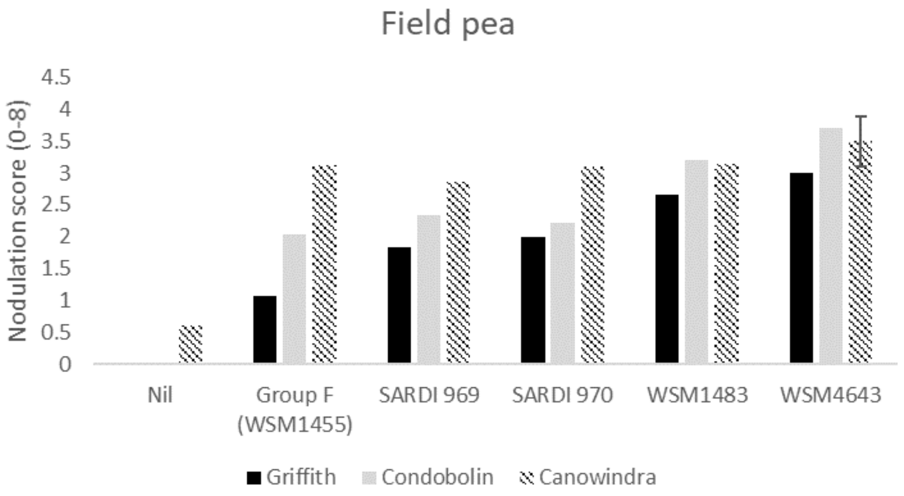

Figure 2. The average nodulation score of 15 field pea plants at Griffith, Condobolin and Canowindra where seed was inoculated with peat slurry containing a no rhizobia (nil), the current Group F strain, or one of four experimental strains. A score of 4 is considered adequate under the system developed by Yates et al. (2016)

For vetch, WSM1483 and WSM4643 produced significantly higher nodulation than the current Group F at Griffith and Condobolin (Figure 3). None of the experimental strains produced significantly higher nodulation than the current Group F at Canowindra. SRDI970 showed poor compatibility with vetch at Condobolin and Canowindra producing very low nodulation scores. It is critical that strains considered for potential release showed strong compatibility across the potential host range.

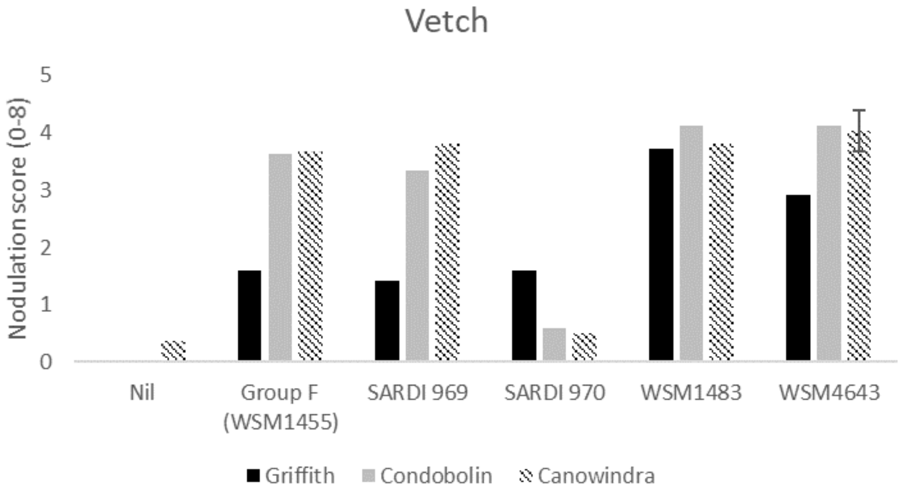

Figure 3. The average nodulation score of 15 vetch plants at Griffith, Condobolin and Canowindra where seed was inoculated with peat slurry containing a no rhizobia (nil), the current Group F strain, or one of four experimental strains. A score of 4 is considered adequate under the system developed by Yates et al. (2016)

Faba beans were grown only at Canowindra and there were no experimental strains that gave nodulation scores greater than those achieved by the current Group F strain (Figure 4).

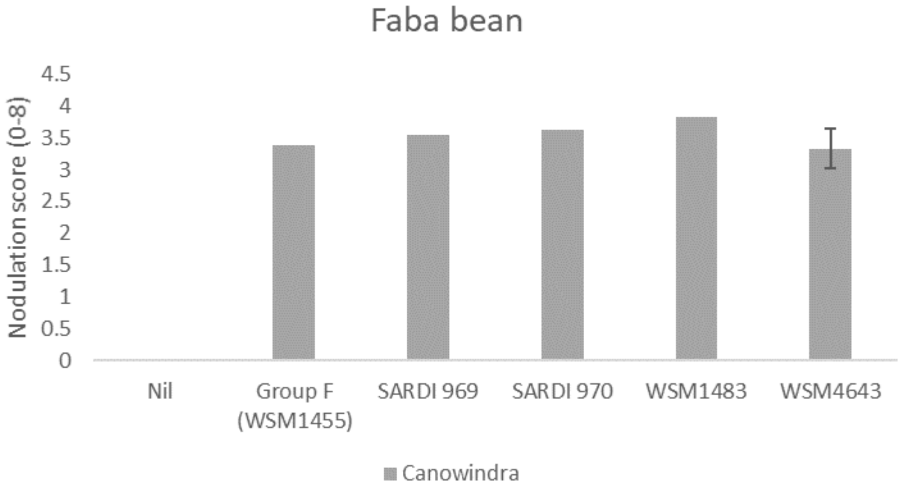

Figure 4. The average nodulation score of 15 faba bean plants at Canowindra where seed was inoculated with peat slurry containing a no rhizobia (nil), the current Group F strain, or one of four experimental strains. A score of 4 is considered adequate under the system developed by Yates et al. (2016)

Samples were collected to determine nitrogen fixation and these are still undergoing processing as are samples collected to determine grain yield. However, based on results to date, it would appear that strains WSM1483 and WSM4643 offer considerable potential to increase nodulation in acidic soils and also have good compatibility with the potential host range. Research is ongoing within the Australian Inoculant Research Group to determine the manufacturability and stability characteristics of the elite strains, as this is a critical consideration in the practical delivery of elite strains to the marketplace.

Are elite strains the answer to increasing pulse production and adaptation?

The development of elite rhizobial strains is an important step forward in increasing pulse production, but it is not a silver bullet. Certainly, pulse production in central and southern NSW is likely to be constrained by acidic soils which are widespread throughout the region and our results indicate that elite strains may increase nodulation in these circumstances. The current strain of Group F was isolated from soils with a pH much higher than that encountered through much of the target growing regions of central and southern NSW and therefore strains selected from soils more comparable in pH are likely to have production and survival advantages. However, our results also show differences in host plant tolerance to soil acidity, with lentil nodulation still well below the level considered adequate even with acid tolerant rhizobia. Thus, soil acidity is potentially impacting the host plant and/or the formation of an effective symbiosis. So are tolerant host plants the answer? Potentially they are also a tool to improve adaptation and production of pulses in acid soil regions. However, what must be considered is that if the acid soil problem is not addressed, it will continue to worsen. The results of our soil survey show that a large percentage of commercial paddocks have soil pH_{Ca}<5.0. Acid tolerant rhizobia and acid tolerant host plants can only do so much and certainly once soil pH falls below 5.0, other problems come into play including reductions in the efficiency of use of applied nutrients. Also, the impact of herbicide residues needs to be considered as these can impact the host plant, rhizobia and the host plant-rhizobia symbiosis. This project is in its early stages and further evaluation is required through time and across sites to determine the impact that elite rhizobial strains may have on potential pulse production.

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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 author would like to thank them for their continued support. The authors also wish to acknowledge the financial and in-kind contributions of Local Land Services and Central West Farming Systems towards the soil survey results presented in this paper.

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Biserrula: its fit in the system

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Key words

biserrula, seed yield, seed bank, drought tolerance, yellow serradella, subterranean clover

GRDC code

9175959

Take home messages

- Biserrula has been the most successful pasture legume to establish and produce seed under severe drought conditions in the 450 mm rainfall region in 2018 and 2019
- The deep root system and capacity of sustained periods of indeterminate growth confer better adaptation under variable and severe moisture stress. Biserrula appears to have greater plasticity in initiating reproductive growth compared to French serradella, which is also deep-rooted and has capacity for long periods of indeterminate growth
- Results from 2019 indicate an early season experimental line of yellow serradella also has significant potential in this region
- Both biserrula, French serradella and yellow serradella were superior to subterranean clover in producing seed for subsequent regeneration
- Both biserrula and hard seeded serradellas can be used in on-demand roles in rotations to increase nitrogen supply to crops. Understanding hard seed attributes are required for success
- The use of nursery paddocks to determine which legume species to grow can be a very useful tool.

Background

Poor reliability of autumn breaks, short springs and drought have reduced the reliability of traditional annual legume species such as subterranean clover and annual medics. Lucerne has been used in many areas to at least partially fill the gap left by traditional legumes, but soil acidity can limit its adaptation and maintaining adequate groundcover in lucerne paddocks can be a problem in many instances. Over the past few decades there has been considerable development of annual legume species with improved adaptation to climatic and soil challenges. Both 2018 and 2019 have allowed assessment of production and survival attributes of a range of annual legumes under extreme drought conditions in the GRDC northern region. In both years, biserrula has exhibited the capacity to produce viable quantities of seed to facilitate ongoing regeneration. This paper reports on the seed production achieved by biserrula under drought conditions and also identifies other species as having considerable potential under such conditions. The principles of use of these hard seeded species in rotations is also briefly discussed.

The importance of setting up a seedbank

For annual pasture species, the establishment of an adequate seedbank is critical to the ongoing success of the pasture. A key weakness of traditional annual legumes with their shallow root systems is their inability to maintain growth for long enough in spring to allow seed set. Species such as subterranean clover and annual medics have root systems that typically do not extend beyond 80-100 cm. In contrast, annual legume species such as biserrula and serradella have root systems that may extend beyond 200 cm. Root systems of biserrula and serradella also develop relatively rapidly meaning that they have greater capacity for survival if adverse moisture conditions are experienced following germination. Additionally, both biserrula and serradella are capable of long periods of indeterminate growth, meaning they will continue to grow and produce seed while moisture is available, whereas traditional legumes are largely determinate in their growth. Rapid developing, deep root systems and capacity for extended periods of reproductive growth are attributes that have considerable potential to enable formation of adequate seedbanks, particularly under adverse climatic conditions.

Seedbank formation under severe drought conditions

In 2018 and 2019, replicated (n=3) field sites were established approximately midway between Ungarie and Kikoira in NSW to evaluate the performance of nine annual legumes (only results for biserrula, serradella and subterranean clover shown in this paper). Annual rainfall was only 50% and 57% of the long-term average in 2018 and 2019, respectively (Figure 1). Growing season rainfall was 31% and 33% of the long-term average in 2018 and 2019, respectively.

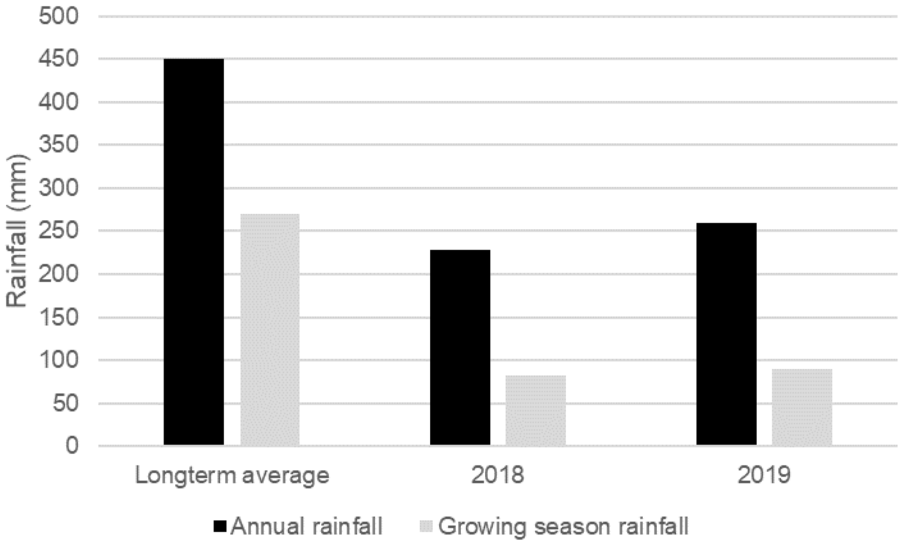

Figure 1. The long-term annual and growing season rainfall (mm) and rainfall for 2018 and 2019 for a field site located between Ungarie and Kikoira NSW

Generally, a minimum target of 100-150 kg seed/ha is required to support adequate regeneration of annual legumes in subsequent years (based on traditional legume species). In 2018, Casbah biserrula produced more than 170 kg seed/ha (Figure 2). In contrast Dalkeith subterranean clover produced less than 10 kg seed/ha. Interestingly, the biserrula had produced one third of its total seed by late October. Late rainfall in October resulted in growth recommencing in biserrula and additional seed production. Margaritaⓓ French serradella, a hard seeded French serradella of similar maturity time to Casbah biserrula was also included in the field trial. Despite similar maturity times, the Margaritaⓓ French serradella had not commenced pod formation by late October and produced 80 kg seed/ha. Biserrula appears to have greater plasticity in commencement of reproductive growth under the low moisture conditions experienced in 2018.

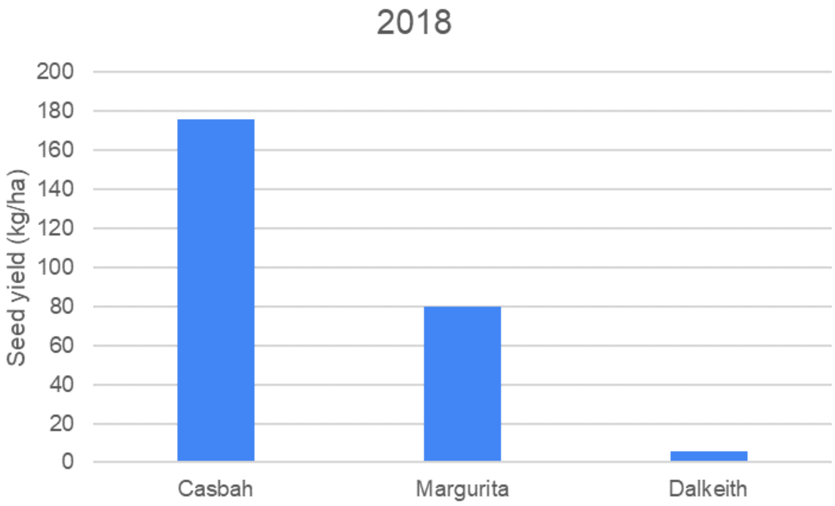

Figure 2. Seed production (kg/ha) of Casbah biserrula, Margurita French serradella and Dalkeith subterranean clover at a field site between Ungarie and Kikoira, NSW in 2018

In 2019, a new field trial was established. An experimental line of an early maturing, moderately hardseeded yellow serradella (87GEH72.1a) was included along with Casbah biserrula and Dalkeith subterranean clover. In 2019, only 5 mm rainfall was received in September and none in October. Despite this, the Casbah biserrula still produced more than 80 kg seed/ha and the experimental yellow serradella, more than 130 kg seed/ha, while Dalkeith subterranean clover produced less than 10 kg seed/ha (Figure 3). Whether 80 kg seed/ha of biserrula is sufficient for regeneration remains to be seen. However, biserrula has very small seeds (approximately 1,000,000 seeds/kg) compared to traditional species such as subterranean clover (110,000 to 150,000 seeds/kg) and therefore seed number per unit area may be sufficient for biserrula.

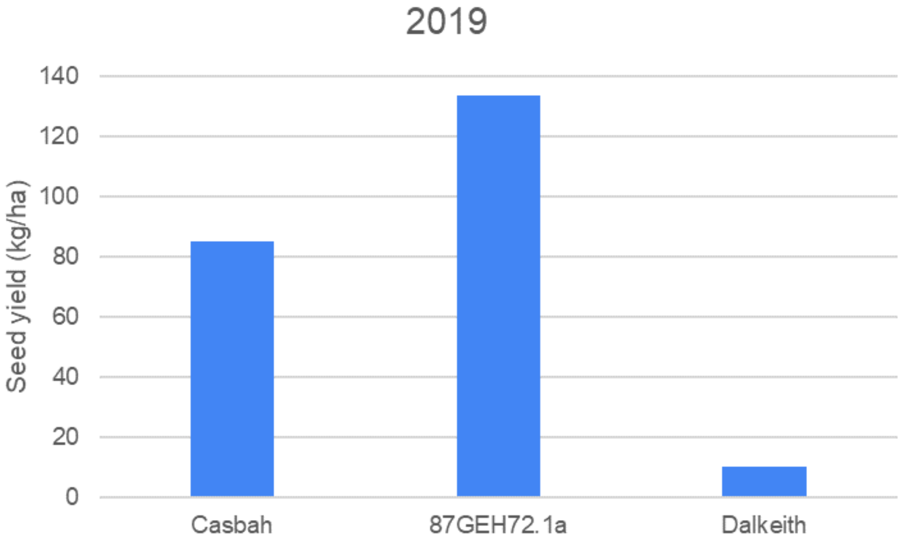

Figure 3. Seed production (kg/ha) of Casbah biserrula, an experimental line of yellow serradella (87GEH72.1a) and Dalkeith subterranean clover at a field site between Ungarie and Kikoira, NSW in 2019

What our results have shown under very trying growing conditions, is that biserrula has the capacity to form relatively large seedbanks under adverse conditions and there are experimental lines of yellow serradella that also have significant potential. Previously, our field experiments across many areas of central and southern NSW have shown biserrula has the capacity to produce more than 500 kg seed/ha under growing conditions where rainfall is between 30% lower and close to average for the year and growing season. Hardseeded French serradella has shown similar attributes in the same conditions. Previously, yellow serradella has generally produced less seed than either biserrula or French serradella under the same growing conditions as biserrula and French serradella. The experimental yellow serradella used in this field trial appears to have considerable potential.

Using hardseeded legumes in the rotation

Biserrula has a significantly higher hard seed level in the autumn following seed set compared to traditional legumes. In NSW, we have measured hard seed levels in the autumn following seed set of 70->90% for Casbah biserrula, whereas subterranean clover frequently has <30% hard seed at the same point in time. The high residual hard seed level of biserrula means that regeneration in the second year can be variable. For this reason, it is suggested that the paddock be cropped to give time for hard seed to break down. Cropping in the second season also makes sense as it allows the crop to utilise nitrogen fixed by biserrula in the year of establishment. In the third year, the paddock could be allowed to regenerate, or alternatively it could be cropped again, if desired. Research is currently ongoing to determine how long biserrula seed will persist in the soil.

For other hard seeded species, rotation strategies may need to be varied compared to biserrula. For example, for hardseeded French serradella (e.g. Margurita), hard seed levels in the autumn following seed set vary from 40-60% in NSW. Thus, regeneration in the second year is likely to be better than for biserrula, but consideration should also be given to cropping to utilise nitrogen fixed in the establishment year. Rotations of one-year crop to one-year pasture are common for hardseeded French serradella.

Yellow serradella can vary considerably in hard seed level between varieties. For example, in NSW, varieties such as Santorini can have residual hard seed levels similar to Casbah biserrula. However, for varieties such as Avila, residual hard seed levels are generally around 50%. The early maturing experimental line used in the 2019 study reported in this paper also has residual hard seed level of around 50%. Thus, rotations utilising yellow serradella may be similar to those of biserrula or may more like those used for hardseeded French serradella depending on the yellow serradella variety selected.

A key point to stress is that selection of species of hardseeded legume to use in a cropping rotation should firstly consider how well adapted the species are to local soil and climatic conditions. Once suitable species are identified, then consideration needs to be given to selection of varieties that will fit the local environment and the rotation to be imposed. A significant advantage of hardseeded legumes is their ability to persist through a cropping phase and regenerate without the need for resowing. In essence, they can be used as an on-demand break in the cropping rotation once a seedbank is established.

Livestock and biserrula

Biserrula has capacity to cause outbreaks of primary photosensitisation in grazing livestock. Studies at Charles Sturt University showed reductions in photosensitisation incidence where other species contributed 10-30% of pasture on offer. Therefore, once a seedbank is established either deliberate introduction of other species into the sward (e.g. sowing a low rate of cereal) or allowing annual grasses to regenerate may reduce incidence. Animals should be closely monitored for signs of photosensitisation and removed from pasture if it occurs. Biserrula is not highly palatable to grazing livestock and they will tend to select other species including problem cropping weeds such as annual ryegrass prior to grazing biserrula. Therefore, biserrula may be a useful tool in controlling problem cropping weeds. Further, information on biserrula and primary photosensitisation including tactics used by producers to reduce incidence can be found in the following link:

(https://cdn.csu.edu.au/__data/assets/pdf_file/0006/2966982/Understanding-photosensitisation-in-sheep-grazing-biserrula-pastures.pdf)

Getting started with hardseeded legumes

One of the most successful ways we have seen producers get started with hardseeded legumes is through the use of nursery paddocks. The new generation of hardseeded legumes that includes biserrula, French serradella, yellow serradella, arrowleaf clover, bladder clover and gland clover are all aerial seed producers. This contrasts with subterranean clover which buries a high proportion of its seed. Aerial seeding of the new generation annual legumes mean they can be harvested with a cereal header. If a nursery paddock is chosen, a number of species of legumes can be evaluated for suitability simultaneously. Small areas (5-20 ha) of a range of species can then be sown as blocks in the paddock. By doing this, the producer can evaluate at relatively low seed cost, a number of options that might suit his/her farm. Seed can then be harvested. This type of system in not unlike bulking up seed of a new cereal variety. The nursery system also lessens the risk of perhaps outlaying large investment on a species that may turn out to be not particularly well suited to the area. Over more than 10 years of having producers use the nursery system as a first step screening to determine which species to grow on their farm, we have frequently seen the choice on what species to proceed with be different to that which the producer was originally considering. Once seed is harvested on-farm, other establishment options such as summer and twin sowing are opened up, but these are topics for another paper!

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 author would like to thank them for their continued support.

The Dryland Legumes Pasture Systems project is supported by funding from the Australian Government Department of Agriculture as part of its Rural R&D for Profit program, the Grains Research and Development Corporation, Meat and Livestock Australia and Australian Wool Innovation. The research partners include the South Australian Research and Development Institute, Murdoch University, the Commonwealth Scientific and Industrial Research Organisation, the WA Department of Primary Industries and Regional Development, and Charles Sturt University (Graham Centre), as well as grower groups.

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Budgeting phosphorus in medium and lower rainfall zones of southern NSW

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Key words

crop nutrition, drought, phosphorus, budgeting

GRDC code

UQ00082

Take home messages

- Soil Colwell phosphorus critical values of wheat and canola to achieve 90 to 95% of maximum yield in southern NSW are 35 to 42 and 22 to 27 mg P/kg respectively
- Starter P applied at sowing consistently increases crop yield
- Soil pH and soil phosphorus buffering index (PBI) can impact on plant available phosphorus and consideration needs to be given to these factors
- Phosphorus stratification in soil can limit yield where most of the measured 0 to 10 cm phosphorus is actually located in the 0 to 5 cm layer, which is the most prone to drying. Colwell P values below 10 cm are less than 10 mg P/kg soil
- Phosphorus export from paddocks in grain is estimated at 2.7 to 3.6 kg P/t of wheat grain production and 4.0 to 6.5 kg P/t of canola seed production
- Phosphorus fertiliser savings after drought or a failed crop are possible where there has been an extensive P fertiliser history, and soil Colwell P values are above crop critical requirements. - As a guide, in a one off exercise, one third of average crop P replacement can be applied down to a base level of not less than 5 kg P/ha in low yielding environments. This is possible because the bulk of the P supplied to crops is provided via the soil reserve and fertiliser P is primarily used to maintain the soil reserve.

Background

Phosphorus (P) is a significant 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 farmers some flexibility in managing P inputs, particularly where cash flow may be limited. 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 considerations after drought and P cycling and uptake.

Phosphorus cycling

Soils of Australia in their native state are deficient in phosphorus (P) with some exceptions through northern NSW and Queensland (e.g. cracking clay soils) which have been depleted in more recent times through cropping. In many of the remaining soils of the cropping zone advisors aim to ensure P fertiliser has been added in amounts that approximately equal P exported in grain plus other losses such as unrecovered P in stubble and soil. P fertiliser that is added to the soil in cropping systems primarily goes into the 'soil reserve' where the P binds to soil minerals, 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 and aluminium. It is very difficult to supply sufficient P for crop needs when P solubility is being controlled by iron and aluminium. The third peak occurs in alkaline soils around pH 8.0 when P is precipitated primarily by calcium. This fixation with calcium is relatively weak and it is generally more economical to apply more P fertiliser than adding amendments to acidify the soil (Figure 1).

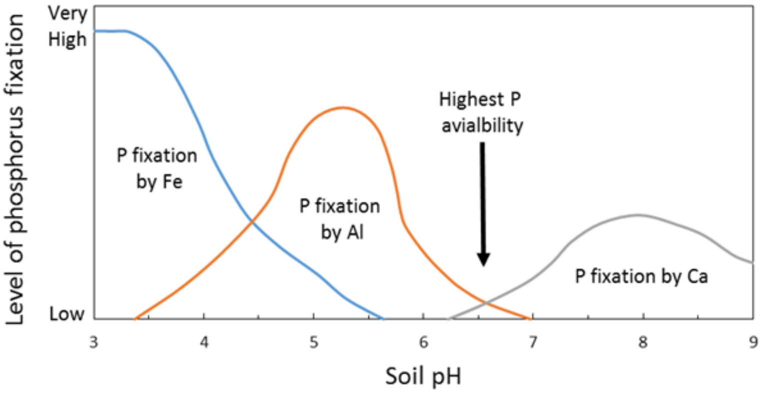

Figure 1. The effect of soil pH on phosphorus availability

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 purposes of this paper we will not provide extensive detail but 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 Mn phosphates [acid soils] and Ca and Mg phosphates [alkaline soils]) and (3) primary P minerals (aged and crystallised Fe, Al, Mn, Ca and Mg phosphates). The soil P reserve (Figure 2) in P adequate soils (Table 2) provides the largest percentage of crop requirements in any one year which is estimated at ~30–80% (Price 2006, Mcbeath et al 2012). Phosphorus fertiliser can directly provide ~20–30% of crop requirements (Price 2006) with available P from stubble making up ~9–44% (Noack et al 2012) and roots ~21–26% (Foyjunnessa et al 2016).

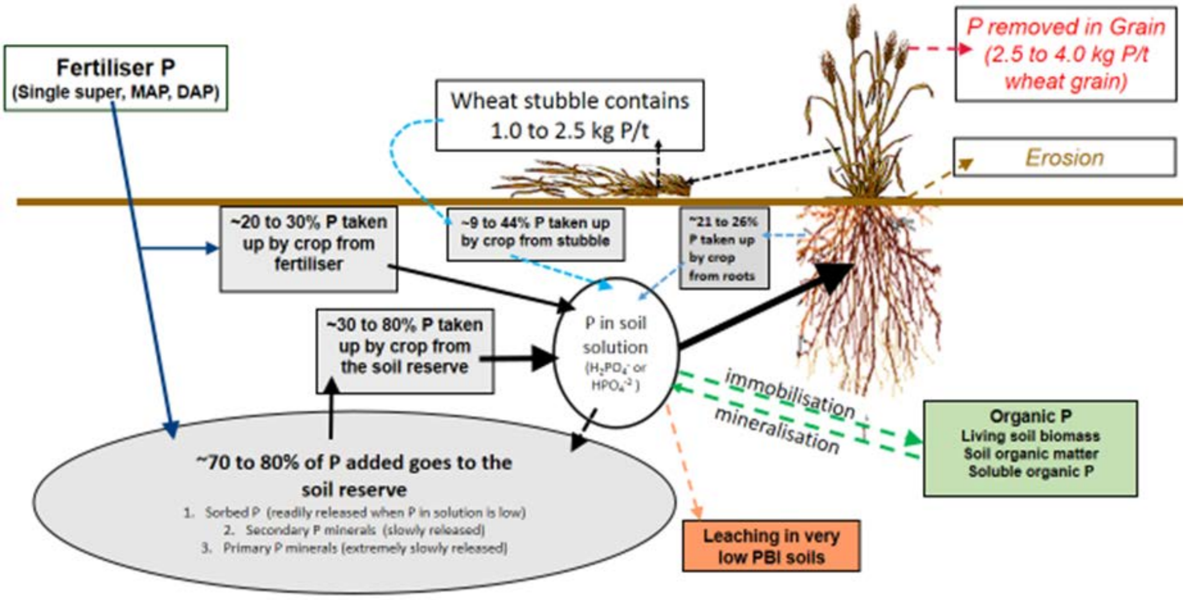

Figure 2. Soil phosphorus cycling in winter cropping systems

Phosphorus Buffering Index (PBI)

The Phosphorus Buffering Index (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 (bound) and solution (readily plant available) phases of the soil. A high PBI therefore results in a greater tendency for P sorption compared with a soil 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 values for wheat. Usually large changes in PBI values are required to change crop critical values. Examples of this are provided in Table 1 calculated from Moody (2007). In addition estimates are also provided from Bell et al (2016) which are quantified from a large data set in the Better Fertiliser Decisions Cropping database (BFDC).

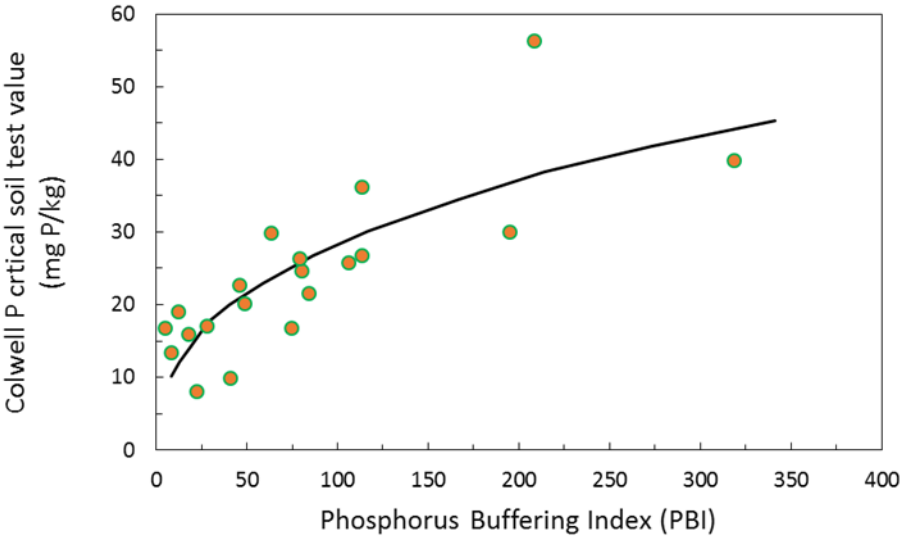

Figure 3. Effect of PBI on critical Colwell-P (0–0.10 m) required for 90% maximum grain yield of wheat. Critical Colwell P = 4.6 x PBI$^{0.393}$ (Moody 2007)

Table 1. Estimated critical Colwell P soil values (mg P/kg soil) for 90% of maximum wheat grain yield when grown in soils with differing PBI (Moody 2007 and Bell et al. 2013)

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

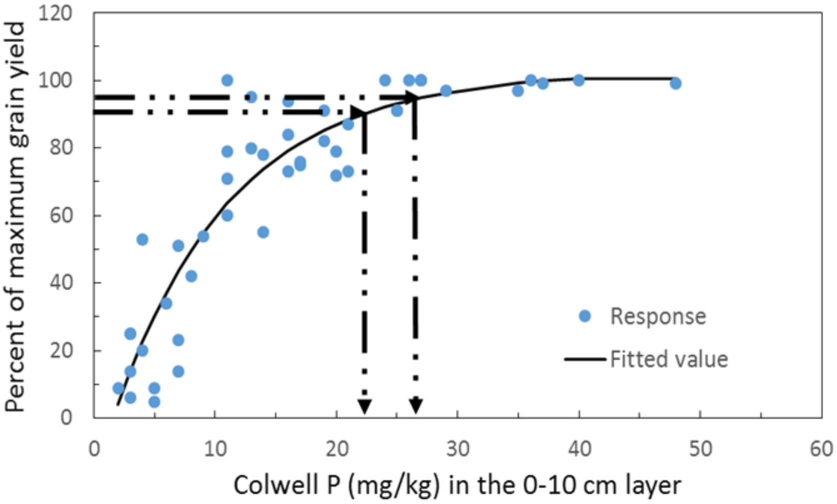

Figure 4. Grain yield response of canola across a range of soil types and States. The y axis is percent of maximum grain yield achieved and the x axis is the soil Colwell P test value. Data taken from the BFDC

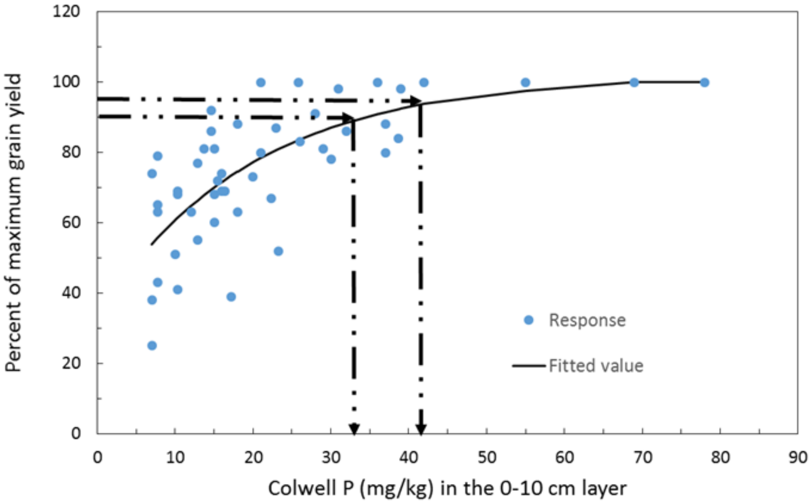

Figure 5. Grain yield response of wheat on red chromosol soils of NSW. The y axis is percent of maximum grain yield achieved and the x axis is the soil Colwell P test value. Data taken from the BFDC

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% of maximum crop production is achieved. This range may differ for different crop species and soil types that have a different PBI value. However, as the figures suggest not all points fit exactly on the line. This can be in part due to variation in seasonal conditions and stratification of P in the surface (0-5cm) when the whole top 10 cm soil section is sampled. 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.

An analysis of data from the BFDC database using Mitscherlich equations indicates the 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 soils indicates Colwell P critical values of 35 and 42 (Figure 5) and for vertosol soils 25 and 35 (Figure 6). Using the Mitscherlich equation provides a slightly higher estimate of critical value than those estimated directly from the BFDC database (Table 2) that use quadratic equations to estimate critical P, however there is still sound general agreement between the values provided above when comparing figures 4, 5 and 6 with Table 2. Consequently growers can have confidence in either using values from Table 2 or figures 4, 5 and 6.

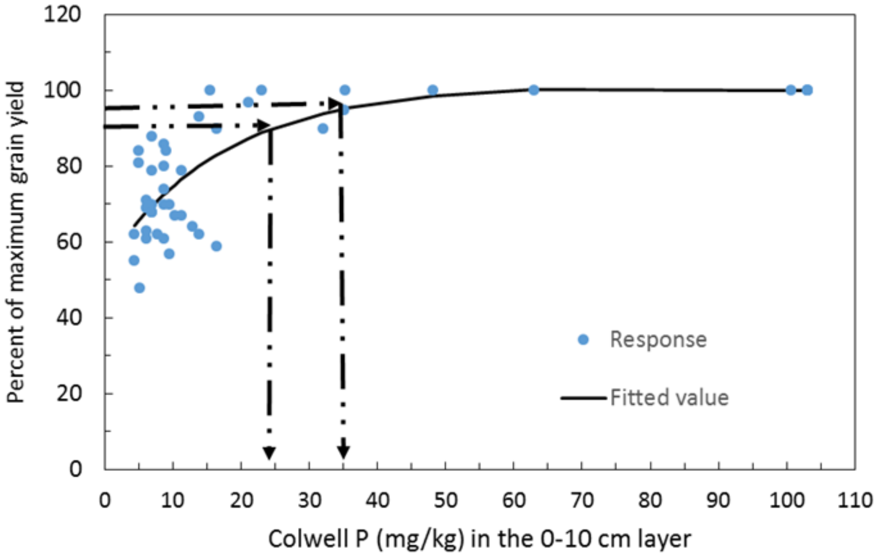

Figure 6. Grain yield response of wheat on Vertosol soils of NSW. The y axis is percent of maximum grain yield achieved and the x axis is the soil Colwell P test value. Data taken from the BFDC

Table 2. 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. 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

Species	**Soil**	**90%**	**95%**	**Location**
Feed barley	All soils	20	25	National
Field pea	All soils	27	34	National
Narrow leaf lupin	All soils	22	26	National
Canola	All soils	20	25	National
Wheat	All soils	24	32	National
Wheat	Chromosol red	30	38	NSW, Qld, Vic
Wheat	Chromosol brown	17	19	WA, SA
Wheat	Chromosol grey	18	21	WA
Wheat	Calcarosol calcic	24	29	SA, Vic, WA
Wheat	Dermosol	27	35	NSW
Wheat	Kandosol red	24	30	NSW
Wheat	Tenosol	16	20	WA, SA, Tas
Wheat	Sodosol brown	27	32	NSW, Vic, SA
Wheat	Vertosol black	25	33	NSW, Qld
Wheat	Vertosol brown	24	32	NSW, SA
Wheat	Vertosol grey	18	21	Vic, NSW, Qld

The sampling depth of P has a significant effect on its critical value. For example, data from the BFDC on the national wheat data set showed that across soil types for sampling at 0-5cm, 0–10cm and 0–15cm Colwell P critical values varies from 31 and 36, 24 and 32 and 15 and 20mg/kg for 90% and 95% of maximum grain yield respectively. The differences in critical Colwell P at different sampling depths may be due to (i) differing soil P status at deeper un-sampled depths, (ii) dilution effects with greater soil sampling depth and P stratification and (iii) the ability of different crop types to recover of P from different depths of soil. Industry standard practice is to sample 0–10cm however knowing P concentrations in the 10–30cm layer can be very informative in P budgeting, potentially allowing for a lower wheat critical value in the surface layers.

P budgeting after drought and P off-take in grain

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.

Table 3. Concentrations 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

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).

This 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).

This provides an estimated 6.1–10.2kg P required /t 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. These budgets are of course very approximate and they must be assessed and adjusted by tracking soil P values to determine if soil test values are increasing (overestimate of P budget), decreasing (under estimate of P budget) 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.

Starter P, often applied as MAP at sowing, is very important for; (i) early root development which assists the plant in exploring the greater soil P reserve, (ii) early tillering and (iii) 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 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 5kg P/ha. As an example if our wheat target yield for 2020 is estimated at 3 t/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 we assume a medium value of 62kg /ha MAP (13.5kg P/ha) as our standard P budget we would reduce this by two thirds down to 18.6kg /ha of MAP or 4.1kg P/ha. This however does not meet the minimum amount rule of 5 P kg/ha so the actual rate of P applied in this case would be 5 kg P/ha (23 kg MAP/ha). At this 23 kg/ha MAP granules are placed in-row at ~3.0-3.5cm spacings when using 25 cm tyne spacing. Wheat sowing rates (50-65 kg/ha) are likely to place seed at every ~2-3cm in-row while the full MAP rate of 62 kg/ha provides an in-row granule spacing of ~1.0cm.

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) is not readily dissolve at high pH and serves as a P sink for surface adsorbed calcium phosphate precipitation. In 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 condition 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 highly concentrated P bands with minimal soil mixing.

P budgeting and off-take in hay

P off-take in hay per hectare is higher than for grain production. Previously we estimated a 1 t/ha wheat crop would remove 2.7-3.6kg P/ha in grain while the hay crop is estimated to remove 1.0-2.0kg P/ha/t. The same comparisons for canola indicate a 1 t/ha grain crop exports 4.0-6.5kg P/ha in seed while the hay exports an estimated 3.0-4.0 kg P/ha/t. In some circumstance where significant hay yields are achieved (e.g. 6 t/ha) large amounts of P are removed (e.g. 6 to 12 kg P/ha for a 6 t/ha hay yield in wheat). Large variations in P off-take in hay are also likely due to hay quality and quantity as well as the proportion of unbaled straw and leaf remaining in the paddock. Note the unbaled leaf component for canola can be significant and rain on cut hay can leach plant available P into the soil. Phosphorus savings in 2020 after hay cut in 2019 are unlikely because of the higher P off-take and soil Colwell P values will have declined more significantly than grain paddocks.

Phosphorus stratification

There are several reasons why P is often highly stratified near the soil surface, including;

- (i) in their native state, most 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.

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 ~55mg P/kg soil in the 0–2.5cm section and increases to ~62 in the 2.5–5cm section as sampling takes in the fertiliser drilled at sowing. At 5–10cm the Colwell P value drops to ~24 and declines further to ~10mg P/kg in the 10–15cm layer. The sampling ‘near row’ has no fertiliser spike in the 2.5–5cm section (e.g. ~37 ‘near row’ compared to ~62 ‘plant row’ in the 2.5–5cm section). The ‘middle row’ (inter-row) section shows very high Colwell P at the soil surface (~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).

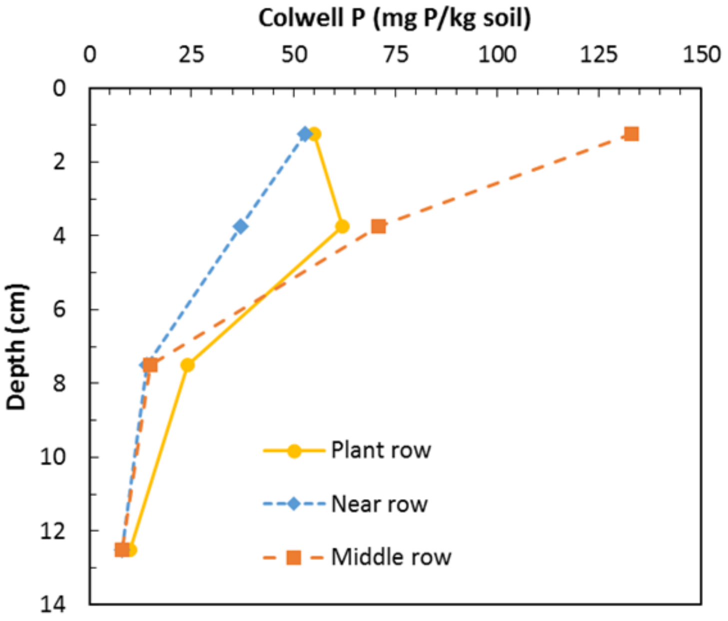

Figure 7. Vertical and horizontal stratification of P measured as Colwell P at the long term Hart experiment. Samples taken in 2017 (Armstrong et al. 2017)

The calculated Colwell P 0 - 10cm from figure 7 for the plant row is ~40.5mg/kg. Where P is high stratified in the soil surface combined with low soil moisture, the question arises how much of this surface P (0-5cm) does the plant root access given a 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. In this case, the estimated Colwell P 0–10cm is 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 of 30 mg/kg instead of 40.5 mg/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 ~20mg P/kg soil. In this contrived scenario, crop yield may be limited by P. While the above scenario's are simplistic (e.g. zero P access in the 0–2.5cm section) and the more likely outcome is low efficiency of P access in the 0–2.5cm, the point is clear that highly P stratified soils have the potential to limit yield particularly where P is highly 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.

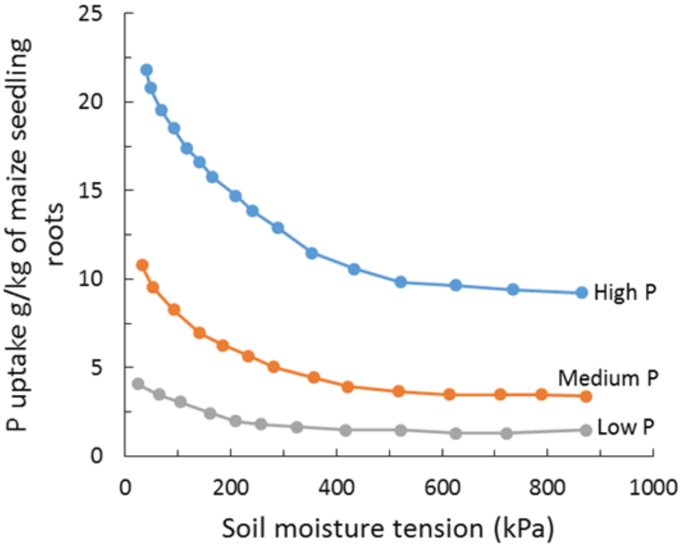

Figure 8. Phosphorus uptake in roots of maize to different soil moisture and soil phosphorus levels (Olsen et al. 1961)

Phosphorus placement at sowing

Compared with broadcasting or banding fertiliser P with seed, the placement of phosphorus 2–6cm below seed has shown significant yield increases in 14 scientific studies (wheat: Alston 1976; 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 2001; Crabtree 1999; Scott et al 2003) and no significant increase in 5 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 values.

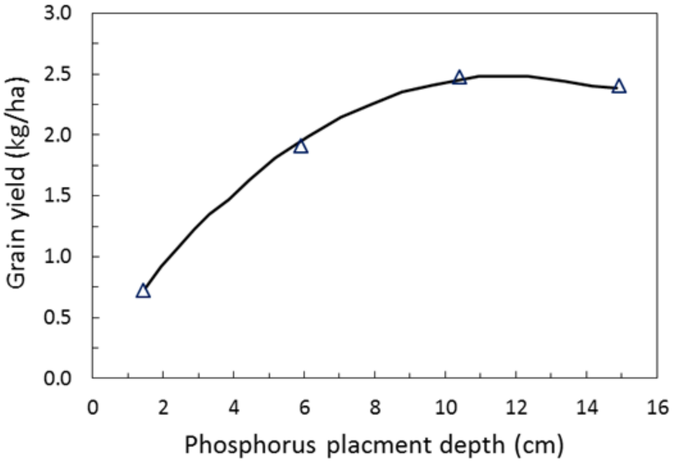

Figure 9. Effect of different depths of P placement at sowing on winter wheat yield in Nebraska (McConnell et al. 1986)

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

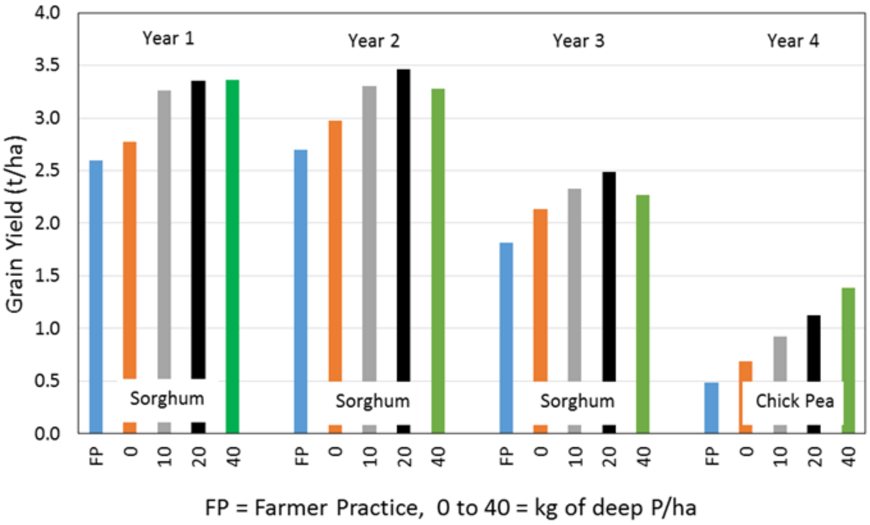

Figure 10. Deep P drill in year 1 (2013) at a depth of 20cm and row spacing of 50cm and the subsequent grain yield response over 4 consecutive years at Dysart QLD for sorghum and chickpea. No additional deep P was applied in subsequent years and annual P at sowing was 6kg/ha (Bell et al. 2016)

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* 2016) shows results from Dysart in Queensland where the deep P was drilled in 2013. The zero deep P rate represents deep drilling at 20cm with no deep P applied, while the farmer practise represents no deep drilling and no deep P. Therefore, the difference between these results is a tillage effect. The percent increase from the zero deep P rate to the best deep P response in each consecutive year was 17%, 11%, 7% and 59%. In year 2 (11% increase) and 3 (7% increase) nitrogen limited maximum yield production (Figure 10). Consequently, the P responses for years 2 and 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.

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 = 30 mm, in season rainfall = 230mm, plant available soil water = 260 mm, soil evaporation = 110 mm, water use efficiency of grain production = 20 kg grain production per mm of crop transpired water, grain yield therefore = 3 t/ha, P budget ~13.5 kg P/ha is the long term average or 62 kg /ha MAP). The second component of the budgeting exercise requires the same approach above 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 export and losses are estimated at 8.25kg P/ha (e.g. half the long term average). The final step is to average the two estimates for the coming seasons crop and in this example that is estimated at ~11kg P/ha (50 kg MAP/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 export plus losses, which is also 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

Maintaining soil phosphorus levels at or slightly above the critical range is important to maintaining crop yield potential and maximising water use efficiency.

Phosphorus budgets can be estimated from grain exports and other losses (e.g. soil and stubble) however the final amount of P to be added should be informed by accurate soil testing.

Very low or very high pH, high PBI and/or high surface P stratification (0-5cm) can reduce the availability of soil P to crops.

Fertiliser savings after drought are possible with P. This is because the extensive history of P application in southern cropping systems of NSW combined with low soil PBI's to ensure 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%).

Starter P should always be added to grain crops at sowing, as research has identified that this approach consistently increases crop yield.

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Acknowledgments

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 author would like to thank them for their continued support. This research was undertaken as part of project UQ82.

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What N is in profile - 3 dry years with minimal mineralisation. What are the results showing? Also, insights from a long-term nutrition site running since 2007 in CNSW

Jim Laycock, Incitec Pivot Fertilisers

Key words

nitrogen, mineralisation, grain nitrogen yield, urea

Take home messages

- Segment deep N’s in 2020 at 0-30, 30-60cm depths to see where the nitrogen is in the profile
- Don’t plant wheat on wheat chasing 2018/19 fertiliser due to potential crown rot infection
- Sustainable continuous cropping systems should include a pulse crop at least twice in a 9-year rotation.

Incitec Pivot Fertiliser’s long term nitrogen by phosphorus trial was established to describe the cumulative effect of 5 different rates of nitrogen fertiliser and 5 different rates of phosphorus fertiliser on grain yield and protein % in a controlled traffic cropping rotation.

This site was commenced in 2007 with soil N to 0-60cm of 160 kg/N/ha sampled pre plant in 2007 (field peas 2006) and a site Colwell phosphorus of 26 mg/kg. There are 25 fertiliser treatments replicated 4 times and the crop rotation is sown over the same plots annually.

One issue seen in 2019 as a result of accurately sowing row-on-row with sub 2cm Real-Time Kinematic (RTK) auto steer, was high levels of crown rot as a result of sowing on exactly the same plant line as last year’s Gregory wheat. One of the strategies to reduce the impact of carry over crown rot infection is avoiding contact with last season’s wheat stubble. When sowing row-on-row, contact with last season’s stubble was maximised and crown rot infection levels were high, and screenings were >15%.

Rotation

2007 – Wheat

2008 – Wheat

2009 – Wheat

2010 – Albus Lupins

2011 – Wheat

2012 – Canola

2013 – Wheat

2014 – Canola – resown

2015 – Wheat

2016 – Wheat

2017 – Canola

2018 – Wheat

2019 – Wheat

Seeding and harvest

A small plot cone seeder with 17.5cm row spacing was used in 2007 – 2009 and 25cm row spacing from 2010. From 2010 sowing, trial site management, harvest, data analysis and trial reports were conducted by Kalyx. From 2015 Kaylx plot seeder used sub 2cm RTK, 6 rows at 23cm row spacing, 1.38m wide plots and 10m plot lengths. Harvest grain yield per hectare was calculated on 2m plot centres.

In 2015 the original 20m long plots were cut in half. From 2015, the 2007 'A trial' N and P rates were retained on the western half and the 2015 'B trial' N and P rates were applied on the eastern half of the original plots. See table 1. The 'A trial' treatments continue to build soil P and N while 'B trial' treatments now run down and also build P and N.

Table 1. Treatment list

2007 – 2019 'A trial' P&N kgs/ha treatments	**2015 – 2019 'B trial' P&N kgs/ha treatments**
40P 0N	0P 0N
40P 120N	0P 30N
40P 90N	0P 60N
40P 60N	0P 90N
40P 30N	0P 120N
30P 0N	10P 0N
30P 120N	10P 30N
30P 90N	10P 60N
30P 60N	10P 90N
30P 30N	10P 120N
20P 0N	20P 0N
20P 120N	20P 30N
20P 90N	20P 60N
20P 60N	20P 90N
20P 30N	20P 120N
10P 0N	30P 0N
10P 120N	30P 30N
10P 90N	30P 60N
10P 60N	30P 90N
10P 30N	30P 120N
0P 0N	40P 0N
0P 120N	40P 30N
0P 90N	40P 60N
0P 60N	40P 90N
0P 30N	40P 120N

Nutrient placement

Triple Super (20% P) was banded with the seed, 50% of the urea (46% N) rate applied at planting banded below and to the side of the seed up until 2014. From 2015 urea is now placed 5cm directly below the seed with the Kaylx plot seeder.

The balance of urea is applied as urea broadcast in wheat at GS31 and at the pre rosette stage in canola. Urea was not applied in 2010 (Albus lupins) and urea was not top-dressed in 2007, 2014 (low yield potential due to replant) and 2018 (dry conditions).

Sulphur has been applied 4 times during the life of the trial as broadcast gypsum (2), banded potassium sulphate (1) and broadcast Gran-Am® (2017). A total of 5kgs/ha of zinc and 2kgs of boron have also been applied.

Urea nitrogen balance at the Grenfell long term NxP trial site

In the absence of deep N testing results for the 2020 season due to the difficulties coring dry soil profiles the annual application of urea nitrogen (kgs/N/ha) and the annual export of grain nitrogen as kgs/N/ha over the current life of the trial from selected treatments is presented in table 2. The method used to balance nitrogen at this site does not consider gains from mineralisation, losses from denitrification, leaching or volatilisation.

Nitrogen mineralised from the soil organic matter and crop residues makes a substantial contribution (~50%) to crop N uptake (Angus and Grace, 2017; Gupta, 2016).

The supply of N from mineralisation is driven by soil moisture, soil temperature and soil organic matter levels. Soil pH also has an effect with slower mineralisation rates on acid soils. Mineralised nitrogen is available throughout the year. Generally, there is more N mineralised and available in autumn and spring and lower availability in winter when soils are at lower temperatures. Whenever there is a rainfall event and surface soil is moist, there is potential for a mineralisation event to occur. Although rainfall events have been few and far between in the past three seasons some nitrogen would still have come into the system.

Potential loss of soil nitrogen through denitrification has been minimal as a result of low rainfall and no waterlogging events. The last potential denitrification events at the Grenfell trial site occurred in 2010 and 2016 (see rainfall figure 1). Nitrate leaching isn't a significant pathway for loss on these soils. (Smith, 2000).

Although volatilisation losses are low on these acid soils during winter, the top dress urea is managed to avoid any loss by topdressing in front of a rainfall event.

Immobilisation of N may occur when plant residues of low N content are decomposing in the soil. Immobilisation represents a temporary unavailability of mineral N in the soil for growing plants to access. Immobilisation was first seen on site in 2015 when wheat on low nitrogen treatments exhibited nitrogen deficiency symptoms where canola residue lay on the soil surface. The residue was concentrated as a chaff pile where the small plot harvester had stopped at the end of each plot.

Grenfell long term NxP trial results

Trial treatments include four rates of nitrogen to supply a total of 30, 60, 90, or 120 kg of nitrogen per hectare annually (unless otherwise indicated). Displayed in figure 2 and table 2 is the total nitrogen supplied as urea for treatments 20P 60N and 20P 120N from the first planting in 2007 and the grain nitrogen removal

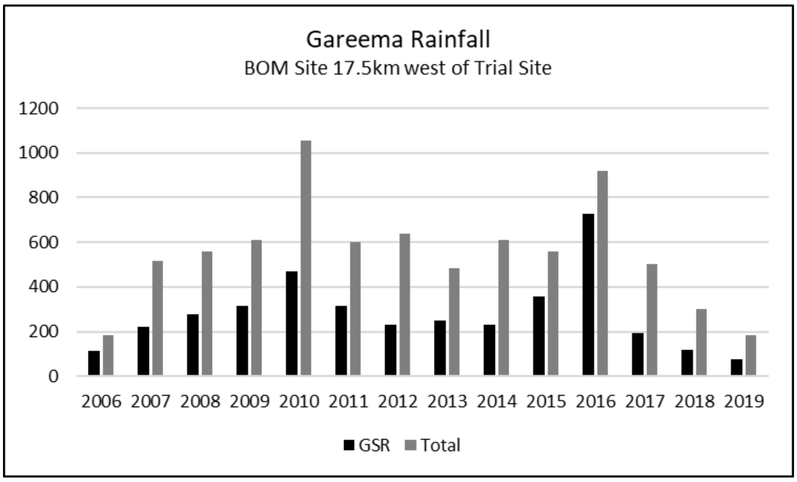

Figure 1. Gareema rainfall 2006 – 2019

Over the 13 years of the trial with treatment 20P 60N there has been 944 kg/grain yield/N removed and 630 kg/urea/N applied for a negative nitrogen balance of -314 kg/N (see table 2 and figure 2).

The 20P 120N treatment has seen 998 kg/grain yield/N removed and 1260 kg/urea/N applied for a positive nitrogen balance of +262 kg/N.

Table 2. A trial grain nitrogen N/kg/ha removal and nitrogen kg/ha applied 2007-2019

Applied N/kgs/ha	07	08	09	10°	11	12	13	14	15	16°	17	18	19	Total N/kgs/ha Removal
20P60N (630N	5*	80	70	247#	73	100	84	25*	110	77	41	26*	6	944N (-314N)
20P120N (1260N)	6*	70	72	234#	74	100	91	25*	138	115	40	26*	7	998N (+262N)
40P120N (1260N)	6	94	80	255	88	90	91	27	122	111	52	25	9	1047N (+213N)
20P (0N)	4	65	69	238	75	95	68	20	62	52	33	19	7	-807N
0P0N	3	65	51	240	40	66	48	5	37	49	12	20	9	-645N

* No top dressed urea

Albus lupins no urea applied, N removal grain % x grain yield

° Significant waterlogging event (see figure 1)

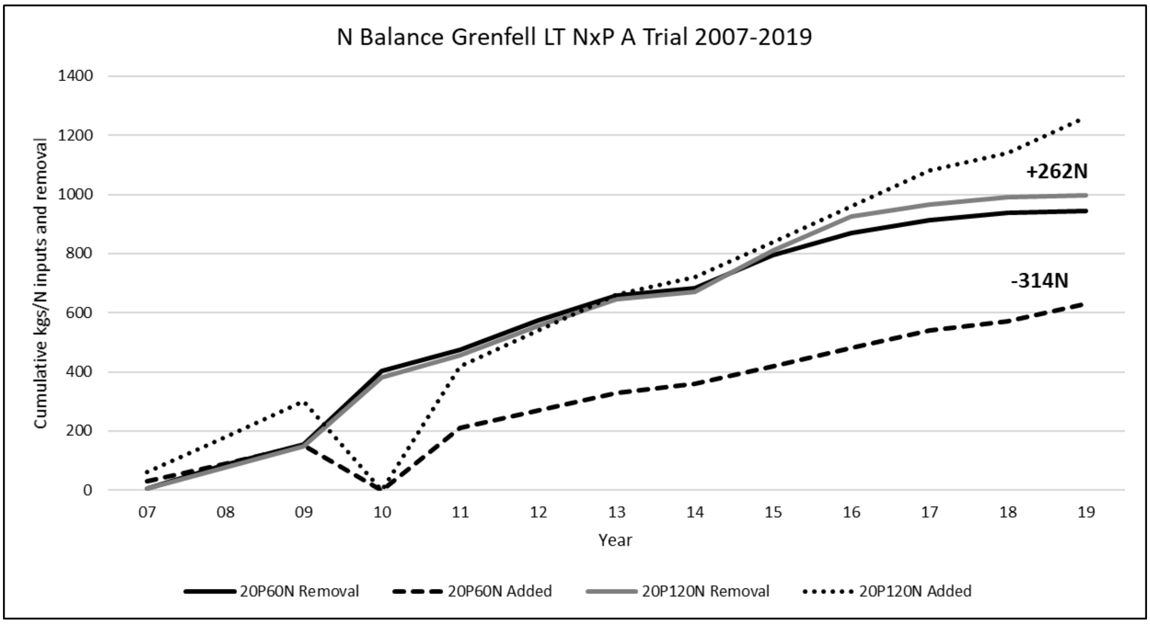

Figure 2. N balance at Grenfell trial 2007 – 2019

The grain yield nitrogen removal for the 20P0N treatment over the current life of the trial has a negative balance of -807 kg/N. Up until 2013 starting profile nitrogen from the field pea crop in 2007 and the albus lupin crop in 2010 have supplied sufficient nitrogen to achieve comparable grain nitrogen yield to the 20P60N and 20P120N treatments.

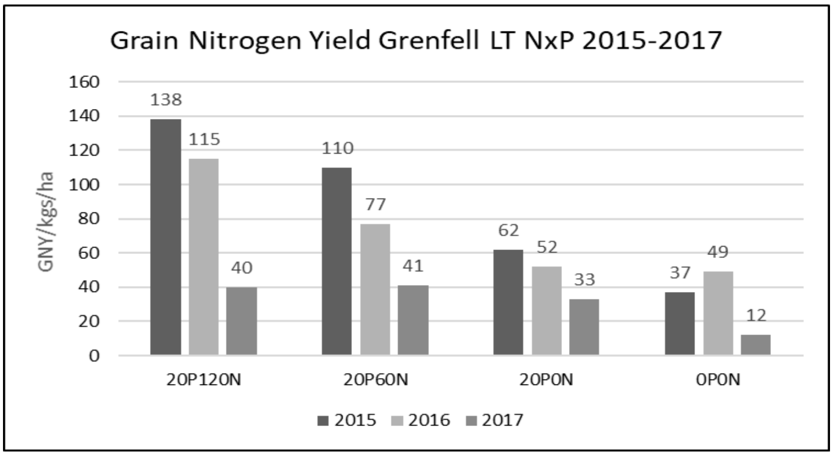

Figure 3. Grain nitrogen yield at Grenfell 2015-2017

The total soil nitrogen pool is being drawn down to an unsustainable level in the 20P60N treatment by removing more N than what is coming into the system (See Figure 4) through mineralisation. In a 500 mm average annual rainfall zone 2-3% of soil total N is mineralised during an average year in southern Australia. This represents 28-42 kg N/ha from a topsoil containing 1% OC (Angus 2016).

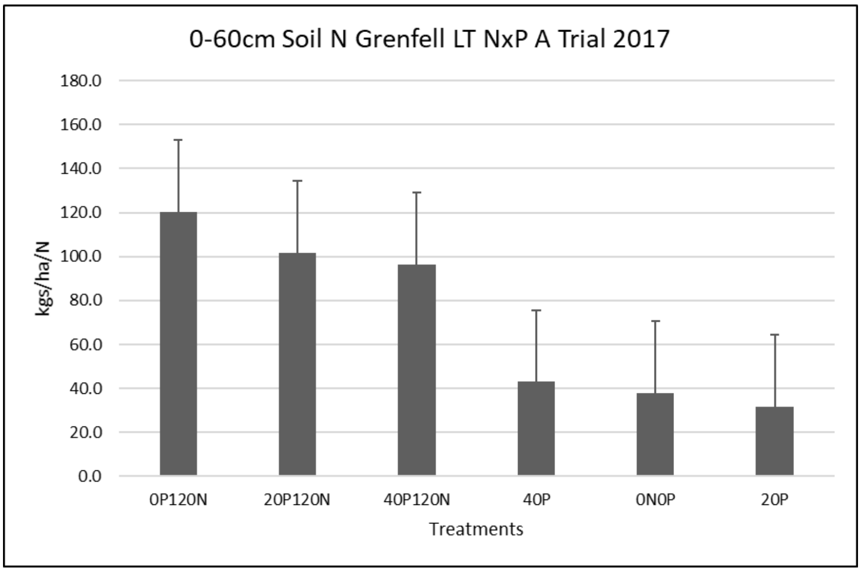

Figure 4. 0-60cm soil N at Grenfell long term NxP A trial 2017

As soil organic carbon levels continue to decline at this site (see Figure 5) and if a pulse crop isn't included in the rotation, total soil nitrogen is likely to decline further.

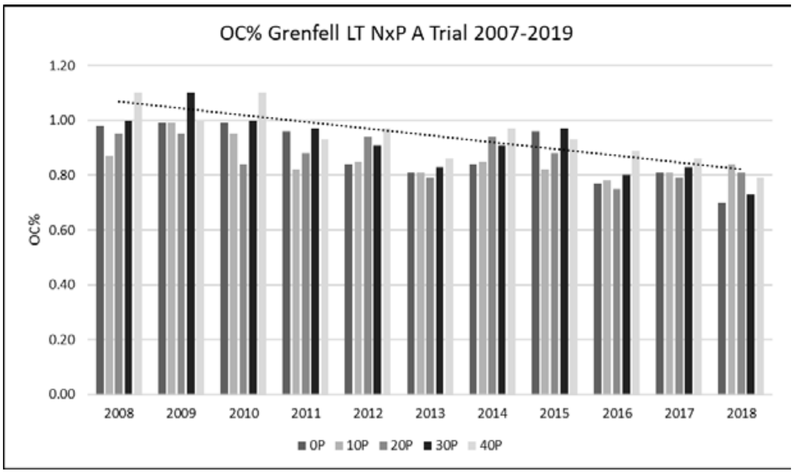

Figure 5. Organic carbon % at Grenfell long term NxP A trial 2007-2019

After 14 years of continuous cropping in an experiment at Harden, NSW, the daily rate of mineralisation, as a percentage of the total nitrogen present, was 30% less than the rate measured after 3-6 years of cropping. This decrease was in addition to the decrease present due to a fall in total organic matter and suggests the quality of organic matter has also decreased. (Angus 2006)

The N balance (Figure 2) also shows the effect of the ongoing drought with the grain yield nitrogen removal declining and continued application of urea nitrogen increasing the cumulative urea nitrogen.

When conditions allow, segmented deep nitrogen sampling will identify where that nitrogen is lying in the soil profile.

Additional research at the Grenfell site, completed, ongoing and proposed includes inquiry on the following issues: 10-30cm BSES P/Colwell P/PBI, 0-10cm DGT P/Colwell P, Mehlich-3, sulphur deficiency in canola, random sampling vs "kitchen method", pH of fertiliser band and surrounding soil, sub-soil acidity, soil boron, diffusion of phosphorus in fertiliser bands, crop response to residual phosphorus, crop response to residual urea nitrogen, urea use efficiency.

Acknowledgements

Thanks to trial site co-operators, Duncan Lander 2007-2015, David Partridge 2016-2019 and Kaylx for managing the site.

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Lasers, machine learning, weed recognition and new innovations in weed management

Guy Coleman, Caleb Squires and Michael Walsh (University of Sydney)

Key words

machine learning, laser weeding, weed control, site-specific weed management

GRDC code

US00084

Take home messages

- Advancements in machine learning, particularly deep learning, are creating opportunities to use non-selective alternative weed control options
- Following a comparison of energy requirements lasers were identified as the most suitable alternative option for further research and development.

Site-specific weed control

The widespread development of herbicide resistance across the northern region and around Australia is driving the need to develop alternative weed management options. The selectivity of several alternatives is linked with their method of application.

Some non-selective alternatives, such as flame weeders may be used inter-row, while commercial broadacre electrical weeders use height to differentiate weeds from crop. Outside of these commercially available implements, most alternatives to herbicides are often more costly, not yet commercialised, lacking research or not sufficiently effective for broadacre cropping.

Machine learning-based weed identification can provide the detection and identification of weeds in the crop using algorithms based on convolutional neural network (CNN) architectures. These can provide the opportunity to use non-selective physical and thermal weed control options for the control of in-crop weeds. Since the demonstration of CNNs as highly accurate for image classification tasks in Krizhevsky et al. (2012), there has been significant advancements such that CNNs may now be used to accurately recognise individual plants, and potentially even the growing points of in-crop weeds. Machine learning-based weed identification enables selectivity on the delivery side of the control. This greatly increases the opportunity to develop previously unviable alternative control options as effective broadacre techniques.

While the opportunities clearly exist, the development of algorithms with consistently high accuracy and precision for use across the grain production region in Australia remains an issue. Recently, companies such as Bilberry (partnering with AgriFac) and now Autoweed are delivering some of the first commercially available camera and CNN-driven site-specific weed control sprayers. Simpler yet highly effective optical-driven camera sprayers such as Weedit® and WeedSeeker® have been in widespread commercial use for the selective control of weeds in fallow throughout the grain growing areas of northern NSW and Qld for many years. Detection-based delivery of herbicide coupled with the ability to differentiate weeds from crop is an important advancement and potentially a weed control game changer when perfected. However, at this stage the level of precision is lower than that needed for delivery of highly targeted alternative control methods.

Four different levels of weed detection (and identification) are currently achievable with state-of-the-art algorithms (Figure 1). The lowest granularity is image classification, which takes an image and provides a probability that the object (and others) exists in that image.

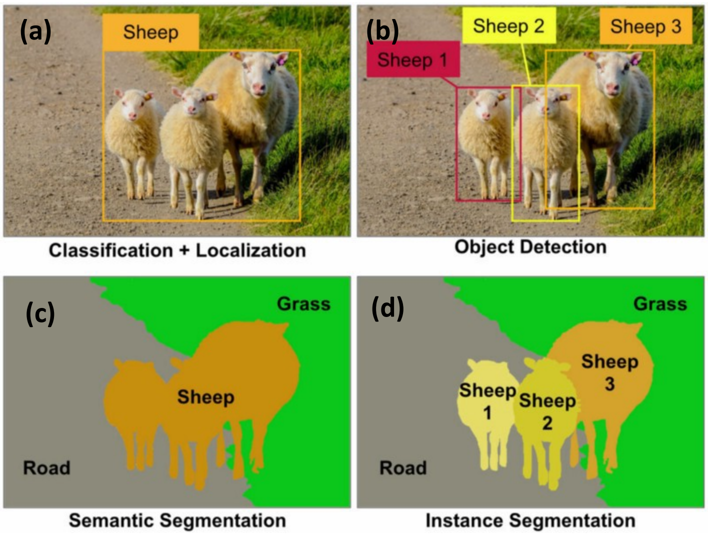

Figure 1. The four levels of object detection, localisation and discrimination from other objects of the same class. Each requires different algorithms and computational performance (Parmar, 2018)

The next level of discrimination is object detection. Object detection algorithms provide information on the number and general location of an object in the image (Figure 1b). Segmentation is the most granular, where every pixel in an image receives a classification (Figure 1c and 1d). Segmentation algorithms provide the level of detection required for delivery of highly targeted alternative control options to individual plants and plant parts, precision beyond the capabilities of current see and spray technology. At the object detection level, the Weed Research Team at the University of Sydney recently demonstrated the capabilities of existing object detection architectures (Figure 2) in differentiating annual ryegrass and wheat. While the demonstration used controlled growing environments and data for algorithm training, a key finding was that a lack of labelled data to train existing algorithms is the main barrier in developing detection algorithms of all four levels.

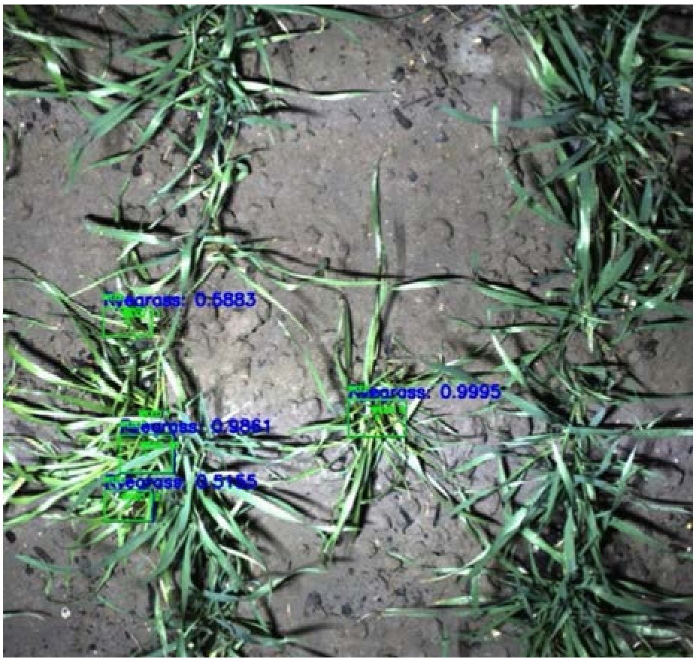

Figure 2. Initial testing of ryegrass detection in wheat has shown that existing machine learning architectures including You Only Look Once (YOLO) and Single Shot Detectors (SSD) are capable of differentiating ryegrass in wheat under controlled circumstances. This demonstration suggested lack of labelled data is the main barrier to development instead of technological advancement

Moving from broadcast to site-specific application shifts the input and cost function of weed control from area-driven to a function of weed density, where the treatment is applied only where it is needed. Importantly, move to site-specificity creates a significant opportunity for cost and input savings, with potential for additional benefits in reduced off target and environmental impacts. It also opens up the possibility of alternative options such as lasers, electrocution and microwaves for practical use in broadacre crop systems.

Based on research comparing the energy consumption of alternative control methods by Coleman et al. (2019), lasers were identified as a potentially viable alternative weed control method. With relatively low power consumption, small size and ease of control, lasers (specifically diode and fibre) were seen as a potentially viable option for weed control. While the method of laser beam generation may differ (be it diode, fibre or CO_2 as a few examples), the fundamental control method is through the highly targeted and concentrated delivery of energy in the laser beam. Similar to other thermal methods, this energy heats plant cells to the point of rupture and death, however, rather than moving an implement, tine, microwave, flame or electrode to the weed, lenses and optics are used to direct and focus the beam from a distance. The energy is also highly targeted, with minimal loss in the process of delivery. The beam width, and hence the density of energy in the beam, can also be varied to treat a larger area. These practicalities of lasers, in comparison with the other control options available, made them a good choice for preliminary assessments.

Aims

With research and development occurring in the weed detection and identification space, there is a requirement for the identification and evaluation of alternative weed control options to couple with new detection technology. The aims of this research are two-fold:

1. Evaluate the efficacy of lasers for the control of winter and summer weeds
2. Identify laser parameters (type, setup and use) required to deliver effective weed control.

Laser weeding

During the 2019 winter season, pot trials on the efficacy of a 25 W, 1064 nm continuous wave diode laser were conducted on representative broadleaf and grass weeds relevant to the northern region, namely turnip weed (*Rapistrum rugosum*) and annual ryegrass (*Lolium rigidum*). The trials evaluated the effect of laser treatment duration, laser beam width (spot size), weed species and weed growth stage on weed control efficacy.

Treatment duration

Using a 5 mm diameter spot size, 60 second treatment times provided 100% control of two and six leaf ryegrass and turnip weed plants (Figure 3). In the two-leaf plants, the 2 second treatment provided control of the turnip weed, but did not control the ryegrass. These results suggest the subsoil growing point of many grass species may protect the plant from lower energy laser treatments. While the treatment time is long for a 25 W laser at 5 mm spot size (1.3 $J/s\ mm^2$), increasing the laser power increases the rate of energy delivery, reducing the treatment time required to deliver an equivalent dose. Where control was not provided, significant reductions were seen in weed biomass in mid-tillering ryegrass.

Laser beam width

While duration of laser treatment changes the total amount of energy delivered, adjusting beam width impacts on the intensity of energy applied to the plant. The intensity of the beam, which is determined by power per unit area or energy density, changes the properties from heating (low intensity) to cutting (high intensity). The 25 W laser was tested with 2, 5 and 10 mm spot widths, providing 8.0, 1.3 and 0.3 J/s mm^2 energy intensities. Larger spot sizes reduce the precision required for the targeting and detection system, however, the less intense energy means the treatment duration must be longer or the plant may not heat enough for cell death.

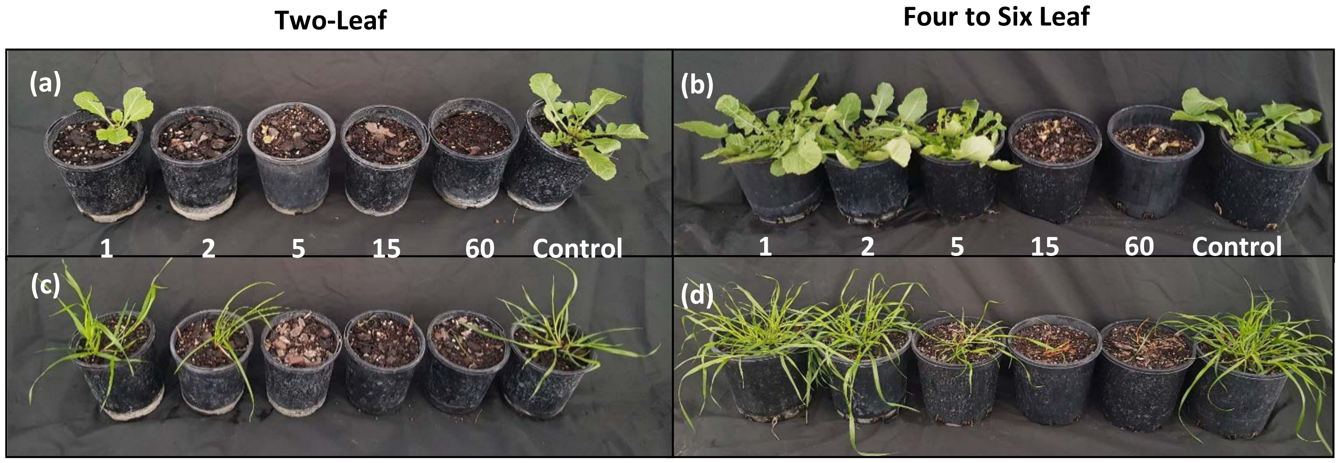

Figure 3. The impact of laser treatment duration at three weeks post treatment from left to right 1, 2, 5, 15, 60 second exposure and control (0) for turnip weed when treated at the two leaf (a) and four to six leaf (b) stage and ryegrass at the two leaf (c) and four to six leaf stages (d). Biomass was assessed three weeks post treatment

At the two-leaf stage, there was a high level of control across all spot sizes for both turnip weed and ryegrass. At the four to six-leaf stage (Figure 4), the biomass reduction of turnip weed increased with increasing energy density (smaller beam width or higher intensity). Ryegrass was not significantly impacted. Using equivalent energy densities, it is estimated a laser of at least 400 W would be required to control four to six leaf stage weeds (including annual ryegrass) under 1 second treatment at a 5 mm beam width.

Future research on lasers will continue to evaluate the temperature thresholds required for control the growing point. A larger laser is expected to be used to assess the impact of the rate of energy delivery on control efficacy. Summer weeds will be tested in March 2020.

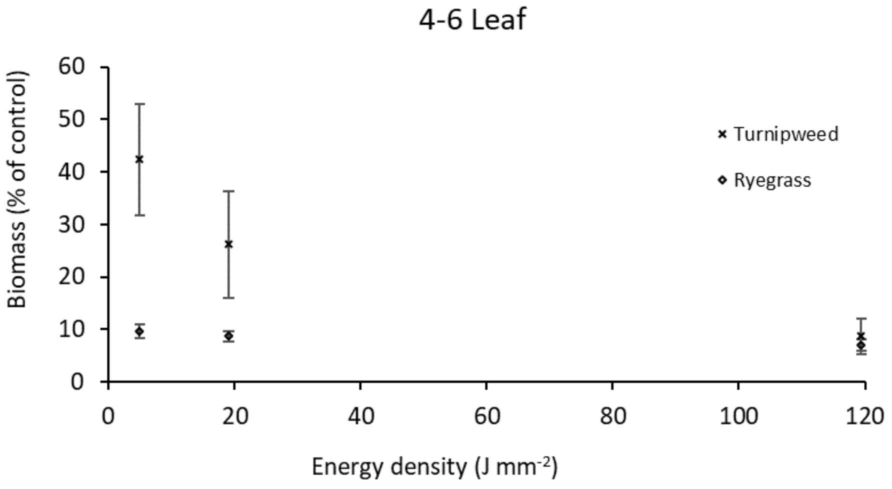

Figure 4. Comparing the impact of energy density (spot size) on plant growth behaviour as a percentage of the biomass of the control. Weeds were treated for 15 seconds using the 25W, 1064 nm diode laser

Conclusion

Weed recognition through machine learning has the potential to enable alternative physical and thermal weed management options not previously considered relevant in broadacre agriculture. When applied on a site-specific basis, the energy costs of thermal control technologies such as lasers and electrocution are significantly reduced. Furthermore, lasers are showing promise as a highly targeted method for control of up to eight-leaf growth stage weeds. Yet even with such opportunity, the delivery of these technologies relies on highly accurate, precise and repeatable weed detection. Training state-of-the-art machine learning algorithms requires significant quantities of labelled image data obtained in diverse field conditions. Thus, a high-quality database of labelled images which reflects the diversity in Australian weeds, crops, and conditions is a pre-requisite and limiting factor for development of accurate weed recognition algorithms.

Concurrent with the development of detection capability, investigation of alternative weed control methods should be completed to determine relevancy and other optimal parameters for use. Initial research has shown that the potential for lasers is high due to the ability to flexibly deliver highly targeted energy, with positive results in both ryegrass and turnip weed.

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 author would like to thank them for their continued support.

The authors would like to thank the project collaborators at the Australian Centre for Field Robotics (ACFR) and the Sydney Astrophotonics and Instrumentation Library (SAIL) who supported the laser weeding trials.

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Summer cover crops in short fallow - do they have a place in central NSW?

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Key words

cover crop, stubble cover, ground cover, short fallow

GRDC code

DAQ00211

Take home messages

- Summer cover crops reduced the winter cash crop (wheat) grain yield by up to 1.5 t/ha at Canowindra and 0.6 t/ha at Parkes
- Grain yield losses were minimised by spraying out the cover crop early
- The grazing value ($/ha) generated from the cover crop more than compensated for the grain yield reduction based on current commodity prices
- Pros of summer cover crops include increased ground cover, reduced soil erosion from wind and water, cooler and more consistent soil temperatures, improved autumn sowing conditions, valuable summer forage for mixed farming operations, quicker soil water recharge compared with bare ground, reduced herbicide applications over the summer fallow, and improved total soil carbon % and assumed microbial activity
- Cons of summer cover crops include reduced mineral nitrogen and reduced grain yield for the following winter cash crop, increased risk of soil water deficit in low rainfall years (or greater reliance on in-crop rainfall), additional seed costs, patchy establishment of summer cover crop due to rapidly drying soils, high herbicide rate required to terminate cover crop, and increased disease risk (stubble and soil) due to green bridge for the following winter cash crop
- Risks associated with cover crops are reduced by: longer fallow period post cover crop for soil moisture recharge and mineralisation of cover residue; incorporating livestock within the system to convert surplus biomass to $/ha; seasons with high rainfall; additional nitrogen fertiliser application for winter cash crop
- The optimum ‘crop type selection’ and ‘spray out timing’ will vary depending on individual paddock and enterprise goals.

Background

Dust storms have been a common sight in central NSW in the summer of 2019/2020 due to the combination of drought and low ground cover. Ground cover levels have been on a decline since 2017 with residual stubble decomposing over this time, and limited opportunity to grow fresh biomass over the past 2-3 years. Factors further reducing ground cover levels include growing low biomass pulse crops (e.g. chickpeas), incorporation of lime, grazing stubbles and baling of failed winter crops. Both the magnitude and duration of the current dry period has been unparalleled and is highlighting the value of ground cover.

The benefits of cover crops to protect the soil from wind or water erosion in low stubble scenarios is well understood, however the use of cover crops as a technique to improve water infiltration and storage to improve grain yield for the following winter cash crop is less clear. Recent GRDC funded research (McMaster 2015) has demonstrated that 50% of yield potential can be attributed to summer rainfall and summer fallow management as a result of increased stored water and nitrogen

(N). Water and nitrogen increase grain yield through grain number (more tillers and more grains per head) and grain size, with a return on investment of controlling summer weeds between $2.20 and $7.20 ha for every dollar invested.

The primary purpose of these experiments was to evaluate if there is a net water gain to the subsequent winter cash crop (wheat) following a summer cover crop, and the associated result on grain yield. The secondary purpose of this project was to evaluate the impact of various spray-out timings (early, mid and late) and crop-types (including single species, mixed species and summer weeds) on the farming system, including grazing value of cover ($), crop nutrition (mineral N and total carbon %), disease pressure (stubble and soil), and soil temperature.

Method

Two sites with zero ground cover were selected in central NSW at Canowindra (high rainfall zone – central east (CE) slopes) and Parkes (medium rainfall zone – central west (CW) plains). Each site consisted of a short and long fallow treatment and the experiment design was a randomised block with 4 replications. Individual plot size was 10m X 10m across all experiments. The following report provides results from the short fallow experiments only, and includes treatment combinations of four cover crops, three spray-out timings and one control (bare ground, weed-free). The summer cover crops were sown using a knife point press wheel plot seeder at 30cm row spacing and the subsequent winter cash crop was sown with a single disc plot seeder (30cm row spacing) due to trash flow requirements. Fertiliser was applied with the seed, at a rate of 50 kg/ha of mono ammonium phosphate (MAP) with the cover crop and 50 kg/ha MAP with the winter crop. The summer cover crops were sown on 26 November (2018) at Canowindra, and 9 December (2018) at Parkes. The subsequent winter crop (Wheat – cv Mustang) was sown on 18 May at Canowindra, and 25 May at Parkes.

Short fallow trial (6-month fallow – November 2018 to April 2019)

Treatment details:

- Treatment 1: Cover crop types = cow peas, forage sorghum, mixed species and summer weeds
- Treatment 2: Spray out timings = 50, 80 and 110 days after sowing the cover crop (DAS)
- Treatment 3: Control = bare ground kept weed-free.

The mixed species included cow peas, lab/lab, forage sorghum, millet, tillage radish and sunflower.

Results and discussion

Seasonal conditions and crop establishment

Table 1. Monthly rainfall and long-term average (LTA) rainfall for Canowindra and Parkes, 2019

Month	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Canowindra													
Rainfall (mm)	39	34	45	53	1	33	34	13	24	21	20	17	7
LTA (mm)	53	57	50	49	40	44	48	50	48	42	51	49	53
Parkes													
Rainfall (mm)	21	28	23	*32*	0	29	25	13	10	18	27	11	7
LTA (mm)	54	58	50	46	43	44	50	51	50	46	56	51	54

Table 2. Seed rate, seed cost and field establishment of summer cover crops at Canowindra and Parkes, 2019

Treatment		Seed rate	Seed size	Seed cost	Seed cost	Canowindra		Parkes	
		(kg/ha)	Seeds/kg	(per kg)	(per ha)	(Plants m^2)[b]	Est (%)	(Plants m^2)[b]	Est (%)
Forage sorghum		9	32100	\$5.20	\$46.80	26.8	93%	22.8	79%
Cow pea		16	9500	\$3.90	\$62.40	12.5	82%	12.6	83%
Mixed species[a]	forage sorghum	2	32100	\$5.20	\$10.40	4.9	76%	5.2	81%
	millet	5	124000	\$2.50	\$12.50	19.5	31%	11.3	18%
	cow pea	4	9500	\$3.90	\$15.60	2.6	68%	3.5	92%
	lab lab	4	4300	\$4.00	\$16.00	1.5	87%	1.5	87%
	sunflower	1	21052	\$20.00	\$20.00	1.3	62%	0.6	29%
	tillage radish	1	44642	\$9.50	\$9.50	5	112%	3.7	83%

[a] = Total seed cost for the mixed species treatment was \$84/ha
[b] = Actual plants established per m^2

Cover crop biomass

Canowindra site

Biomass production ranged from 0.07 to 10.8 t/ha (Table 3) and was influenced by crop type ($P<0.001$), spray-out timing ($P<0.001$) and the interaction between both ($P<0.001$). Highest biomass produced across the site was 10.8 t/ha of forage sorghum (sprayed out late), compared with the lowest biomass produced by summer weeds (sprayed out early) with 0.07 t/ha.

On average across crop-types, forage sorghum (6.5 t/ha) and mixed species (3.4 t/ha) produced much higher biomass than the cow pea (1.3 t/ha) and summer weed (1 t/ha) treatments. Average biomass production further increased as spray-out timing was delayed from early, mid to late with a respective increase of 1.33 t/ha, 2.99 t/ha and 4.85 t/ha. Nitrogen fertility at this site was high (refer to crop nutrients section) and might explain why biomass production was relatively high at this site. Refer to Table 3 for individual biomass treatment results and Table 5 for feed test results.

Parkes site

Biomass production varied from 0.10 to 2.09 t/ha (Table 4) and was influenced by crop type ($P<0.001$), spray out timing ($P=0.005$) and the interaction between both ($P=0.05$). Biomass results were much less than Canowindra, yet the treatments still ranked similarly with forage sorghum (sprayed out late) producing the highest biomass of 2.09 t/ha, and summer weeds (sprayed out early) the lowest at 0.10 t/ha.

On average, forage sorghum (1.48 t/ha) produced more biomass than mixed species (0.94 t/ha), cow pea (0.36 t/ha) and summer weed (0.09 t/ha) treatments. Biomass increased as spray-out timing was delayed from early (0.33 t/ha) to mid (0.95 t/ha), but there was no further increase from mid to late (0.87 t/ha) spray-out timing. Refer to Table 4 for individual biomass treatment results and Table 6 for feed test results.

Interestingly, the millet seed was much less robust than forage sorghum due to lower plant establishment (Table 2) and crop growth appeared to be visually more affected by the higher temperatures than the forage sorghum. For example, the millet foliage turned limp and floppy whilst the forage sorghum foliage became spikier and more erect (similar to a drought stressed wheat crop). Consequently, millet contributed very little biomass in the mixed species treatment.

Soil temperature at 10cm depth

Canowindra site (11 April at 3pm)

The average soil temperature was 22.2°C and ranged from 18.9°C to 24.3°C. Soil temperature reduced as cover crop biomass increased and was affected by crop type (P<0.001), spray-out timing (P<0.001) and their interaction (P<0.015).

On average, the higher biomass crop types had cooler soil temperatures, with forage sorghum and mixed species being a respective 4.4°C and 3.8°C cooler than the bare ground, cow pea and summer weed treatments. There was no significant difference between the lower biomass crop types of cow peas, summer weeds and bare ground treatments. As spray out timing was delayed, the early and mid-timings were 1.3°C and 2.9°C cooler than the bare ground, respectively. Interestingly, there was no additional cooling effect from the mid and late spray-out timing. Refer to Table 3 for individual treatment results.

Additionally, higher biomass plots were cooler and provided a more consistent soil temperature around the mean when compared to bare ground (data not shown). During the period of 8 March to 20 May, when the bare ground treatment had a range (difference between the daily minimum and maximum temperature) of 10°C or 5°C, the forage sorghum (late spray-out) had a respective range of 6.4°C or 2.5°C.

Cooler soil temperatures would be an indication that evaporation rates were initially reduced under the higher biomass plots. Aside from soil water, higher biomass residues could enable earlier sowing opportunities for winter cereal grazing crops as cooler soil temperatures improve coleoptile length and establishment. Soil temperatures greater than 25°C can reduce crop establishment in winter cereals (Edwards 2006). Conversely, the more consistent soil temperatures of the higher biomass plots could potentially enable summer grain crops such as sorghum to be sown into cooler temperatures than previously practised (Serafin *pers. comm*).

Parkes site (measured 12 April at 3pm)

Parkes was 4.7°C hotter than Canowindra, with an average soil temperature of 26.9°C, ranging from 25.8°C to 27.6°C. Soil temperature was significantly affected by crop type (P=0.013), and the interaction between crop type and spray-out timing (P=0.052). Spray out timing was not significant (P=0.697). Parkes is a hotter region which explains the higher soil temperatures; however, the smaller range of soil temperatures is more of an indication of less biomass produced at this site.

Forage sorghum was 0.8°C cooler than the bare ground treatment. There were no significant differences between the lower biomass plots of bare ground, mixed species, cow peas or summer weed treatments. Refer to Table 4 for individual effects.

Crop nutrients (mineral nitrogen and total carbon %)

Canowindra site

Average mineral nitrogen (N) was measured before sowing the winter crop on 1 April. Sampling depth was 1.2 metres and the site average was 272 kg N/ha, and ranged from 195 kg N/ha to 343 kg N/ha. Mineral N was influenced by crop type (P=0.018) and spray out timing (P=0.053), but the interaction between both was not significant (*P*=0.676). Site mineral N was highly variable within treatments, and possibly a legacy effect from the previous canola crop (2018) that was grazed out due to drought.

Highest mineral N was achieved in the bare ground treatment (320.6 kg N/ha), and on average reduced by 79 kg N/ha for the higher biomass crop-types such as forage sorghum and mixed species, and by 46 kg N/ha and 10kgN/ha for the lower biomass crop-types such as cow peas and summer weeds, respectively. Cow peas had little positive effect on soil nitrogen levels and this may be due to: poor nodulation caused from the high temperatures; lazy nodulation due to high nitrogen levels.

Average total carbon percentage was 2% in the 0-10cm soil depth and ranged from 1.75% to 2.25%. Compared with the bare ground treatment (1.76%), total carbon increased by 0.36%, 0.33%, 0.22% and 0.11% in the forage sorghum, mixed species, summer weed and cow pea treatment, respectively. The average total carbon percentage in the 10–30cm was 0.64%, and there were no treatment effects.

Parkes site

Average mineral N was 103.2 kg N/ha and ranged from 61.3 kg N/ha to 152.8 kg N/ha. Mineral N was reduced as the cover crop biomass increased, and was affected by crop type (*P*=0.019), but not by spray-out timing (*P*=0.093) or interaction of both (*P*=0.414)

The bare fallow treatment had the highest mineral N with 152.8 kg N/ha, and then reduced on average by 69.5 kg N/ha, 61.1 kg N/ha, 50 kg N/ha and 34.6 kg N/ha for forage sorghum, mixed species, cow pea and summer weed treatments respectively. Refer to Table 4 for individual effects.

The average total carbon percentage was 1.01% in the 0–10cm depth, and 0.48% in the 10–30cm depth. There was not enough biomass produced to alter total carbon at either depth.

Soil water accumulation

Canowindra site

As expected, over the summer period the various cover crops extracted moisture from the soil profile to grow biomass. After cover crop termination there was approximately a 50mm water deficit between the driest and wettest plot (Figure 1). Soil water levels were affected by crop-type (Figure 2a) and spray-out timing (Figure 2b), but no interaction between the two.

The higher biomass crop-types such as forage sorghum and mixed species extracted more moisture than lower biomass crops such as cow pea and summer weeds (Figure 2a). Additionally, spray-out timing also impacted soil water with the mid and late spray-out timing being approximately 30mm dryer than the early spray-out (Figure 2b). Despite the soil water deficit at cover crop termination, the higher biomass plots recharged quicker than the bare ground treatment resulting in no statistical difference in soil moisture from the 16 April to 12 November. The rate of recharge was a surprising result and warrants further investigation to determine if the higher biomass treatment would overtake the bare fallow moisture levels in a normal year.

The legacy effect of the various forms of ground cover will be monitored throughout the 2020 season.

Summer weed results (soil water) are not included due to the uneven nature of summer weed establishment that was not picked up by the soil neutron probe.

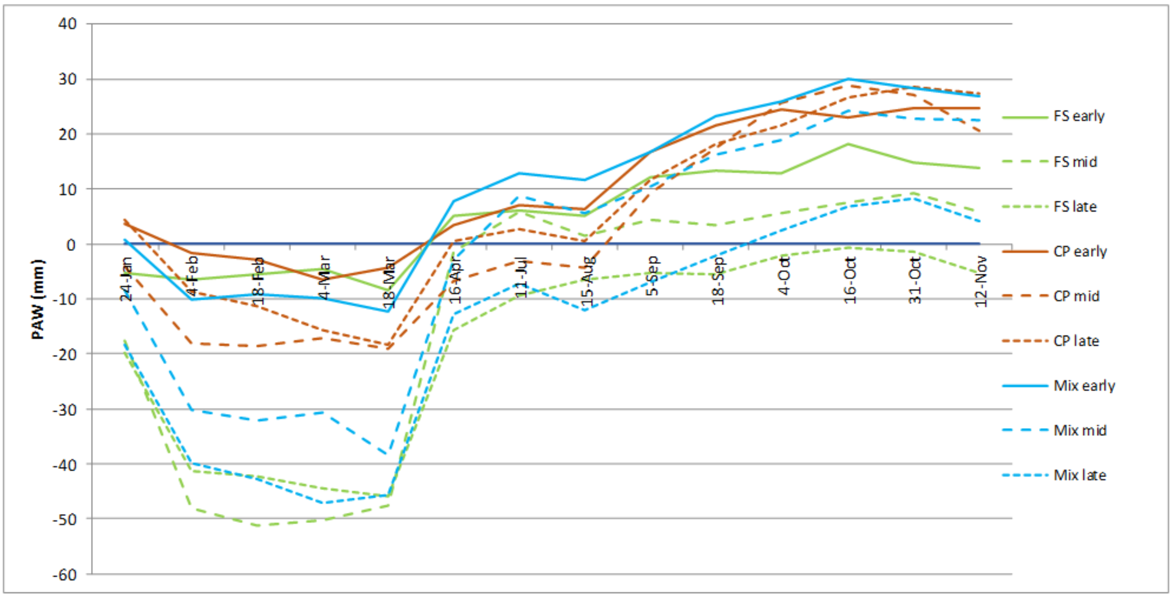

Figure 1. Individual treatment effects on soil water accumulation (+/- mm PAW) compared with the bare ground control at Canowindra NSW

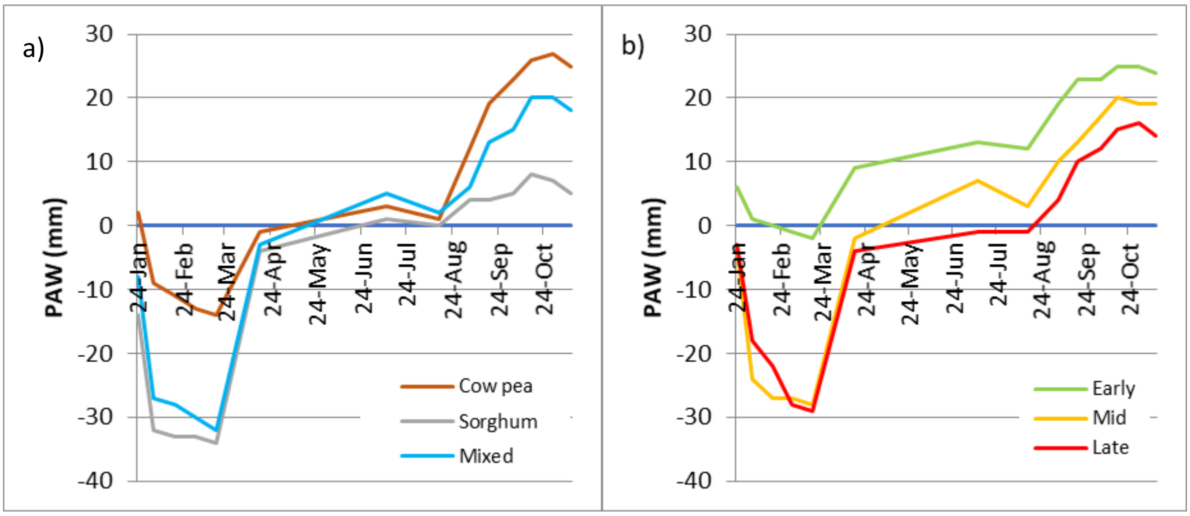

Figure 2. Main effects of cover crop-type (a) and spray-out timing (b) on soil water accumulation compared with the bare ground control at Canowindra NSW

Predicta® B results – (stubble and soil pathogens)

Canowindra site

Diseases that were significantly affected by the various cover crops and spray out timings included: Take all; *Pythium clade* F; *Pyrenophora tritici repentis*; *Pratylenchus neglectus*; *Macrophomina phaseolina* and *Fusarium* spp. Results will be included in a separate report

Parkes site

Diseases that were significantly affected by the various cover crops and spray out timings included: Take all; *Pythium clade* F; *Pratylenchus thornei*; *Macrophomina phaseolina*; *Didymella pinodes* and *Fusarium* spp.

Grain yield results

Canowindra site

The average grain yield was 1.91 t/ha and ranged from 1.13 to 2.93 t/ha. Grain yield was affected by crop-type (*P*<0.001), spray-out timing (*P*<0.001) but not the interaction between both (*P*=0.459).

The highest grain yield (2.93 t/ha) was from the bare ground treatment, and on average reduced by 1.4 t/ha, 1.2t/ha, 1.2 t/ha and 0.6 t/ha from the cow pea, forage sorghum, mixed species and summer weed treatments, respectively. Grain yield reduced as spray out timing was delayed with early, mid and late yielding 2.43 t/ha, 1.72 t/ha and 1.33 t/ha, respectively. Interestingly, the cow peas provided little benefit for the following winter cash crop.

Parkes site

The Parkes site was low yielding with an average grain yield of 0.35 t/ha, ranging from 0.07 to 0.71 t/ha. Grain yield was affected by crop type (*P*<0.001), spray out timing (*P*=0.003) and the interaction between crop type and spray out timing (*P*=0.032).

The highest grain yield (0.71 t/ha) was in the control which was weed-free, bare ground, and on average, grain yield reduced by 0.56 t/ha, 0.51 t/ha, 0.33 t/ha and 0.04 t/ha following forage sorghum, mixed species, cow pea and summer weeds, respectively. Compared with the bare ground treatment, grain yield reduced by 0.27 t/ha and 0.39 t/ha following the early and mid-spray out timing, respectively. There was no further grain yield loss between mid and late spray-out timing. Refer to Table 4 for individual effects.

Table 3. Individual treatment results from short fallow cover crop experiment – Canowindra NSW

Crop type	Spray-out timing	Ground cover biomass (t/ha)	Soil temperature (°C)	Mineral N (kgN/ha)	Total carbon 0–10cm (%)	Total carbon 10–30cm (%)	Wheat grain yield (t/ha)
Bare	Weed-free	0	24.3	321	1.76	0.637	2.93
Cowpea	Early	0.71	24.2	286	1.75	0.608	2.26
	Mid	1.5	23.6	275	1.87	0.623	1.23
	Late	1.73	23.5	266	2	0.675	1.23
Forage sorghum	Early	2.8	21.7	288	1.93	0.683	2.45
	Mid	5.9	18.9	195	2.17	0.595	1.56
	Late	10.8	19.3	245	2.26	0.738	1.13
Mixed species	Early	1.71	22.2	274	2.01	0.615	2.15
	Mid	4.03	19.4	241	2.14	0.55	1.76
	Late	4.51	20	212	2.12	0.72	1.19
Summer weeds	Early	0.1	24.1	343	2.07	0.608	2.84
	Mid	0.51	23.6	316	1.92	0.69	2.33
	Late	2.32	23.8	276	1.95	0.605	1.75
P value		*<0.001*	*<0.001*	*0.03*	*0.15*	*0.907*	*<0.001*
5% Lsd		*1.1*	*1.1*	*80*	*0.36*	*0.236*	*0.5*

Table 4. Individual treatment results from short fallow cover crop experiment – Parkes NSW

Crop type	Spray-out	Cover Biomass (t/ha)	Soil temperature (°C)	Mineral N (kgN/ha)	Total carbon 0–10cm (%)	Total carbon 10–30cm (%)	Grain yield (t/ha)
Bare	Weed free	0	27.1	153	1.01	0.49	0.71
Cowpea	Early	0.27	27.1	126	1	0.51	0.48
	Mid	0.4	27.3	82	0.99	0.49	0.33
	Late	0.42	27	100	0.95	0.54	0.34
Forage sorghum	Early	0.47	26.5	104	1.02	0.43	0.28
	Mid	1.86	25.8	86	1.12	0.51	0.1
	Late	2.09	26.8	61	1.07	0.57	0.07
Mixed species	Early	0.47	27.2	96	1.01	0.45	0.37
	Mid	1.42	27	84	0.97	0.45	0.15
	Late	0.94	26.1	95	1.08	0.46	0.09
Summer weeds	Early	0.1	27	119	0.97	0.5	0.63
	Mid	0.12	26.9	116	0.1	0.43	0.62
	Late	0.04	27.6	120	1.02	0.46	0.77
P value		*<0.001*	*0.019*	*0.015*	*0.655*	*0.851*	*<0.001*
5% Lsd		*0.754*	*0.9*	*42*	*0.153*	*0.159*	*0.159*

Table 5. Cover crop feed quality results and potential lamb production results – Canowindra

Crop type	Spray out time	Yield (t DM/ha)	Metabolisable energy (MJ/kg DM)	Crude protein (%)	Liveweight gain (kg/ha) [1]	Value of gain ($/ha) [2]
Cowpea	Early	0.7	10.7	23.3	85	297
	Mid	1.5	10.2	17.6	161	563
	Late	1.7	10.1	17.6	176	617
Forage sorghum	Early	2.8	10.2	14.5	300	1051
	Mid	5.9	10.3	10.2	522	1827
	Late	10.8	11.1	7.9	1062	3716
Mixed species	Early	1.7	11.0	19.9	228	799
	Mid	4.0	10.1	12.7	400	1399
	Late	4.5	10.4	11.3	469	1643

1. Crossbred wether lambs (Border Leicester x Merino or Dorset x Merino), 6 months old, 30 kg live weight utilising 80% of the crop grown.
2. Lamb value of $3.50 per kg.
3. These results are based on feed test results conducted from dry matter samples, sheep were not actually grazed.

Table 6. Cover crop feed quality results and potential lamb production results – Parkes

Crop type	Spray out time	Yield (t DM/ha)	Metabolisable energy (MJ/kg DM)	Crude protein (%)	Liveweight gain (kg/ha) [1]	Value of gain ($/ha) [2]
Cowpea	Early	0.3	11.1	24.7	37	130
	Mid	0.4	10.0	23.0	40	138
	Late	0.4	10.9	20.3	53	185
Forage sorghum	Early	0.5	10.5	12.6	50	176
	Mid	1.9	11.0	12.8	234	818
	Late	2.1	10.5	9.7	218	761
Mixed species	Early	0.5	10.7	16.2	56	196
	Mid	1.4	10.9	13.9	177	619
	Late	0.9	10.6	11.3	100	352

1. Crossbred wether lambs (Border Leicester x Merino or Dorset x Merino), 6 months old, 30 kg live weight utilising 80% of the crop grown.
2. Lamb value of $3.50 per kg.
3. These results are based on feed test results conducted from dry matter samples; sheep were not actually grazed.

Conclusion

Summer cover crops provide a series of pros and cons for the following winter cash crop. Individual paddock goals, enterprise mix, rainfall and commodity prices will ultimately determine if the pros outweigh the cons. There needs to be a clear understanding of how the cover crop will integrate and benefit the broader farming system.

Soil water recharge following a cover crop is much quicker than bare ground, yet a soil water deficit would occur if no rain falls after cover crop termination. Even in a wet year, there is likely to be a nitrogen deficit for the following winter cash crop that would require correcting with additional nitrogen fertiliser. Presumably, as total carbon % increases, the reliance on supplementary nitrogen could reduce over time with an understanding this will take a number of years.

Grain only cropping operations with short fallows (6 month) are likely to increase the financial risk profile when growing summer cover crops, as yield was reduced at both experiment sites following a cover crop compared with bare ground. Management techniques that retain stubbles and control summer weeds are still considered best practise, as no additional water is used to grow the biomass. However, the use of cover crops as a ‘one off’ technique to protect the soil from wind or water erosion in low ground cover scenario’s may be warranted but considered a ‘one off’ rather than regular annual management operation.

Conversely, mixed farming enterprises have good reason to capitalise on the increased biomass of a summer cover crop given the current prices for red meat (Tables 5 and 6). According to these results, the grazing value would more than compensate for the winter crop grain yield penalty. Nutrients such as nitrogen would need to be adequate to support such a high output system, however the additional income from the livestock enterprise would compensate for the additional nutritional expenses.

Whilst not absolute, disc seeders are an integral part of the cover cropping system as they improve crop establishment in rapidly drying soils (associated with summer plantings) and provide for the high trash flow requirements of the cover crop system. A patchy cover crop will be no better than a weedy fallow, so crop establishment is an important factor. Consideration needs to be given to seeding depth, particularly for multi-species mixes as the seed size range within the mix will determine the potential seeding depth. For example, millet needs to be sown shallow, but forage sorghum and cow peas can be sown much deeper.

The improved rate of soil water recharge was interesting, and the legacy effects will be monitored throughout the 2020 season to evaluate if the higher biomass treatments overtake the bare fallow.

A separate report will detail results from summer cover crops in LONG fallow paddock scenarios.

Useful resources

https://grdc.com.au/resources-and-publications/all-publications/publications/2019/blackleg-management-guide

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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. Sincere thankyou to John Piltz (NSW DPI) for feed test analysis, Peter Roberts and Jess Perry for field work assistance and the local grower and advisor committee that helped direct this research. Special thankyou to our trial hosts Stuart and Ellen McDonald of Canowindra, and Matt Burkitt of North Parkes Mines.

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Decisions for a profitable 2020

Discussion session

Notes

Managing chickpea diseases after the drought

Kevin Moore, Steve Harden, Kristy Hobson and Sean Bithell, NSW DPI, Tamworth

Key words

chickpea, disease risk, Ascochyta, Phytophthora, Sclerotinia, root lesion nematode (RLN), management, fungicide rain fastness

GRDC code

Grains Agronomy & Pathology Partnership - A strategic agreement between GRDC and NSW DPI (DAN00213): BLG209 Pulse Integrated Disease Management – Northern NSW/QLD

Take home messages

- Do not underestimate disease risks after a drought – pathogens survive longer and can still threaten your 2020 chickpea crops
- Unless you are in a high risk Ascochyta situation, it is unlikely there will be a cost benefit applying a foliar fungicide to 2020 crops until after the disease is detected
- However, if you are at a high risk of Ascochyta, apply a foliar fungicide before the first post emergent rain event
- High risk situations include planting into paddocks with active Ascochyta inoculum and planting seed that has not been properly treated
- Recent research has shown the Ascochyta fungicides Aviator Xpro and Veritas are rain fast (up to 100 mm rain in 150 minutes)
- Phytophthora and Sclerotinia levels will not have declined much during the drought and pose a medium to high risk in 2020
- Root Lesion Nematodes may have declined during the drought but if numbers at the start of the drought exceeded 10/g soil, it may still be sufficient to cause damage in 2020 chickpea crops.

How drought affects plant diseases

- Drought reduces the breakdown of plant residues. This means that inoculum of some diseases does not decrease as some might expect and will carry over for more than one growing season. The expected benefits of crop rotation may not occur
- Bacterial numbers decline in dry soil. Some bacteria are antagonists of soil borne fungal diseases. These diseases can be more severe after drought
- Abandoned, or drought stressed crops still set seed. Summer/autumn rains can lead to large numbers of volunteers. Low stock numbers make it difficult to control these volunteers, which can host Ascochyta, viruses and virus vectors, and other pathogens
- Weeds that are stressed by drought may be harder to kill and can harbour pathogens
- Soil water and nitrogen may be unbalanced and these are likely to impact diseases in 2020 and beyond.

Chickpea disease risks after the drought and advice for 2020 chickpea farmers

- Ascochyta is unlikely to cause widespread problems in 2020 unless it is wetter than average as inoculum levels have not increased in past two seasons and even if infected with Ascochyta, all varieties recover well during dry conditions. For these reasons, unless you are in a high risk situation, there will be no cost benefit applying Ascochyta fungicides until the disease is detected. High risk situations include planting into paddocks where active inoculum is known to be present (see following examples at Tulloona and Moree) and planting seed of unknown pathogen status that has not been properly treated. In these situations, apply an Ascochyta fungicide before the first post-emergent rain event, then monitor the crop 10-14 days after rain.

- If Ascochyta is detected, apply a registered fungicide before the next rain event. This is especially important during the reproductive stage as Ascochyta on pods causes abortion, seed infection and seed defects. If you miss a spray; fungicides with limited curative activity are now available however they have a limited time of use and tight intervals for application after an infection event occurs. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/chickpea-ascochyta-research-what-if-i-miss-a-spray-are-there-salvage-options-with-new-chemistry-how-long-do-fungicides-persist)

- Under drought conditions, some plant pathogens survive longer than normal; Ascochyta inoculum for 2020 chickpea crops may have originated in 2017 or even 2016. In August 2019, volunteer chickpeas in a crop of wheat at Tulloona had Ascochyta lesions. That paddock had grown chickpeas in 2016 (under high Ascochyta pressure); wheat in 2017 and chickpeas in 2018 (crop abandoned due to drought). Rain in Oct/Nov 2018 allowed Ascochyta to develop on abandoned plants, and seed left in the paddock germinated on rain in March 2019 to produce the volunteers that got infected during rain events in May, June and July 2019. Another example of how drought can prolong survival of inoculum was provided in August 2019, when we received chickpea stubble from a paddock at Moree that had grown chickpeas in 2017. The stubble contained fungal fruiting bodies. We soaked the stubble in water for several hours then applied the water suspension to chickpea seedlings; 7 days later symptoms and pycnidia of Ascochyta developed on the seedlings, proving that the inoculum had persisted on the nearly two-year old chickpea residue. Both the Tulloona and Moree paddocks are considered high risk if planted to chickpeas in 2020.

- Remember, the Ascochyta fungus is evolving: In our 2010 Tamworth disease management trial, unprotected PBA HatTrickᶲ (then rated moderately resistant (MR)), lost 37% yield to Ascochyta; while in the 2016 trial, unprotected PBA HatTrickᶲ lost 97% yield to Ascochyta. PBA HatTrickᶲ is now rated moderately susceptible (MS) and will require fungicide under conditions that favour Ascochyta. The good news is that whilst Ascochyta can now cause more damage on unprotected PBA HatTrickᶲ, it is just as easy to manage as when PBA HatTrickᶲ was rated MR.

- Phytophthora root rot (soil borne) and Sclerotinia diseases (soil borne and air borne) are considered moderate to high risk in 2020 because although inoculum loads are unlikely to have increased, their survival will have been prolonged by the drought.

- Botrytis seedling disease (BSD, seed borne) is only likely in crops planted with seed produced in the 2016 (and possibly 2017) crop year. In any case proper seed treatment provides 100% control of BSD.

- Botrytis grey mould (BGM, air borne); the BGM fungus is ubiquitous, has a very wide host range and is a good saprophyte - if conditions favour BGM i.e. dense canopies, warm humid weather, it will occur.

- Root lesion nematodes (RLN, *P. thornei* soil borne) can survive dry periods. Recent research has shown it takes a double break of 40 months free of host plants to reduce numbers to a minimum threshold (2/g soil) so it is unlikely the current drought will have reduced RLN numbers if they started high (40/g) which was likely in the 2016 season. Even starting numbers of 10/g still need a break of 30 months https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil.

- Viruses are an unknown threat after a drought. Most need green plants as reservoirs (some are seed borne) and hosts for their vectors. However, as vectors can fly or be blown in from regions that have not experienced drought, viruses are still a risk to 2020 chickpea crops.

Seed quality

Obtaining good quality seed after a drought may be an issue in 2020. In Nov/Dec 2019, we tested seed from as far back as 2016 and whilst germination of all lots exceeded the Pulse Australia (PA) minimum standard of 70%, some lots were slow getting there, indicating possible loss of vigour. All planting seed should be germination tested and if it meets the PA standard, we recommend it be treated and 'test planted' into paddocks intended for chickpeas in 2020, and the number that emerge counted – this is your best indicator of seed and seedling vigour and may assist identify herbicide residues, but should not be relied on as the sole indicator for this, as symptoms of residual herbicides can in some situations be slow to develop. Paddock emergence tests are best done in March/April.

If you are sourcing seed from outside your region e.g. interstate, be sure the variety is suitable for your farming system and have the seed germination and pathogen tested.

Irrespective of age and origin, all planting seed should be treated with a registered seed dressing – these control seed borne Ascochyta (internal and external), seed borne Botrytis (BSD) and protect seedlings from a range of opportunistic soil organisms that can reduce seedling vigour and establishment under less than favourable conditions e.g. cold or wet soils, deep planting. Planting quality, treated seed is your best bet of healthy seedlings – these will have a rapidly growing root system to obtain nutrient and moisture, be more competitive with weeds and less susceptible to disease.

Predicta®B for assessing Ascochyta risk

The value of Predicta®B as an Ascochyta management tool has not been determined because we do not know what the numbers mean in terms of risk or management. Predicta®B results that are positive for Ascochyta on samples collected after the drought should not be surprising give the persistence of inoculum under drought conditions. On the other hand, a negative result does not mean your Ascochyta risk is nil or low as the test is only as good as the sampling method and inoculum can arrive in your paddock after sampling via wind, machinery, vehicle, animals, surface water flows or untreated seed.

Chickpea Ascochyta Research Update: Is efficacy of Aviator Xpro and Veritas reduced by rain after application?

Previous research (2007) at Tamworth using a rainfall simulator showed that efficacy of the fungicides Barrack720® (720g/L chlorothalonil) and Dithane® Rainshield® (750g/kg mancozeb) on chickpea Ascochyta on cultivar Jimbour was not significantly reduced by 50mm rain in 10 minutes. 150mm in 30 minutes also did not reduce efficacy of Barrack720 but did reduce slightly the efficacy of Dithane. Such rainfall intensities are not common in chickpea crops grown in eastern Australia. From these experiments we concluded that plant tissue sprayed with these fungicides would still be largely protected if rain fell after application (new growth after application would not be protected as both products are protectants only). The 2010 chickpea season (that had frequent rain events) supported this conclusion.

The recent registrations of Aviator Xpro® and Veritas® (both in 2018) for chickpea Ascochyta (with restrictions on number of applications and timing – see labels for details) raised the question of how rain fast are these products.

Two experiments were conducted at Tamworth Ag Institute in December 2019 - January 2020 to determine the effect of simulated rain on the efficacy of Aviator Xpro and Veritas on Ascochyta; Unite®720 (720g/L chlorothalonil) and water were the control treatments. The first experiment (4 reps) was with cv Kyabraⓓ and the second (4 reps) with cvs Kyabraⓓ and PBA Seamerⓓ.

As the results were the same, we report here the second experiment. Plants were sprayed with water, Unite, Aviator Xpro or Veritas using a backpack sprayer with a 1m boom fitted with 110/015 flat fan nozzles at 50cm spacing and a walking pace of approximately 6kph. The fungicide treatments were allowed to air dry for 2hr when the 'rain' plants were placed in the rainfall simulator and exposed to 50mm over 75 minutes or 100mm over 150min (recorded by two rain gauges at each side of the simulator pad). After removal from the simulator, plants were allowed to air dry for 2h, arranged on racks in replicate boxes (55L plastic with clear lids), inoculated to run off with a cocktail (2,000,000 conidia/mL) of 20 Ascochyta isolates obtained from commercial chickpea crops and the boxes placed in a controlled environment facility operating at 12h/12h day/night 15C/20C. Leaf wetness was maintained with ca 50mm depth water in the base of the boxes and firm fitting lids. After 48h the lids were removed and plants were examined for Ascochyta. Five days after inoculation (DAI) first symptoms (petiole wilting) were evident and at 9 DAI, Ascochyta was assessed by counting the numbers of petioles, leaves and stems with symptoms.

The only plants that developed Ascochyta were those sprayed with water; PBA Seamerⓓ had less disease than Kyabraⓓ.

We conclude from this experiment that efficacies of chickpea Ascochyta fungicides Veritas and Aviator Xpro with a 2 hour dry period after spraying and prior to rain occurring, are not affected by simulated rainfall of 50mm in approximately 75min or 100mm in approximately 150min. As such intensities are uncommon during chickpea seasons in areas of Australia where Ascochyta occurs, it is reasonable for growers to be confident that once these fungicides have dried on plant tissues, those tissues will remain protected.

Acknowledgements

This work is part of a major co-investment between NSWDPI & GRDC. The research is possible by the significant contributions of growers through trial cooperation and permission to sample their crops and we thank them for their continued support.

Thanks to Beefwood, Moree; CanBerra, Banana; Woods Seeds, Goondiwindi and Parraweena, Blackville for seed for trials; agronomists for maps and help with crops; Pulse Australia, and chemical companies for products for trials.

Thanks also to Paul Nash and Gail Chiplin for outstanding technical support.

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