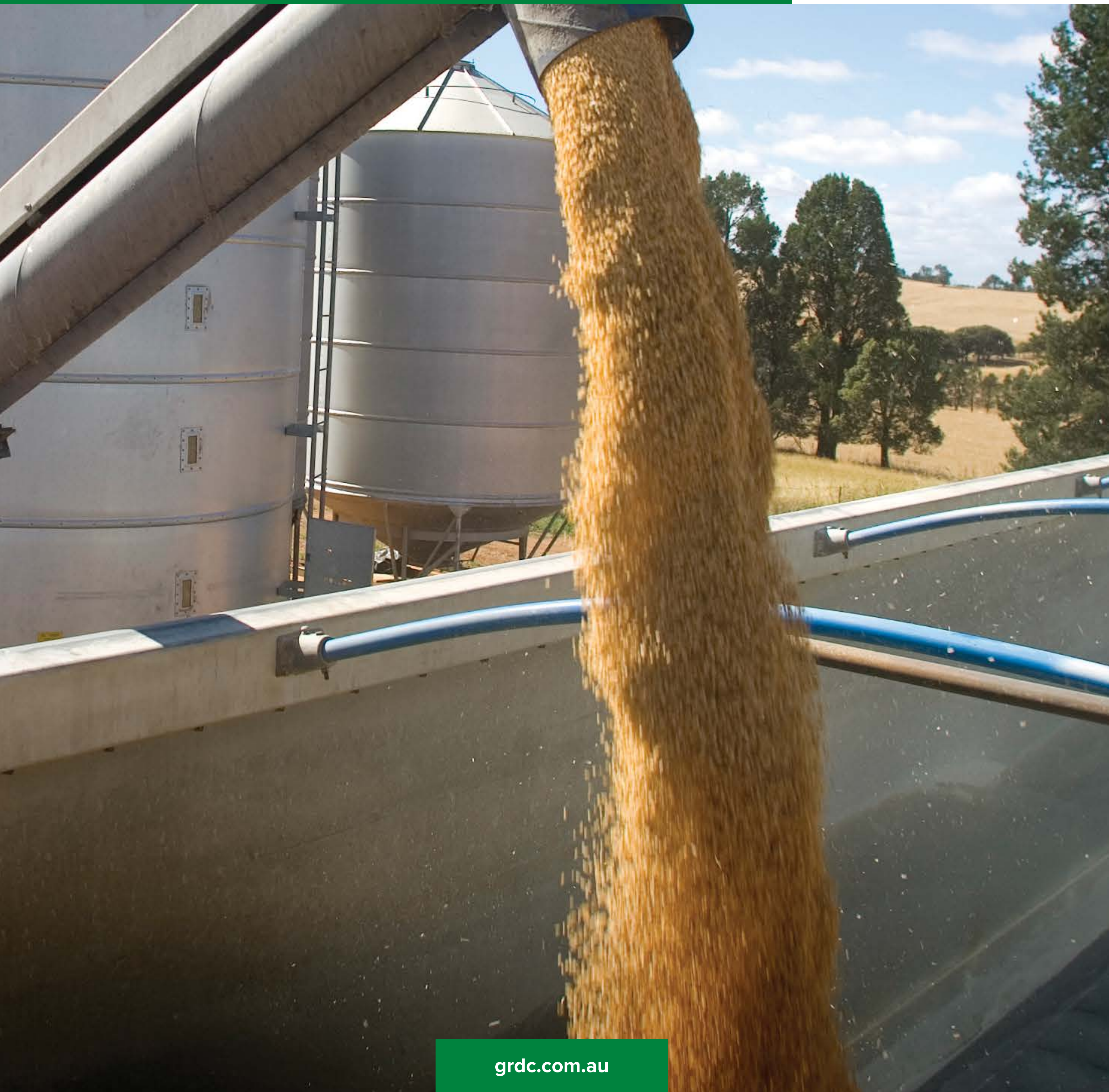
MEANDARRA QLD
WEDNESDAY 3 MARCH 2021

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION



GRDC 2021 Grains Research Update Welcome

If you are reading this, then chances are you are sitting in one of the GRDC's first face-to-face events since COVID-19 changed our lives.

Welcome.

We at the GRDC understand how challenging the past year has been for all Australians, but we also appreciate how well positioned agriculture has been to respond to and work through the restrictions that have come with this global pandemic.

Across many areas of Queensland and New South Wales, an improvement in seasonal conditions has also provided a much-needed reprieve for growers, advisers, agronomists, researchers and those associated with the grains industry.

With that positive change in circumstances comes a thirst for the latest information and advice from grains research and development – we trust that these GRDC Grains Research Updates will help guide your on-farm decisions this season and into the future.

While COVID-19 has forced temporary changes to our traditional Update locations and audience numbers, these events still offer the high quality, seasonally relevant research, development and extension information you have come to depend on. This year our Updates will also be live streamed to ensure the information is available to all who need it.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above to continue to work in situations constricted by COVID-19 regulations.

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

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

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

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

This year we have less people on the ground – as a result of COVID-19 restrictions – but more than ever we are available to listen and engage with you. So if you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au.

Regards,
Gillian Meppem
Senior Regional Manager – North

GRDC Grains Research Update
MEANDARRA

Wednesday 3 March 2021

Meandarra Bowling Club, 4 Walton St, Meandarra

Registration: 8:30am for a 9am start, finish 3:00pm

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	
9:10 AM	**The drivers of phenology for more profitable sowing decisions** – balancing risk of abiotic stresses when selecting cereal varieties to optimise yield potential in SW Queensland.	Felicity Harris (NSW DPI)
9:45 AM	**New cereal varieties - how are they likely to behave on the Western Downs and why?**	Douglas Lush (AGT)
10:10 AM	**Identification of crop-specific and varietal tolerance limits to salinity and sodicity.**	Jack Christopher (UQ)
10:40 AM	**Morning tea**	
11:05 AM	**Amelioration for sodicity -** deep ripping and soil amendment research. Engineering challenges; yield responses to ripping, gypsum and organic matter placement in constrained soils**.**	David Lester (DAF Qld)
11:30 AM	**Cereal pathology update** - learnings from 2020; planning for 2021; latest trial outcomes; barley powdery mildew in 2020; is stripe rust the death knock for some varieties?	Lislé Snyman (DAF Qld)
12:00 PM	**Impact of Ascochyta on chickpea when disease occurs at different growth stages.**	Kevin Moore (NSW DPI)
12:30 PM	**Lunch**	
1:10 PM	**Optimising chickpea sowing and flowering dates for maximum yield.**	Allan Peake (CSIRO)
1:40 PM	**Weed ecology, seed persistence and retention -** implications for management and harvest weed seed capture. (Barnyard grass, feathertop Rhodes grass, windmill grass and sow thistle). **Also: New data on resistance in feathertop Rhodes grass and sow thistle.**	Bhagirath Chauhan (UQ/QAAFI)
2:10 PM	**Cooling grain in storage** – steps to optimise aeration. On-farm data of attainable grain storage temperatures in summer/ winter; aeration equipment options; fan selection; and managing aeration systems.	Alex Conway (Control Unlimited)
2:35 PM	**Storage pests and clever ways to control them.**	Philip Burrill and Greg Daglish (DAF Qld)
3:00 PM	**Close**	

Contents

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Phenology is FUNdamental – applying key project learnings to optimise grain yield

Felicity Harris[1], Hugh Kanaley[1], Rick Graham[1], Stephen Morphett[1], Peter Matthews[1], Peter Roberts[1], David Burch[1], Nick Moody[1], Greg Brooke[1], Hongtao Xing[1] and Michael Mumford[2]

[1] *NSW Department of Primary Industries*
[2] *Department of Agriculture and Fisheries, Queensland*

Keywords

optimal flowering period, frost, heat stress, risk

GRDC code

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

Take home messages

- Aim to target the optimal flowering period (OFP) for your growing environment – know your risk
- Match varietal phenology and sowing time – use the right variety for the right sowing date
- Remain disciplined with sowing dates – don't sow too early!

Background

The 'Optimising yield potential of winter cereals in the Northern Grains Region' project has been a co-investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP) in collaboration with QDAF. From 2017-2020, field experiments were sown across ten locations in New South Wales and Queensland where annual rainfall ranged from 184 to 853 mm and grain yields ranged from 0.2-10 t/ha. The project aimed to provide a better understanding of wheat phenology and yield responses across different environments to refine sowing recommendations and improve yield stability and profitability of growers in the northern grains region (NGR).

The consistent messages presented from the project to date have centered around synchronising crop development (phenology) with seasonal conditions to ensure that the optimal flowering period (OFP) is matched to the growing environment. In previous GRDC Update papers, we combined model simulation and field validation to determine OFPs across locations in the NGR, whereby the OFP varied in timing and duration, as well as for different yield levels (Harris *et al.* 2019, 2020). As flowering time is a function of the interaction between variety, management and environment, the two primary management levers growers can pull to ensure flowering occurs at the optimal time and yield is maximised are *time of sowing* and *variety selection*.

Apply these key project findings to reduce risk and optimise grain yield:

Understand differences in phenology of commercial wheat varieties

In wheat, flowering is generally accelerated under long-day photoperiods and varieties can be broadly classified into two main types: *winter* or *spring*, distinguished by their response to vernalisation and their adaptation to different sowing dates. Winter types can be sown early and will remain vegetative for an extended period (e.g. DS Bennett⊕, LRPB Kittyhawk⊕). This extended vegetative period arises from a genetic requirement of the plant to experience prolonged cold temperatures to trigger flowering (vernalisation). This delays cold-sensitive reproductive stages to ensure flowering coincides with optimal seasonal conditions in spring.

In contrast, spring types generally do not require a period of cold temperature to initiate flowering. However, they can vary in their responses whereby exposure to cold temperatures can hasten their development (e.g. LRPB Nighthawk⦶) or have no effect on development (e.g. Dart⦶, Sunprime⦶). There are multiple combinations of vernalisation and photoperiod genes which influence phenology responses, as such we have observed significant variation in flowering response among both winter and spring types across environments and in response to sowing time. The figures below present the range in flowering date responses across years and sowing dates for two sites and highlights the risk of precocious flowering in quicker spring types.

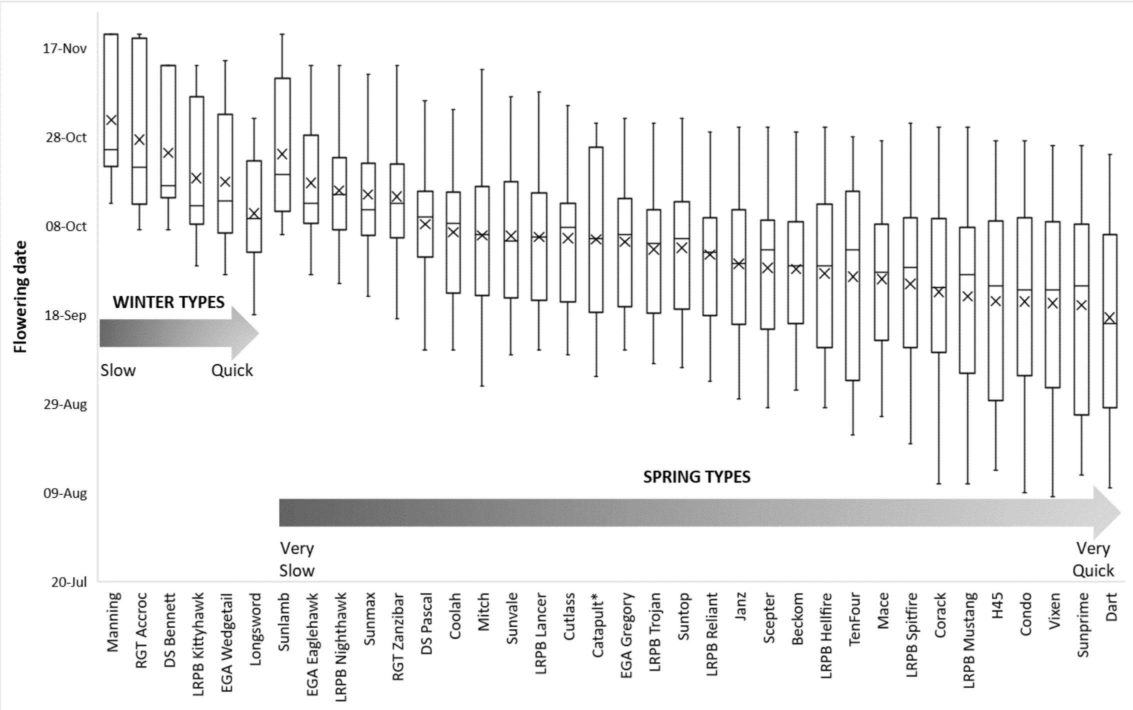

Figure 1. Flowering date responses of genotypes across four sowing dates from early-April to late-May for Wagga Wagga (2018), Marrar (2019) and Harefield (2020) experiments. Asterisk indicates Catapult⦶ only evaluated in 2019, 2020 seasons.

(Varieties Manning, Bennett, Kittyhawk, Wedgetail, Longsword, Sunlamb, Nighthawk, Sunmax, Zanzibar, Pascal, Coolah, Mitch, Lancer, Cutlass, Catapult, Gregory, Trojan, Suntop, Reliant, Scepter, Beckom, Hellfire, TenFour, Mace, Spitfire, Corack, Mustang, Condo, Vixen, Sunprime and Dart are varieties protected under the Plant Breeders Rights Act 1994.)

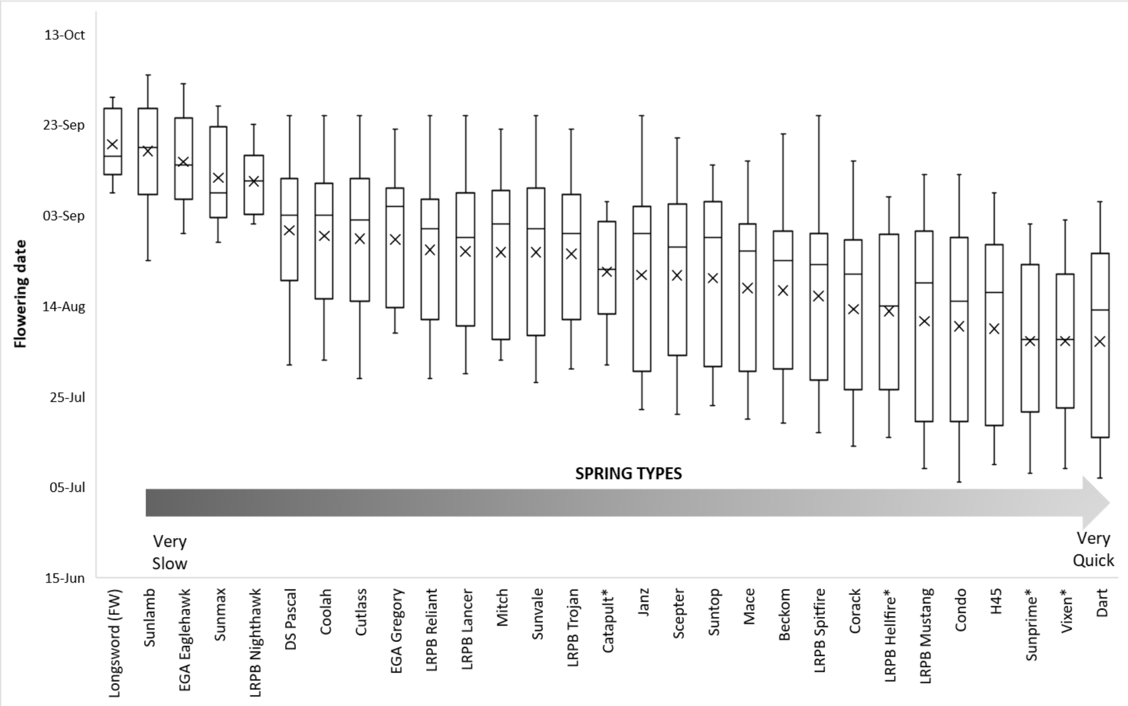

Figure 2. Flowering date responses of genotypes across three sowing dates from mid-April to late-May for Edgeroi (2017) and Narrabri (2019, 2020) experiments. FW – Fast winter type, asterisk indicates genotype only evaluated in two years at Narrabri (2019, 2020).
(Varieties Longsword, Sunlamb, Sunmax, Nighthawk, Pascal, Coolah Cutlass, Gregory, Reliant, Lancer, Mitch, Trojan, Catapult, Scepter, Suntop, Mace, Beckom, Spitfire, Corack, Hellfire, Mustang, Condo, Sunprime, Vixen and Dart are varieties protected under the Plant Breeders Rights Act 1994.)

Need to match varietal phenology and sowing time with environment

Generally, slower developing winter types are more suited to cooler, medium-high rainfall environments in southern NSW which have a longer growing season and increased risk of frost. Winter types when sown early are capable of high water-limited yields, can spread sowing risk and also be a useful frost mitigation tool. However, the vernalisation requirement of these winter types makes them less suited to warmer environments of northern NSW and QLD, where we observed flowering dates later than the OFP and often significant yield penalties in comparison to more adapted mid-quick spring types sown within their recommended window.

In contrast, quicker developing spring types are better adapted to regions with shorter growing seasons, and in environments or later sowing scenarios where frost and heat stress occur in close proximity to each other. Despite the variability across environments and seasons, we were able to identify varieties which were able to maintain relatively stable grain yields across many sowing dates at some sites and which may offer more flexibility to growers.

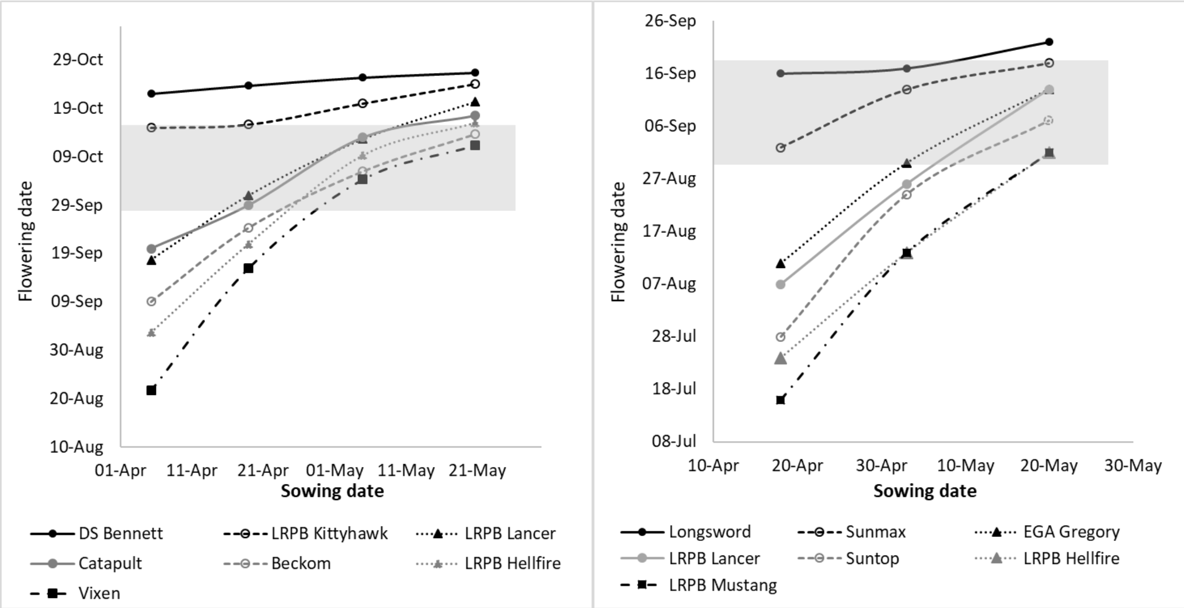

Figure 3. Mean flowering date responses of selected genotypes at a) Wagga Wagga (2018), Marrar (2019) and Harefield (2020) and b) Edgeroi (2017) and Narrabri (2019, 2020) across sowing dates. Shaded box indicates optimal flowering period for each location.

(All the varieties mentioned in the figure above are varieties protected under the Plant Breeders Rights Act 1994.)

Know the risk of getting it wrong - #SowSlowEarly

Winter types – we have observed a yield penalty in many mid-fast winter types when sown prior to early April. This is often due to difficulties establishing crops when soil temperatures are high and there is rapid drying of the seed bed following a rain event. The vernalisation response of some winter varieties has also been observed to be less stable when sown very early, which can result in stem elongation occurring earlier and an increased risk of frost damage. Unless grazing is the primary purpose, sowing prior to early April can increase crop water use under warm temperatures. This can lead to increased likelihood of excessive vegetative growth, taller crop heights and lodging, as well as increased disease pressure.

Spring types – although we have observed significant variation in phenology responses to sowing date amongst spring types, when sown early (when temperatures are warmer and days longer) flowering behaviour is unpredictable and varies substantially across seasons (Figure 1, Figure 2). As such there is increased risk of spring types flowering earlier than the OFP and grain yield penalties due to frost damage or insufficient accumulation of biomass when sown earlier than their recommended windows.

Key recommendation is to remain disciplined with sowing dates – don't sow too early!

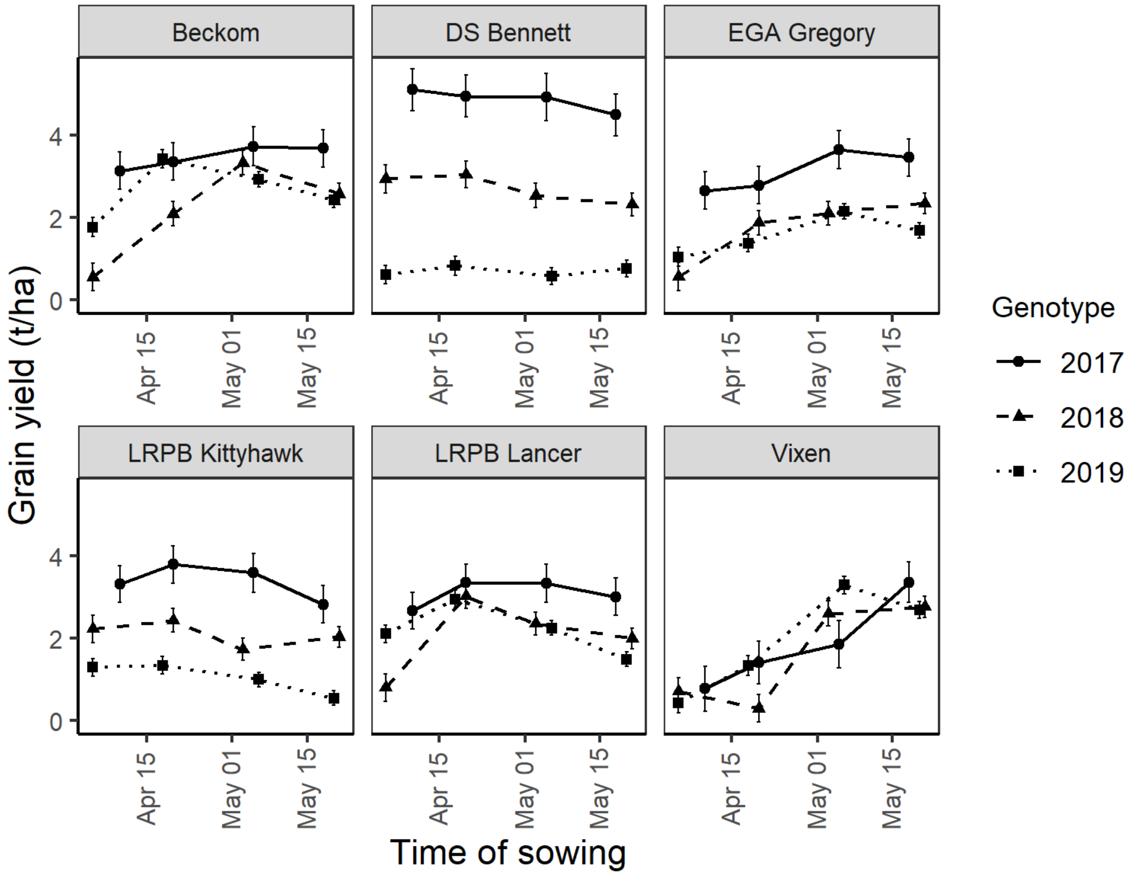

Figure 4. Yield response to sowing time predictions (BLUPs) for a subset of six genotypes for Wagga Wagga in 2017 and 2018 and Marrar in 2019. Vertical error bars denote the 95% confidence interval.
(All the varieties mentioned in the figure above are varieties protected under the Plant Breeders Rights Act 1994.)

Comparing wheat and barley - watch this space...

Compared to wheat, barley is considered to be more widely adapted, have superior frost tolerance and offer higher yield potential across environments in southern Australia. A comparative analysis of the best performing barley and wheat genotypes (defined as the highest yielding treatment) where experiments were co-located across production environments at eight sites in NSW from 2015-2020 is presented in Figure 5. The OFP where yield was maximised for barley was found to be 10-14 days earlier than for wheat, and barley maintained a yield advantage over wheat at yield levels ranging from 1.5-9.6 t/ha. Our understanding of the specific interactions between phenology and environment in barley and the differences in yield physiology between the cereals species is limited. In 2020, a new project was initiated to quantify the flowering time, yield and quality responses of barley, relative to wheat across a range of sowing times. *Preliminary data from 2020 will be presented at the updates.*

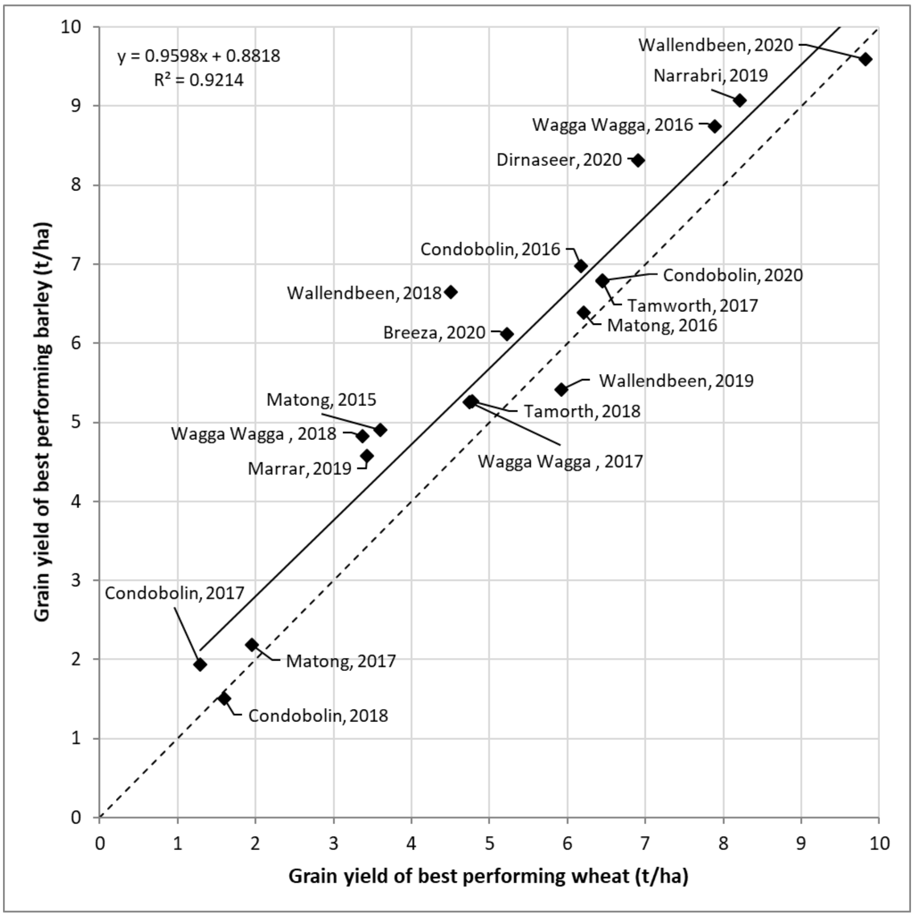

Figure 5. The relationship between the best performing wheat and barley genotypes (sown at optimal time for each environment from mid-April to late-May) at nine sites in NSW from 2015-20. Dotted line indicates 1:1 relationship.

References

Harris, F, Xing, H, Brooke, G, Aisthorpe, D, Matthews, P, Graham, R (2020) Yield stability across sowing dates: how to pick a winner in variable seasons? Proceedings of the GRDC Grains Research Updates, presented at Wagga Wagga, Corowa, Dubbo, Nyngan, Goondiwindi, Barellan and Lake Cargelligo.

Harris, F, Graham, R, Burch, D, Brooke, G, Matthews, P, Xing, H (2019) Hot vs Cold: balancing the risks associated with abiotic stresses in wheat. Proceedings of the GRDC Grains Research Updates, presented at Dubbo and Spring Plains, 2019.

Useful resources

https://grdc.com.au/ten-tips-for-early-sown-wheat

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Sincere thank you for the technical assistance of Mary Matthews, Jessica Simpson, Ian Menz, Jordan Bathgate and Dean Turner at the Harefield, Dirnaseer and Wallendbeen sites; Braden Donnelly and Daryl Reardon at the Condobolin site and Michael Dal Santo, Jim Perfrement, Jan Hosking and Bruce Haig at the and Narrabri sites in 2020. Thank you also to the Moloney, Hazlett and Ingold families for their support and co-operation in hosting field experiments in 2020.

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We also acknowledge the input and contribution of James Hunt (La Trobe University) and Kenton Porker (SARDI) throughout the 'Optimising grain yield potential of winter cereals in the Northern Grains Region' project and research collaboration in the GRDC project ULA9175069 'Development of Crop Management Packages for Early Sown, Slow Developing Wheats in the Southern Region.

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New cereal varieties - how are they likely to behave on the western Downs and why?

Douglas Lush, AGT Breeding

Key words

variety performance (general, specific), yield potential, new cereal varieties, variety evaluation

Take home messages

- With an unprecedented number of cereal variety releases in the past few years, it is important to know where they come from and the value that they may provide to farmers on the western Downs. The western Downs is a significant section of the larger south west Queensland (SWQ) region.
- Yield data provided has been extracted from the NVT database for the SWQ region
- Utilise the tools available for evaluating the potential of new varieties:
  - NVT (yield and disease ratings) includes multiple sites and years and is easily accessible
  -Company data that is often provided with the release of the new variety
  - Local agronomy trials and demonstrations
- Recent variety releases have features that provide value on the western Downs
  - Sunchaser⚭ & Sunflex⚭ have the longest coleoptile lengths in their maturity groups (AGT assessment from multiple years)
  - Sunblade CL Plus⚭ has a distinct advantage with a unique combination of high yield, prime hard classification and Clearfield® Intervix® tolerance
  - Suncentral⚭, Sunmaster⚭ and Sunblade CL Plus⚭ are new generation Suntop⚭ lines with improvement in yield performance and adaptation
  - LRPB Hellfire⚭ was released in 2019 as a higher yielding replacement for LRPB Spitfire⚭
  - LRPB Stealth⚭ was released in 2020 as an alternative in the slow spring maturity group
  - Beast⚭ and Leabrook⚭ offer high yield and large grain size in a Compass⚭ plant type.

Evaluating newly released varieties

Commercial breeding organisations have in recent years have released, six new barley varieties, one new durum variety and eight new wheat varieties for the northern region. These are described in the 2021 Queensland Winter Cereal Crop Sowing Guide.

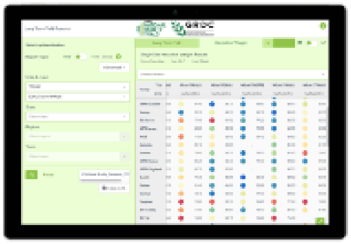
With a large number of new varieties without an established a track record, how should farmers and agronomists go about evaluating the potential of individual varieties to suit their farming enterprise? Considering varietal choice should consider disease resistance and paddock disease pressure (especially crown rot, root lesion nematodes and stubble borne pathogens) as well as phenology to facilitate a large enough sowing window and to mitigate against frost risk. As reported in the 2021 Queensland Winter Crop Sowing Guide, “the wheat breeding members of Australian Crop Breeders (ACB) have worked together to develop a consistent approach to describing wheat variety maturity” (Table 1).

Table 1. Wheat maturity assessment

Northern region			
Maturity description	**Quick wheat boundary***	**New varieties**	**Slow wheat boundary***
Quick spring		Sunprimeɸ	LRPB Mustangɸ
Quick - mid spring	LRPB Mustangɸ	LG Goldɸ, Suncentralɸ, LRPB Hellfireɸ, Sunchaserɸ	Suntopɸ
Mid spring	Suntopɸ	Sunblade CL Plusɸ, Sunmasterɸ	LRPB Reliantɸ
Mid - slow spring	LRPB Reliantɸ		EGA Gregoryɸ
Slow spring	EGA Gregoryɸ	LRPB Stealthɸ, Sunflexɸ	Sunzellɸ
Slow -very slow spring	Sunzellɸ		Sunmaxɸ
Very slow spring	Sunmaxɸ		N/A

Source: 2021 Queensland Winter Crop Sowing Guide * The new varieties should fit in between quick and slow maturity indicator (boundary) varieties.

With those thoughts in mind, the following tools will assist farmers and agronomists in selecting the best variety for particular paddocks.

1. 
   Long Term MET Yield Reporter
   Instantly view thousands of MET results and measurements in your web browser
2. Breeding organisation data, grain yield and overall adaptation, (more information over more environments)
3. NVT Disease Ratings
   The NVT Disease Ratings application provides quick access to current disease resistance ratings for the varieties in the NVT system. Compare varieties head-to-head for diseases relevant to you.
4. Local agronomy trials and demos
5. Other tools – industry personnel

Utilising the data collected through the National Variety Trials (NVT) has got a lot easier and the first data to check when evaluating yield performance is the Long Term Yield Reporter (LTYR). This utilises the individual sites across multiple years to establish a statistically valid estimate of yield performance at varying levels according to your search parameters.

Wheat and barley yield performance

Figure 1. shows the predicted yield generated from trials grown from 2016 to 2020, for a selection of early season wheat varieties for the South West Queensland region (including the Western Downs). Similar results are displayed for main season wheat trials (Figure 2), and barley trials (Figure 3) demonstrating that newer varieties are performing very strongly but have fewer years of data supporting them.

Early season wheat

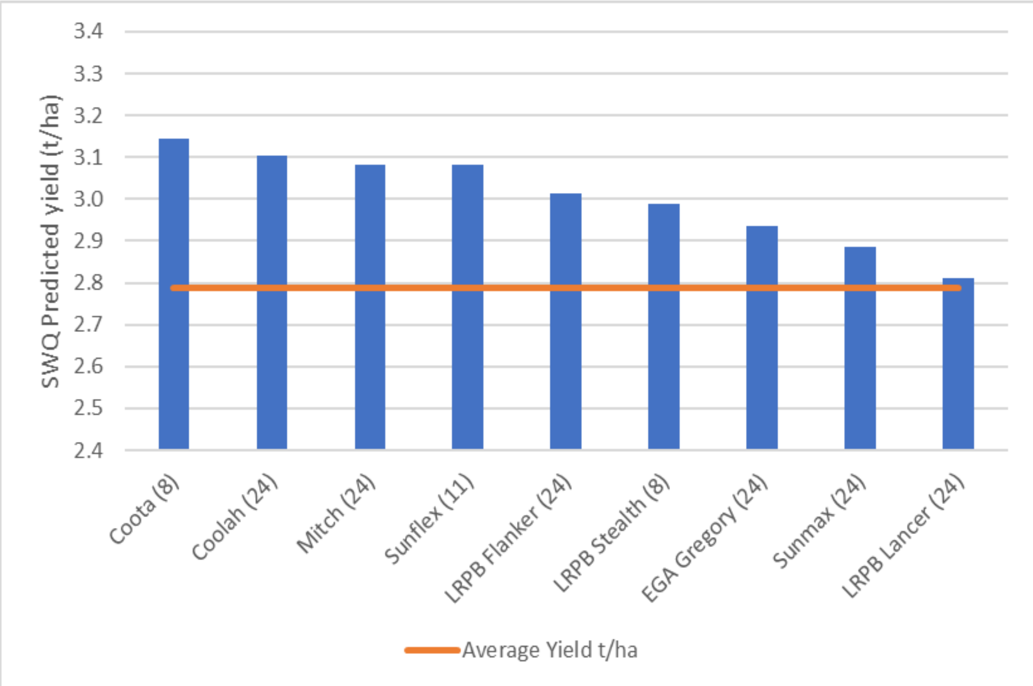


Figure 1. NVT Long Term Yield Reporter Output – Early season trials - South West Queensland. Source: NVT long term MET analysis, early season trial series SWQ 2016-2020. (): Number of trials that each variety was present in, across the SWQ dataset [24]
(⦶All the varieties in figure 1 are protected under the Plant Breeders Rights Act 1994)

Main season wheat

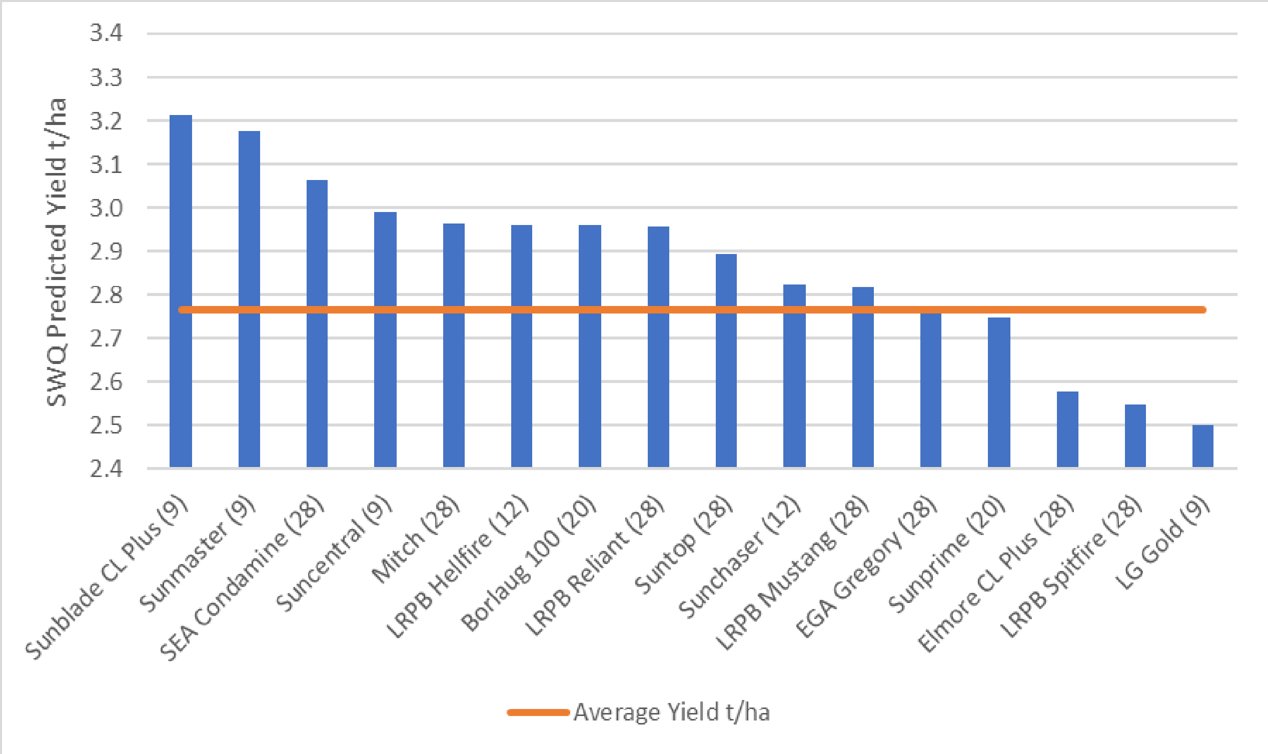


Figure 2. NVT Long Term MET analysis – Main season trials - South West Queensland.

Source: NVT long term MET analysis, main season trial series SWQ 2016-2020. () :Number of trials that each variety was present in, across the SWQ dataset [28]

(ⓅAll the varieties in figure 2, except SEA Condamine, are protected under the Plant Breeders Rights Act 1994)

Breeding organisations utilise the NVT data to support the release of new varieties, but their initial decisions are founded on their own trial data. For example the release of SunmasterⓅ was based on excellent performance in four years of AGT trials (Figure 3) in the northern region, including trials within the western Downs at Meandarra and Dulacca. The AGT information has also been supported by independent GRDC NVT trials. Other company's undertaking plant breeding will also have examples similar to that provided here for SunmasterⓅ.

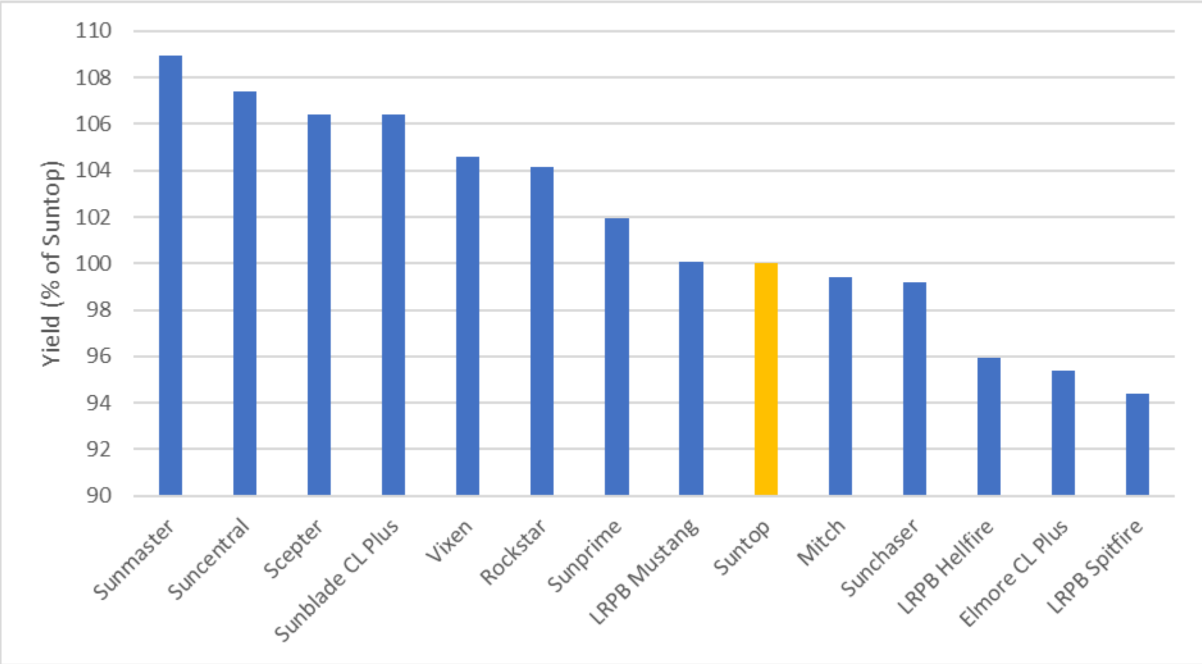


Figure 3. Grain yield expressed as a percentage of the yield of Suntop
(Source: AGT long term MET analysis, main season trial series 2017-2020, northern region)
(⦹All the varieties in figure 3 are protected under the Plant Breeders Rights Act 1994)

Barley

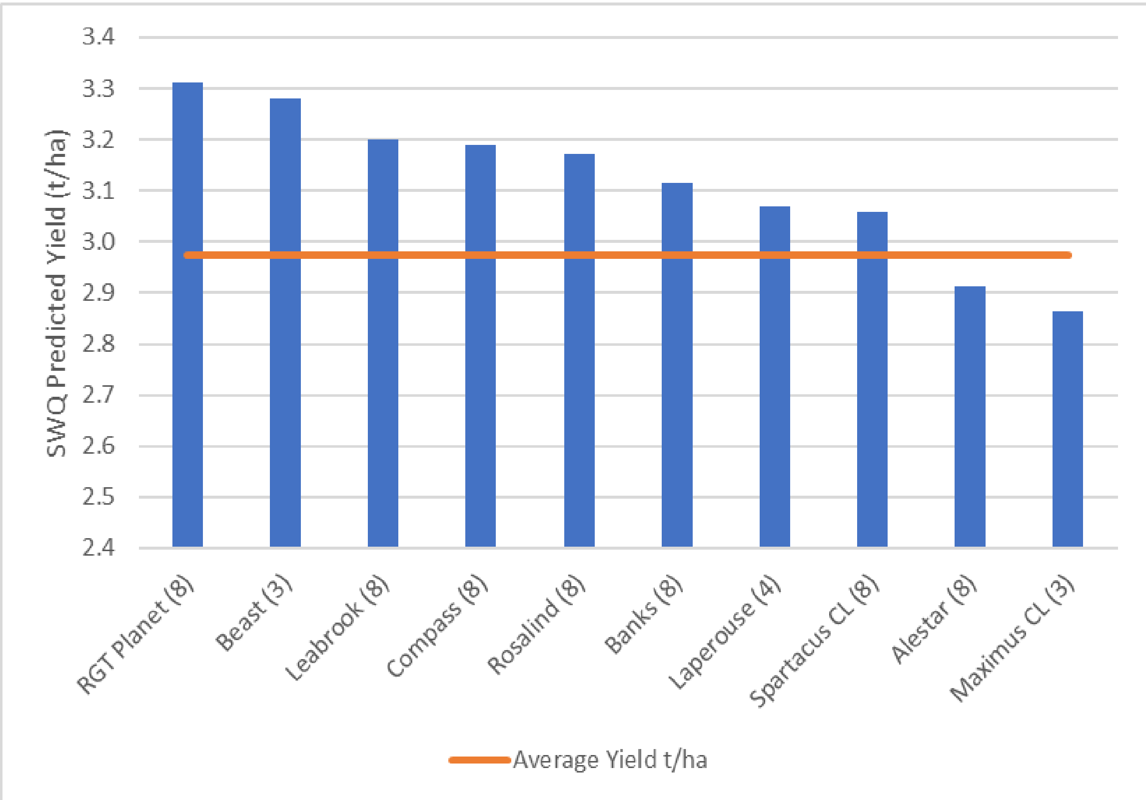


Figure 4. NVT Long Term MET analysis – Barley main season trials - South West Queensland.
(Source: NVT long term MET analysis, barley main season trial series SWQ 2016-2020)
(): Number of trials that each variety was present in, across the SWQ dataset [8]
(⦹All the varieties in figure 4 are protected under the Plant Breeders Rights Act 1994)

While assessing yield performance is best done using the tools of MET analyses and the NVT Long Term Yield Reporter, assessing NVT individual site data can be useful for evaluating physical grain quality. Table 2 displays the average grain quality results for the released SWQ barley trials in 2019 (Mungindi) and 2020 (Mungindi and Westmar). BeastФ and LeabrookФ are CompassФ types with high yield and large grain size, ideal for medium to low rainfall environments.

Table 2. Grain quality assessment of SWQ NVT barley variety sites from 2019 and 2020

	1000 grain weight	**Retention (Screenings >2.5 mm sieve)**	**Screenings (<2.2mm sieve)**	**Protein**	**Test weight**
Variety name	**g/1000 seeds**	**%**	**%**	**%**	**kg/hectolitre**
AlestarФ	41.70	72.47	4.57	13.83	69.87
BeastФ	47.47	86.03	1.37	13.63	68.73
CompassФ	47.03	89.40	1.23	13.70	69.63
LaperouseФ	40.03	81.23	1.33	13.90	73.37
LeabrookФ	46.23	91.10	0.93	13.23	69.00
Maximus CLФ	42.07	80.10	1.77	12.93	70.30
RGT PlanetФ	42.50	73.37	2.90	13.47	69.07
RosalindФ	40.37	77.77	2.63	14.00	70.10
Spartacus CLФ	41.73	73.07	2.57	13.93	69.70

Source: NVT SWQ site grain quality data. Average values obtained from 1 site in 2019 (Mungindi) and 2 sites in 2020 (Mungindi and Westmar).

Variety disease performance

While grain yield is often regarded as the definitive measure of the success or failure of a variety, there are a number of reasons why a variety will maintain a high and consistent yield. One of the main determining factors in yield stability is an ability to cope with disease pressures. To that end the GRDC engage service providers to develop ratings for key cereal diseases and pathotypes that occur in your region. The ratings for newly released varieties are often provisional until a number of years of data have been accrued and analysed. These results are made available through the GRDC publications, Queensland Crop Sowing Guide and/or the NVT Disease Ratings app on the website or mobile device.

Table 3. NVT foliar disease ratings updated with 2020 data

Variety name	**NVT consensus ratings**			
	Stripe rust (East)	**Stem rust**	**Leaf rust**	**Yellow leaf spot**
	2020_Yr (East) 134E16A+17+ 27+ 198 E16 A+ J+ T+ 17+/64E0A-	**2020_Sr**	**2020_Lrw**	**2020_YLS**
Borlaug 100Ⓓ	**SVS**	MR	**MR**	MR
CoolahⒹ	**RMR**	MR	**RMR/MS**	MSS
CootaⒹ	**MR/MSp**	RMR	**MS**	MSS
EGA GregoryⒹ	**MR**	MR	**RMR/MS**	S
Elmore CL PlusⒹ	**MR**	MR	**RMR**	S
LG GoldⒹ	**SVS**	MSS	**MRMS/SVS**	S
LRPB FlankerⒹ	**RMR**	RMR	**RMR/MSS**	MS
LRPB HellfireⒹ	**MR**	MR	**MSS**	MSS
LRPB LancerⒹ	**RMR**	R	**RMR/MRMS**	MRMS
LRPB MustangⒹ	**RMR**	MRMS	**MSS**	MSS
LRPB ReliantⒹ	**MR**	R	**RMR**	S
LRPB SpitfireⒹ	**MR**	MR	**S**	MSS
LRPB StealthⒹ	**RMR**	R	**RMR/S**	MS
MitchⒹ	**MR**	MRMS	**MSS**	MSS
RockStarⒹ	**MRMS/Sp**	MR	**S**	MRMS
ScepterⒹ	**MSS**	MRMS	**MSS**	MRMS
SEA Condamine	**MRMS/MSp**	MRMS	**RMR/MRMSp**	MSS
Sunblade CL PlusⒹ	**MR**	MS	**MRMS/MSSp**	MSS
SuncentralⒹ	**MRMS/Sp**	MRMS	**RMR/MRMSp**	MS
SunchaserⒹ	**RMR**	MR	**R**	MS
SunflexⒹ	**RMR**	MR	**RMR/S**	MS
SunmasterⒹ	**MR**	MS	**RMR/MSp**	MSS
SunmaxⒹ	**RMR**	MRMS	**MS**	MS
SunprimeⒹ	**RMR**	MRMS	**MR/S**	MSS
SuntopⒹ	**MRMS**	MRMS	**MR**	MSS
VixenⒹ	**MRMS/SVSp**	MRMS	**SVS**	MRMS

Source: NVT consensus ratings 2020. R: Resistance, MR: Moderately Resistant, MS; Moderately Susceptible, S: Susceptible, VS: Very Susceptible, p: provisional rating (based on one year of data)

In addition to the latest NVT pathology ratings in Table 3, and previous seasons of pathology ratings (including crown rot resistance), AGT have been conducting trials exploring yield performance in the presence of crown rot. Trials are planted with sterilised seed inoculated with *Fusarium pseudograminearum* fungus. The aim being to evaluate the potential of varieties to produce grain in paddocks with moderately high levels of crown rot.

Table 4 outlines the differences in some key varieties and their ability to achieve a high grain yield in comparison to SuntopⒹ. This is not an experiment to demonstrate tolerance, as we have not included nil plots to compare yield with and without crown rot added, therefore results are displaying a combination of genetic ability to achieve a high yield and an ability to maintain grain yield in the presence of crown rot.

Table 4. AGT MET analysis of yield performance in crown rot (CR) inoculated trials.

name	Yield % of Suntop MET analysis 17-20	Years of testing	2019 NVT rating - CR resistance
Suncentral⯑	112	4	-
LRPB Mustang⯑	108	2	MSS
Sunprime⯑	108	4	Sp
Sunmaster⯑	107	4	-
Coota⯑	105	3	-
Sunchaser⯑	104	4	MSSp
Sunblade CL Plus⯑	102	4	-
LRPB Hellfire⯑	102	1	MSSp
LRPB Reliant⯑	101	2	MS
Suntop⯑	100	4	MSS
LRPB Spitfire⯑	96	4	MS
Elmore CL Plus⯑	92	4	S
EGA Gregory⯑	87	4	S

Source: AGT long term MET analysis Narrabri crown rot trials 2017-2020 *: NVT crown rot ratings following the 2020 season were not available at the time of printing. M=moderate; S=susceptible; p= provisional

Major advantages of recently released varieties

One of the current topics of conversation regarding varieties is coleoptile length and how it contributes to improved establishment in moisture seeking circumstances. AGT have released two varieties that have shown longer coleoptile length than currently available varieties of similar maturities. Sunchaser⯑, released in 2019, has shown promising results as a quick-mid spring wheat, and Sunflex⯑ as a slow spring wheat released in 2020.

Table 5. AGT coleoptile length data

AGT coleoptile length assessment			
Quick-mid spring & quick spring wheat varieties		**Slow spring wheat varieties**	
Name	**Length (mm)**	**Name**	**Length (mm)**
Sunchaserᶲ (36)	113	Sunflexᶲ (30)	97
Elmore CL Plusᶲ (36)	106	Cootaᶲ (30)	93
Suntopᶲ (36)	101	Sunvaleᶲ (30)	92
LRPB Spitfireᶲ (36)	100	LRPB Lancerᶲ (30)	90
Sunmasterᶲ (30)	100	Coolahᶲ (30)	89
Suncentralᶲ (30)	98	EGA Gregoryᶲ (30)	88
Sunblade CL Plusᶲ (30)	94	Mitchᶲ (30)	86
LRPB Reliantᶲ (30)	93	LRPB Flankerᶲ (16)	86
LRPB Mustangᶲ (30)	93	Suntimeᶲ (24)	83
Sunprimeᶲ (36)	90	Sunmaxᶲ (30)	81

Source: AGT coleoptile length experiments 2017-2020, () Number of reps tested across years.

Elmore CL Plusᶲ was released in 2012 and has been the go-to variety for growers in the northern region seeking a Clearfield® (imi tolerant) wheat variety. AGT released Sunblade CL Plusᶲ in 2020 as a brand-new Clearfield® wheat variety. Sunblade CL Plusᶲ has big advantages over its main comparator Elmore CL Plusᶲ. It is the first Clearfield® Wheat variety to achieve an APH classification and considering it is bred from Suntopᶲ it has sound crown rot and *Pratylenchus thornei* tolerance. Ultimately it is Sunblade CL Plusᶲ's yield performance that gives it a distinct advantage over its competitors, both Clearfield® and general varieties.

Suntopᶲ has been a successful variety in the western Downs since its release in 2012. High and consistent yield performance based on adaptability through crown rot and root lesion nematode tolerance combined with sodic soil tolerance. Three new varieties with a Suntopᶲ background have been released recently. Sunblade CL Plusᶲ, Suncentralᶲ & Sunmasterᶲ have displayed high yield in AGT and NVT trials and offer considerable potential (Figures 2 and 4).

Discussion

In an attempt to understand the potential that different cereal varieties hold for each region there are a lot of factors to consider: paddock history, yield performance, grain quality, expected disease pressures, farming enterprise goals and many more. What we have seen in this case is that there is no clear winner in all situations, but that individual varieties have a niche to fill.

I have noticed a change in the parentage of varieties that reflects the progress that breeding has made by introducing the more adapted varieties as parents. When I first started presenting at field days, Baxterᶲ and Sunvaleᶲ were very popular varieties and there was a dominance of Cook in the breeding of these and other common varieties at that time. Progress a few years and EGA Gregoryᶲ was established as a dominant variety in the northern region, consequently 10 to 15 years later EGA Gregoryᶲ is one of the main parents we see in the varieties released in the past 5 years. What we are seeing now is a shortening of the breeding time frame. Suntopᶲ was released in 2012, and only 8 years later we are starting to see the result of using Suntopᶲ as a parent and the influence it will have on adaptation throughout the Western Downs and the northern region.

The GRDC NVT data base provides growers with an independent source of varietal information and the Long Term MET data clearly demonstrates the benefits adoption of new cereal varieties can provide to the profitability of grain growers.

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Identification of crop –specific and varietal tolerance limits to acidity, salinity and sodicity

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Key words

soil constraints, chloride toxicity, variety selection, proxy traits

GRDC codes

UA000159: Improving wheat yields on sodic, magnesic and dispersive soils

UOQ1803-003RTX: Economics of ameliorating soil constraints in the northern region: Spatial soil constraint diagnoses

Take home messages

- In Qld and NSW, the soil constraints affecting the greatest cropping areas are sodicity combined with toxic chloride (Cl) concentrations. Acid sub-soils are also important in some areas
- Reduced ability to extract soil water from deeper layers is the main affect reducing yield
- Crop-specific tolerance limits vary between species and between soil constraints
- Tolerance to soil constraints differs between varieties of wheat
- Robust ranking would allow growers and breeders to select the most tolerant varieties, but high spatial soil variation over short distances makes consistent ranking difficult
- We are testing whether pre-screening for proxy traits in the laboratory and using remote sensing to account for spatial variation in the field can be used to increase our ability to select the most tolerant varieties.

Introduction

Successful dryland crop production in the north-eastern Australia depends on utilising soil moisture accumulated in the period preceding sowing. Due to the high clay content of the soils in the region, these soils can potentially store 200-250 mm of water in the soil profile or more. However, soil constraints, especially in the subsoil, reduce the effective rooting depth thus also reducing the amount of water and nutrients that plants can obtain from the soil, resulting in reduced crop yield (e.g. Figure 1) (Dang et al. 2006 and 2016).

High sodicity in surface soil and subsoil, high salinity and phytotoxic concentration of chloride (Cl) in the subsoil, alkalinity, subsoil acidity and compaction are common soil constraints in many semi-arid regions worldwide and in particular Queensland and NSW (Figure 2, Table 1). These soil constraints often occur in combination and can interact with each other to create unique environments for root growth at a given location (Nuttall et al. 2003). They may also vary both spatially and temporally. Spatial variation can occur within a field, across the landscape and with depth in the soil profile.

Spatial variability and the interactions between constraints can limit agronomic and management options. Variability in the impact on crop growth and yield is also compounded by the interaction between constraints and environmental factors, particularly the timing and amount of rainfall relative to the crop development cycle.

The amelioration of soils affected by constraints is usually expensive, if it is possible at all. The application of ameliorants (e.g. gypsum for sodicity) can sometimes improve surface soils (Page et al

2020, 2021). However, amelioration of constraints occurring in the subsoil is not usually practical. Where subsoil constraints are present, the selection of crops or varieties tolerant to soil constraints and the identification of traits for pre-selection may provide a long-lasting, tangible solution to improve yields.

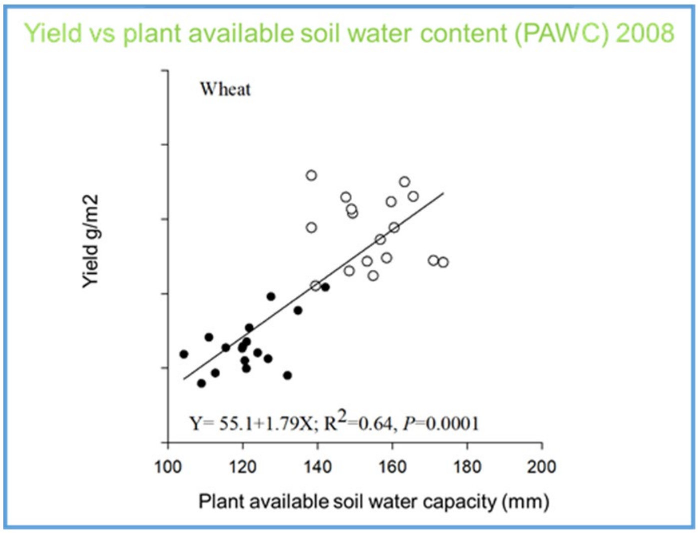

Figure 1. Wheat yield versus soil water extracted between sowing and maturity (plant available soil water capacity, Dang et al., 2016). Solid dots represent data for a highly sodic site and open dots a less-sodic site.

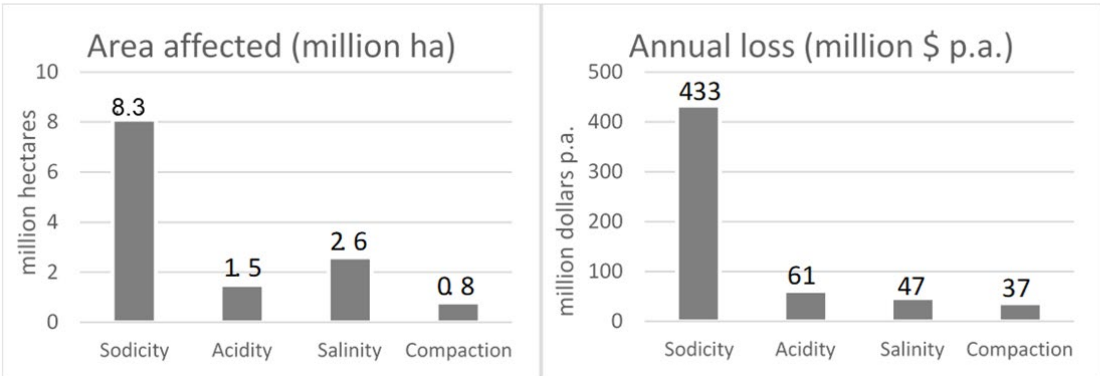

Figure 2. Area affected and annual financial loss due various soil constraints in Queensland and NSW (Orton et al. 2018)

Table 1. Sodicity combined with high chloride concentration at depth represent the main soil constraints in QLD and NSW (Orton et al. 2018).

Region	Area of cropping land affected (million ha)		Estimated cost in lost production
	Sodicity	Subsoil Cl	(million $/yr)
Central Qld	1.4	0.7	59.5
Southern Qld	1.4	0.9	85.4
Northern Qld	3.0	1.0	157.0
Central NSW	1.3	<0.1	54.3
Southern NSW	1.0	<0.1	77.0
Total	**8.1**	**2.7**	**433.1**

Crop-specific tolerance limits vary between species and between constraints

Saline soils

Soil salinity refers to the amount of salt dissolved in the soil solution and is quantified by measuring the electrical conductivity of a saturated soil extract (ECe). Lower ECe values are generally more favourable for crop production.

A recent survey of published studies on the tolerance of 17 crop species reported that the tolerance thresholds for soil constraints varied between species and between constraints (Page et al., 2021). The tolerance levels of different crops for soil salinity were classified using a 'traffic light' system (Figure 3). Salinity levels for which little if any reduction in yield was reported in the literature were classified green. Levels where some yield loss might be observed (depending on soil type, season and variety) are represented in yellow, while those where loss was reported for most soils, seasons and varieties are represented in red. For example, the studies indicate that the more tolerant cereals, such as barley and millet, will typically perform well up to salinity levels of ECe 5 ds/m. However, they usually suffer severe damage at levels above ECe 10 ds/m (Figure 3). In contrast, more sensitive cereals, such as maize and sorghum, only performed well up ECe 2 ds/m and suffered severe damage at levels greater than ECe 5 ds/m. Some legume species were even more sensitive (Figure 3).

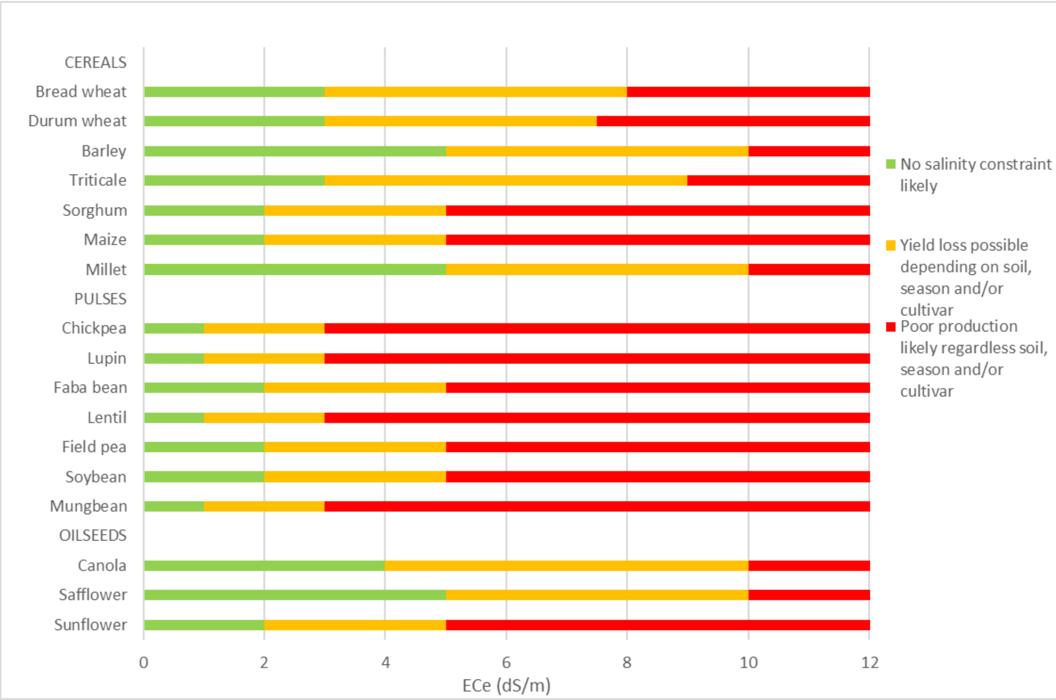

Figure 3. Soil EC_e tolerance limits proposed for crop species when grown under rainfed conditions in subtropical regions (Page et al., 2021).

Acid soils

The adverse effects of soil acidity generally increase with lower pH values measured in the soil solution.

Just as for salinity, the tolerance thresholds of crops varied between the 17 species and between constraints (Page et al., 2021). However, the ranking of the crops was very different. Results are represented here in Figure 4, again using the 'traffic light' system described above. For acidity, the cereals sorghum, maize and millet were able to tolerate more severe acidity levels than many other species, with good growth to as low as pH 5.5 and severe yield loss once pH dropped below pH 4.8.

In contrast, the most sensitive cereals were durum and barley, which performed well only down to pH 6.0 and suffered severe yield loss below pH 5.3. Some legume species were also similarly sensitive (Figure 4).

Thus, the crop species most suitable for a particular paddock can vary greatly depending on which are the most prevalent soil constraints. Crop and cultivar choice are also affected by the season and the variety.

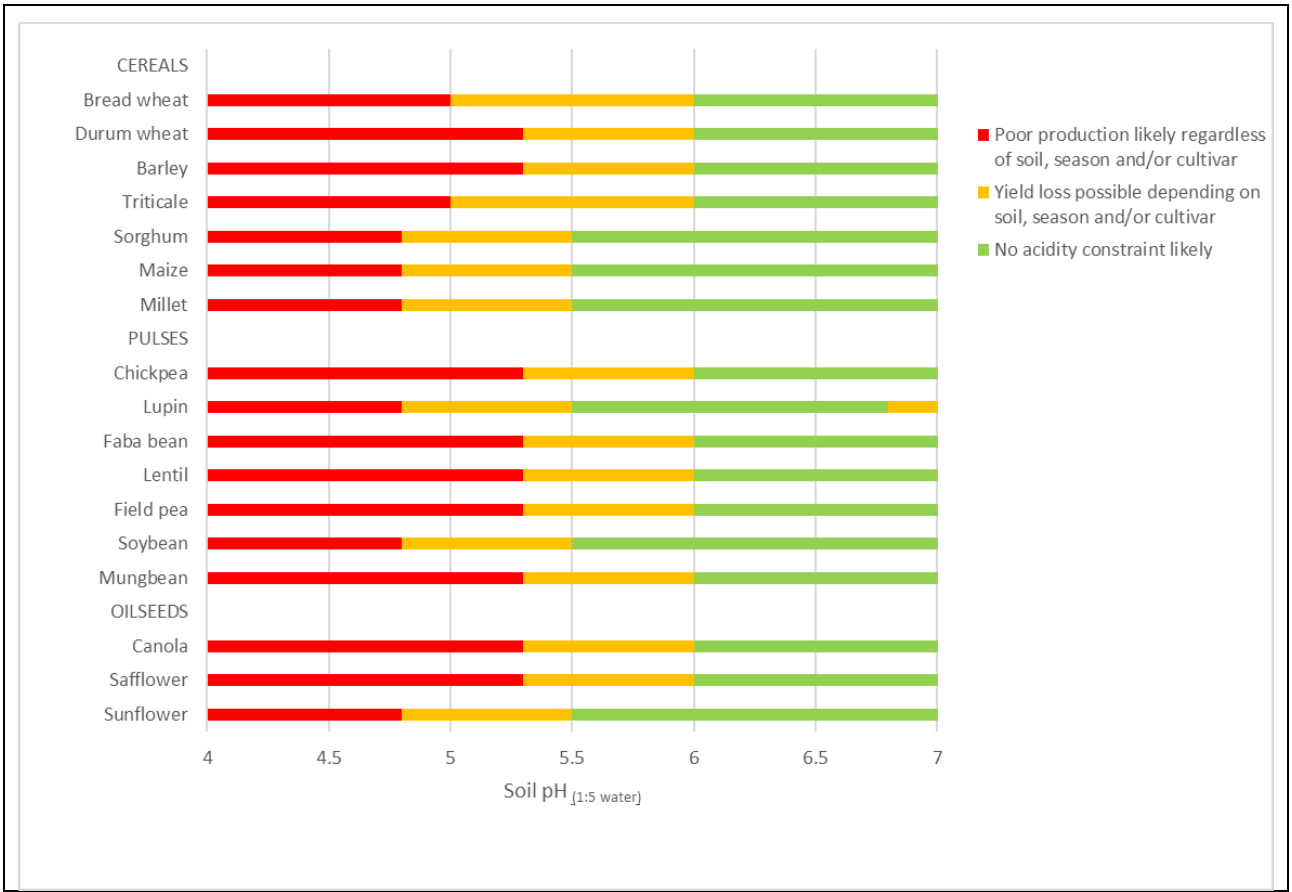

Figure 4. Soil $pH_{w1:5}$ tolerance limits proposed for crop species when grown under rainfed conditions in subtropical regions (Page et al., 2021).

Sodic soils

The literature report also indicated that tolerance to soil sodicity varies between species, although there is not currently enough information available to publish 'traffic light' boundaries for sodicity. However, it is clear that there are differences in the tolerance of different species and varieties to sodic conditions. Improving our understanding about which are the best species and varieties for areas with sodic soils is an important research priority and will help improve productivity, particularly when sodicity occurs in the subsoil and is difficult to ameliorate.

Tolerance to sodicity varies between cultivars of wheat

A limited number of cultivars have been tested at contrasting sites in several seasons

As part of a GRDC co-funded project 'Improving wheat productivity on sodic, saline and dispersive soils', (UA00159, 2015 to 2020), trials in Queensland were conducted at a highly-sodic site and a less-sodic site in each season to compare tolerance to soil constraints between certain wheat genotypes (Figure 5).

A key aim of this project was to characterise the tolerance to soil constraints of wheat genotypes in all the major Australian cropping regions. To achieve this, a core set of lines from all over Australia were tested in all regions. A small number of lines from Qld and NSW were included in each season. A comprehensive comparison of current commercial cultivars in each region was not a focus. However, data on the small number of Qld and NSW cultivars tested do show genotypic differences.

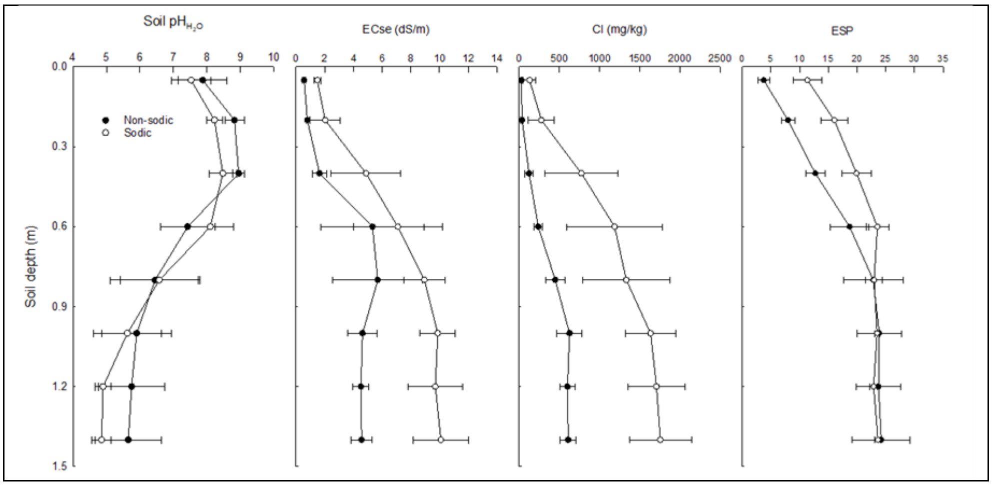

Figure 5. Average and standard errors of soil constraints for the less-sodic and highly sodic sites during 2015-19 experiments.

Soil and seasonal variability complicate field comparisons

The effects of soil constraints vary both spatially and temporally complicating attempts to compare genotypes in the field. Spatial variation in the field occurs both across the landscape and with depth in the soil profile (Figure 5). High levels of variation at the surface over distances of a few metres are common, particularly after levelling (Figure 6). There are also complex interactions among the various physio-chemical constraints (Nuttall et al., 2003). These complicated interactions can limit the agronomic and management options. Variability in the impact on the crop growth and yield is compounded by the complex interactions between the physiochemical constraints and environmental factors, particularly the timing and amount of rainfall relative to the crop development cycle. This leads to variation in genotype ranking from season to season and the ability to ascribe differences between genotypes to soil constraints.

Spatial variability

To find genetic differences in the presence of high spatial variability, it is necessary to have many plots for each genotype spread across the trial. During UA00159, 4 replicate plots per genotype were used in most years with 6 replicates in 2020. This compares to 2 or less replicates per genotype in standard multi-environment genotype trials. The need for such high numbers of replicates limits the number of lines that can be tested each year.

Figure 6. Drone image of a highly constrained trial site near Goondiwindi in 2020 showing spatial differences in canopy cover likely due to small scale differences in soil constraints.

We are currently using remote sensing information from drones to determine whether information on canopy cover might be used to compensate for some of the spatial variation in soils to improve detection of genetic difference.

Temporal variability

The ability to discriminate between genotypes for tolerance to sodic soils with variable subsoil constraints in field experiments varied greatly in each season during project UA00159 (Figure 7). In 2015 and 2016, higher than average in-crop rainfall meant that plants were less reliant on access to water from the soil. Thus, rankings in these seasons are less likely to be representative of tolerance to soil constraints.

Conversely, during 2019 when in-crop rainfall was extremely low, the high-constraints trial could not be harvested at all. In dry years more generally, genotypic differences are usually much harder to differentiate because of very low yield.

In years when in-crop rainfall is near the district average, as in 2017, 2018 and 2020, discrimination between genotypes was much better.

Discrimination for tolerant genotypes varies greatly with in-crop rainfall

Year	geno #	ICR (mm)	Yield (t/ha) Soil constraints Low	High		Diff %	Geno SSC diffs?
2015	36	209	4.06	3.64	ns	10.3	No
2016	38	325	4.02	4.00	ns	0.5	No
2017	44	132	1.61	0.37	*	77.0	Yes
2018	18	69	2.33	0.93	*	60.1	Yes
2019	22	<10	<0.5	0	NA	NA	No

Long-term average ICR = ca. 170 mm
District average yield 1.5-2.0 t/ha

Figure 7. Differences between mean yield at a highly sodic site and less sodic site in each season as

well as differences in genotype ranking between sites were most evident in years where in-crop rainfall (ICR) and site mean yields were close to the district average.

Genetic differences in tolerance can be found

Despite the challenges discussed above, genetic differences between varieties could be identified particularly in seasons 2017, 2018 and 2020. In general, the yield ranking of genotypes at the less-sodic site was not a good indicator of the ranking at the highly sodic site. This indicates that testing on highly sodic soils is likely to be required to identify varieties best for those sites. For example, in 2018 the cultivars Corack⊕, Mitch⊕, Trojan⊕ and Mace⊕ ranked highly at the non-sodic site, while the wheat genotypes Flanker⊕, Corack⊕, Janz and Sunco ranked highly at the sodic site (Figure 8). However, given the small number of varieties tested to date, it is not yet possible to determine sufficient economic value that would provide useful grower advice on variety choice at this time.

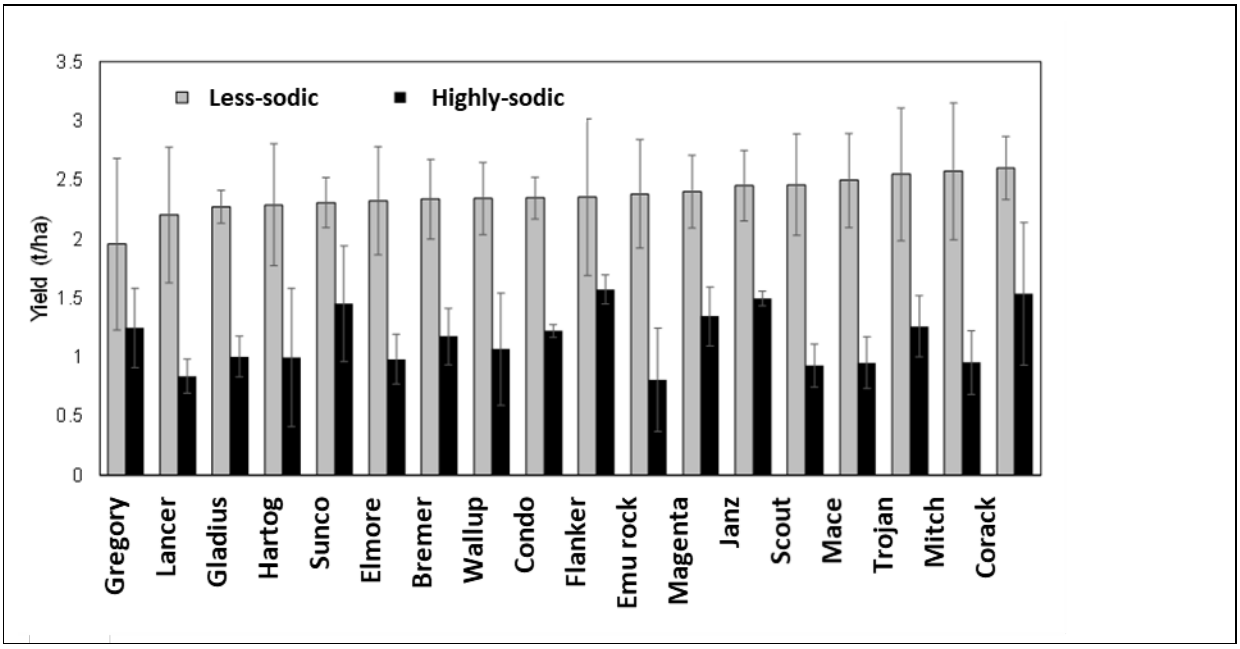

Figure 8. Mean grain yields of wheat lines at the sodic site in 2018, ranked in ascending order of yield at less-sodic site in 2018.

(⊕ The varieties Gregory, Lancer, Gladius, Elmore, Bremer, Wallup, Condo, Flanker, Emu rock, Magenta, Mace, Trojan, Mitch and Corack are protected under the Plant Breeders Rights Act 1994.)

Proxy traits could help identify prospective cultivars and breeding lines

Proxy traits are often used in research and breeding where the primary trait, in this case performance on sodic sites, is hard or expensive to measure. Field validation is always needed; however, proxy traits can sometimes be used to quickly identify genotypes most likely to perform well. Even if the proxy trait is not highly accurate in identifying the best performing lines, it may be useful to identify the vast bulk of lines that are not likely to be well adapted. This can reduce the number of lines requiring highly replicated field trials at multiple sites in multiple years.

Thus, proxy traits can potentially be used

1. To provide recommendations to growers, by helping identify the most prospective cultivars for expensive field testing
2. In breeding programs aiming to develop more tolerant lines, to screen out the bulk of low ranking lines.

Potential proxy traits have been identified

Potential proxy traits associated with tolerance to sodic soils with high Cl at depth include lower concentrations of Cl in the youngest mature leaf blades close to flowering as well as higher concentrations of calcium and potassium (Figure 8; Dang et al 2016).

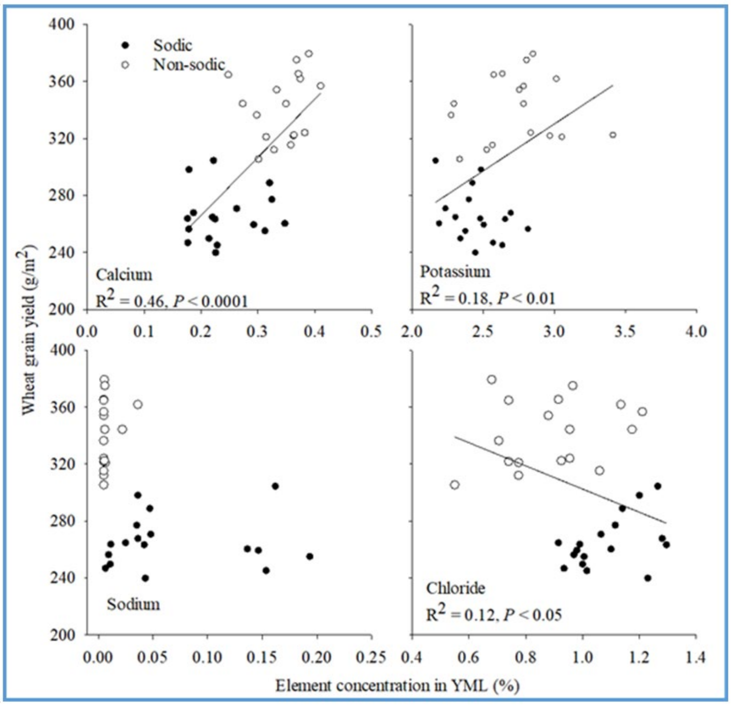

Figure 9. Concentrations of elements in the youngest mature leaf (TML) of wheat near flowering (Dang et al. 2016). Solid dots represent data for a highly sodic site and open dots a less-sodic site.

Additionally, a number of traits have been identified as associated with better establishment in the presence of a soil crust (which can often form on sodic topsoils). These include rapid germination, increased emergence force with greater hypocotyl diameter and narrower root angle (Anzooman et al. 2018, 2019).

Thus, choice of species and variety are important for optimising return on sites with soil constraints. The most tolerant species and variety differs depending on the most limiting constraint.

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Amelioration for sodicity - deep ripping and soil amendment addition across NSW and Qld. Engineering challenges. Yield responses to ripping, gypsum and OM placement in constrained soils

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Key words

yield maps, soil testing, ground truthing, dispersion, sodicity, ripping

GRDC code

USQ1803-002RTX

Take home messages

- Benefits of subsoil amendments are more likely in poorer seasons
- Adjustment in agronomy may be necessary to take advantage of improved subsoil conditions
- Considerable challenges remain in identifying engineering solutions to deeper amendment applications.

Background

Model analyses suggest a yield gap between water-limited potential yield and currently achieved production exists across northern Australian grain regions. This yield gap is a function of physical, chemical and biological factors in each soil, including capacity of soil to store and release water for efficient plant use. Many regions where yield is constrained contain dispersive soil within the surface 50cm and deeper. Sodicity (a high exchangeable sodium percentage) is a major cause of aggregate dispersion and may compromise soil structure. Dispersive behaviour decreases both soil water availability and nutrient acquisition, increases risk of runoff and erosion, and impairs biological (soil microbial and plant root) activity. Acidity, salinity (presence AND absence) and compaction further constrain yield potentials. However this project focuses on sodicity as the major constraint with often related constraints considered as compounding and/or interacting factors.

Amelioration of subsoil constraints is an expensive process. The engineering challenges and energy requirements are significant. It is important to acknowledge that production benefits from subsoil amendment are more likely to be observed in poorer seasons. In good seasons, root function and activity, and soil moisture, will be able to sustain yield from surface activity and extraction where soils are often less constrained. However in poorer seasons where subsoil moisture is required to finish a crop, subsoil amelioration will have a proportionately larger impact on yield. Hence, we expect that the return on investment in subsoil amelioration to be larger in poorer seasons, than in higher decile seasons with more growing season rainfall.

A series of linked investments is assessing the economics of ameliorating constrained surface and sub-surface soils in the northern region. The program has four areas covering:

(i) Spatial soil constraint identification
(ii) Amelioration and management of soil constraints
(iii) Economics of adoption, and
(iv) An overarching communications and extension program.

The research into soil amelioration and management has two components led by the University of Southern Queensland (USQ). First is a set of six small-plot core experiments exploring detailed amelioration research. There are three sites in northern and central New South Wales (NSW) managed by the University of New England (UNE), and three sites in southern Qld managed by the Department of Agriculture and Fisheries (DAF).

This paper covers the challenges of core site implementation, describes the treatments being studied and the adaptations needed to deliver these treatments to depth in our constrained soils. It also extends to discussing the realities of attempting this process at a commercial scale. Finally it reports on the first season of field trial responses.

Core site selection

The USQ team undertook extensive surveying of 30 fields across central and northern NSW and southern Qld. The areas were clustered around 6 locations (Trundle, Armatree, Spring Ridge, Talwood, Millmerran and Meandarra), with 5 fields surveyed at each. Field surveying included capture of yield maps if available, satellite NDVI imagery, and soil mapping with EMI. Using a combination of yield, site elevation and EMI maps, bare soil colour imagery and grower experience, four survey points where selected for soil sample collection and analysis. After consolidating data 'core' experimental sites where selected in each of the six hub areas: three in NSW and three in Qld.

Core site characterisation

All sites were generally alkaline in the upper profile with an exchangeable sodium percentage (ESP) well over the 6% nominal threshold for healthy crop growth. Profile chloride (Cl) values were generally low, indicating that sodicity was likely to be the primary restriction.

Chemical characteristics of the six core experiments are below:

Location: Armatree
Soil type: Brown Sodosol, not dispersive (0-10cm) to dispersive (10-20) surface, to strongly alkaline and dispersive at depth, compact surface layers

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	6.0	5.3	0.20	3.7	3.4	0.91	1.00	9.0	10		58
10-20	7.8	6.8	0.20	8.5	7.9	2.63	0.83	19.9	13		7
30-40	9.3	8.3	0.45	13.1	12.6	5.78	0.81	32.3	18		8
60-70	9.4	8.4	0.58	12.3	13.4	6.35	0.96	33.0	19		6

Location: Forbes
Soil type: Brown Vertosol, not dispersive (0-10cm) to dispersive (10-20) surface, to strongly alkaline and dispersive at depth

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	6.3	6.1	0.39	8.7	7.7	2.13	0.77	19.3	11		89
10-20	7.9	6.9	0.30	15.4	10.2	4.76	0.55	30.9	15		12
30-40	9.1	8.2	0.64	12.5	11.3	8.14	0.49	32.5	25		4
60-70	9.1	8.3	0.85	11.3	10.4	9.57	0.56	31.9	30		1

Location: Spring Ridge

Soil type: Black Vertosol, moderate ESP and salinity in surface, increasing to high ESP and salinity at depth, but both are non-dispersive due to the salinity

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	8.2		0.54	31.7	41.7	3.3	2.4	79.1	4		100
10-20	8.2		0.62	37.2	43.5	5.2	1.4	87.3	6		
30-40	8.3		1.94	31.0	51.5	13.9	1.0	97.4	14		
60-70	8.3		2.52	28.7	56.7	19.5	1.1	106	18		

Location: Dulacca

Soil type: Grey/Brown Vertosol (nominally Ulimaroa). Surface soils not spontaneously dispersive, subsurface highly dispersive.

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	8.5	7.7	0.21	18.1	8.0	2.73	0.93	29.8	9	43	9
10-20	8.8	7.8	0.25	15.8	9.8	3.99	0.61	30.3	13	53	14
30-40	8.1	7.3	0.46	15.4	12.3	7.10	0.45	35.3	20	102	4
60-70	6.8	6.7	0.66	12.0	12.8	8.83	0.48	34.1	26	275	8

Location: Millmerran

Soil type: Grey/Brown Vertosol (nominally Moola). Surface and subsurface soils not spontaneously dispersive, very compact soil through the profile.

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	6.6	6.3	0.15	8.4	6.6	2.37	0.31	17.7	13	153	38
10-20	8.7	7.4	0.24	10.6	9.0	3.36	0.20	23.2	14	330	5
30-40	6.9	6.2	0.38	9.5	15.	6.82	0.14	31.4	22	428	3
60-70	6.4	5.5	0.43	10.2	16.4	8.79	0.18	35.5	25	457	2

Location: Talwood

Soil type: Red/Brown Vertosol (nominally Arden). Surface soils not spontaneously dispersive, subsurface highly dispersive at 60-70cm.

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	8.3	7.6	0.17	27.5	4.7	1.8	1.3	35.5	11	22	18
10-20	8.7	7.9	0.23	27.8	7.0	3.8	0.7	39.3	10	26	3
30-40	8.9	7.8	0.36	22.5	9.4	7.0	0.4	39.4	18	73	2
60-70	9.2	7.9	0.44	20.3	9.9	9.9	0.5	40.7	24	163	2

Experiment treatments

This research focussed on eliminating sodium as a constraint for the upper 50 cm of a soil profile. It was 'proof-of-concept' research, intended to explore effects on soil water storage and grain yields under gypsum application rates to remediate the ESP to ≤ 3% in either or both of the top 20 cm of soil and half of the soil volume in bands from 20 cm down to 50 cm depth. Organic matter (OM) also acts to limit aggregate dispersion (as well as providing nutrients at depth) and, whilst not reducing ESP, may act to improve water holding capacity and pore stability. Gypsum rates (often ≥ 15 t/ha) were compared against a high rate subsoil (≈ 20 cm deep) compost (Qld)/lucerne pellet (NSW) application (≈ 10 t/ha), and the application of elemental sulfur to dissolve calcium carbonate to produce gypsum in-situ and lower alkalinity.

The rates chosen are considerably higher than the likely economically viable rates and were deliberately chosen to determine if subsoil remediation to remove dispersive constraints would result in improved production outcomes beyond the first year. With that in mind, it is worth considering that the cost in diesel of ripping to depth without adding the necessary amendment is unlikely to be recovered. Repeated, smaller gypsum/OM applications coupled with deep ripping to place them is cost prohibitive. Hence, single, large, additions may ultimately be best practice.

Similar treatment structures are used in both NSW and Qld, with both physical and chemical ameliorants, a range of options exploring impacts and/or interactions between tillage (shallow and deep), deep placement of nutrients (as inorganic or organic forms), surface and subsurface applications of gypsum to reduce ESP to < 3%, incorporating organic amendments (lucerne pellets in NSW and composted feedlot manure in Qld), and applying elemental sulfur (ES) to decrease soil pH and generate gypsum in situ (Table 1).

Surface gypsum treatments were spread onto the soil, and then incorporated by ripping to 20 cm. Actual application rates for gypsum varied with each site based on calculations that capture the required Ca to lower the ESP to <3%, but the overall structure of the experiment stayed the same.

The applied gypsum rate for subsurface placement was banded with 50% of the total needed for the whole 20 to 50 cm layer of soil. For example, if a total of 20 t/ha of gypsum was theoretically needed to remediate the entire 20 to 50 cm layer, in this application 10 t/ha was applied to ensure the right amount of gypsum within each band (assuming the band covers 50% if this zone). In NSW, it was assumed that the band only treated 25% of the profile, so only 25% of the total gypsum needed was applied – 5 t/ha in the example. Further details on how it was applied are outlined later in this paper.

Table 1. Treatment structure for core soil constraints sites in southern Queensland

Treatment	Rip (≈ 20 cm)	Surface Gyp	Deep NP(K)Zn (≈ 20 cm)	Rip > 20 cm	Deep Gyp (≈ 20 cm)	Deep OM (≈ 20 cm)	Deep ES (≈ 20 cm)
1							
2	Y						
3	Y		Y				
4	Y	Y	Y				
5	Y		Y	Y			
6	Y		Y	Y	Y		
7	Y	Y	Y	Y	Y		
8	Y	Y	Y				
9	Y	Y	Y	Y			Y
10	Y	Y	Y (*)	Y			
11	Y	Y		Y		Y	
12	Y	Y		Y		Y	Y
13	Y	Y		Y	Y	Y	Y

Deep NP(K)Zn rate is 50 kg N, 30 kg P, 50 kg K and 1.5 kg Zn apart from * rate which matches N and P addition from deep compost application. Gyp = Gypsum, OM = Organic matter ES = elemental sulfur

Engineering and application challenges

Application rates for all ameliorants are substantial, with rates often greater than 6-10 t/ha being applied. With such large amounts of product required, logistically it is challenging to source, transport and apply the treatments at each site, especially with deep (~20 cm) applications.

Applicators are not going to be universally capable machines for putting ameliorant at depth – it is very challenging to engineer something to measure and distribute all manner of materials. The deep placement machine used in Qld required amendments with the physical characteristics of being relatively fine and easily flowable in order to be metered and delivered to depth. This was achieved by using 6 mm screened feedlot compost, and air drying natural mined gypsum to reduce moisture content. All materials were screened at the top of the applicator bin through a 12mm screen to further exclude lumps. In NSW, flow problems were resolved by using pellets and prills – a more expensive solution.

Metering of products was achieved through fluted rollers (Figure 1). Further changes were undertaken adapting it for use in the soil amendment experiments. Modifications included 75 mm chutes for amendment delivery down the back of the applicator tine and inclusion of a crumble roller for smoothing the surface slightly.

Figure 1. Metering unit for amendment application on the Qld research machine, with ruler for scale.

Given the 'proof-of-concept' intent of much of the research, interpretation of individual specific effects is challenging. What the research outcomes do confirm is there exists a significant upside in yield achievable with combinations of physical and chemical inputs.

Grain yield

Millmerran was planted to sorghum for 2019-20, while Dulacca, Armatree, Forbes and Spring Ridge all had winter crops in 2020. While experiments are similar across the Qld and NSW components, the results for the different states are reported separately.

Grain yield responses in Qld

In Qld, yield increases have been recorded at both the harvested sites. At Millmerran (Table 2), grain yields increased up to ≈25% or 750 kg/ha. In general, treatments with combinations of surface gypsum and subsurface NPK (i.e. trt 4, 7, 8 and 13) had the largest yield gains.

Table 2. 2019-20 Grain yield (GY) for sorghum at Millmerran

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein
1	Control	2970	133	0	0	a	11.1
2	Shallow rip	2910	188	-60	-2	a	10.7
3	Banded fert	3300	188	330	11	abcd	10.7
4	Surface gyp + shallow rip	3580	133	610	21	bcd	10.4
5	Deep rip	3430	188	460	15	abcd	10.6
6	Deep gyp	3120	188	150	5	ab	10.9
7	Surface + deep gyp	3750	133	780	26	d	10.7
8	Surface gyp + deep rip	3750	188	780	26	cd	10.2
9	ES + surf gyp	3250	188	280	10	abc	10.6
10	Nutrient control	3500	188	530	18	bcd	11.0
11	Surface + deep OM	3370	188	400	13	abcd	10.4
12	ES+OM	3360	188	390	13	abcd	10.5
13	All	3700	188	730	25	cd	10.5

* Treatments with the same letter do not significantly differ (P<0.05)

At Drillham (Table 3), grain yields increased up to ≈60% or 1,250 kg/ha. Three treatments in particular provided the largest increases, treatments 10, 12 and 13. Commonality of these treatments is all have tillage to 30 cm, and either have high nutrient supplies from the high NP rates (treatment 10), or the composted feedlot manure (12 and 13). Deeper ripping (to 30cm) and lower nutrient inputs (50N,30P) increased yields by 800 kg/ha (40%), but it appears the higher nutrient supply plots allowed greater yields to be recorded.

Table 3. 2020 Grain yield (GY) for wheat at Drillham

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein
1	Control	2110	66	0	0	a	13.7
2	Shallow rip	2200	133	90	5	ab	13.5
3	Banded fert	2520	133	410	20	bcd	14.4
4	Surface gyp + shallow rip	2320	133	210	10	abc	14.0
5	Deep rip	2990	133	880	42	fgh	13.3
6	Deep gyp	2860	133	750	35	defg	13.8
7	Surface + deep gyp	2580	133	470	22	bcde	13.8
8	Surface gyp + deep rip	2910	133	800	38	efg	13.8
9	ES + surface gyp	2690	133	580	27	cdef	13.5
10	Nutrient control	3310	133	1200	57	hi	13.9
11	Surface +deep OM	3010	133	900	43	fgh	13.7
12	ES + OM	3200	133	1090	52	ghi	13.6
13	All	3420	133	1310	62	i	13.6

* Treatments with the same letter do not significantly differ (P<0.05)

Grain responses in NSW

The Armatree site produced a 4.5t/ha crop at around 15% protein and had significant differences between treatments in both grain yield, and biomass at flowering (Table 4). In general, deep ripping and the addition of nutrients, as banded fertiliser or contained in the organic amendment, increased growth and yields by approximately 20%. However, the organic matter treatments (11-13) ran out of water during grain fill due to the very large biomass produced, resulting in similar yields to the controls, with higher protein and screenings levels.

Table 4. 2020 Grain yield (GY) for wheat at Armatree

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein	Screenings
1	Control	4470	188	0	0	abcd	15.5	0.8
2	Shallow rip	4740	210	270	6	abcde	15.8	1.2
3	Banded fert	5040	210	570	13	abcde	14.8	0.9
4	Surface gyp + shallow rip	5210	210	740	17	bcde	15.4	1.2
5	Deep rip	5390	210	920	21	cde	14.7	1.1
6	Deep gyp	5460	210	990	22	cde	15.0	1.1
7	Surface + deep gyp	5110	188	640	14	bcde	14.6	1.2
8	Surface gyp + deep rip	5330	188	860	19	cde	15.0	1.0
9	ES + surface gyp	5630	210	1160	26	e	14.9	1.0
10	Nutrient control	5340	210	870	19	bcde	14.8	1.1
11	Surface + deep OM	4390	210	-80	-2	abc	16.3	2.1
12	ES + OM	4570	210	100	2	abcde	17.0	3.1
13	All	4340	188	-130	-3	ab	17.1	2.2

* Treatments with the same letter do not significantly differ (P<0.05)

Forbes had no significant differences in canola grain yield, but the organic treatments did increase protein and reduce oil content (Table 5). The site was waterlogged for most of winter, and still had moisture in the profile at harvest, so any differences in plant available water capacity, or root penetration to depth, were unlikely to have shown up in this season. The plant population was also extremely variable due to the surface roughness from the ripping and waterlogging from 70mm of rain immediately after sowing. This variation has been included in the statistical analysis, but also suggests that small-seeded canola may not be the best crop for growing immediately after a ripping program.

Table 5. 2020 Grain yield (GY) for canola at Forbes

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein	Oil
1	Control	2470	194	0	0	ns	19.9	44.9
2	Shallow rip	2530	222	60	2	ns	19.9	44.3
3	Banded fert	3070	193	600	24	ns	20.3	43.9
4	Surface gyp + shallow rip	2710	192	240	10	ns	20.4	45.0
5	Deep rip	2680	176	210	9	ns	20.8	43.2
6	Deep gyp	2650	193	180	7	ns	21.4	42.7
7	Surface + deep gyp	3010	172	540	22	ns	20.6	43.7
8	Surface gyp + deep rip	2840	192	370	15	ns	20.4	44.0
9	ES + surf gyp	2700	193	230	9	ns	20.4	43.7
10	Nutrient control	2750	193	280	11	ns	20.2	44.2
11	Surface + deep OM	2630	173	160	6	ns	22.4	40.6
12	ES + OM	2570	192	100	4	ns	22.5	40.4
13	All	2590	192	120	5	ns	21.6	41.7

* Treatments with the same letter do not significantly differ (P<0.05). ns = not significant difference

Spring Ridge also had no significant differences in biomass at flowering, or barley grain yield (Table 6). The high yield reflects the good season in 2020 and suggests that the site may not be as constrained as originally thought. We are uncertain if this lack of observed yield constraint is long term, or due to the above average rainfall in early 2020 which may have resulted in short term leaching of the salinity found in the initial sampling.

Table 6. 2020 grain yield (GY) for barley at Spring Ridge

Trt		Yield	SE	Delta GY	Rel GY%	LSD*
1	Control	6520	226	0	0	ns
2	Shallow rip	6030	253	-490	-8	ns
3	Banded fert	6170	256	-350	-5	ns
4	Surface gyp + shallow rip	6410	254	-110	-2	ns
5	Deep rip	6320	256	-200	-3	ns
6	Deep gyp	6360	256	-160	-2	ns
7	Surface + deep gyp	6700	227	180	3	ns
8	Surface gyp + deep rip	6050	227	-470	-7	ns
9	ES + surf gyp	5760	256	-760	-12	ns
10	Nutrient control	6460	254	-60	-1	ns
11	Surface + deep OM	6170	256	-350	-5	ns
12	ES + OM	6270	254	-250	-4	ns
13	All	6310	227	-210	-3	ns

* Treatments with the same letter do not significantly differ ($P<0.05$) ns = no significant difference.

Conclusions

We present one year of results, after a very wet summer/autumn which allowed all plots to refill after treatment application except for the Talwood site which has been planted in mid-January 2021. The 2021 crop will give a better indication of long term effects of treatments, and (possibly) under more typical conditions. Increases in yield as a result of the ripping may also require extra nutrients to achieve the increased yield potential.

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Cereal pathology update – learnings from 2020, planning for 2021

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GRDC codes

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Take home messages

- High levels of powdery mildew infection were observed in 2020 barley crops
- Powdery mildew is a highly variable pathogen of barley with virulence varying in response to varietal resistance
- Continuous barley cropping increases the risk of stubble-borne diseases
- Management strategies for foliar diseases include resistant varieties, crop rotation, seed treatment, regular crop monitoring and timely fungicide application
- Resistance to fungicides have been reported in powdery mildew, net form of net blotch (NFNB) and spot form of net blotch (SFNB) in Australia
- Limit fungicide application by spraying only when necessary, rotate fungicides with different modes of action and use recommended rates
- Seed-treatment will provide protection against seed-borne diseases, smut and early development of powdery mildew
- Effective seed treatment depends on product choice, application rate and efficacy of application.

Background – learnings from 2020

Rainfall in the 2020 season in Queensland was lower than expected, hence disease incidence was also lower than anticipated.

However, conditions resulted in high levels of powdery mildew (PM) infection, particularly on varieties with low levels of resistance. Powdery mildew (*Blumeria graminis* f. sp. *hordei*) is a disease synonymous with barley cultivation world-wide. Under mild humid conditions, it will infect leaves and leaf sheaths of plants. It is easily recognisable by the white, fluffy mycelial growth, particularly on upper leaf surfaces. Older colonies turn dull grey and often produce small, black fruiting bodies. Environmental conditions in Qld generally become unfavourable for the pathogen and disease does not persist to adult plant stages. Consequently, yield losses are usually below 15%. In the 2020 season, infections persisted later into the season, despite conditions becoming less favourable.

Both loose smut and covered smut were detected in a number of barley crops in Qld in 2020, with losses in yield and quality reported. Affected crops had not been treated with an effective seed treatment. Seed-treatment applied effectively would have avoided yield loss.

Net blotch was present at low levels and was most conspicuous in irrigated crops. Net blotch in barley is caused by one of two forms of *Pyrenophora teres* (*P. teres*). Net form net blotch (NFNB) is caused by *P. teres* f. *teres* (*Ptt*) and spot form net blotch (SFNB) is caused by *P. teres* f. *maculata* (*Ptm*). The two forms share the same shape and structure (morphology) and can only be distinguished by plant symptoms and molecular characterisation. Symptoms of NFNB are characterised by net-like dark brown necrotic lesions, whereas SFNB symptoms are characterised by dark circular or elliptic brown spots surrounded by a yellow chlorotic area.

Net form net blotch occurs regularly in the northern region and samples are collected from crops annually. However, only 5 samples of NFNB were collected or submitted for pathotyping in 2020. SFNB was present at very low levels in isolated crops, unlike 2019 where despite dry conditions SFNB was widespread in Qld barley crops. Moisture stress may have contributed to crops being more vulnerable to infection.

Spot blotch (SB) (*Bipolaris sorokiniana)* has previously been confined to the warmer and more humid coastal areas of Qld. In recent years however, an increased number of SB samples have been collected from Central Qld (CQ). This could be attributed to the increased area sown to barley in CQ. With an increasing area sown to barley, the incidence of SB is expected to increase under favourable conditions and may become a significant yield constraint.

Powdery mildew

Powdery mildew (PM) survives between seasons on volunteer barley and barley stubble. When conditions become less favourable, the pathogen undergoes sexual reproduction and forms fruiting bodies (cleistothecia) in existing colonies. These persist until the new growing season and release ascospores under favourable temperature and moisture conditions, infecting the new crop. The mildew colonies produce airborne conidia (asexual spores) that spread the disease within and between crops.

A survey of Australia's barley powdery mildew population was conducted by Dreiseitl and Platz in 2010 and 2011. This study identified 27 pathotypes and 16 major genes effective against all PM isolates tested. Largely as a result of its sexual reproductive stage, the pathogen can evolve rapidly, resulting in new pathotypes which can damage previously resistant varieties. Since then, pathotypes that are virulent against the resistance genes *Mla3*, *Mla9*, *Mla12* and *MlLa* have been identified, thus reducing the number of effective major resistance genes.

Virulence for *MlLa* is responsible for the increased disease levels occurring in certain varieties i.e. Commander⦶, Mackay, Compass⦶, Hindmarsh⦶, and La Trobe⦶. This gene is present in many of the current varieties, with high levels of PM observed on Rosalind⦶ and Spartacus CL⦶ in Qld in 2020.

The *mlo* gene provides resistance to all isolates. Varieties that have this gene include Granger⦶, Westminster⦶ and RGT Planet⦶. Other commercial varieties resistant to powdery mildew and their effective resistance genes include Fairview⦶ (*Mla13*), Flinders⦶ (*Mla1*) and Scope⦶ (*Mla7*).

Smut

Barley hosts two species of smut – loose smut (*Ustilago nuda)* and covered smut (*Ustilago hordei*). In both, infection results in florets producing thousands of spores, instead of grain. Spore masses are encased in a membrane. This membrane is quite fragile in loose smut and ruptures soon after head emergence, releasing the spores. However, in covered smut, the membrane is much more persistent, often breaking during harvesting.

Both species were detected in a number of barley crops in Qld in 2020. Loose smut has been reported in previous years, with crops of the Hindmarsh⦶ lineage e.g. Hindmarsh⦶, La Trobe⦶ and Rosalind⦶, often infected.

Loose smut is most conspicuous around flowering when infected heads, bearing a mass of dark brown to black sooty spores, are visible. In plants infected with loose smut, the membrane ruptures soon after heading, releasing airborne spores which infect surrounding florets. Infection occurs under moist conditions at temperatures around 16 – 22°C. Florets are susceptible to infection from flowering to about one week after pollination. Germinating spores infect the ovary and the fungus survives as mycelium within the embryo of the infected seed. Once infected seed is sown, it germinates and carries the fungus in the growing point of the plant becoming visible as a black spore mass at head emergence. Loose smut is well adapted for survival with infected plants usually being slightly earlier than healthy plants, ensuring an adequate supply of inoculum when the bulk of the crop is flowering.

Heads infected with covered smut frequently emerge later than healthy heads and often being shorter and harder to see. As with loose smut, grains are replaced with a mass of black powdery spores. These are released during the harvesting process and contaminate healthy grain. The spores germinate after planting, infecting emerging seedlings, growing through the plants where they eventually replace the grain with spores. The fungus is favoured by temperatures of 14 – 25°C.

Loose smut is exclusively internally seed-borne, while covered smut is either externally seed-borne or survives in the soil. The life cycle of loose smut in barley is the same as in wheat; however barley loose smut will not infect wheat and vice versa.

Disease management

Barley foliar pathogens are a significant challenge to the grains industry and a major constraint to profitable barley production, affecting both yield and quality. Many of these pathogens are genetically and pathogenically diverse, able to reproduce sexually and can rapidly develop new virulence and overcome genetic resistance.

The adoption of stubble retention practices has led to an increase in the incidence of stubble-borne diseases. Planting successive barley crops in the same paddock increases pathogen incidence.

Growing a high yielding, well adapted, resistant variety provides the most economic and environmentally friendly means of disease control. Genetic resistances need to be durable to provide long-term protection. The PM resistance gene *mlo* has been effective in Europe for more than 50 years but has not been widely adopted in Australian breeding programs due to its association with lower yields in the Australian environment. It is however present in some varieties, mostly from European descent including Grangerᶲ, Westminsterᶲ and RGT Planetᶲ. Other commercial varieties resistant to powdery mildew and their effective resistance genes include Fairviewᶲ (*Mla13*), Flindersᶲ (*Mla1*) and Scopeᶲ (*Mla7*).

In susceptible varieties where yield potential is high, fungicidal control of PM can be justified. Foliar fungicides should be aimed at protecting the top two leaf layers. The identification of PM populations that are resistant to or have reduced sensitivity to Group 3 (DMI) fungicides in WA, highlights the importance of resistance breeding.

Net form net blotch is best controlled by sowing varieties rated MS or better and a combination of cultural practices. The NFNB pathogen persists on plant residue. Cultivation of the same variety will lead to an increase in the presence of pathotypes virulent on that particular variety and put increased pressure on effective resistance genes. Best practice includes crop rotation with non-host crops such as wheat, canola and chickpea. NFNB is also seed-borne and can spread with infected seed. Various seed treatment products are registered for NFNB control.

Resistance to Group 7 and Group 3 fungicides has been identified in NFNB populations in SA and WA, respectively, with reduced sensitivity identified in WA populations to other Group 3 (DMI) fungicides. To ensure that fungicides remain effective, it is important to limit fungicide application by spraying only when necessary, rotate fungicides with different modes of action and use fungicides at recommended rates. Avoid using tebuconazole as a stand-alone product in barley to avoid indirect fungicide resistance selection. By applying it for PM control, you can indirectly select for NFNB or SFNB isolates resistant to tebuconazole, without the intention of controlling those diseases. Isolates resistant to fungicides can be spread through infected seed. It is beneficial to all to ensure that we use fungicides in such a way that we protect their longevity.

Fungicide applications are more effective if applied before disease becomes established in the crop. This requires regular monitoring to ensure crops can be sprayed at the first sign of disease. When conditions are favourable for disease development, more frequent crop inspections will be needed and repeat fungicide applications may be necessary.

The level of smut in a crop is a function of

- Varietal susceptibility
- The number of grains infected in the previous seed crop
- The efficacy and rate of the seed treatment applied and
- The precision of the seed treatment process.

Resistance to smut is available; but has never been a priority of Australian barley breeding programs. Seed treatment has provided economical control in the past and is likely to continue to do so. Several fungicides are registered for the control of smut; but the levels of control vary among products.

Conclusion and 2021 planning

The absence of many diseases in 2020 in the northern region does not mean that we can be complacent. With favourable environmental conditions, pathogens will continue to cause yield and quality loss and we have to make the right decisions to ensure that we can stay ahead of disease development and the evolution of the pathogen.

Continuous monitoring of the pathogen populations provides information on the virulence in the Australian pathogen populations and aids in the identification of effective resistance for use in the development of resistant varieties. There are still a range of major resistance genes effective against our powdery mildew population and increasing evidence of useful adult plant resistance genes. These need to be used in a manner that ensures the resistances will be durable. We know that *mlo* resistance is effective and durable and encourage Australian breeders and pre-breeders to utilise it as a source of resistance.

The reappearance of smut in barley is a reminder to maintain effective fungicide treatment of planting seed. If seed is sourced from a crop known to have been infected with loose smut, it would be useful to treat seed at the higher recommended rate. The increased incidence may be due to a variety of reasons, including good infection conditions, application of lower rates of fungicide or ineffective application or varietal susceptibility. Quality routine seed treatment should continue to provide effective smut control.

References

2020 Queensland winter crop sowing guide

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2021 Queensland winter crop sowing guide

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The economics of managing Ascochyta in chickpea when disease occurs at different growth stages and implications for spray timing

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Key words

chickpea, Ascochyta, management, gross margin, profitability

GRDC code

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

Take home messages

- Impact of Ascochyta at different growth stages was investigated in a 2020 field experiment at Trangie with varieties Kyabra⍉, PBA HatTrick⍉ and PBA Seamer⍉
- Ascochyta caused yield losses from 100% to nil depending on when the disease occurred, and the variety grown
- Highest gross margin (GM)'s (> $800/ha) occurred with the lowest incidence of Ascochyta and also with the least susceptible variety, i.e. PBA Seamer⍉
- Manage Ascochyta early and grow varieties with best resistance to minimise impact of Ascochyta
- Follow current Ascochyta advice to maximise enduring profitability.

Why did we do this research?

Current management of chickpea Ascochyta in north central/northern NSW and southern QLD is based on results of field trials conducted mostly at Tamworth, grower experiences and feedback from agronomists. The Tamworth experiments have tried to simulate what happens in most farmers crops, i.e. initial infection occurs during the first post emergence rainfall event – accordingly, all the Tamworth experiments have established Ascochyta during that event. But what is the impact if infection occurs at later stages of growth and how does that affect management? The Trangie Agricultural Research Centre provided an opportunity to address that question – the soil and climate are typical of the Macquarie valley, a major chickpea production region. Overhead irrigation (lateral) and inoculation with conidia and infected spreader plants optimised infection and disease development.

Experiment details

Treatments

Aim: to assess the impact of Ascochyta blight (AB) disease occurring at three different growth stages, on yield of three chickpea varieties with different levels of AB resistance.

Ascochyta treatments (5):

1. **LOW (NIL)**: un-inoculated (NIL disease = CONTROL) plus foliar chlorothalonil fungicide (1.0 L/ha, chlorothalonil 720g/L) applied before rain or irrigation events

2. **HIGH**: inoculated with disease twice (at seedling (SDG, 3-4 nodes) and vegetative (VEG, 7-8 nodes) growth stages); NIL fungicide applied
3. **SDG**: inoculate with disease at seedling stage (3-4 nodes), allow disease to progress for 2-3 rain events to 7-8 nodes, then control disease for rest of season with chlorothalonil
4. **VEG**: protect plants from emergence to vegetative stage (7-8 nodes) with chlorothalonil; inoculate with disease and allow to progress for 2-3 rain events to first pods, then control disease with chlorothalonil
5. **POD**: protect plants from emergence to reproductive stage (first pods) with chlorothalonil, inoculate with disease and allow disease to progress through to harvest.

Variety treatments (3, and level of AB resistance):

1. **Kyabra**ɸ VS = Very susceptible
2. **PBA HatTrick**ɸ MS = Moderately susceptible
3. **PBA Seamer**ɸ MR = Moderately resistant

Replication: 4 reps

Method

The experiment was conducted at Trangie Agricultural Research Centre in central west NSW, on a grey vertosol soil with access to overhead (lateral) irrigation. The experiment was sown as a randomised block design using a small plot seeder, with each plot 2m x 10m. Buffer plots were sown (with PBA Seamerɸ) at the same plot size between each treatment plot, to reduce the impact of inter-plot interference from Ascochyta inoculation and fungicide application. A back-pack sprayer with a 2m wide hand-held wand and 015 110 degree flat fan nozzles @ 50cm, was used to apply both Ascochyta inoculum and fungicide. Buffer plots received the full set of six fungicide applications.

Ascochyta disease was generated in treatment plots by a combination of two inoculation methods:
1. Ascochyta applied to whole plot as conidial suspension (600,000 conidia/mL), and
2. Ascochyta infected spreader plants transplanted to centre of plot.

Ascochyta treatments for each growth stage were applied just prior to either a forecast rain event, or irrigation.

Ascochyta treatment and fungicide were applied as follows:

up to 1 July	NIL fungicides applied prior to first disease treatment
1 July	**inoculation 1 - SDG & HGH treatments (pre-irrigation)**
9 July	fungicide 1 pre-rain - applied to LOW, VEG & POD (not SDG or HGH)
5 August	**inoculation 2 - VEG & HGH treatments (pre-rain)**
13 August	fungicide 2 pre-rain – applied to LOW, SDG & POD (not VEG or HGH)
9 September	fungicide 3 pre-rain – applied to LOW, SDG & POD (not VEG or HGH)
19 September	**inoculation 3 - POD treatment (pre-rain)**
29 September	fungicide 4 pre-rain – applied to LOW, SDG & VEG plots (not POD or HGH)
7 October	fungicide 5 pre-rain – applied to LOW, SDG & VEG plots (not POD or HGH)
21 October	fungicide 6 pre-rain – applied to LOW, SDG & VEG plots (not POD or HGH)

Site details & agronomy management

Sowing date: 26 May 2020
Harvest date: 27 November 2020
Seed treatment:
PBA Seamerɸ pre-treated with thiram at purchase
Kyabraɸ & PBA HatTrickɸ treated with P-Pickel T® pre-sowing

Fertiliser at sowing: Granulock® Z @ 80 kg/ha
Inoculant: Group N, liquid inject at sowing
Target plant density: 30 plants/m^2
Actual establishment achieved:
Kyabra⦸ & PBA Seamer⦸ = 31 plants/m^2 (new seed)
PBA HatTrick⦸ = 21 plants/m^2 (retained seed ex 2019 harvest, poor storage conditions)
Buffers between treatment plots: PBA Seamer⦸ at 30 plants/m^2

Herbicide management:
pre-sow: TriflurX® (trifluralin 480 g/L) @ 1.7 L/ha
PSPE: Terbyne® Xtreme® (terbuthylazine 875 g/kg) @ 0.86 kg/ha
in-crop: haloxyfop 520 @ 100 mL/ha + clethodim 240 @ 250 mL/ha
Fungicide application:
up to 6 chlorothalonil 720g/L @ 1.0 L/ha for LOW (NIL disease) treatment; total number of applications varied for each growth stage treatment
Insecticide & mouse management:
17 Sept Affirm® (emamectin) insecticide @ 300 mL/ha (by plane)
6 Oct Altacor® (chlorantraniliprole) insecticide @ 70 g/ha (by plane)
12 Oct Zinc phosphide mouse bait @ 1.0 kg/ha (by plane)
Harvest management:
desiccation not required due to heatwave conditions from 15 November on
experiment harvested at 9% moisture content.
Pre-sowing rainfall (1/01/20 to 25/05/20): 351 mm
In-crop rainfall (26/05/20 to 27/11/20): 201 mm in 49 events
Plus in-crop irrigations: 20 mm (as 2 x 10 mm events)

Table 1. Summary of dates of disease inoculations and fungicide applications for 2020 Trangie chickpea Ascochyta management trial, relative to dates of subsequent rain or irrigation events.

2020 date	Disease inoculation	Fungicide application	Rain > 2.0mm	Irrigation (mm)	Cumulative >2.0mm # Events	Cumulative >2.0mm (mm)
01 Jul	SDG & HIGH		0.0	10.0	1	10.0
09 Jul		LOW, VEG & POD				
10-13 Jul			31.6		2	41.6
25-27 Jul			35.8		3	77.4
05 Aug	VEG & HIGH					
06-12 Aug			19.2		4	96.6
13 Aug		LOW, SDG & POD				
14-22 Aug			18.8		5	115.4
09 Sep		LOW, SDG & POD	3.8		6	119.2
14 Sep			0.0	10.0	7	129.2
19 Sep	POD					
19-25 Sep			33.8		8	163.0
29 Sep		LOW, SDG & VEG				
7 Oct		LOW, SDG & VEG	6.8		9	169.8
17 Oct			3.4		10	173.2
21 Oct		LOW, SDG & VEG				
23-25 Oct			17.6		11	190.8
4-5 Nov			7.8		12	198.6

Table 2. Log of operations for 2020 Trangie experiment on managing chickpea Ascochyta when disease occurs at different growth stages: Inoc = inoculation, DAS = days after sowing, DAI = days after inoculation.

	Ascochyta treatment			
Operation	**HIGH**	**SDG**	**VEG**	**POD**
Sow date	26/05/2020	26/05/2020	26/05/2020	26/05/2020
1st Inoc date	1/07/2020	1/07/2020	5/08/2020	19/09/2020
2nd Inoc date	5/08/2020	not done	not done	not done
1st Inoc DAS	36	36	71	116
2nd Inoc DAS	71	not done	not done	not done
Score 1 date	26/08/2020	26/08/2020	26/08/2020	26/08/2020
Score 2 date	1/10/2020	1/10/2020	1/10/2020	1/10/2020
Score 3 date	14/10/2020	14/10/2020	14/10/2020	14/10/2020
Score 1 DAI	56	56	21	na
Score 2 DAI	92	92	57	12
Score 3 DAI	105	105	70	25

Results

The effects of Ascochyta treatment, Variety and Ascochyta x Variety were highly significant (P<0.001) for all variables measured.

Disease incidence

The seedling, (SDG) and HIGH Ascochyta treatments were inoculated on 1 Jul 20, 36 days after sowing, DAS (Table 2). The HIGH treatment was inoculated a second time on 5 Aug (71 DAS) to maximise disease development (Table 2). This resulted in severe early disease (assessed on 26 Aug) in KyabraΦ, moderate disease in PBA HatTrickΦ and demonstrated the improved Ascochyta resistance in PBA SeamerΦ (Table 3). The vegetative, VEG treatment was inoculated on 5 Aug (71 DAS), prior to which plants had been protected with foliar fungicide applied on 9 Jul. This regime produced low disease in KyabraΦand PBA HatTrickΦ at the 1^{st} and 2^{nd} assessments (26 Aug, 1 Oct) and nil in PBA SeamerΦ (Table 3). The podding, POD treatment was inoculated on 19 Sep (116 DAS), prior to which plants had been protected with foliar fungicides applied on 9 Jul, 13 Aug and 9 Sep. This regime produced nil disease in all three varieties at the 1^{st} assessment (26 Aug) and low disease at the two subsequent assessments (1 Oct, 14 Oct) (Table 3). We assign the low incidence of Ascochyta with the POD treatment as a consequence of the three fungicide sprays applied before inoculation and less favourable seasonal conditions.

Table 3. Incidence of Ascochyta (% plot with disease) in Kyabra⦶, PBA HatTrick⦶ and PBA Seamer⦶ chickpeas when disease was established at different growth stages but controlled before and after; l.s.d. (*P*=0.05) for Scores 1, 2 & 3 = 13.26%, 8.63% & 11.74%, respectively.

Variety	Ascochyta treatment	Score 1 26 Aug 20	Score 2 01 Oct 20	Score 3 14 Oct 20
Kyabra ⦶	LOW	1.3	0.0	5.2
PBA HatTrick ⦶	LOW	0.0	0.0	11.2
PBA Seamer ⦶	LOW	0.0	0.0	3.0
Kyabra ⦶	SDG	92.0	57.5	70.0
PBA HatTrick ⦶	SDG	37.5	22.5	40.0
PBA Seamer⦶	SDG	0.0	0.0	2.8
Kyabra ⦶	VEG	8.8	12.5	31.2
PBA HatTrick ⦶	VEG	5.0	8.8	22.5
PBA Seamer⦶	VEG	0.0	0.0	3.0
Kyabra ⦶	POD	0.0	0.5	7.8
PBA HatTrick ⦶	POD	0.0	2.5	5.2
PBA Seamer⦶	POD	0.0	0.0	3.8
Kyabra⦶	HIGH	88.8	100.0	100.0
PBA HatTrick ⦶	HIGH	32.5	52.5	57.5
PBA Seamer ⦶	HIGH	0.0	0.0	4.0

This approach, i.e. inoculating Ascochyta at different times and protecting before and after, allowed us to determine the impact of disease at those stages on yield.

Impact on yield

Table 4. Effect of Ascochyta on grain yield, gross margin (GM) and yield loss for three chickpea varieties when disease occurs at different growth stages; l.s.d. (*P*=0.05) yield 286 kg/ha. GM is based on chickpea price of $600/t, fungicide product $16/ha/application, fungicide ground rig application $5/ha, other production costs $300/ha.

Variety	Ascochyta Treatment	Yield (kg/ha)	GM ($/ha)	% Yield Loss (kg/ha)
Kyabra ⦶	LOW	1878	701	0
PBA HatTrick ⦶	LOW	1840	678	0
PBA Seamer ⦶	LOW	2138	857	0
Kyabra ⦶	SDG	10	-399	99
PBA HatTrick ⦶	SDG	965	174	48
PBA Seamer⦶	SDG	2080	843	3
Kyabra ⦶	VEG	1483	506	21
PBA HatTrick ⦶	VEG	1504	518	18
PBA Seamer ⦶	VEG	2211	943	-3
Kyabra ⦶	POD	2041	862	-9
PBA HatTrick ⦶	POD	1880	765	-2
PBA Seamer ⦶	POD	2101	898	2
Kyabra ⦶	HIGH	0	-300	100
PBA HatTrick ⦶	HIGH	234	-160	87
PBA Seamer ⦶	HIGH	1903	842	11

Grain yield (Table 4) ranged from nil (Kyabra⦶ HIGH) to over 2 t/ha (all PBA Seamer⦶ treatments). For the very susceptible Kyabra⦶, lowest yields occurred with the SDG and HIGH treatments with yield losses of 99% and 100% respectively. The moderately susceptible PBA HatTrick⦶ also had lowest yields for SDG and HIGH treatments, with losses of 48% and 87% respectively (Table 4). The least susceptible variety PBA Seamer⦶ only lost 3% and 11% yield from SDG and HIGH treatments.

Gross Margins (GM)

The highest GM's occurred with the lowest incidence of Ascochyta (LOW) and also with the least susceptible variety PBA Seamer⦶ (Table 4). All PBA Seamer⦶ treatments, including the one with most Ascochyta, (HIGH) had GM over $800/ha (Table 4). However, the experiment showed that controlling Ascochyta in the very susceptible Kyabra⦶ is profitable with a GM of $701/ha and $862/ha for the LOW and POD treatments respectively.

Conclusions

Generating chickpea Ascochyta at different stages of growth showed when and how disease affects yield. The impact of disease on a chickpea crop depends primarily on when the disease occurs, how it is managed, and the variety grown. Allowing Ascochyta to establish early in the life of your crop results in greatest impact on yield and lowest profitability, even if the disease is subsequently controlled with foliar fungicides. This is especially true for very susceptible and moderately susceptible varieties. Your best option for minimising impact of Ascochyta on chickpea production and maximising profitability is to follow current recommendations (Moore and Heuston, 2020) by controlling disease early and growing the least susceptible variety. This approach will also reduce the build-up and carryover of Ascochyta inoculum for your and your neighbour's future chickpea crops.

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Optimising chickpea sowing and flowering dates for maximum yield

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Key words

sowing date, pulse crops, chickpea, flowering date, frost risk, APSIM, agronomy

GRDC code

CSP1904-005RXT: The adaptation of pulse (chickpea and lentil) across the northern grains region.

Take home messages

- Water-limited potential yield of chickpea is constrained by frost risk, heat risk and the effect of chilling temperatures (<15°C average daily temperature) on flower abortion, so it is important to match the flowering and pod initiation phases with optimal climatic conditions
- Grain yield of chickpea can decrease by more than 250 kg/ha per week as flowering is delayed into warmer weather conditions
- The highest grain yields from field trials in 2019 were achieved with early sown crops (often with a lower harvest index than later sown crops), using the best locally adapted cultivars
- Preliminary sowing date recommendations have been prepared for a range of northern region locations for desi and kabuli chickpeas
- As 2019 was a dry season with low disease pressure, we recommend further research to test the adaptation of different cultivars to early sowing across a range of seasons.

Introduction

Chickpeas can adapt to a range of seasonal conditions, partly due to their indeterminate growth habit that allows them to continue producing branches and flowers until the crop dies due to water or heat stress. This allows the crop to replace flowers lost to environmental stresses such as frost or cool temperature flower abortion, as long as enough soil water is still available. However, there are considerable knowledge gaps in the understanding of the physiological drivers of crop growth and development for chickpea.

The GRDC funded 'Pulse Adaptation' project, studied the flowering and yield formation response of chickpea across a range of environments during the 2019 season. The project aim was to determine when flowering needs to occur to maximise grain yield, and when crops should be sown in order to achieve these flowering dates.

What did we do?

We conducted time-of-sowing experiments in nine environments across QLD and NSW in 2019, with drought conditions experienced at each site. Our four 'detailed' sites had both irrigated and rainfed treatments across three sowing dates; Gatton, Narrabri, Condobolin, and Greenethorpe (near Young), and used just 2 or 3 cultivars for each crop type. The remaining 'regional trial' locations were conducted as rainfed experiments: Emerald, Millmerran, Gatton, Come-by-Chance (near Walgett), Caragabal (near West Wyalong), and Trentham Cliffs (just over the NSW border from Mildura).

Regional trials also had three sowing dates but had 4 or 5 cultivars relevant to the local environment in each experiment. Where conditions were too dry to establish on the desired sowing date, each sowing date received the same amount of irrigation (10-20 mm) to assist with germination. Sowing soil water was low at Caragabal (40 mm), moderate at Millmerran and Mildura (90 and 110 mm) and high at Emerald and Walgett (130 and 140 mm). Pests and diseases were managed using best-practice control methods for each species in each location.

We then used the APSIM model to investigate the relationship between sowing date, flowering date (specifically, the data of the appearance of the first flower on 50% of plants) and grain yield. APSIM is useful for predicting crop performance as it can be used to study the entire agricultural production system (climate, soil, crops, management) simultaneously, and in different combinations. Historical chickpea data was used along with data from the 2019 experiments to re-build the chickpea model within APSIM NextGen (i.e. the new 'Next Generation' APSIM modelling environment).

The APSIM chickpea model was refined and tested until we were confident that the model simulations of field data were acceptable. Then the model was used to predict the date of the appearance of the first flower, podding date and water-limited potential yield for the last 20 years (2000-2019), for a range of sowing dates (every fortnight from 1st March to 1st August) at 13 locations across the northern region. All simulations assumed that stored soil water on the 1st of March was 60mm (south of Dubbo) or 90 mm (north of Dubbo). Simulated row spacing was 40 cm, sowing depth was 5 cm and plant population was 30 plants/m^2. Water-limited potential yield is defined as the APSIM simulated yield of a crop for a given soil type using the rainfall and soil water available, but assuming that frost, diseases, pests and nutritional disorders have not affected yield. Studies are currently being supported by GRDC into the effect of frost on chickpea pod-set and grain yield, and these will be used to improve APSIM with a physiological frost response function once they are completed. In the interim, we used climate data and existing knowledge of frost thresholds to compare frost risk across locations.

Frost and heat-stress risk assessments were conducted by examining daily minimum and maximum temperatures with the potential for frost/heat stress (below +2°C and above +30°C at the standard met-station height of 1.2 m) across the same 20 years of climate data used in the simulations. Accumulated degrees below/above these thresholds for a given time period (e.g. last week in August) was calculated, and then compared with the time periods that recorded the most severe frost conditions at Breeza and the worst heat-stress conditions at Emerald over the entire year. This created a relative risk that could be used to compare different production environments in assessing the flowering and sowing dates needed to avoid extreme temperature events.

What did we find?

1. Model construction and testing – flowering and podding

The scientific literature shows there is variation for the relationship between photoperiod (i.e. duration of daylight in each day) and time of flowering in pulse crops (e.g. Daba et al., 2016), ranging from strong photoperiod responses to photoperiod neutral. Using data from our field trials we showed that the desi cultivars had a strong relationship between thermal time from emergence to the appearance of the first flower (i.e. date of first flower appearance on 50% of plants) and photoperiod at the end of the photoperiod insensitive phase (400 to 600 degree-days after emergence depending on cultivar). Kabuli cultivars had highly variable flowering responses ranging from similar photoperiod responses to the desi cultivars, to probable photoperiod neutral responses (data not shown). The date of first flower appearance was simulated acceptably for key desi and kabuli cultivars (Figure 1a,1b). The introduction of a new standardised phenology key for chickpea (Whish et al., 2020) will improve the consistency of phenology data collection between researchers across Australia. Further data should be collected using the new phenology key to widen testing environments and seasons and improve our understanding of the flowering response for chickpea.

The date of pod initiation is another important crop development stage in pulse crop modelling, as it represents the point at which the crop begins to partition biomass into pods and grains. A function was developed to account for chilling sensitivity of chickpea that prevents pollination and causes flower abortion at mean daily temperatures below 15°C (Clarke and Siddique, 2004). This approximated data from Srinivasan et al. (1998), Clarke and Siddique (2004) and Warren et al. (2019)

to predict the date of beginning of pod development in chickpeas as a set number of days since the appearance of the first flower when average temperature exceeded 15 degrees (default = 5). The function predicts the date that 50% of plants have at least one 1cm long pod on the main stem (when pod development is easily detectable with field scoring), so it is not predicting the date of successful pollination per se. The function worked satisfactorily in both Desi and Kabuli chickpeas (Figure 1c, 1d) but was more accurate in Kabuli chickpeas when simulating data from 2019. The desi cultivars PBA Slasherⓓ, PBA Strikerⓓ and PBA Seamerⓓ all produced outliers where pod development began sooner than predicted by APSIM on the first time of sowing in certain environments. These data may be caused by the tendency for crops to begin setting pods in a spell of warm weather, after which they can be aborted when cold conditions return. Further study will be required to fully assess the ability of different cultivars to produce and retain pods under cool temperatures.

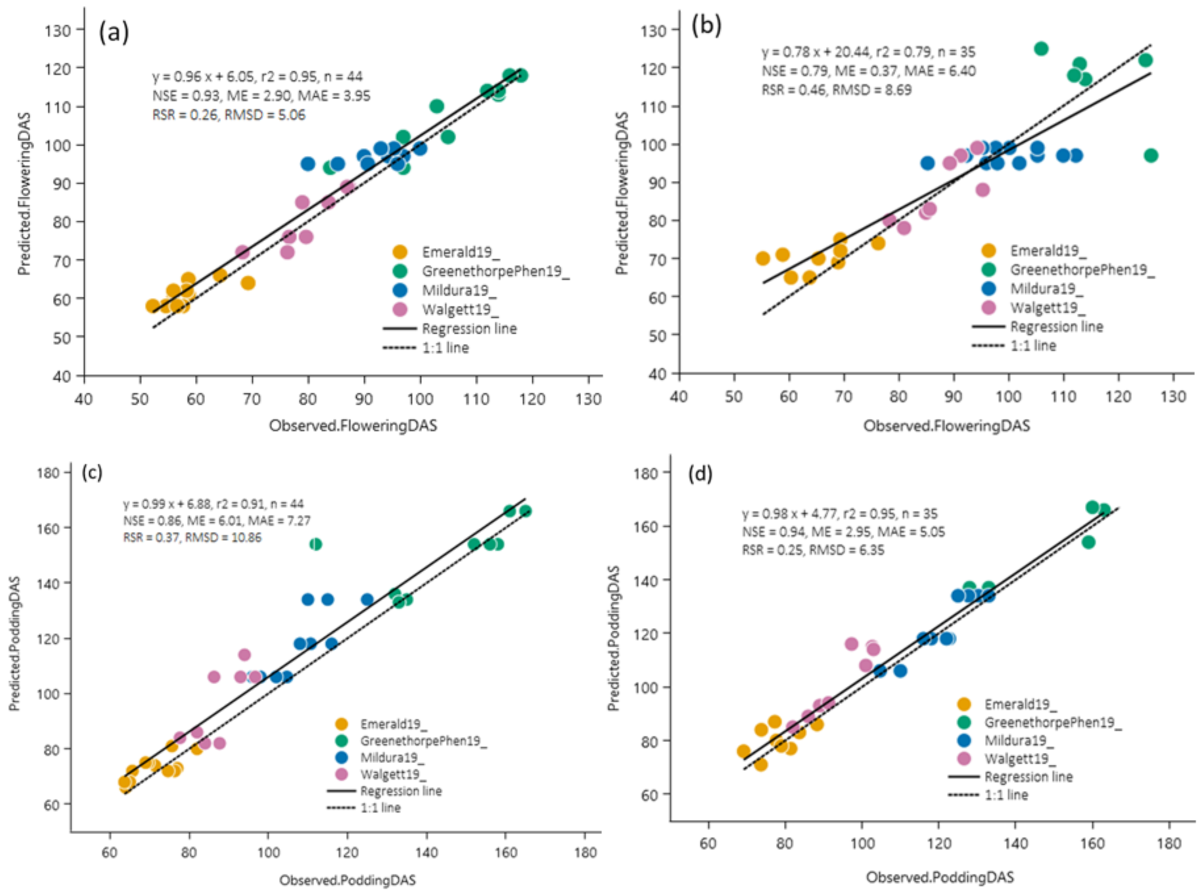

Figure 1. APSIM predicted vs observed appearance of first flower for (a) desi and (b) kabuli chickpeas, and podding date for (c) desi and (d) kabuli chickpeas, compared across regional trials in 2019.

__2. Model construction and testing – grain yield prediction__

The second purpose of the model was to predict water-limited potential yield, i.e. the potential yield for crops assuming that frost, nutrient deficiencies and disease are not encountered. At some point in the future it will be possible to build frost damage into the model once research into the effects of frost on chickpea is completed. In the meantime, it is helpful to understand what yields are possible if frost effects are ignored, as it shows what yield gains could be achieved by developing more frost tolerant cultivars. Model testing against experiment grain yields is presented in Figure 2.

Unlike flowering date, it isn't expected that the models will accurately simulate grain yield of every cultivar because of the local adaptation to soils and diseases that different cultivars can possess. The model is designed to simulate 'water-limited potential yield', which is represented by the best performing cultivars in each environment. While the maximum grain yield for each environment was simulated reasonably well for each crop, it was noticeable that grain yield for the earliest time of sowing was overpredicted at most locations except Emerald in the chickpea simulations (data not shown). This may have occurred because the effects of cold temperature or frost on flower viability and pod-set are not being fully simulated. Alternatively, the first time of sowing typically has the highest biomass and potential yield, so any nutritional limitations are more likely to impact grain yield in the early time of sowing. Further research is necessary to determine the reasons for these yield gaps.

An example of this is shown in Figure 3 where PBA HatTrick⫯ had similar field-measured grain yield across sowing dates and irrigation treatments at Greenethorpe, but potential (simulated) yield of the irrigated early sown treatments was much higher than measured grain yield, causing a large 'yield gap'. In this experiment PBA Slasher⫯ was much closer to achieving potential yield across sowing dates under irrigation and achieved 50% more grain yield in the irrigated trial on the first time of sowing compared to the third time of sowing, but still had a sizeable yield gap of 1 t/ha on the early sowing date. Further research is needed to determine if cultivar choice or other agronomic practices can be used to improve grain yield in conjunction with early sowing dates under favourable conditions.

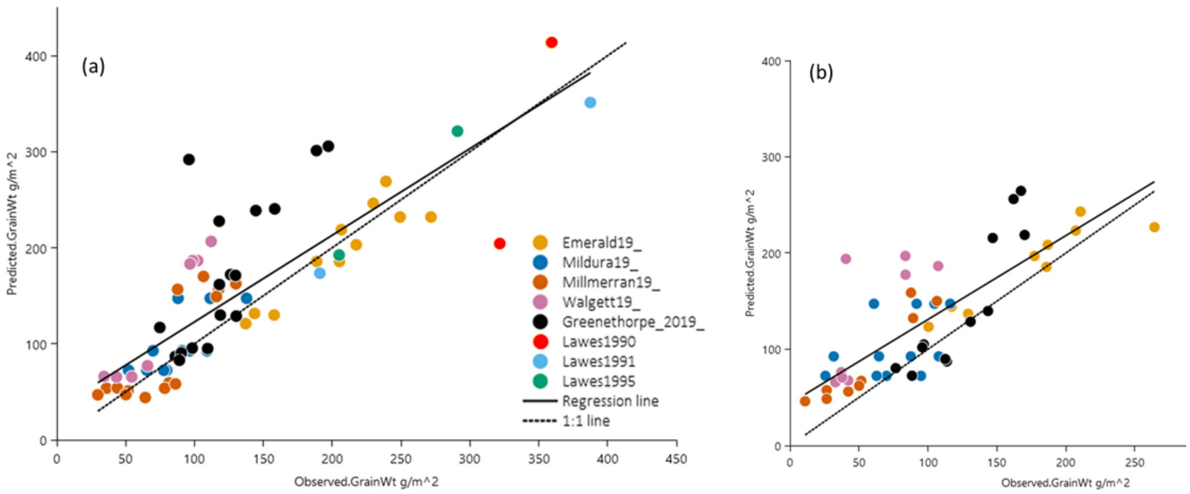

Figure 2. Predicted vs observed grain yield (a) desi and (b) kabuli cultivars, across historical data and 2019 regional trials.

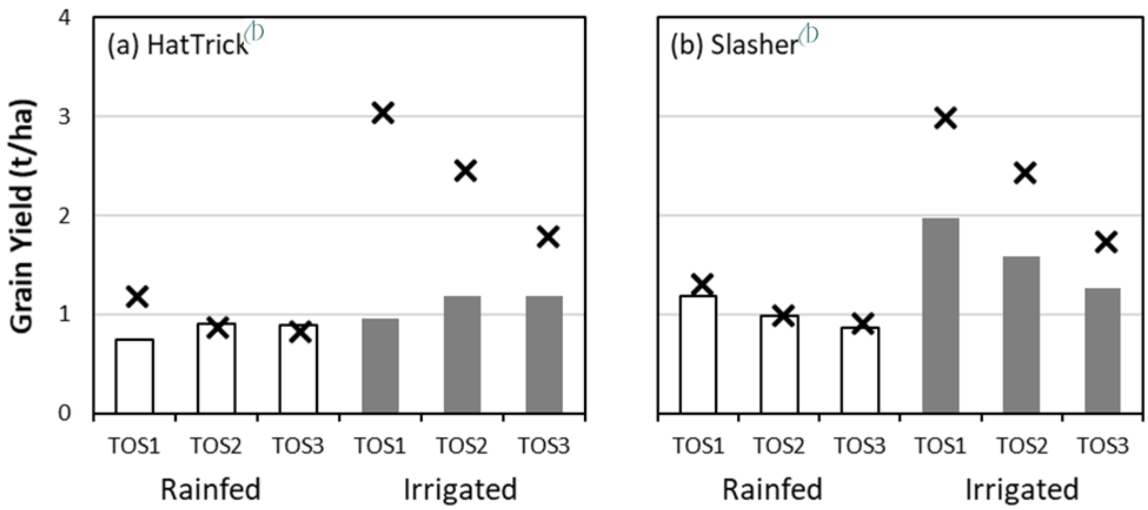

Figure 3: Measured grain yield (bars) and APSIM simulated grain yield (crosses) for the desi cultivars (a) PBA HatTrick⦸ and (b) PBA Slasher⦸ across three times of sowing (TOS) at Greenethorpe, 2019. Sowing dates were 30-April, 21-May, 12-Jun. Standard error is ≤ 0.1 t/ha for all measured yield data.

3. Regional field trial results

Despite the tendency of early sown crops to have larger yield gaps as discussed above, early sowing still achieved the best grain yield in our regional field trials in 2019 for at least some cultivars at each location (Figure 4). Our earliest sowing dates in southern NSW were not as early as the earliest sowing date of Richards et al. (2020) who observed lower grain yield in crops sown on the 15th of April compared to the 30-April in southern NSW, also in 2019. The focus of our final activity for this project was understanding the optimum flowering time to avoid frost and heat shock and maximise grain yield.

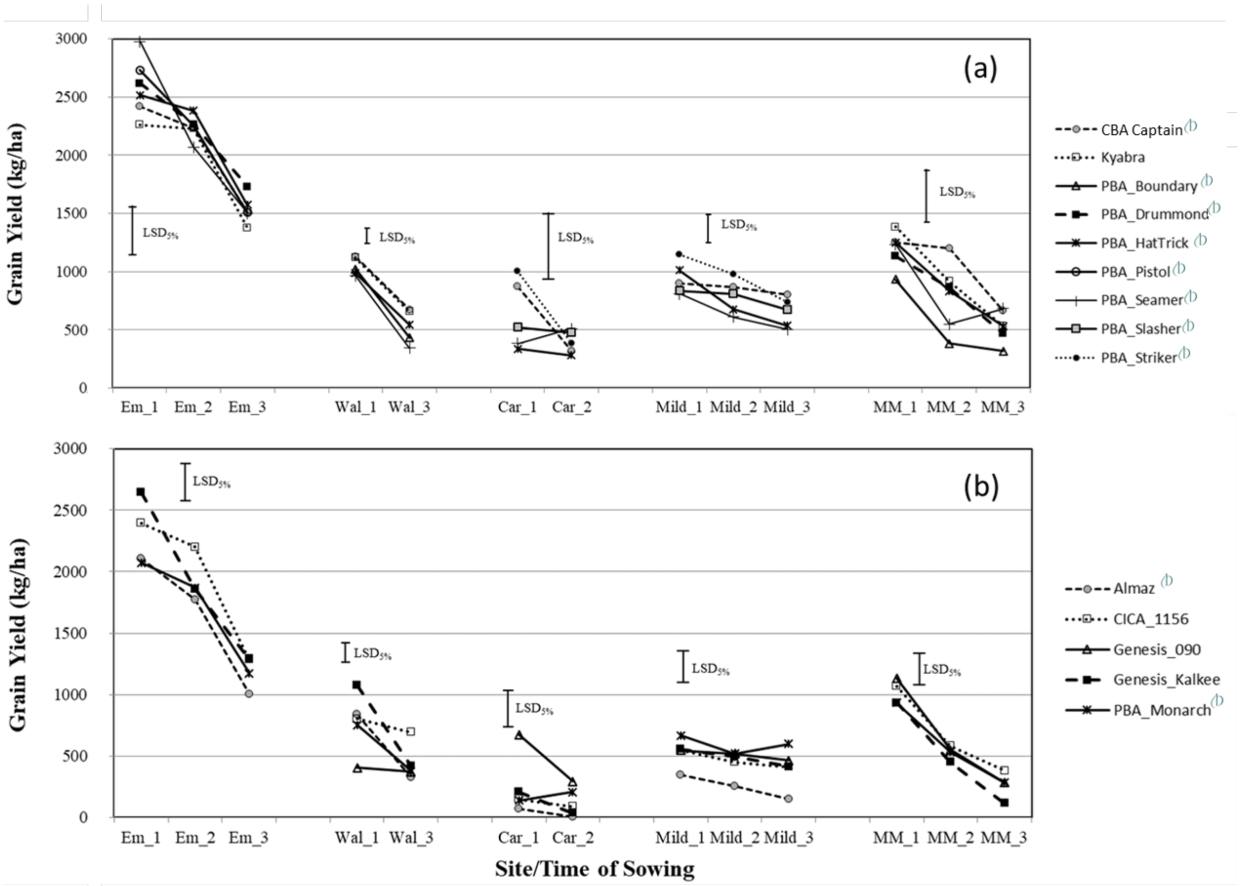

Figure 4. Grain yield vs time of sowing and location for (a) desi chickpea, and (b) kabuli chickpea from three sowing dates in five rainfed experiments in 2019. Sites and sowing dates were: Em = Emerald (10-May, 3-June, 27 June), Wal = Walgett (21-May, 28-Jun), Car = Caragabal (8-May, 17-Jun), Mild = Mildura (1-May, 18-May, 7-Jun), MM = Millmerran (17-Jun, 2-Jul, 15-Jul). Only two sowing dates were achieved at Caragabal due to low soil moisture and lack of rainfall during the sowing window. The second sowing date at Walgett for desi and kabuli chickpea were destroyed by wild pigs prior to emergence.

4. Variation of optimum flowering window, sowing date and potential yield across the northern region

Our ultimate aim was to use APSIM to show how flowering time (measured as the appearance of the first flower) varies with sowing date across the northern region. In addition, we linked this information with water-limited potential yield and an assessment of relative frost/heat risk, to help growers understand when they should be sowing chickpea to achieve maximum grain yield. The data is presented in a series of charts (Figure 5-10). Due to the number of locations we have simulated, data for each crop or subspecies is presented across two pages, with the more northern sites on the first page, and locations in central and southern NSW presented on the second page. Graphs for Emerald and Mildura are presented on a separate page as they have different optimum sowing periods to most other locations, with Dalby and Meandarra on the final page of graphs as a late addition for these updates in 2021.

For ease of presentation we have presented results for one cultivar for each chickpea type (i.e. PBA HatTrick⦶ for desi chickpeas and Almaz⦶ for kabuli chickpeas). If quicker/slower maturing cultivars are chosen by growers then sowing date should be adjusted to be slightly later or earlier. Local knowledge can be used in the interim to decide whether alternative cultivars will flower earlier or later than our simulated cultivars. It should be noted that the flowering benchmark used in this study is the appearance of the first flower on 50% of plants, which can occur much earlier than the date a crop is flowering prolifically and is not always easy to identify in the field.

Interpreting the potential yield graphs

Potential yield is 'water-limited': i.e. a simulated or predicted yield that uses the historical rainfall and available soil water, but assumes that frost, diseases, pests and nutritional disorders have not affected yield. As discussed above, the model does account for the effect of cool temperatures on flower pollination/abortion (e.g. Clarke and Siddique, 2004) by delaying the beginning of pod-set, so the emphasis herein is on the risk of intermittent frost events that may cause yield-limiting damage to floral structures and developing pods. In the following figures, the box and whisker plots have a small black line which indicates the median yield. The yield from 50% of years fall inside the box (i.e. yields from 10 years, with five years either side of the median yield), and the box whiskers represent 1.5 times the value of the adjacent quartile (i.e. between the median and the edge of the box), while grey dots represent outliers beyond this range.

Determining optimal sowing date

In the following figures, a shaded box is used to connect three-graph sets from the same location showing the predicted optimal time of flowering and pod initiation. The beginning of this 'optimum flowering window' is determined by assuming that the earliest flower needs to appear in the last fortnight when relative frost risk is still above 20% (i.e. approximately one day with a minimum temperature of 0°C in the week), as additional experiments suggest that the most sensitive growth stage to stress possibly falls 100 degree days later than the appearance of the first flower (Dreccer et al., 2020). The end of the optimum flowering window is the point when relative heat risk of 20% is avoided, or when 5 weeks have elapsed since the window opened. An arrow has been inserted in the week where average temperature increases above 15 degrees (and the risk of cool temperature flower abortion is reduced), to help demonstrate when pod-set is likely to begin. In the middle graph of each set it is possible to determine which sowing dates can be used to achieve the optimal flowering dates, by referring across to the y-axis. Potential yield data to the left of the optimum flowering window are at high risk of not being achieved due to frost risk.

Additional important notes

1. These simulations were conducted using an average sowing depth of 5cm. The effect of sowing depth on chickpea phenology may vary across the northern region, and further study is needed to determine how much earlier deep-sown crops should be sown to achieve the flowering dates presented here.
2. Frost risk varies markedly within short distances. Data in these figures may not apply to farms that are closely situated to the locations for which we have provided simulations, due to differences in elevation and aspect between met stations and individual fields.
3. Simulations have been prepared using 60-90 mm of stored soil water prior to sowing, depending on location (i.e. 60 mm south of Dubbo, 90 mm north of Dubbo). Water-limited potential yield will vary from what we have presented, if more or less water is available at sowing.

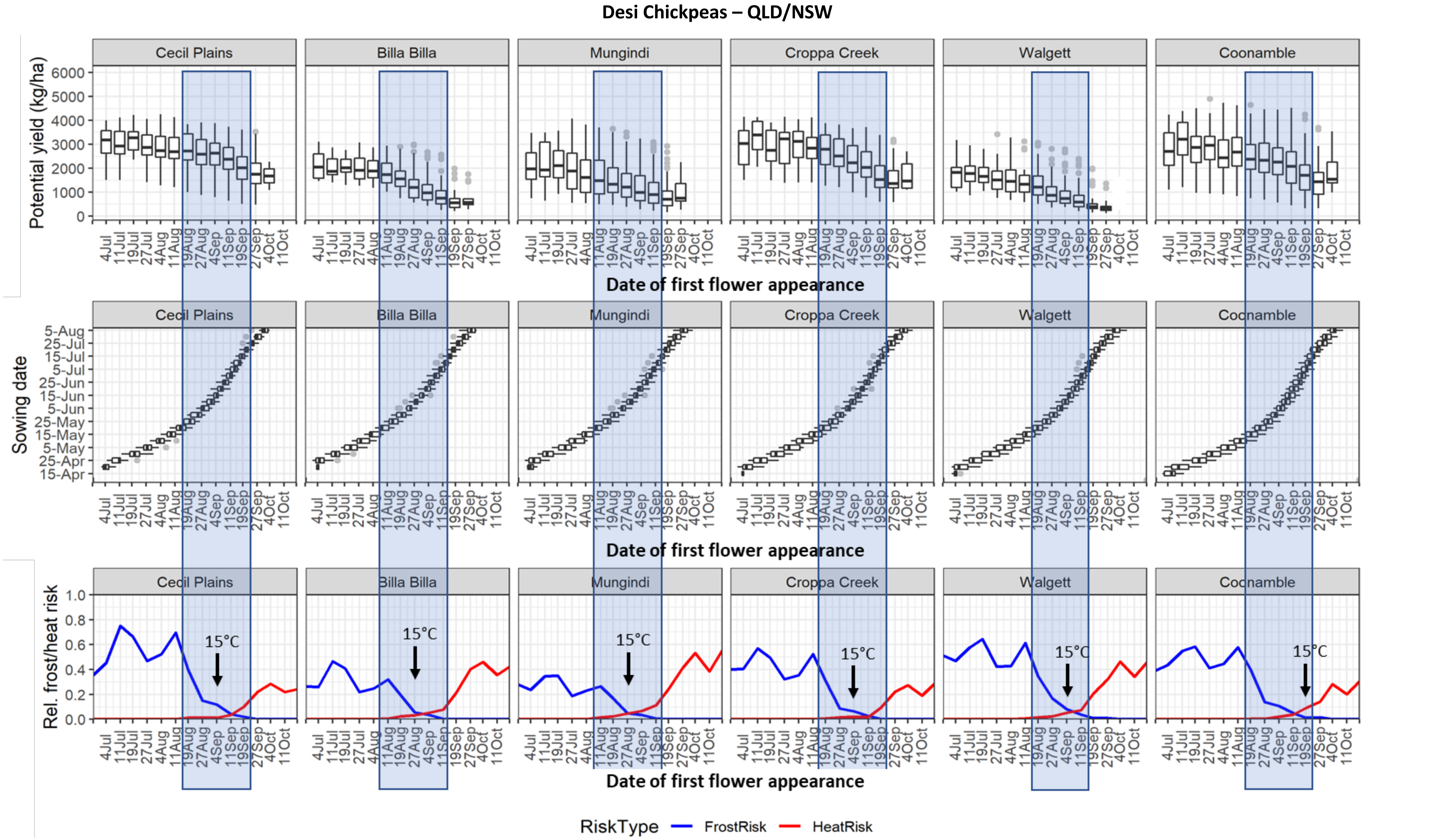

Figure 5. Water-limited potential yield, sowing date and relative frost/heat risk, plotted against the date of first flower appearance for PBA HatTrick⦶ at six environments in QLD and northern NSW. Shaded area represents the predicted optimum window for appearance of first flowers. Arrows and '15°C' mark the first week that has an average daily temperature ≥15°C in the second half of the year, i.e. when conditions become favourable for pod-set.

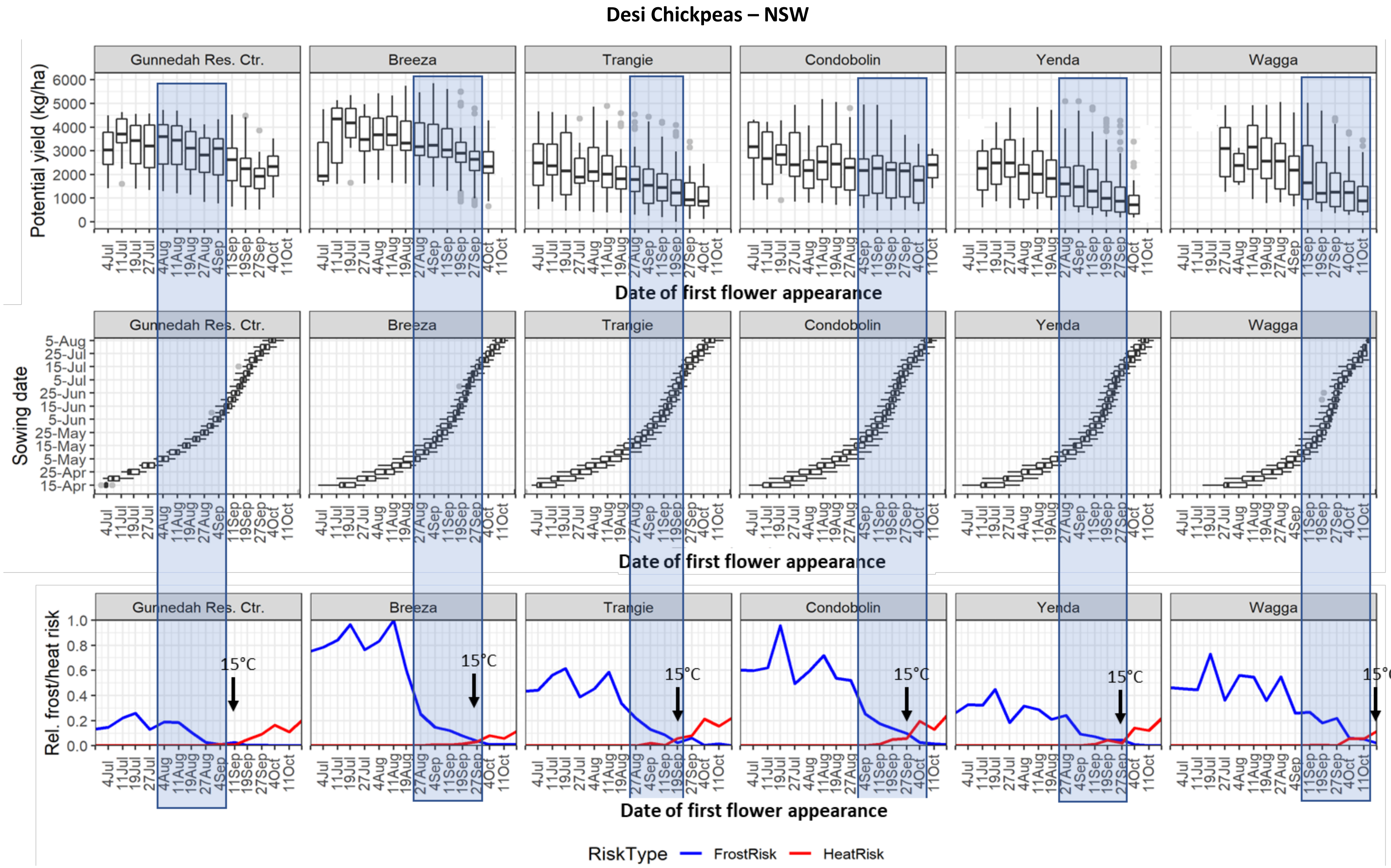

Figure 6. Water-limited potential yield, sowing date and relative frost/heat risk, plotted against the date of first flower appearance for PBA HatTrick⊕ at six environments in NSW. Shaded area represents the predicted optimum window for appearance of first flowers. Arrows and '15°C' mark the first week that has an average daily temperature ≥15°C in the second half of the year, i.e. when conditions become favourable for pod-set.

Kabuli Chickpeas – QLD/NSW

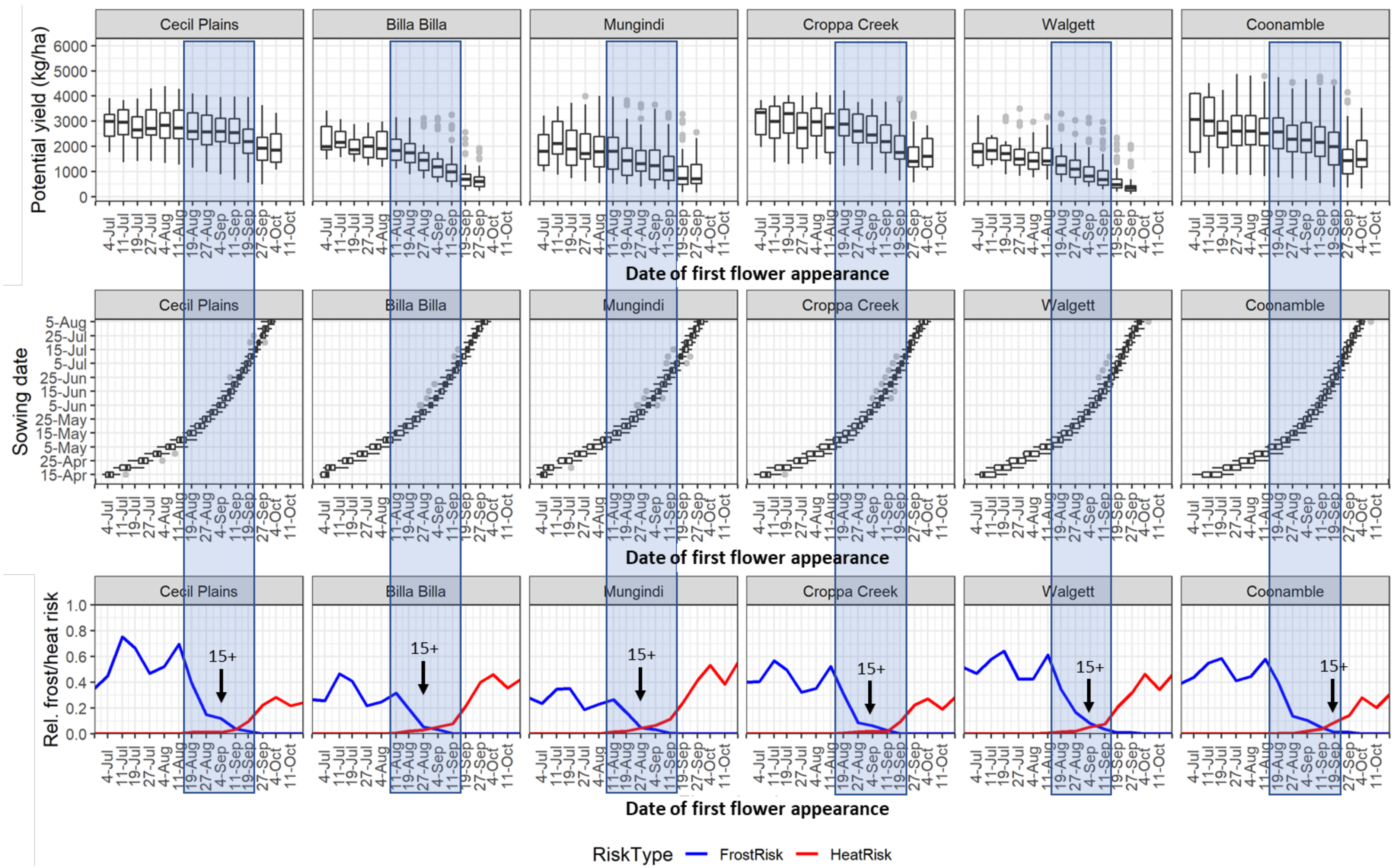

Figure 7. Water-limited potential yield, sowing date and relative frost/heat risk, plotted against the date of first flower appearance for Almaz⁽ᵇ⁾ at six environments in QLD and northern NSW. Shaded area represents the predicted optimum window for appearance of first flowers. Arrows and '15°C' mark the first week that has an average daily temperature ≥15°C in the second half of the year, i.e. when conditions become favourable for pod-set.

Kabuli Chickpeas – NSW

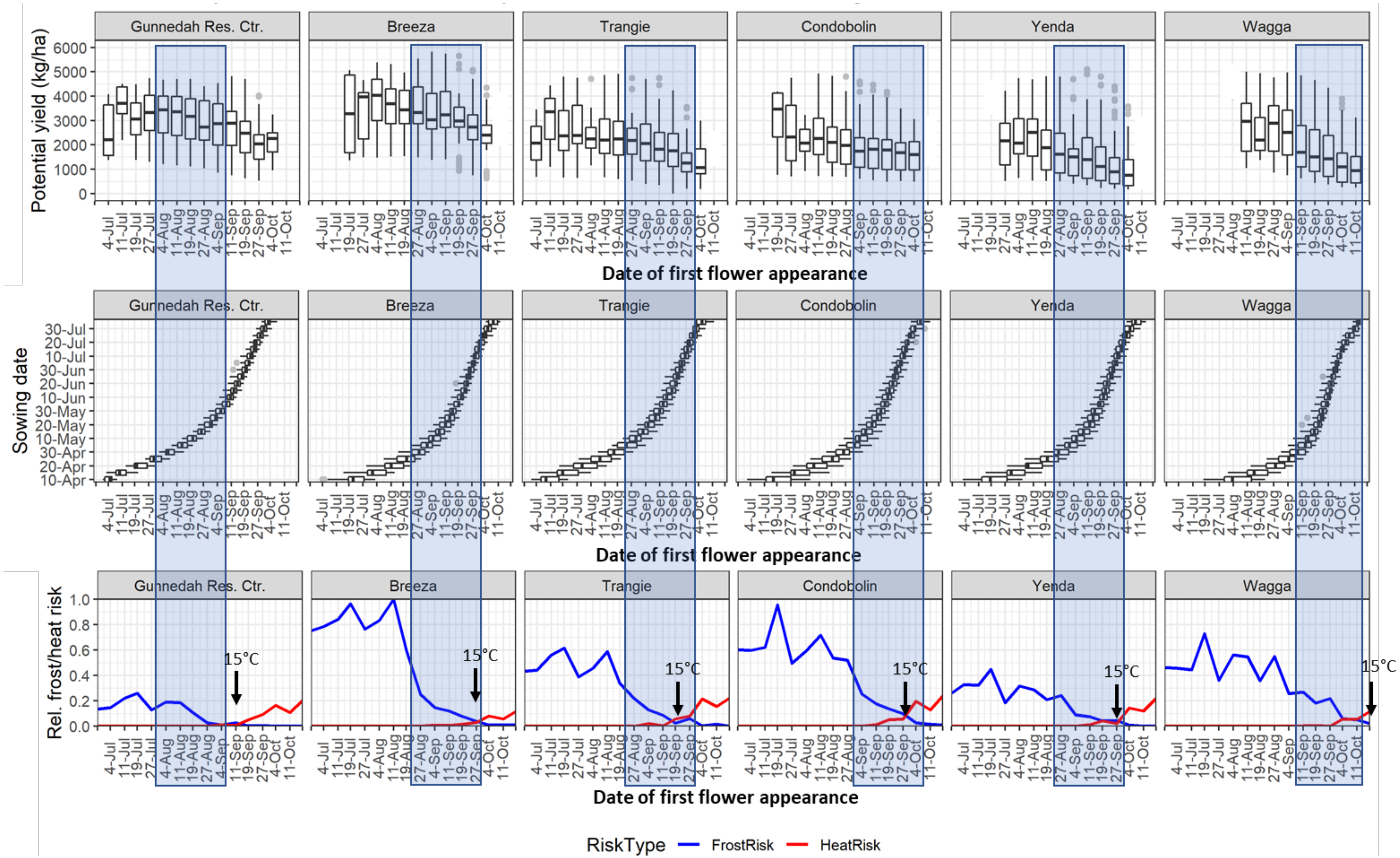

Figure 8. Water-limited potential yield, sowing date and relative frost/heat risk, plotted against the date of first flower appearance for Almaz⁽ᵇ⁾ at six environments in NSW. Shaded area represents the predicted optimum window for appearance of first flowers. Arrows and '15°C' mark the first week that has an average daily temperature ≥15°C in the second half of the year, i.e. when conditions become favourable for pod-set.

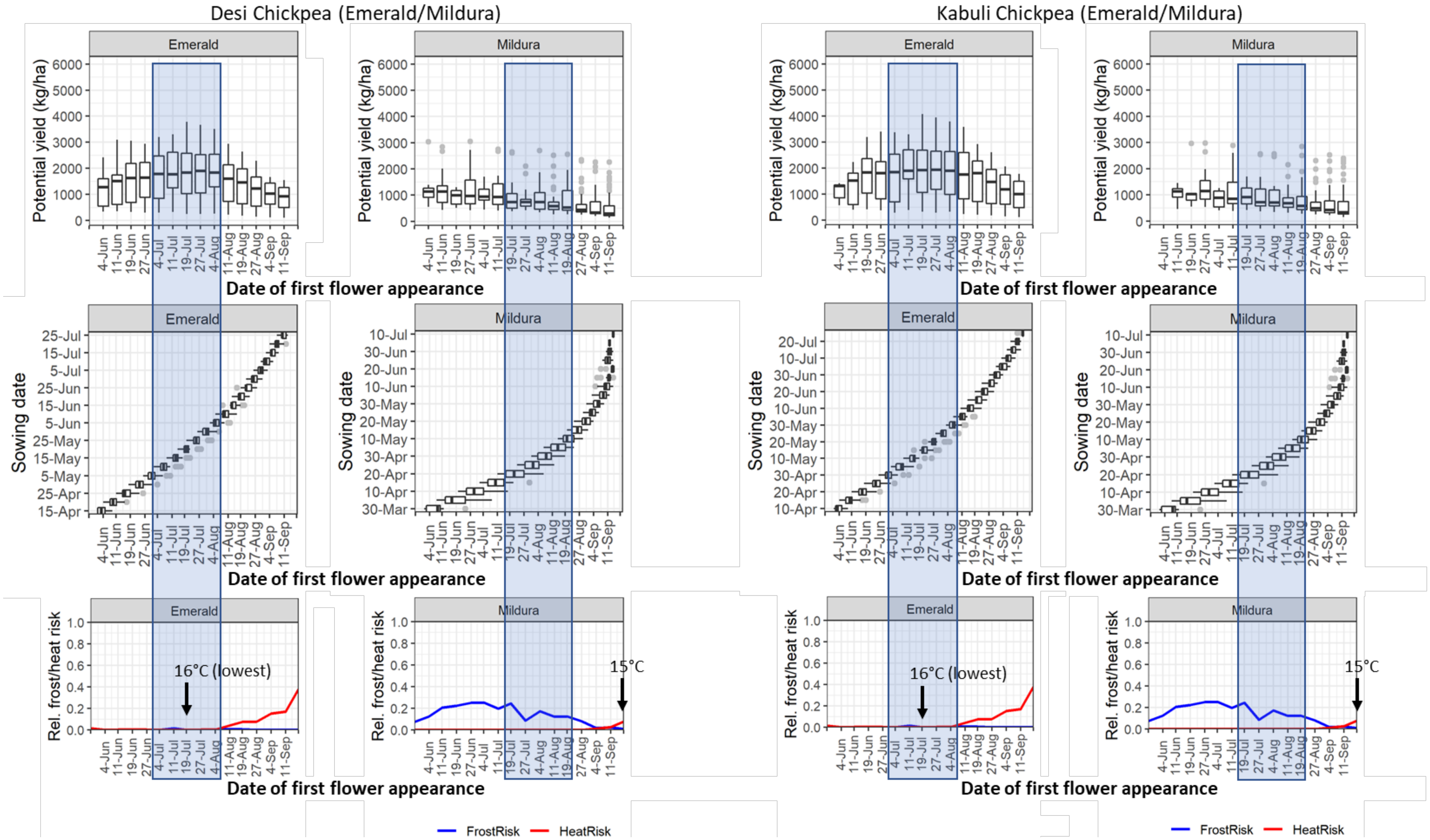

Figure 9. Water-limited potential yield, sowing date and relative frost/heat risk, plotted against the date of first flower appearance for PBA HatTrick⦶ and Almaz⦶ at Emerald and Mildura. Shaded area represents the predicted optimum window for appearance of first flowers. Arrows and '15°C' mark the first week that has an average daily temperature ≥15°C in the second half of the year, i.e. when conditions become favourable for pod-set.

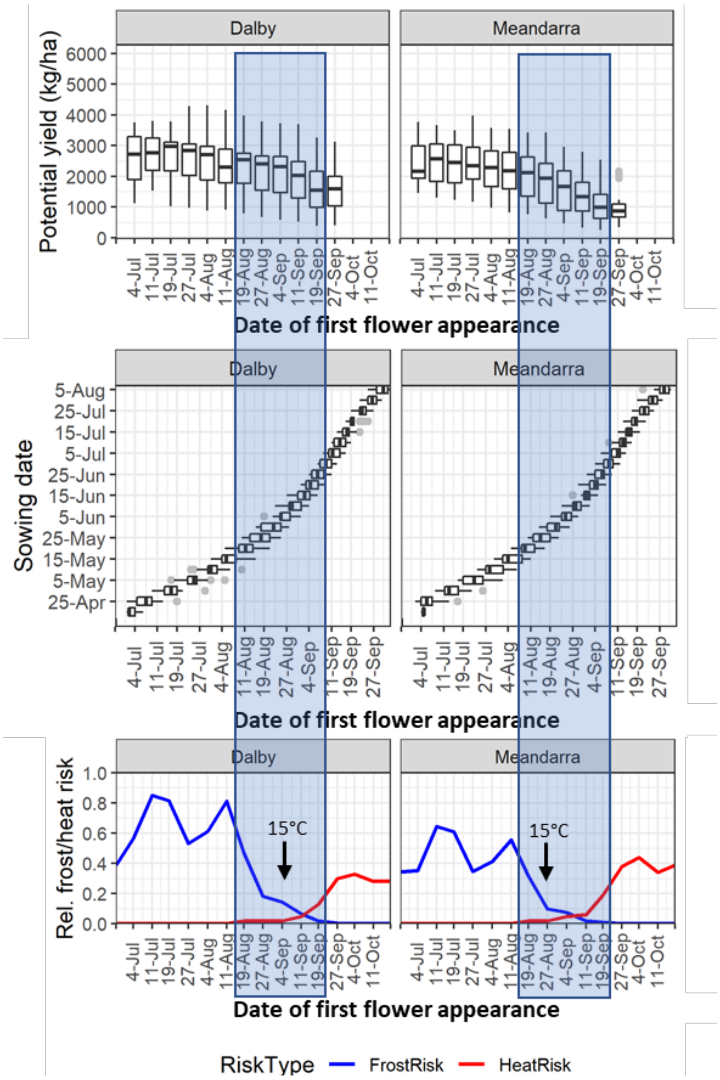

Figure 10. Water-limited potential yield, sowing date and relative frost/heat risk, plotted against the date of first flower appearance for PBA HatTrick⁽ᵇ⁾ at Dalby and Meandarra. Shaded area represents the predicted optimum window for appearance of first flowers. Arrows and '15°C' mark the first week that has an average daily temperature ≥15°C in the second half of the year, i.e. when conditions become favourable for pod-set.

Trends and observations

Water-limited potential yield declines rapidly in spring with later sown crops, particularly in the more northern environments.

Within the optimum flowering window, yield declined up to 300 kg/ha per week that first flower appearance was delayed in the most extreme situations (e.g. Cecil Plains, Billa Billa (Figure 5) and Meandarra (Figure 10)). Although the model showed a tendency to over-predict grain yield on early sowing dates in some environments (Figure 3), yield was lower for later sowing dates in the field trials (Figure 11), where grain yield declined at between 60 and 225 kg/ha per week that the first flower appearance was delayed, depending on location and time-of-sowing. While it can be difficult to determine if yield reductions are due to heat stress, water stress or simply the shorter growing season experienced by late sown crops, delayed flowering into warmer weather conditions reduced yield in the 2019 field trials and the simulations. However in wet seasons delayed sowing may not have the same yield penalty, so further research is necessary to investigate the relationship between time of sowing and yield across a range of locations and seasons.

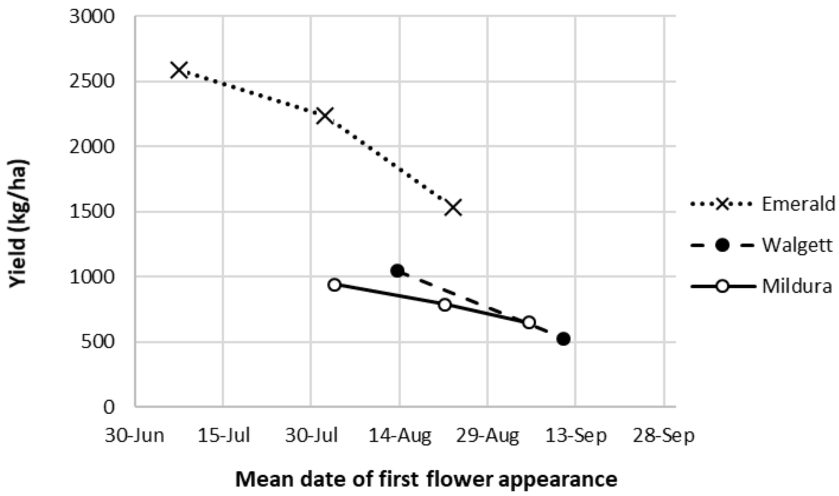

Figure 11. Mean grain yield vs mean date of first flower appearance across 5 desi chickpea varieties from three 'time-of-sowing' field experiments conducted in 2019. Markers (cross or circles) represent data generated from a single sowing date. The Caragabal and Millmerran experiments were not included due to uneven emergence that prevented accurate assessment of plot flower appearance.

It is unclear whether ultra-early sowing could provide even greater yield advantages in a dry season.

While most northern sites reached the 15°C threshold for pod-set 2-3 weeks after the beginning of the optimum flowering window, the more southern sites had a larger gap (e.g. 5 weeks at Wagga and 9 weeks at Mildura). While early sown crops may not set pods for many weeks after the first flower appears, the increased biomass development and/or root growth that occurs during this delay may be important for maximising grain yield in a dry season. While Richards et al. (2020) identified a yield penalty associated with ultra-early sowing in southern NSW, their results were obtained in different environments to those of southern QLD and northern NSW. Further research is recommended in both high and low frost-risk environments with a range of stored soil water to understand how long this infertile flowering phase can continue before significant yield loss occurs. This research would help define the optimum flowering window and sowing dates with more precision for a range of environments and seasons.

Frost risk varies over short distances within the landscape, so individual farms or paddocks may have different risk profiles (and optimum sowing dates) to those presented here.

Recent work by AMPs Research in wheat has shown that the top sections of some sloping paddocks on the Liverpool Plains can be sown 4-6 weeks earlier due to lower frost risk. Similarly, it is important to understand that the charts presented here may not be applicable to nearby farms or paddocks due to differences in local topography. For example, our first simulations for the Liverpool Plains used the Gunnedah Resource Centre meteorological station, but we later realised this data was not representative of most farms in the Gunnedah district. We then compared these simulations with the equivalent data from nearby Breeza (side-by-side comparison in Figure 6 or 8) showing a much greater frost risk at Breeza compared to the Resource Centre for the same dates in August. Growers should seek independent advice on frost risk for their individual locality and be careful about making large changes to their normal sowing dates based on data presented here.

Kabuli cultivars are generally slower maturing than desi cultivars.

Growers swapping between the two types for the first time need to be mindful of sowing Kabuli chickpeas earlier than desi chickpeas, to flower in the same optimal flowering window.

Extremely early and ultra-late sown crops have the lowest water-limited potential yield.

Some growers in southern NSW are experimenting with spring-sown chickpea to avoid the overly wet, winter growing conditions they encounter in good seasons. However, they may struggle to generate acceptable grain yield unless they are in a cool environment and/or have a genuinely full profile of moisture, and experience good spring rainfall. Further simulations could be conducted to investigate these possibilities.

Effect of deep sowing and water stress on optimum sowing date

As discussed above, the predictions of optimum sowing date in Figures 5-10 assume a sowing depth of 5cm. As chickpea is often sown deeper than this, it is possible growers may need to take this into account when deep sowing, by sowing earlier than the sowing dates presented here to achieve the same flowering date. However, experiments in Western Australia on sandy soils have shown negligible differences for emergence date and flowering date for an early-season chickpea experiment sown at 5 and 20 cm (Rich and Lawes, 2020). Additional anecdotal evidence suggests that while the delay may be small in a warm environment (e.g. Central QLD), it may be larger in cooler environments such as the Liverpool Plains. A rule of thumb used by some agronomists is to allow one days delay in emergence for every additional centimetre of sowing depth, however it is possible that deep sown seedlings may be accumulating ‘heat units’ toward their phenological development while underground, so delayed emergence may not lead to an equivalent delay in the appearance of the first flower. More research is necessary to determine the effect of sowing depth on emergence date and phenology processes across QLD and NSW pulse production regions. Growers and agronomists are advised to keep records on this information for individual fields, as it probably varies between soil types and location.

Additional experiments from 2019 also showed that flowering date sometimes occurred earlier in rainfed plots compared to irrigated plots, suggesting that water stress may hasten reproductive processes. The trend was not consistent across locations and cultivars, but in the most extreme case (Genesis 90 at Greenethorpe) flowering processes were 10-19 days earlier in rainfed treatments compared to irrigated treatments, while at Gatton no differences were detected in flowering date for any cultivar but podding date was 4-12 days earlier in rainfed treatments of both PBA HatTrick⦹ and Genesis 90. The degree of water stress was probably different between these locations, which would explain the variable results. Further work is needed to determine how different severity of water stress might impact on the occurrence of the optimal flowering window for specific situations and soil types. Wet conditions might reasonably be expected to delay flowering (and hence require earlier sowing to achieve the same flowering date) as has been observed in crops such as wheat. However, disease control may be more difficult in conjunction with early sowing in wet seasons, so optimum sowing date from a grower’s perspective may ultimately not differ greatly between wet and dry years.

Conclusions

The use of crop models in conjunction with field experiments has successfully transformed agronomic practices across Australia in the last three decades. The investment made in improving modelling capacity of chickpea through this project has increased confidence in the prediction of flowering date, potential yield, optimum flowering windows and the sowing dates needed to achieve them. We have also demonstrated the need for further research into cultivar response to early sowing, understanding the optimum length of the infertile flowering phase, and improving our understanding on the effect of water stress and sowing depth on phenology.

The process of investigating experiments using the models also provides direction for future research by highlighting the scientific ‘bottlenecks’ that improved prediction and understanding of crop performance. Additional research is needed across additional seasons to ensure that the predictions of crop performance apply to a range of seasonal conditions, not just the extreme drought conditions experienced during 2019. Model testing in additional environments and seasons will undoubtedly highlight further strategic research priorities that could be addressed to benefit Australian grain farmers into the future.

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 authors would like to thank them for their support. CSIRO, NSWDPI, SARDI, QDAF, USYD, UQ-QAAFI, The Australian Federal Government, QLD, NSW and SA State Governments are also acknowledged for directly and indirectly contributing to project funding. We would also like to thank Zvi Hochman and Heidi Horan (CSIRO), Richard McCallum, Mark Richards and Kirsty Hobson (NSWDPI), Helen Bramley and Josie Clarke (University of Sydney) for their contributions to the project that were not reported in this paper. We thank Paul McIntosh (Pulse Australia and the Australian Herbicide Resistance Initiative) for assisting with disease control protocols, and Neil Huth (CSIRO) for assisting with APSIM model development. We also acknowledge the incredible work carried out by the many technical staff from many organisations in successfully planning and conducting the extensive field trial program, which was instigated at short notice.

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Persistence and retention of weed seeds in the northern grain region of Australia: implications for management

Bhagirath Chauhan, The University of Queensland

Key words

harvest weed seed control, Queensland, seed bank, weed biology, weed ecology, weed management

GRDC code

UA00156

Take home messages

- Seed persistence (at the surface and 2 cm depth) and seed retention of nine weed species was evaluated
- Surface seeds of feathertop Rhodes grass (FTR) and windmill grass (WMG) persisted for <1 year while common sowthistle and Mexican poppy seeds persisted for <1.5 years. Bladder ketmia and sesbania pea seeds persisted for >3.5 years
- Burial increased seed persistence. Buried seeds of Mexican poppy, turnip weed, button grass, bladder ketmia and sesbania pea persisted for >3.5 years
- Turnip weed plants retained all seeds at wheat harvest, whereas common sowthistle dispersed 95% of seeds. Sesbania pea, FTR, and WMG all had greater than 80% seed retention at mungbean harvest, suggesting the most potential of using harvest weed seed control.

Background

Weeds are one of the most important biological constraints to grain production in Australia. In the northern grain region of Australia, weeds cause an annual revenue loss of $140 million, which includes yield loss in wheat, barley, oats, canola, pulses and sorghum, and yield loss from fallow weeds (Llewellyn et al. 2016). These losses can be reduced by adopting integrated weed management (IWM) programs. However, to develop effective and sustainable IWM programs, information on weed biology is a pre-requisite. For example, knowledge of weed seed bank persistence is critical for the development of IWM tactics for herbicide-resistant or difficult-to-control weeds. However, such information is not available for some major and emerging weed species, especially in the northern grain region.

Similarly, information on weed seed retention at crop harvest may be used to create the opportunity to use harvest weed seed control (HWSC) tactics and prevent the build-up of weed seed banks. However, such information is not available for most weed species in the northern region. In this paper, major findings of the ‘Emerging weeds’ project are discussed for seed persistence and seed retention of three winter weeds; common sowthistle (*Sonchus oleraceus*), Mexican poppy (*Argemone mexicana*), and turnip weed (*Rapistrum rugosum*) and six summer weeds; grass species: button grass (*Dactyloctenium radulans*), feathertop Rhodes grass (FTR; *Chloris virgata*), liverseed grass (LSG; *Urochloa panicoides*) and windmill grass (WMG; *Chloris truncata*); broadleaf species: bladder ketmia (*Hibiscus tridactylites*) and sesbania pea (*Sesbania cannabina*). Seed retention of winter weeds was assessed in a wheat crop and summer weeds in a mungbean crop.

Materials and methods

Seed collection

Seeds of common sowthistle, Mexican poppy and turnip weed were collected in October/November 2015 from wheat or chickpea fields. Seeds of bladder ketmia, button grass, FTR, LSG, sesbania pea and WMG were collected in March/April 2016 from sorghum, mungbean or summer fallow fields. Seeds of all species were collected from Dalby, Chinchilla or Gatton regions. Seeds were dried in a screenhouse for 2-3 days.

Seed persistence

Fifty seeds of each species were placed (within 7-10 days after collection) in nylon bags and the bags were buried at 2 cm depth or placed on the soil surface in a field at the Gatton campus of the University of Queensland. There were three replications of each treatment. The bags were exhumed at 3, 6, 12, 18, 24, 30, 36 and 42 months after seed placement in the field and seeds were examined in the laboratory for their germination characteristics (germination, dormancy and viability). In this paper, only the viability component (i.e., seed persistence) is presented. Rainfall for the first year after seed placement is shown in Figure 1.

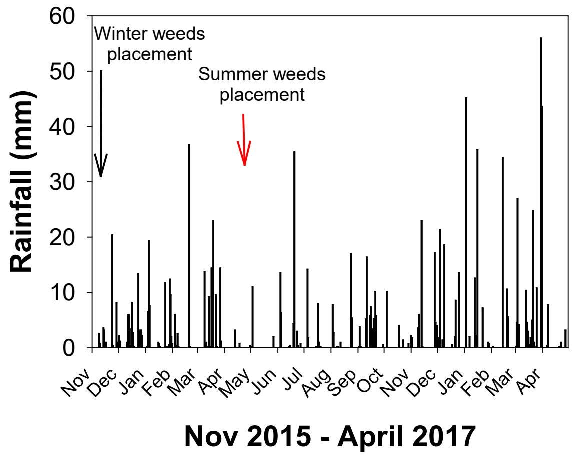

Figure 1. Rainfall (mm) at Gatton from November 2015 to April 2017. Winter weed seeds were placed in the field in November 2015 and summer weed seeds in April 2016.

Seed retention

Winter weeds (common sowthistle, Mexican poppy and turnip weed) were established in a wheat crop. The crop was planted in May 2016 and May 2017 at a seeding rate of 60 kg/ha in 18 cm row spacing using a tyne seeder. Plots were sprinkle irrigated four times on alternate days starting from seeding to ensure good crop and weed emergence. Seed traps (4 trays/plot) were placed in the field to determine the temporal pattern of seed shed in different weed species. Seeds collected in these traps were retrieved carefully from seed maturity until harvest at a weekly interval to quantify the rate of seed shed. For common sowthistle, seed dispersal was computed based on the numbers of flower heads that dispersed or remained on the plant at the time of harvest.

Summer weeds were established in a mungbean crop. The crop was planted in October 2016 and November 2017 at a seeding rate of 30 kg/ha in 50 cm rows using a tyne seeder. After planting, weed seeds were mixed with sand and broadcast. As mentioned above, plots were regularly watered to ensure good crop and weed establishment. The plots were regularly hand-weeded to remove all weeds except the target species. Seed traps, made of PVC pipes and lined with cloth at the bottom to hold seeds and to drain water, were randomly placed in the crop. Seed retention was computed based on the seeds collected in the traps at crop harvest. These results were also confirmed by visually observing the seed head/panicle/inflorescence.

There were three replications of each treatment in each year; however, data for only one year is shown as the response was similar across the two years.

Results and discussion

Seed persistence

Winter weeds

Common sowthistle seeds placed on the soil surface degraded rapidly, with less than 5% of seeds remaining after 12 months (Figure 2). At 18 months after seed placement, persistence of common sowthistle seeds was zero. Buried seeds took 2 years for complete seed depletion. Common sowthistle seeds have no to very low dormancy levels (Manalil et al. 2018), suggesting that most seeds will germinate after good rainfall events and result in the rapid depletion of the seed bank. Seed burial, by creating dark conditions, may enforce dormancy in some seeds, resulting in longer persistence for buried seeds compared with surface seeds.

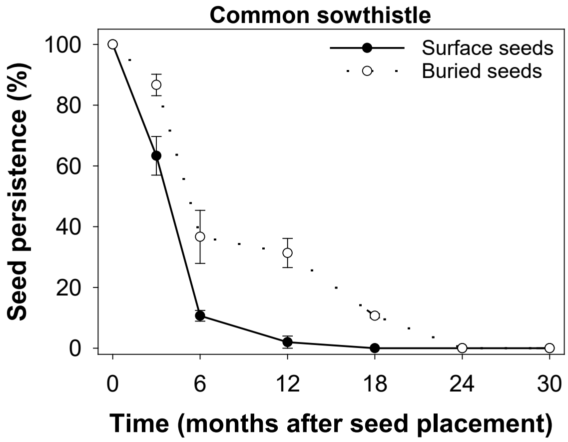

Figure 2. Persistence of common sowthistle seeds placed on the soil surface or buried at 2 cm.

Mexican poppy seeds placed on the soil surface depleted very rapidly, resulting in <10% viable seeds after 3 months (Figure 3). These results of the rapid depletion of the surface seeds were confirmed in another study (data not shown). No seeds remained viable on the soil surface at 18 months. In contrast, this species showed high persistence levels for buried seeds. At 42 months, up to 33% of buried seeds were still viable, suggesting that burial by tillage or planting operations will increase the persistence of Mexican poppy seeds.

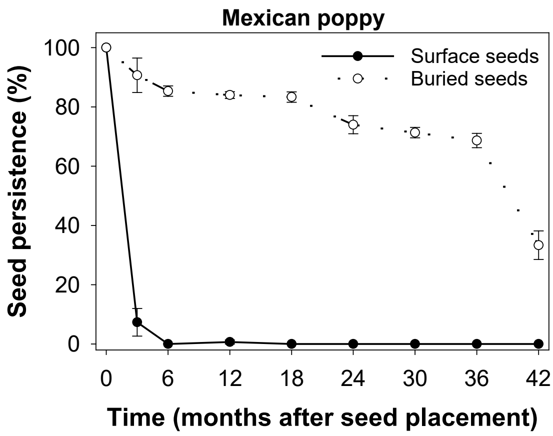

Figure 3. Persistence of Mexican poppy seeds placed on the soil surface or buried at 2 cm.

In 3 months, about 80% of turnip weed seeds placed on the soil surface were depleted (Figure 4). However, it took 30 months to deplete the rest of the seed bank. Seeds of this species are highly dormant, which is mainly due to the pod wall (Chauhan et al., 2006). Seeds on the soil surface experience high fluctuations in temperature and moisture conditions, which soften the pod wall and allow for high seed germination and depletion. Burial of seeds by any means will delay the decay of the pod wall, resulting in longer persistence of buried seed banks. About 8% of buried seeds of turnip weed were still viable at 42 months (last exhumation in this study).

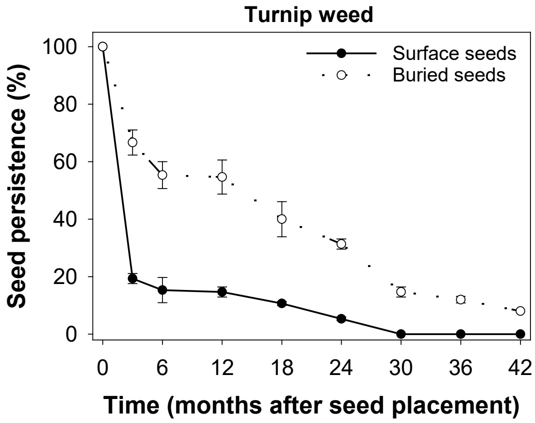

Figure 4. Persistence of turnip weed seeds placed on the soil surface or buried at 2 cm.

Summer weeds

Grass species: About 15% of button grass seeds remained viable on the soil surface at 12 months after placement on the soil surface and 5% remained at 24 months (Figure 5). It took 3 years to completely deplete the seed bank of button grass on the soil surface. Buried seeds persisted much longer; 9% of seeds were viable at 42 months. Physical scarification stimulates seed germination in button grass, suggesting that seed burial will delay the natural scarification process and result in longer persistence of button grass seeds.

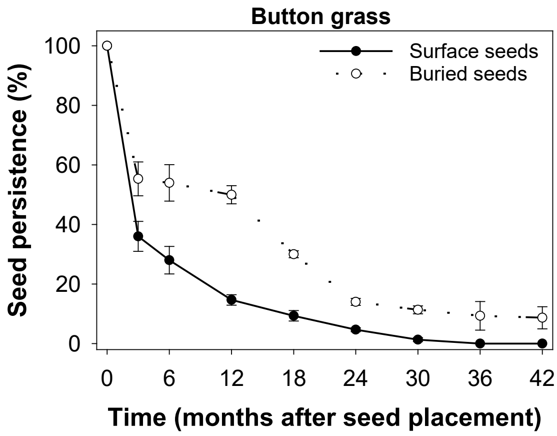

Figure 5. Persistence of button grass seeds placed on the soil surface or buried at 2 cm.

Feathertop Rhodes grass (FTR) seeds on the soil surface depleted very fast (Figure 6). Only 31% of seeds remained viable at 6 months and no surface seeds were found to be viable at 12 months. Buried seeds persisted slightly longer with 9% viable seeds at 12 months and no viable seeds at 18 months. FTR seeds have a moderate level of dormancy and can germinate at a wide range of temperatures ranging from 15/5 °C alternating day/night temperatures to 35/25 °C temperature regimes. Good rainfall events in the first 12 months might have resulted in the germination of most seeds (Figure 1).

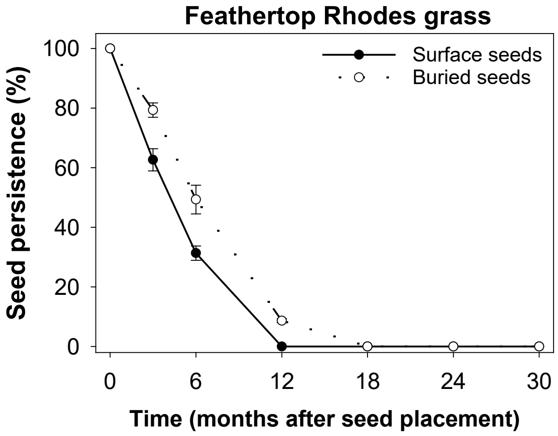

Figure 6. Persistence of feathertop Rhodes grass seeds placed on the soil surface or buried at 2 cm.

The depletion of the liverseed grass (LSG) seed bank on the soil surface was significant with 15% of seeds remaining at 12 months, less than 1% at 18 months and no viable seeds at 24 months after seed placement (Figure 7). Buried seeds persisted longer with 12% viable seeds at 24 months and 3% at 36 months. It took 3.5 years to completely exhaust the buried seed bank of LSG. In our lab studies, LSG was found to have a moderate level of seed dormancy. Fresh seeds had 40% germination, which increased to 90% after 4 months. These results suggest that most LSG seeds will germinate in the first years after shedding but some seeds may remain ungerminated in the soil for another two years.

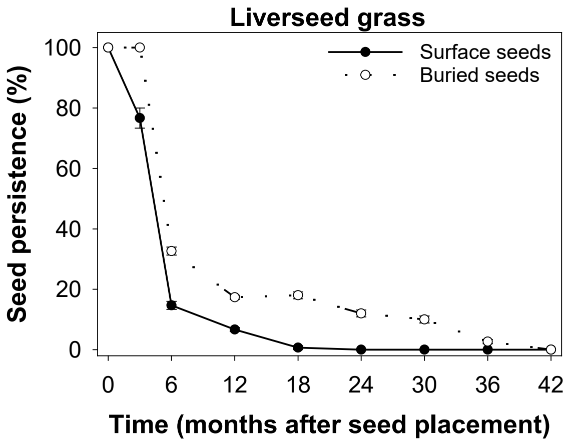

Figure 7. Persistence of liverseed grass seeds placed on the soil surface or buried at 2 cm.

Windmill grass (WMG), a closely related species of FTR, seeds behaved similarly to FTR on the soil surface. Total seed depletion was observed at 12 months after seed placement (Figure 8). Buried seeds of WMG persisted longer than FTR seeds. About 20% of buried seeds were viable at 12 months and 3% at 18 months but no seeds survived at 24 months.

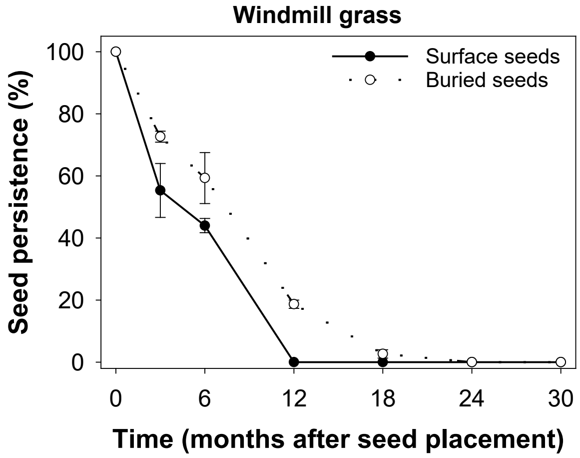

Figure 8. Persistence of windmill grass seeds placed on the soil surface or buried at 2 cm.

Broadleaf species: Among all the studied species, bladder ketmia had the greatest level of seed bank persistence. About 3% of the seeds were still viable at 42 months after placement on the soil surface (Figure 9). At the same time, 63% of seeds were viable at 2 cm depth. The time required to lose half of the life of buried bladder ketmia seeds could not be established in this study. Elsewhere, about 25% of bladder ketmia seeds survived after 7 years of burial (Uremis and Uygur, 2005; Westre et al., 1996). This species has hard-seeded or physical dormancy (Chauhan, 2016), suggesting that seed depletion will be quicker for seeds present on the soil surface than when buried in the soil.

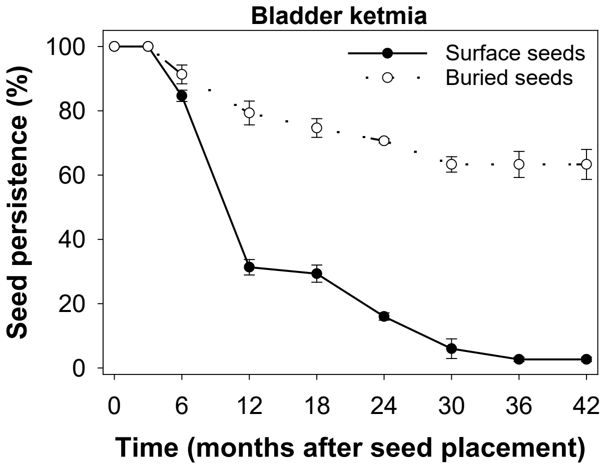

Figure 9. Persistence of bladder ketmia seeds placed on the soil surface or buried at 2 cm.

Sesbania pea behaved similarly to bladder ketmia as both species are known to have physical seed dormancy (Iqbal et al., 2019). However, the seed bank persistence level of sesbania pea was lower than bladder ketmia. About 1% of surface seeds and 8% of buried seeds were viable at 42 months after seed placement (Figure 10).

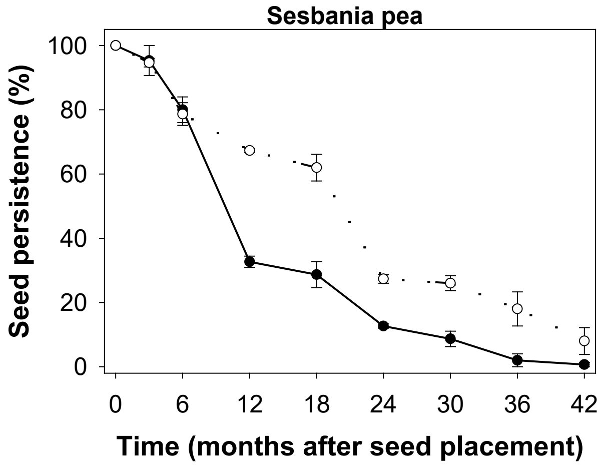

Figure 10. Persistence of seasbania pea seeds placed on the soil surface or buried at 2 cm.

All nine weed species were arranged in ascending order in terms of time required to complete depletion of their seed banks (Figure 11). FTR and WMG surface seeds took the shortest time (12 months) for complete depletion. Common sowthistle and Mexican poppy took 18 months for 100% seed depletion on the soil surface. Surface seeds of bladder ketmia and sesbania pea, both hard-seeded species, were still viable on the soil surface at 42 months, suggesting that these seeds will keep germinating in no-till farming systems beyond 3 years of their shedding. Buried seeds of all weed species persisted longer than surface seeds. This is not a surprising result as buried seeds have reduced risks from seed predators and fatal-germination factors such as high fluctuations in temperature and moisture conditions.

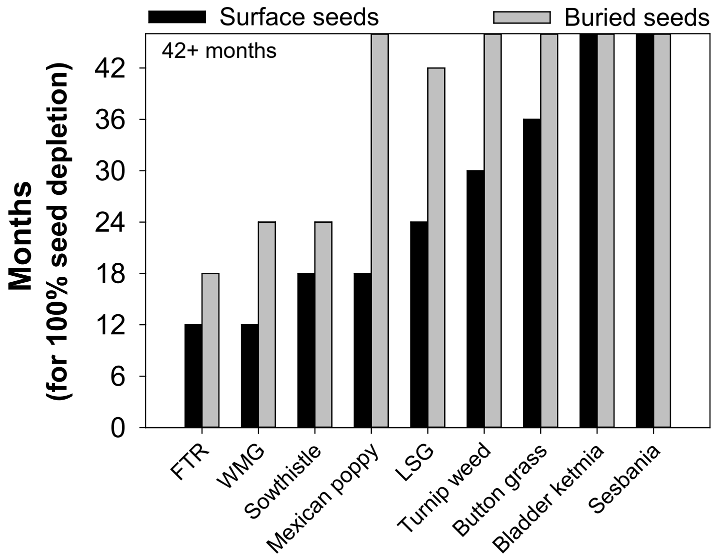

Figure 11. Number of months required to deplete complete seed banks of different weed species. Seeds were placed on the soil surface or buried at 2 cm soil depth. 42+ means more than 42 months.

Seed retention

Winter weeds in wheat

Common sowthistle produced a maximum of 193,000 seeds/m² but 95% of these seeds had dispersed at wheat crop harvest (Figure 12). In contrast, 100% of seeds were retained for turnip weed, which produced 32,000 seeds/m². These results suggest that turnip weed exhibits high seed retention at wheat harvest and employing HWSC practices is likely to reduce its seed bank in the soil

(Manalil and Chauhan, 2019). The author observed that turnip weed in a poorly-established crop in the northern grain region can grow more than 4-5 cm in stem diameter which may impede harvest and HWSC suitability. Therefore, in such situations, seed sterilising practices may need to be used.

Seed-capturing practices may not have desired results for common sowthistle in wheat. As common sowthistle matured much earlier than the wheat crop, most seeds had dispersed before crop harvest (Manalil et al., 2020a). These results suggest that a higher level of seeds of this weed species could be captured in a shorter duration crop or variety. Common sowthistle seeds could also be captured from late-emerging weed seedlings.

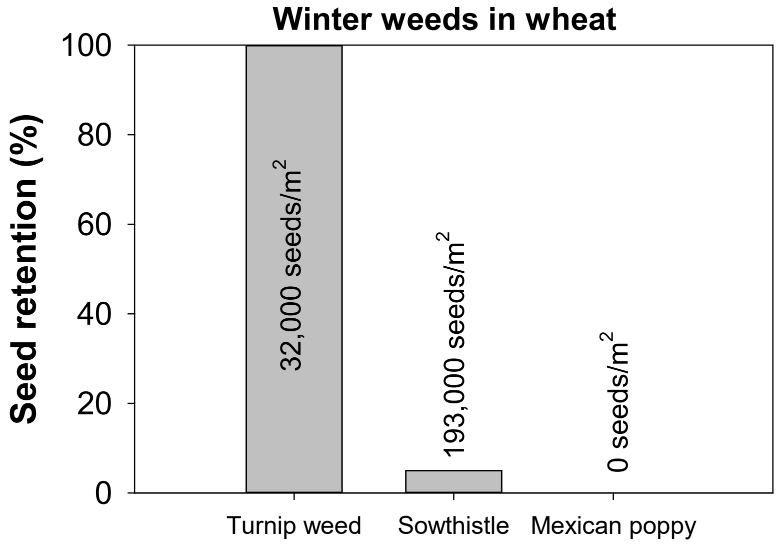

Figure 12. Seed retention (>15 cm from the surface) of winter weeds in a wheat crop. Maximum seed production (seeds/m^2) by these species is also given as text.

Mexican poppy emerged was severely impacted through competition from the 18 cm row wheat crop (Manalil and Chauhan, 2019). These weed plants reduced wheat yield by 20% but did not produce a single seed, suggesting the weed-suppressive benefits of narrow-row planted crops. However growers have observed Mexican poppy seed production in wider row winter cereals, chickpea and winter fallow fields.

Summer weeds in mungbean

Among the broadleaf weed species, sesbania pea retained 100% of seeds at mungbean harvest and bladder ketmia retained 60% of seeds (Figure 13). Among the grasses FTR, WMG, LSG and button grass retained about 95, 85, 75 and 70% of seeds at mungbean harvest. Weeds, such as button grass and FTR, produced more than 100,000 seeds/m^2, but seed retention of at least 60% suggests opportunities for HWSC. Similar results may not be possible in a longer-duration summer crop, for example, sorghum. In a previous study, only 60% of FTR seeds were retained at sorghum crop harvest (Mahajan et al., 2020).

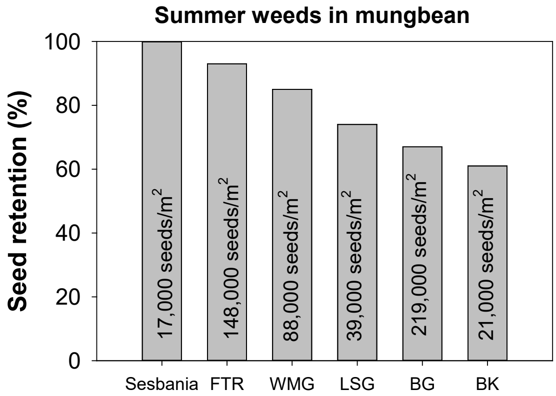

Figure 13. Seed retention of summer weeds in a mungbean crop. Maximum seed production (seeds/m^2) by these species is also given.

Turnip weed, button grass, bladder ketmia and sesbania pea produced a significant number of seeds (Figures 12 and 13), which were found to persist longer than 3.5 years (Figure 11). These characteristics enhance the adaptive potential of such weed species to become problematic and hard-to-control weeds. However, high seed retention and differential maturity periods between crops and weeds provide an opportunity for controlling such weed species through HSWC practices. Crop topping and desiccants may also be possible options in some crops.

FTR is becoming an increasing problem in the northern grain region of Australia. In these trials, it produced almost 150,000 seeds/m^2 in mungbean; however, its seeds persisted only for a year on the soil surface and 1.5 years in the soil (2 cm depth). These results suggest that prevention of seed set can rapidly deplete seed banks of FTR, and similar weed species. The most effective management of such weeds is to prevent seed set and drive down the existing seed bank through intensive management.

Conclusion

Weed seed bank persistence was variable between species and depths. Seeds persistence ranged from less than 12 months (for example, FTR and WMG) to more than 42 months (for example, turnip weed, Mexican poppy and button grass). Therefore, IWM programs need to consider the variation between weed species. Burial increased seed bank persistence of all nine weed species, suggesting that sowing operations or soil cracks may increase their persistence even in no-till farming systems.

Future research needs to evaluate the seed bank persistence of different weed species in different rainfall regions, soil conditions and crop residue situations. For example, some weeds in southern Australia were found to persist longer in a drier year compared with a wetter year.

With the exception of Mexican poppy in a highly competitive wheat crop in this trial, all the other eight weed species produced a considerable number of seeds and some with very high dormancy levels (e.g., bladder ketmia and sesbania pea). However, except for common sowthistle, all other weed species retained at least 60% of seeds at crop maturity. There is the potential for seed-sterilising and seed-capturing technologies which can reduce further seed input to the soil seed bank. It should be noted that no herbicide weed control was used in this study. Later weed germinations, which often are not controlled by herbicides, may have higher seed retention at harvest. Therefore, there is a need to evaluate seed retention of these weed species in combination with different weed control practices. Similarly, crop planting time and crop row spacing may also affect seed retention by affecting the competitive ability of the crop. Seed retention can also be influenced by weed seedling emergence time through affecting weed phenology, including weed height. Before HWSC practices become a necessary component in the northern region, there is a need to evaluate seed retention affected by the above-said factors.

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The importance and process of optimising grain aeration systems

Alex Conway, Control Unlimited

Key words

silo aeration systems, grain aeration, aeration controllers, optimising grain storage, aeration fans

Take home messages

- Increasing the number of grain aeration fans doesn't always increase airflow in grain storage facilities
- Grain storage aeration systems should be set up to achieve airflow rates of 2 to 4 litres of air, per second, per tonne of grain (L/s/t) for cooling or 15 to 25 L/s/t for drying
- Grain temperatures under 23°C during summer storage and less than 15°C during winter are best to maintain grain quality and manage insect and pathogen incursion.
- Grain type, grain bed depth and moisture content are key considerations when aerating stored grain
- There are four key hardware components to optimise aeration performance in grain storage facilities: these include fans, vents, ducting and an aeration controller
- Its best to perform monthly checks to ensure aeration systems are operating effectively.

Control Unlimited is a company that manufactures automatic aeration controllers for fans used in grain storage facilities. Our company regularly undertakes research to characterise storage facility aeration systems. The aim of this research is to better understand how to optimise the process of cooling or drying grain. Recent research has identified that adding more fans to a silo can decrease the total airflow if fan performance limits are reached. The findings prompted the need to review aeration systems to ensuring all components are matched appropriately to the task.

Fundamental targets

Appropriate airflow rates

Airflow rates measured in grain storage are most typically referred to in litres of airflow, per second, per ton of grain (L/s/t). Targeting the correct airflow rate is extremely important as without sufficient airflow the grain becomes increasingly susceptible to mould development and insect infestation. Measuring aeration fan airflow is not difficult and can be undertaken using the GRDC Grain Storage Fact Sheet 'Performance testing aeration systems.' The optimal airflow rates for both long-term grain maintenance (e.g. cooling airflow rates) and ambient air grain drying (e.g. drying airflow rates) are as follows:

- Cooling airflow rate: 2 - 4 L/s/t
- Drying airflow rate: 15 - 25 L/s/t

Safe temperatures

Regular monitoring of grain temperatures is integral to ensuring seed stored for planting purposes maintains acceptable seed viability. Cool storage conditions also minimise the risk of mould and insect damage. This is most easily monitored using a grain temperature probe and should be checked monthly when checking for insect pests in stored grain. Grain storage aeration systems should target temperatures of:

- Summer: 18-23°C
- Winter: less than 15°C

Key considerations

With the fundamental targets of air flow rate and target temperature in mind, there are a number of additional factors that need to be considered when evaluating an aeration system and how it is intended to be used:

Grain type

The type of grain being stored can cause variation in airflow rates. Larger grains such as chickpeas and mung beans enable higher airflow rates due to the large air spaces between grain. However, small grains such as canola provide far greater resistance to air movement which results in higher back pressures being applied to fans and results in lower airflow rates though grain. Grain type needs to be considered when purchasing or setting up grain storage facilities.

Grain bed depth

The height to which a silo is loaded also has a profound impact on the performance of aeration systems. A fully loaded silo 10 metres tall will require considerably more airflow to counter the extra back pressure on fans when compared to loading it half-full to a bed depth of 5 metres.

Moisture content of grain

Operation of aeration equipment requires a different approach depending on the moisture content of the grain stored. For example, the temporary storage of high moisture grain has a greater susceptibility to self-heat, so requires effective air distribution and longer fan run times each day than grain stored at receivable moisture (e.g. 12.5%).

Hardware for optimised aeration systems

In order to achieve the optimal airflows and grain temperatures there are four major hardware components that allow this to be attained. They are aeration fans, ducting, silo vents and an automatic aeration controller.

Aeration fans

The size and number of fans on a silo is integral to achieving a desired airflow and must be done with the silo size and fan performance curves in mind. This should be achieved in consultation with a silo manufacturer or grain aeration specialist if required. When considering if additional fans should be added to a storage it is important to note that this will increase the static backpressure, so each extra fan will contribute less to total airflow. When configured correctly, added fans will still supply as much additional airflow as possible (Figure 1). However, if backpressure created by additional airflow exceeds the performance of the fans, the total airflow through the grain is undesirably reduced (Figure 2). Fitting extra fans without checking air flow and back pressure can be a waste of both equipment and electricity. Seeking professional advice is critical to ensure the number of fans and their design performance are matched with the storage and aeration system.

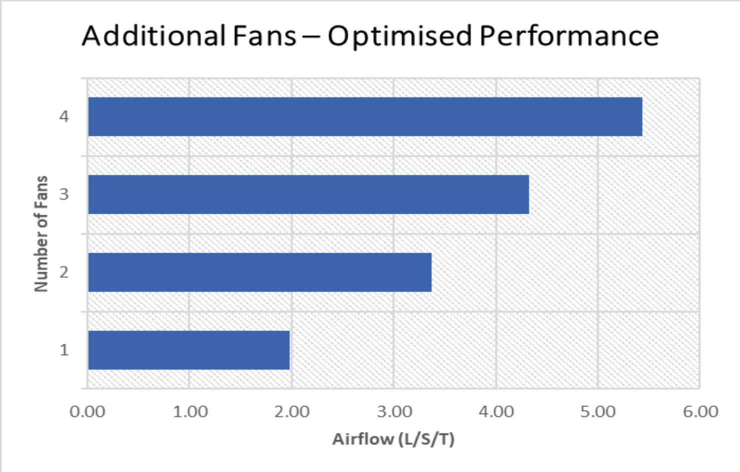

Figure 1. An optimised aeration fan configuration

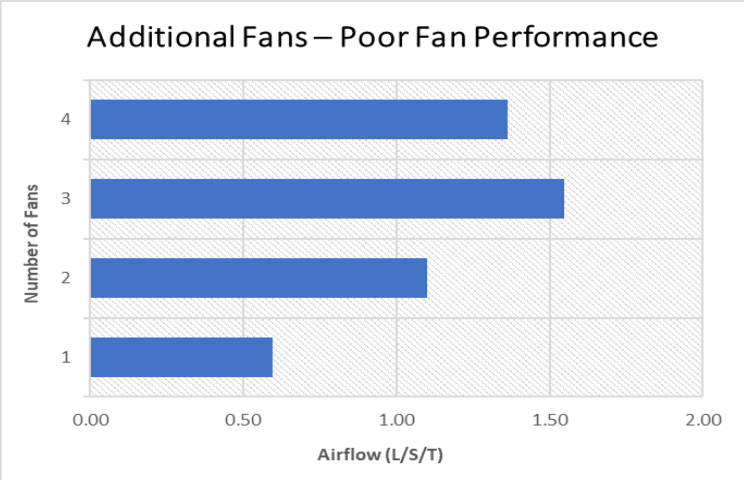

Figure 2. Poorly sized aeration fan configuration

Ducting

Ducting comes in various shapes and configurations; however, this is typically not as important as their length and placement in the silo. Ducting should be as long as possible and evenly placed between the wall and tip of the cone. Sufficient distance should be observed so that air can't easily escape up the wall (approximately 300 mm from wall) and far enough away from the bottom slide that the ducting doesn't interfere with silo unloading.

Silo vents

Vents are the best way to ensure maximised performance of the fans by releasing any excess pressure in a silo. This simply ensures that air is not trapped and pressurising the headspace of the silo. To avoid pressurising the headspace the typical rule of thumb is for every 500 L/s of airflow, a 0.9 m^2 vent area is required. The best way to test this is by measuring airflow with all vents open, and then perform another test with both vents, roof manhole and silo top fill hole open to see if any additional airflow is achieved. If the airflow rate increases after this second test it, indicates that the storage requires additional ventilation. For any smaller storages under approximately 100 tonnes, opening the top fill hole, or using a tin hat with mesh sides on the fill hole is generally sufficient ventilation.

Automated aeration controller

An important component of an aeration system is an automated aeration controller. This piece of equipment will accurately and reliably select the best air to introduce into the storage to keep grain temperatures as low as possible for maintenance of long term grain quality. However, not all aeration controllers are the same, there are several different theories of operation to be aware of:

- Set-point: The temperature and humidity set points are manually selected for when the fan will run.
- Automatic
    - Time proportioning controller (TPC): Fans are controlled in accordance with an algorithm that targets the best air available for the aeration mode that is selected.
    - Adaptive discounting controller (ADC): Controls fans based on a modelled cooling process given an array of information including grain condition, stack size and aeration system, manually entered by the operator.

The most common form of aeration controller is TPC so the focus of this paper will be directed towards this controller type. These systems vary between manufacturers, but controllers can typically manage up to 24 silos with the one system and have functions to automatically start and stop generators when they are required at remote sites. They work using a three stage cooling process. This is further represented in Figure 3.

- **Continuous**: runs the fans constantly unless the humidity setpoint is reached (typically 85% RH), to ensure that fans are not running through rain events or heavy dew mornings. This function should be used for the first 5 days (120 hours total) after grain has been placed in a silo to provide maximum fan run time to remove harvest heat from the grain and even out the moisture content throughout the storage.

- **Purge or rapid:** This function is used for the next 7 days of the storage period. Fans run approximately 12 hrs each day (84 hours total). The fans will typically be run during the night when the temperature is at its coolest to continue bringing down the grain temperature. It still incorporates a humidity override function (i.e. will not run if the humidity setpoint is reached).

- **Protect or maintenance:** Used for long-term grain maintenance where fans run for approximately 100 hours per month. This mode endeavours to select the coolest air available to introduce into the silo to keep the storage temperature as cool as possible. Most TPC controllers have an algorithm that allows them to adapt to local conditions, meaning that if a heat wave passes through, the fan will not run during this warmer period until more normal temperature conditions return (refer to figure 3 from 14/12/20 – 23/12/20).

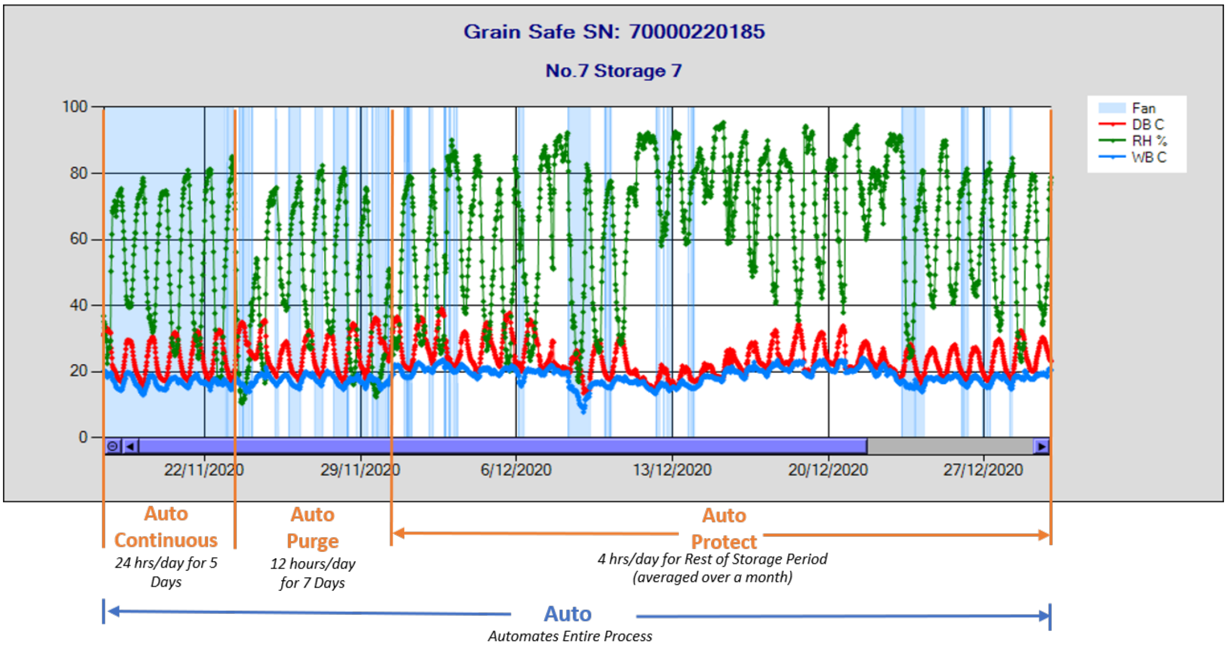

Figure 3. Aeration controller modes

Economics

The investment in aeration systems scales better as the volume of grain being stored increases. For an example, 8 elevated silos with a capacity of 180 tonnes each, storing grain valued at $270/t equates to $388,800 worth of grain.

Using this example, aeration fans will cost 0.2% of the value of grain over a 10-year period. A further 0.1% will be required for all ducting, 0.17% to cover vents, 0.12% for an automated aeration controller and another 0.2% for an aeration control cabinet. The cost of all the equipment to optimise a new aeration system for this example would be less than 1% of the value of grain it protects, over 10 years. The running costs of the fan then depend on variables such as the system, time in storage and energy costs. Estimated running costs per tonne include 35 cents for the first month then 15 cents per month of storage thereafter.

Monitoring

Grain in storage requires regular and consistent monitoring, just as a crop does throughout the growing season. This allows any problems or equipment faults to be detected early before any significant damage can occur to the grain. A monitoring schedule performed monthly should involve:

- Fan testing: a well-equipped aeration controller will typically provide a 'test' function that allows the operator to temporarily test each aeration fan for any faults
- Temperature testing to ensure the grain mass is within the target range for the time of year
- Monitor grain moisture to ensure it is remaining consistent
- Check for pests in traps and sieve grain.

The industry is also moving toward remote grain monitoring where live temperature and moisture readings can be viewed on a smart phone or computer. This technology is still adapting into a format suitable for Australian conditions and is something to keep in mind to improve monitoring efficiency and become aware of any issues as soon as they develop.

Conclusion

In summary, aeration systems should be targeting airflows of 2 to 4 L/s/t for cooling and 15 to 25 L/s/t for drying. Grain temperatures in summer should aim for between 18 and 23 degrees Celsius, and below 15 degrees in winter. The influence of grain type, grain bed depth and moisture content need to be understood and managed. Ensure the four major components of an aeration system: fans, ducting, venting and an aeration controller, are set up correctly in consultation with a silo manufacturer or aeration specialist. The investment in quality on-farm storage with aeration can be maximised by regular monitoring of the system over its lifespan.

Declaration

The author work for Control Unlimited which manufactures automatic aeration controls for grain storage facilities.

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Storage pests - clever ways to control them

Philip Burrill and Greg Daglish, DAF Qld

Key words

grain storage pests, storage insect life cycle, storage pest movement, field ecology, non-chemical controls, grain storage pest control

GRDC codes

CRCNPB50089, CRCNPB50149 and PBCRC3039

Take home messages

- Stored grain insect pests are not limited to farm storages, and can be caught flying across the wider rural landscape
- Flights can occur year-round in Queensland, with lower numbers in the cooler months
- Major pests can fly at least 1-2 km searching for grain
- Although small, grain beetles can live and reproduce for several months
- Finding 5 adult beetles in 1 litre of sieved grain means there could as many as 450 pests in that 1 litre. We simply cannot see the egg, larval or pupal life cycle stages easily
- Reducing grain temperatures in storage can slow down, or completely stop, the insect pest life cycle. Aeration cooling should aim to achieve grain storage temperatures of 18-23˚C during summer months and under 15˚C in winter.

Learning more about your enemy

For controlling agricultural pests, the more we understand their ecology, including life cycles and what conditions enable them to multiply and thrive, the better able we are to identify their weaknesses. Recent research, much of it in collaboration with the University of Queensland, has provided new insights into the ecology of insect pests of stored grain. This research information enables the development of an effective 'package of control measures' often referred to as an integrated pest management (IPM) strategy.

By using a combination of non-chemical and chemical control measures we can minimise storage pest numbers, grain losses and the costs they add to grain sales. The additional benefit is extending the useful life span of grain protectant and fumigation products used to control pests. Repeated overuse or reliance on chemical controls often lead to the development of pesticide resistance.

Examples of non-chemical pest control strategies include good hygiene, aeration cooling and regular monthly pest monitoring in conjunction with good storage record keeping. Combining these strategies significantly reduces over reliance and repeated use of valuable pest control products such as phosphine fumigation.

As we continue to conduct research on storage pests in the laboratory, and in the field around farm storage facilities, we learn how to refine the use of and extract the best results from hygiene, aeration, pest monitoring and strategic use of grain fumigations when required.

Storage pests on your property

Where do storage pests come from? The short answer is that they may

(i) Fly into a farm from other locations

(ii) Already be present but undetected on the farm or

(iii) Enter the farm via machinery (e.g. headers).

Recent research used traps to study storage pests on multiple grain farms in the Condamine region in Queensland. This research, as well as follow-up studies in Central Queensland and other states, has provided a clearer understanding of how far these insects can fly and when they are most active.

Two of the most common causes for grain rejections are the lesser grain borer (*Rhyzopertha dominica*) and the rust red flour beetle (*Tribolium castaneum*). These pests were trapped all year round in the Condamine region, although numbers were lower in the cooler months (see Figure 1 for lesser grain borers). Significantly, both pests were trapped away from grain storage areas (at least 1 km), including in native forests.

Genetic analysis of the trapped beetles provided further evidence of flight dispersal across the region.

Although less common, the rusty grain beetle, previously known as flat grain beetle (*Cryptolestes ferrugineus*) is of concern because it can develop a very strong level of resistance to the fumigant phosphine. Research conducted in New South Wales has confirmed that this pest is also an active flyer, and a study in Central Queensland showed it colonising experimental grain bulks at least 2 km from the nearest farm storages.

In contrast, the rice weevil (*Sitophilus oryzae*, Figure 2), has little or no flight activity. However, the closely related maize weevil (*Sitophilus zeamais*) which infests stored maize and potentially other cereals, has strong flight activity.

Although much more pronounced in southern regions, flight activity of storage pests is generally lower in winter than during other seasons. Flights of key storage pests is less likely when the daily maximum temperature is lower than 20°C.

These studies show that Queensland growers should be aware of the almost year-round threat posed by flying storage pests. Concerningly, all Australian trapping studies have shown a sudden increase in flying beetles (on farms and further afield) after winter but well before the start of the winter cereal harvest. This means that flying storage pests pose a threat to grain as it is put into storage.

Apart from bulk stored grain, pests can breed in small grain residues present in headers and other farm machinery and infest newly harvested grain. Grain spillages may also provide infestation sites. Rust-red flour beetles can also be found in cotton seed, and recent research suggests that adults are probably feeding on micro-fungi growing on the lint but not reproducing on the cotton seed.

Evidence of storage pest breeding in the standing crop is limited. Exceptions include the maize weevil and the cowpea weevil (*Callosobruchus maculatus*) which infests stored mungbeans and other pulses.

Despite their small size, recent research shows that adult storage pests can be surprisingly long-lived. For example, adult lesser grain borers and rust-red flour beetles trapped in flight in Central Queensland, and then held in the laboratory, typically lived for more than 3 months, with females producing 100s of adult progeny. Population growth can be rapid as Figure 3 shows for lesser grain borers in wheat.

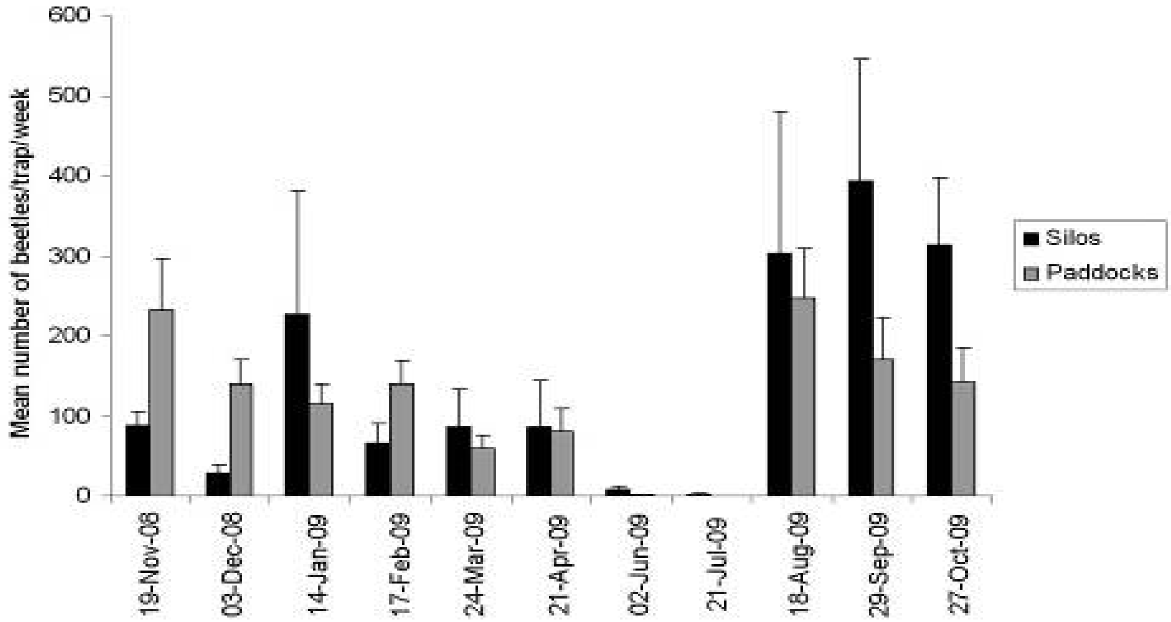

Figure 1. Numbers of flying lesser grain borers (*Rhyzopertha dominica)* trapped each month on 15 farms in the Condamine region, Queensland at the silos and 1 km away from storages in paddocks.

Figure 2. The rice weevil (*Sitophilus oryzae*)*,* a serious pest of stored grain, is not a good flyer

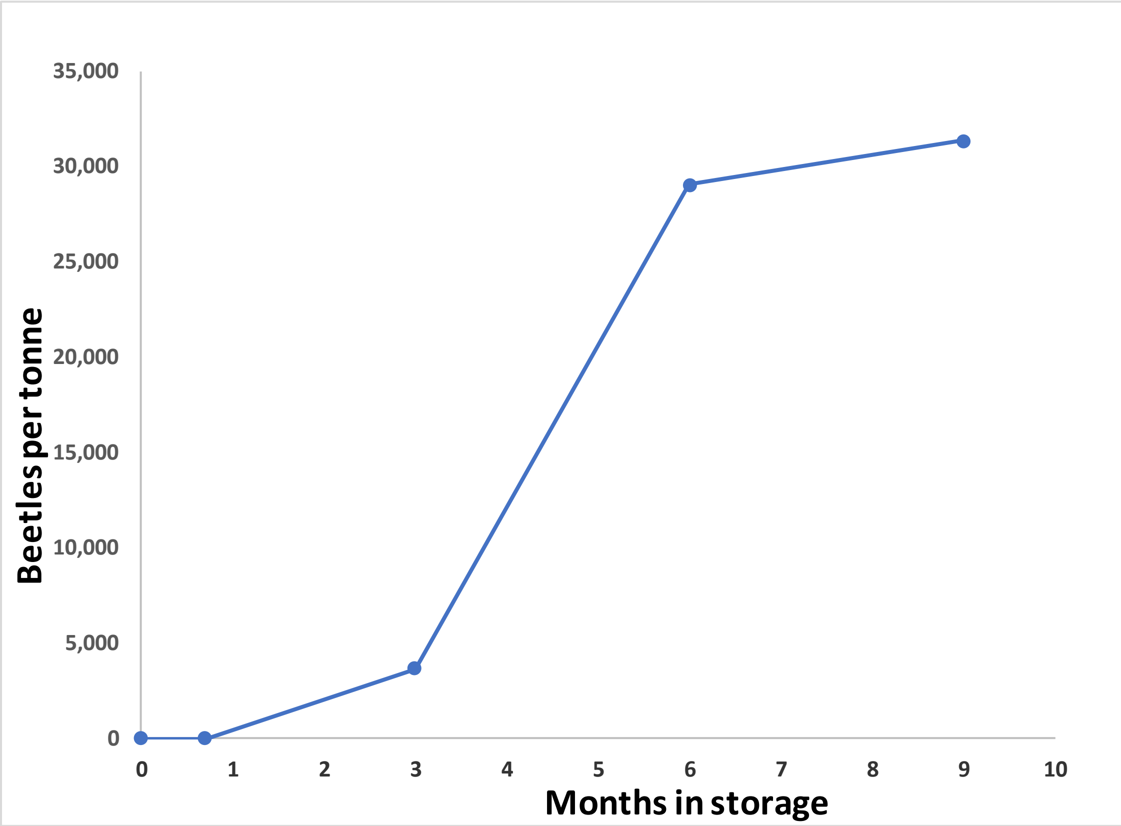

Figure 3. Rapid population increase of lesser grain borers (*Rhyzopertha dominica)* during summer in a natural infestation of wheat stored in a 1 tonne bag from October to July.

Pest control – non-chemical strategies

1. Manage grain temperatures in storage

Storage pests, like all insects, rely on the external environment for heat and this has major implications for their ecology and management. Australia's climate and our late spring to summer harvesting of wheat and barley, provide conditions that are well suited to storage pests. Straight out of the paddock, we typically see wheat and barley grain temperatures of 30-35˚C going into storage. These temperatures are known to be ideal for rapid breeding and population increase of the main storage pests: lesser grain borer (*Rhyzopertha dominica*), rust-red flour beetle (*Tribolium castaneum*), rusty grain beetle (*Cryptolestes ferrugineus*), saw-toothed grain beetle (*Oryzaephilus surinamensis*), rice weevil (*Sitophilus oryzae*) and cowpea weevil (*Callosobruchus maculatus*).

Unless grain temperatures are reduced quickly in storage using aeration cooling (Figure 4), pest numbers will increase rapidly, along with the associated grain damage.

Figure 4. Silos fitted with aeration cooling and also designed to be sealable (air-tight) when required for effective fumigations

The rust-red flour beetle is a common storage pest and the following published laboratory information provides an example of the impact of lowering grain temperatures on the breeding rates of storage pests.

With a starting population of 100 adult rust-red flour beetles placed on wheat at a grain temperature of 30-35˚C, the population increases to 24,000-25,000 in 8 weeks. When grain temperature was reduced to 25˚C, numbers increased to 15,000. However, if grain temperature was reduced to 20˚C, the population of beetles did not increase, remaining at only 100 after 8 weeks.

Practices to reduce grain temperature in storage include:

- Aeration cooling: ensure each component of aeration equipment on silos (fans, ducting, vents and the fan auto-controller) are designed and managed to achieve the best results
- Run fans as soon as the first few truckloads go into storage at harvest time
- Monitor the grain temperatures in storage each month with a grain temperature probe. Aeration should achieve 18-23˚C during summer months and under 15˚C in winter.

2. Hygiene to reduce pest numbers

Cleaning out old grain residues and dust from empty silos and any grain handling equipment is the first important step in reducing pest populations around grain storage facilities.

A good strategy is to clean out silos as they become empty – 'clean as you go'.

However, it is also worthwhile to combine this with a timely, once a year, major storage facility hygiene clean-down that includes silo repairs and maintenance. Research on the field ecology of various storage pests has identified winter time, when insect flight activity is minimal, is the most effective time for a major annual hygiene effort on storages (e.g. Figure 1).

For lesser grain borers, rust-red flour beetles and rusty grain beetles, the colder winter months of June and July were when beetles were not very active. This is the ideal time to do the main storage hygiene clean down and maintenance work, well before the massive increase in flight actively starting in August. Leaving the silo clean down to just before harvest in November is too late.

How far can storage pests fly? Field research in the Condamine region and Central Queensland showed that various storage pests had little trouble flying 1-2 km to find grain to infest. So, even a farm with good hygiene should be alert to the possibility of incoming pests.

Be careful with old grain residues. If dumped in a heap on the property, storage pests will breed in it and fly back to your grain storage facility. Burn, bury or spread the waste grain out to less than 20 mm deep.

Hygiene practices for improved pest control:

- Aim to make small changes and improvements to storage facilities that allow for easy silo and equipment clean-down
- Before purchasing new silos, check internal design for ease of clean out. Consider hygiene when planning a new farm storage facility
- Either physically clean, or wash out grain residues from empty silos, followed up with a diatomaceous earth (DE) (e.g. Dryacide®) dust or slurry treatment. Remember to clean out under aeration ducting
- Clean out empty silos within 1-2 weeks of out-loading. Plan for an annual hygiene and storage maintenance time during winter. This will reduce the large spike in pest numbers taking flight in August.

3. Monitor storage pests and conditions – keep storage records

Regular monthly checks of grain in storage is essential to ensure the storage facility is an asset to the business and not a liability. Storage pests are not easily seen in grain and can do significant damage in 2-3 months.

Unfortunately the vast majority of a pest population in stored grain is virtually invisible. The immature stages – eggs, larvae and pupae – are very difficult to see. Table 1 shows the results from sampling of farm silos for storage pests. The results show that if we sieved 600 adult beetles in a tonne of grain, there could be close to 60,000 eggs, larvae and pupae that we do not see.

Table 1. Numbers of adult beetles versus undetected immatures (eggs, larvae or pupae) in four silos containing wheat. *After sieving out the adults the samples were held in the laboratory for a number of weeks until all the eggs, larvae or pupae developed into beetles.

Silo	Insects per tonne	
	Beetles	Immatures*
1	588	59,413
2	250	21,913
3	0	4,220
4	0	15,533

Monitoring and storage record keeping for reliable results:

- Clearly number each silo and keep up-to-date storage records of where each variety and grain quality segregations are stored. Record any grain treatments for a commodity vendor declaration (CVD)
- Use grain insect sieves and probe traps to check for storage pests each month (Figure 5). Identify and record pest numbers
- Use a grain temperature probe to measure grain temperatures in storage. This helps understand the performance of the aeration cooling system and current insect pest activity

- Fixed cables inside silos such as OPI™ grain cables may be an option for monitoring storage conditions (for example, see http://www.advancedgrainmanagement.com/products). Warning-cables with sensors measuring both temperature and relative humidity may suffer damage to the relative humidity sensor following a phosphine fumigation, as phosphine gas is corrosive and will damage exposed electrical components.

Figure 5. A probe trap (L) and an insect sieve (R) used for regular grain inspections

Regular monthly checks for pests helps minimise costly delays at the time of delivery. Your business reputation as a reliable supplier of grain is improved when you consistently supply quality grain for sale without pest detections.

Up-to-date farm storage records support successful marketing by know where each grain quality segregation is stored and the condition it is in.

Summary - Top five practices for successful storage

1. **Aeration**: When correctly designed, installed and managed, it provides cool grain temperatures and promotes more uniform grain moisture conditions. Aeration reduces storage problems such as moulds and insect pests, plus helps maintain grain quality, seed germination and vigour
2. **Hygiene**: A good standard of storage hygiene is crucial in keeping storage pest numbers to a minimum. Good hygiene for silos, augers and trucks reduces the risk of grain contamination
3. **Monitoring**: To prevent serious damage, undertake monthly checking of grain in storage for insect pests (sieving / trapping) as well as checking grain quality and temperature. Keep monthly storage records, including any grain treatments applied
4. **Fumigation**: In Australia, only fumigant gases (e.g. phosphine) are registered to deal with live insect pest infestations in stored grain. To achieve effective fumigations, the silo must be sealable and gas-tight to the Australian Standard AS2628 to hold the gas concentration for the required time. Use fumigants according to the label directions
5. **Grain protectants**: Grain protectant insecticide sprays provide another line of defence against storage pests. Always check with potential grain buyers first. Treat cereal grain at harvest time with a registered grain protectant. Use according to label directions.

Warning: Grain protectant notes do not apply to the grains industry in Western Australia where their use is restricted. In all cases, refer to product labels to determine correct use patterns.

Further information

- GRDC GrowNotes – Grain Storage, National, June 2020 https://storedgrain.com.au/grdc-grownotes-grain-storage/

- Grain storage information web site: www.storedgrain.com.au
- or phone 1800 WEEVIL for GRDC grain storage extension specialist

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CBA Captain⊕: a new desi variety for the northern region

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Take home message

CBA Captain⊕ is a new broadly adapted desi chickpea variety for the northern region and other chickpea growing areas of Australia. The variety was evaluated as CICA1521 and has higher yields in northern NSW and southern QLD than PBA HatTrick⊕. CBA Captain⊕ has a medium seed size and is expected to have similar disease ratings to PBA HatTrick⊕. Seed of CBA Captain⊕ is available in the northern region for the 2021 season from the following seed partners; Galleon Grains, PB Agrifood, PB Seeds and Woods Seeds.

Significant yield advantage over PBA HatTrick⊕

CBA Captain⊕ has been included in National Variety Trials (NVT) since 2015. During this six-year period there have been two favourable seasons in north west NSW (2016 and 2020) and a number of dry seasons (2018 and 2019). CBA Captain⊕ has shown great consistency in yield despite the highly variable seasons. In the southern areas of north-west NSW, CBA Captain⊕ has consistent yield gains over PBA HatTrick⊕ (Table 1). At the time of writing this paper, the long term yield reporter using 2020 trials were not available. Readers are encouraged to visit nvtonline.com.au.

Table 1. Long term yield (2015-2019) of CBA Captain⦶ and current chickpea varieties, expressed as a % of the mean yield, in NVT in Trangie, Narromine and Coonamble. The mean yield of all varieties in each of the 5 contributing trials was used to assign that trial to a 'yield grouping'. This enables varietal performance to be better evaluated in different yield situations

		Yield group (t/ha)			
		1	**1.5**	**2.0**	**3.0**
	Mean yield (t/ha)	0.91	1.25	1.84	2.96
Variety	No trials in total & for each yield group	2	1	1	1
CBA Captain⦶	**5**	**108**	**110**	**110**	**112**
Kyabra⦶	5	113	98	97	68
PBA Boundary⦶	5	110	101	103	89
PBA Drummond⦶	1	107			
PBA HatTrick⦶	5	101	95	96	88
PBA Seamer⦶	5	95	102	102	115

Source: https://app.nvtonline.com.au/lty/table/chickpea-desi/nsw/nw/trangie,narromine,coonamble/?lty-type=yield&stacked=1

Table 2. Long term yield (2015-2019) of CBA Captain⦶ and current chickpea varieties, expressed as a % of the mean yield, in NVT at Bellata, north west NSW. The mean yield of all varieties in each of the 4 contributing trials was used to assign that trial to a 'yield grouping'. This enables varietal performance to be better evaluated in different yield situations

		Yield group (t/ha)		
		1.0	**1.5**	**2.0**
	Mean yield (t/ha)	0.96	1.18	1.65
Variety	No trials in total & for each yield group	2	1	1
CBA Captain⦶	**4**	**109**	**121**	**104**
Kyabra⦶	4	113	68	96
PBA Boundary⦶	4	104	95	96
PBA Drummond⦶	1	115		
PBA HatTrick⦶	4	97	86	96
PBA Seamer⦶	4	96	116	102

Source: https://app.nvtonline.com.au/lty/table/chickpea-desi/nsw/ne/bellata/?lty-type=yield&stacked=1

Ascochyta blight

CBA Captain has undergone Ascochyta blight (AB) testing in the field at Tamworth and Horsham as well as single isolate testing under controlled conditions in Adelaide and Tamworth.

An increase in the aggressiveness of the AB pathogen has been observed both in the northern and southern regions (Ford et al., 2018). Increased levels of disease have been recorded on CBA Captain and other varieties such as PBA Seamer from these isolates collected in 2017 compared to isolates collected in 2015 (Table 3). The distribution of the more aggressive isolates in the northern region is currently unknown, due to the reduced chickpea area and dry seasons over the past two years, however a cautious disease rating from the NVT pulse disease rating system for CBA Captain is expected. For northern isolates this is likely to be a Moderately Susceptible rating for Ascochyta blight. At the time of writing this paper the 2021 NVT pulse disease ratings were unavailable. Readers are encouraged to visit nvtonline.com.au for updated AB ratings.

Table 3. Mean disease index of chickpea varieties in single isolate AB screening conducted at Adelaide. The index is calculated as the sum of (% main stems broken + % of stems with lesions + % side branches with disease + % leaves with disease) divided by 4. (0 = healthy plant, 100 = heavily diseased plant)

	Isolate collection location and year							
Name	Yallaroi NNSW 2015	Curyo VIC 2015	Graman NNSW 2016	Curyo VIC 2016	Gurley NNSW 2017	Pt Broughton SA 2017	Gurley NNSW 2017	Curyo VIC 2018
CBA Captain	**40**	**50**	**77.1**	**76.3**	**29.2**	**26.7**	**67.9**	**89.6**
Kyabra			100	100	100	100	100	100
PBA Boundary	81.3	67.9	100	100	77.1	55.4	90	100
PBA Drummond	97.1	100	100	100	66.7	97.5	83.3	100
PBA HatTrick	87.5	61.7	86.3	94.2	66.7	48.8	67.9	68.3
PBA Seamer	31.7	37.5	83.8	90.8	29.2	39.2	65.4	84.6
Lsd	*20.6*	*27.2*	*18.1*	*16.2*	*24.7*	*19.2*	*26.6*	*28.6*

Phytophthora root rot

CBA Captain was included in Phytophthora root rot (PRR) yield loss trials conducted at Warwick QLD, over several years (Table 4). Yield losses for CBA Captain from PRR in these trials have ranged from 38.7 to 93.4 %. Similar variability in yield loss has also been observed for PBA HatTrick; an explanation of the seasonal impacts on yields and varietal PRR disease rankings is provided in Bithell et al., 2018. In 2020, NVT pulse disease rating testing was conducted for PRR for the first time. It is expected that a review of all variety ratings for PRR will be conducted to align with the NVT disease rating definitions. The 2020 ratings were not available at the time of writing this report, please see nvtonline.com.au for updated ratings.

Table 4. Yield (t/ha) in the absence of PRR and yield loss (%) from PRR across 2016 to 2018 for CBA Captain⫯ and other current chickpea varieties. Adapted from Bithell et al., 2018, Bithell et al., 2019

	2016		2017		2018	
Name	Yield (t/ha) in the absence of PRR	% yield loss from PRR	Yield (t/ha) in the absence of PRR	% yield loss from PRR	Yield (t/ha) in the absence of PRR	% yield loss from PRR
CBA Captain⫯	**4.06**	**75.1**	**2.74**	**93.4**	**1.94**	**38.7**
PBA Boundary⫯	3.98	95.2	2.63	82.5		
PBA Drummond⫯					2.49	68.1
PBA HatTrick⫯	4.02	90.0	3.31	78.2	2.28	40.5
PBA Seamer⫯	4.08	76.7	3.23	90.4	2.81	61.5
Yorker	4.06	68.3	3.50	97.3	2.84	40.1

Phenology and other agronomic traits

CBA Captain⫯ is early flowering when sown in the mid-May to mid-June sowing window, approximately six days earlier than PBA HatTrick⫯ (Table 5). Flowering data collected from early May sown chilling tolerance trials (BLG111) indicates that CBA Captain⫯ can flower up to 24 days earlier than PBA HatTrick⫯ depending on winter daytime temperatures. An increased understanding of the drivers of chickpea phenology is expected with new GRDC investments in this area. Although there is some data indicating that CBA Captain⫯ may produce pods earlier in some environments (e.g. Kingaroy, 2019), it is expected that days to first pod is similar to current varieties.

Table 5. Phenology data (2017-2020) collected for CBA Captain⫯ and current chickpea varieties from breeding and chilling tolerance trials in northern NSW and southern QLD

		CBA Captain⫯		Kyabra⫯		PBA Drummond⫯		PBA HatTrick⫯		PBA Seamer⫯	
Sowing date	Location	DTF	DTP	DTF	DTP	DTF	DTP	DTF	DTP	DTF	DTP
15/6/2017	Spring Ridge	**102**		103				103		102	
23/5/2018	Moree	**91**		96		97		98		97	
7/5/2018	Tamworth	**101**	**134**	112	134	120	134	125	135	126	134
12/6/2018	Tamworth	**96**	**108**	99	108	97	108	102	108	99	
13/5/2019	Narrabri	**77**	**108**	83	106			80	108		
15/5/2019	Breeza	**106**	**122**	105	123			105	122		
17/5/2019	Kingaroy	**79**	**91**	82	95			81	96		
10/06/2020	Narrabri	**86**		88		88		89		88	

DTF = days to flower from sowing
DTP = days to pod from sowing

CBA Captain⫯ has early to mid-maturity, earlier than PBA HatTrick⫯. CBA Captain⫯ has an erect plant type with good height to lowest pod and plant height. Under the high biomass producing conditions of 2016 and 2020, CBA Captain⫯ had less lodging than PBA HatTrick⫯ at seven sites across northern NSW and southern QLD (Table 6).

Table 6. Mean lodging score at northern NSW and southern QLD breeding sites in 2016 and 2020 for CBA Captain⦶ and current chickpea varieties. 1 = erect, 9 = flat.

Location	**Year**	**CBA Captain⦶**	Kyabra⦶	PBA Drummond⦶	PBA HatTrick⦶	PBA Seamer⦶
Edgeroi	2016	**3.7**	2.3		5.3	5.3
North Star	2016	**4.3**	3.0		7	3.3
Rowena	2016	**5.3**	5.3		6.7	6.3
Warwick	2016	**6.0**	6.3		6.3	5.3
Warra	2016	**3.3**	2.0		6.0	2.7
Roma	2016	**3.7**	3.0		6.0	4.7
Rowena	2020	**1.7**	1.3	1.3	3.0	1.0

In December 2020, Tamworth Agricultural Institute received more than 240 mm of rain. Plots of CBA Captain⦶ were observed to have remained standing with good harvestability compared to PBA HatTrick⦶ which had lodged considerably.

In 2019 and 2020, large seed multiplications and demonstration blocks of CBA Captain⦶ were harvested by commercial harvesters throughout the northern region. No negative feedback regarding the harvestability of CBA Captain⦶ were reported.

Grain quality

CBA Captain⦶ has a yellow-brown seed coat and angular seed shape, not unlike PBA HatTrick⦶. The seed size of CBA Captain⦶ is larger than PBA HatTrick⦶, similar to PBA Seamer⦶ and PBA Drummond⦶ but smaller than Kyabra⦶ (Table 7). CBA Captain⦶ has a higher or similar split yield than PBA HatTrick⦶ and PBA Drummond⦶ at six sites across southern QLD and northern NSW.

Table 7. Seed size (grams per 100 seeds) and split yield % (SY%) for CBA Captain⦶ and other current chickpea varieties at six sites in northern NSW and southern QLD

	CBA Captain⦶		Kyabra⦶		PBA Drummond⦶		PBA HatTrick⦶		PBA Seamer⦶	
Site Year	100 SW	SY%	100 SW	SY%	100 SW	SY%	100 SW	SY%	100 SW	SY%
Roma 2017	**19.8**	**52.9**	21.9	72.5			20.1	40.8	20.8	44.8
Spring Ridge 2017	**22.5**	**53.2**	24.6	45.1			18.9	44.3	21.3	55.7
Warra 2017	**21.7**	**72.3**	24.2	67.5			22.5	70.5	24.1	73.7
Moree 2018	**21.5**	**41.2**	25.1	46.9	22.2	36.7	20.2	42.9	21.5	42.0
North Star 2018	**23.7**	**46.0**	27.2	64.1	24.0	39.7	22.0	39.2	23.5	45.3
Warra 2019	**22.3**	**50.7**	24.2	32.6	22.4	38.0	21.8	37.4	22.2	38.7

100SW = grams per 100 seeds
SY% = split yield % (yield of dhal using a standard SKE milling method without pre-conditioning seeds; Wood et al 2008).

Seed partners

CBA Captain⊕ will be delivered to the northern region through the following seed partners; Galleon Grains, PB Agrifood, PB Seeds and Woods Seeds to distribute seed to QLD and NSW.

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

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