GRAINS RESEARCH UPDATE

STRATEGIC STEPS – ENDURING PROFIT

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

West Wyalong

Wednesday 25th July

9.00am to 1.00pm

West Wyalong Services & Citizens Club

100 Monash Street, West Wyalong

#GRDCUpdates

West Wyalong GRDC Grains Research Update
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Central West Farming Systems Inc (CWFS)

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

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

The group is managed by an Executive Committee comprising of 9 farmers & 3 industry representatives. CWFS currently has over 350 members. These are predominately farmers, although we are also strongly supported by private advisers, agribusiness, research organisations and universities. Core funding for our activities derive from industry and Government funding programs. Our major funding partners currently include the Grains Research and Development Corporation (GRDC). CWFS works closely on a number of projects with universities, the newly formed Soil CRC (with CWFS having representation on the Board), the Low Rainfall Collaboration Group and other farming systems groups at a national and regional level.

Our current projects include:

- Maintaining profitable farming systems with retained stubble in Central West NSW
- Crop Sequencing
- Overdependence on Agrochemicals
- Soil Acidity and pH Management for Central West Farming Districts
- Women and Youth in Agriculture
- Irrigated canola and cereals
- Nitrogen use efficiency

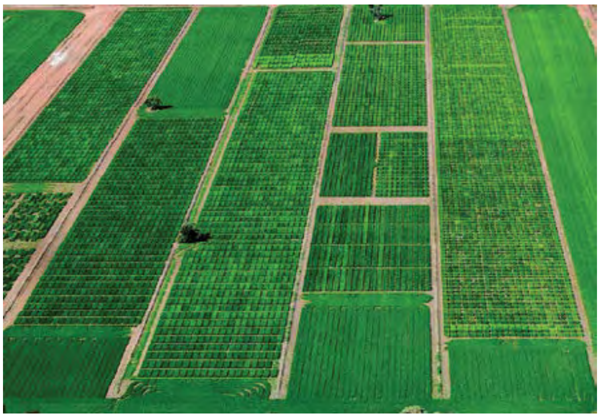
Project funders include Farming Together, Landcare, Soil CRC, Local Land Services and GRDC.

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

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

CWFS has developed an AgMarketing program which supports women (in its initial phase then open to all) in their substantial on-farm commodity marketing role.

The focus on marketing is embedded in a value chain approach and build participants' ability and confidence to better manage their whole farm enterprise.



Irrigation research

In 2014 CWFS officially commenced irrigation research via its Condobolin based irrigation site. This has provided CWFS with an unprecedented opportunity to expand its areas of research into irrigated crop varieties, irrigation technologies & techniques, and water use efficiencies within an irrigation system.

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

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Pulse rhizobia performance on acid soils

Ross Ballard[1], Elizabeth Farquharson[1], Maarten Ryder[2], Matthew Denton[2], Frank Henry[3], Rachael Whitworth[4], Barry Haskins[4] and Ron Yates[5].

[1]South Australian Research and Development Institute; [2]University of Adelaide; [3]DEDJTR Agriculture Victoria; [4]AgGrow Agronomy NSW; [5]WA Department of Primary Industries and Regional Development.

ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project codes: DAS00128, UA00138

Keywords

- soil acidity, rhizobia, inoculation, nodulation, faba bean, lentil, N_2-fixation.

Take home messages

- Inoculation of faba bean, lentil and field pea with rhizobia (*Rhizobium leguminosarum* bv. *viciae*) is critical on acid soils. Nodulation is improved by increased application rate of inoculation products.
- The lower limit of $pH_{(Ca)}$ for reliable nodulation with the commercial strains of faba bean and field pea rhizobia is 5.0.
- Liming to increase soil pH and increased rates of inoculation should be considered where soil $pH_{(Ca)}$ is below 5.0.
- Several strains of rhizobia with improved acidity tolerance have shown promise in the field on faba bean and broad bean. They are being more widely tested to develop a case for commercial release.
- Contact between rhizobia and incompatible pesticides should be avoided when sowing pulses on acid soils.

Background

Recent expansion of the pulse industry is seeing crops increasingly grown on soils below $pH_{(Ca)}$ 5.5. Faba beans are the pulse of choice in high rainfall acidic soil environments of south eastern Australia, while the high value of lentils is similarly seeing it sown on acidic soils in lower rainfall areas. The impact of acid soils on pulse production is also likely to increase as soils continue to acidify (Helyar et al. 1990), particularly where the sub-surface soil is acidic and difficult to ameliorate with lime.

Faba bean and lentil are recognised as being sensitive to soil acidity. A substantial part of this sensitivity is due to impacts on the symbiosis with reduced levels of nodulation and N_2-fixation reported on acidic soils (Burns et al. 2017). Another signpost of the sensitivity is that the rhizobia (*Rhizobium leguminosarum* bv. *viciae*) that nodulate these pulses (and also field pea and vetch) persist at lower numbers or are often absent in acid soils ($pH_{(Ca)}$<6). Inoculation is therefore recommended with a moderate to high chance of inoculation response on these soils (Drew et al. 2012a, 2012b, Denton et al. 2013).

Two inoculant strains are produced commercially. WSM-1455 (Group F) is produced mainly for faba bean and lentil, but is often also used on field pea. Sulfonylurea (SU)-303 (Group E) is produced for field pea and vetch. In our experience, these two inoculant strains are competent and reliably form nodules when used to inoculate pulses sown into soils above $pH_{(Ca)}$ 5.0, but are constrained below this level.

The performance of strains of rhizobia with improved acidity tolerance and other practices that can be used to improve pulse nodulation and N_2-fixation on acid soils are described in this paper.

Acid tolerant strains of rhizobia

Strains identified that improved nodulation in low pH hydroponic experiments

Hydroponic experiments have been used to determine if strains of rhizobia isolated from acid soils provided any advantage over the commercial inoculant strains at low pH. Plant growth solutions were maintained at pH 4.2, the point where the nodulation of field pea by inoculant strains SU-303 and WSM-1455 had previously been shown to be severely reduced in the test system.

Eleven rhizobia strains, comprising five from the South Australian Research and Development Institute (SARDI) (SRDI strains) and six from Murdoch University (WSM strains selected for field pea, supplied by Dr Ron Yates), were tested for their ability to nodulate Kaspa⁽ᵇ⁾ field peas at low pH.

The strains of rhizobia varied in their ability to form nodules. Inoculant strain WSM-1455 performed better than SU-303. Of the new strains, SRDI-954, SRDI-969, WSM-4643, WSM-4644 and WSM-4645 all nodulated more than 70% of plants. SRDI-969 stood out because it also increased nodule numbers more than six-fold, compared with both commercial inoculant strains (Figure 1).

Performance of rhizobia strains in the field

Rhizobia strains with putative acid tolerance were tested in the field between 2015 and 2017. Strains SRDI-954, SRDI-969, SRDI-970 and WSM-4643 performed best and provided substantial levels of improvement over the commercial inoculants at some sites, as described below.

2015 field trials

Strains SRDI-954 and SRDI-970 were initially provided as peat cultures to Maarten Ryder for testing in a GRDC Regional Cropping Solutions Network (RCSN) project examining a range of treatments to improve broad bean production on Kangaroo Island, SA.

In a small plot trial, both strains of rhizobia significantly increased the nodulation of broad bean compared to the current commercial strain — nodulation ratings were higher and more uniform. In addition, shoot nitrogen (N) and fixed N were almost doubled. In a complementary grower run trial (replicated four times), SRDI-954 again produced more nodules than WSM-1455, increased grain yield by 8% and the amount of N fixed by more than 40kg/ha. In these short term trials, the new rhizobia strains were more effective at improving nodulation than other agronomic treatments that included the addition of prilled lime (data not shown).

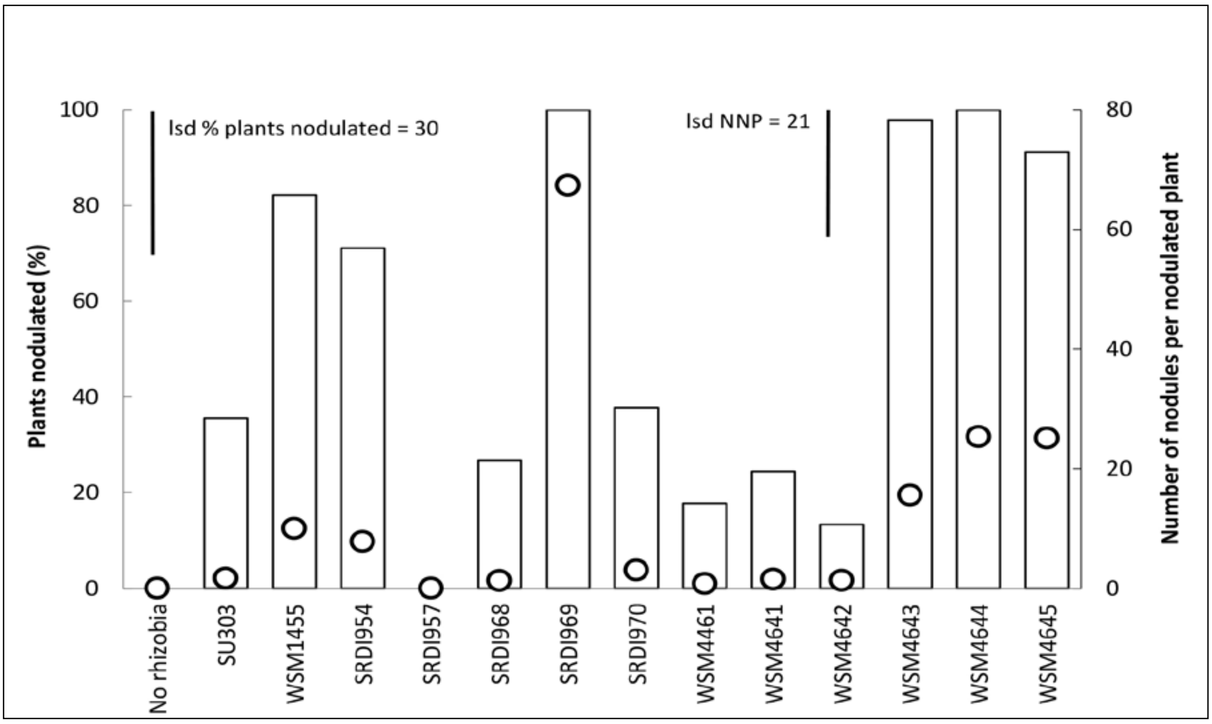

Figure 1. Effect of inoculation treatment on the percentage of Kaspa⁽ᵇ⁾ field pea seedlings forming nodules (left axis, columns) and the number of nodules per nodulated plant (NNP) (right axis, circles) at 20 days after inoculation.

2016 field trials

Following the promising results in 2015, the cohort of rhizobia strains was expanded and tested at another three locations in 2016 (Kangaroo Island, SA, Wanilla, SA, and Ballyrogan, VIC). Strains were applied at approximately four times the recommended rate, a strategy that we now believe probably moderated the extent of differences between the commercial inoculant and new strains of rhizobia (discussed later in section on inoculation rate).

The field sites were below $pH_{(Ca)}$ 5.0 (4.8, 4.9 and 4.6) and responsive to inoculation, due to the absence of naturalised rhizobia. Mean nodulation across the three sites was increased five-fold by the commercial inoculant strain (Table 1). Again, strain SRDI-954 significantly increased faba bean nodulation (+64%) on Kangaroo Island and averaged 124% across the three sites. Some strains did less well (e.g. WSM-4645).

N_2-fixation was significantly improved by inoculation, but was not further improved by the new strains of rhizobia (strain SRDI-969 ranked highest at 107%). On these acid soils, the best nodulated beans fixed approx. 150kg N/ha (not including roots).

Mean (three sites) grain yield with the commercial inoculant was 3.74t/ha and 3.93t/ha (105%) for strains SRDI-969 and WSM-4643, but the values were not significantly different (5% LSD). The grain yield result for WSM-4643 was largely driven by its good performance at one site.

Over the three measures (nodulation, grain yield and N_2-fixation), strains SRDI-954 and SRDI-969 were calculated to be 108% compared to the E/F inoculant. Strain SRDI-969 delivered the most consistent benefit (113%, 107% and 105%). Strain WSM-4645 was 69% of the E/F inoculant.

Two plant bioassays assessed the persistence of rhizobial strains in the soil. Soils were collected in the summer (2017) following the trials and used to inoculate plants growing in rhizobia-free media in the greenhouse. None of the rhizobial strains had persisted in the soil at a level substantially above the control treatments, meaning re-inoculation will be necessary even if the acid tolerant strains are used. The result also indicates there is still an opportunity for improvement beyond what is offered by the strains currently being evaluated.

Further evaluation of the strains was undertaken in 2017 and included a comparison of strain performance at a standard inoculation rate.

2017 field trials

Three trials were sown in 2017, comprising two faba beans and one lentil trial.

With faba bean at Wanilla (Eyre Peninsula, SA), rhizobia strains SRDI-954 and SRDI-969 outperformed WSM-1455 for both nodulation and grain yield, when applied to seed as a peat slurry at the standard rate of inoculation (Fig. 2). This site remained dry for four weeks after sowing, adding an additional stress on the rhizobia.

Nodulation results from a second faba bean trial sown at Chatsworth in VIC and a lentil trial near Griffith in southern NSW are shown in Table 2. It is the first time the new strains have been examined on lentil and demonstrates they competently nodulate that species. Growing conditions (waterlogging at Chatsworth, severe frost and below average rainfall at Griffith) were more limiting to grain yield than N2-fixation at both sites. There were no significant differences in grain yield.

Table 1. Mean data for nodulation, N2-fixation and grain yield across three sites expressed a percentage of the commercial E or F inoculant strain.

	Nodulation % commercial inoculant	N_2-fixation % commercial inoculant	Grain yield % commercial inoculant
No rhizobia	20	47	50
Control (E or F inoculant)	100	100	100
SRDI-954	124	100	102
SRDI-969	113	107	105
SRDI-970	111	102	103
WSM-4643	99	93	105
WSM-4644	83	74	91

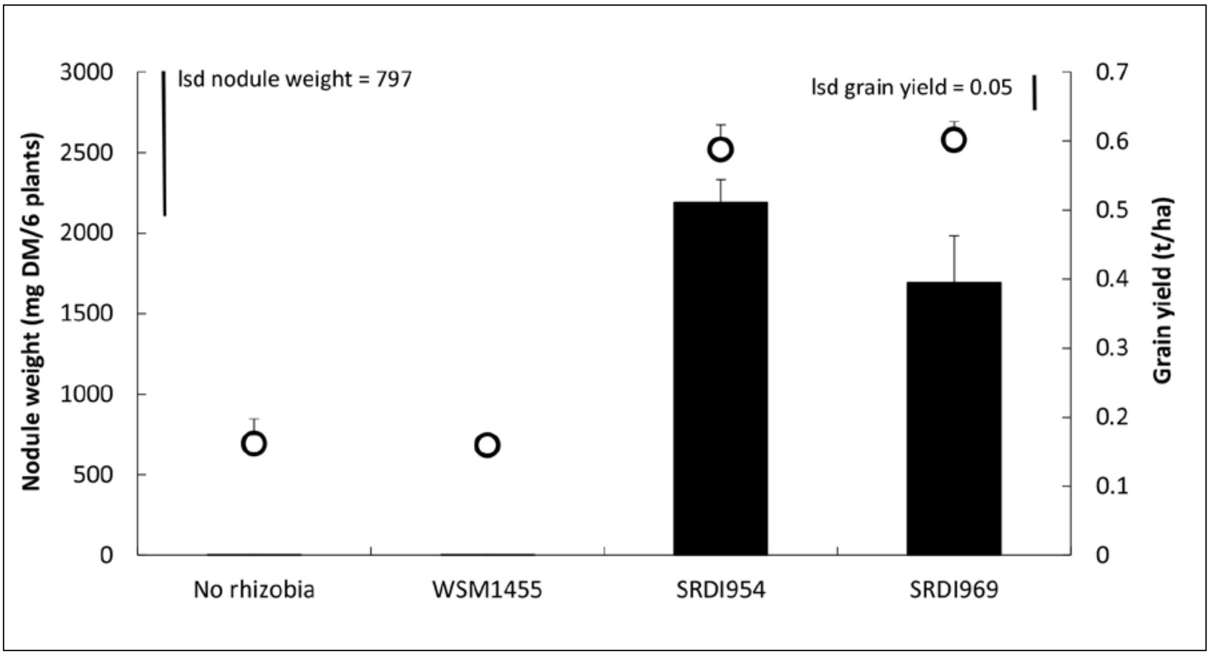

Figure 2. Effect of rhizobia strain on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⁽ᵈ⁾ faba bean at Wanilla, Eyre Peninsula, SA in 2017. Site pH$_{(Ca)}$ = 4.3, sown into dry soil 28 April. Standard rate of inoculation. Standard error of means shown as bars above columns and circles.

Overall field performance

The field results highlight the importance of good nodulation to establishing viable faba bean, lentil and field pea crops on very acid soils. Strain SRDI-954 improved nodulation over WSM-1455 at five sites and was equal at three sites where it has been tested. Strains SRDI-969, SRDI-970 and WSM-4643 improved nodulation at about a third of the sites where they have been tested. Further evaluation of the strains is planned for 2018, with increased emphasis on lentil.

\The WSM strains are primarily being developed for field pea on acid soils (Ron Yates, DAFWA). Based on our assessment of those strains, WSM-4643 is preferred for the pea inoculant because it was by far the most effective of the WSM strains on faba bean.

A new strain for faba bean (and possibly lentil) could be commercially available in 2022, subject to further work being completed to satisfy the criteria required for the replacement of a major inoculant strain.

Inoculation rate

Increasing the rate of inoculation has been shown to improve the nodulation and grain yield of faba bean in an acidic soil. Doubling the rate of inoculant applied as a peat slurry increased nodulation by 52% and grain yield by 41%, despite it being limited by seasonal conditions (Fig. 3). WSM-1455 only

Table 2. Effect of strain of rhizobia on the nodulation of faba bean and lentil.

	Chatsworth, VIC PBA Zahra⁽ᵈ⁾ faba bean pH$_{(Ca)}$ 4.7	Griffith, NSW PBA Ace⁽ᵈ⁾ lentils pH$_{(Ca)}$ 4.9
	Nodulation Score (0 to 5)	Nodulation nodules/plant
No rhizobia	0.50	1
WSM-1455 Gp F @ std rate	0.83	21
WSM-1455 Gp F @ double rate	1.15	32
SRDI-954	1.48	40*
SRDI-969	1.42	39*
SRDI-970	2.28*	Not tested
WSM-4643	2.15*	44*
Least significant difference (5%)	0.84	15

** Significantly different from WSM-1455 applied at standard rate*

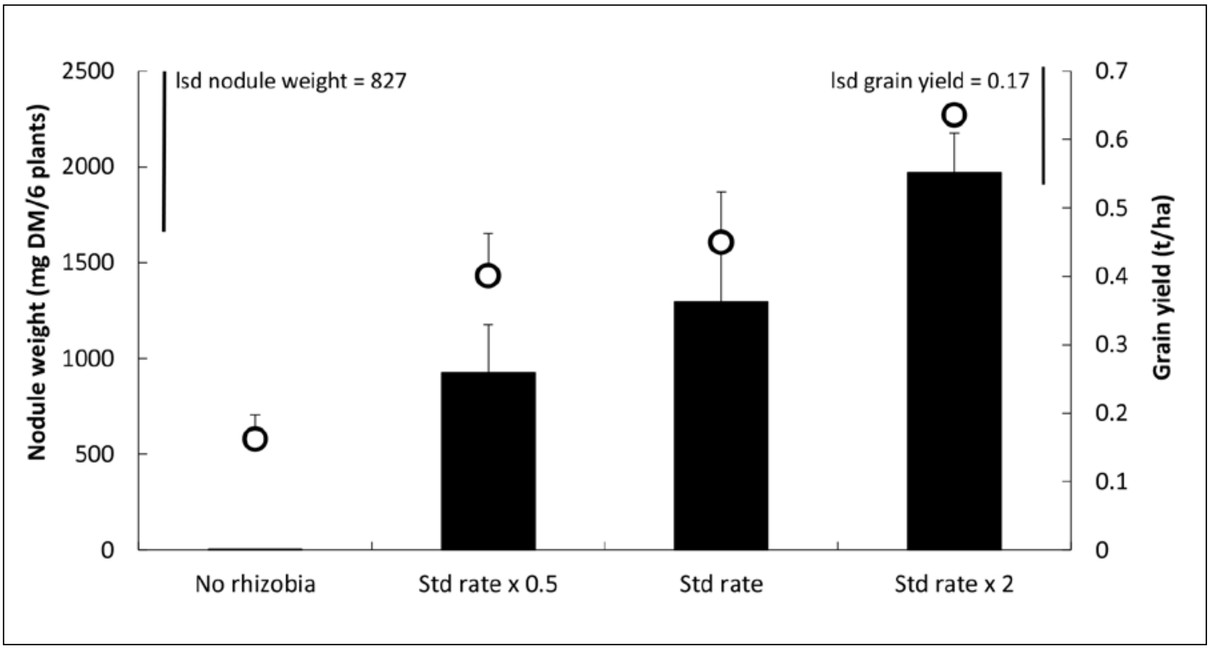

Figure 3. Effect of inoculation rate on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⁽ᴰ⁾ faba beans at Wanilla, Eyre Peninsula, SA, in 2017. Site $pH_{(Ca)}$ = 4.3, sown into dry soil 28 April. Values are the mean of three rhizobia strains (WSM-1455, SRDI-954 and SRDI-969). No-rhizobia treatment excluded from statistical analysis. Standard error of means shown as bars above columns and circles.

produced an acceptable level of nodulation at double the standard rate (data not shown).

Better nodulation in response to increased inoculation rate is commonly reported (Denton et al. 2013, Roughley et al. 1993) and provides a practical way of improving nodulation where pulses are sown for the first time, especially on hostile soils. However, a note of caution; growers have provided feedback that seeder blockages have resulted when they have increased the inoculation rate, so testing a small test batch of seed first to avoid such problems is suggested.

Pesticides

Particular care needs to be taken where rhizobia are applied with pesticides on seed, especially where it is to be sown into acidic soils. Rhizobia are best applied last and as close as possible to sowing. Within six hours is commonly recommended by inoculant manufacturers. The impacts of seed applied pesticides on rhizobia is often masked where there are naturalised rhizobia present in the soil, but are more likely to be seen on acid soils where there are no rhizobia. An example of such an impact is shown in Figure 4. The treatment of faba bean seed with Apron® Φ (metalaxyl) or P-Pickle T (PPT) (thiram and thiabendazole) fungicide prior to the application of rhizobia (as a peat slurry to the seed) caused significant reductions in both the amount of N fixed and grain yield. These reductions were the result of fewer rhizobia surviving on the seed and reduced nodulation (data not shown).

ΦApron® is not currently registered on faba bean. This product on faba bean is used for research purposes only. Commercial application of this product must adhere to label requirements.

Where pesticide application is necessary, granular rhizobial inoculant may provide a better option, reducing direct exposure of the rhizobia to the pesticide.

Inoculant formulation

Peat inoculant applied as a slurry to seed is the most common method used by growers and is reported to provide consistent and high levels of nodulation across a broad range of environments (Denton et al. 2009, 2017). This method provided satisfactory nodulation in our studies when used to deliver the acid tolerant strains of rhizobia, although granules on occasion have provided additional benefit. Specifically, nodulation by WSM-1455 was improved on two occasions where Novozymes ‘TagTeam®’ granules were used (Table 3).

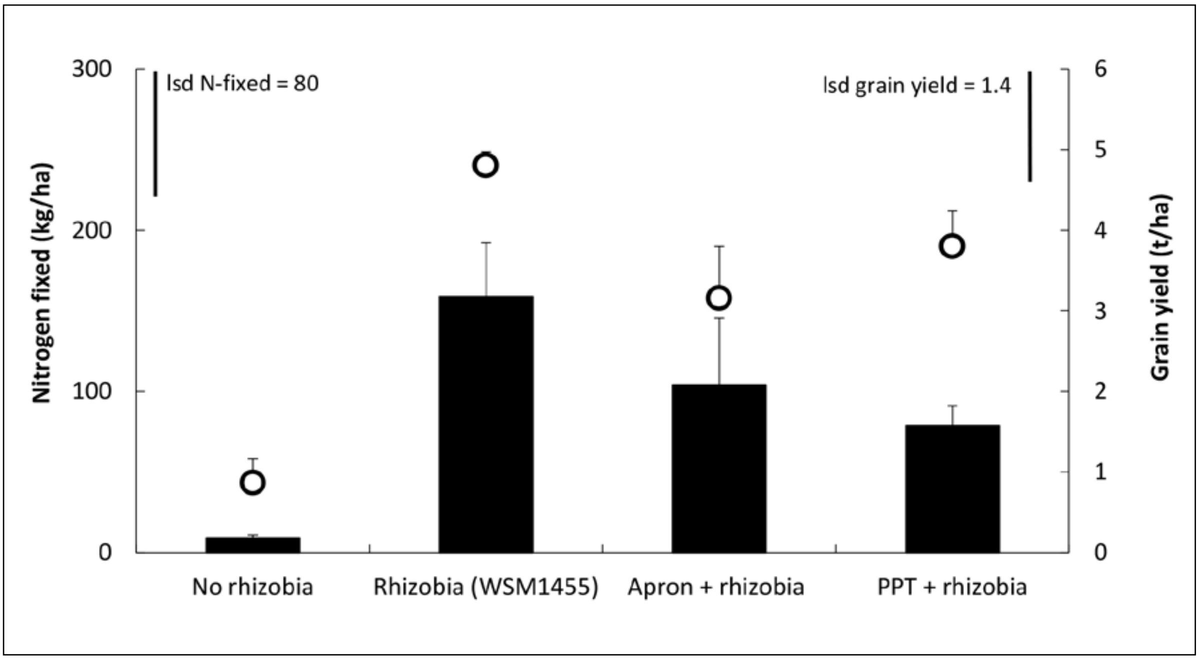

Figure 4. Effect of pesticide application to seed on nodule weight (left axis, columns) and grain yield (right axis, circles) of PBA Samira⫽ faba beans inoculated with Group F rhizobia (WSM-1455) at Ballyrogan VIC, 2016. Site pH ($_{Ca}$) = 4.6. Standard error of means shown as bars above columns and circles.

Table 3. Effect of inoculant formulation and inoculant strain on the nodulation of PBA KareemaA broad bean on Kangaroo Island, SA (sown after break) and PBA SamiraA faba beans at Wanilla, SA (sown dry). Within a site, values followed by the same letter are not significantly different.

Site	Peat slurry on seed with strain WSM-1455	TagTeam® Granule with strain WSM-1455	Peat slurry on seed with strain SRDI-954
Kangaroo Island, SA (nodule score, 0 to 5)	1.5 a	2.7 ab	3.3 bc
Wanilla, SA (mg nodule dry weight/6 plants)	273 a	1758 b	2190 b

At the dry sown Wanilla site (2017), where the performance of various inoculant formulations containing WSM-1455 was assessed, nodulation was positively correlated with the number of cells delivered by the product (the combination of the rhizobia number in the product and application rate) (Fig. 5).

The result demonstrates that granules can work in an acidic soil, but in step with the efficacy of inoculants more generally, their performance is likely to be dependent upon the number of rhizobia they deliver. Granules provide the possibility of being able to separate the rhizobia from seed applied pesticides and fertilisers which is desirable, and so the delivery of the improved rhizobia strains in a 'high count' granule may provide opportunity for further improvement.

Liming

The development of new rhizobia strains should not be seen as a replacement for liming. Even with good inoculation practice on acid soils, nodulation can remain below potential and rhizobial colonisation of the soil is limited, so the addition of lime is still needed. Liming to raise soil pH above pH($_{Ca}$) 5.0 also corrects nutritional deficiencies and toxicities that more broadly limit crop performance.

Further, since nitrate leaching after pulse growth is a significant contributor to soil acidification, liming is important to counter this and prevent further acidification.

Improved rhizobia will still be of benefit where soils are limed, especially where there are acidic sub-surface soil layers that are difficult to remediate due to the slow movement of lime down the profile.

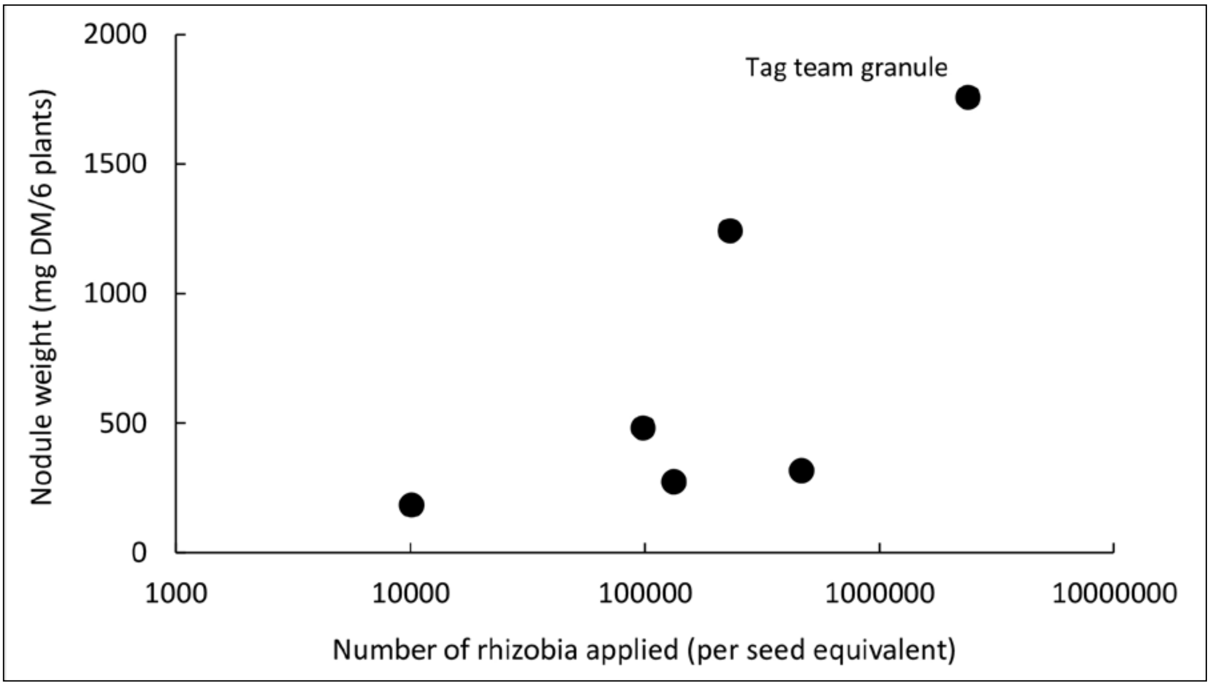

Figure 5. Relationship between number of rhizobia delivered at sowing by different inoculant formulations of rhizobia and the nodulation of PBA Samira⁽ᶦ⁾ faba beans sown at Wanilla, Eyre Peninsula, SA in 2017.

Discussion

There are reasonable prospects that a strain of rhizobia with improved acid tolerance can be selected for faba beans which are being grown on some very acid soils. An improved strain would also have the potential to be used on lentils which are in the same inoculation group. Improved acid tolerance of the rhizobia strains for faba beans and lentils may provide the potential to expand these crops into new environments and improve their performance in existing acid soil areas.

Where a rhizobia strain with improved acidity tolerance is combined with good inoculation practice, it should be possible to remove symbiotic constraints to faba bean production between $pH_{(Ca)}$ 4.5 and 5.0. The lower pH limit for lentils needs to be clarified, but they are generally regarded as more sensitive than faba beans. None of the rhizobia strains tested thus far appear to be able to persist in soil below $pH_{(Ca)}$ 5.0, therefore re-inoculation will be essential each time the crop is grown.

Until a new strain is available, growers should consider increasing their inoculation rate and avoid exposing the rhizobia to pesticides, where it is practical to do so.

Improved rhizobia should be seen as an accompaniment, not a replacement for liming. Liming remains important to prevent further acidification and is therefore critical to the longer term sustainability of the farming system. Surface soil (0-10cm) should be limed to at least $pH_{(Ca)}$ 5.0, noting that a higher target may be needed to achieve adequate amelioration where acidity is prevalent below the soil surface.

Further testing is needed and planned to satisfy the criteria for a rhizobia strain replacement, with a view to replacing WSM-1455 in 2022.

Useful resources

Inoculating Legumes: A Practical Guide:

https://grdc.com.au/resources-and-publications/all-publications/bookshop/2015/07/inoculating-legumes

Soil Acidity:

http://www.agbureau.com.au/projects/soil_acidity/

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WSM strains were provided by Dr Ron Yates, Department of Primary Industries and Regional Development.

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Notes

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Phenology responses of barley in southern NSW

Felicity Harris[1], Kenton Porker[2], Ben Trevaskis[3] and David Burch[4].

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GRDC project code: DAN00173

Keywords

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

Take home messages

- Barley genotypes with alternative development patterns showed variation in flowering date in response to sowing time.
- High grain yields were achieved across a range of barley variety x sowing date combinations, and through varied yield components.

Background

The adaptation and yield potential of barley are dependent on matching phenology and sowing time of varieties to ensure heading date and grain formation occurs at an optimal time, with minimal exposure to abiotic stresses. In recent years, early heading date has been positively correlated with grain yield, and as such there has been a breeder focus on varieties with rapid development. This paper discusses phenology responses of some current barley varieties in conjunction with some novel genetic lines, yield responses with respect to sowing date, and opportunities for genotypes with alternative development patterns in southern NSW.

Barley phenology and yield development

The life cycle of barley consists of a series of phases with key development events which mark their start and completion. The timing and duration of these phases are directly related to the formation of specific grain yield components. These include the vegetative, early reproductive, late reproductive and grain filling phases. During the vegetative phase, leaves and tillers are initiated prior to the transition to the early reproductive stage, when spikelet development commences. Spikelet primordia continue to be initiated up until awn primordia appearance, which coincides with early stem elongation, and marks the transition to the late reproductive stage. This is also indicative of the determination of maximum grain yield potential. In the late reproductive phase, spike growth and differentiation occur up until anthesis. Following anthesis, and during the grain-filling phase, the embryo develops, producing a viable seed for a subsequent generation — this phase also coincides with the establishment of grain weight (Kirby and Appleyard, 1987).

The grain yield of barley is therefore determined by three main components — spike density, grains per spike, and individual grain weight, with phenology having a direct effect on the formation of each of these components and overall grain yield. Grain yield has been more closely associated with grain number than grain weight in barley — this has also been maintained in environments characteristic of terminal drought (Porker et al. 2016).

Drivers of phenology

Developmental progression is controlled by the interaction of genotype with temperature and photoperiod. In barley, patterns in phasic development are dependent on three sets of genes which control vernalisation (*Vrn*) response, photoperiod (*Ppd*) response and earliness *per se*. Accumulated temperature generally accelerates development of all phases, while there is an additional effect of vernalisation in some responsive genotypes, by which progression from vegetative to reproductive development is dependent on fulfilling a response to cold temperatures. The direct influence of vernalisation is to alter the length of the vegetative phase, which can indirectly affect the duration of subsequent phases. As barley is a long-day (LD) plant, the rate of development is increased with longer day-lengths. However, individual genotypes of current commercial varieties have varying levels of responsiveness to photoperiod. In photoperiod sensitive genotypes, short-day (SD) conditions prolong the vegetative phase and delay the transition to reproductive development, while long-day conditions decrease time to floral initiation. In vernalisation responsive genotypes, following saturation of the vernalisation response, long days hasten progressive inflorescence development and stem elongation. Vernalisation is essentially the prerequisite for long days to reduce the time to flowering (Distelfeld and Dubcovsky, 2009). Barley genotypes differ in flowering time after vernalisation and photoperiod responses have been accounted for — this variation is generally referred to as earliness per se (*Eps*) (Karsai et al. 2001).

Phasic development is readily modified by selection and breeding which can lead to improved adaptation to an environment. The most adapted Australian varieties are characterised as having a relatively short duration to heading and strong response to increase in photoperiod, for example cv. La Trobe⁽ᵈ⁾ (Porker et al. 2016). Currently, there is only one winter variety suited to early sowing cv. Urambie⁽ᵈ⁾, which has been bred for grazing purposes afforded by an extended vegetative phase in response to a vernalisation requirement. However, recent introductions from Europe of some alternative long-season spring varieties, such as RGT Planet, may present opportunities for earlier sowing.

2017 results

A field experiment was conducted at Wagga Wagga Agricultural Institute, NSW, to determine the influence of variation in phenology patterns on grain yield and components. Sixteen near isogenic lines (NILs) were used that contained different combinations of *vernalisation and photoperiod* genes derived from ultra-early barley genotype WI4441 (developed by Ben Trevaskis, CSIRO), three French winter genotypes (Secobra Research) with strong vernalisation and five commercial genotypes with varied development. These were sown on three dates, 21 April, 8 May and 26 May in 2017.

Phenology and grain yield

There was substantial variation in flowering date for the genotypes sown across the three sowing dates. Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering occurs at an appropriate time. In 2017, the genotypes and sowing date combinations which flowered mid-September to early October generally had the greatest yields (Figure 1). In southern NSW, this response is common, generally driven by the high risk of frost damage early, and heat and moisture stress later.

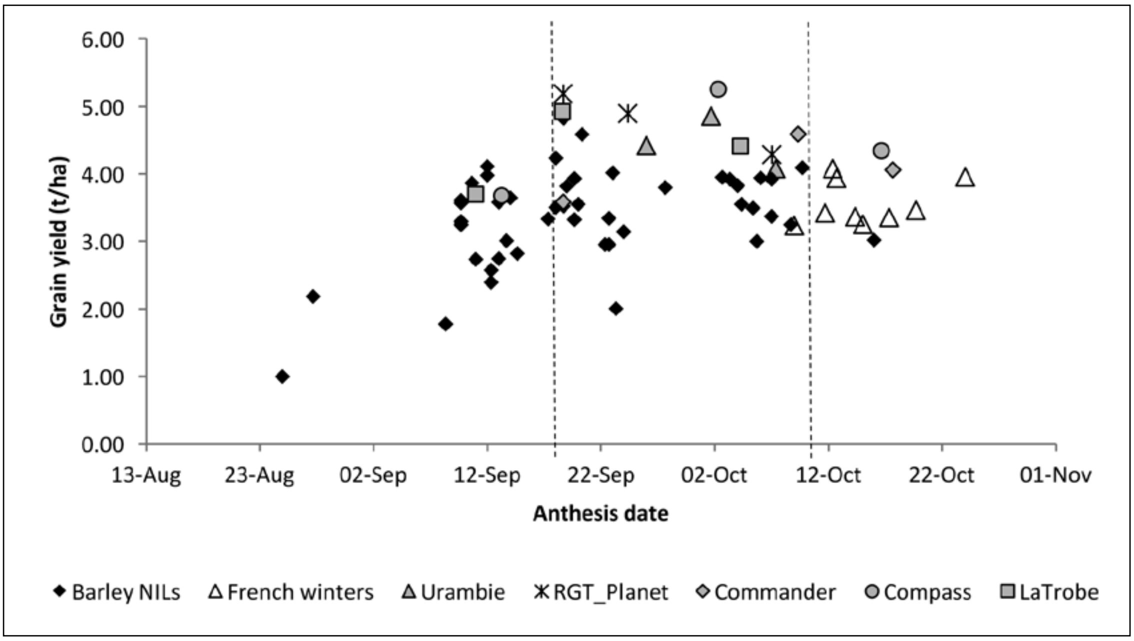

Figure 1. Relationship between anthesis date and grain yield of genotypes sown 21 April, 8 May and 26 May at Wagga Wagga in 2017. Dashed lines indicate optimal flowering period.

Trials conducted from 2014-2017 have indicated that mid-May sowing of many spring varieties, such as LaTrobe⁽ᵈ⁾, Compass⁽ᵈ⁾ and Commander⁽ᵈ⁾ achieve optimal flowering times, however, the increased photoperiod of Commander⁽ᵈ⁾ means it flowers slightly later than the faster developing genotypes. Urambie⁽ᵈ⁾ is suited to earlier sowing due to its vernalisation and photoperiod responses, and is relatively stable in its flowering response across sowing dates. RGT Planet is a longer-season spring genotype which offers an alternative phenology pattern, in which its vegetative period is slightly longer than spring types, with an extended reproductive phase. RGT Planet has shown some flexibility across sowing dates and is capable of being sown earlier than most other fast developing commercial spring genotypes. The NILs were all relatively quick to flower, however the genetic variation in phenology responses indicated there may be alternative development patterns suitable for achieving optimal flowering time in southern NSW worth exploring. The French winter lines had later flowering dates compared to the current commercial genotypes, indicative of a stronger vernalisation response comparative to Urambie⁽ᵈ⁾. Despite flowering outside the optimal time, they achieved relatively high stable grain yields across the sowing dates, and highlight opportunities for slower developing barley genotypes, which may be better suited to an earlier April sowing.

Grain yield components

Results from the 2017 field experiments indicated that relative to the site mean, grain yield was predominately driven by increased grain number responses in most varieties (Figure 2a). However,

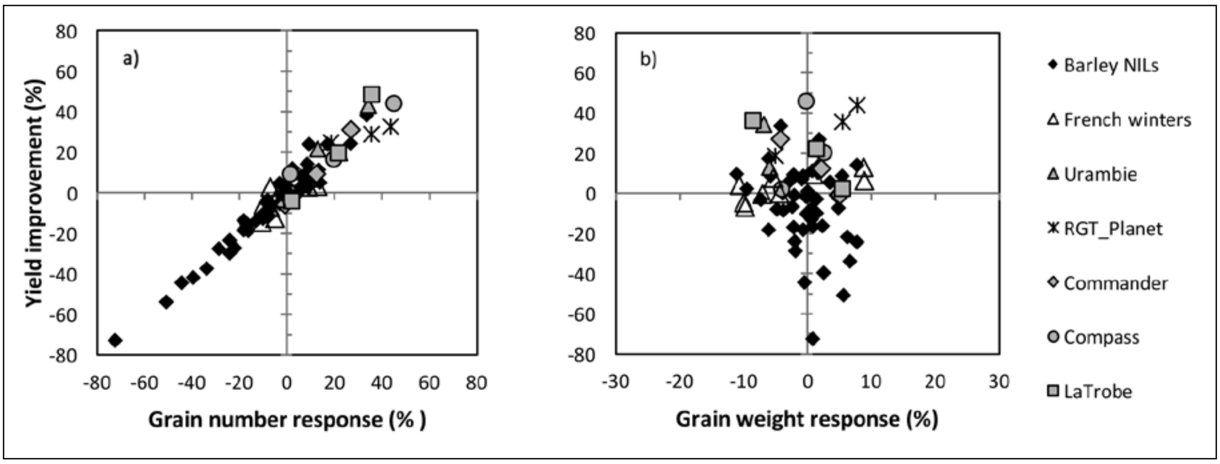

Figure 2. Relationship between yield improvement and its components — a) grain number (grains/m^2), and b) average grain weight (mg). Data is expressed as a percentage of the site mean.

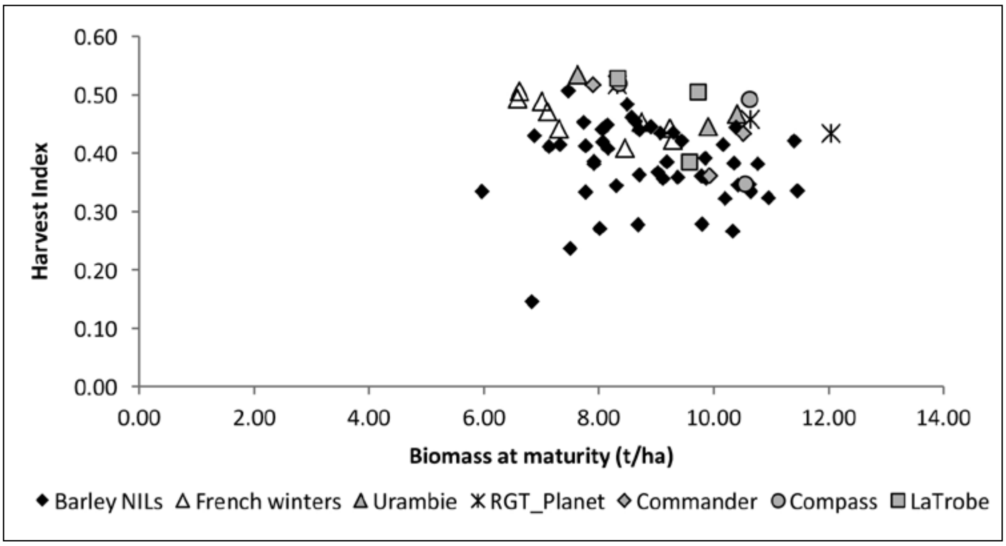

Figure 3. Relationship between HI and biomass at maturity of genotypes sown 21 April, 8 May and 26 May at Wagga Wagga in 2017.

there was varied influence of grain weight on yield improvement among genotypes for the three sowing dates (Figure 2b). Adapted varieties RGT Planet and Compass⁽ᵈ⁾ maintained a relative high grain number and weight across most sowing times. In contrast, UrambieA had a trade-off between grain number and grain weight at all sowing times, as did LaTrobe⁽ᵈ⁾ when it achieved highest yields from 8 May sowing date.

In 2017, harvest index (HI) (ratio of grain yield to biomass) was maintained under high biomass levels (Figure 3). An analysis of the grain yield components shows that barley genotypes vary in their ability to achieve yield in response to sowing time. For example, LaTrobe⁽ᵈ⁾ had the highest grain yield from sowing on 8 May, and this was largely attributed to a high number of spikes/m^2 while maintaining grains/spike and moderate grain weight. In contrast, RGT Planet had highest grain yield from an earlier 21 April sowing date, achieved through a high spike density coupled with high grain weights, with moderate grains/spike.

Summary

Our data suggested there is scope for exploring alternative development genes for more varied phenology patterns in barley for earlier April sowing, but these options are currently limited. There are differences in flowering date and yield development in response to sowing time in the barley NILs, French winter lines, and commercial varieties that growers can exploit. Urambie⁽ᵈ⁾ and RGT Planet offer opportunities for earlier sowing compared with other spring varieties best suited to mid-May sowing in southern NSW. However, RGT Planet does not have a vernalisation requirement like Urambie⁽ᵈ⁾ and growers should be cautious when considering sowing earlier than May in frost prone environments. Compared to other cereals, barley is an adaptive crop, capable of achieving high stable grain yields across a range of genotype x sowing time combinations and through varied yield components. However, matching variety and sowing time to achieve flowering at an appropriate time for the growing environment is the most effective management strategy in optimising grain yields.

Acknowledgements

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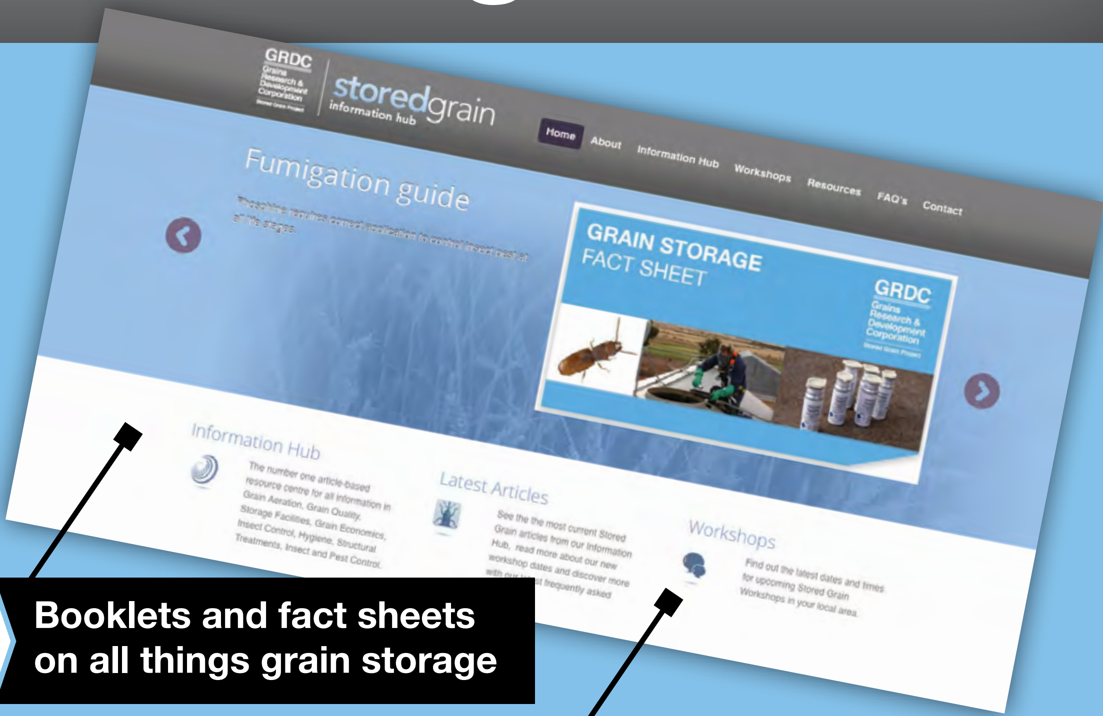

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Barley agronomy results from the central west and Riverina NSW, 2017

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GRDC project code: DAN00173

Keywords

- variety update, time of sowing , nitrogen fertiliser, weed management.

Take home messages

- The target flowering date for barley sown in central west NSW is the last week of August to the first week of September.
- La Trobe⦸ and Compass⦸ are responsive to nitrogen (N) fertiliser provided sufficient rainfall occurs during the grain filling period.
- New barley varieties provide improved yield potential if there is adequate rainfall, however La Trobe⦸ remains the yield benchmark in low yielding environments.

2017 seasonal and production summary

The 2017 growing season was impacted with lower than average winter rainfall throughout much of NSW, resulting in an estimated statewide barley yield of 1.5t/ha. This is a 26% decrease on the 10 year average to 2016. Barley total production in 2017 fell by 56% compared to the record year of 2016, with a total statewide production of 1,185 kt (ABARES, 2017). Frost events were widespread across the state with yield losses attributed to stem frost and frost induced sterility. Low rainfall inhibited the production of later tillers, although above average rainfall in October boosted crop yields in milder longer season regions of the state. The world indicator price for barley (France feed barley, FOB Rouen) was forecast to average US$180 per tonne (December 2017), a 14% increase on 2016 prices.

New barley varieties

AGTB0015 (Australian Grains Technologies)

AGTB0015 is suited to the medium to high rainfall areas with yields comparative to or in excess of the current yield benchmarks and with improved standability, head retention and grain size. AGTB0015 entered the malt accreditation process in 2017, with a decision due in 2020.

Biere⦸ (GrainSearch)

Biere⦸ (GS 9516-06) is a short season variety with malt potential. Flowering seven days earlier than La Trobe⦸, it is intended for medium to low rainfall zones due to faster maturity, and is most suited to 2-3t/ha environments. It has entered stage 1 malt accreditation in 2017, although it will be repeated in 2018 due to insufficient seed.

Bottlerᶲ (GrainSearch)

Bottlerᶲ (HV16) is an export malt type grain suited to medium to high rainfall zones currently being evaluated to replace Baudinᶲ. While it has malt characteristics, it has currently not been entered into the malt accreditation process.

Compassᶲ (University of Adelaide)

Compassᶲ is derived from Commanderᶲ, with improved grain yield and plumpness. It is slightly later to flower than La Trobeᶲ, with an increased tendency to lodge in wet conditions. Compassᶲ is currently undergoing stage 2 malt evaluation, with a possible decision by 2018.

Explorerᶲ (University of Adelaide)

Explorerᶲ is a late season, high rainfall variety, intended for a similar environment to Westminsterᶲ. Field trials indicate its yield is consistently 12% higher than Westminsterᶲ with similar agronomic traits.

RGT Planetᶲ (Seed Force)

RGT Planetᶲ was released in Europe in 2010 and has since been the top yielding malt variety in many countries. It was introduced to the NVT program in 2016 and was the highest yielding variety in 60% of the sites in NSW. Field trials indicate RGT Planetᶲ is early flowering and late maturing, with the flexibility to adapt to early or late season finishes.

Spartacus CLᶲ (InterGrain)

Spartacus CLᶲ is an imidazolinone tolerant barley with similar grain yield, quality and agronomic characteristics to La Trobeᶲ. Spartacus CLᶲ is higher yielding than Scope CLᶲ, flowering 10 days earlier and has a lower risk of head loss. Spartacus CLᶲ has been released as a feed barley although it is being evaluated for malt accreditation, with a possible decision by March 2018.

Varietal response to sowing date at Condobolin 2017

The date in which a barley crop flowers is determined by varietal selection and environment. It is important for growers to be aware of the differences in a varieties' phasic length in order to maximise yield when making varietal and sowing decisions. Early flowering varieties' such as Hindmarshᶲ and La Trobeᶲ have become popular due to their yield stability in medium to low rainfall cropping zones, however, early flowering dates expose the crop to the risk of frost damage. Conversely, late flowering times can result in moisture stress during grain fill and subsequent yield penalties. Experiments conducted in 2017 assessed the flowering date and yield response of a number of commercially available varieties over a range of sowing dates in central western NSW.

Method

A replicated split plot experimental trial was conducted at Condobolin in 2017 (Table 1). The site received below average rainfall at the beginning of the growing season, and was impacted by frost damage throughout the flowering period. Sowings were conducted at three dates in order to represent early, main and late season sowings.

Table 1. Site characteristics for Condobolin Agricultural Research and advisory station 2017.

Soil Type	Red-brown chromosol
Rainfall	GSR (Apr-Sep): 99mm (LTA GSR 209mm)
Previous crop	Fallow
Fertiliser	70kg/ha MAP (sowing) Starting N 114kg/ha

Results and discussion

Eighty-four frost events occurred throughout the growing period in Condobolin, with 26 nights recording temperatures of below -2°C. Frost and low rainfall were the major limitations to crop yield.

There were significant effects observed between varieties ($P < 0.001$), and sowing dates ($P = 0.003$) at Condobolin (Table 2). The 12 May (mid-season) sowing date had the greatest grain yield overall, with a mean yield of 1.68t/ha in Condobolin. The late season sowing was the lowest yielding at Condobolin with a mean of 1.50t/ha.

Mid-May sowings yielded significantly greater than early and late sown treatments overall, although varieties AGTB0015, Bottlerᶲ, IGB1305, RGT Planetᶲ and Urambieᶲ all yielded significantly higher when sown on April 24. All varieties with the exception of Fathomᶲ and RGT Planetᶲ incurred a yield penalty in the late sowing compared to mid-season. This experiment and prior years' experiments indicate that in the central west of NSW, the target flowering date is the last week of August to the first week of September in order to avoid frost induced yield losses and ensure sufficient soil moisture for grain fill (Figure 2). It is important to note that decisions on varieties and sowing dates require knowledge of multi-year trends, as a single season may not be representative of the typical regional growing environment.

Table 2. Grain yield and flowering date of sixteen barley varieties from three times of sowing (TOS) at Condobolin 2017.

Variety	TOS 1 - 24 April, 2017		TOS 2 - 12 May, 2017		TOS 3 - 25 May 2017	
	Grain Yield (t/ha)	Heading date (GS55)	Grain Yield (t/ha)	Heading date (GS55)	Grain Yield (t/ha)	Heading date (GS55)
AGTB0015	1.86	28-Aug	1.73	9-Sep	1.69	16-Sep
Biere⁽ᵈ⁾	1.45	12-Aug	1.48	30-Aug	1.36	10-Sep
Bottler⁽ᵈ⁾	1.94	8-Sep	1.57	17-Sep	1.48	21-Sep
Commander⁽ᵈ⁾	1.85	9-Sep	1.95	20-Sep	1.79	25-Sep
Compass⁽ᵈ⁾	1.78	25-Aug	1.90	10-Sep	1.59	22-Sep
Fathom⁽ᵈ⁾	1.72	24-Aug	1.86	8-Sep	1.86	15-Sep
Hindmarsh⁽ᵈ⁾	1.11	20-Aug	1.55	8-Sep	1.36	14-Sep
IGB1305	1.81	11-Sep	1.72	18-Sep	1.38	23-Sep
IGB1512	0.99	18-Aug	1.73	8-Sep	1.71	16-Sep
La Trobe⁽ᵈ⁾	1.61	20-Aug	1.82	8-Sep	1.54	17-Sep
RGT Planet⁽ᵈ⁾	1.88	4-Sep	1.56	12-Sep	1.56	18-Sep
Rosalind⁽ᵈ⁾	1.36	17-Aug	1.38	7-Sep	0.95	23-Sep
Spartacus CL⁽ᵈ⁾	1.32	19-Aug	1.61	7-Sep	1.46	18-Sep
Urambie⁽ᵈ⁾	1.74	17-Sep	1.41	22-Sep	1.39	26-Sep
Westminster⁽ᵈ⁾	1.60	17-Sep	1.68	22-Sep	1.18	26-Sep
WI4982	1.48	7-Sep	1.96	10-Sep	1.73	17-Sep
Mean (TOS)	**1.59**	**31-Aug**	**1.68**	**13-Sep**	**1.50**	**21-Sep**

l.s.d (*P*<0.05) TOS 0.09 t/ha, Variety 0.24 t/ha

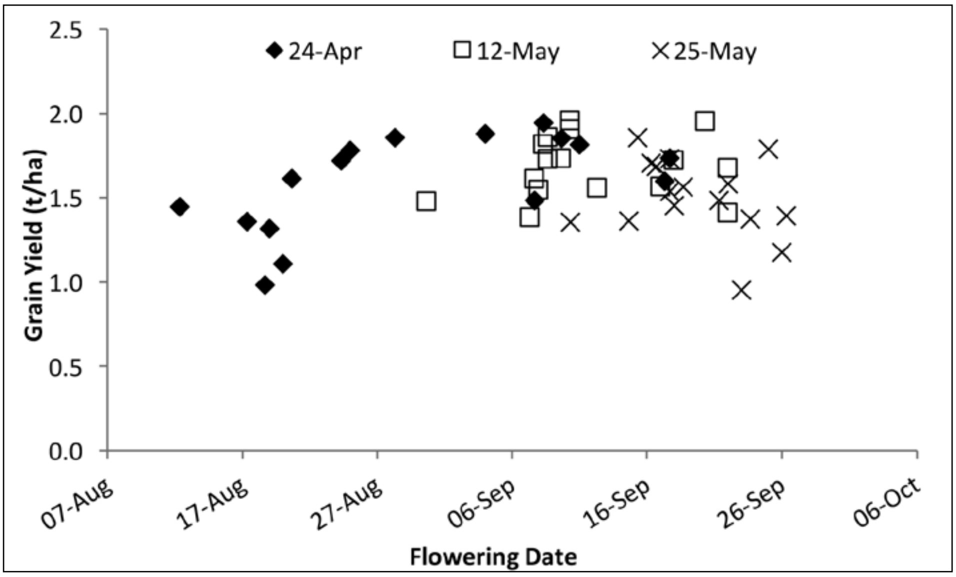

Figure 1. Flowering date and grain yield of barley varieties sown at three dates at Condobolin 2017. l.s.d. (*P* < 0.05) Time of sowing 0.09 t/ha, Variety 0.24 t/ha.

Yield and quality responses to nitrogen fertiliser

For barley to be accepted for malt, it must have a grain protein concentration of between 9% and 12%. The addition of N fertiliser can boost yields in environments where water is not limiting. However, high N rates combined with moisture stress may result in high grain protein concentration, reduce retention (grain retained above 2.5mm sieve), increase screenings (grain below 2.2mm sieve) and reduce grain weight. Increased lodging may also occur in susceptible varieties such as Commander⁽ᵈ⁾ and Compass⁽ᵈ⁾. A series of field experiments were conducted to assess the yield and quality responses of four commercial barley cultivars to different N treatments.

Method

Field experiments were conducted in the Riverina and central west of NSW assessing varietal responses to N fertiliser between 2013 and 2016. Malting varieties Commander⁽ᵖ⁾, GrangeR⁽ᵖ⁾, La Trobe⁽ᵖ⁾ and Compass⁽ᵖ⁾ (currently undergoing malt accreditation) were sown in randomised complete block trials with 0, 30, 60, 90 and 120kg/ha of N applied as urea at sowing.

Results and discussion

Averaged over all years, there was a significant decrease in yield as N applications increased, while grain protein concentration significantly increased (Table 3). Yield and subsequent quality responses were highly variable over the four years of the experiment, due to large differences in available moisture year to year. Yield reduction following N application can in part be attributed to decreased grain size, which significantly reduced retention and increased screenings. Hectolitre weights were also significantly reduced with increasing N. Number of ears per square metre was unchanged in all varieties except for La Trobe⁽ᵖ⁾, which significantly increased. There was a significant variety by N interaction for grain protein, screenings, hectolitre weight and anthesis biomass. There was no interaction for yield, retention, grain weight, harvest index, and grain weight per ear, indicating no difference in varietal response to N application.

The highest yielding variety in all treatments was La Trobe⁽ᵖ⁾, while Compass⁽ᵖ⁾ had equal or lower grain protein concentrations to La Trobe⁽ᵖ⁾. While lower grain protein concentrations may be due to yield dilution, a comparison of total protein yield per hectare (Figure 2) indicates that La Trobe⁽ᵖ⁾ and GrangeR⁽ᵖ⁾ convert N fertiliser into grain protein more readily, while Compass⁽ᵖ⁾ has a greater capacity to convert N fertiliser into yield while suppressing grain protein.

An analysis of agronomic efficiency (kg grain yield per kg of N applied), it was found that La Trobe⁽ᵖ⁾ and Compass⁽ᵖ⁾ were significantly more responsive to N fertiliser than GrangeR⁽ᵖ⁾ and Commander⁽ᵖ⁾. The agronomic efficiency of all varieties decreased at higher N applications, indicating that in sites

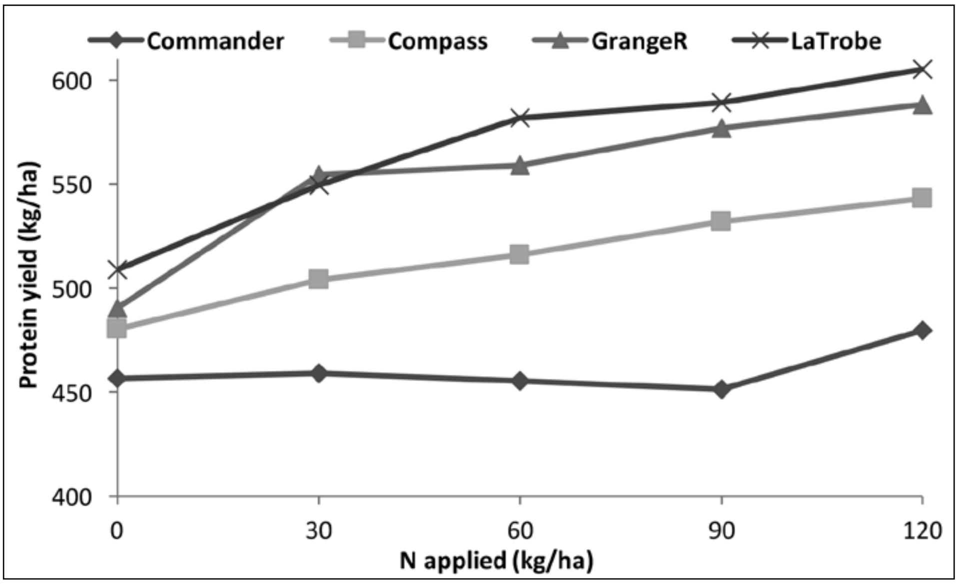

Figure 2. Protein yield of four barley varieties treated with five concentrations of N fertiliser. l.s.d ($P < 0.05$) (Variety) 22 kg/ha.

Table 3. Grain yield and quality of four barley varieties treated with five nitrogen (N) rates between 2013 and 2016.

N Treatment	Grain yield (t/ha)				Grain protein (%)			
(kg N/ha)	Commander⁽ᵖ⁾	Compass⁽ᵖ⁾	GrangeR⁽ᵖ⁾	LaTrobe⁽ᵖ⁾	Commander⁽ᵖ⁾	Compass⁽ᵖ⁾	GrangeR⁽ᵖ⁾	LaTrobe⁽ᵖ⁾
0	3.4	3.95	3.59	4.15	13.4	12.2	13.6	12.3
30	3.3	3.92	3.75	4.13	13.9	12.8	14.8	13.3
60	3.14	3.76	3.54	4.25	14.5	13.7	15.8	13.7
90	3.08	3.82	3.65	4.19	14.6	13.9	15.8	14
120	3.16	3.73	3.55	4.09	15.2	14.5	16.6	14.8
l.s.d ($P = 0.05$)	Variety 0.24 t/ha, N rate 0.10 t/ha				Variety 0.30 %, N rate 0.21 %, V x N 0.39 %			

where yield is limited by other nutrients or moisture limitation, high N applications may only serve to decrease grain size and increase protein.

Agronomic efficiency is highly dependent on moisture availability. In a comparison of low rainfall years, such as that in 2015 compared with high rainfall years such as 2016 demonstrated, a 72% increase in the efficiency of all varieties' capacity to convert N fertiliser into protein was observed. In higher yielding environments additional N applications may need to be applied to a low protein variety such as Compass⁽ᴰ⁾ in order to ensure its grain protein concentration is sufficient for malt quality.

Comparison of four high yielding varieties under different water treatments at Condobolin 2017

Since its commercial release in 2013, La Trobe⁽ᴰ⁾ barley has become the most widespread malting variety in the low and medium rainfall zone, due to consistently high yields and desirable malt characteristics. Since then, several barley varieties have entered the market, with comparable yield and quality characteristics, providing varietal alternatives for growers in the medium to low rainfall zone. This experiment assesses the performance of La Trobe⁽ᴰ⁾ against newly released barley varieties Compass⁽ᴰ⁾, Rosalind⁽ᴰ⁾ and RGT Planet⁽ᴰ⁾ under different irrigation treatments.

Method

Please refer to Table 1 for site conditions. Four irrigation treatments were applied to the experiment, as described in Table 4. The growing season was divided into pre and post anthesis phases, assuming an anthesis date of September 1. The rainfed treatment was naturally occurring rainfall, while full irrigation consisted of 120mm of additional water. Pre and post-anthesis irrigation consisted of 60mm of irrigation water applied either before or after anthesis.

Results and discussion

Yield

There was a significant yield difference in irrigation treatments and variety, with a significant interaction between the two. La Trobe⁽ᴰ⁾ was the lowest yielding variety overall, although there was no significant yield difference between varieties in the rainfed treatment (Figure 3). The highest yielding varieties were Rosalind⁽ᴰ⁾ and RGT Planet⁽ᴰ⁾ in the fully irrigated treatment, Compass⁽ᴰ⁾ and Rosalind⁽ᴰ⁾ in the post–anthesis irrigation treatment and RGT Planet⁽ᴰ⁾ and Rosalind⁽ᴰ⁾ in the pre–anthesis irrigation treatment (Table 5).

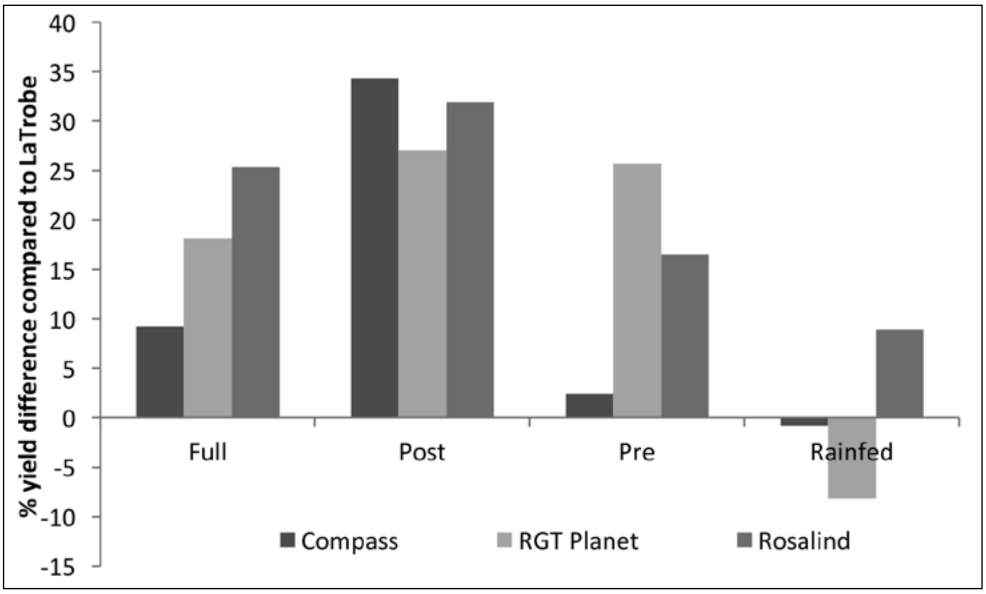

Figure 3. Percentage difference in grain yield of three barley cultivars as compared to La Trobe⁽ᴰ⁾ when treated with four irrigation treatments.

Table 4. Four irrigation treatments applied to four barley varieties at Condobolin, NSW 2017.

Watering timing	Rainfed (mm)	Pre-anthesis irrigation (mm)	Post-anthesis irrigation (mm)	Full irrigation (mm)
Pre anthesis	93	153	93	153
Post-anthesis	6.2	6.2	66.2	66.2
Total	**99.2**	**159.2**	**159.2**	**219.2**

Table 5. Yield (t/ha) and yield components of four barley varieties treated with different irrigation regimes.

		Irrigation treatment				
		120mm irrigation	Rainfed	60mm Pre-anthesis	60mmPost-anthesis	Mean
Yield (t/ha)	Compass⦸	2.80	1.31	1.92	2.01	**2.01**
	La Trobe⦸	2.55	1.32	1.88	1.32	**1.77**
	RGT Planet⦸	3.01	1.22	2.36	1.68	**2.07**
	Rosalind⦸	3.19	1.44	2.19	1.74	**2.14**
	Mean	**2.89**	**1.32**	**2.09**	**1.69**	**2.00**
	l.s.d. (*P* = 0.05)	**Variety 0.14, Treatment 0.09, Interaction 0.29**				
No. grains/m^2	Compass⦸	9551	6277	8336	7584	**7937**
	La Trobe⦸	8982	6601	8130	6701	**7604**
	RGT Planet⦸	9586	5275	8899	6359	**7530**
	Rosalind⦸	9879	5485	8189	6543	**7524**
	Mean	**9500**	**5910**	**8389**	**6797**	**7649**
	l.s.d. (*P* = 0.05)	**Variety 645, Treatment 643, Interaction 1290**				
No. tillers/m^2	Compass⦸	558	375	492	619	**511**
	La Trobe⦸	611	467	578	551	**552**
	RGT Planet⦸	486	316	462	491	**439**
	Rosalind⦸	612	429	630	514	**546**
	Mean	**567**	**397**	**540**	**544**	**512**
	l.s.d. (*P* = 0.05)	**Variety 52.4, Treatment 28.2, Interaction 0.29**				
Grain No/tiller	Compass⦸	17.2	16.9	17.4	12.7	**16.0**
	La Trobe⦸	15.2	14.2	14.3	12.2	**14.0**
	RGT Planet⦸	19.8	16.8	19.2	13.1	**17.2**
	Rosalind⦸	16.5	13.1	13.3	12.8	**13.9**
	Mean	**17.1**	**15.3**	**16.0**	**12.7**	**15.3**
	l.s.d. (*P* = 0.05)	**Variety 0.97, Treatment 0.72, Interaction 1.94**				
Thousand grain weight (g)	Compass⦸	49.3	38.5	42.4	42.7	**43.2**
	La Trobe⦸	43.1	35.9	37.1	38.6	**38.7**
	RGT Planet⦸	51.2	36.9	42.0	42.2	**43.1**
	Rosalind⦸	46.6	36.9	39.7	39.9	**40.8**
	Mean	**47.5**	**37.0**	**40.3**	**40.8**	**41.4**
	l.s.d. (*P* = 0.05)	**Variety 0.59, Treatment 0.36, Interaction 1.17**				

Yield components

Grain yield is a factor of three components; grain weight, tiller number and number of grains per tiller. The main driver for grain yield in this experiment was total grains per square metre (Figure 4), with an r^2 value of 0.88 between grain yield and number of grains per square metre. This indicates that the greatest drivers of yield are tillers per square metre and number of grains per tiller. La Trobe⦸ produced significantly more tillers than other varieties, with RGT Planet⦸ producing the least. This difference has been offset by more kernels per spike and larger grain weight in RGT Planet⦸.

There was a significant varietal effect from the irrigation treatment on grain number per tiller, thousand grain weight and tillers per m^2. Number of grains per m^2 was not affected by variety, but was affected by irrigation treatment. When assessing yield stability in high and low water availabilities, La Trobe⦸ demonstrated the smallest decrease in yield, grains per m^2, tillers per m^2 and thousand grain weight. RGT Planet⦸, while yielding competitively in the irrigated treatment, had the greatest decrease in yield, grains per m^2, tillers per m^2 and thousand grain weight. While RGT Planet⦸ has demonstrated a capacity for high yields when moisture is available, it does not demonstrate a yield advantage over other varieties when moisture is limiting.

Quality

There were significant differences between variety and irrigation treatments with a significant interaction for protein, screenings, retention, test

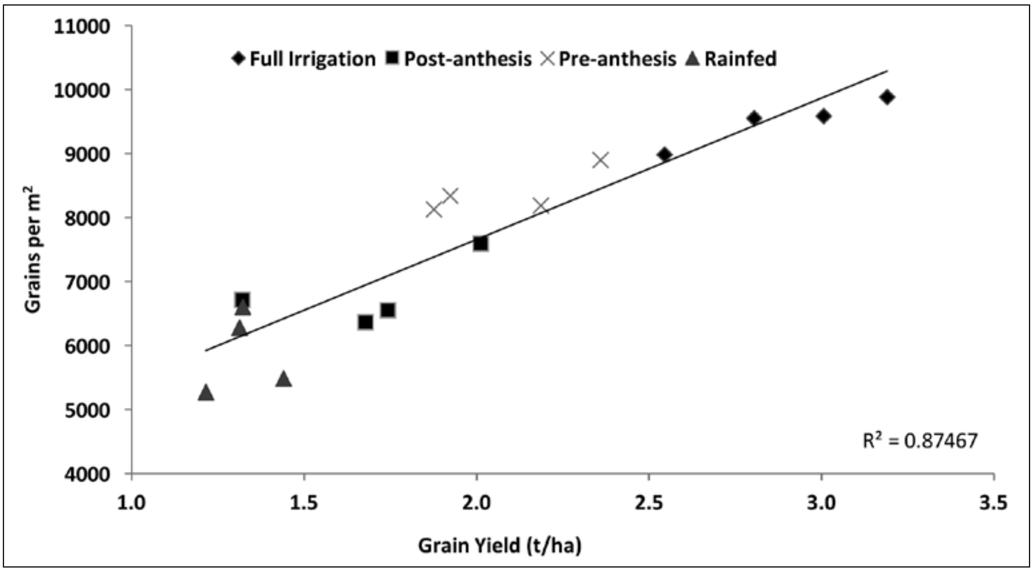

Figure 4. Relationship between grain number per square metre and total grain yield for four barley varieties treated with four irrigation practices.

Table 6. Yield (t/ha) and yield components of four barley varieties treated with different irrigation regimes.

		Irrigation treatment				
		120mm irrigation	Rainfed	60mm Pre-anthesis	60mmPost-anthesis	Mean
Protein (%)	Compass⊕	12.3	13.5	12.3	14.8	**13.2**
	La Trobe⊕	13.5	13.3	12.8	15.7	**13.8**
	RGT Planet⊕	12.0	13.6	12.0	14.7	**13.1**
	Rosalind⊕	12.4	13.8	13.3	15.0	**13.6**
	Mean	**12.6**	**13.5**	**12.6**	**15.1**	**13.4**
	l.s.d. (P = 0.05)	**Variety 0.4, Treatment 0.3, Interaction 0.7**				
Test weight (kg/HL)	Compass⊕	65.9	62.3	63.8	65.1	**64.3**
	La Trobe⊕	67.9	64.3	64.9	66.4	**65.8**
	RGT Planet⊕	67.6	62.6	63.9	65.6	**64.9**
	Rosalind⊕	67.2	63.7	64.8	65.4	**65.3**
	Mean	**67.1**	**63.2**	**64.4**	**65.6**	**65.1**
	l.s.d. (P = 0.05)	**Variety 0.35, Treatment 0.28, Interaction 0.7**				
Retention (>2.5mm)	Compass⊕	98.5	85.3	90.8	94.2	**92.2**
	La Trobe⊕	93.9	74.3	70.0	87.7	**81.5**
	RGT Planet⊕	98.0	63.0	82.8	90.2	**83.5**
	Rosalind⊕	96.8	73.3	81.0	88.8	**85.0**
	Mean	**96.8**	**74.0**	**81.2**	**90.2**	**85.5**
	l.s.d. (P = 0.05)	**Variety 1.8, Treatment 1.4, Interaction 3.6**				
Screenings (<2.2mm)	Compass⊕	0.4	2.1	1.2	1.1	**1.2**
	La Trobe⊕	0.7	2.9	4.6	1.6	**2.5**
	RGT Planet⊕	0.5	4.1	2.0	2.1	**2.2**
	Rosalind⊕	0.5	4.6	3.1	2.0	**2.5**
	Mean	**0.5**	**3.4**	**2.7**	**1.7**	**2.1**
	l.s.d. (P = 0.05)	**Variety 0.34, Treatment 0.29, Interaction 0.69**				
Harvest Index	Compass⊕	0.51	0.49	0.50	0.48	**0.5**
	La Trobe⊕	0.53	0.52	0.51	0.52	**0.5**
	RGT Planet⊕	0.54	0.47	0.52	0.47	**0.5**
	Rosalind⊕	0.52	0.48	0.49	0.49	**0.5**
	Mean	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
	l.s.d. (P = 0.05)	**Variety 0.01, Treatment 0.01, Interaction 0.02**				

weight, harvest index and thousand grain weight (Tables 5 and 6). Compass⏀ and RGT Planet⏀ demonstrated the greatest ability to suppress grain protein concentration, although this may have been in part due to yield dilution. When moisture stress occurred, RGT Planet⏀ demonstrated significantly lower retention rates of 63%, which has the potential to affect receival prices if accepted for malt in the future. There was a significant difference in grain protein concentration within the fully irrigated treatment, with La Trobe⏀ significantly higher than RGT Planet⏀, although there was no difference in the rainfed treatment between any of the varieties. As with previous experiments, a high yielding variety like La Trobe⏀ can have a genetic tendency to accumulate high grain protein (Table 6).

While new barley varieties on the market have greater yield potential if there is improved moisture availability, if sowing in a region where there is the potential of low rainfall such as central west NSW, there is minimal competitive advantage over the benchmark variety La Trobe⏀. However, under higher rainfall scenarios, new varieties do provide a competitive advantage to La Trobe⏀, although none of the other three varieties assessed in this experiment can currently be accepted for malt.

Cultural management of grass weeds within barley crops.

Herbicide options for in-season control of grass weeds in cereal crops can be limited. While some products are marketed specifically for wild oat control in cereals, herbicide applications must be timed correctly, or they can be ineffective, damage the crop and encourage herbicide resistance in future weed generations. One non-chemical management strategy is to select a cereal variety with sufficient early season vigour to out-compete weeds, precluding, or reducing reliance on herbicide use. This experiment used oat weed surrogates to assess the competitiveness of 18 commercial barley varieties for their capacity to suppress or out-compete weeds during the growing season in 2016.

Table 7. Site characteristics for the Condobolin Agricultural Research and Advisory Station 2016.

Soil Type	Red-brown chromosol
Rainfall	GSR (Apr-Sep): 467mm (mean GSR 209mm)
Previous crop	wheat
Fertiliser	70kg/ha MAP (sowing)

Method

Wintaroo⏀ oats (*Avena sativa* L.) were used as a surrogate for wild or black oats (*Avena fatua*, L.). Seeds were distributed onto the surface of experimental plots with a target plant density of 60 plants/m^2 prior to sowing. As plots were sown, some oat seeds were incorporated into the soil, simulating natural weed seed distribution. Barley varieties were sown in accordance with regional farming practices, with a target density of 125 plants/m^2.

Results and discussion

Grain yield

As oat biomass increased per m^2, barley yields decreased (Figure 5). There was no significant difference in total biomass/m^2 in the presence or absence of oats although the number of total tillers decreased in the presence of oats. There was a significant effect on yield of oat affected plots compared to control (oat free) plots (Table 8). All varieties had a yield penalty in the presence of oats with the exception of Bass⏀ and Buloke⏀ which showed no significant yield difference. The most impacted varieties were GrangeR⏀, Spartacus⏀ and Urambie⏀ (Table 9).

Table 8. Performance of barley yield components in the presence and absence of Wintaroo⏀ oats. ANOVA F probabilities for variety (V), Oat treatment (T), and interaction.

Yield Component	Weed Treatment		ANOVA F probability[a]		
	Nil	Oats	V	T	V X T
Grain Yield (t/ha)	4.28	3.45	NS	**	NS
Tillers/m^2	647	516	**	**	NS
Grain Weight (mg)	47.29	46.34	**	**	NS
Grains/tiller	18.35	19.51	**	*	NS
Grain weight per tiller (g)	0.87	0.90	**	NS	NS
Grain number/m^2	11 649	9 904	NS	**	NS
Dry matter/m^2 (g)	1 018	787	**	**	NS
Dry matter/tiller (g)	1.051	0.976	**	**	NS
Harvest Index	0.45	0.48	**	**	NS

[a]NS = not significant; * and ** = significant at the 0.05 and 0.01 levels of probability.

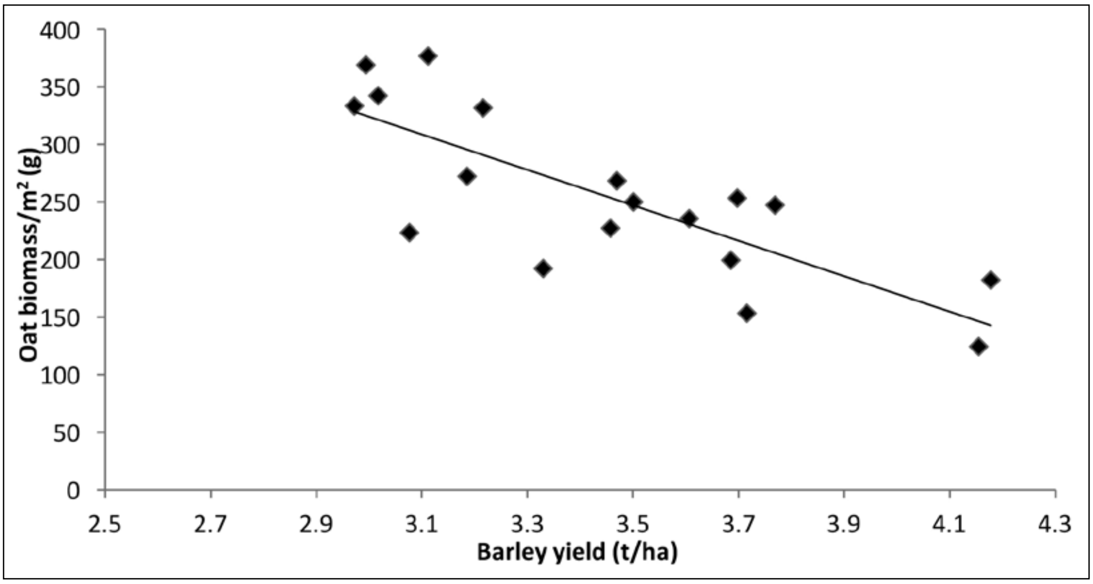

Figure 5. Relationship between oat biomass collected from experimental plots and barley yield (r^2 = 0.62).

Yield component analysis

The presence of oats significantly influenced all yield components except for grain weight per tiller (Table 8). Varietal competitiveness was assessed by comparing the percentage change in yield component due to the presence of oats (Table 9) as compared to oat free control plots.

Varietal capacity to supress oats

Measurement of dry oat biomass/m^2 at harvest demonstrated some correlation (r^2 = 0.41) with yield. While the capacity to suppress weed development is associated with reduced yield losses, some varieties, such as Flinders⦸ and Gairdner demonstrate small yield reductions with average oat suppression. Meanwhile, Fathom⦸ and Commander⦸ demonstrated the strongest capacity to suppress oat development, although ranked sixth and eighth for yield losses in the presence of oats (Figure 6). While early season oat suppression is important for maximising yield, other mechanisms contribute to specific varieties' capacity to perform in the presence of oats. The barley varieties used

Table 9. Percentage change in yield components in the presence of oats. * indicates a significant (*P* =0.05) treatment effect.

Variety	Yield	Grain weight	Tillers/m^2	Grains/tiller
Bass⦸	0.2	-0.8	-11.4*	15.8*
Buloke⦸	-0.6	-2.2*	-23.8*	18.3*
Commander⦸	-15.4*	0.0	2.9	-9.7*
Compass⦸	-19.3*	-3.1*	-9.9*	-19.1*
Fathom⦸	-13.3*	1.0*	-26.3*	-0.1
Flinders⦸	-12.4*	0.6	-16.1*	-2.2
Gairdner	-13.1*	-0.3	-13.0*	4.8*
GrangeR⦸	-32.4*	-4.8*	-23.5*	-2.2
Hindmarsh⦸	-18.5*	-0.5	-15.1*	4.4
La Trobe⦸	-16.8*	-0.6	-13.7*	14.6*
Maritime⦸	-10.5*	-3.2*	-21.5*	8.1*
Oxford	-23.1*	-4.5*	-26.6*	12.9*
Rosalind⦸	-29.5*	-3.3*	-36.7*	6.1*
Scope CL⦸	-14.24*	-1.4*	-20.1*	15.2*
Spartacus CL⦸	-31.27*	0.8	-43.5*	23.3*
Urambie⦸	-29.84*	-3.9*	-14.1*	8.9*
Westminster⦸	-28.95*	-5.1*	-34.7*	8.5*
Wimmera⦸	-29.74*	-5.1*	-5.3	-4.3

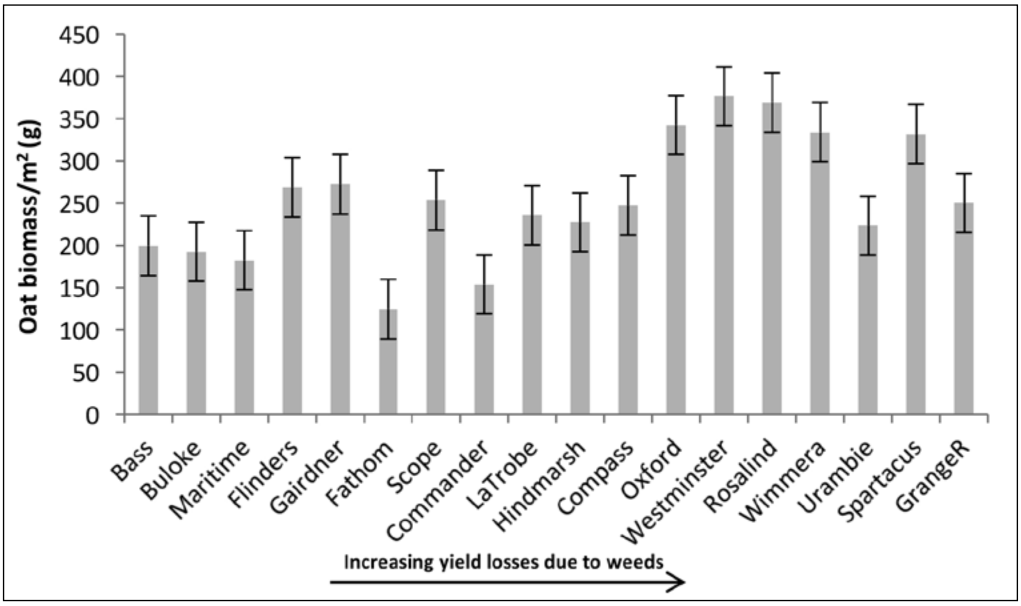

Figure 6. Total biomass/m^2 of oats recorded within experimental plots. X axis ranked in order of the percentage yield loss for each respective variety in the presence of oats. Error bars indicate 5% l.s.d. between varieties for total oat biomass present per m^2.

in this experiment varied widely in morphology and phenology. Despite this variation, and yield losses in oat treatments there was no single trait that led to superior oat suppression. This experiment indicated that a combination of varietal traits such as early season vigour, shading effects and environmental suitability contribute to oat suppression through diverse mechanisms.

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Notes

Optimising grain yield of wheat in southern NSW

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GRDC project code: DAN00213

Keywords

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

Take home messages

- High grain yields can be achieved from a range of genotype x sowing date combinations with wheat, however there is variation in genotype responses across environments in southern NSW.
- Whilst flowering time is important in maximising grain yield potential, pre-flowering phases can have a significant influence on grain yields.

Introduction

Wheat development is predominately controlled through varied responses to vernalisation (*Vrn*) and photoperiod (*Ppd*) genes. Genotypes responsive to vernalisation require a period of cold temperatures (accumulated most rapidly in the range 3°C to 10°C) to progress from vegetative to reproductive development, whilst time to flowering is accelerated during long-days in photoperiod sensitive genotypes. The range in development patterns in Australian wheat varieties (due to responses to *Vrn* and *Ppd*) provides growers with flexibility in their sowing window. Grain yield is maximised when genotype and sowing date are matched so that flowering occurs when the risk of early frost damage and later, heat and moisture damage, is low. Generally, in southern NSW, winter wheat can be sown from early March through to April, slow developing spring wheat from late-April to early May and mid-fast developing wheat from early May onwards and all flower within an optimal window.

This paper discusses phenology and yield responses to sowing date for a core set of wheat genotypes in southern NSW. These results are part of a project aimed at optimising grain yield potential in the northern grains region (NGR) co-invested by the Grains Research and Development Corporation (GRDC) and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP) project.

Grain yield responses to sowing time

In 2017, field experiments were conducted across eight sites in the NGR in central and southern QLD, northern NSW and southern NSW. This paper presents results from three sites in southern NSW (Wagga Wagga, Cudal and Condobolin). A range of genotypes with varied development (and with different combinations of *Vrn* and *Ppd* genes) were sown on three dates — 20 April, 5 May and 18 May, with an additional early sowing at the Wagga Wagga site on 10 April.

Flowering time

Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering occurs at an appropriate time. Generally, the genotype and sowing date combinations which flower early to mid-October at Wagga Wagga and Cudal, and mid-September to early October at Condobolin have the greatest yields. In southern NSW, this response is commonly driven by the high risk of frost damage early, and heat and moisture stress later.

In 2017, there was substantial variation in flowering date for the genotypes sown across sowing dates and sites. The flowering window was shorter at Wagga Wagga (Figure 1) than for Cudal (Figure 3) and Condobolin (Figure 4). This is a direct influence of early stem frost damage, which resulted in significant tiller death and late regrowth of tillers in faster developing genotypes, consequently affecting uniformity of plot maturity. Flowering dates are expressed as 50% of emerged heads with visible anthers, as such many of the recorded flowering dates reflect that of the later tillers and do not account for early tiller losses. At the Wagga Wagga site, there was a significant influence of tiller survival (percentage of tillers which produced a spike) on grain yields across the first three sowing dates (Figure 2). The faster developing genotypes had lower tiller survival scores in the earlier sowing times, whilst the later developing genotypes which remained vegetative for longer were exposed to less frost events and were able to maintain tillers.

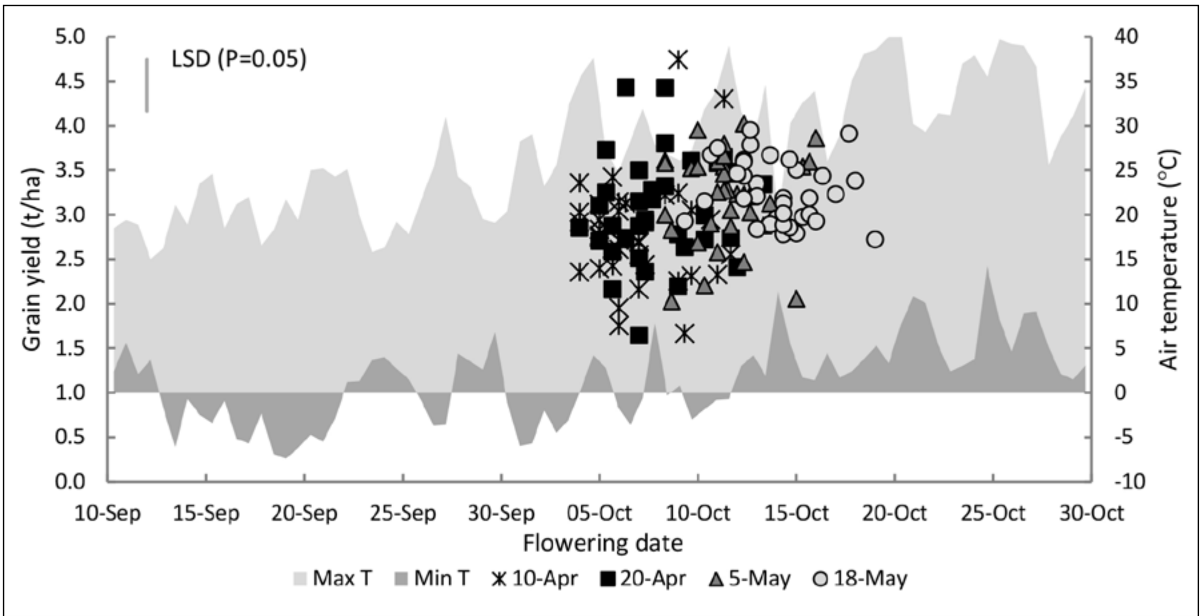

Figure 1. Relationship between grain yield and flowering date across four sowing dates at Wagga Wagga, 2017. Shaded areas indicate minimum (Min T) and maximum (Max T) temperatures.

Note: Flowering dates for Wagga Wagga were significantly affected by early stem frost damage.

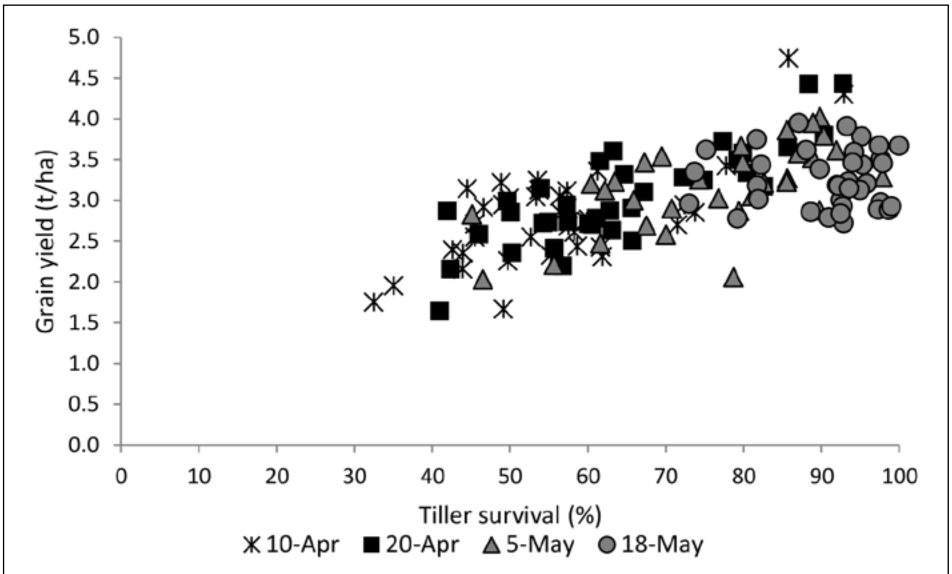

Figure 2. Relationship between grain yield and tiller survival (%) across four sowing dates at Wagga Wagga, 2017.

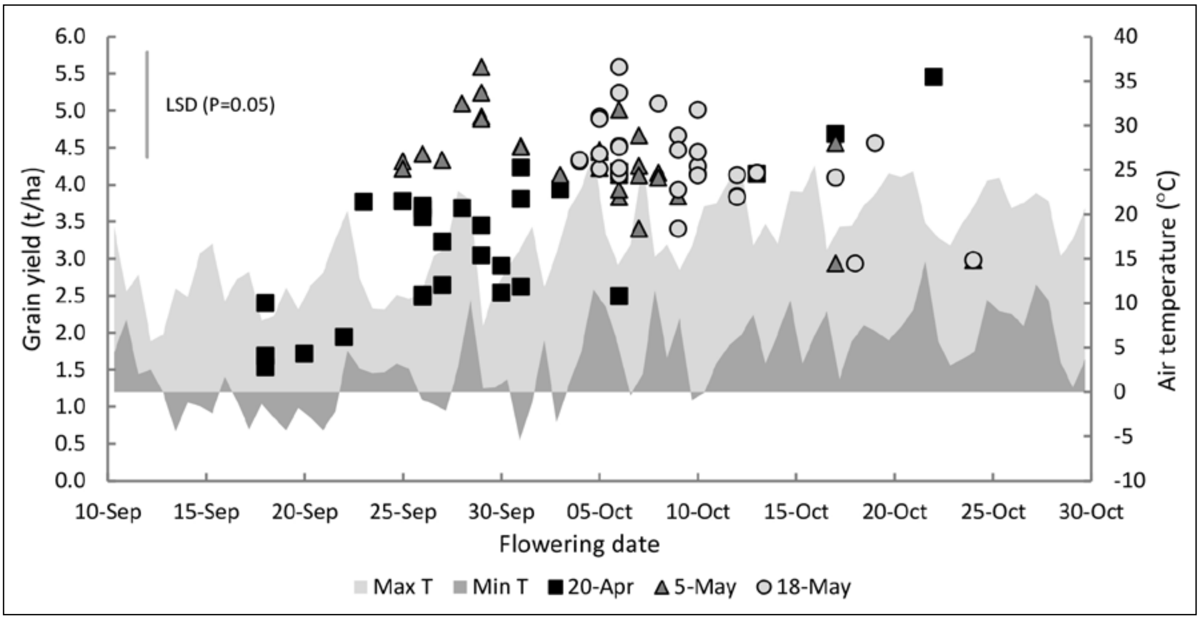

Figure 3. Relationship between grain yield and flowering date across three sowing dates at Cudal, 2017. Shaded areas indicate minimum (Min T) and maximum (Max T) temperatures.

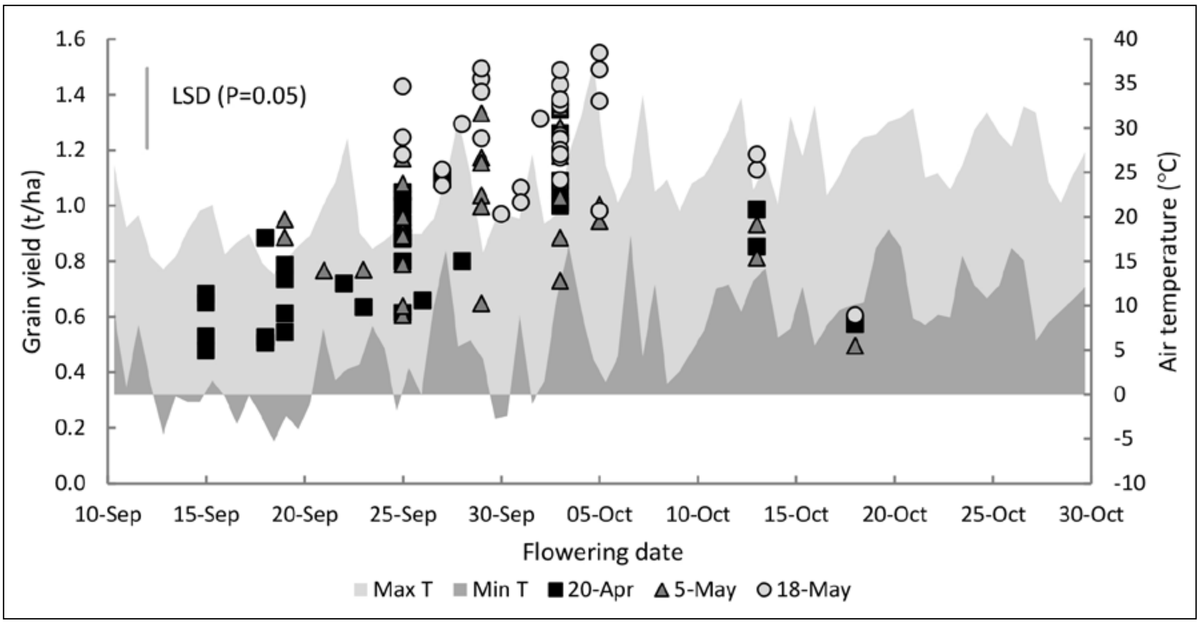

Figure 4. Relationship between grain yield and flowering date across three sowing dates at Condobolin, 2017. Shaded areas indicate minimum (Min T) and maximum (Max T) temperatures.

Grain yield

Within the genotypes, there were different yield responses to sowing time across the three sites in 2017, as indicated in Figure 5 (Wagga Wagga), Figure 6 (Cudal) and Figure 7 (Condobolin). Generally, slow developing genotypes had highest yields when sown early (indicated by negative slope), for example, Manning⁽ᵎ⁾ (winter type, strong vernalisation response) and Kittyhawk⁽ᵎ⁾ (winter type). In contrast, many faster developing, spring genotypes had greatest yields in later sowing times (indicated by positive slope), for example, Scepter⁽ᵎ⁾. In 2017, the number and severity of frost events were a major contributor to grain yield across all experimental sites. Despite the extreme frost conditions, some spring genotypes were able to maintain relatively stable grain yields across many sowing dates at some sites (indicated by flatter slope), for example, EGA_Gregory⁽ᵎ⁾ and Beckom⁽ᵎ⁾. Whilst the general yield response curves for each site location were similar, there was some variability in specific genotype responses across the three sites, indicating there may be differences in the suitability of genotypes across growing environments of southern NSW.

In 2017, winter and long-season genotypes achieved high yields from early sowing and were relatively stable across sowing dates at the Wagga Wagga and Cudal sites (Table 1). This is likely due to the extended vegetative phase (afforded by vernalisation responses), which reduced exposure to frost events during early reproductive development and resulted in flowering at an optimal time. In contrast, faster developing genotypes were exposed to several frost events during stem elongation through to flowering when sown early, which significantly reduced yield potential. However, the shorter growing season and terminal drought conditions at Condobolin favoured genotype and sowing combinations which were able to regulate flowering time (and minimise early frost damage), for example, fast winter or long-season types at early sowing dates (e.g. Kittyhawk⦇, Longsword⦇), and fast spring types with a quick grain-filling period when sown later. The extended growing season of slow winter types such as Manning⦇ did not achieve high grain yields at the Condobolin site (Figure 7).

Note: While all seasons are unique, it is important to consider suitability of varieties based on matching phenology and sowing time for your growing environment. Long term yield comparisons of varieties across a range of environments are available at GRDC National Variety Trials.

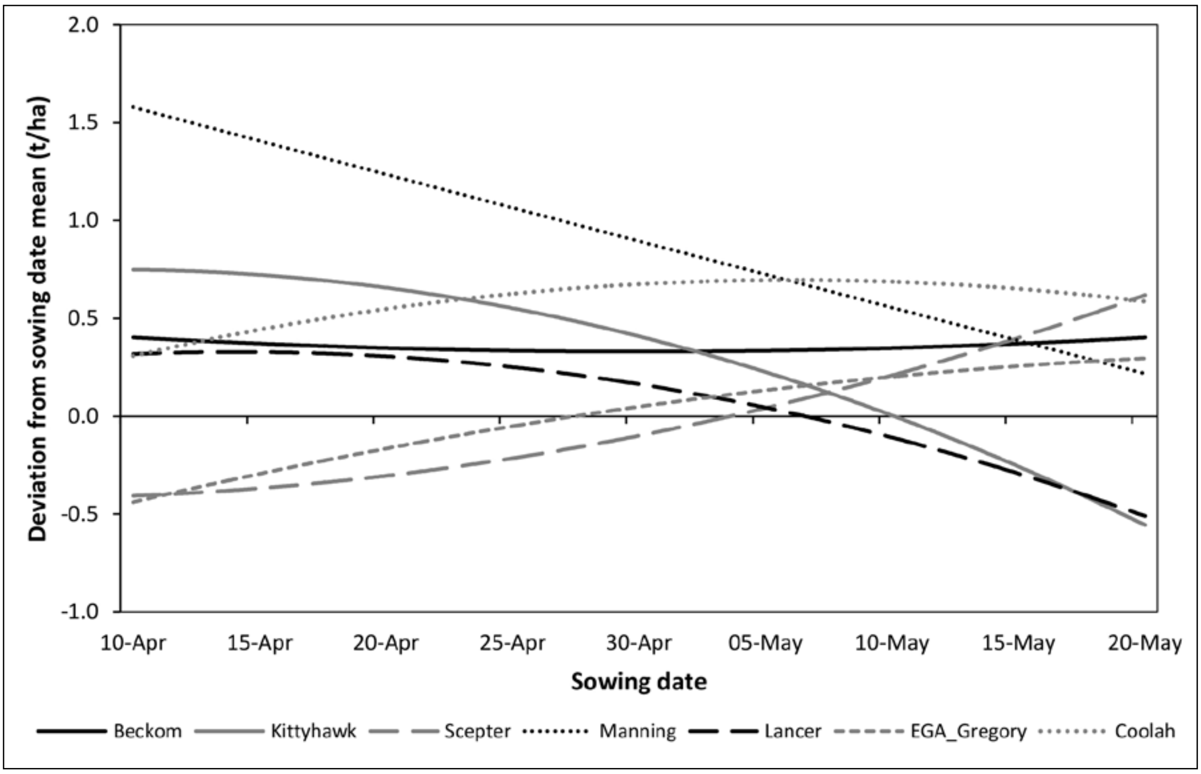

Figure 5. Genotype by sowing date response in 2017 for selected genotypes. Response is presented as deviation from sowing date mean across four sowing dates (SD) at Wagga Wagga. Sowing date mean: SD 1 (10 April) 2.79t/ha; SD 2 (20 April) 3.03t/ha; SD 3 (5 May) 3.20t/ha; SD 4 (18 May) 3.26t/ha.

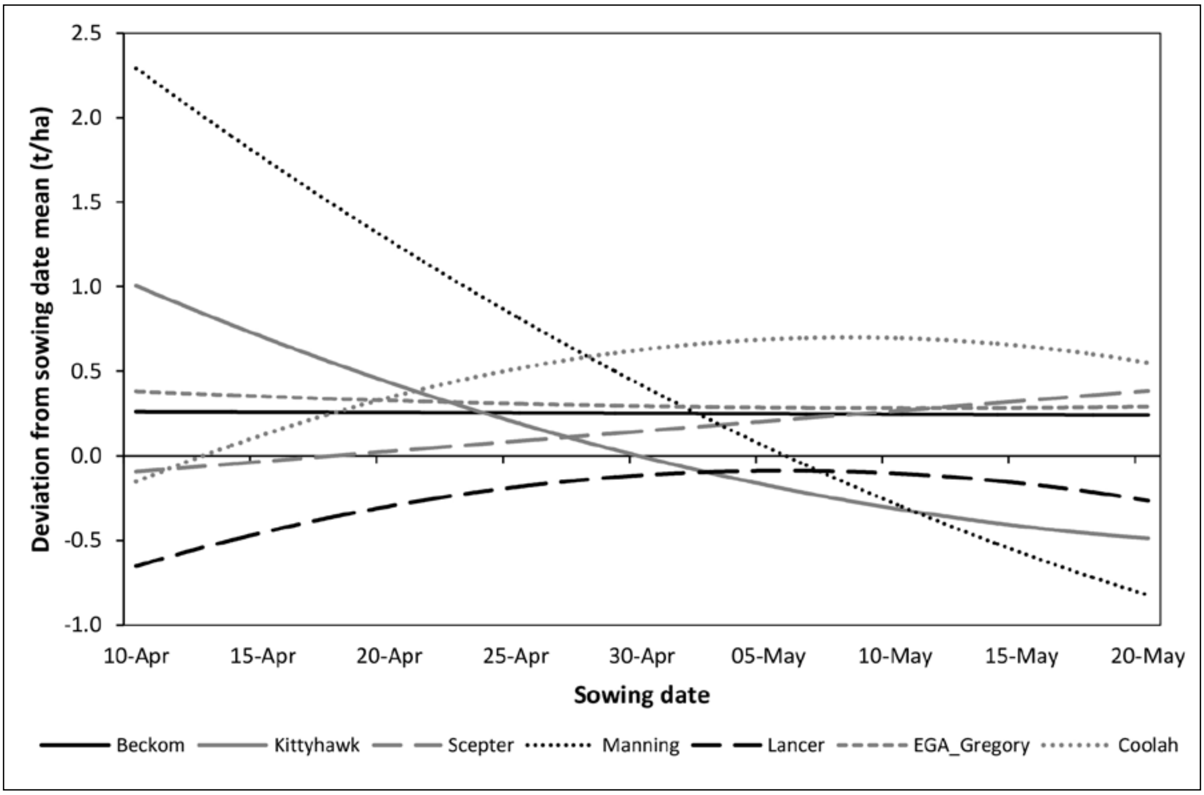

Figure 6. Genotype by sowing date response in 2017 for selected genotypes. Response is presented as deviation from sowing date mean across three sowing dates (SD) at Cudal. Sowing date mean: SD 1 (20 April) 3.18t/ha; SD 2 (5 May) 4.91t/ha; SD 3 (18 May) 4.31t/ha.

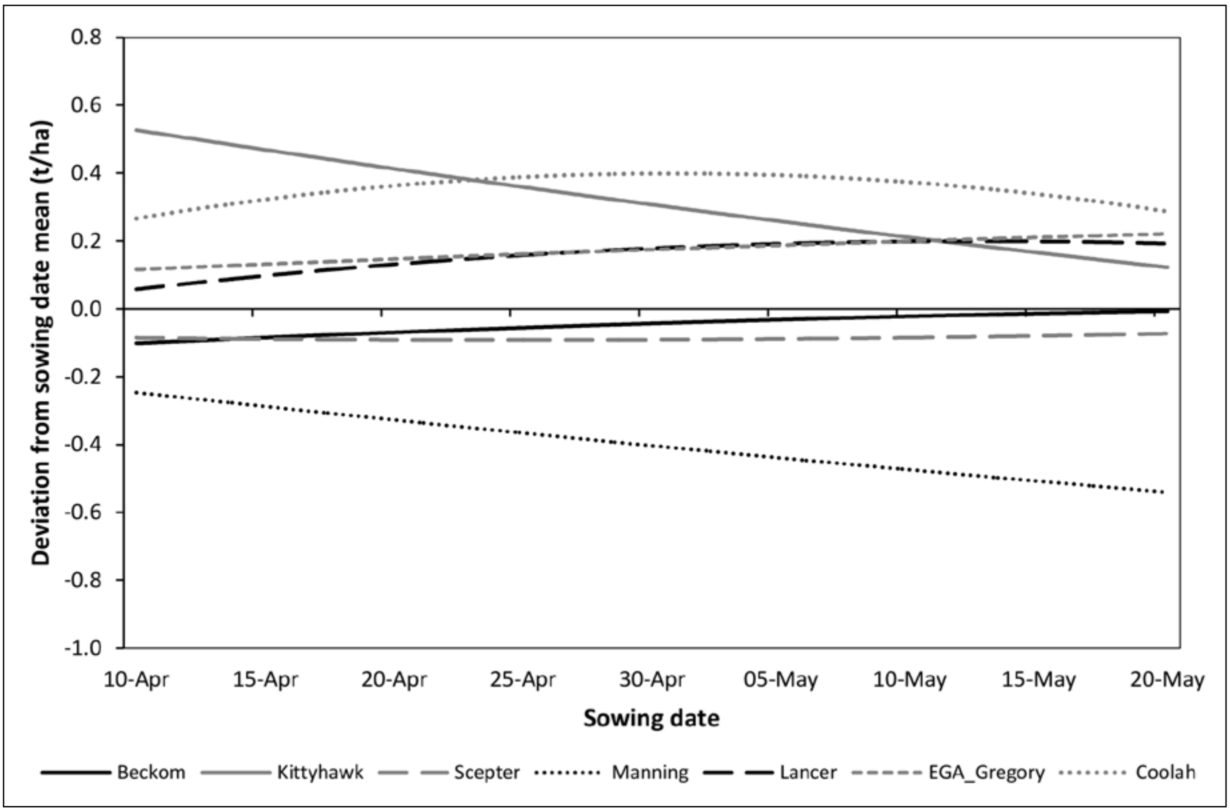

Figure 7. Genotype by sowing date response in 2017 for selected genotypes. Response is presented as deviation from sowing date mean across three sowing dates (SD) at Condobolin. Sowing date mean: SD 1 (20 April) 0.82t/ha; SD 2 (5 May) 0.97t/ha; SD 3 (18 May) 1.24t/ha.

Table 1. Grain yield of genotypes across sowing dates (SD) at Wagga Wagga, Cudal and Condobolin field sites. Percentage of sowing date mean in parentheses.

	Wagga Wagga								Cudal						Condobolin					
Genotype	SD1: 10-Apr		SD2: 20-Apr		SD3: 5-May		SD4: 18-May		SD1: 20-Apr		SD2: 5-May		SD3: 18-May		SD1: 20-Apr		SD2: 5-May		SD3: 18-May	
Beckom[d]	3.24	(116)	3.32	(110)	3.54	(111)	3.67	(113)	3.77	(118)	4.85	(99)	4.92	(114)	0.72	(88)	0.95	(98)	1.25	(100)
Condo[d]	1.66	(60)	2.74	(90)	2.21	(69)	2.78	(85)	2.40	(76)	4.42	(90)	4.32	(100)	0.65	(79)	0.61	(62)	1.09	(88)
Coolah[d]	3.04	(109)	3.61	(119)	4.02	(126)	3.79	(116)	3.05	(96)	5.64	(115)	4.15	(96)	1.09	(133)	1.35	(139)	1.25	(101)
Corack[d]	1.95	(70)	2.16	(71)	2.06	(64)	3.35	(103)	1.72	(54)	4.30	(88)	5.09	(118)	0.48	(58)	0.64	(66)	0.97	(78)
Cutlass[d]	3.12	(112)	3.11	(102)	3.54	(111)	3.50	(107)	2.65	(83)	5.24	(107)	5.01	(116)	0.63	(77)	0.91	(93)	1.49	(120)
Dart[d]	2.16	(77)	2.36	(78)	2.47	(77)	2.96	(91)	1.69	(53)	4.05	(83)	4.21	(98)	0.68	(83)	0.77	(79)	1.07	(87)
DS_Darwin[d]	2.95	(106)	2.85	(94)	3.38	(106)	3.19	(98)												
DS_Faraday[d]	2.74	(98)	3.34	(110)	3.60	(112)	3.67	(113)												
DS_Pascal[d]	2.42	(87)	2.91	(96)	3.52	(110)	2.97	(91)	4.23	(133)	4.66	(95)	4.25	(99)	1.00	(122)	1.33	(137)	1.44	(116)
EGA_Eaglehawk[d]	2.92	(104)	3.15	(104)	3.46	(108)	2.89	(89)	3.94	(124)	5.69	(116)	4.13	(96)	1.26	(154)	1.28	(132)	1.55	(125)
EGA_Gregory[d]	2.44	(87)	2.63	(87)	3.60	(112)	3.44	(105)	3.56	(112)	5.19	(106)	4.66	(108)	0.94	(114)	1.17	(121)	1.49	(120)
EGA_Wedgetail[d]	2.70	(97)	3.28	(108)	3.28	(103)	3.00	(92)	2.49	(78)	5.06	(103)	4.16	(97)	1.09	(133)	0.73	(75)	1.17	(95)
H45[d]	2.39	(86)	2.73	(90)	2.87	(90)	3.46	(106)												
Janz	2.69	(96)	2.78	(92)	3.61	(113)	3.21	(98)	3.78	(119)	5.40	(110)	4.13	(96)	0.80	(97)	0.96	(99)	1.46	(118)
Kiora[d]	2.77	(99)	3.73	(123)	3.27	(102)	3.01	(92)	2.90	(91)	4.48	(91)	4.10	(95)	1.07	(130)	0.94	(97)	1.38	(111)
Kittyhawk[d]	3.42	(123)	3.80	(125)	3.54	(111)	2.72	(84)	4.17	(131)	4.58	(93)	3.84	(89)	1.35	(164)	1.18	(122)	1.24	(100)
Lancer[d]	2.94	(105)	3.58	(118)	3.22	(101)	2.79	(86)	2.54	(80)	4.83	(98)	3.40	(79)	0.88	(107)	1.17	(121)	1.36	(110)
Longsword[d]	2.25	(81)	2.51	(83)	3.05	(95)	3.23	(99)	3.94	(124)	5.31	(108)	4.22	(98)	1.00	(122)	1.04	(107)	1.41	(114)
LRPB_Mustang[d]	2.61	(94)	2.87	(95)	3.02	(94)	3.38	(104)	1.68	(53)	4.79	(98)	4.89	(113)	0.51	(62)	0.89	(92)	1.31	(106)
LRPB_Reliant[d]	3.05	(109)	2.94	(97)	3.20	(100)	3.62	(111)	3.23	(102)	4.63	(94)	5.24	(122)	0.88	(108)	1.15	(119)	1.49	(120)
Mace[d]	2.35	(84)	2.41	(80)	2.58	(81)	3.19	(98)	2.62	(82)	4.74	(97)	4.33	(101)	0.61	(74)	0.79	(81)	1.07	(86)
Manning[d]	4.30	(154)	4.43	(146)	3.79	(119)	3.59	(110)	5.46	(172)	4.60	(94)	2.98	(69)	0.57	(70)	0.50	(51)	0.61	(49)
Mitch[d]	2.83	(102)	3.25	(107)	3.58	(112)	2.86	(88)	3.68	(116)	5.29	(108)	3.83	(89)	0.61	(75)	1.03	(106)	1.24	(100)
RGT_Accroc	4.74	(170)	4.43	(146)	3.95	(123)	3.75	(115)	4.68	(147)	5.19	(106)	4.56	(106)	0.85	(104)	0.81	(84)	1.13	(91)
Scepter[d]	2.31	(83)	2.99	(99)	2.90	(91)	3.95	(121)	3.45	(109)	5.62	(115)	5.59	(130)	0.73	(90)	0.88	(91)	1.20	(97)
Spitfire[d]	2.33	(83)	2.20	(72)	2.69	(84)	3.13	(96)	1.94	(61)	4.96	(101)	4.47	(104)	0.53	(64)	0.65	(67)	1.01	(82)
Sunlamb[d]	3.22	(115)	3.17	(105)	2.88	(90)	2.88	(88)	4.15	(130)	4.64	(94)	2.93	(68)	0.99	(120)	0.93	(96)	1.19	(96)
Sunmax[d]	3.14	(113)	3.48	(115)	3.46	(108)	3.01	(92)	2.51	(79)	5.79	(118)	4.44	(103)	1.01	(123)	1.24	(128)	1.38	(111)
Suntime[d]	2.55	(91)	2.70	(89)	2.83	(88)	2.84	(87)	3.69	(116)	4.38	(89)	4.52	(105)	0.80	(98)	1.00	(103)	0.98	(79)
Suntop[d]	3.36	(120)	3.50	(115)	3.66	(114)	3.18	(98)	3.71	(117)	4.85	(99)	3.93	(91)	0.89	(108)	1.09	(112)	1.18	(95)
Sunvale	2.85	(102)	3.65	(120)	3.23	(101)	2.93	(90)	3.81	(120)	4.90	(100)	4.13	(96)	1.05	(128)	1.20	(124)	1.24	(100)
TenFour	1.75	(63)	1.64	(54)	2.03	(63)	3.44	(105)												
Trojan[d]	2.71	(97)	2.72	(90)	3.86	(121)	3.46	(106)	2.49	(78)	4.69	(96)	4.51	(105)	0.79	(96)	1.08	(111)	1.29	(104)
Mean	**2.79**	**(100)**	**3.03**	**(100)**	**3.20**	**(100)**	**3.26**	**(100)**	**3.18**	**(100)**	**4.91**	**(100)**	**4.31**	**(100)**	**0.82**	**(100)**	**0.97**	**(100)**	**1.24**	**(100)**
LSD (SD)	**0.29**								**0.38**						**0.05**					
LSD (Genotype)	**0.08**								**0.82**						**0.16**					
LSD (SD x Genotype)	**0.58**								**1.42**						**0.28**					

Summary

There are differences in grain yield responses to sowing time of wheat genotypes across growing environments in southern NSW, indicating that particular varieties can be exploited by grain growers. Genotypes vary in their response to vernalisation and photoperiod, which influences early development phases, as well as flowering time. The extreme frost conditions experienced in 2017 had a significant effect on grain yields at the three experimental sites, and highlighted the importance of the timing and length of pre-flowering development phases. Whilst matching variety and sowing time to achieve flowering at an appropriate time for each growing environment is the most effective management strategy in optimising grain yields, future research will also investigate the contribution of pre-flowering phases to yield development.

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Notes

Management of crown rot in southern NSW farming systems

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ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project code: DAN00175

Keywords

- crown rot, *Fusarium pseudograminearum, Fusarium culmorum.*

Take home messages

- The frequency of winter cereals in a rotation influences the build-up of crown rot inoculum within paddocks.
- Risk of losses in grain yield can be minimised by monitoring inoculum levels over time and implementing management strategies to reduce them.
- Crown rot can have negative impacts on grain quality and gross margins even without observing obvious symptoms and grain yield losses.
- Significant reductions in crown rot inoculum levels can be achieved by growing two consecutive non-host crops.

Background

This paper is a summary of the research conducted to date under the National Crown Rot Management Program - Southern Component of DAN00175, consisting of results from:

1. Longitudinal surveys of soil and stubble borne pathogens in southern NSW (sNSW).
2. Crown rot non-host crop rotation, duration and crop sequence trial.
3. Crown rot varietal yield loss trials undertaken from 2011-2017.

Crown rot is estimated to cause $79 million annually in economic losses to Australian cereal growers (Murray and Brennan, 2009). *Fusarium pseudograminearum* and *F.culmorum* are the two most common casual agents of this disease. The crown rot fungi are soil and/or stubble borne fungal pathogens which restrict the flow of water and nutrients to developing heads when moisture or heat stress occurs during the critical grain filling stage. This can result in pinched grain or heads with no grain, otherwise known as 'whiteheads'. Crown rot fungi infect winter cereals including barley, bread wheat, triticale and durum wheat, in order of decreasing tolerance to the pathogen (Milgate, Goldthorpe and Baxter, 2017 p. 139). The crown rot fungus can also survive in a range of grass weed hosts including ryegrass, wild oats annual phalaris.

Crown rot is favoured by wet, cool winters and dry, hot spring conditions. It may be identified early in the growing season as browning of the outer leaf sheaths at the base of infected tillers, stunted yellow plants or single dead tillers. More reliable identification can occur in periods of moisture stress. Typically, honey coloured stem browning extending from the sub-crown internode upwards to the first or second node on infected stems occurs.

As opposed to take-all, where all tillers on a single plant will express whiteheads, crown rot will cause scattered whiteheads across the paddock with individual tillers on plants affected. Grain yield loss and downgrade of grain quality can still occur without the expression of whiteheads (Milgate et al. 2017 p. 139).

The prevalence of crown rot in southern NSW farming systems has increased due to the adoption of 'no-till' cropping systems and the most common rotation being based on tight cereal and canola sequences. The presence of crown rot, along with other crown and root diseases, in southern NSW farming systems creates 'disease complexes' which have negative impacts on grain yield, protein and quality.

These disease complexes can be managed through an integrated approach which focuses on monitoring and setting in place rotations which act to reduce the risk of losses across the whole farming system. Besides crop rotation, other management practices that can be implemented involve effective weed management programs to reduce grass weed hosts in-crop and fallow situations, inter-row sowing between cereal stubble, early sowing within a variety's ideal sowing window and ensuring adequate nutrition for the season, particularly zinc.

This paper brings together research of several elements of the integrated management of crown rot for growers to consider implementing.

Method

PreDicta B™ analysis underpins the methodologies used to assess soil and stubble borne pathogen levels in the experimental plots and paddock surveys. PreDicta B™ estimates selected soil and stubble borne pathogen levels using DNA assays developed by the South Australian Research and Development Institute (SARDI).

The individual methodologies for the paddock survey, non-host crop rotation, duration and sequence trial, along with the crown rot varietal yield loss trial, are discussed here.

Longitudinal survey of soil and stubble borne diseases in southern NSW farming systems

There were 93 paddocks in the survey set covering high, medium and low rainfall zones across southern NSW from 2014 to 2017. The paddocks were assessed in the cereal phase only, with the yearly rotation recorded on each. The paddock survey sampling is providing 'real world' data to support findings on trial work currently being undertaken.

Soil and stubble samples are collected, starting at a permanent GPS location, collecting from the centre moving outwards in a spiral pattern. Ten soil cores and 10 pieces of stubble are collected at the points along the spiral. The samples are bulked, homogenised and a sub-sample taken for analysis. The sub-sample is comprised of 500g of soil and 30 random pieces of cereal stubble 4¬–5cm long, ensuring the crown was present on the stubble (Milgate et al. 2017 p. 139). The pre-sowing samples were collected in April of the sowing year and the post-harvest samples collected in January of the following year. The sub-samples are then sent off for analysis by SARDI.

Non-host crop rotation, duration and sequence trial

The trial is a randomised paired split plot trial with five replicates consisting of 600 plots in total, with 120 different treatments over the five years starting in 2014 and finishing in 2018. The trial examined a one or two year non-host crop cycle, different combinations of crop sequences, fungicide treatments and controls. A non-host crop is anything other than a cereal. There are three wheat variety treatments — very susceptible (VS), susceptible (S) and tolerant (T). Other treatments include one barley treatment, along with four non-host crops including canola, lupin, field pea and a vetch/wheat mix to simulate a hay cut. The term tolerant (T) has been used instead of resistant, as there are currently no fully resistant varieties to crown rot, but varieties differ in their tolerance to the pathogen. The methodology to assess pathogen levels in this trial is the same method used in the paddock survey — PreDicta B™. The collection method is based on a random sample from plots instead of a structured spiral pattern as used at the paddock scale.

The treatments displayed in Figure 4 of this paper include two up front fungicides for comparison. These were Rancona® Dimension (ipconozole 25g/L and metalaxyl 20g/L applied to wheat seed at a rate of 320mL per 100kg) and Jockey® Stayer®Φ (fluquinconazole 167g/L applied to wheat seed at a rate of 450mL per 100kg).

ΦJockey® Stayer® is not registered to control Crown rot in wheat at this rate. This rate is used for research purposes only. Commercial application of this product must adhere to label rates.

1. *Crown rot varietal yield loss trial*

The yield loss trials consisted of 'plus crown rot' and 'minus crown rot' treatments with four replicates assessing 17 wheat and eight barley varieties. The crown rot 'plus' treatment consists of viable wheat or barley seed sown with sterilised durum seed inoculated in the laboratory with multiple isolates of the crown rot fungus. The crown rot inoculated seed is sown at a rate of two grams per metre of trial row. Yield reduction caused by crown rot is assessed at harvest by comparing the grain weights between the plus and minus treatments.

Table 1. Treatment details from rotation sequence and duration experiment shown in Figure 4.

Year	Treatment name	Details
2014	Durum	Caparoi⍉
2015	Canola	ATR-Gem⍉
2016	Wheat-Tol	Emu Rock⍉
	Wheat-Tol+Jockey	Emu RockA +Jockey® Stayer®
	Wheat-Tol+Rancona	Emu RockA +Rancona® Dimension
	Wheat-S	LongReach Lincoln⍉
	Wheat-S+Jockey	LongReach Lincoln⍉ +Jockey® Stayer®
	Wheat-S+Rancona	LongReach Lincoln⍉ +Rancona® Dimension
	Pea	PBA Oura⍉
	Lupin	Mandelup⍉

Pathogen levels within plots were determined by PreDicta B™ analysis of 30 randomly selected pieces of stubble from individual plots which were bagged with 500g of sterilised soil. This identifies if contamination occurs between treatments or background levels of crown rot are naturally occurring and those affected plots removed from the analysis.

Results and discussion

Longitudinal survey of soil and stubble borne diseases in southern NSW farming systems

A trend consistently appearing from the paddock survey data is the prevalence of crown rot in southern NSW farming systems. Table 2 displays the percentage of post-harvest sampled paddocks which were infected with crown rot from 2014 to 2016. The high incidence of crown rot indicates that inoculum levels are present before sowing and developing during the growing season. The inoculum is surviving over the summer in the stubble and soil, ready to infect cereal crops in the following year. Sampling post-harvest gives the flexibility to make management decisions, such as changing cereal type or crop type for the following year if inoculum levels are found to be high and a risk to the next cereal crop within the rotation sequence.

The survey data collected from 2014 to 2017 is showing strong trends relating to pre-sowing crown rot inoculum levels when comparing the duration of non-host crops between cereal crops (Figure 1) and the effects of the previous crop on pre-sowing levels of inoculum (Figure 2).

Figure 1 shows the pre-sowing increase in inoculum and risk levels associated with sowing cereal on cereal. As the number of years between sowing non-host crop increases, the pre-sowing crown rot inoculum significantly increases. Essentially, a cereal crop sown after a non-host crop (0 years) has a close to below detectable limits (BDL) risk, translating to a 0–5% potential yield loss (McKay et al. 2015). After three years of continuous cereal, or two years since a non-host crop, the risk level is deemed medium and relates to a potential 5-30% yield loss (McKay et al. 2015) under the right conditions such as moisture or heat stress during grain filling. Losses of this magnitude and higher were observed in the 2017 Condobolin crown rot yield loss trial (Figure 6).

The effect that the previous crop can have on the pre-sowing levels of crown rot inoculum is shown in Figure 2. The majority of the data is located in the canola and wheat columns — this is typical of southern NSW farming systems which sow these crops in tight rotations. The issue that arises with these types of rotations is that a single break of canola away from cereal is not necessarily reducing crown rot inoculum to a safe level to sow a cereal crop without risk of significant yield losses in the following year. On average, the canola paddocks reduced the inoculum levels more compared to wheat. Wheat had approximately 50% of the paddocks fall into the medium to high risk category

Table 2. Prevalence of crown rot in the southern NSW paddock survey, 2014 to 2016 post-harvest sampling.

Year	No. of paddocks sampled	Percentage (%) of paddocks with crown rot fungi present (post harvest)
2014	41	73
2015	34	91
2016	39	85

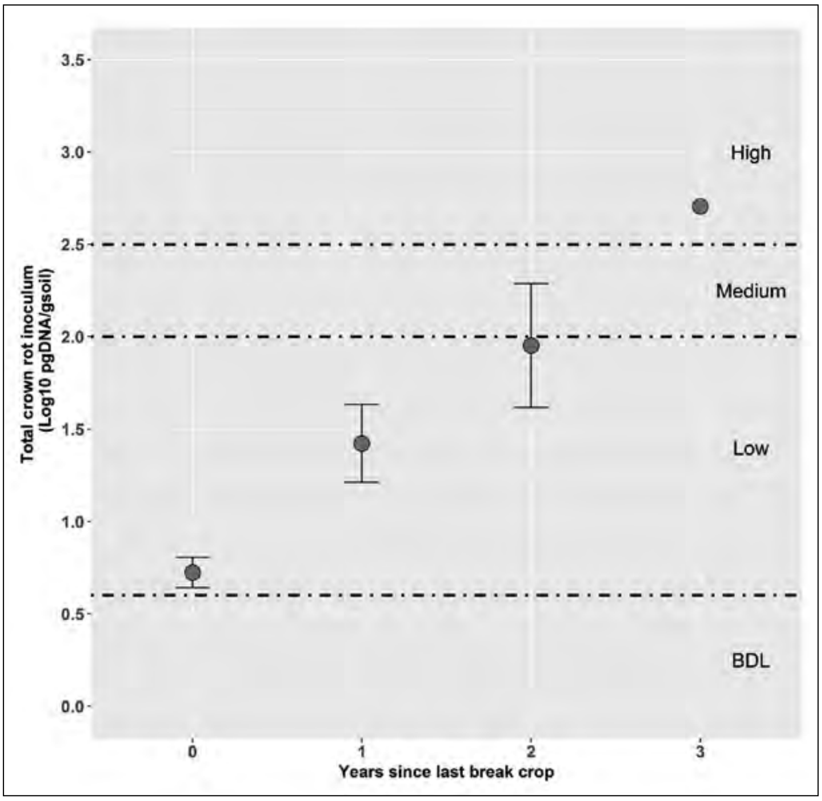

Figure 1. Effect of the number of years since non-host crops on pre-sowing levels of crown rot (*F. pseudograminearum + F. culmorum*) prior to sowing 2014 to 2017 (number of paddocks = 147) measured by PreDicta B™ analysis. Log risk levels: Below detection limits = <0.6. Low = 0.6 –<2.0. Medium = 2.0 –<2.5. High = ≥ 2.5 for bread wheats in southern NSW.

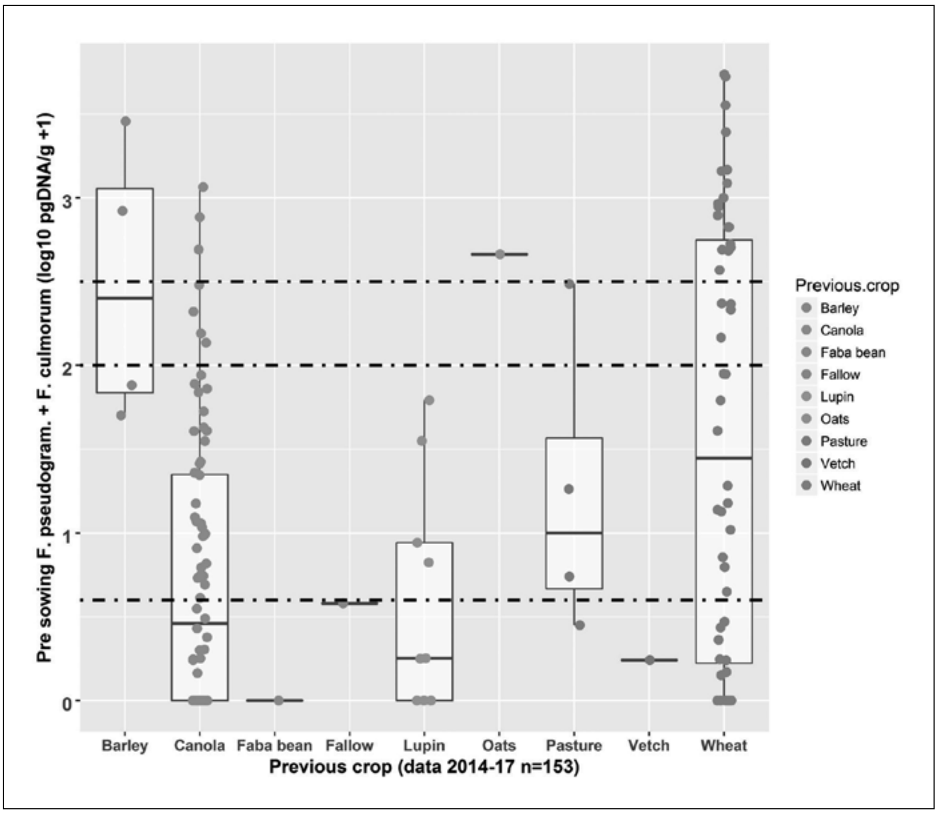

Figure 2. Previous crop effects on the background levels of crown rot (*F. pseudograminearum + F. culmorum*) prior to sowing 2014 to 2017 measured by PreDicta B™ analysis. Log risk levels: Below detection limits = <0.6. Low= 0.6–<2.0. Medium= 2.0–<2.5. High= ≥ 2.5 for bread wheats in southern NSW.

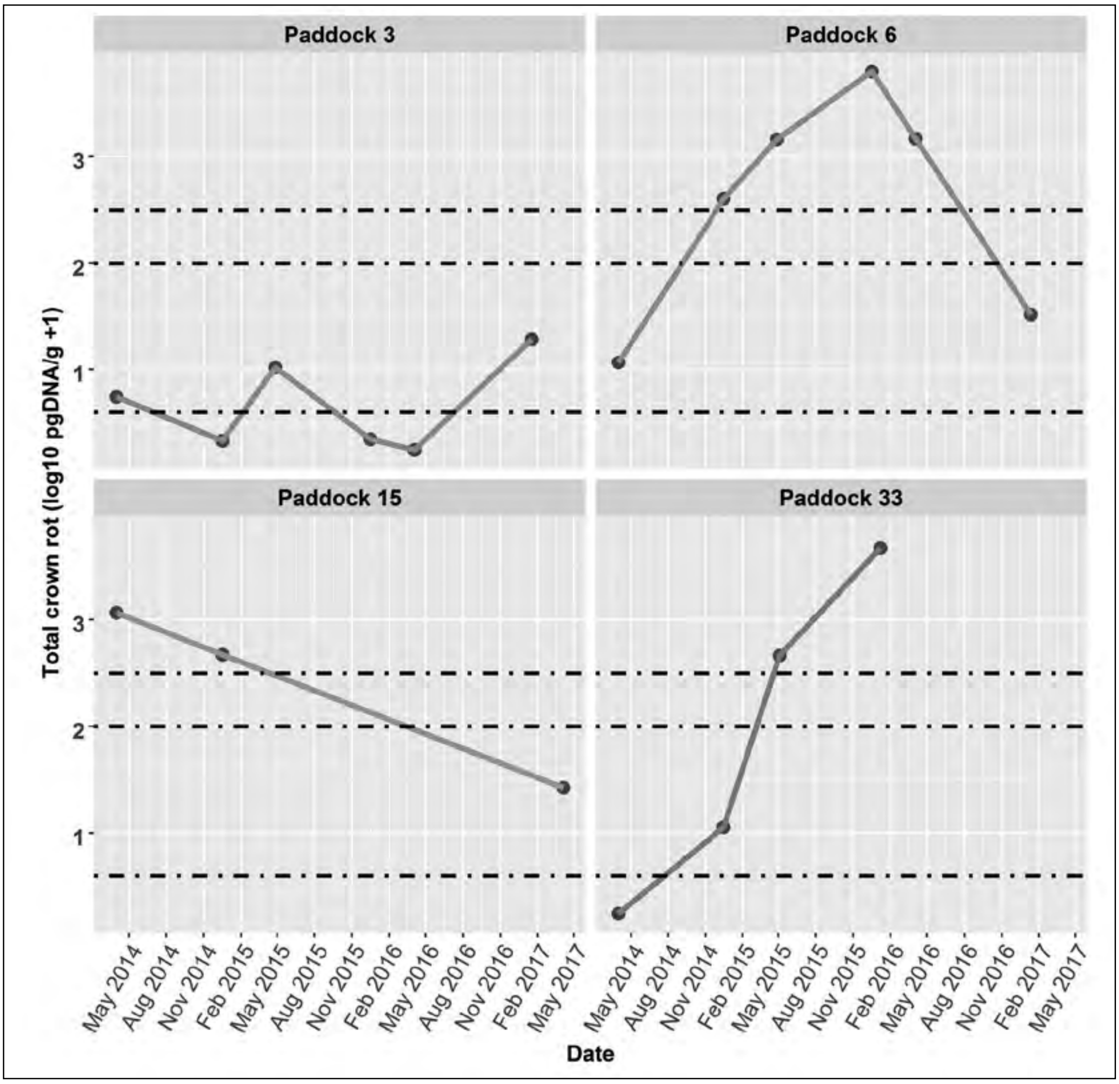

Figure 3. Crown rot (F. *pseudograminearum + F. culmorum*) levels of four paddocks during the growing season from pre-sowing to post-harvest in 2014 to 2016 and pre-sowing 2017. Log risk levels: Below detectable limits = <0.6, low= 0.6–<2.0, medium= 2.0–<2.5 and high= ≥ 2.5 for bread wheats in southern NSW.

for yield loss. However, a concerning result is the number of canola paddocks that fell into the medium to high risk category which could result in between 5–60% yield loss (McKay et al. 2015). This indicates that sowing a single non-host crop may not allow enough time to reduce disease levels. The other non-host crops show lower inoculum levels; however, they do not have enough data points to draw any solid conclusions, but are broadly in line with the findings of other published research.

Knowing the risk level and how a particular paddock behaves is critical to making management decisions to maximise yields and economic returns. Not all paddocks will behave the same way during inoculum build-up and depletion as can be seen in Figure 3. The paddock survey covers a large geographical area of southern NSW and therefore samples across different topographical, climatic and agronomical boundaries. Paddocks 3, 6 and 33 in Figure 3 are based on similar rotations, but show very different inoculum behaviour over time. This may be accounted for by interactions between grower management decisions, pathogen and abiotic factors. Paddock 33 is what would be considered a 'typical' steady build-up of crown rot, while Paddock 3 is 'atypical' of crown rot build-up when sowing continuous cereals. Paddock 15 differs to the other paddocks in rotation. This paddock demonstrates what sowing a non-host crop for two years can do to reduce inoculum levels from a high risk to low risk.

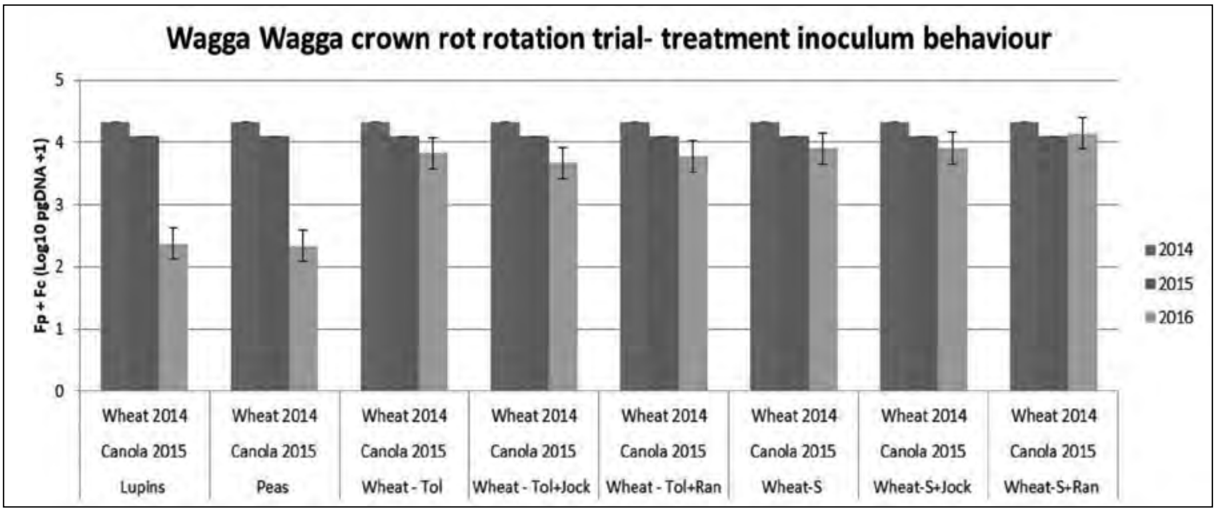

Figure 4. Crown rot inoculum (*F. pseudograminearum* + *F. culmorum* level behaviour in the Wagga Wagga crop rotation and sequence trial when comparing one and two year non-host crop rotations. Log risk levels: Below detectable limits= <0.6, low= 0.6–<2.0, medium= 2.0–<2.5 and high= ≥ 2.5 for bread wheats in southern NSW. Seed treatments: Rancona® Dimension (Ran) and Jockey® Stayer® (Jock).

Effective methods for inoculum reduction through crop type and sequence

Maximising inoculum reduction with optimal profitability is being investigated in this trial. The trial is in its fourth year and is providing insight relating to the importance of rotations and the way they influence inoculum behaviour.

The effect of introducing a one or two year non-host crop into the rotation on inoculum loads is demonstrated in Figure 4. The eight treatments displayed had the same rotation in 2014 (wheat) and 2015 (canola), but different crop rotations in 2016, creating a one or two year break from a cereal crop. The lupin and pea crops sown in 2016 greatly reduced the inoculum loads to approximately $\log_{10}$ 2.40 (250 pgDNA/per gram of soil) or medium risk, as compared to sowing a wheat crop which ranged from log10 3.70 - 4.10 (4700 – 14000 pgDNA/per gram of soil) or high risk. Under the right climatic conditions, medium risk translates to a potential 5–30% yield loss and high to 15-60% yield loss (McKay et al. 2015). This demonstrates the importance of using non-host crops to reduce inoculum levels for two years.

The Rancona® Dimension seed treatment was added to determine its ability to suppress crown rot infection under high disease pressure. Take-all, along with crown rot, is present at the trial site. To account for compounding effects it may have on yields, an additional seed treatment of Jockey® Stayer® was added. This combination of root diseases accurately depicts the disease complexes frequently facing cereal growers in southern NSW.

Inoculum levels fell across all treatments shown in Figure 4 during 2016, except for Wheat-S +Ran. Despite the reduction, all wheat treatments for 2016 showed the levels of inoculum remained above $\log_{10}$ 3.70 or high risk. This level is regarded as very high and would cause significant yield loss and grain quality degradation under climatic conditions conducive to the expression of crown rot (i.e. hot and dry during grain filling).

The importance of choosing a more tolerant or resistant variety is illustrated in Figure 4. There is an increase of inoculum by the susceptible, Wheat-S, treatment compared to the more tolerant, Wheat-T treatment. Wheat and barley commercial varieties do differ in their tolerance to crown rot. This has been demonstrated by crown rot varietal yield loss trials which will be discussed here.

Results from the paddock survey data, the crown rot non-host crop rotation, duration and sequence trial, support the principle that a two year non-host crop break can reduce inoculum levels to a lower point than sowing a single year of a non-host crop.

What this trial will help reveal is whether: 1) A crop type or a certain crop sequence, such as either peas-canola or canola-peas, will cause a greater reduction in crown rot levels than the other, and 2) does it make a difference or is it just the break length that is key? To date, the crop type that has shown the most significant reduction of crown rot inoculum levels in the trial is field peas.

Crown rot varietal yield loss trial

Since 2011, crown rot yield loss trials have been conducted at Wagga Wagga, Cowra and/or Condobolin research stations, totaling 12 trials. It has become apparent from these trials that there are barley and wheat varieties which perform better in the presence of crown rot and appear more tolerant. Barley, rather than wheat, is the higher yielding cereal type in the presence of crown rot infection. One of the reasons for this is due to barley being earlier maturing and avoiding the full effects of moisture stress during grain filling. If a cereal must be grown in a high crown rot risk situation, barley will usually experience lower grain yield losses than wheat. However, barley will still maintain or increase crown rot inoculum levels, result in reduced grain quality and will not address the underlying disease pressure.

Throughout the duration of the yield trials, there have been wheat varieties that display higher yield and lower yield losses in the presence of crown rot when compared to other varieties in the trials. Consistently from 2011 to 2017, Emu RockΦ, SuntopΦ, WaaganΦ, LongReach MerlinΦ and LongReach TrojanΦ have had higher grain yields than other wheat varieties in the presence of crown rot. More recently, newer varieties have been added into the trial (2016 and 2017) and of these newer varieties, SceptorΦ, CorackΦ, and BeckomΦ have had higher grain yield compared to the other wheat varieties tested in the presence of crown rot infection.

Barley varieties, CompassΦ, HindmarshΦ and CommanderΦ have produced higher grain yields when compared to other barley varieties in the presence of crown rot through the 2011 to 2017 trials. More recently, 2016 and 2017, the addition of newer varieties has seen LaTrobeΦ and RosalindΦ produce yields higher than the other tested barley varieties in the presence of crown rot.

If crown rot risk is high and a cereal must be grown, the current advice is that a grower selects a variety that is best suited to their environment agronomically, regardless of crown rot tolerance. However, if there are two or more suitable varieties, the more tolerant one should be chosen. An example of this can be seen below in Figure 5 and Figure 6. BassΦ is considered suitable in a medium to high rainfall zone. At Condobolin in 2017, BassΦ yielded the lowest and had the greatest yield loss of 35% (Figure 5), between the plus and minus treatments (data not shown). Being a longer season variety, it struggled to perform in a short season environment and it encountered moisture and heat stress during grain filling. This confirms the recommendation of choosing an agronomically suitable variety first despite the crown rot tolerance.

At Wagga Wagga, like at Condobolin, BassΦ yielded the lowest of the barleys (data not shown). However, the overall yield difference between BassΦ and other varieties was substantially smaller, as it was grown within its preferred environment. Further to that, the yield difference between the BassΦ

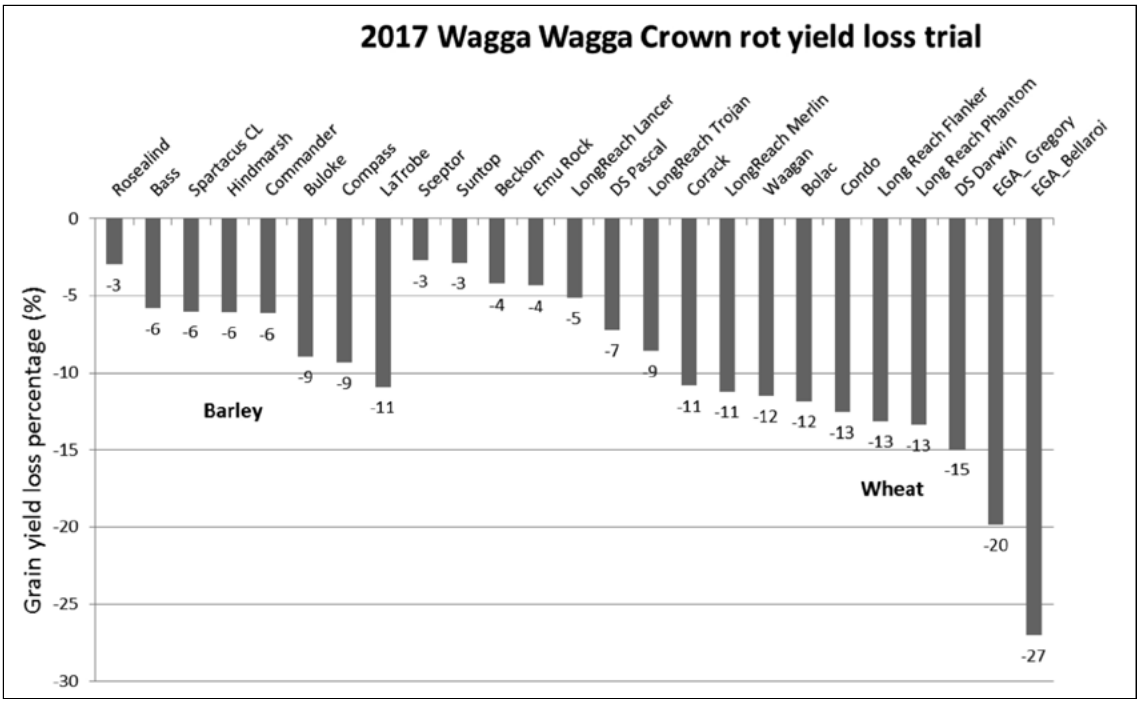

Figure 5. Grain yield reduction between plus crown rot and minus crown rot treatments for eight barley and 17 wheat varieties at the Wagga Wagga Agricultural Institute, 2017.

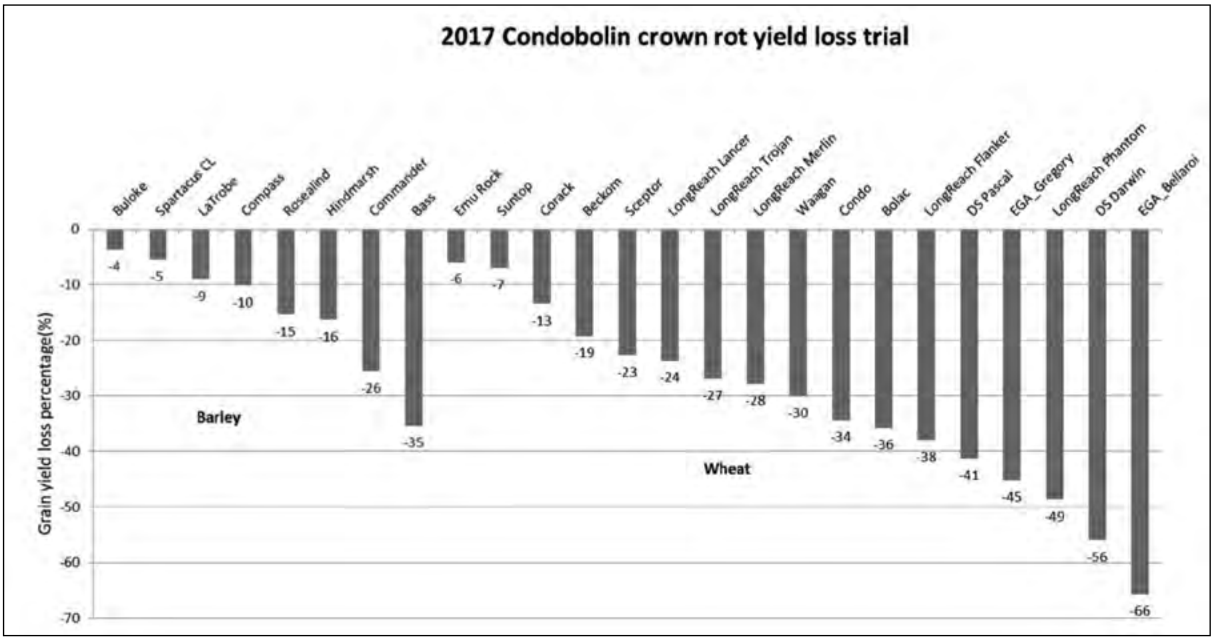

Figure 6. Grain yield reduction between plus crown rot and minus crown rot treatments for eight barley and 17 wheat varieties at the Condobolin Agricultural Research and Advisory Station, 2017.

plus and minus treatments was 6% (Figure 6), as moisture and heat stress was not as severe as at the Condobolin site during grain filling in 2017.

A variety selection of LaTrobe⁽ᴾ⁾ or Hindmarsh⁽ᴾ⁾, which are more commonly grown at Condobolin, would increase yields and reduce crown rot losses. This further displays the importance of variety selection for a particular environment.

Crown rot can affect crop profitability, not just through grain yield losses, but through reduced grain quality: increased screenings, test weight reductions, retention reductions and variation in protein. These factors combine to downgrade grain quality and pricing, adding a 'multiplier' effect to any reduced yield. Analysis on the 2015 Wagga Wagga crown rot yield loss trial found that the figure ($) lost per hectare varied between varieties depending on yield, tolerance and grain quality downgrades (Milgate and Baxter 2015, p. 159).

On average, across the 18 varieties, $78.51 per hectare was lost due to yield reduction and grain quality downgrades (Milgate & Baxter 2015, p. 159). The majority of the varieties lost $20-$80 per hectare with Commander⁽ᴾ⁾ most severely penalised at $288.60. This was due to a combination of yield losses and downgrading grain quality from malt to feed grade (Milgate and Baxter 2015, p. 160).

Yield losses and downgrades in grain quality can occur without obvious crown rot symptoms such as stem browning and whiteheads. More importantly, downgrades in grain quality can occur without observing yield losses, indicating that an economic impact can occur without knowing there is an underlying issue.

Conclusion

Management of crown rot in farming systems is a difficult task. There is no easy option and the issue must be managed culturally and through an integrated approach. Quite often there are one or more soil and stubble borne diseases present in a paddock which can add to crown rot yield losses and grain quality downgrading. Crown rot can cause yield losses without obvious symptoms and cause grain quality downgrades without yield losses being observed.

The keys to managing crown rot include the ability to assess risk, paddock rotations that have two years of non-host crops or have flexibility in paddock rotations to implement two year non-host crops if crown rot inoculum levels warrant it, effective weed management programs to reduce grass weed hosts in-crop and fallow situations, inter-row sowing between cereal stubble, early sowing within a variety's ideal sowing window and ensuring adequate nutrition for the season, particularly zinc. Also, select the more tolerant cereal type or variety to crown rot that is best suited to your region. There are seed fungicide treatments available for the suppression of crown rot, however they have shown little efficacy as a single management tool and must be used as a part of an integrated management approach.

Sowing two non-host crops in succession has been demonstrated to significantly reduce crown rot inoculum levels. The benefits of successive non-host crops are two-fold including the ability to use two control opportunities for problem weeds and the ability of legumes to fix nitrogen which can reduce nitrogen costs in a following cereal crop.

Useful Resources

https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/tt-crownrotwintercereals

https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-trial-results-2014

https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results-2015

https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

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Impact of stripper fronts and chaff lining on harvest weed seed control

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GRDC project code: US00084

Keywords

- stripper front, harvest weed seed control, HWSC, chaff lining.

Take home messages

- Stripper fronts can collect a similar percentage of annual ryegrass seed to conventional fronts.
- The suppression of weed germination increases as the amount of chaff increases.
- Germination patterns differ between weed species as well as chaff type.

Introduction

Grain producers have become more proficient atMany annual weeds in Australian cropping systems retain their seed at maturity and thus are collected by the harvester. Harvest weed seed control (HWSC) is enabled by a suite of management practices all of which target the seed of weeds during harvest. Current HWSC systems include narrow windrow burning, chaff lining, chaff carts, bale direct and seed destruction (Walsh et al. 2013).

Two factors influence the level of control provided when using HWSC. Firstly, the proportion of weed seed production entering the front of the harvester; and secondly, the efficacy of the HWSC system used.

An increasing number of Australian grain growers are adopting stripper harvester fronts to preserve standing stubble post-harvest. These fronts use rows of fingers on a spinning rotor to pluck grain heads and pods from mature crop plants. Compared to cutting and collecting the grain-bearing plant sections like conventional header fronts, stripper fronts leave more stubble standing.

By reducing the quantity of material being processed by the harvester stripper fronts increase the speed and efficiency of harvesting. Anecdotal evidence suggests that stripper fronts are particularly effective in harvesting lodged and fallen crops, as the fingers can lift and remove the heads without the need for collecting large amounts of crop material.

The use of stripper fronts does have some disadvantages. Tall standing stubble carries increased fire risk and requires sowing equipment which can clear the stubble. Harvester settings need to be changed due to the decreased volume being processed, which requires some expertise and experience. A faster harvest rate can have logistical implications - for example; more grain trucks may be required to keep up with the harvester.

The weed seed collection efficacy of stripper fronts is currently unknown. Because HWSC relies on weed seeds entering the harvester, it is important to determine whether stripper fronts will achieve weed seed collection proportions similar to conventional fronts.

As one of the most popular HWSC systems, chaff lining has potential for wide-spread adoption across Australia owing to its relative low cost and ease-of-implementation. Chaff lining is the practice of concentrating the weed seed bearing chaff fraction directly behind the harvester rather than on controlled traffic farming (CTF) tram tracks. The chaff environment is likely to be suboptimal for seed persistence and seedling establishment, and therefore, this practice has the potential to be as effective as other forms of HWSC in depleting weed seed banks.

Methods

Weed seed collection

The annual ryegrass seed collection effectiveness of stripper and conventional harvester fronts was compared in wheat paddocks on two different farms near Wagga Wagga during December 2017. The annual ryegrass plants selected were scattered over a large area of each paddock, and a variety of plant sizes were included.

At each site 20 representative plants were collected pre-harvest to determine the average number of seeds per annual ryegrass tiller. The annual ryegrass seed collection for the conventional front was obtained by counting the number of seeds on the plant above 15cm as well as the number of seed below 15cm. It was assumed that seeds occurring above 15cm, the recommended HWSC cutting height, would be collected during harvest when using a conventional front.

At each site, 50 additional plants were marked pre-harvest and the number of seeds present on each was estimated. Once the stripper front had harvested the area, any remaining plant material (standing or on the ground) was collected. The number of seeds collected after harvest were compared with the number estimated to have been on the plant originally to determine the weed seed collection efficacy of the stripper front.

Chaff production

The amount of chaff produced by stripper and conventional fronts, in this case a draper type front was determined by collecting the chaff produced during the harvest of three 100m lengths of wheat crop for each front. During harvest a large bag was attached to the chaff-line chute at the back of the harvester. The same harvester was used for each of the lengths and the harvest height was set at 15cm for the draper front lengths. The chaff produced from each length was collected and weighed.

Chaff lining

Pot trials at three locations; Toowoomba, Wagga Wagga and Narrabri investigated the influence of wheat, barley, canola and lupin chaff on the seedling emergence of annual ryegrass. At each location eight rates of chaff (0, 3, 6, 12, 18, 24, 30, and 42t/ha) were placed over annual ryegrass seed on the surface of pots/trays filled with potting mix. Once the chaff was evenly spread across the soil surface, the pots were watered thoroughly and kept moist for the duration of the study. Emerging annual ryegrass seedlings were counted and removed every seven days for 28 days. Differences between chaff types and rates were assessed using the total germination over the 28-day period.

The chaff rates used in the pot experiments are designed to mimic the rates of chaff that may occur in a field situation. To calculate the rates of chaff that might be expected in a field situation, the following formula was used:

Chaff amount = 0.3 x grain yield (t/ha) x (harvester width (m)/tramline width (m))

This formula is based on previous experimentation in wheat (data not shown), where chaff yield was determined to be equivalent to approximately 30% of the harvested grain weight. For example, using a wheat yield of 3.5t/ha, a 12m harvester width and a 30cm chaff line width, the amount of chaff concentrated into a chaff line would be 42t/ha.

Results and discussion

Seed collection

At both sites it was estimated that a conventional front cutting at 15cm would have collected the same proportion of ryegrass seed, approximately 85% (Figure 1). At Site 1 the proportion of seeds collected by the stripper front was identical to that of a conventional front. This result clearly highlighted the potential for stripper fronts to be used in conjunction with HWSC systems. In contrast though at site 2 a lower proportion of ryegrass seed was collected by the stripper front. This could be due to numerous factors; row spacing was greater at this site and the harvester was running faster and higher than at Site 1, which could have reduced the seed collection and, therefore HWSC efficacy. The result at this site indicates that when using a stripper and a HWSC system there will need to be some attention given to ensuring maximum annual ryegrass seed collection.

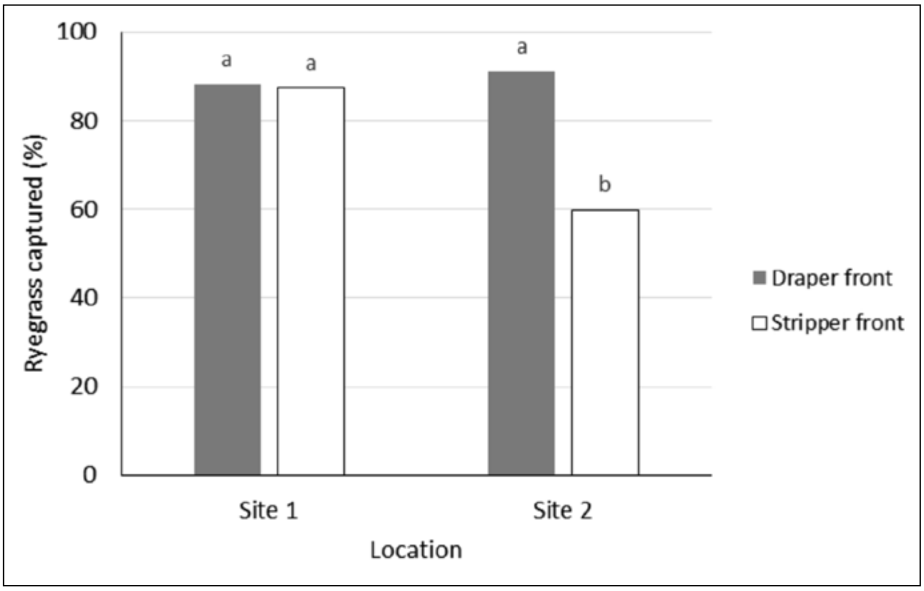

Figure 1. Percentage of ryegrass seed collected by stripper front and conventional front at two locations (Means with same letter are not significantly different)

A stripper front can collect a similar proportion of annual ryegrass seeds as a conventional front. However, header speed, height, settings, crop variety and row spacing can all influence the weed seed collection by both types of harvester front. The amount of weed seeds collected by all harvester fronts is also dependent on the weather and the amount of seed shedding which has occurred before harvest.

Chaff production

The draper front produced over twice the amount of chaff compared to the stripper front (Figure 2). This is likely due to the larger amount of crop material collected by a draper front compared to a stripper front resulting in a substantial amount of straw material exiting in the chaff fraction.

Figure 2. Amount of chaff fraction (kg) produced when harvesting using two different harvester fronts (Means with same letter are not significantly different)

Chaff lining

At all three locations, increasing amounts of wheat chaff reduced annual ryegrass germination and emergence. There were differences between locations in the amount of chaff required to significantly reduce germination. At Wagga Wagga the presence of any chaff resulted in a significant reduction in ryegrass emergence (Figure 3) but there was no difference between 3 and 12t/ha and 30 and 42t/ha gave the largest emergence reduction. At Narrabri (Figure 4) it was not until 18t/ha of chaff was produced that there was a significant reduction in annual ryegrass germination while at Toowoomba (Figure 5) it was not until 24t/ha of wheat chaff was present that there was a reduction in emergence.

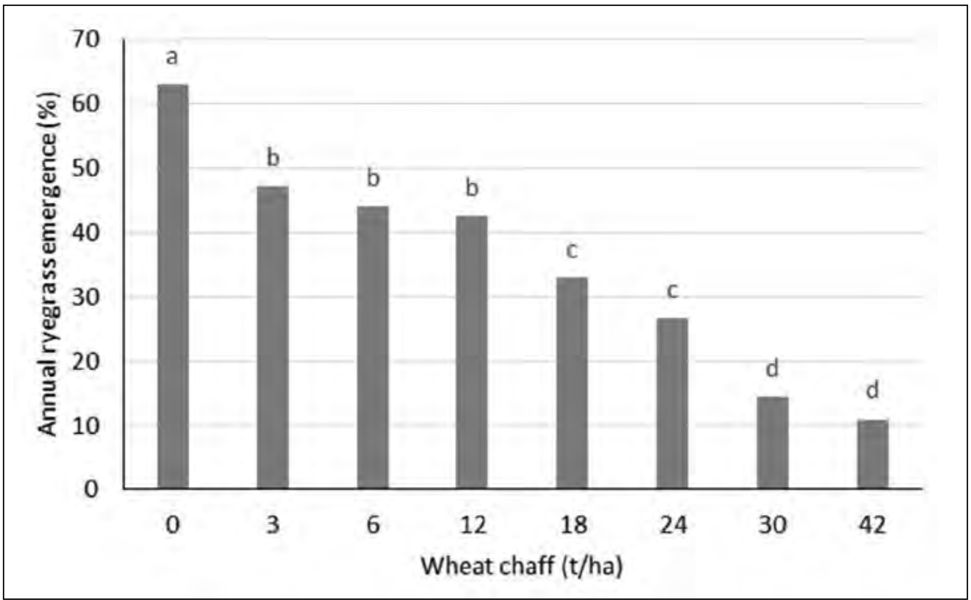

Figure 3. Emergence of annual ryegrass through wheat chaff at eight different rates (t/ha) in a pot trial conducted at Wagga Wagga, NSW (Means with same letter are not significantly different).

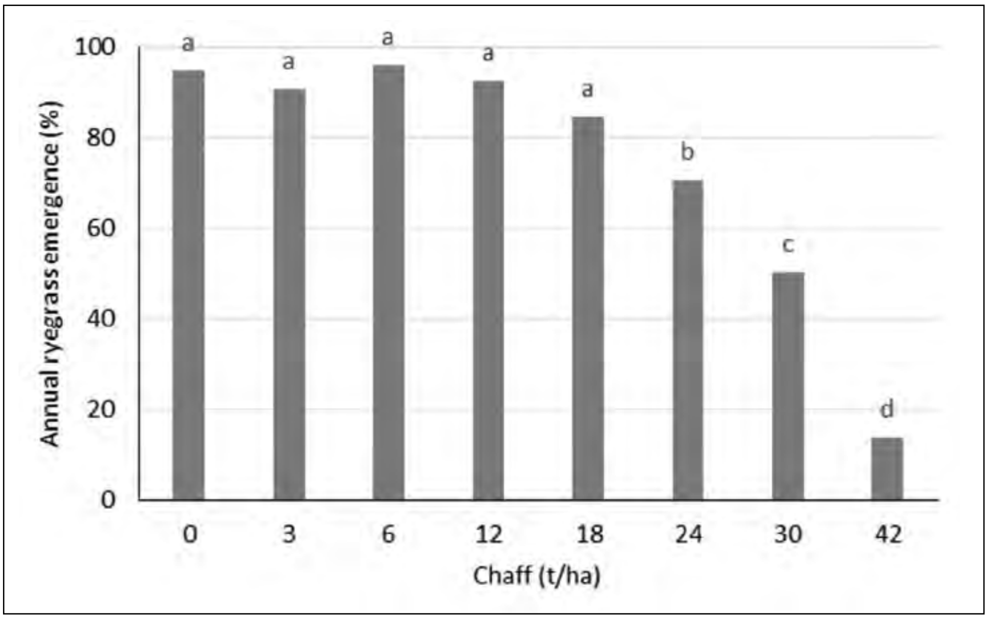

Figure 4. Emergence of annual ryegrass through wheat chaff at eight different rates (t/ha) in a pot trial conducted at Narrabri, NSW (Means with same letter are not significantly different).

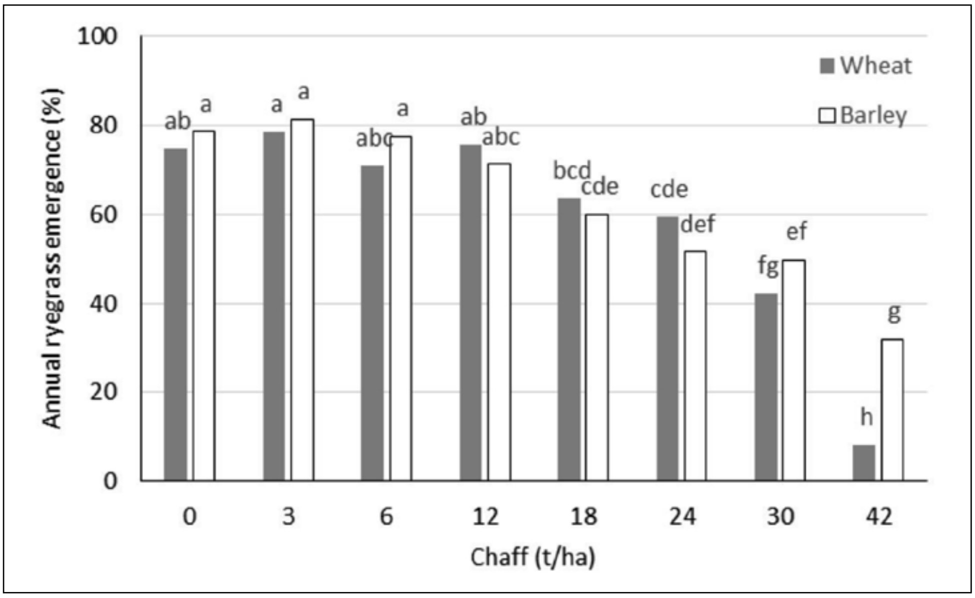

Figure 5. Emergence of annual ryegrass through wheat and barley chaff at eight different rates (t/ha) in a pot trial conducted at Toowoomba, Qld (Means with same letter are not significantly different).

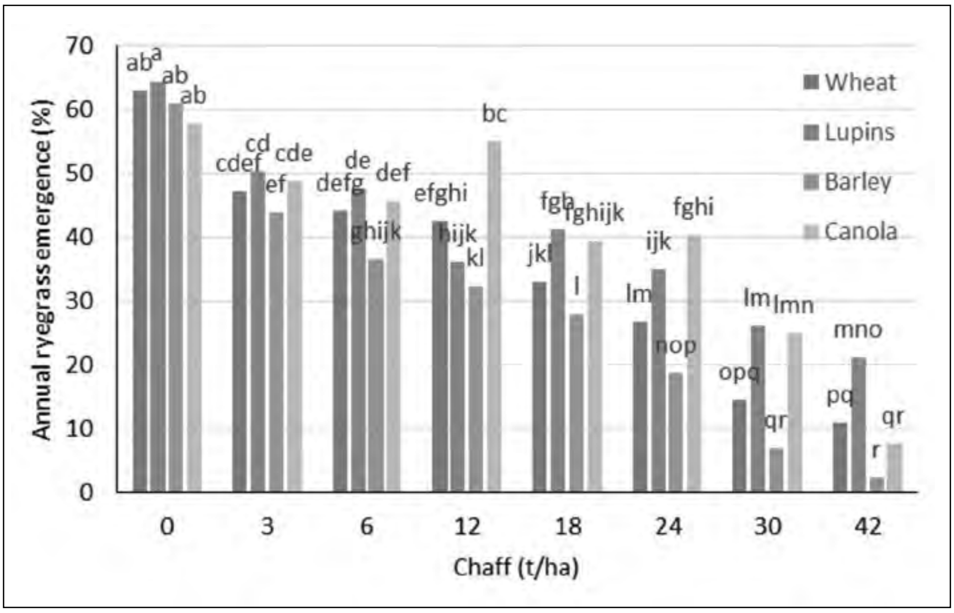

Figure 6. Emergence of annual ryegrass through wheat, lupin, barley and canola chaff (left to right column bars, respectively) at eight different rates (t/ha) in a pot trial conducted at Wagga Wagga, NSW (Means with same letter are not significantly different).

The chaff type also influenced emergence but results were variable. At Toowoomba there was no difference between wheat and barley chaff except at 42t/ha when wheat had a significantly lower level of emergence than the barley chaff (Figure 5). At Wagga Wagga, while there was interaction between species and chaff amount (Figure 6) overall barley inhibited emergence better than wheat, and both were better than canola and lupins.

The greater emergence inhibition by the barley chaff at Wagga may be due to it being a greater physical barrier. That is, for any weight of chaff more barley chaff was needed than wheat chaff with lupins and canola requiring even less. It is however unlikely that all crops and/or species are going to have the same chaff percentage, and a harvester using a stripper front is also going to produce less chaff (Figure 2) for a chaff line. A barley crop is likely

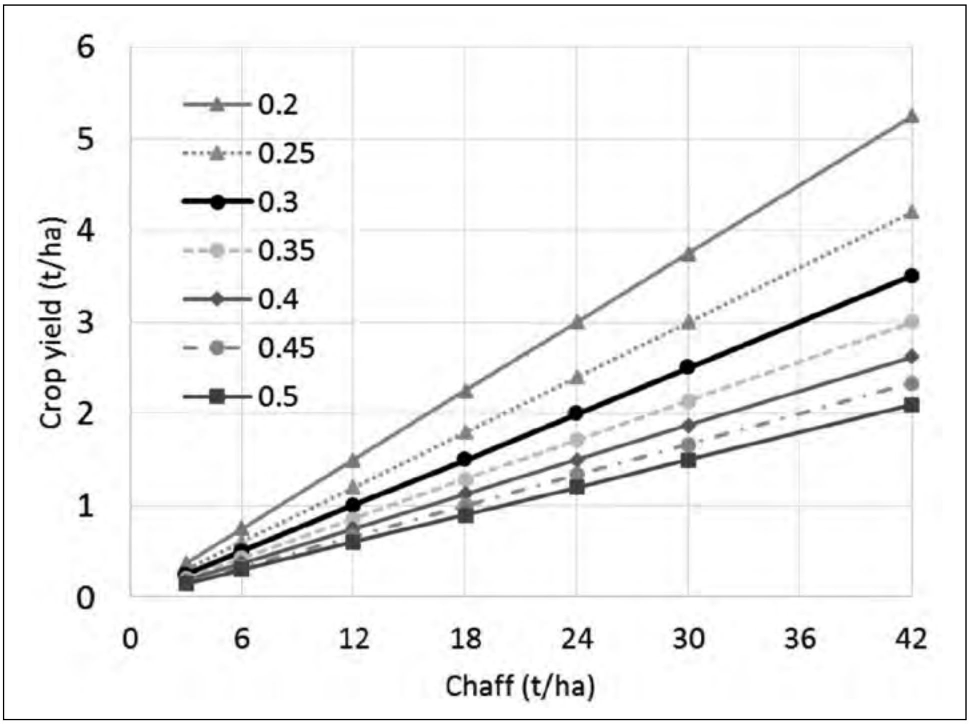

Figure 7. Estimated crop yield for various chaff rates at different chaff proportions for 12m wide harvester and 0.3m chaff line.

to have a lower chaff proportion than a wheat crop. With a 12m wide harvester forming a chaff line 30cm wide and a chaff proportion of 0.3 then 42t/ha of chaff equates to a 3.5t/ha crop (Figure 7). However, if the chaff proportion is 0.2 then 42 t/ha equates to a 5.25t/ha crop conversely with a chaff proportion of 0.5 a crop of only 2.1t/ha is required to produce a chaff line of 42t/ha.

Conclusions

It was found that a stripper front can collect the same proportion of weed seeds as a conventional front but this will depend upon several crop and harvesting conditions. Consequently, the results indicate that the use of stripper fronts is compatible with HWSC but care is needed in harvester operation to maximise seed collection and the influence of crop architecture on weed seed collection needs further investigation.

The results of the pot experiments indicate that emergence of annual ryegrass can be significantly suppressed by chaff with suppression increasing with increasing amounts of chaff.

Different crop species also provided different rates of reduction in emergence, although for wheat and barley the relative effectiveness varied between the two locations. At Toowoomba there was no difference between the two crops except at the highest chaff rate when wheat provided a higher inhibition of emergence while at Wagga Wagga barley gave increased emergence inhibition overall. At Wagga Wagga where lupins and canola were also tested these chaff types provided a lower rate of reduction in seedling emergence than the two cereal chaff types.

Further work is needed on the chaff proportions of the different crops to determine if the chaff rates used here were appropriate for all species. Additionally with less chaff produced by a stripper front, chaff lining will be less effective than when using a conventional front in crops with the same grain yield. In summary, chaff lining can considerably reduce weed emergence given sufficiently high chaff loads.

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Key farming decision points to improve water use efficiency and profit on red soils

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GRDC project codes: CSP00111, CSP00174, CSP00186, CFF00011

Keywords

- crop sequence, fallow management, sowing date, nitrogen, timeliness, soil acidity, tillage.

Take home messages

- Combinations of agronomic decisions, not single factors drive the highest efficiency and profit in grain production.
- The central west of New South Wales (NSW) has one of the highest grain yield responses to the application of strict summer fallow weed management practices.
- Good crop sequence and fallow management provides the opportunity for early and timely sowing of crops for well-prepared operators to maximise yield and minimise risk, with multiplying effects at the whole-farm scale. Early crops can be grazed on mixed farms providing further benefits.
- In-crop (post-sowing) management should be about protecting the potential, not fixing problems – monitor well, evaluate the return, and be timely and effective.

Business profit drivers and scope for improvement

Several recent studies of commercial farm businesses emphasise the dramatic changes in the economics and risk of grain farming in recent years as cropping intensity has increased. As farm size, cropped area and land values increased, so too have debt levels, machinery costs and total interest, so that despite improvements in productivity, farm income to cost ratios have decreased significantly. However, the fact that the top 25% of grain businesses make double the return on capital (8.8%) as compared to the other 75% (4.5%) (ABARES 2015), emphasises the point that **'it is not what you do, but how well you do it'** that defines the success of most farm businesses. Numerous recent studies of the key drivers of successful businesses emphasise three important areas – (1) agronomic and technical; (2) business and financial and (3) people and relationships (e.g. Hillicoat et al., 2018) and they make important reading.

As a farming systems agronomist, my talk will focus on the agronomic and technical drivers of success, where a consistent message in studies of successful intensively cropped farms (in addition to sound financial management) is the importance of more frequent monitoring and measurement to assist in management decisions, and timeliness in implementing them.

Recent national studies of 'yield gaps' between the water-limited potential of crops and those achieved by growers suggest there is significant scope for improvement – including in the central west, where wheat and canola crops achieved around 50-60% of water-limited yield potential for the years 1990 to 2015 (www.yieldgapaustralia). Field studies investigating the economic performance of a range of different 3 to 4 year crop sequences and management suggest differences in the average annual gross margin of up to $400/ha between the best and worst crop sequence and management options, and $150/ha difference between the best and common district practice. Thus, there appears to be significant scope to improve management for increased profit – but what are the key decisions that can provide the biggest 'bang for the buck', while managing business risk?

Here we provide a framework to consider them, and evidence for their impact using examples from the central west, or nearby environments on red soils where possible.

Management levers for high efficiency and profit – at paddock and farm scale

No one technology – be it a new variety, tillage system, new machine, or fertiliser – will alone close existing yield gaps to maximise yield and profit. Highly efficient systems must combine several pre-crop and in-crop management strategies that only together can capture, store and use water most efficiently (Figure 1). It is convenient to discuss them alone to consider the scale of the response possible – but the key message is that maximum efficiency is only achieved when they act together.

Long-term soil management

Long-term management decisions can affect the capacity of the soil to capture, store and supply water to the crop. Some examples include:

- Soil structure: pasture phases, maintaining cover (stubble, cover crops), no-till, controlled traffic (CT) and gypsum on sodic soils all act to maintain stable soil structure for maximum water capture and storage. Many red soils in central NSW are prone to hard-setting and crusting if excessively tilled or left bare.
- Weed seed banks: pasture phases, diverse rotations, hay, herbicide rotations, and inclusion of non-herbicide weed management tactics such as harvest weed seed management, all act to keep weed seed banks at low levels.
- Nitrogen (N) fertility: inclusion of legumes (pasture or pulses), increased N fertiliser and more efficient N use will preserve long-term soil fertility.

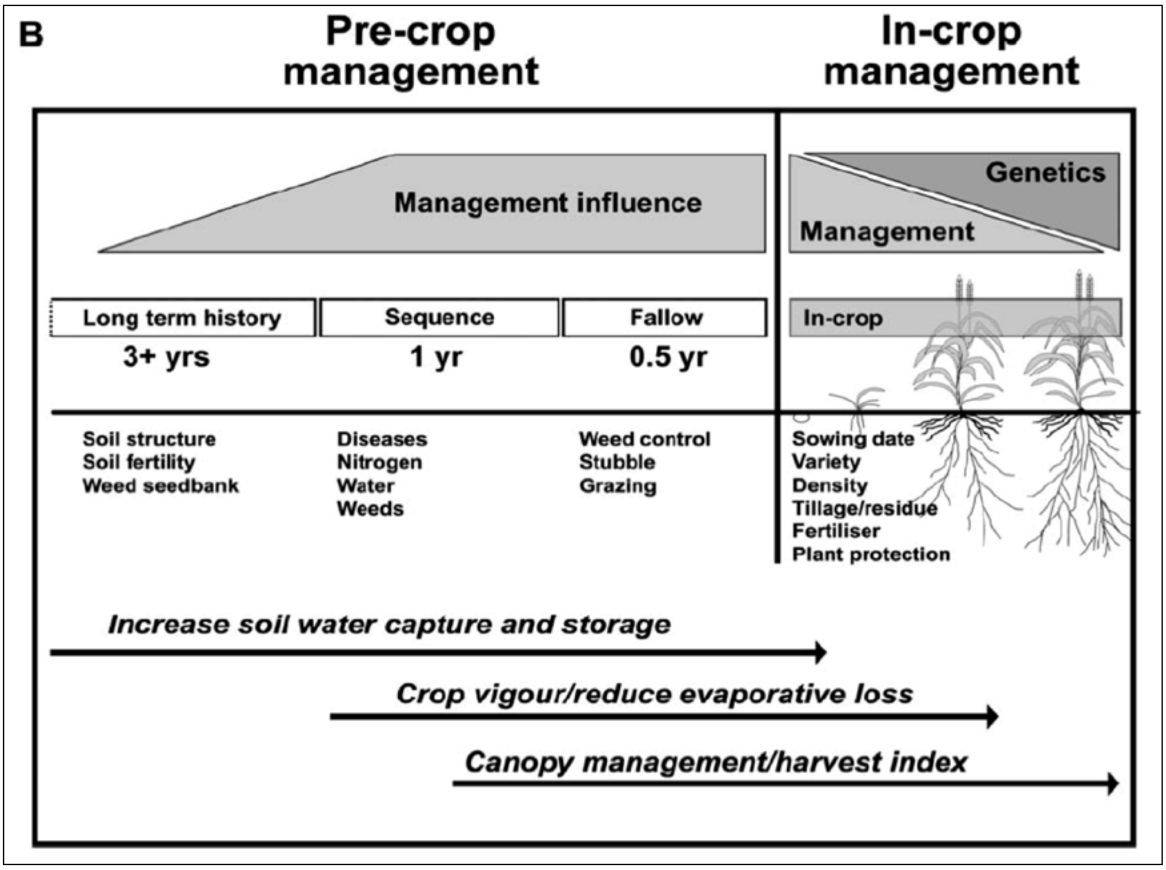

Figure 1. Using water efficiently requires a combination of pre-crop and in-crop management to capture, store and use water to produce grain. No single management factor alone drives efficiency and much of the effort occurs well before seeding (Kirkegaard and Hunt 2010).

- Sub-soil constraints: on red soils, soil acidification is inevitable without regular addition of lime, and sub-surface acidity (5-15cm) due to insufficient incorporation is an emerging issue.

Flexibility may be required to deal with short-term issues (e.g. strategic tillage, stubble reduction, consecutive cereals) but these are of little consequence provided a longer-term strategy of sound soil management is maintained.

A suitably diverse crop sequence

- System choice: economic modelling to compare continuous cropping and mixed farms at low rainfall sites in southern Australia including West Wyalong show that while continuously cropped farms and mixed farms may have similar profitability in average seasons, the continuously cropped farm was able to better capitalise in good seasons, but were at greater risk in poor seasons (Analysis by Ed Hunt, Michael Moodie and Mallee Sustainable Farming). Less diverse, continuously cropped farms (i.e. 100% cereal) had the lowest economic performance in all but the very best of seasons, supporting much of the experimental data related to the benefits of diversity.
- Crop sequences in central NSW remain cereal-dominated (approximately 80% cereal) and this increased to 93% during the millennium drought (2002-2010) when limited early sowing opportunities and dry springs increased the risk of legume and oilseed break crops. GRDC-funded research in several projects confirmed that in all areas including central west NSW and other low rainfall sites, crop sequences that were more diverse were as profitable, or more profitable, than continuous cereal rotations – and that diversity in both crops and practices (graze, hay, brown manure) were required to cost-effectively manage paddocks with herbicide resistant weed or disease problems (http://www.farmlink.com.au/project/crop-sequencing). In a range of experiments over the last five years, the most profitable crop sequences often made $450/ha more annual average gross margin than the worst, and around $150/ha more than common district sequences (Peoples et al., 2015). Predicting the longer-term economic benefits is difficult as the weed and disease control benefits of diverse sequences are not captured by farming systems models such as APSIM, which focus on water and N.
- Long-fallowing is still used to manage production risks associated with cropping in central and south west NSW's variable climate. Fallows comprised 25-30% of farm area between 2000 and 2010 but with more favourable seasons this has now declined to 5-10%. Fallowing can provide benefits at the whole-farm level by compressing the sowing window allowing more crops to be sown on time, and reducing risk in specific crops by providing stored water and N. In theory, long fallowing and early sowing are complementary practices, as the fallow reduces weeds and diseases which can be difficult to control in early sown crops, and early sowing with slow developing cultivars allows the crop to better use soil water and N that is stored during the fallow. Stored soil water also helps to establish early sown crops when there is minimal autumn rainfall.

Summer fallow management – weeds, stubble and stock

- Weeds: in a national study on the potential value of summer rainfall (Hunt and Kirkegaard, 2011), the red soils of central west NSW had some of the greatest predicted opportunity to capitalise on summer rainfall to produce grain because:
  - o equi-seasonal rainfall means there is significant rain to store in summer;
  - o the red loam soils have good water-holding capacity; and
  - o dry and variable springs mean the stored water is extremely valuable to fill grain.

  Preserving summer fallow rain through strict weed management and retained stubble was predicted to contribute 58% of wheat grain yield (0.5 to 2.0t/ha) and be profitable in 91% of years. In a subsequent series of experiments in the central west (2010 to 2012, Haskins and McMaster 2010; Kirkegaard et al., 2014), strict summer weed control increased the amount of stored water by 48mm at sowing, and mineral N by 59kg/ha, increased yield by 1.1t/ha with a return on investment of $6.45 for every $ spent. Delayed or missed sprays could halve the percentage return on investment (ROI) by reducing the water and N available to crops, but were always preferable to not spraying at all.
- Maintaining stubble cover to protect soil structure, increase infiltration and water storage over summer is accepted practice. The main decision in regard to the need to manage, reduce or

remove stubble prior to sowing, is to ensure effective and timely seeding. At least 3t/ha of cereal residue (70% cover) is required over summer to capture most of the benefits of stubble in the majority of seasons. Heavier stubble loads can increase the duration of soil water storage in the surface by slowing evaporation, but the benefits for early sowing depend on the timing of rainfall at sowing. A good policy is to retain stubble whenever you can, but manage it to ensure a timely seeding operation and good weed control.

- Livestock: recent studies on red soils at Condobolin and Temora have shown that light grazing of stubble in summer has little impact on water storage or the yield of subsequent crops, provided sufficient cover (70%, >3t/ha) is retained on the soil surface. On the contrary, the yield of some crops increased due to increased soil mineral N after grazing stubble in some seasons. Consequently whole-farm income is generally unaffected or improved by careful stubble grazing. Overgrazing is the bad decision – **'sheep do damage with their mouths, not their hooves!'**

Fit crops to the growing season – variety and sowing time management

Good fallow management will increase the opportunities for well-prepared growers to capitalise on early and timely sowing opportunities as the crops can be sown and established into water stored from the summer fallow rainfall. The need to sow on time to ensure flowering occurs at the optimum time to maximise yield potential is widely recognised, with at least 5% reduction in yield potential for every week delay past the optimum sowing date. As autumn rainfall declines and sowing programs increase, the sowing window for common fast-maturing spring varieties is being stretched. Establishing crops earlier on stored moisture can increase yield at the paddock scale if suitable varieties with appropriate phenology are used (Table 1). Some recent examples are shown in Tables 1 and 2.

In 2014, Wedgetail⚙ sown 17 April after long fallow out-yielded Suntop⚙ (at that time the highest yielding milling cultivar in south west NSW National Variety Trial) sown 22 May by 1.4t/ha. In 2015 Wedgetail⚙ sown 15 April after fallow, out-yielded Condo⚙ (at that time the highest yielding milling cultivar in south west NSW National Variety Trial) by 1.5t/ha (Hunt et al., 2015) (Table 1). As new, slower-maturing varieties (e.g. Kittyhawk⚙ , Longsword⚙) are developed, more opportunities to capitalise on early sowing will emerge.

Table 1. Yield of early-sown, slow maturing varieties compared with later-sown fast maturing varieties sown after long fallow at Rankin Springs in 2014 and 2015.

Variety	2014 Grain yield (t/ha)		2015 Grain yield (t/ha)	
	Sowing date		Sowing date	
	17 April	22 May	15 April	14 May
Wedgetail⚙	5.8	4.6	6.2	4.9
Eaglehawk⚙	4.4	4.4	5.1	4.5
Gregory⚙	4.0	4.9	5.3	4.0
Suntop⚙/Condo⚙	4.0	4.4	3.0	4.7
LSD (P<0.05)	0.4		0.5	

For canola in the tough 2017 season at Condobolin, the slower developing variety Wahoo⚙ sown early (6 April) after good fallow rainfall (313mm), had double the yield of the faster maturing variety Stingray⚙ under both dry conditions (122mm growing season rainfall) and when rainfall was supplemented with 150mm irrigation (272mm growing season rainfall) (Table 2) (Brill et al., 2018).

Table 2. Yield of earlier-sown slower maturing canola variety was superior to later-sown fast variety even in the tough 2017 season at Condobolin at 0.5 to 1.6t/ha yield levels (Brill et al., 2018).

Variety	2017 (Dry) Grain yield (t/ha)		2017 (Wet) Grain yield (t/ha)	
	Sowing date		Sowing date	
	6 April	20 April	6 April	20 April
Stingray⚙ (fast)	0.4	0.4	0.7	1.0
Wahoo⚙ (mid-slow)	0.9	0.8	1.6	1.6

Success with early sowing requires good paddock selection and preparation, and ensuring the right variety is chosen that will flower at the optimum time for the selected sowing time. A recent e-booklet providing *Ten Tips to Early-sown Canola* can be accessed at: https://grdc.com.au/10TipsEarlySownCanola.

On mixed farms early-sown crops also provide opportunities for grazing to further increase profit. Best-bet management guidelines are available for grazing crops, but the key decision is the lock-up time https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/managing-dual-purpose-crops-to-optimise-profit-from-grazing-and-grain-yield-north.

Careful timing of livestock removal prior to the elongation of stems (cereals) or buds (canola) and with sufficient biomass to achieve the target grain yield are key to profitable outcomes. High stock prices compared to grain may favour prolonged grazing. **'Luck is when opportunity meets preparedness.'**

Managing nitrogen (N) well

Without adequate N, the yield and profit potential established with good sequence, fallow and sowing operation management will not be realised. Attention to the long-term N fertility has been covered in the 'Long-term soil management' section of this paper. Persistent low protein in cereal crops (<10%) and pre-sowing soil N of < 50kg/ha in the top 60cm may be signals of N-rundown, and a trigger for legume inclusion or increased N rates. Nitrogen is a significant input cost and a driver of yield (and quality) in non-legume crops and the general '4R principles (right product, right rate, right time, right place)' promoted by IPNI should be adopted (http://www.ipni.net/4R). In most cases the following basic decisions will assist:

- Soil test March-April.
- If < 40kg N/ha (0-60cm) apply some upfront N, especially if soil water store is good, crops are sown early for grazing, and especially for canola. Separate seed and fertiliser.
- Most N can be top-dressed at stem elongation according to seasonal conditions and yield targets, at rates to ensure the total mineral N supplied to the crop (soil + fertiliser) is 40kg/ha per tonne of expected wheat yield; 35 kg/ha/t for barley and 80 kg/ha/t for canola. Relying on soil mineralisation for N makes sense in the short-term, but will run down soil fertility in the longer-term if legume pastures and crops are not included.

In central west NSW, seasonal uncertainty means N management is more about farm finances than agronomy. What are the consequences of not getting a return in the current season? Target crops where the return on investment is most likely – weed-free, sown on time, following a good break. If you err on the side of too much N, remember canola is less likely to hay-off than wheat and much of the N will remain in the system.

Crop protection – in-crop 'fine tuning' with weeds and disease

Good long-term soil, crop sequence, fallow management, variety choices and harvest weed-seed management will mean that in-crop management of weeds and diseases often becomes a matter of cost-effectively protecting the yield when necessary with good monitoring and sound economic decisions. One exception is the longer-term focus on running down the weed seedbank, which requires monitoring and weed management action to minimise weed survivors every year in every paddock. The management of most diseases (e.g. rust in cereals, blackleg in canola, Ascochyta in chickpea) involve a series of integrated approaches over time (residue management, variety choice, fungicide programs). Some decisions (seed dressings) are cheap insurance, while some such as later canopy fungicide sprays require careful assessment of the likely costs and return. Unlike N, there is no chance to recoup costs from unnecessary crop protection inputs, as there are no residual benefits beyond the active period. So, prepare and monitor well, be realistic about your yield potential and response to treatment, and be timely and effective with the application.

Capturing the synergies from the system

Whole-farm multipliers

Do the yield increases at paddock-scale (Tables 1 and 2) in one year translate to the whole farm, and across seasons? The capacity to start the farm sowing program earlier with slower-maturing crops provides a multiplying effect across the farm in any particular year, as all paddocks move into a better sowing window and the sowing program is completed earlier. The benefits in specific years for a typical 20-day sowing program can be significant and are generally higher on deeper soils in higher rainfall areas, but diminish on shallow soils and as you move from southern to northern NSW. The central west is a transition area, but increases in estimated whole-farm wheat yields for a site such as Condobolin by sowing slower maturing wheat varieties when the opportunity arises on a red soil with 200mm plant available water capacity (PAWC) to 1.6m, is estimated to be 5 to 17% (Flohr et al., 2018).

Legacy effects

Will the higher yielding crops simply 'steal' water from following years – how often will the profile re-fill?. In the last 5 to 10 years, novel early sowing systems involving slower-maturing varieties suited to earlier sowing have been developed. In central west NSW, wheat varieties such as Wedgetail have provided such options for some time, but newer wheat and canola varieties with appropriate agronomy packages are currently in development. The most recent experimental and simulation

Table 3. The predicted average wheat yield for novel, long-coleoptile wheats sown from 15 March in different rotations, as compared with the current baseline of spring wheat sown from 29 April for a typical 20-day sowing program at Condobolin (Flohr et al., 2018).

Cropping system, wheat variety and management	Mean wheat yield (t/ha)
Continuous spring wheat, short coleoptile, sow from 29 April (Baseline)	2.3
Continuous fast winter wheat, long-coleoptile, sow from 15 March	3.1
As above, rotation with forage legume	3.5
As above, rotation with long-fallow	4.0

evidence (Hunt et al., 2018; Flohr et al., 2018) suggest that capturing opportunities to sow early when they arise, especially with longer coleoptile, fast maturing winter wheats could provide a further boost to farm productivity by using more of the season and more of the soil water. Sequences with forage legumes or fallow provide stored water and N that can boost subsequent wheat yields (Table 3). Such varieties, now in development can be sown deep into stored water in March and established on stored summer rain (rather than waiting for an autumn break) and have a stable optimum flowering window due to vernalisation requirement that stabilises flowering irrespective of sowing time. Table 3 shows the predicted average yield benefit for a 20-day sowing program for these novel wheat types at Condobolin, as compared to existing spring wheat sown late April to mid-May. The early sowing can especially capitalise on the water and N saved by previous legumes or fallows.

The increased efficiency predicted by these novel systems involving earlier sowing systems are now being tested at paddock and whole-system scale in GRDC funded projects CFF00011 and ULA9174837.

Conclusion

Evidence suggests that with combinations of current, best practice management technologies, focussed on the cost-effective capture, storage and use of rainfall, significant increases in whole-farm productivity, efficiency and profit are possible. New wheat and canola varieties with flexible sowing windows that maintain optimum flowering times will provide an excellent additional tool to shift whole-farm sowing programs into an earlier and more efficient window in the face of drying autumns and more variable springs. Success requires a combination of decisions that combine to provide a step-change in farm productivity potential with systems that manage the risk in variable climates.

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, and the author would like to thank them for their continued support. We especially thank staff and technicians at CSIRO, NSWDPI and grower groups (FarmLink Research, CWFS) who assisted with field experiments associated with GRDC projects CSP00111, CSP00174, CSP00186, CFF00011 and ULA9174837.

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

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Notes

THE 2017-2019 GRDC NORTHERN REGIONAL PANEL

FEBRUARY 2018

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHAIR - JOHN MINOGUE

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

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DEPUTY CHAIR - ARTHUR GEARON

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

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ROGER BOLTE

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

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ROY HAMILTON

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

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DR TONY HAMILTON

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

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ANDREW MCFADYEN

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

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PETER MCKENZIE

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

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GRAHAM SPACKMAN

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

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BRUCE WATSON

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

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DR JO WHITE

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

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LUCY BROAD

Lucy Broad is the General Manager of the Grains Research and Development Corporation's (GRDC) Grower Communication and Extension business group. Lucy holds a Bachelor of Science in Agriculture, majoring in agronomy, and prior to working at the GRDC spent the last 13 years as Director and then Managing Director of Cox Inall Communications and Cox Inall Change, Australia's largest and leading public relations agency working in the Agribusiness and Natural Resource Management arena. Her entire career has been in communications, first with the Australian Broadcasting Corporation and then overseeing communications and behaviour change strategies for clients across the agriculture, natural resource management, government and not-for-profit sectors.

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NORTHERN REGION GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK

FEBRUARY 2018

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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

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

GROWER SOLUTIONS GROUP AND REGIONAL CROPPING SOLUTIONS NETWORK CONTACT DETAILS:

NORTHERN GROWER ALLIANCE (NGA)

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

GRAIN ORANA ALLIANCE (GOA)

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

CENTRAL QUEENSLAND GROWER SOLUTIONS GROUP

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

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

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

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

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

BURDEKIN QUEENSLAND:

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

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

REGIONAL CROPPING SYSTEMS NETWORK (RCSN) SOUTHERN NSW

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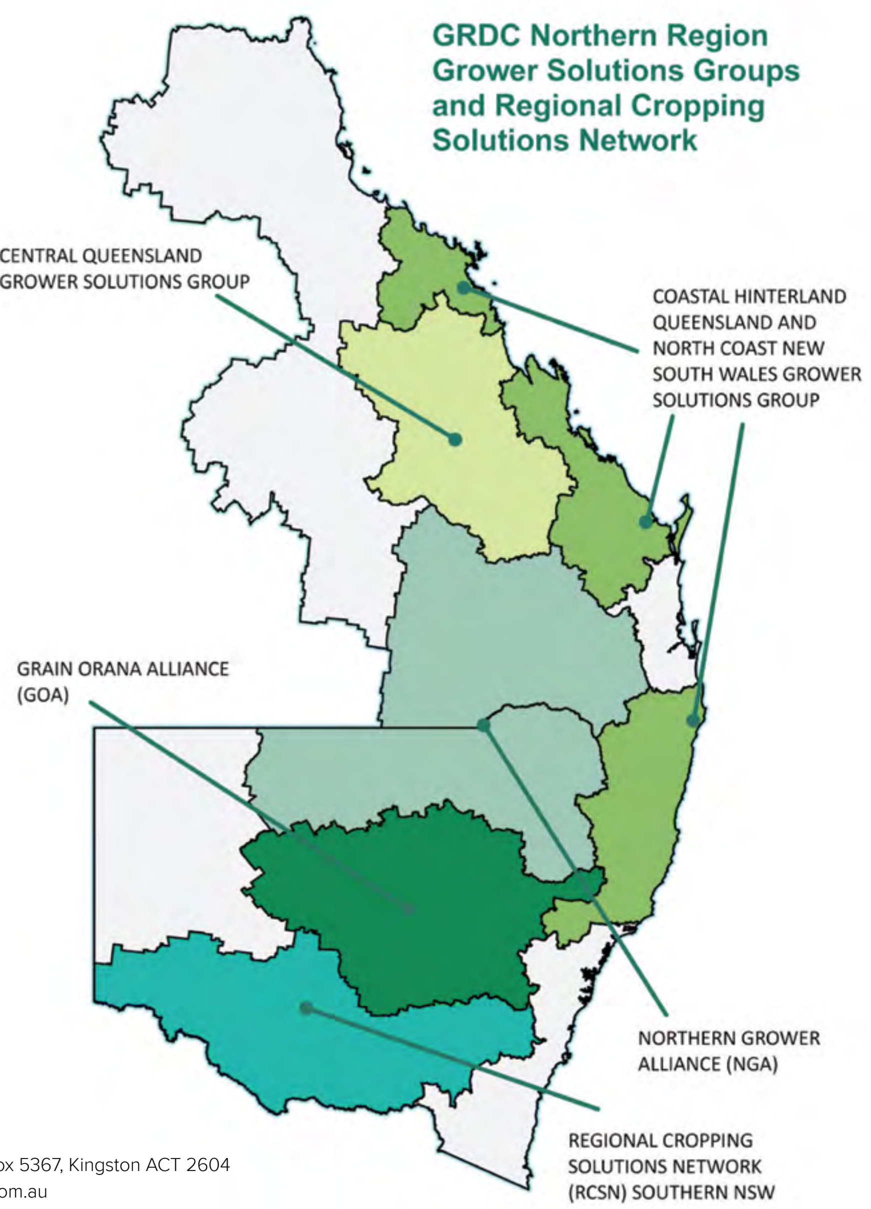
The Southern New South Wales Regional Cropping Solutions Network (RCSN) was established in 2017 to capture production ideas and opportunities identified by growers and advisers in the southern and western regions of New South Wales and ensure they translate into direct GRDC investments in local R, D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



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

- Partnering organisation: CWFS

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2018 West Wyalong GRDC Grains Research Update Evaluation

1. Name [ ]

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

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

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

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

3. Pulse rhizobia performance on acid soils: *Ross Ballard*

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

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

4. Cereal agronomy update: *Felicity Harris*

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

5. Crown rot management through crop rotation and crop sequences: *Brad Baxter*

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

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6. Impact of stripper fronts and chaff lining on harvest weed seed control: *Annie Rayner and John Broster*

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7. Key farming decision points to improve WUE and profit on red soils: *John Kirkegaard*

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

Your next steps

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

9. What are the first steps you will take?
e.g. seek further information from a presenter, consider a new resource, talk to my network, start a trial in my business

Your feedback on the Update

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

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

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

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

Comments

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

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

Thank you for your feedback.