WEEK 2
NSW/QLD
THURSDAY 24
FRIDAY 25
FEBRUARY 2022

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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Agendas for Northern GRDC Grains Research Updates, online
Week 2 – 24 and 25 February 2022

Thursday 24 February 2022 - Capitalising on great seasons; root architecture and a new tool to estimate soil water

Time (AEDT)	Topic	Speaker
8:30 AM	GRDC	Richard Holzknecht (GRDC)
8:35 AM	What are the ideal roots for wheat? How different architectures affect yield in different environments. Exploratory research as part of an international program of projects in the IWYP (International Wheat Yield Partnership).	Lee Hickey (University of Queensland)
9:10 AM	A sub-paddock tool (Soil Water Nowcasting) to estimate PAW at depth across the paddock by incorporating different data layers	Tom Bishop (University of Sydney)
9:45 AM	Capitalising on great seasons when they occur - is that the most profitable strategy and where is balance point for risk and reward? What do more profitable growers do?	Simon Fritsch (Agripath)
10:20 AM	Morning tea	

Thursday 24 February 2022 - Weeds

Time (AEDT)	Topic	Speaker
10:50 AM	Herbicide resistance threats for SNSW and the economics of integrated harvest weed seed control systems on headers.	Mike Walsh (University of Sydney)
11:15 AM	Killing glyphosate resistant weeds - making the most of sprays applied by optimising application; water quality; adjuvants and tank mix do's and don'ts	Maurie Street (Grains Orana Alliance)
11:45 AM	Five years of crop competition research in the northern grains region - lessons learned and opportunities for growers	Asad Shabbir (University of Sydney)
12:10 PM	An agronomists observations on new pre-emergent options and their fit in the farming system	Greg Condon (Grassroots Agronomy/WeedSmart)
12:35 PM	Lunch	

Thursday 24 February 2022 - Canola

Time (AEDT)	Topic	Speaker
1:35 PM	Better canola establishment from better quality grower retained seed and seed placement - key traits for seed quality and how do you grow a crop with these traits?	Col McMaster (NSW DPI)
2:05 PM	Managing upper canopy blackleg and sclerotinia in lower and medium rainfall canola crops	Maurie Street (Grains Orana Alliance) and Kurt Lindbeck (NSW DPI)
2:50 PM	Hyper yielding canola agronomy; outcomes, benchmarks decision points, key levers and interactions to capitalise on great seasons or irrigation. Varieties, N and fungicide lessons learnt	Rohan Brill (BrillAg)
3:20 PM	Close	

Friday 25 February 2022 - Chickpeas

Time (AEDT)	Topic	Speaker
8:30 AM	Ascochyta management in chickpeas - timing x environment x variety	Hayley Wilson & Kurt Lindbeck (NSW DPI)
9:05 AM	Phytophthora root rot and waterlogging in chickpea – minimising risk and management options	Sean Bithell & Nicole Dron (NSW DPI)
9:35 AM	Chickpea chilling tolerance - unpacking when yield potential is generated in chickpeas and how different commercial cultivars accumulate yield.	Neroli Graham (NSW DPI)
10:00 AM	A new diagnostic tool for botrytis in chickpeas – in-paddock biosensors - progress towards development of an in-paddock diagnostic device that is cheap, reliable, and accurate and mapping *Ascochyta rabiei* aggressiveness and understanding the pathogen adaptation to disease management strategies	Ido Bar (Griffith University)
10:25 AM	Morning tea	

Friday 25 February 2022 - Farming systems - dual purpose crops in the medium rainfall zone of central/southern NSW and summer sown pasture legumes

Time (AEDT)	Topic	Speaker
10:55 AM	Dual purpose crops - their roles, impact and performance in medium rainfall farming systems	John Kirkegaard (CSIRO)
11:25 AM	Practicalities and economics of integrating dual purpose crops into the whole of farming operation in the medium rainfall zone	John Francis (Agrista)
11:55 AM	Dual purpose crops - a growers perspective	John Bruce (Grower, Cobram NSW) & Joe Mason (Grower, Gollan, NSW)
12:25 PM	Cranking up crop yields and livestock production using summer sown pasture legumes. Revisiting fundamental soil and agronomy with new technologies to increase production and rotation flexibility.	Belinda Hackney (NSW DPI)
12:55 PM	Close	

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Friday 25 February 2022

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Can we improve the roots of durum wheat to maximise yield?

Lee Hickey[1], Anton Wasson[2], Yichen Kang[1], Samir Alahmad[1]

[1] University of Queensland
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Key words

root system architecture, root angle, root distribution, soil moisture, yield

GRDC code

9177334 UOQ1903-007RTX

Take home message

- A major gene (QTL) for seminal root angle (*qSRA-6A*) influences root distribution and could be used by durum breeders to develop new cultivars with optimal root systems
- Introgression lines were generated by backcrossing the major QTL into an elite durum cultivar
- Extensive root coring of the introgression lines under field conditions identified lines with significantly altered root distributions
- Durum lines carrying the wide allele for the QTL tend to produce more roots in the upper soil layer, which can enhance water extraction from the upper soil layer. This type of root system can enhance yield potential in environments where soil moisture is not limiting
- The introgression lines provide valuable genetic resources for plant breeders and researchers to further study the value of root systems in different production scenarios.

Introduction

Root system architecture is a representation of the spatial and temporal distribution of root growth in the soil and thus is critical for water uptake throughout the season. Root systems are complex in nature and comprise a large number of component traits, many of which are important, but their yield advantage is yet to be thoroughly explored (Ober *et al.,* 2021). For durum wheat, a trait that may influence the direction and distribution of roots in the soil space is seminal root angle. Seminal root angle determines the direction of root growth and distribution of roots in different layers of the soil profile. For instance, a narrow root angle could lead to deeper root growth which may be beneficial for accessing moisture in deep soil layers under terminal drought conditions. On the other hand, a wide root angle could lead to a higher proportion of shallow root growth, which may be beneficial for taking up nutrients and soil moisture in the upper soil layers. The value of different root systems is highly context-dependent and likely changes depending on the environmental conditions and management practices.

Thus far, a substantial body of research suggests that optimised root systems can improve resource acquisition, resulting in improved crop yield under both favourable and adverse conditions. Modern crop improvement programs, however, struggle to incorporate selection for root traits, largely due to the challenges associated with phenotyping root structure, a lack of understanding of the genetic controls of root system architecture, and an inability to assess the value of root traits in specific environment types.

In this study, we investigated the ability to modify root system architecture by targeting selection of the seminal root angle trait. This was achieved by backcrossing a major QTL for seminal root angle (*qSRA-6A*) into the durum cultivar DBA Auroraᶲ. The changes to RSA were explored through a series of phenotyping experiments performed under controlled and field conditions. We anticipate these results will help guide the development of new cultivars with optimised root systems that maximise yield.

Investigating the potential to manipulate root systems of elite durum cultivars

The major gene (i.e., QTL) modulating seminal root angle, named *qSRA-6A* (Alahmad et al., 2019), was introgressed into the durum wheat cultivar DBA Auroraᶲ. This was achieved by applying marker-assisted selection using linked DNA markers in a backcrossing scheme under speed breeding at The University of Queensland, QLD, Australia. This resulted in the development of BC_2F_5 introgression lines that were 87.5% genetically similar to DBA Auroraᶲ but differed for *qSRA-6A.* A total of 11 introgression lines were developed, including 6 which carried the ‘narrow’ allele and 5 which carried the ‘wide’ allele.

To determine whether introgression of *qSRA-6A* into the DBA Auroraᶲ background was successful, the 11 introgression lines and DBA Auroraᶲ were evaluated in a rhizobox phenotyping platform under controlled glasshouse conditions (St Lucia campus, The University of Queensland, QLD, Australia). The 12 genotypes were evaluated using a randomised complete block design with four replicates per genotype. Rhizoboxes were constructed from wood panelling and lined with black plastic to contain the potting mix and to facilitate root imaging. The rhizoboxes were filled with UQ23 potting media (70% composted pine bark 0–5 mm, 30% cocoa peat, mineral fertiliser) pre-mixed with 2g/L of Osmocote® slow release fertiliser and a total of four plants were grown in each. After 44 days of growth, the rhizoboxes were opened and roots extracted from three depths: upper (0-30cm), middle (30-60cm) and bottom (60-90cm) layers. The roots were washed, dried and weighed to determine dry root mass (mg) in each layer.

Unpaired t-tests revealed that introgression lines carrying the ‘wide’ allele for the QTL produced significantly more roots in the upper layer ($P \leq 0.05$), whereas introgression lines carrying the ‘narrow’ allele produced significantly more roots ($P \leq 0.01$) in the deepest layer (Figure 1A, B). Notably, no significant difference was observed in the total (overall) root biomass produced by ‘wide’ and ‘narrow’ lines (Figure 1B). Thus, targeted selection of a major QTL for root angle successfully changed the distribution of roots in the DBA Auroraᶲ background without impacting the total carbohydrate allocated to root growth.

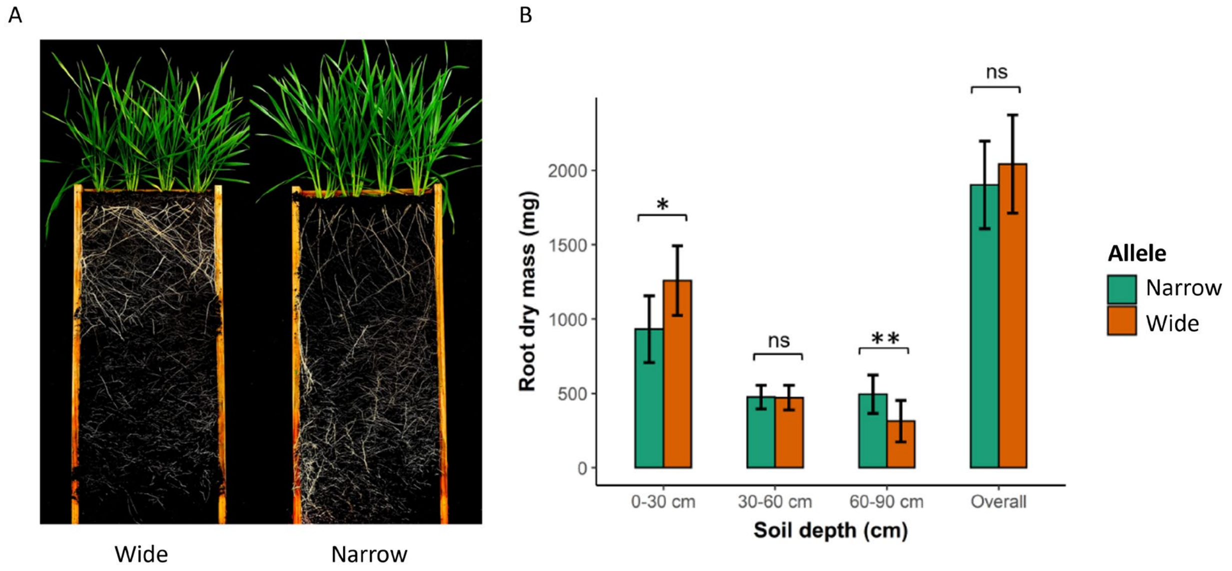

Figure 1: Comparison of root distribution for DBA Aurora⦶ introgression lines that carry 'wide' and 'narrow' alleles for the major root angle QTL *qSRA-6A*. (A) visual representation of root distribution in the rhizoboxes. (B) Comparison of root dry mass extracted for the three depth layers and the total (overall) root dry mass. The green colour represents the narrow root angle allele and red represents the wide root angle allele. The significance level of contrasts between the two root angle alleles in unpaired t-tests is shown as symbols above the bars: $P \leq 0.05$ '*', $P \leq 0.01$ '**', and no significant difference "ns".

Characterising the elite pre-breeding lines for root distribution in the field

To explore root distribution changes under field conditions, the DBA Aurora⦶ introgression lines were evaluated in a field trial conducted at the University of Queensland's Gatton Research Farm (27°32'34"S; 152°19'59"E) in 2021. The 12 genotypes were sown in standard 7-row plots (6m long x 1.52m wide) according to a randomised complete block design with eight replicates, where four replicates were mulched at flowering for root coring (Figure 2A) and four replicates were machine harvested at maturity to measure grain yield.

Root phenotyping was performed using a 'core-break' method described by Wasson *et al.* (2014). This involved careful removal of intact soil cores, breaking the core into 10cm intervals (from 10-100cm), and visual counting of the number of roots visible on each surface of the break (Figure 2A:C). The number of root breaks per interval down the soil profile correlates well with root length density (Wasson et al., 2014). To account for within-plot variability, four cores were sampled per plot from the two inner and intra rows of the 'destructive' plots. Raw root count data were modelled to account for variations between operators and spatial effects across the trial. The root distribution for each genotype was estimated using a smoothing function with a generalized additive model, which had the effect of integrating over all the depths in the profile.

Figure 2: Overview of the ‘core-break’ method used for field-based root phenotyping. (A) Soil coring of the destructive plots that were mulched at flowering time. (B) Breaking of intact cores every 10cm. (C) Visual counting of roots on each surface of the break.

A total of 6 of the 11 introgression lines showed root distribution patterns that were significantly different to DBA Aurora⌽ (Figure 3). Five of the six lines produced significantly fewer roots in the upper soil layers and two of these lines, UQDR045, a ‘narrow’ line, and UQDR5, a ‘wide’ line, also produced a significantly higher proportion of roots in the deeper soil layer. ‘Narrow’ line (UQDR53) showed a root distribution that was similar to DBA Aurora⌽ with the exception of more roots in the deepest soil layer.

The introgression lines generated in this study show significant difference in root distribution under field conditions, thus providing valuable genetic resources for plant breeders and researchers to further study the value of different root systems in a range of production scenarios.

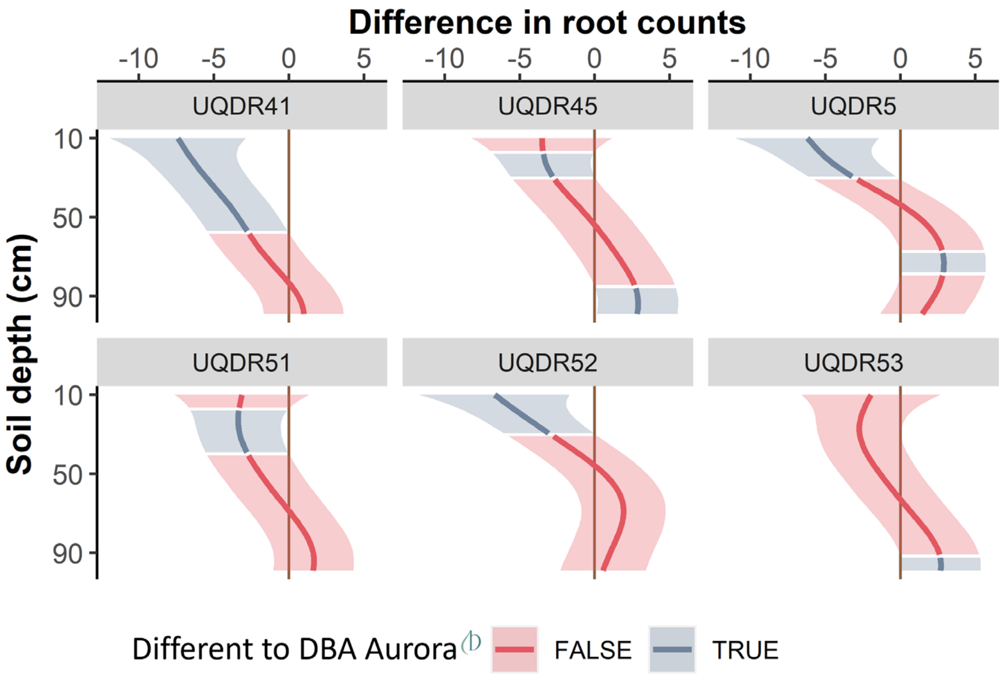

Figure 3: Root distributions for the six durum wheat introgression lines that showed significantly different root systems in comparison to DBA Aurora⦶.

Understanding the relationship between root distribution, water extraction and durum yield

Interestingly, the introgression lines carrying the 'wide' allele produced significantly higher yield compared to lines carrying the 'narrow' allele in the Gatton 2021 trial (Figure 4A).

To investigate the relationship between root distribution, water extraction and yield in this environment, soil coring was performed during early grain filling and harvest for a subset of the introgression lines. Coring was performed using a hydraulic soil corer mounted to the back of a trailer. A total of three intact cores were sampled per plot. The cores were divided into 20cm intervals down to 1m depth. Soil samples were weighed and dried to calculate soil moisture. Mean soil moisture at each depth were compared for groups of lines carrying the 'narrow' and 'wide' alleles using an unpaired t-test.

Analysis of the soil moisture data at early grain filling revealed a trend that lines carrying the 'wide' allele tended to extract more soil moisture in the upper soil layers in comparison with the lines carrying the 'narrow' allele, particularly within the top 20cm depth ($p = 0.065$). At harvest, the soil moisture under 'narrow' and 'wide' lines was similar at all soil depths (Figure 4B). This suggests the timing of water extraction was critical, where higher water extraction early in the season was likely a key contributor to the higher yield produced by the lines carrying the 'wide' allele. Thus, lines with a wider and shallower root system were able to extract more water during the vegetative stage and take advantage of in-season rainfall, which was likely converted to biomass and subsequently yield.

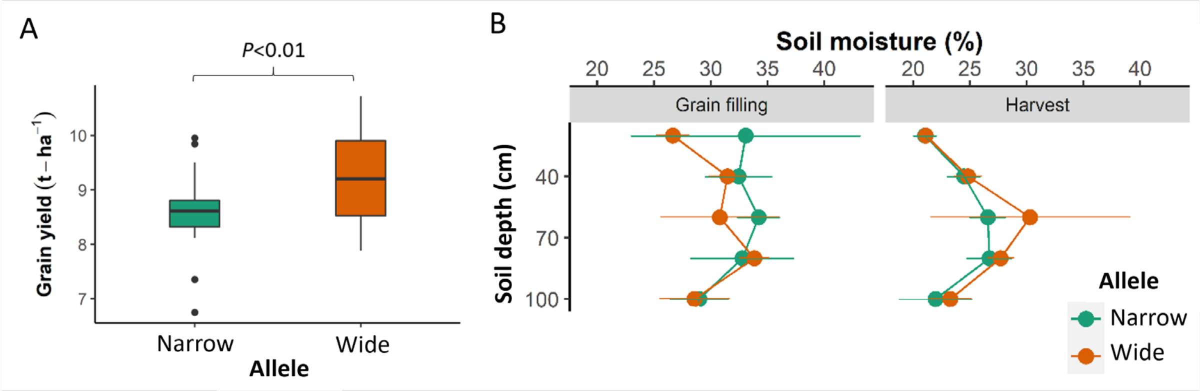

Figure 4: (A) Boxplots comparing grain yield for the introgression lines at Gatton in 2021. Comparison of means performed using an unpaired t-test. (B) Soil moisture at grain-filling and harvest for lines carrying 'narrow' and 'wide' alleles for the major root angle QTL *qSRA-6A.* Means of soil moisture at each depth were compared between alleles using an unpaired t-test. While interesting trends were observed, no significant difference was detected at any soil depth.

Notably, the yield trial was conducted on a deep cracking clay soil with a high water-holding capacity, and at the time of sowing the soil had a full profile of water. The trial also received 326mm of rainfall during the season (May to November) with 177mm rainfall from flowering to harvest time which meant water supply was likely not limiting during the grain-filling period. It is important to consider if the Gatton trial received less in-season rainfall, the lines carrying the 'narrow' allele may have produced a yield advantage due to water savings early in the season.

Overall, these results highlight the value of designing cultivars that are capable of producing roots where soil resources are available. In this environment, root proliferation in the upper soil layers was advantageous due to water and nutrient availability. Not only was water available but also nutrients including nitrogen and phosphorus that are critical to support crop growth and performance. However, the yield outcome would likely be different in other environments where water and nutrient resources vary either temporally or spatially.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We also give thanks to Charlotte Rambla and Sarah Van Der Meer for assistance with root phenotyping, and CSIRO staff for maintaining the field trial at Gatton.

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Sub-paddock tool (Soil Water Nowcasting) to estimate PAW at depth across the paddock by incorporating different data layers

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Key words

digital agriculture, soil water, nowcasting, spatial prediction

GRDC code

UOS2002-002RTX

Take home message

- An approach for predicting soil water using a water balance model driven by nationally available geospatial data is presented
- Relative trends in soil water can be predicted at the within-paddock scale
- The absolute value of soil water in mm is less well predicted with the hypothesised reason being national-scale digital soil maps used to estimate the soil water bucket size are causing much of the errors
- The model can be calibrated with local soil moisture probes to improve predictions and overcome errors in the estimate of the soil water bucket size
- On-farm data whether moisture probes and/or spatial estimates of bucket size will improve the model predictions

Introduction

This project is funded by the GRDC and called 'Soil water nowcasting for the grains industry'. It is led by the University of Sydney in a collaboration with CSIRO, University of Southern Queensland, Australian National University and the Bureau of Meteorology. It aims to deliver a scientific framework to estimate plant available water (PAW) in real time (nowcast) at the sub-paddock scale. The approach is based on remotely sensed digital data with use made of a range of current data sources and the capacity to make use of next generation data sources. The project will test, develop and refine data assimilation processes, mechanistic and data driven soil water balance modelling to predict PAW using the combined expertise of the five different research organisations and strong collaborations with grower networks and industry.

In this paper we present the underlying model that is deployable anywhere in Australia using freely available data. We present quality of the fit for the model and present options for calibration. We illustrate its use with 2 applications (i) on-farm 30 m spatial resolution estimates of soil water (ii) 500 m spatial resolution estimates of soil water for the Murray-Darling Basin.

The water balance model

To simulate the movement of water between soil layers, a modified version of a soil water balance model described in Wimalathunge and Bishop (2019) was used which can be represented as:

$\Delta S = R + I - ET - DD - RO$;

where S = soil water, R = precipitation, I = irrigation, ET = evapo-transpiration, DD = deep drainage and RO = runoff, Δ = Delta, change

The soil water bucket size determines the partitioning between RO, DD and soil water. In the approach implemented here, the bucket size is estimated from particle size fractions and organic carbon. The model represents the soil profile with five soil layers bounded by the standard depths from the Soil Landscape Grid Australia (SLGA) of 0-5, 5-15, 15-20, 30-60 and 60-100 cm. This can be modified depending on the underlying soil data. Table 1 shows examples of model inputs that are available nationally and are publicly available, and possible local or on-farm alternatives.

Table 1. Data inputs for model.

Input	National (publicly available)	Local (on-farm)
Soil bucket size	Bureau of Meteorology (5km grid)	Farm soil maps
Precipitation	Soil Landscape Grid of Australia (90m grid)	Weather station
Evapo-transpiration	MODIS ET (MOD16) (500m raster)	Weather station

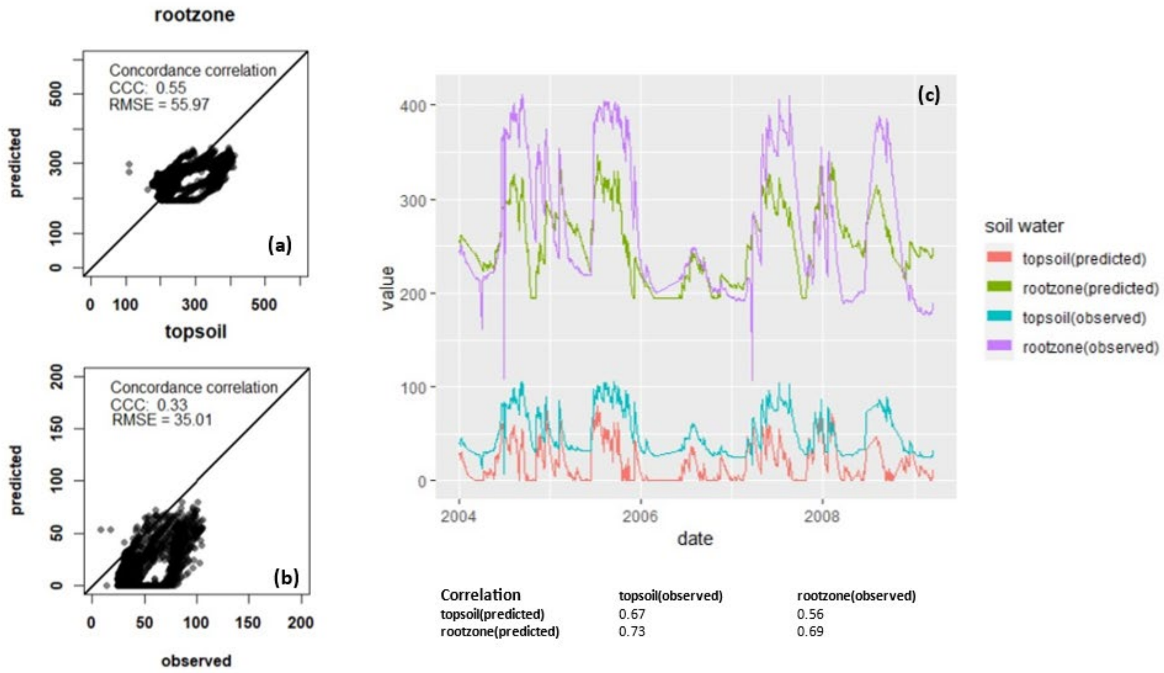
The model operates on a daily timestep and can be deployed anywhere in Australia using the national data in Table 1. The model can be run with default parameters related to rooting depth and conductivity between soil layers or these can be calibrated based on local soil moisture data, typically from moisture probes.

Model quality

To test the model quality we have applied it to 6 sites from OzNet hydrological monitoring network which was established in 2001. The sites are located near Wagga Wagga under cropping and grazing systems. Across the sites the soil has a clay content of 15-30% in the topsoil and the 35-40% in the subsoil. The probes have been field calibrated allowing for testing of the model in terms of its accuracy in mm of soil water and its ability to estimate general trends which we assess with the correlation coefficient. In this paper we test the version of the model which uses national inputs as described in Table 1.

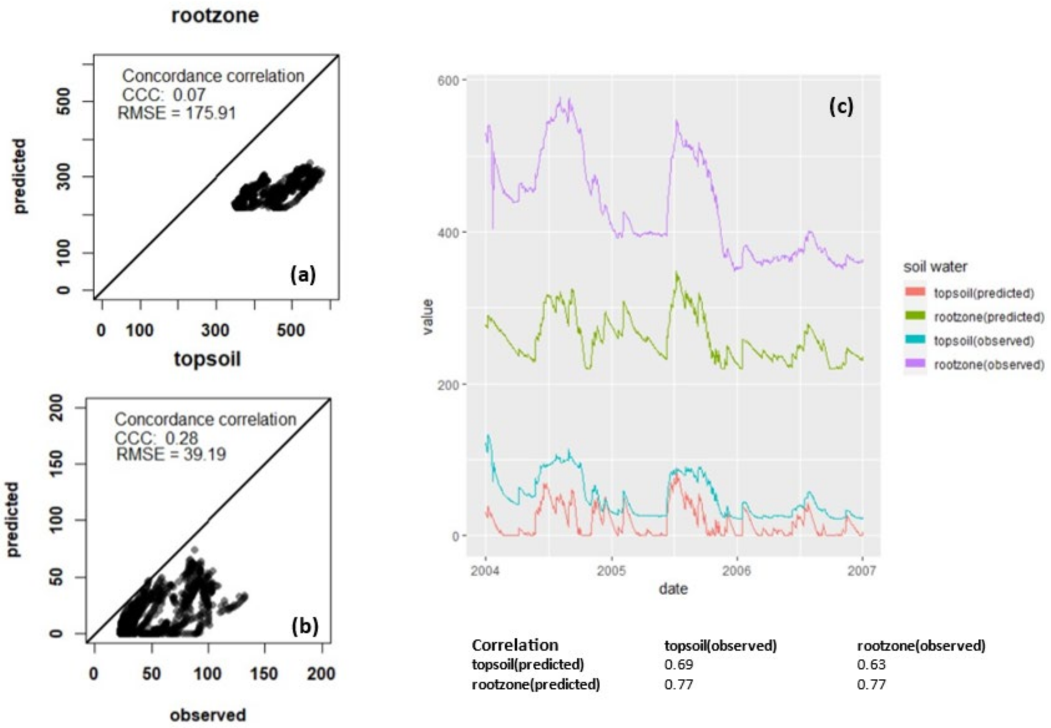
Across the 6 sites the correlation between observed and predicted ranged from 0.57-0.67 (mean = 0.66) for the 0-30 cm layer and from 0.48-0.77 (mean = 0.68) for the whole profile which is from 0-100 cm. This means that the predictions are a reasonable representation of the general trends in the observed data. In terms of predicting soil water in mm the accuracy ranged from 22-58 mm (mean = 34 mm) for the 0-30 cm layer and from 33-176 mm (mean = 78 mm) for the whole profile (0-100 cm).

Figure 1 and 2 show examples of sites where both sites are predicted well in terms of the general trend as evidenced by the high and lows matching. This is also shown by the correlation values which are generally around 0.6. However, in terms of predicting actual soil water the performance is not as good with clear differences between the time series traces of predicted and observed soil water. This is most noticeable in Figure 2 with the hypothesised reason being that the estimate of the soil water bucket size is incorrect meaning there is bias in the predictions.



Correlation	topsoil(observed)	rootzone(observed)
topsoil(predicted)	0.67	0.56
rootzone(predicted)	0.73	0.69

Figure 1 Site 6: the comparison between the probe measurements and model estimates (a) root zone; (b) topsoil; (c) time-series of soil water topsoil (0-30 cm) and root zone (0-100 cm).

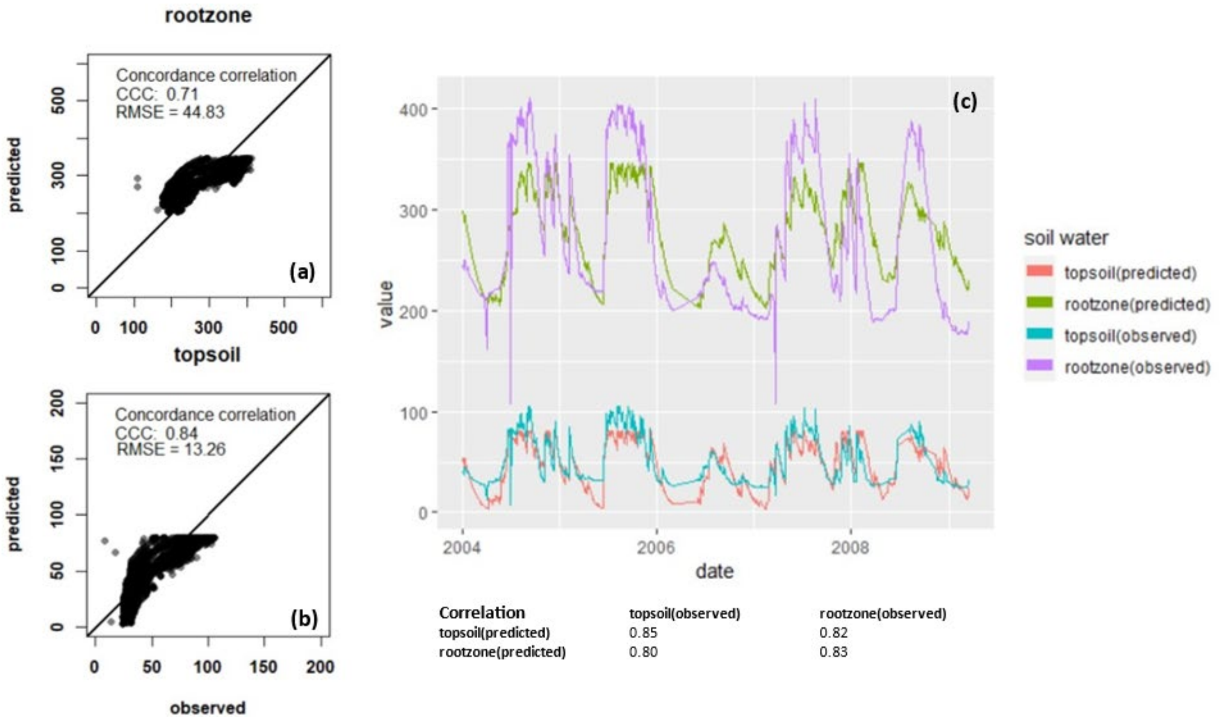


Correlation	topsoil(observed)	rootzone(observed)
topsoil(predicted)	0.69	0.63
rootzone(predicted)	0.77	0.77

Figure 2. Site 12: the comparison between the probe measurements and model estimates (a) root zone; (b) topsoil; (c) time-series of soil water topsoil (0-30 cm) and root zone (0-100 cm) from 2004 to 2007.

When we calibrate the model to the soil moisture probes we found that the correlations were similar and they ranged from 0.42-0.85 (mean = 0.72) for the 0-30 cm layer and from 0.26-0.83 (mean = 0.67) for the whole profile (0-100 cm). As expected the accuracy improved with calibration and ranged from 13-33 mm (mean = 22 mm) for the 0-30 cm layer and from 21-128 mm (mean = 55 mm) for the whole profile (0-100 cm).

Figure 3 and 4 presents results for when we calibrate the model and illustrate two important points. The first is that calibration improves the predictions in terms of their accuracy and correlation when the estimate of the bucket size is reasonable as shown in Figure 3. When the bucket size is too poorly predicted the model parameters cannot be changed enough to overcome this constraint as shown in Figure 4 where the model predictions reach a “ceiling’. While the parameters can be changed to make the model more accurate overall this results in prediction of a mean value for parts of the time series meaning the correlation is worse.



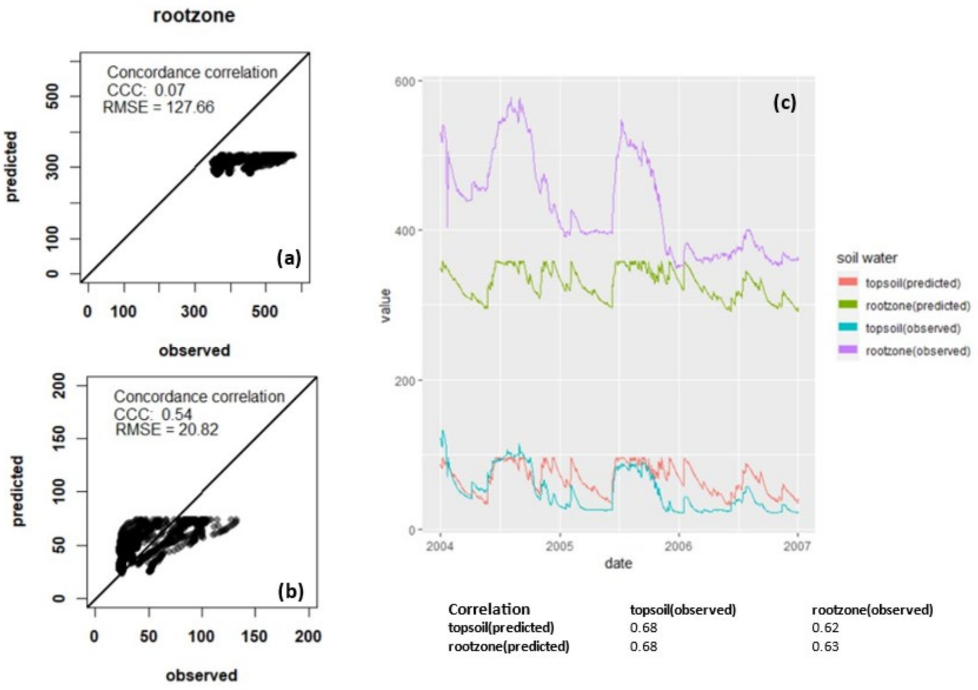
Correlation	topsoil(observed)	rootzone(observed)
topsoil(predicted)	0.85	0.82
rootzone(predicted)	0.80	0.83

Figure 3. Site 6: the comparison between the probe measurements and calibrated model estimates (a) root zone; (b) topsoil; (c) time-series of soil water topsoil (0-30 cm) and root zone (0-100 cm).

Applications

While we continue to work on the underlying the model and improve the inputs, an important outcome of the project is that the approach is scalable to the nation and modular in that users can provide their own data. Here we show 2 applications.

The first application is where we have applied the model to a 5000 hectare farm in northern NSW where the grower has invested in developing a digital soil map of their farm in terms of the bucket size. Here we show soil water and plant available water (PAW) where PAW is the amount of soil water between the crop lower limit and the drainage upper limit (Figure 5). This is estimated from a particle size and carbon soil samples using a pedo-transfer functions specific to Vertosols.



Correlation	topsoil(observed)	rootzone(observed)
topsoil(predicted)	0.68	0.62
rootzone(predicted)	0.68	0.63

Figure 4. Site 12: the comparison between the probe measurements and calibrated model estimates (a) root zone; (b) topsoil; (c) time-series of soil water topsoil (0-30 cm) and root zone (0-100 cm) from 2004 to 2007.

Figure 5 shows that much of the stored soil water across the farm is not accessible by the plants.

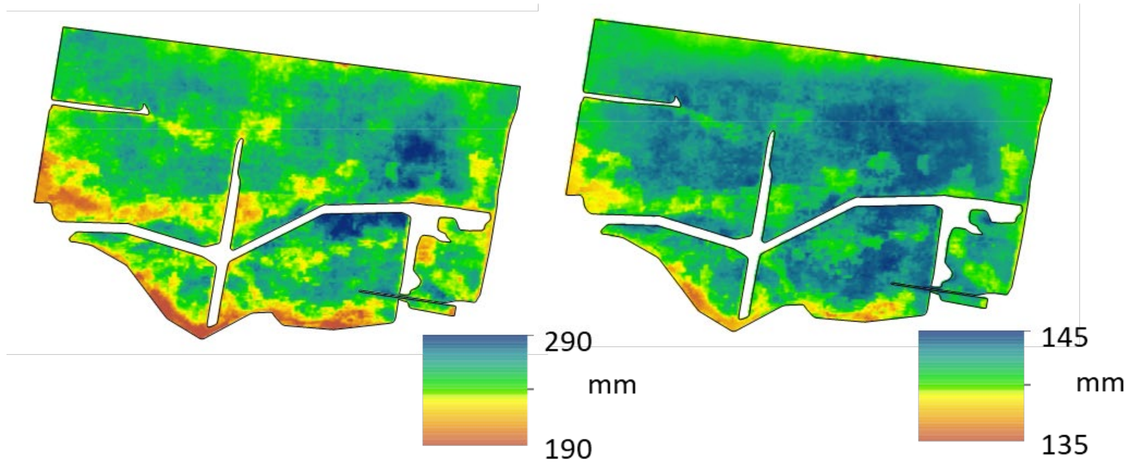


Figure 5. Maps of soil water for 0-90 cm at 30 m spatial resolution on August 31st 2020 (left) and total soil plant available water (PAW) (right).

The second application is an estimate of plant available water for the Murray-Darling Basin for which we have created a prototype data product at 500 m on a daily time step for 2000-2020. Figure 6 shows a map of PAW for 0-100 cm for January 1st 2019 as an example. The model was deployed on Gadi, one of the high performance computers available to researchers as part of our national computational infrastructure (NCI). The deployment for the MDB was a test case to assess the feasibility of deploying the model over large regions in terms of the compute time and the actual cost of the processing power and data storage requirements. The initial results from this are pleasing in terms of their cost-efficiency and we are now looking to update the data product to be (i) more real-time (ii) include all cropping regions in Australia (iii) give predictions at a finer spatial resolution. We are also planning on releasing a web-based dashboard of the soil water predictions so growers can zoom into their farm to examine the model predictions in more detail.

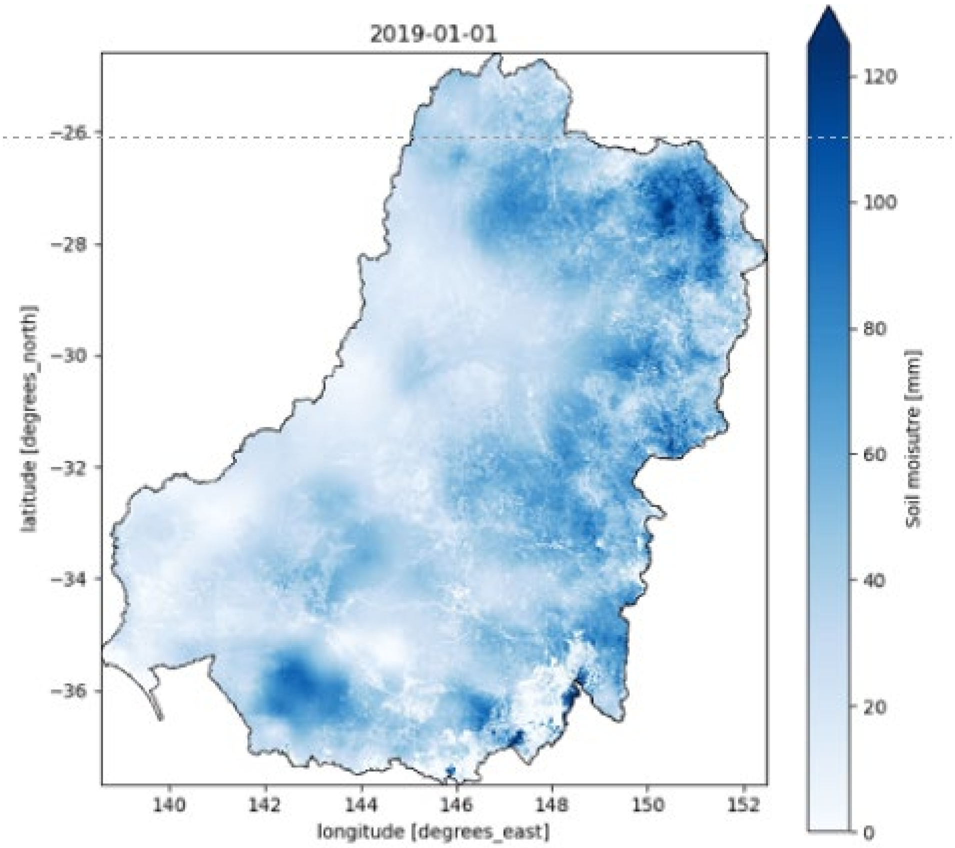


Figure 6. Map of plant available soil water across the Murry-Darling Basin for 0-100 cm at 500 m spatial resolution on 1st January 2019.

Conclusions

Based on this work, the current water balance model can predict the relative patterns of soil moisture quite well but is more inconsistent when predicting absolute values in mm of soil water. This means that generally we can help growers determine highs and lows quite well but are not quite there for using the predictions of mm soil water for direct decision support, for example to estimate potential yield using water-use efficiency equations. The biggest source of errors seems to be from the underlying estimates of the bucket size, which carry through to the calibrated model. Further work is needed to confirm this. Concurrent work in this project undertaken by CSIRO is improving the bucket size estimates from the Soil-Landscape Grid of Australia (SLGA) for the cropping regions of Australia. It should also be noted that growers could invest in developing digital soil maps of their farms and not have to rely on national soil datasets such as the SLGA. This could be as farm-specific maps or ones developed by grower groups or consultants for small regions.

We now have the workflow developed to deploy the model across large regions at a moderate spatial resolution (500) and over farms at a high spatial resolution (30 m). We can do this with different combinations of national and on-farm equivalents as shown in Table 1. We are now interested in getting feedback on the model predictions from growers. As part of this process we will deploy the model on your farm at a 30-90 m spatial resolution and ask for feedback in the form of a short survey and/or comparison with other on-farm data such as crop yield maps, moisture probes etc.

If interested please contact the project lead, Tom Bishop whose contact details are below.

References

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Capitalising on great seasons when they occur - is that the most profitable strategy and where is balance point for risk and reward? What do more profitable growers do?

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Thursday 24 February 2022
Weeds

Herbicide resistance threats for SNSW and economics of impact mills

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Keywords

glyphosate resistance, impact mills, HWSC, annual ryegrass, wild oats, sowthistle

GRDC code

US00084, UCS00020

Take home message

- Growers are urged to restrict annual ryegrass population densities to help mitigate the ongoing and widespread evolution of herbicide resistance in this weed species
- Annual ryegrass and sowthistle are at high risk for the evolution of herbicide resistance and a range of weed control strategies are required for the effective management of these species
- Efficient harvester setup and operation can potentially be used to offset the increased costs of using impact mills during the harvest of high yielding crops.

Background

The NSW crop production region covers a diverse range of growing season conditions. Rainfall patterns vary markedly across the region, from summer dominant in the north to winter dominant in the south. Accordingly, the winter growing seasons are longer and cooler in the south, supported primarily by in-season rainfall and shorter and warmer in the north with greater crop reliance on stored soil moisture (Figure 1). As production practices are adapted to changing climates, regional variability in production practices can provide insights into future weed problems. For example, in southern NSW with an apparent shift in focus on soil moisture storage during summer fallow phases for use by subsequent winter crops, summer weed control will become increasingly important along with the need to avoid resistance evolution in summer weed species.

The use of herbicides to successfully control crop weed infestations has been integral to the success of conservation cropping systems in southern NSW and elsewhere in Australia. But over reliance on herbicides has led to the widespread evolution of herbicide resistant weed populations, particularly in annual ryegrass that is by far the most dominant weed of this region (Broster *et al.* 2019). As demonstrated by high frequencies of multiple resistant annual ryegrass populations across many Australian cropping regions (Boutsalis *et al.* 2012; Owen and Powles 2018) this weed is especially prone to resistance evolution. Multiple resistance means the loss of multiple herbicides for the control of annual ryegrass and as this weed is by far the most prolific weed in southern NSW cropping, this means the loss of these herbicides for use on other weeds also. The introduction of harvest weed seed control has helped to reduce the reliance on herbicides, however there are several constraints that prevent the use of these systems in every crop.

Methods

Weed species and herbicide resistance surveys

Over the five-year period from 2013 to 2017, approximately 1,000 cropping paddocks across New South Wales were surveyed at winter crop maturity (Nov. and Dec.) (Figure 1). Each year 75 to 150 paddocks depending on the size of the cropping region were surveyed, with weed species and density data recorded and seed samples collected for subsequent screening.

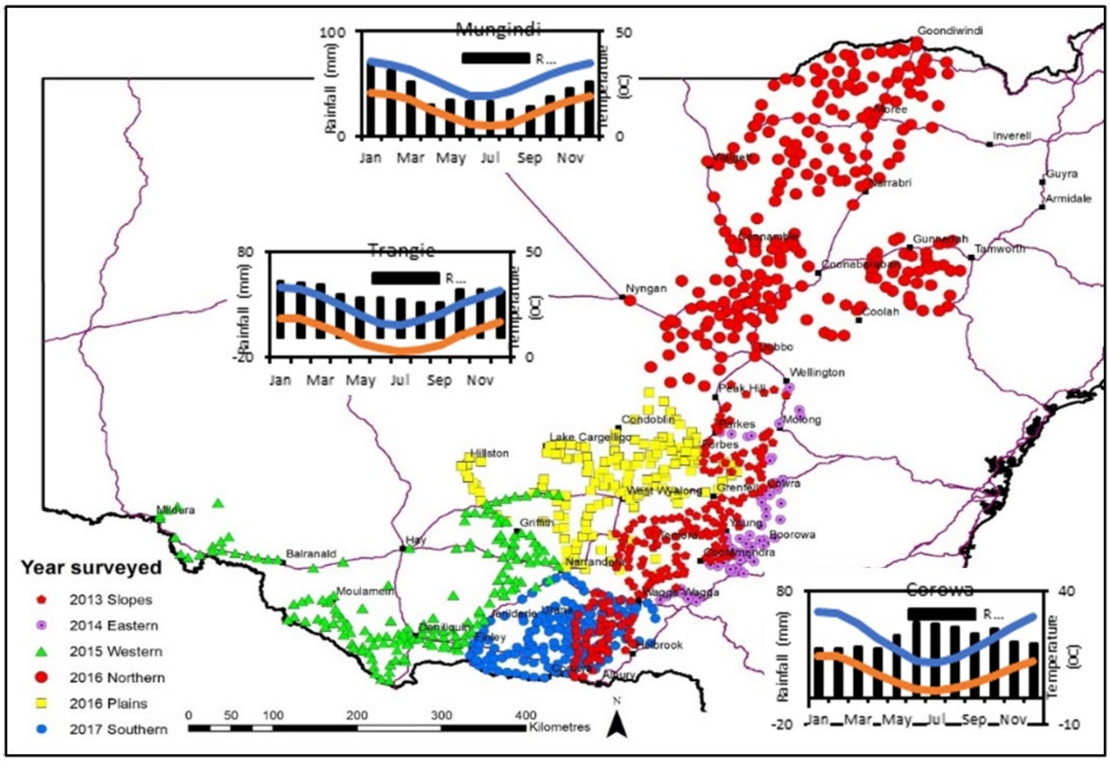

Figure 1. Location of cropping paddocks surveyed in each of the NSW cropping regions during random weed seed collection surveys conducted at the end of each growing season from 2013 to 2017. Embedded line and bar graphs depict long-term (60+ years) monthly average rainfall and temperature data for three representative locations that indicate growing season differences across the cropping region (Bureau of Meteorology 2021).

Herbicide resistance screening

When weed seedlings had reached the three to five leaf stage, herbicide treatments were applied at the upper recommended label rate for each herbicide to the weed species being screened. Herbicides were applied together with appropriate adjuvants (if required) using a twin-nozzle (TeeJet XR110015, Springfield, IL, USA) cabinet sprayer calibrated to deliver 85 L water ha^{-1} at 250 kPa.

Plant mortality was assessed 21 days after treatment, by determining whether the growing point was chlorotic or new growth was visible, as well as comparing with the known susceptible populations. Known susceptible and resistant plant biotypes were used as controls in all experiments, with 100% control of the known susceptible population and high survival (e.g., >90%) of the known resistant populations. In cases where the seed quantity for a population was low, some herbicides were omitted and not all herbicide treatments were repeated. Herbicide resistance screening was conducted under 'ideal' conditions for plant seedling growth, herbicide treatment and treatment effects thus, herbicide efficacy in the field may be lower than was observed in this survey.

Populations were classified as herbicide resistant when >20% of plants survived the upper recommended rate.

Economics of impact mill systems

The costs of using impact mills were compared using the calculator developed by Peter Newman, a farm business consultant with Planfarm. Three scenarios were compared using this calculator and defined cost parameters (Table 1).

- **Scenario one:** influence of higher yielding crops (wheat 5.0 t/ha, legume 3.0 t/ha and canola 3.0 t/ha) on impact mill costs
- **Scenario two:** influence of harvester operation (chaff yield as a % of grain = 0.1) on impact mill costs.
- **Scenario three**: influence of the doubling of nitrogen fertiliser prices on HWSC system use costs.

Table 1. Economic and agronomic parameters used when comparing the influence of harvest scenarios on the operation costs of impact mill systems.

Crops	**Area (ha)**	**Yield (t/ha)**
Cereal	1500	2.5
Legume	750	1.5
Canola	750	1.5
		total tonnes of grain
Total crop area (ha)	3000	6000
Number of harvesters	1	those fitted with HWSC tool
Chaff yield as % of grain yield	0.33	
Fertiliser		$/unit
Urea price ($/t)	500	1.00 N
Muriate of potash price ($/t)	600	1.21 K
MAP price ($/t)	685	2.66 P
Ammonium sulphate ($/t)	280	0.29 S
Operating costs		
Depreciation %	10	
Interest %	4	
Harvest cost $/hour	400	per harvester and chaser bin
Harvest rate ha/hour	10	
Harvest cost $/ha	40	
On farm fuel cost ($/L)	1.10	
Extra fuel due to impact mill (L /t grain harvested)	1	
% reduction in harvest capacity	10	
Wearing parts cost ($/per t grain)	1	$ per t grain
Impact mill	Fitted cost ($)	
Vertical iHSD ®	90,000	
Seed Terminator	120,000	
Redekop™	110,000	

Results and discussion

Weed species occurrence

In SNSW the frequency of occurrence for annual ryegrass (82%) and wild oats (68%) in the weed survey was more than double that of any of the other recorded species.

Sowthistle (25%) was the next most prolific weed of SNSW recorded during these surveys as mature plants at the end of the winter growing season (Table 2). This species is also summer growing and where soil moisture is adequate can be expected to emerge and establish at any stage during summer and winter growing seasons. As sowthistle is prolific, resistance prone and favoured by no-till cropping systems, this will continue to become increasingly difficult to manage in SNSW cropping systems (Chauhan *et al.* 2006; Widderick *et al*. 2010; Werth *et al.* 2017).

Table 2. Five most commonly observed winter annual weed species of the NSW cropping regions as recoded at winter crop harvest during annual random surveys conducted over a five-year period, 2013 to 2017 (number in brackets represent percentage of occurrence in surveyed fields)

Ranking	**NSW average 2013 to 2017**	**Southern NSW 2017**
1	Ryegrass (68.5)	Ryegrass (81.5)
2	Wild oats (59.9)	Wild oats (67.9)
3	Sow thistle (34.2)	Sow thistle (25.3)
4	Barley grass (17.0)	Brome grass (13.6)
5	Wireweed (15.4)	Barley grass (8.6)

Herbicide resistance in southern NSW

Annual ryegrass and wild oats

The very high potential for herbicide resistance evolution in annual ryegrass populations ensures that this species will continue to dictate weed management programs in southern NSW. Very high frequencies of Group 1 (A) (fop only) and 2 (B) (su and imi) herbicide resistant annual ryegrass populations were present throughout the southern NSW cropping region (Table 3). These high levels of resistance to post-emergence selective herbicides, has led to increased reliance on residual herbicides for control of annual ryegrass. There were also significant levels of Group 1 (fop only) resistance found in wild oat populations (Table 3). As annual ryegrass is the most frequently occurring weed across the region then resistance in annual ryegrass must often be first considered before strategies to manage other weeds can be formulated. This can complicate the strategies needed to control populations where multiple weeds are present.

Table 3. Frequency of resistance to commonly used herbicides in randomly collected annual ryegrass and wild oat populations collected from the 2017 winter crop survey of southern NSW cropping paddocks (Resistant = >20% survival)

Herbicide group		Herbicide[a]	Annual ryegrass	Wild oats
Old	New		Resistant populations (%)	
A (fop)	1 (fop)	Diclofop /clodinafop	85	30
A (dim)	1 (dim)	Clethodim	3	0
B (SU)	2 (SU)	Sulfometuron / iodosulfuron	74	0
B (Imi)	2 (Imi)	Imazamox + imazapyr	75	-
D	3	Trifluralin	1	-
J	15	Triallate	-	0
J/K	15	Prosulfocarb + s-metolachlor	0	-
K	15	Pyroxasulfone	0	-
M	9	Glyphosate	7	0

[a] Herbicides applied at the upper recommended rate; - indicates not screened with this herbicide

Sowthistle

There is a very high frequency of chlorsulfuron resistance in NSW populations of sowthistle (94%) Resistant populations were found to be uniformly distributed throughout the NSW and Qld cropping regions (Figure 2A). In contrast, few if any chlorsulfuron susceptible sowthistle populations were found outside of the southern NSW cropping region.

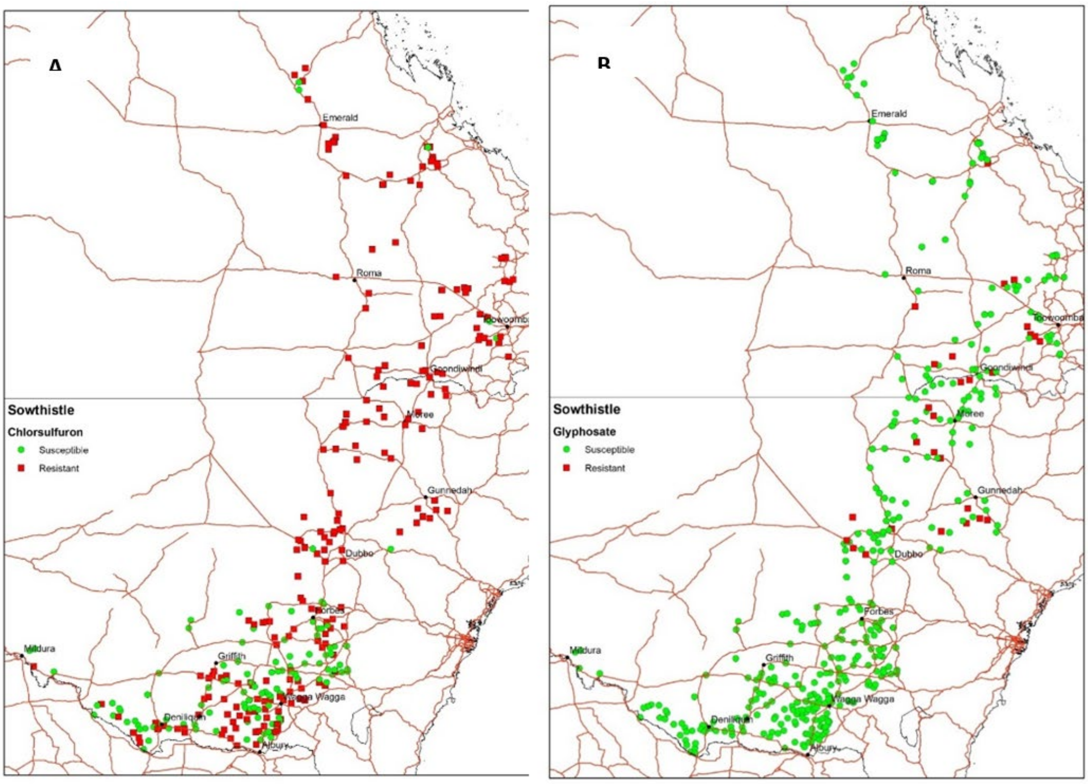

Figure 2. Maps showing (A) chlorsulfuron resistant and susceptible and (B) glyphosate resistant and susceptible populations of sowthistle that were randomly collected during an end-of-season random surveys of the northern grain's region in 2016.

A concerningly high frequency of glyphosate resistance was identified in randomly collected sowthistle (14%) populations (Figure 2B). The majority of the resistant populations were collected from the northern areas of the survey region where there has been an intense selection pressure for glyphosate resistance due to the reliance on this herbicide for summer fallow weed control over many years. As sowthistle is prolific throughout southern NSW, the concern is that an increasing focus on summer fallow weed control will result in similar levels of resistance in this region.

Economic considerations of impact mill systems

Influence of crop harvest program

When grain yields are increased (doubled) as occurred in many areas this last harvest, the costs of running impact mills are estimated to have increased by $4 to $5/ha (Table 4). This cost is related to the increased time taken to harvest a hectare which translates to greater fuel use and wear per unit area. Consequently, the cost of using an impact mill is estimated to increase from around $14 to $18/ha.

Table 4. Predicted influence of high crop yields on the operating costs of impact mills during grain crop harvest

Impact mill	Average yield	High yield
	Cost ($/ha)	
Vertical iHSD	13	18
Seed Terminator	15	19
Redekop	14	18

Harvester setup and operation is becoming increasingly important for improving the efficiency of grain harvest. The original estimate of a 1:3 chaff to grain ratio used as a standard parameter here was based on research conducted several years ago prior to the current understanding of harvester setup and operation (Broster *et al.* 2016). More recently collected data suggests that chaff ratios are much lower when there is a focus on harvester setup (Broster *pers. Comm.*). The impact of reduced chaff production during a more efficient harvest operation results in an estimated $3/ha reduction in impact mill operation costs (Table 5).

Table 5. Predicted influence of harvester setup on the operating costs of impact mills during grain crop harvest

Impact mill	Standard chaff:grain ratio (0.33)	Low chaff:grain ratio (0.1)
	Cost ($/ha)	
Vertical iHSD	13	10
Seed Terminator	15	12
Redekop	14	11

When fertiliser inputs due to HWSC related nutrient removal (concentration in tramlines or windrows) are included in the cost calculations for HWSC systems, Impact mill systems are economically comparable to the other apparent ’cheaper‘ options such as chaff lining and chaff tramlining. The concentration and removal of harvest residues results in nutrient concentration into small areas (e.g., chaff lining, tramlining) or removal (e.g. baling, burning). As impact mill systems allow all residues and thus all nutrients contained in stubble and chaff to be retained in the paddock, then these systems are more 'nutrient efficient'. To compare the impact of increasing fertiliser prices on HWSC costs, a doubling of nitrogen fertiliser costs was used in comparison with the standard. In this scenario there was a $5 to $10/ha increase in cost for all but the impact mill HWSC systems. The indication is that nutrient placement costs can have a greater influence on HWSC system economics than operational costs during harvest (Table 6).

Table 6. Predicted Influence of higher nitrogen prices on the costs of using HWSC systems during grain crop harvest

HWSC system	N Unit price $1.00/kg	N Unit price $2.00/kg
	Cost ($/ha)	
Narrow windrow burn	35	45
Chaff line	16	21
Chaff Deck	17	22
Chaff cart	22	27
Bale Direct	73	88
Vertical iHSD	15	15
Seed Terminator	16	16
Redekop	16	16

Conclusion

The widespread distribution of annual ryegrass combined with the high frequencies of resistance in populations ensure that this weed will continue to dominate weed management decisions in southern NSW cropping programs. The ongoing challenge for the region's growers is to maintain very low densities of this weed in their cropping systems to slow the continuing evolution of resistance and loss of herbicide resources for the control of annual ryegrass and other weed species, such as wild oats. With an increasing focus on summer weed control there is increased pressure to select for glyphosate resistance evolution in sowthistle populations that are prolific throughout the region. As observed in other areas, over reliance on glyphosate has already resulted in widespread resistance in sowthistle populations. There are economic constraints to the use of impact mills during the harvest of higher yielding crops. However, there may an opportunity to mitigate this impact through improved harvest setup and operation.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

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Killing glyphosate resistant ryegrass? Application does matter

Maurie Street and Ben O'Brien, Grain Orana Alliance

Key words

herbicide, resistance, annual ryegrass, spraying, water quality, water rate, spray quality

GRDC code

GOA2006-001RTX- Agronomic management of weeds, crop nutrition and farming practices in Central NSW to maximise crop profitability.

Take home messages

- How and when herbicides are applied resulted in significant variation in the numbers of Annual Ryegrass (ARG) survivors as it influences the delivery of the 'intended dose'
- Many factors can reduce the delivery of the 'intended dose' to the target weed, two major factors identified in this work are:
  - Poor water quality
  - Inappropriate spray quality and timing
- Growers with poor quality water should consider using another water source or ameliorating the water
- The small target leaf area of seedling ARG means that large spray droplets were often ineffective.
  - Delaying application, increased water rates, or using spray qualities more capable of contacting and adhering to the weed resulted in significantly fewer survivors
- Herbicide resistance is not always the sole cause for spray failure
  - Growers and advisors should critically assess spray failures, as resistance is one of many factors that may contribute to poor levels of control.

Background

In 2020, GOA presented a paper at the GRDC Updates reviewing GOAs recent experimental observations in controlling problematic annual ryegrass (ARG) populations.

A copy of the paper can be found at https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/02/is-our-ryegrass-really-getting-harder-to-kill-through-our-over-reliance-on-glyphosate

These findings showed that in several cases the assumption of glyphosate resistance was incorrect despite poor control by commercial applications on the targeted populations. Furthermore, some of the populations with confirmed glyphosate resistance were also controlled with only moderate label rates.

These findings reminded us that the causes of commercial spray failures are not always due to resistance. Contributing factors to weed control failure could include but are not limited to; inappropriate water rates, poor water quality, inappropriate droplet size for the target plant, poor spray timing or antagonism with other tank mixed herbicides.

This is not to suggest that herbicide resistance is not real or not the sole reason for failure in some circumstances, however in the presence of resistance, shortcomings in our efforts to control weeds are being highlighted by poor control, which if rectified, could be much improved.

GOA has undertaken several investigations to better understand the potential influence of some key parameters of spray application. These are outlined below.

Delivering the intended dose

The investigations detailed in this paper focuses on annual ryegrass with glyphosate resistance.

Some resistance mechanisms are relatively weak, while others are very strong. If a resistance mechanism is relatively weak, the weed population can still be dose responsive, where increasing the rate applied increases weed mortality. In these cases, improved spray practices allowing one to 'deliver more of the intended dose', will often be reflected in improved levels of weed control. However, if the resistance mechanism is strong and the lethal dose required is higher than is commercially or legally possible, it is suggested that improving spray practice will have little or no benefits.

Results of herbicide resistance testing conducted on ARG sampled by GOA in the central west of NSW over several years has shown that weak glyphosate resistance is relatively common, and that many of these populations should be controllable at higher label rates. However, in a number of cases, despite appropriate rates of glyphosate being applied, commercial control was often sub optimal.

More detailed investigations suggested that many spray operations may not delivering the intended dose and consequently were instead providing only a sub lethal dose, resulting in spray survivors. For example, if a grower has an ARG population that has moderate levels of resistance at 1 L/ha of glyphosate but is rate responsive and the population can be controlled at 1.5 L/ha. If they were to apply 1.5L/ha to appropriately sized weeds, an acceptable level of control could be expected. However, if using poor quality water, the intended dose could be reduced by impurities in the water neutralising some of the glyphosate. If we then added a further complication of poor droplet contact and adherence to the target weed, it is plausible that the lethal dose is reduced further. In this example it is possible that the intended dose of 1.5L/ha is only being delivered to the ARG population at 1 L/ha and as such many ARG plants survive.

GOA has run a series of trials, detailed below, that has demonstrated the potential impact or water and spray practices on weed control outcomes.

All trial results are analysed by ANOVA with a confidence interval of 95%, results with the same lettering are not significant different.

Water quality, adjuvants, or water conditioners

In 2018 SOS Macquarie analysed 180 ground water sources (bores) used for spraying throughout the region. The results summarised in Figure 1 below show that ~80% samples exceed acceptable limits for either pH or bicarbonate levels as a spray carrier. Accompanying information for the samples submitted indicated that for many growers, this was their only reliable source of spray water (Hulme, unpublished).

This data shows that spray water quality for many growers is less than ideal for use without some sort of amelioration (which may not always be possible) and that is likely to impact herbicide performance. In response to this many growers are adding either sulfate of ammonia (SOA) or Li700® to address issues associated with water quality.

Of the water quality issues listed in Figure 1 above, total hardness and bicarbonate levels are the factors most critical to consider when applying glyphosate. High levels of calcium and magnesium in hard water will cause glyphosate to bind-up, thus reducing its efficacy.

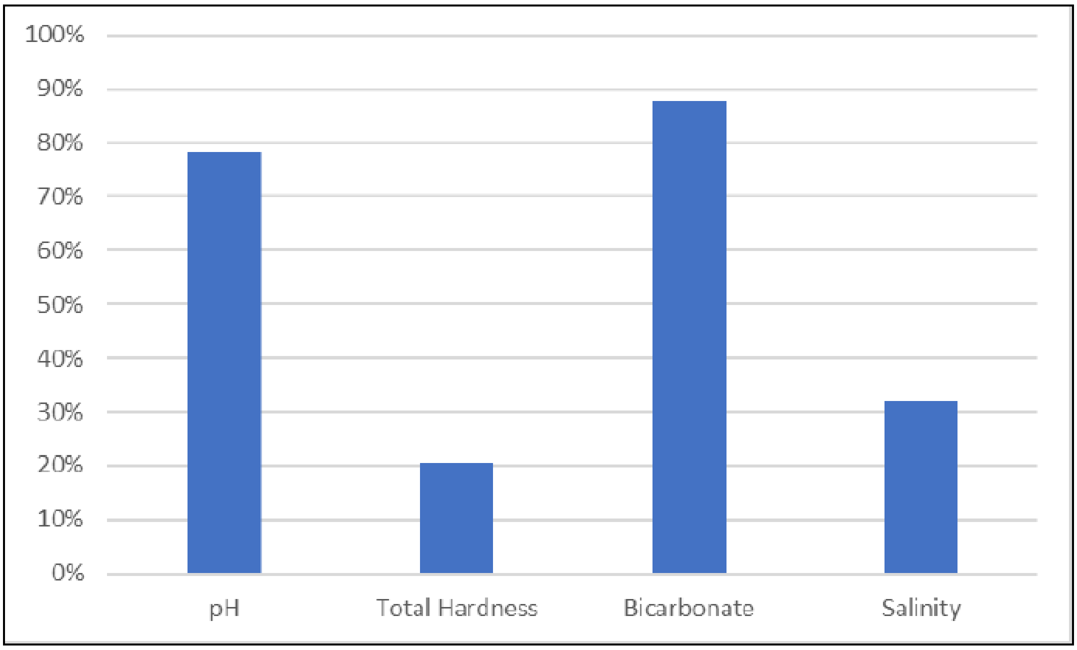

Figure 1. Proportion of samples analysed that exceeded critical levels (Hulme, unpublished)

SOA precipitates much of the calcium out of solution before glyphosate is added to the tank, thus minimising the impact that hard water has on glyphosate efficacy. Additionally, SOA can help glyphosate move across the leaf membrane and aid uptake by the plant.

Li700 is primarily used to reduce spray water pH although it also has properties as a wetting agent. However, pH is less of an issue to consider when applying glyphosate, as glyphosate is a weak acid it benefits from application in a slightly acid solution but will, by itself reduce spray water pH. As such, the addition of Li700 as an acidifying agent does not add much to efficacy (except where pH is very high, water rates are high and glyphosate rate is low), however its use may still be warranted for its wetting agent characteristics.

Results

In 2021 GOA established a trial to investigate the relative impact of water quality and the use of these two common additives when used with glyphosate on ARG control.

The trial was established in the Autumn of 2021 at Narromine NSW. At the time of application there was a population of three leaf to early tillering ryegrass present at 120 plants/m^2. A 'Quick-Test' confirmed the population to have dose responsive glyphosate resistance as shown in Table 1.

Table 1. Herbicide resistance testing results to applications of glyphosate on annual ryegrass populations sampled at Narromine in 2021

Herbicide	Herbicide Group	Paddock Sample	
		Survival %	**Rating**
Glyphosate @ 285 g.a.i./ha	Group M	80	RR
Glyphosate @ 541 g.a.i./ha	Group M	10	R
Glyphosate @ 855 g.a.i./ha	Group M	0	S

The trial tested three water sources- rainwater, bore water and the same bore water after filtration through a commercial 'PureDrop' desalination plant (RO water). The PureDrop plant filters water by reverse osmosis to separate much of the salts from the bore water and can treat 30,000 L per day and runs off 240-volt mains power. This process improved the water quality to be very similar to that of the rainwater tested (Table 2).

Table 2. Results of water analysis of three water sources used for herbicide applications near Narromine 2021

Analyte	Unit	Bore	Reverse osmosis (RO)	Rain
pH		7.3	6.6	5.8
Electrical conductivity	dS/m	2.2	0.02	0.02
Bicarbonate alkalinity	mg $CaCO_3$/L	330	14.00	8.90
Bicarbonate alkalinity	meq/L	6.6	0.28	0.18
Water hardness	mg $CaCO_3$/L	550	2.30	2.50
Calcium (dissolved)	mg/L	38	<0.10	0.19
Chloride	mg/L	480	<15	<15
Sodium (dissolved)	mg/L	300	3.4	<0.5
Salinity class		3	1	1
Total dissolved ions	mg/L	1,500	15	11
Sodium adsorption ratio (SAR)		5.60	0.97	0.14
Sodicity class		1	0	0
Total alkalinity	mg $CaCO_3$/L	330	14	8.9

The trial also tested two different spray additives, two water rates (50 L/ha & 100 L/ha) and two rates of glyphosate (low & high). All treatments were applied with AIXR110-015 nozzles at 3 bar pressure applying a coarse spray quality. Speed was varied to apply the two water rates.

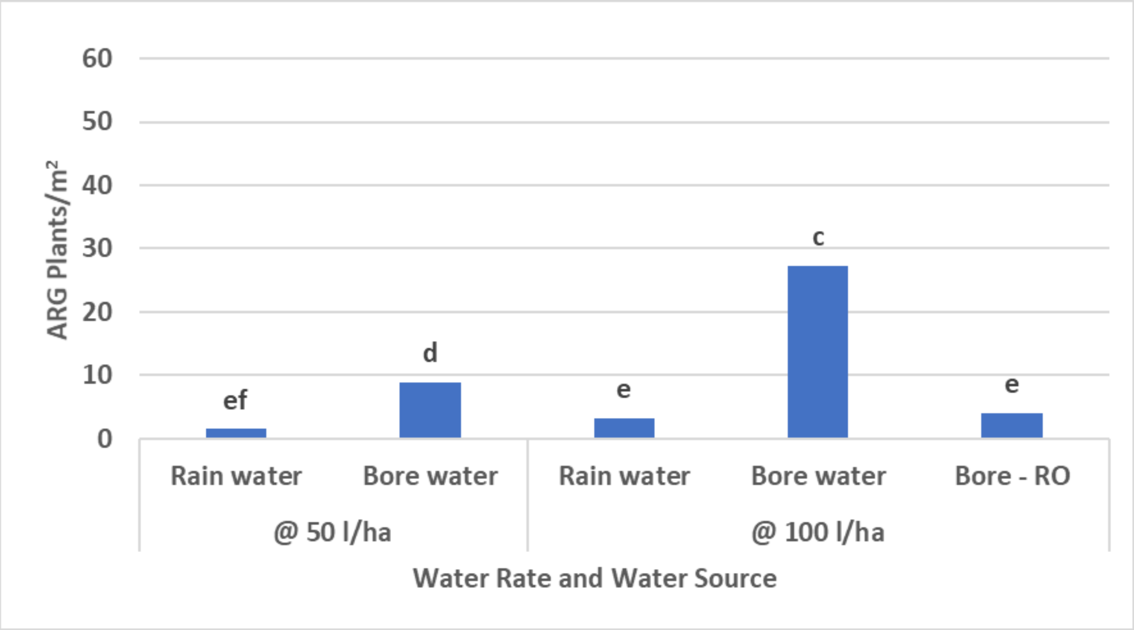

Figure 2. Surviving ARG numbers (34 DAA) assessed after a low rate of glyphosate using three different water sources and two water rates near Narromine 2021

As can be seen in Figure 2, using rainwater resulted in fewer ARG survivors than using bore water at either water rate. Increasing the water rate when using rainwater did not impact on ARG survivors but did when using bore water. Using the RO bore water resulted in fewer ARG survivors, similar to that achieved by the use of rainwater.

Increasing the rate of glyphosate when using bore water, at the higher water rate, resulted in significantly fewer ARG survivors. Increasing the rate of glyphosate when applying 50 L/ha of rainwater also reduced survivors from 1.6 plants/m^2 down to less than 1 plant in 10m^2 as illustrated in Figure 3.

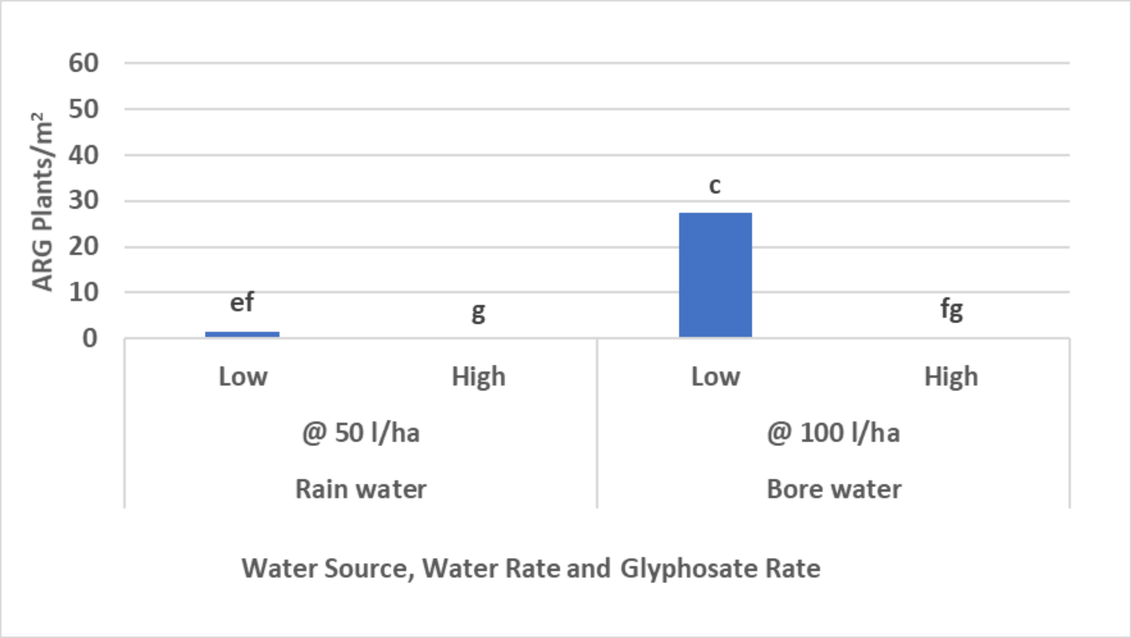

Figure 3. Surviving ARG numbers (34 DAA) after the use of two water sources, at two water rates using a 'Low' and a 'High' rate of glyphosate near Narromine 2021

Adding SOA or SOA + Li700 to bore water at the low rate of glyphosate resulted in fewer ARG survivors compared with no spray additives. Where Li700 alone was added to bore water, it resulted in more ARG survivors than bore water with no spray additives as shown in Figure 4).

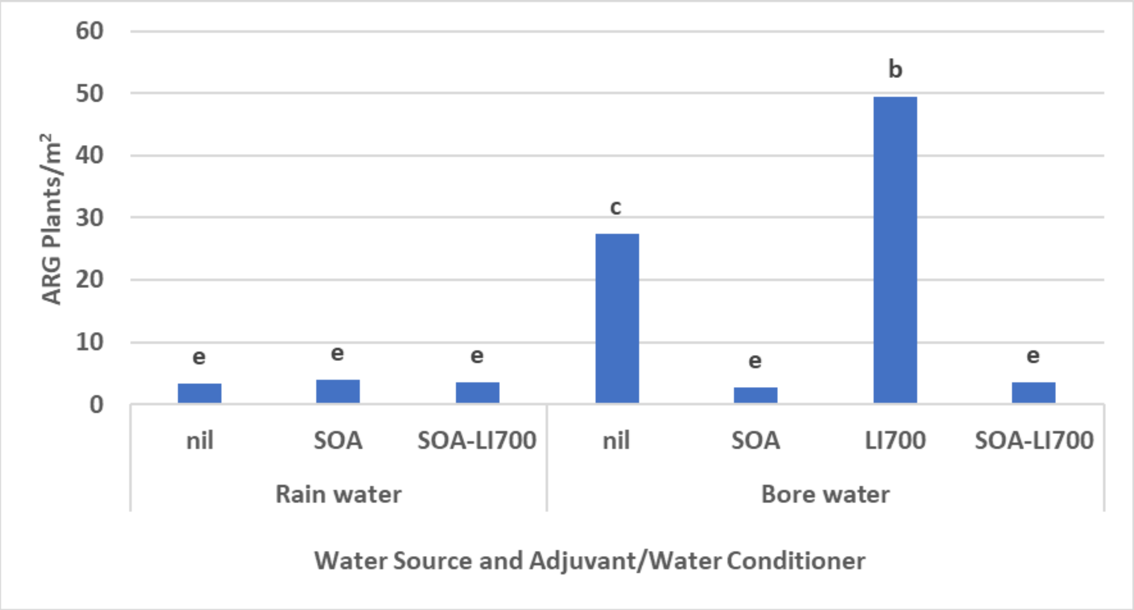

Figure 4. Surviving ARG numbers (34 DAA) in response to two water sources at 100 L/ha and added adjuvants/water conditioners when using a 'low' rate of glyphosate near Narromine 2021

The addition of SOA or SOA & Li700 to rainwater and the low rate of glyphosate did not impact ARG survivors (Figure 4), while adding SOA when applying glyphosate in bore water reduced the numbers of ARG survivors similar to that of when using rainwater.

Increasing the glyphosate rate in bore water with no spray additives resulted in almost no ARG survivors (Figure 5).

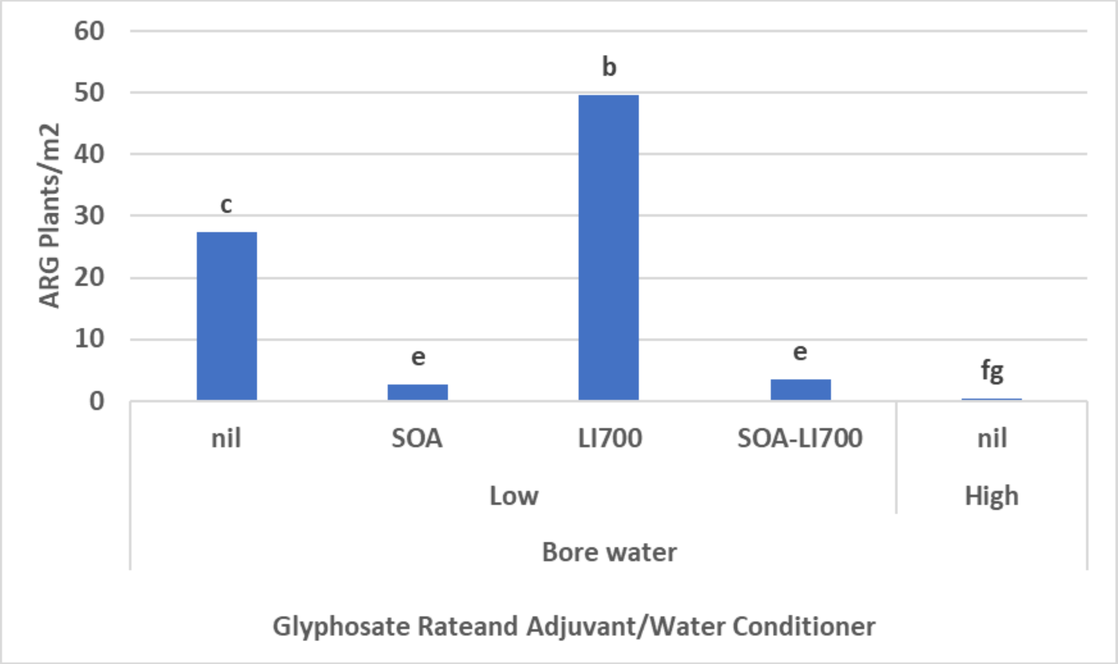

Figure 5. Surviving ARG numbers (34 DAA) in response to spray additives and 'Low' and 'High' glyphosate rates when applied in 100 L/ha of bore water near Narromine 2021

Spray quality, water rate and application timings

In Autumn 2021, GOA established three trials to investigate the effects of spray qualities, water rate and time of application on the control of seedling ARG.

The trials tested three spray qualities, achieved using differing nozzles including, Turbo Teejet (TT) Air Induction Extended Range (AIXR)] and Turbo Teejet Air Induction (TTi) at 4 bar operating pressures. The nozzles produced a Fine (F), medium (M) and extremely coarse (XC) spray qualities, respectively. Two water rates were tested by manipulating application speeds- 8 km/h to apply 100L/ha and 16 km/h for 50L/ha. All treatments were applied using rainwater as the carrier.

***NOTE:** Some brands/formulations of glyphosate have labelled, minimum spray quality requirement of no smaller than coarse to very coarse to be used, additionally some tank mix partners may also require minimum spray qualities larger than those tested in this work regardless of the brand or formulation of glyphosate.*

At each of the sites, two application timings were tested. The first targeted at ARG in the 1-3 leaf stage and the second at 9-11 days later. The major flush of ARG germinated at the trial sites during rain events about 21 days prior to the first application.

Table 3. Trial location and application dates - 2021

Trial Location	Date of first application	Date of second application
Forbes	7th April 2021	16th April 2021
Peak Hill	8th April 2021	19th April 2021
Coolah	9th April 2021	20th April 2021

Forbes trial

The Forbes site had an ARG population of 300 plants/m^2. Subsequent resistance testing demonstrated the population to have rate responsive glyphosate resistance as shown in Table 4 below.

Table 4. Herbicide resistance testing results to glyphosate in annual ryegrass populations, Forbes 2021

Herbicide	Herbicide Group	Paddock Sample	
		Survival %	Rating
Glyphosate @ 285 g.a.i./ha	Group M	40	R
Glyphosate @ 541 g.a.i./ha	Group M	15	R
Glyphosate @ 855 g.a.i./ha	Group M	0	S

Using an XC spray quality at the earlier spray timing and low water rate resulted in the highest surviving population of ARG (Figure 6). Increasing the water rate, using a XC, did not significantly improve the results at the earlier timing. Only where application was delayed, and the high-water rate was used was there a significant reduction in ARG populations when using an XC spray quality.

Applying a F or M spray quality at the earlier timing resulted in significantly fewer ARG and there was no advantage to delays in application or increasing water rates using these spray qualities.

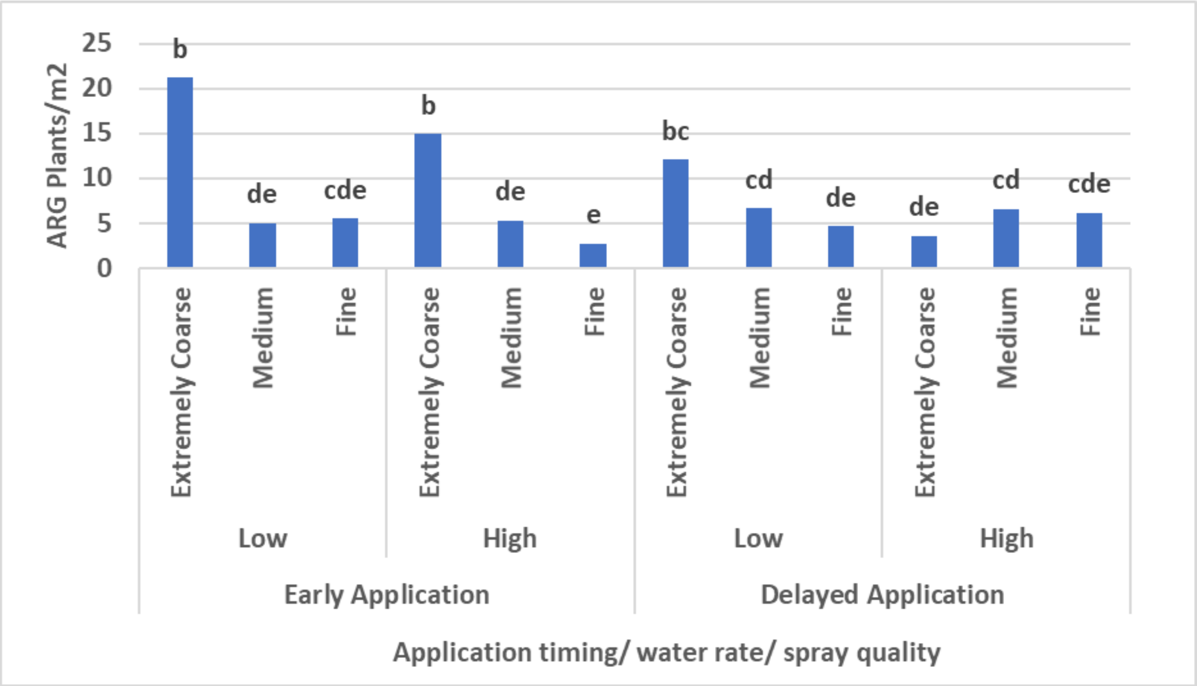

Figure 6. Surviving ARG numbers (43 DAA) in response to time of application, water rate (low= 50L or high=100L) and spray quality near Forbes 2021

Peak Hill

The Peak Hill site had an ARG population of 200 plants/m^2. Subsequent resistance testing of the population demonstrated a very low level of resistance to glyphosate as shown in Table 5.

Table 5. Herbicide resistance testing results to glyphosate in annual ryegrass populations sampled at Peak Hill in 2021

Herbicide	Herbicide Group	Paddock Sample	
		Survival %	**Rating**
Glyphosate @ 285 g.a.i./ha	Group M	10	R
Glyphosate @ 541 g.a.i./ha	Group M	0	S
Glyphosate @ 855 g.a.i./ha	Group M	0	S

The highest surviving populations of ARG were observed in the early spray timing, with the low water rate applied as an XC spray quality (Figure 7). Increasing the water rate at the early timing and same spray quality did not result in fewer ARG survivors. Delaying the application time with XC spray quality did result in fewer ARG survivors than the XC applied early, but there was no difference between water rates at the later timing.

Applying a F or M spray quality at the early timing resulted in fewer ARG survivors compared with XC spray quality for both water rates. There was no advantage to delaying spraying when using F or M at any given water rate. Where spraying was delayed there was no difference between any of the three spray qualities or water rates, except when a F quality was applied in the high-water rate.

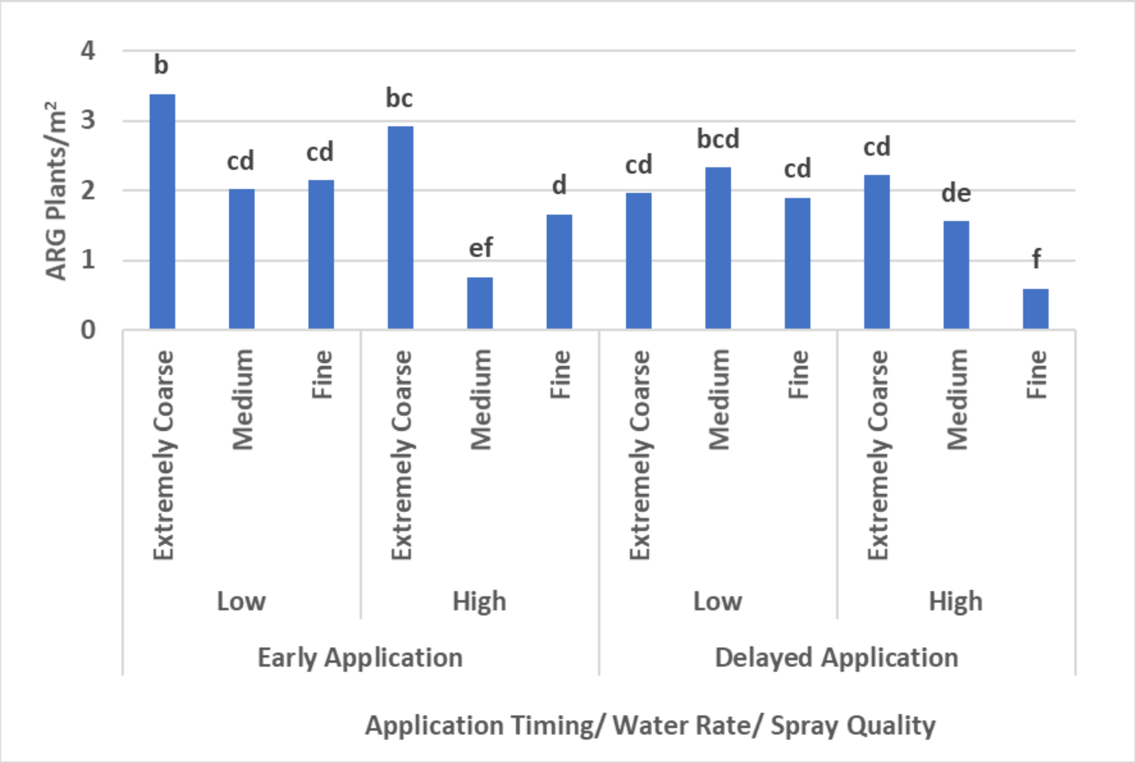

Figure 7. Surviving ARG numbers (29 DAA) in response to time of application, water rate and spray quality near Peak Hill 2021

Coolah

The Coolah trial had a dense population of 414 plants/m^2. Subsequent resistance testing demonstrated a very high level of resistance to glyphosate as shown in the Table 6 below.

Table 6. Herbicide resistance testing results to glyphosate in annual ryegrass populations, Coolah 2021

Herbicide	Herbicide Group	Paddock Sample	
		Survival %	Rating
Glyphosate @ 285 g.a.i./ha	Group M	100	RRR
Glyphosate @ 541 g.a.i./ha	Group M	100	RRR
Glyphosate @ 855 g.a.i./ha	Group M	80	RR

No measurable effects were detected in any of the treatments applied in this trial.

Discussion

ARG populations at all sites were high and the level of control was also high following many of the treatments applied, with most achieving over 90% control, a threshold often quoted as achieving commercially acceptable control. Despite these very high levels of control, high numbers of ARG survived in some cases. For example, at Forbes, the worst performing treatment achieved 93% control when compared to the untreated control (Figure 6), but around 20 plants/m^2 survived the application. Some of the better performing treatments at the same site reduced populations to as low as 3 plants/m^2 equating to 99% control (Figure 6).

In fallow situations ahead of sowing the poorer levels of control achieved by some treatments in these experiments would be commercially unacceptable and would require follow up control measures, such as a double knock. However, improving control by only a few percent is very worthwhile and, achievable as has been demonstrated by this research.

It should also be noted that the populations these trials were carried out on were all confirmed with varying levels of glyphosate resistance. Three of four sites are suggested to be typical in the region with resistance detected at lower rates of glyphosate and rated as susceptible at higher rates. At these three sites, more acceptable control was achieved simply by employing several practical and affordable measures - manipulating water source/quality, water rate, spray timing and spray quality.

At the fourth site, which had very high levels of resistance, no discernible difference in control was achieved from the treatments tested. This demonstrates that as the level of resistance exceeds appropriate labels rates, the ability to counter resistance by 'delivering the right dose correctly' is diminished. This re-enforces the benefits in testing populations to not only confirm the presence of resistance, but also to what level.

Water quality: The water quality trial highlighted the importance of using good quality water. In this case rainwater resulted in the best results without the need to add anything to the water. With good quality water there was also minimal upside or downside to using higher water rates. However, it should be remembered glyphosate is best applied in concentrated droplets to improve uptake. Increasing water rates can dilute spray concentrations. Longer term, growers who lack a supply of good quality water should consider investment in filtration systems (such as reverse osmosis) or installation of additional rainwater tanks or seek other 'better quality' sources of spray water. If this is not an option growers could look to modify or address the quality issues.

SOA is beneficial in addressing water hardness and bicarbonates common in bore water sources and resulted in significantly less ARG survivors when using bore water. The SOA acts to tie up the calcium and magnesium ions that can bind to and inactivate glyphosate.

Li700 primarily reduces the spray solution pH which should have been on face value, useful with the higher pH of the bore water. However, glyphosate is a weak acid and ample evidence is available that its use alone is sufficient to reduce the spray solution to acceptable pH levels. Interestingly, survival of ARG was significantly higher where it was used alone.

Water rates: Optimum water rates are most commonly accepted to be influenced by spray quality and the type and size of the target. Using 'contact' type products as opposed to translocated product like glyphosate will also change this dynamic.

But this work has also shown that it also interacts with water quality. As was shown at the Narromine trial, increasing water rates when using poor quality water increased ARG survival. The same effect was not evident with rainwater. These results illustrate the impact that dilution of glyphosate in more water with high levels of hardness reduces the intended dose of glyphosate before it can be delivered to the target.

SOA can be used to overcome water quality issues but that comes at an added cost, and the cost increases with water rate as its use rate is set based on water volume rather than the area on which the spray is applied. Consequently, water rates should be kept to a minimum when using poor quality water to minimise the potential tie-up of glyphosate and/or costs of amelioration and maximise the glyphosate concentration in the spray solutions. If using good quality water, only the latter is applicable.

Lower water rates need to be balanced against the needs to achieve sufficient coverage of the target weed, which is also linked to spray quality but glyphosate being a translocated product has a less reliance on good coverage to control weeds compared to many other herbicides.

Spray quality: The target weed for these trials was seedling ryegrass, a small upright weed with a waxy leaf that can prove difficult to both hit with a spray droplet and for that droplet to be retained without bouncing or rolling off the leaf.

These trials showed that the XC spray quality resulted in significantly more ARG survivors. And increasing water rates did not improve the outcomes in any trial unless spraying was delayed allowing the target to grow to a larger size suggesting that the droplets were just too large to be retained on the target at that growth stage.

It is worth noting at this point that the first time of application was already three weeks after the germinating rain. The delayed application was applied some 4 ½ weeks after the germinating rain, way too late to be spraying effectively for the other weeds most likely present to facilitate sowing or conserve moisture. Arguably delaying application was simply not a practical option in these situations.

However, spray qualities of F and M resulted in significantly fewer ARG survivors even at the earlier application timing and in most cases increased water rates or delays in application were not justified to improve control further. However, the risk of increased drift and/or evaporation losses from using these finer spray qualities should be taken into consideration as they can result in a reduction in efficacy, represent a loss from the system (increased cost). Further to this several glyphosate labels and potential tank mix partners now stipulate spray qualities to be coarse (C)-very coarse (VC) so using the finer spray qualities tested in this trial are not legally able to be done. Growers and advisors must check the specific labels of their intended products of use because there are differences.

It should be also noted that the XC spray quality in this trial is far coarser than the M tested. It is plausible that employing a spray quality in between the two tested such as a C-VC spray quality may have achieved similar results as the M without the downside risks noted above but this may require further testing to confirm.

However, the nozzle combinations were chosen as they are common nozzles that growers use. A survey completed by SOS Macquarie in 2019 showed the most common nozzle types were the TTi (XC) and the AIXR (M). Less than 9% of survey respondents indicated they possess a nozzle capable of producing coarser spray qualities than an AIXR but finer than the TTi, that is. they cannot produce a C-VC spray quality.

This highlights the need for growers to consider purchasing additional nozzle options to increase the spray qualities available to them. But in the interim, for most growers the selection of a AIXR producing a M spray quality is far more effective than selecting a XC.

Using higher herbicide rates: In these experiments, the use of higher glyphosate rates, that were still within label limits, resulted in the lowest numbers of survivors at the two sites where resistance was at low levels. But the benefits from increasing glyphosate rates was most evident when using poor quality water, seemingly ‘trumping’ the negative impacts of poor quality water, even when used at high rates.

This serves to highlight the benefit of using robust rates for the weeds targeted. However, in these situations the addition of SOA would also be recommended. The combination of robust label rates and addressing the issue of low-quality water would ensure the best possible outcome from the money invested.

Again, resistance testing to determine rate responsiveness of any given population may give a good indication of suitable application rates.

Slow growing annual ryegrass

An observation at all sites was the slow growth in the ARG populations established with early autumn rainfall. At all three trial sites the first time of spraying was approximately 3 weeks after the germinating rains. It would be generally accepted that spraying should be completed by this time, yet much of the ARG was still quite small at 1-3 leaf and control proved to be variable in response to spray applications.

This places growers into a conundrum when there are early seasonal breaks as experienced in 2020 and 2021. Spray timing for most Autumn/Summer weeds may be too early for ARG resulting in escapes surviving through sowing and into the crop (Figure 8). The shift toward using coarser spray qualities in summer fallows (which is now a legal requirement for phenoxy herbicides and for some glyphosate formulations) is likely to have exacerbated the problem.

Figure 8*.* Annual ryegrass survivors in young barley crop, Wongarbon 2020

Conclusions

Addressing factors that limit the plant receiving the 'intended dose' can improve control. Key factors can be optimising- water source/quality, water rate, spray quality, herbicide rate and timing. However, the improved control achieved using lower water rates where water quality is poor was quite stark as was the reduction in control when using XC spray quality as opposed to the other spray qualities tested.

Growers with poor quality spray water should look to other sources of water where possible otherwise consider ameliorating the water. The RO bore water proved as good as the rainwater when tested and the addition of SOA to bore water proved valuable in most cases.

The small spray target in seedling ARG proved very difficult to control with the XC spray quality in these trials and simply increasing water rates was not effective in improving outcomes. Spraying had to be delayed to achieve good control, which is not always an ideal option.

Alternatively, growers could target a M spray quality which improved control and reduced the need to delay spraying and/or increase water rates. Further work may be useful to investigate if spray qualities between the M and XC tested remain effective but reduce the risks associated with finer qualities.

Getting spray application right will not be enough to control highly resistant populations but in populations with lower or developing levels of resistance it is of paramount importance. Knowledge of the resistance status (including rate responsiveness) via testing will inform management decisions for such populations.

These outcomes further support the suggestion that all spray failures, even in resistant populations are not always just the because of 'resistance.' To assume that it is, will leave valuable control opportunities on the table. Growers and advisors should critically assess spray failures, as resistance is one of many factors that may contribute to poor levels of control.

Acknowledgements

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Faba bean competition effects on common sowthistle - lessons learned and opportunities for growers

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Take home message

- Faba bean competition effects on sowthistle were increased by reducing crop row spacing from 50 to 25 cm and increasing crop density from 20 to 30 plants m-2
- At Hermitage in southern Queensland, sowthistle biomass and seed production were decreased by 36% and 18%, respectively when faba bean density was increased from 20 to 30 plants m-2
- At Narrabri in northwest New South Wales, sowthistle biomass and seed production were decreased by 28% and 10%, respectively when faba bean row spacing was decreased from 50 to 25 cm
- The cultivars Nanuᶲ and Nasmaᶲ were more weed suppressive at Hermitage and Narrabri, respectively with Nasmaᶲ yielding 9% higher at Narrabri compared to Nanuᶲ and Wardaᶲ when grown in the presence of 10 plants/m2 of sowthistle.

Introduction

Reliance on herbicides alone has resulted in the evolution of herbicide resistance in many weed populations infesting northern region grain production systems. There is a need for regular use of alternative weed control practices into weed management programs to counter the widespread evolution of resistance. Crop competition is an effective strategy of weed suppression that reduces the reliance on herbicides. Agronomic practices such as crop row spacing, plant density and choice of cultivar, can be used to enhance the competitiveness of crops against weeds.

The research reported here explores the combined impacts of faba bean row spacing, crop density and cultivar on common sowthistle growth and reproductive development with benefits to crop yield in the presence of weeds and substantial reductions in weed seed set.

Materials and methods

Four faba bean cultivars were tested in field trials at Narrabri and Hermitage in 2021. Nasmaᶲ and Wardaᶲ were tested at both sites while Marneᶲ and Nanuᶲ were evaluated at Narrabri, NSW and Hermitage, Qld sites, respectively. Faba bean was planted on 25 cm and 50 cm row spacings at two densities (20 and 30 plants m^{-2}). A sowthistle density of 10 plants m^{-2} was used across both sites.

Within each main plot, a fixed quadrat (2 × 1m^2) was used as a sub-plot for weed treatment. Within each quadrat, the crop and weed plants were thinned to the required density. Quadrats in 25cm row plots contained four crop rows, while quadrats in 50 cm row plots contained two crop rows. At the Hermitage site, sowthistle seed was sown in these quadrats the day after crop planting, then irrigated to ensure weed emergence. At the Narrabri site, sowthistle seedlings, grown in trays, were transplanted into designated quadrat areas approximately two weeks after crop emergence.

At crop maturity, weed and crop plants within the designated quadrat areas were hand harvested and placed in separate paper bags for the determination of biomass and seed production of sowthistle as well as the yield of faba bean. All bags were transferred to a dehydrator and dried at 70^{o}C for 3 days. After drying, sowthistle plants were weighed and seed production was calculated by counting the total seeds in 5 representative randomly selected seed heads from each sample bag. The average seed number of these five heads was then multiplied by the total number of seed heads in the sample to calculate the total number of seeds per 1 m^2. Faba bean plants were processed in a thresher for the collection of grain and calculation of yield.

Each main plot was a cultivar × row spacing × crop density treatment and within each main plot, the weed treatment formed the subplot. There were four replicates for each main treatment and each experiment was laid out in a randomized complete block design. The data on weed biomass and seed production at Narrabri site was $\log_{10}$ transformed to pass the normality test for ANOVA. For each site, a three-way ANOVA was performed using Genstat 19th Edition on the data for all growth traits (weed biomass, weed seed production, and faba bean yield) with row spacing, crop density and cultivar as the main factors. Treatment mean comparisons were assessed based on Fisher's Least Significant Differences (LSD) test at p = 0.05.

Results

Hermitage

Reducing faba bean crop row spacing, increasing crop plant density and cultivar choice all increased the crop competition effects on sowthistle growth. When row spacing was decreased from 50 to 25 cm, sowthistle biomass was reduced (P <0.05) by 14% (Table 1). Increasing faba bean plant density from 20 to 30 plants m^{-2} reduced (P <0.001) the biomass of sowthistle, on average, by 36%. There were consistent reductions in sowthistle biomass across cultivars when crop density was increased from 20 to 30 plants m^{-2}. At narrow spacing (25 cm), increasing the plant density from 20 to 30 plants m^{-2} of Nanu⦶ and Nasma⦶ treatments reduced sowthistle biomass by 50% and 39%, respectively. At the wide row spacing (50cm) and low faba bean plant density (20 plants m^{-2}), Warda⦶ was poorly competitive and allowed sowthistle to produce on average 33% greater biomass than Nasma⦶ and Nanu⦶.

Table. 1 Effect of faba bean row spacing, density and cultivar on biomass of sowthistle at Hermitage, Qld.

Row spacing (cm)	Crop density (plant m^{-2})	Sowthistle biomass (g m^{-2})		
		Nanu⦶.	Nasma⦶	Warda⦶
25	20	79.0 bcd	81.6 cd	64.6 abc
	30	38.8 a	50.6 ab	40.7 a
50	20	75.3 bcd	63.2 abc	102.3 d
	30	63.0 abc	51.9 ab	57.3 abc
LSD (P = 0.05)		25.4		

Decreasing row spacing from 50 to 25 cm reduced ($P = 0.017$) sowthistle seed production by 18% (Table 2). When faba bean plant density was increased from 20 to 30 plants m^{-2}, sowthistle seed production was reduced ($P < 0.001$) by 29%. There were consistent reductions in sowthistle seed production across cultivars when plant density was increased from 20 to 30 plants m^{-2}. At narrow row spacing, the high crop plant density of Nanuɸ reduced sowthistle seed production by 45% ($P = 0.05$) as compared to the low plant density of this cultivar. For cultivars Nasmaɸ, and Wardaɸ, a similar weed suppressive trend was evident, but the differences were not significant ($P > 0.05$). At a row spacing of 50cm, Wardaɸ reduced the sowthistle seed production by 44% at high crop density compared to the low crop density (Table 2).

Table. 2 Effect of faba bean row spacing, density and cultivar on seed production of common sowthistle at Hermitage, Qld.

Row spacing (cm)	Crop density (plant m^{-2})	Sowthistle seed count (m^{-2})		
		Nanuɸ	Nasmaɸ	Wardaɸ
25	20	111378 bc	100630 abc	91564 abc
	30	61503 a	71999 ab	70032 a
50	20	115104 c	83908 abc	150373 d
	30	96230 abc	81046 abc	85333 abc
LSD ($P = 0.05$)		34490.1		

Faba bean crop row spacing, plant density and cultivar all contributed to the yield of faba bean. Decreasing row spacing from 50 to 25 cm increased ($P < 0.001$) faba bean yield by 20%. Faba bean yield was increased ($P < 0.05$) by 11% when crop plant density was increased from 20 to 30 plants m^{-2}. At narrow spacing, all three cultivars (Nasmaɸ, Nanuɸ, Wardaɸ) planted with high density (30 plants^{-2}) on average yielded 37% greater than low density (20 plants^{-2}) (Table 3).

Table. 3 Effect of faba bean row spacing, density and cultivar on yield of faba bean at Hermitage, Qld.

Row spacing (cm)	Crop density (plant m^{-2})	Faba bean yield (t ha^{-1})		
		Nanuɸ	Nasmaɸ	Wardaɸ
25	20	2.6 abc	2.4 ab	2.6 abc
	30	3.2 c	3.1 bc	2.9 bc
50	20	2.4 ab	2.4 ab	2.1 a
	30	2.5 abc	1.9 a	2.3 ab
LSD ($P = 0.05$)		0.67		

Narrabri

Reducing faba bean crop row spacing, increasing crop plant density and cultivar choice all increased the crop competition effects on sowthistle growth. When row spacing was decreased from 50 to 25 cm ($P < 0.001$) sowthistle biomass was reduced by 28%. Nasmaɸ reduced ($P = 0.034$) sowthistle biomass on average 15% more than Nanuɸ and Wardaɸ (Table 4). At narrow row spacing and high crop density (30 plants m^{-2}) of Marneɸ sowthistle biomass was reduced by 26% ($P < 0.05$) when compared to the low crop density (20 plants m^{-2}).

Table. 4 Effect of faba bean row spacing, density and cultivar on biomass of common sowthistle at Narrabri, NSW.

Row spacing (cm)	Crop density (plant m^{-2})	Sowthistle biomass (g m^{-2})		
		Marneⓓ	Nasmaⓓ	Wardaⓓ
25	20	1.52 bcd	1.13 a	1.39 abc
	30	1.13 a	1.25 ab	1.25 ab
50	20	1.92 d	1.51 abcd	1.91 d
	30	1.78 cd	1.58 bcd	1.86 d
LSD (P = 0.05)		0.38		

Reducing faba bean crop row spacing, increasing crop plant density and cultivar choice all increased the crop competition effects on sowthistle seed production. Decreasing row spacing from 50 to 25 cm reduced (P <0.001) sowthistle seed production by 10%. Nasmaⓓ reduced (P = 0.04) sowthistle seed production on average 8% more compared to Nanuⓓ and Wardaⓓ. Faba bean density had no effect on seed production of sowthistle at this site (Table 5).

Table. 5 Effect of faba bean row spacing, density and cultivar on seed production of common sowthistle at Narrabri, NSW.

Row spacing (cm)	Crop density (plant m^{-2})	Sowthistle seed (m^{-2})		
		Marneⓓ	Nasmaⓓ	Wardaⓓ
25	20	3.3 abc	2.9 a	3.2 abc
	30	3.0 ab	3.1 ab	3.1 ab
50	20	3.5 bc	3.2 abc	3.4 bc
	30	3.5 bc	3.3 abc	3.6 c
LSD (P = 0.05)		0.39		

Reduced faba bean crop row spacing, and cultivar choice contributed to the yield of faba bean. When crop row spacing was decreased from 50 to 25 cm faba bean yield increased (P = 0.01) by 13%. Nasmaⓓ yielded on average 9% more (P > 0.05) compared to Wardaⓓ or Marneⓓ. Crop density had no effect on faba bean yield at Narrabri (Table 6).

Table. 6 Effect of faba bean row spacing, density and cultivar on yield of faba bean at Narrabri, NSW.

Row spacing (cm)	Crop density (plant m^{-2})	Faba bean yield (t ha^{-1})		
		Marneⓓ	Nasmaⓓ	Wardaⓓ
25	20	3.0	3.1	2.7
	30	2.6	3.0	2.7
50	20	2.4	2.4	2.6
	30	2.5	2.8	2.4
LSD (P = 0.05)		0.66		

Summary

Crop competition is an effective weed management approach that can reduce the pressure on herbicides. Faba bean competition effects on sowthistle are increased by reducing crop row spacing (25 cm) and increasing crop density (30 plants m^{-2}). Reduced crop row spacing consistently reduced sowthistle seed production and biomass across both Hermitage and Narrabri sites. At Narrabri, sowthistle biomass and seed production were decreased by 28% and 10%, respectively when faba bean row spacing was decreased from 50 to 25 cm. At Hermitage, sowthistle biomass and seed production were decreased by 36% and 18%, respectively when faba bean density was increased from 20 to 30 plants m^{-2}. The cultivars Nanuᶲ and Nasmaᶲ were more weed suppressive at Hermitage and Narrabri, respectively with Nasmaᶲ yielding 13% higher at Narrabri as compared to Nanuᶲ and Wardaᶲ. More competitive planting configurations and cultivars also resulted in increased yield in these field trials.

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An agronomists observations on new pre-emergent options and their fit in the farming system

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Thursday 24 February 2022
Canola

Better canola establishment from better quality grower retained seed and seed placement - key traits for seed quality and how do you grow a crop with these traits?

Colin McMaster, NSW DPI

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Fungicide on canola in the low and medium rainfall zones of NSW – Great investment, safe insurance or a waste of money?

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Key words

canola, fungicide, sclerotinia, upper canopy blackleg, Alternaria black spot, powdery mildew

GRDC code

GOA2006-001RTX

Take home messages

- Despite being a high yielding year with a favourable spring, there were few instances of consecutive wet days during the flowering period of canola at trial sites in 2021. This resulted in sclerotinia stem rot (main stem) infection averaging only 4% of plants across sites
- Fungicide treatments were effective at reducing disease in canola, but rarely provided complete control
- A reduction in disease did not guarantee an increase in grain yield and an increase in yield did not guarantee an increase in profit
- In low to medium rainfall environments, spring foliar fungicide use on canola may best be viewed as insurance but with a low probability of a pay out, rather than a reliable investment
- Decision support tools are available to help predict the likelihood of a sclerotinia outbreak and therefore when the use of fungicides is more likely to be justified.

Background information

Five trials were conducted by GOA and Brill Ag across southern and central NSW low and medium rainfall zones in 2020 to determine the response of canola to the application of fungicide during the flowering stage, in what was an above average year for canola grain yield.

Multiple diseases were present at most sites including sclerotinia stem rot, upper canopy blackleg, powdery mildew and Alternaria. Various fungicide products and timings were able to reduce the level of these diseases but there was only a positive return on investment (ROI) (compared to untreated) in two of the five sites and only to a small number of specific treatments. Where there was a positive ROI, it was difficult to attribute the yield response to the reduction in any one disease. This trial series was repeated in 2021 with four sites across low to medium rainfall environments of southern and central NSW.

Methodology

Trial sites were geographically located to represent a range of climates and farming systems (Table 1). Each trial was sprayed with a ute-mounted boomspray onto existing commercial crops to ensure that the canopy remained intact, minimising open space for air to circulate. The plots were usually 40-50 m² in size with an area of approximately 15-20 m² harvested with a small plot harvester when the crop was ripe (direct head, not desiccated). All other crop inputs were completed by the grower.

Table 1. Site description for four canola fungicide response trials conducted in NSW, 2021.

Location	Region	Average annual rainfall	Average growing season rainfall	Variety
Ganmain	Eastern Riverina	475 mm	280 mm	44Y94 CL
Rankins Springs	Northern Riverina	420 mm	250 mm	44Y90 CL
Trangie	Central-west plains	495 mm	240 mm	44T02 TT
Wongarbon	Central-west slopes	580 mm	300 mm	44Y94 CL

Two products (Table 2) were used with multiple combinations of timings and rates. The trial used a randomised complete block design, with five replicates and the results were analysed by ANOVA at a 95% confidence level.

Table 2. Description of fungicide products used in four canola fungicide response trials conducted in NSW, 2021.

Trade name	Active ingredient 1	Group	Active ingredient 2	Group
Aviator® Xpro®	Prothioconazole	3	Bixafen	7
Prosaro®	Prothioconazole	3	Tebuconazole	3

There were three product application timings, 10, 30 and 50% bloom at Ganmain and Trangie, and two timings at Rankins Springs and Wongarbon, 30 and 50% bloom. These spray timings are overlaid on daily rainfall, recorded at the site in Figure 1. There were few instances of consecutive days of rainfall >10 mm at any site until late September and into October, when crops were either at late flowering or had completed flowering.

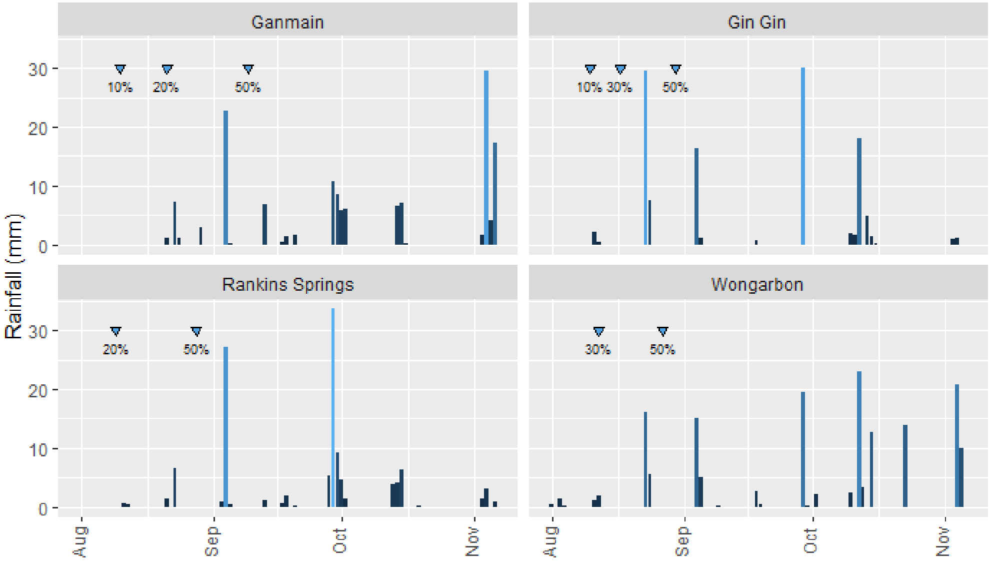


Figure 1. Daily rainfall received (vertical lines) and spray timings (inverted triangles) for four canola fungicide response trials conducted in NSW, 2021. Timings are bloom stage timing, e.g. 10% is 10% bloom stage. Measurements are from a tipping bucket rain gauge installed at the site. There was approximately 7.5 and 5 mm of rain recorded at Ganmain and Rankins Springs in the first week of August before the rain gauges were installed.

Disease assessment

Sclerotinia – two areas of 1 m^2 were assessed in each plot, with the number of plants with sclerotinia (basal, main stem and branch) counted along with the total number of plants in the assessment area to determine infection rates.

Upper canopy blackleg – A 0-4 score was allocated for the same two locations that were assessed for sclerotinia:

- 0 = no infection observed
- 0.5 = at least one lesion found
- 1 = lesion present
- 2 = lesions common
- 3 = lesions common causing damage
- 4 = lesions common causing branch death

Alternaria black spot – The upper canopy blackleg scoring system was adapted for Alternaria with some minor adaptions:

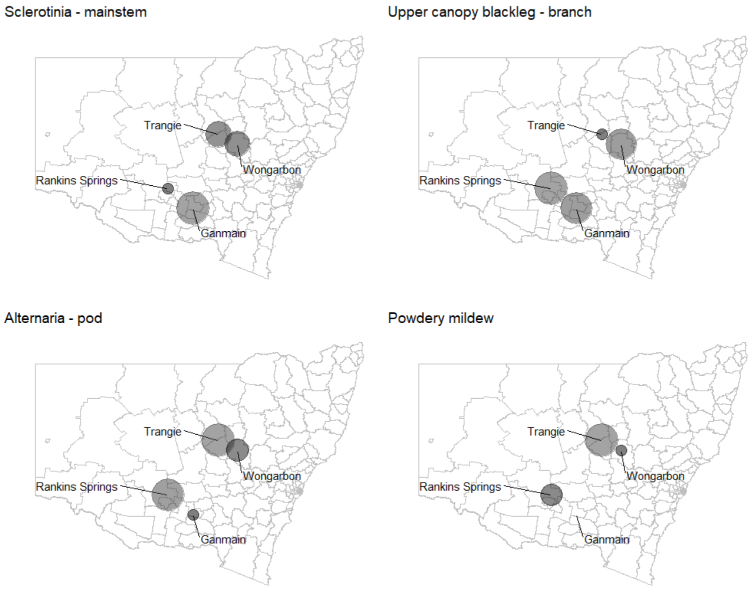
- 0 = no infection observed
- 0.5 = at least one lesion found
- 1 = lesion present
- 2 = lesions common with 1-5% of pod/stem area infected
- 3 = lesions common with 5-15% of pod/stem area infected and low-level early pod senescence.
- 4 = lesions common with >15% of pod/stem area infected and high level of early pod senescence.

Powdery mildew – An assessment was made of the proportion of stem area infected with powdery mildew (two locations per plot as per sclerotinia).

Results

Geographic disease distribution

Sclerotinia infection levels increased to the south and east of the trial's region as illustrated in Figure 2, but only to a maximum of ~8% of plants with main stem infection at Ganmain. Further west, Rankins Springs had a very low 0.4 % of plants with main stem sclerotinia infection. Upper canopy blackleg (branch) infection was generally less severe than 2020, with very low infection levels at the Trangie site and low-moderate levels at other sites. Alternaria and powdery mildew infection levels were generally lower than 2020 observations but were highest at the western sites, Rankins Springs and Trangie with no powdery mildew observed at Ganmain.



Sclerotinia - mainstem

Upper canopy blackleg - branch

Alternaria - pod

Powdery mildew

Figure 2. Severity of the diseases Sclerotinia stem rot (main stem), upper canopy blackleg (branch), Alternaria (pod) and powdery mildew across five canola fungicide response trials in NSW in 2021. Larger circles represent greater infection levels (data presented from untreated control). Data presented is dimensionless and no comparison can be made between diseases.

Ganmain

Ganmain had the highest level of sclerotinia infection of the four sites with 7.8% and 2.6% of main stems and branches infected respectively. All fungicide treatments reduced sclerotinia infection but the very early fungicide (5-10% bloom) was less effective than later applications. Several fungicide treatments reduced upper canopy blackleg, but infection levels were only low-moderate in the untreated control. No treatment tested reduced Alternaria at this site although the disease incidence was quite low.

Both two-spray strategies of Aviator Xpro followed by Prosaro resulted in yield higher than the untreated control, with Aviator Xpro at 5-10% bloom followed by Prosaro at 50% bloom yielding 0.3 t/ha (8.5%) above the untreated control. Single applications of any fungicide as well as Prosaro followed by Aviator Xpro did not increase grain yield.

It is difficult to ascertain the main drivers of the yield response at this site. The two-spray Aviator Xpro followed by Prosaro treatments did control sclerotinia, but so too did single sprays of Aviator Xpro or Prosaro at 20-30% bloom but without the yield response. The two-spray Aviator Xpro followed by Prosaro treatments also reduced upper canopy blackleg infection levels, suggesting that the yield response was from reducing the level of multiple diseases.

Table 4: Canola grain yield, oil% and disease response to fungicide in a crop of 44Y94 CL at Ganmain in 2021

	Yield (t/ha)	**Oil (%)**	**Sclero MS (%)**	**Sclero Br. (%)**	**UC BL Br.**	**Alt. pod**	**PM (%)**
Aviator Xpro @ 800mL/ha @ 5-10% bloom	3.59	47.2	4.0	0.3	0.5	0.7	
Prosaro @ 450mL/ha @ 20-30% bloom	3.57	47.3	0.7	0.7	1.2	0.8	
Aviator Xpro @ 800mL/ha @ 20-30% bloom	3.50	47.4	0.0	0.0	1.1	0.7	
Aviator Xpro @ 800mL/ha @ 5-10% bloom f/b Prosaro @ 450mL/ha @ 50% bloom	3.84	46.8	0.3	0.0	0.6	0.6	
Aviator Xpro @ 800mL/ha @ 20-30% bloom f/b Prosaro @ 450mL/ha @ 50% bloom	3.78	47.8	0.0	0.0	0.5	0.6	
Prosaro @ 450mL/ha @ 20-30% bloom f/b Aviator Xpro @ 800mL/ha @ 50% bloom	3.70	47.4	0.0	0.0	1.0	0.6	*Nil*
Prosaro @ 450mL/ha @ 50% bloom	3.55	47.4	1.2	0.0	1.4	0.7	
Aviator Xpro @ 800mL/ha @ 50% bloom	3.64	47.8	1.4	0.4	1.1	0.5	
Untreated control (UTC)	*3.54*	*47.8*	*7.8*	*2.6*	*1.5*	*0.7*	
l.s.d. ($p<0.05$)	0.22	0.5	1.7	1.1	0.5	0.3	

Sclero MS = Proportion of plants with sclerotinia infection on the main stem. Sclero Br. = proportion of plants with sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate result is significantly different to the untreated control.

Rankins Springs

No fungicide treatments increased yield compared to the untreated control at Rankins Springs. There was a yield reduction from Aviator at 50% bloom. Sclerotinia levels at maturity were negligible and there were low-moderate levels of upper canopy blackleg (branch), Alternaria (pods) and powdery mildew. No fungicide treatment reduced the incidence of sclerotinia, albeit at a very low level of infection. All treatments reduced the incidence of upper canopy blackleg (Br.) and Alternaria except Prosaro at 50% on upper canopy blackleg. All treatments except Aviator at 50% bloom reduced the incidence of powdery mildew. Various fungicide treatments reduced (but did not completely control) these diseases.

Table 5: Canola grain yield, oil % and disease response to fungicide in a crop of 44Y90 CL at Rankins Springs in 2021.

	Yield (t/ha)	**Oil (%)**	**Sclero MS (%)**	**Sclero Br. (%)**	**UC BL Br.**	**Alt. pod**	**PM (%)**
Prosaro @ 450mL/ha @ 20-30% bloom	2.80	44.0	0.0	0.0	0.4	0.9	4
Aviator Xpro @ 800mL/ha @ 20-30% bloom	2.77	43.7	0.0	0.0	0.7	1.2	7
Aviator Xpro @ 800mL/ha @ 20-30% bloom f/b Prosaro @ 450mL/ha @ 50% bloom	2.64	44.1	0.5	0.0	0.5	0.8	2
Prosaro @ 450mL//ha @ 20-30% bloom f/b Aviator Xpro @ 800mL/ha @ 50% bloom	2.78	43.2	0.0	0.0	1.3	0.6	5
Prosaro @ 450mL/ha@ 50% bloom	2.75	43.9	0.8	0.8	1.4	0.9	5
Aviator Xpro @ 800mL/ha @ 50% bloom	2.49	43.7	0.7	0.0	1.2	0.6	11
Untreated control (UTC)	*2.82*	*43.6*	*0.4*	*0.9*	*1.7*	*2.0*	*13*
l.s.d. (*p<0.05)*	0.32	n.s.	n.s.	n.s.	0.4	0.3	5

Sclero MS = Proportion of plants with sclerotinia infection on the main stem. Sclero Br. = proportion of plants with sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate result is significantly different to the untreated control.

Trangie

There were slightly higher disease levels at Trangie compared with Rankins Springs but similarly to Rankins Springs, fungicide did not increase grain yield. Sclerotinia infection levels were low (4% of main stems infected) in the untreated and all fungicide treatments reduced this to negligible levels. Minimal blackleg was observed even in the untreated control. Alternaria and powdery mildew levels were moderate. Several fungicide treatments reduced (but did not eliminate) Alternaria infection. Similarly, several fungicide treatments reduced powdery mildew levels, but only two-spray strategies reduced infection to less than 10% of stem area infected (from 32% in the untreated control).

Table 6: Canola grain yield, oil% and disease response to fungicide in a crop of 44T02 TT at Trangie 2021.

	Yield (t/ha)	**Oil (%)**	**Sclero MS (%)**	**Sclero Br. (%)**	**UC BL Br.**	**Alt. pod**	**PM (%)**
Aviator Xpro @ 800mL/ha @ 5-10% bloom	3.53	45.5	0.4	0.0	0.1	1.8	20
Prosaro @ 450mL/ha @ 20-30% bloom	3.39	45.5	0.0	0.0	0.1	2.3	22
Aviator Xpro @ 800mL/ha @ 20-30% bloom	3.36	45.3	0.3	0.0	0.0	1.4	21
Aviator Xpro @ 800mL/ha @ 5-10% bloom f/b Prosaro @ 450mL/ha @ 50% bloom	3.43	45.8	0.0	0.0	0.0	1.1	5
Aviator Xpro @ 800mL/ha @ 20-30% bloom f/b Prosaro @ 450mL/ha @ 50% bloom	3.47	46.1	0.5	0.0	0.1	1.3	7
Prosaro @ 450mL/ha @ 20-30% bloom f/b Aviator Xpro @ 800mL/ha @ 50% bloom	3.33	45.6	0.0	0.0	0.0	0.8	5
Prosaro @ 450mL/ha @ 50% bloom	3.60	45.7	0.7	0.0	0.1	1.4	15
Aviator Xpro @ 800mL/ha @ 50% bloom	3.44	45.5	0.7	0.0	0.1	1.3	21
Untreated control (UTC)	3.43	45.4	4.0	1.1	0.2	2.1	32
l.s.d. (*p<0.05)*	0.27	0.7	1.6	0.7	0.2	0.6	9

Sclero MS = Proportion of plants with sclerotinia infection on the main stem. Sclero Br. = proportion of plants with sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate result is significantly different to the untreated control.

Wongarbon

All treatments reduced sclerotinia and powdery mildew levels compared to the untreated control, while some treatments reduced upper canopy blackleg infection and Alternaria. Like the Ganmain site, a reduction in sclerotinia to negligible levels did not guarantee a yield response from fungicide as only the two-spray treatments and Aviator Xpro at 20-30% bloom increased grain yield compared to the untreated control.

Table 7. Canola grain yield, oil%, and disease response to fungicide in a crop of 44Y94 CL at Wongarbon in 2021.

	Yield (t/ha)	**Oil (%)**	**Sclero MS (%)**	**Sclero Br. (%)**	**UC BL Br.**	**Alt. pod**	**PM (%)**
Prosaro @ 450mL/ha @ 20-30% bloom	4.15	47.2	0.0	0.0	0.8	1.0	0.9
Aviator Xpro @ 800mL/ha @ 20-30% bloom	4.30	47.1	0.2	0.0	0.7	0.8	0.5
Aviator Xpro @ 800mL/ha @ 20-30% bloom f/b Prosaro @ 450mL/ha @ 50% bloom	4.42	47.5	0.0	0.0	0.5	0.8	1.4
Prosaro @ 450mL @ 20-30% bloom f/b Aviator Xpro @ 800mL/ha @ 50% bloom	4.27	46.8	0.0	0.0	0.7	0.5	0.9
Prosaro @ 450mL/ha @ 50% bloom	4.06	47.4	0.3	0.3	1.1	1.1	2.6
Aviator Xpro @ 800mL/ha @ 50% bloom	4.17	47.0	0.6	0.3	0.9	0.6	0.4
Untreated control (UTC)	4.01	47.2	3.6	1.2	1.5	1.1	6.8
l.s.d. (*p<0.05)*	0.26	n.s.	1.1	1.1	0.6	0.3	1.8

Sclero MS = Proportion of plants with sclerotinia infection on the main stem. Sclero Br. = proportion of plants with sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate result is significantly different to the untreated control.

Gross margin analysis

A partial gross margin analysis was completed in 2020 and 2021 where the total income (incorporating yield and oil) was calculated then costs deducted from each treatment. Fungicide costs were assumed to be the same across seasons, but the assumed canola price reflected each season, with $550 and $850/tonne in 2020 and 2021 respectively. Application cost was assumed as $13/ha per fungicide application in both seasons, which may vary from grower to grower. Wheel tracking damage from spray applications was not considered.

There was only one treatment out of 28 site* treatment combinations with an economic benefit compared to the untreated control in 2021, despite the yield response and very high canola price of $850/t. Where a price of $550/tonne was used in the analysis of the 2021 results, no treatments were profitable at any site. Two of the 28 site* treatment combinations lost money in 2021 with $850/tonne canola price. Using a canola price of $550/tonne on the 2021 yield responses, four of 28 site* treatment combinations would lose money, all of these at the western sites of Rankins Springs and Trangie.

Table 8. Summary of yield and economic response to fungicide application over that of the UTC over two years of trials

Year	Site	Maximum yield response (t/ha) compared to UTC (% increase over UTC)	Treatments with yield > UTC/no. of treatments	Treatments with GM > UTC*	Assumed Price $/t	$/ha net economic benefit of best treatment over UTC
2020	Ganmain	Nil	0/10	0/8	$550	Nil
	Kamarah	0.4 (16%)	8/9	2/7		$190
	Temora	0.66 (21%)	6/11	4/9		$320
	Warren	Nil	0/9	0/8		Nil
	Wellington	0.26 (7%)	2/10	0/10		Nil
2021	Ganmain	0.3 (8%)	2/8	0/8	$850	Nil
	Rankins Springs	Nil	0/6	0/6		Nil
	Trangie	Nil	0/8	0/8		Nil
	Wongarbon	0.41 (10%)	3/6	1/6		$289

*Some treatments were not included in the gross margin analysis as the products had not been priced at the time. Gross margin calculated with assumed price of $850/tonne in 2021 and $550/tonne in 2020. GM = Gross Margin. UTC = Untreated Control.

Discussion and conclusion

Canola is susceptible to several diseases including sclerotinia, blackleg, Alternaria and powdery mildew, and fungicides can be used to reduce the incidence of each of these diseases. However, a yield benefit from reducing disease is not guaranteed and two years of trials conducted by GOA and Brill Ag in low-medium rainfall regions of NSW have shown that across a range of products and timings, a yield response was less likely than no yield response, with only 23 of 77 sites* treatment combinations resulting in higher grain yield. As reduced disease does not guarantee increased yield, increased yield does not guarantee increased profit. In 2021 only one site * treatment combinations resulted in a higher gross margin compared to the untreated control.

Growers considering fungicide applications on canola in similar environments to where these trials were conducted, maybe could view it more as insurance than an investment. In considering fungicide as insurance, growers should question how often do weather conditions justify fungicide application in these environments and where yield is reduced, what is the overall penalty on income from the disease versus the costs of spraying? And simply observing sclerotinia in a crop at harvest does not mean that it would have been worth spraying with fungicide. As shown in the trial outcomes over the last two years, which were some of the wettest on record, coupled with high grain prices and very high yields, the insurance was only economically justified in a small number of cases.

Although these trials were conducted in two ‘wet’ years, there were few instances of consecutive wet days through the critical crop flowering period which is essential for the sclerotinia to infect the crop. This is common for low to medium rainfall environments and likely the primary reason why sclerotinia is a sporadic and infrequent disease in these environments.

Another factor for consideration of applying fungicides is that crop yield potential and price received can have a significant bearing on the resulting economic benefit. As detailed above, the combination of high yields and high prices in 2021 did result in one case returning a healthy return on the money invested of around $289/ha. However, had the price for canola been $550/t, there was no treatment that returned enough yield benefit to result in a return greater than not spraying at all. It could be surmised that if yield potential was lower, the potential for any application to be profitable could be lower again.

Tools are available to assist in the prediction of sclerotinia outbreaks and the likelihood of fungicides reducing yield loss from disease and the economic case for their use (see https://www.agric.wa.gov.au/apps/sclerotiniacm-sclerotinia-management-app). The use of these may give growers the confidence to make more informed fungicide application decisions.

Although diseases such as Alternaria and powdery mildew seem more prevalent in the lower rainfall, warmer environment from this trial work, their control by fungicides appears to be variable and there is little evidence of increased yield where these diseases were reduced.

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Managing upper canopy blackleg infection (UCI) in medium and high rainfall regions

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canola, blackleg, stubble management

GRDC codes

UOM1904-004RTX, UM00051, CSP00187, MGP1905-001SAX

Take home messages

- Increased canola stubble area and the increased area sown to canola will reduce the ability of growers to maintain a 500m buffer between one-year-old stubble and current crops
- Canola stubble quantity (t/ha) rather than stubble management has the largest effect on blackleg disease
- Seasonal conditions will influence whether crown canker or Upper Canopy Infection (UCI) will be more significant and potentially warrant control. It will be rare to have severe forms of both versions of blackleg in the same year
- Crown canker years occur from late sowings, resulting in plants remaining as seedlings during the winter infection period
- Upper Canopy Infection years will likely result from early sowing times resulting in plants commencing flowering in late June/early August. Early flowering will result in increased infection and will provide the fungus with more time to cause damage prior to harvest
- The decision to use a fungicide is not clear cut. You must first understand the disease risk profile of your crop
- Prior to sowing, use the BlacklegCM decision support tool to identify high risk paddocks and explore management strategies to reduce yield loss
- Fungicide application for UCI is a separate decision-making process from crown canker control. UCI fungicide application can result in very variable yield returns. You must understand the risk before applying a fungicide.

Introduction

In recent years the area sown to canola in NSW and Victoria has increased significantly. This has been driven by excellent and consistent prices for canola and favourable seasons for production (especially in 2020 and 2021). The main areas of significant expansion have been into medium and lower rainfall regions, which in the past have not been traditional canola producing districts. Whilst in medium to high rainfall areas the area sown has remained relatively stable. However, what has changed in these regions is the amount of canola stubble in the farming system and the resulting increase in disease pressure.

Increased canola density will increase blackleg inoculum (spore density)

The fungus that causes blackleg survives on old canola stubble and releases airborne spores that infect new season crops each year. The more canola stubble there is present from the previous year, the higher the disease pressure will be from blackleg. This is especially true for crops grown within 500m of the previous seasons' stubble.

If stubble remains intact it will release blackleg spores within the growing season. Spore release has been measured from old canola stubble for up to four years. However, the blackleg fungus will release fewer spores as the stubble and the fruiting bodies age, that is, one- year-old stubble produces more spores than two- year-old stubble etc. The main driver is stubble quantity from the previous season and the resulting spore release per piece of stubble (this is inoculum load). Previous work showed that approximately 99% of spores originate from the previous year's canola stubble. Canola stubble more than 1 year old produces fewer spores and has less stubble material to harbour the disease due to decomposition.
Heavy canola stubbles from 2021 will be increasing disease pressure on 2022 canola crops. High stubble loads will be the most important driver for blackleg development in medium to high rainfall regions.

Commencement of flowering will influence the development of UCI

Observations from commercial crops and research undertaken at Horsham has shown canola that commences flowering early is more prone to developing UCI compared to canola that commences flowering later in the season. It appears that canola bolting and flowering in mid to late winter is exposed to high levels of spore release and hence more prone to developing UCI, as opposed to canola that is still in the cabbage stage at this time and more prone to developing the traditional stem canker.

Your crop is unlikely to get both crown canker and UCI in the same year, therefore you need to know which form of the disease you need to manage this year.

Findings over the past few years have indicated that most years will be defined as a crown canker or UCI year, but rarely both. In most regions 2021 was a crown canker year. That is, as an agronomist or grower you will be managing for either crown canker or UCI. The risk is determined by the timing of sowing (germination).

1. **Crown canker** - severe crown canker is most likely to develop when plants are infected during the early seedling stage (cotyledon to 4th leaf). The driving factor for seedling infection is the length of time that the plant is exposed to blackleg infection while in the seedling stage. Therefore, the risk of seedling infection, which leads to crown cankers, is very variable from season to season. Once plants progress to the 4th leaf stage they are significantly less vulnerable to crown canker. That is, older plants will still get leaf lesions, but the pathogen is less likely to cause damaging crown cankers as the fungus cannot grow fast enough to get into the crown. Typically, plants sown early in the growing season (April) will develop quickly under warmer conditions and progress rapidly past the vulnerable seedling stage, whereas plants sown later (mid-May) will progress slowly and remain in the vulnerable seedling stage for an extended period.
2. **Upper Canopy Infection (UCI)** – UCI occurs when the plants become reproductive early in the growing season, typically when crops commence flowering in late June/early August. This results in cool moist conditions which are conducive for infection events but also allows enough time for the pathogen to cause tissue necrosis prior to harvest. That is, UCI flower and branch infection can occur at any time, but it only results in yield loss if it occurs early in

the season. This is because the pathogen must grow from the infection point to within the vascular tissue of the plant where the necrosis occurs causing yield loss. In 2021, crops that commenced flowering in early September in many cases did get UCI infection, but the infection did not progress to the vascular tissue and no yield losses resulted.

Upper canopy blackleg fungicide application

Blackleg Upper Canopy Infection (UCI) refers to infection of the upper stem, branches, flowers and pods and whilst we are constantly improving our understanding regarding these new symptoms, there is still a very large knowledge gap of how individual cultivars react to UCI. Furthermore, our research shows that similar symptoms of UCI can cause very severe economic impact in one season and have no economic impact in another. As such, our recommendations for managing blackleg UCI are constantly evolving.

Monitor crops for UCI development

Symptoms of UCI will begin to appear some time before the disease becomes damaging. Scout canola crops for symptoms of UCI as crops commence stem elongation. The main symptom will be leaf lesions on the upper foliage, suggesting active infections taking place and opportunities for secondary infections via pycnidiospores. Monitor crops regularly (every 7-10 days) and check for new leaf lesions and changes in lesion size. Leaf lesions on the oldest leaves at ground level are unlikely to contribute to UCI.

Should I apply a fungicide for UCI protection?

This question is a real dilemma, get it wrong and it will cost your crop a lot of money, but there is no way to predict economic return accurately yet. Current research is working on improving knowledge including determining timing of infection leading to yield loss. Research also looks at weather parameters associated with yield loss and strategies for screening for genetic resistance.

However, you can still determine if your crop is likely to be a high, moderate or low risk situation.

1. **Time to commencement of flowering.** Crops that flower earlier in the season are at a higher risk. They will flower in cooler wetter mid-late winter/early spring which is more conducive for blackleg infection.
2. **Time from the commencement of flowering to harvest.** We hypothesise that the fungus requires a certain amount of time from when it initially infects the plant to when it causes the damage (internal infection) that leads to yield loss. The longer time period from infection to harvest = increased risk of yield loss.

The date of 1st flower and the time from 1st flower to harvest are good predictors of yield loss. This knowledge can in hindsight explain why in some regions/years yield loss can occur whilst in other years yield loss may not occur. Obviously, these key dates change between regions. For example, if two crops flower on August 7th but the Barellan crop is mature on October 25th and the Cootamundra crop matures on November 25th then there is higher potential for damage to the Cootamundra crop.

1. Spring rainfall and temperature. Preliminary data suggests that given enough time, UCI will cause damage to the vascular tissue in the stems and branches resulting in yield loss to the pods. However, similar levels of disease can cause different amounts of yield loss depending on the weather during pod fill. Pods that ripen without moisture stress and during cool weather can tolerate more disease. Imagine a partially blocked xylem. On a cool day the plant can still get sufficient moisture, but on a hot day the partially blocked xylem cannot deliver enough moisture.

2. Genetic resistance. This is the missing piece of the puzzle. We do know that effective major gene resistance (Resistance Groups) will stop blackleg and if your cultivar has effective major gene resistance your crop will not get any UCI. However, it is difficult to determine if you do have effective major gene resistance as it depends on the blackleg population on your farm. The best way to determine major gene resistance is to monitor your crop for leaf lesions. Major gene resistance is effective across all plant parts so if there are no leaf lesions it means that there could be no blackleg present or more likely that your cultivar has effective major gene resistance.
3. The other resistance is cultivar quantitative resistance, this is often indicated by the blackleg rating of your cultivar. Although it is possible for cultivars to have a high blackleg rating from major gene but low quantitative resistance. However, if your cultivar has an R rating, then it should either have effective major gene or excellent quantitative resistance. But what does adequate quantitative resistance mean for UCI control? To be honest the answer is ’we don’t know‘. However, we do know that cultivars with adequate quantitative resistance develop UCI symptoms, but we are suspicious that these cultivars may then have less damage to the vascular tissue than more susceptible cultivars. This could be very similar to how cultivars react at the seedling stage, that is, a MR rated cultivar and a MS cultivar both have leaf lesions, but the MS then develops more crown canker and subsequent yield loss. The reality is that we need to develop a robust blackleg rating system for UCI – we’re working on it.

What are the steps to determining a UCI spray decision?

1. Leaf lesions – presence of leaf lesions indicates that blackleg is present and that your cultivar does not have effective major gene resistance. No leaf lesions = no reason to spray.
2. New leaf lesions on upper leaves as the plants are elongating – this observation is not critical but does give an indication that blackleg is active as the crop is coming into the susceptible window. However, a few wet days at early flower will still be high risk even if there were no lesions on new leaves up to that point. Remember it will take at least 14 days after rainfall to observe the lesions. More lesions = higher blackleg severity.
3. Date of 1st flower and targeted date of harvest - the earlier in the season flowering occurs is higher risk. This date will vary for different regions. Generally, shorter season regions can more safely commence flowering at an earlier date compared to longer season regions. Earlier harvest date results in less time for the fungus to invade the vascular tissue and cause yield loss. Consequently, if you’re in a long growing season rainfall region and your crop flowers in early August and is harvested in December, then you are in a very high-risk situation.
4. Yield potential – yield potential is simply an economic driver. A 1% return on a 3t/ha crop is worth more money than a 1% return on a 1t/ha crop.

Fungicide application for UCI

1. Fungicide application timing. Research has shown a wide window of response times with useful results (assuming that you have a damaging level of disease) from 1st flower to 50% bloom. However, we suggest aiming for 20%-30% bloom (15-20 open flowers off the main stem) for a number of reasons. Firstly the 20%-30% bloom stage is as late as you can go and still get good penetration into the canopy. Your main aim is to protect the main stem which will have a greater impact on yield compared to individual branches. Secondly the 20%-30% bloom spray will control any initial infections that have already occurred. Thirdly the 20%-

30% bloom timing will provide protection for a few weeks into the future; therefore UCI will only start occurring again after the 50% bloom stage and hopefully by then any infections will occur too late to cause significant yield loss.

2. A fungicide application at 20%-30% bloom also provides protection from early development of sclerotinia stem rot. The opportunity to manage several diseases with a single fungicide application can increase the economic justification of the operation.
3. Pod infection is unlikely to be controlled through fungicide application. Pod infection occurs when there are rainfall events during podding and the fungal spores land directly on the pods and cause disease. We have found that severe pod infection can lead to an additional 20% yield loss. Unfortunately, no fungicides are registered for application during podding due to MRL regulations. Major gene resistance will control pod infection.

How can I determine if I should have sprayed for UCI?

1. Check for external lesions.
2. Cut branches and stems to check for blackened pith, which is indicative of vascular damage and likely yield loss
3. Observe darkened branches. These branches go dark after vascular damage and are indicative of yield loss.
4. Pod infection will cause yield loss. Unfortunately there is nothing that can be done to prevent pod infection.
5. Leave unsprayed strips to check for yield returns.

Summary - management of blackleg in medium to high rainfall regions

Increased pressure from blackleg is driven by the intensity of canola production in the district, as the blackleg pathogen survives and is released from old canola stubble. Here are some important points to consider:

1. One in four-year canola rotations and 500m isolation between this year's crop and last year's stubble reduces risk significantly**.** Monitor crops for both UCI and crown canker so that you know if you need to retain or change practices.
2. Distance to canola stubble – crops sown adjacent to one-year-old stubble will have the highest amount of disease pressure, so maintain a 500m buffer if possible.
3. Cultivar resistance – cultivars rated R-MR or above have very low risk of developing crown cankers. MR rated varieties will develop cankers but only if grown under high disease severity, for example canola/wheat/canola in high rainfall. www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide
4. Pathogen population – if you've grown the same cultivar for several years and disease severity is increasing and you then sow a cultivar from the same resistance group, you will be at a higher risk of crown cankers developing.
5. Monitor crops regularly for blackleg symptom development and progression of disease. Take regular photos of symptoms if necessary, as means of recording changes.
6. Fungicides for UCI – if your crop has blackleg lesions (mainly on upper leaves) at stem elongation and it has commenced flowering in late June/early August it is more likely to benefit from a fungicide application. Later flowering crops are unlikely to have yield losses. Cultivar resistance to UCI has been shown to be effective but we do not yet have a reliable

cultivar screening system. If your cultivar has had significant yield increases from 20%-30% bloom fungicide applications in previous years, it is likely to be susceptible and benefit from fungicide application.

7. Consider the economic returns from a foliar fungicide application (price for product, yield potential, spring rainfall outlook). Use the BlacklegCM App to determine potential economic returns for fungicides for crown canker.

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- Marcroft Grains Pathology website: www.marcroftgrainspathology.com.au
- https://www.grdc-nvt.com.au/login
- NSW DPI Winter Crop Variety Sowing Guide (Disease updates, variety resistance, fungicide products).

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Managing sclerotinia stem rot of canola in 2022

Kurt Lindbeck, NSW Department of Primary Industries

Key words

sclerotinia stem rot, canola, foliar fungicides

GRDC codes

DAN 00177, UM 0051, BLG 206

Take home messages

- Outbreaks of sclerotinia stem rot are sporadic and dependent on the growing season conditions. Saturated canopy conditions for more than 48 hours during flowering favour the development of the disease
- Current and adjacent paddocks with histories of sclerotinia disease in broadleaf crops over the last four years are an indicator of potential risk for this season's crop
- The frequency of canola or lupin in a paddock is very important in determining the risk of a sclerotinia outbreak, as these crops are very good hosts for the disease and can quickly build up levels of soil borne sclerotia
- Foliar fungicides for management of the disease are best applied at 20 – 30% bloom (15-20 flowers off the main stem) for main stem protection
- In low to medium rainfall regions outbreaks of sclerotinia stem rot are sporadic and the returns from foliar fungicide applications must be considered carefully.

How does the disease develop?

The complexity of the disease cycle of sclerotinia stem rot results in disease outbreaks being sporadic compared to other diseases. There are several key stages that must be synchronised and completed in order for plant infection to occur. Weather conditions must be suitable for the pathogen at each stage. These stages of development include:

1. Softening and germination of soil borne sclerotia
2. Apothecia development and release of ascospores
3. Infection of petals by air-borne ascospores
4. Senescence of infected petals in the presence of moisture and subsequent stem infection

Weather conditions during flowering play a major role in determining the development of the disease. The presence of moisture during flowering and petal fall will determine if sclerotinia stem rot develops. Dry conditions during this time can quickly prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development.

What are the factors that drive the development of sclerotinia stem rot?

- **Frequency of sclerotinia outbreaks.** The past frequency of sclerotinia stem rot outbreaks in the district can be used as a guide to the likelihood of sclerotinia developing this season.

Paddocks with a recent history (last 5 years) of sclerotinia outbreaks are an indicator of potential risk, as well as those paddocks that are adjacent. The frequency of canola and lupin in the paddock can also increase disease risk. Canola and lupin are very effective hosts for the disease and can quickly build up levels of soil-borne sclerotia.

- **Commencement of flowering.** The commencement of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. **Canola crops which flower earlier in winter (late June - July) are more prone to disease development and exposure to multiple infection events.**
- **Spring rainfall**. Epidemics of sclerotinia stem rot occur in districts with reliable late winter and spring rainfall with long flowering periods for canola. These provide long periods of canopy wetness necessary for the disease to develop, at least 48 hours or more. Overnight dews generally don't trigger epidemics of the disease.

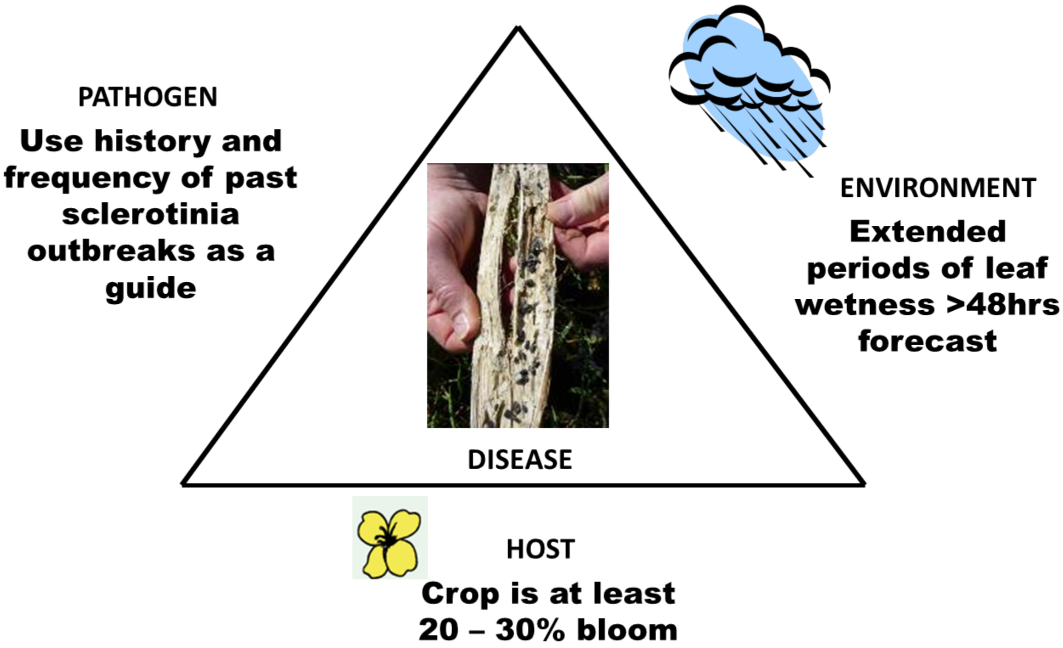

Figure 1. Factors that drive the development of sclerotinia stem rot

Pre-sowing sclerotinia management

Crop rotation

- Rotate canola once in every 4 to 5 years to reduce build-up of sclerotia
- Incorporate lower-risk crops into the crop rotation e.g. cereals, field pea and faba bean
- Separate last year's canola stubble and new seasons' crops by at least 500m
- Ascospores spread within 100m to 400m of the apothecia

Burning

- Burning of stubbles and windrows will kill some sclerotia, but will not significantly reduce the risk of disease

Clean seed

- Always use seed free of sclerotia where possible
- Grade retained seed for sowing to remove sclerotia if in doubt
- Grain receival standards allow a maximum of 0.5 per cent sclerotes in the sample.

Variety selection

- There are no Australian canola varieties with known resistance to sclerotinia. Some differences may be observed in the level of stem rot in some seasons. This is likely to be related to the timing of flowering and infection events.

Crop Management

- Always follow the recommended sowing time and seeding rate for your region
- Early maturing varieties sown early can be prone to developing stem infection due to the earlier commencement of flowering when conditions are wet for prolonged periods.
- Once flowering starts, the crop becomes susceptible to infection and prolonged exposure to infested senescent petals means greater chance of stem infection
- Bulky crop canopies can retain more moisture and are conducive for the development of stem infections
- Wider row spacing or reduced seeding rates can increase air-flow through the canopy, reducing moisture retention and potential for infection.

Use SclerotiniaCM app (see useful resources) to determine the most appropriate management strategies for your district.

Post sowing sclerotinia management - fungicide application

- Use foliar fungicides to prevent early stem infection via infested petals
- Always use fungicide products that are currently registered in Australia, there are several new products registered for use in 2022
- Timing of foliar fungicide application is more important than choice of fungicide product in reducing potential levels of stem infection
- Foliar fungicide application is most effective before an infection event
- Application of foliar fungicide at 20-30% bloom stage is most effective in reducing main stem infection and most yield loss by protecting early petals from infection and penetration of fungicide product into the crop canopy to protect potential infection sites from falling petals
- Multiple foliar fungicide applications may be essential in high-risk-disease districts with a high yield potential. Applications at both 10 -20% and 50% bloom provide critical early and follow up protection from multiple infection events
- Use high water rates (at least 100 litres per hectare) to achieve adequate coverage and penetration into the canopy
- Foliar fungicides generally have an active life of two to three weeks. The protection provided may wear off during the critical infection period or where crops have an extended flowering period. A single fungicide application too early may not be effective

- Foliar fungicides will have no effect on managing basal infections, as this occurs below the soil surface and beyond the activity of foliar fungicides.

Always

- Determine disease risk as your crop enters the flowering period
- Assess bloom stage, seasonal conditions and weather forecasts to identify the potential risk to your crop
- Identify how many consecutive wet days are forecast as the crop commences flowering and the week ahead, especially consecutive wet days of 48 hours or more
- Monitor crops for disease development and identify the types of infection. Basal and main stem infections cause the most yield loss.

Useful resources

- NSW DPI Winter Crop Variety Sowing Guide (Disease updates, variety resistance, fungicide products).
- SclerotiniaCM App for iPad and android tablets

Acknowledgements

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Managing upper canopy blackleg infection (UCI) in lower and medium rainfall regions

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GRDC codes

UOM1904-004RTX, UM00051, CSP00187, MGP1905-001SAX

Keywords

canola, blackleg, stubble management

Take home messages

- Increased canola stubble area and the increased area sown to canola will reduce the ability of growers to maintain a 500m buffer between one-year-old stubble and current crops
- Canola stubble quantity (t/ha) rather than stubble management has the largest effect on blackleg disease
- Seasonal conditions will influence whether crown canker or upper canopy infection (UCI) will be more significant and potentially warrant control. It will be rare to have severe forms of both versions of blackleg in the same year
- Crown canker years occur from late sowings, resulting in plants remaining as seedling during the winter infection period
- Upper canopy infection years will likely result from early sowing times resulting in plants commencing flowering in late June/early-mid July. Early flowering will result in increased infection and will provide the fungus with more time to cause damage prior to harvest
- The decision to use a fungicide is not clear cut. You must first understand the disease risk profile of your crop
- Prior to sowing, use the BlacklegCM decision support tool to identify high risk paddocks and explore management strategies to reduce yield loss
- Fungicide application for UCI is a separate decision-making process from crown canker control. UCI fungicide application can result in very variable yield returns. You must understand the risk before applying a fungicide.

Introduction

In recent years the area sown to canola in NSW has increased significantly. This has been driven by excellent and consistent prices for canola, and favourable seasons for production (especially in 2020 and 2021). The main areas of expansion have been into medium and lower rainfall regions, which in the past have not been traditional canola producing districts. Generally, levels of disease in these areas was negligible, and blackleg was not considered to impact on canola production.

Increased canola density will increase blackleg inoculum (spore density).

The increased area sown to canola now has the potential for blackleg to impact in the medium to lower rainfall regions. The fungus that causes blackleg survives on old canola stubble and releases airborne spores that infect new season crops each year. The more canola stubble there is present from the previous year, the higher the disease pressure will be from blackleg. This is especially true for crops grown within 500m of the previous seasons' stubble.

If stubble stays intact it will release blackleg spores within the growing season. Spore release has been measured from canola stubble for up to four years. However, the blackleg fungus will release fewer spores as the stubble and the fruiting bodies age, e.g., one- year-old stubble produces more spores than two- year-old stubble. The main driver for disease is stubble quantity (amount of canola stubble left behind at harvest) and the resulting spore release from this stubble. Previous research showed that approximately 99% of spores (that infect new seasons' crops) originate from the stubble from the previous year's canola crop, and that older canola stubble (more than 12 months old) produced fewer spores and had less stubble material to harbour the disease due to decomposition.

Commencement of flowering will influence the development of UCI

Observations from commercial crops and research undertaken at Horsham has shown canola that commences flowering early is more prone to developing UCI compared to canola that commences flowering later in the season. It appears that canola bolting and flowering in mid to late winter is exposed to high levels of spore release and hence more prone to developing UCI, as opposed to canola that is still in the cabbage stage at this time and more prone to developing the traditional stem canker.

Your crop is unlikely to get both crown canker and UCI in the same year, therefore you need to know which form of the disease you need to manage this year.

Findings over the past few years have indicated that most years will be defined as a crown canker or UCI year, but rarely both. In most regions 2021 was a crown canker year. That is, as an agronomist you will be managing for either crown canker or UCI. The risk is determined by the timing of sowing (germination).

1. Crown canker - severe crown canker is most likely to develop when plants are infected during the early seedling stage (cotyledon to 4th leaf). The driving factor for seedling infection is the length of time that the plant is exposed to blackleg infection while in the seedling stage. Therefore, the risk of seedling infection, which leads to crown cankers, is very variable from season to season. Once plants progress to the 4th leaf stage they are significantly less vulnerable to crown canker. That is, older plants will still get leaf lesions, but the pathogen is less likely to cause damaging crown cankers as the fungus cannot grow fast enough to get into the crown. Typically, plants sown early in the growing season (April) will develop quickly under warmer conditions and progress rapidly past the vulnerable seedling stage whereas, plants sown later (mid-May) will progress slowly and remain in the vulnerable seedling stage for an extended period.
2. Upper Canopy Infection (UCI) occurs when the plants become reproductive early in the growing season, typically when crops commence flowering in late June/ early-mid July. This results in cool moist conditions which are conducive for infection events but also allows enough time for the pathogen to cause tissue necrosis prior to harvest. That is, UCI flower and branch infection can occur at any time, but it only results in yield loss if it occurs early in the season. This is because the pathogen must grow from the infection point to within the

vascular tissue of the plant where the necrosis occurs causing yield loss. In 2021, crops that commenced flowering in early August in many cases did get UCI infection but the infection did not progress to the vascular tissue and no yield losses resulted.

Upper canopy blackleg fungicide application

Blackleg Upper Canopy Infection (UCI) refers to infection of the upper stem, branches, flowers and pods. Whilst we are constantly improving our understanding regarding these new symptoms, there is still a very large knowledge gap of how individual cultivars react to UCI. Furthermore, our research shows that similar symptoms of UCI can cause very severe economic impact in one season and have no economic impact in another. As such, our recommendations for managing blackleg UCI is constantly evolving.

Monitor crops for UCI development

Symptoms of UCI will begin to appear some time before the disease becomes damaging. Scout canola crops for symptoms of UCI as crops commence stem elongation. The main symptom will be leaf lesions on the upper foliage, suggesting active infections taking place and opportunities for secondary infections via pycnidiospores. Monitor crops regularly (every 7-10 days) and check for new leaf lesions and changes in lesion size. Leaf lesions on the oldest leaves at ground level are unlikely to contribute to UCI.

Should I apply a fungicide for UCI protection?

This question is a real dilemma, get it wrong and it will cost a lot of money, but there is no way to predict economic return accurately yet. Current research is working on improving knowledge including determining timing of infection leading to yield loss, weather parameters associated with yield loss and strategies for screening for genetic resistance.

However, you can still determine if your crop is likely to be in a high, moderate or low risk situation.

1. Time of commencement of flowering. Crops that flower earlier in the season are at higher risk as they flower in the cooler wetter period of late winter/early spring which is more conducive for blackleg infection.
2. Time from the commencement of flowering to harvest. We hypothesis that the fungus requires a certain amount of time from when it initially infects the plant to when it causes the damage (internal infection) that leads to yield loss. The longer time period from infection to harvest = increased risk of yield loss.

The time of 1st flower and time from 1st flower to harvest are good predictors of yield loss. This knowledge can in hindsight explain why in some regions/years yield loss can occur whilst in other years yield loss may not occur. Obviously, these key dates change between regions, for example, if two crops flower on August 7th but the Barellan crop is mature on October 25th and the Cootamundra crop matures on November 25th then there is higher potential for damage to the Cootamundra crop.

1. Spring rainfall and temperature. Preliminary data suggests that UCI given enough time will cause damage to the vascular tissue in the stems and branches resulting in yield loss to the pods. However, similar levels of disease can cause different amounts of yield loss depending on the weather during pod fill. Pods that ripen without moisture stress and during cool weather can tolerate more disease. Imagine a partially blocked xylem; on a cool day the plant can still get sufficient moisture, but on a hot day the partially blocked xylem cannot deliver enough moisture.

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3. Date of 1st flower and targeted date of harvest - the earlier in the season flowering occurs is higher risk. This date will vary for different regions. Generally, shorter season regions can more safely commence flowering at an earlier date compared to longer season regions. Earlier harvest date results in less time for the fungus to invade the vascular tissue and cause yield loss. Consequently, if you're in a long growing season rainfall region and your crop flowers in early August and is harvested in December you are in a very high-risk situation.
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Summary - management of blackleg in low to medium rainfall regions

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4. Pathogen population – if you've grown the same cultivar for several years and disease severity is increasing and then you sow a cultivar from the same resistance group, you will be at a higher risk of crown cankers
5. In lower rainfall regions early sowing may be preferable to maximise yields, resulting in early flowering crops. Understand the seasonal risk based on sowing/germination timing and be aware of symptoms of UCI
6. Monitor crops regularly for blackleg symptom development and progression of disease
7. Fungicides for UCI – if your crop has blackleg lesions (mainly on upper leaves) at stem elongation and it has commenced flowering in late June/early-mid July it is more likely to

benefit from a fungicide application. Later flowering crops are unlikely to have yield losses. Cultivar resistance to UCI has been shown to be effective but we do not yet have a reliable cultivar screening system. If your cultivar has had significant yield increases from 20%-30% bloom fungicide applications in previous years, it is likely to be susceptible and benefit from fungicide application

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DAN 00177, UM 0051, BLG 206

Take home messages

- Outbreaks of sclerotinia stem rot are sporadic and dependent on the growing season conditions. Saturated canopy conditions for more than 48 hours during flowering favour the development of the disease
- Current and adjacent paddocks with histories of sclerotinia disease in broadleaf crops over the last four years are an indicator of potential risk for this season's crop
- The frequency of canola or lupin in a paddock is very important in determining the risk of a sclerotinia outbreak, as these crops are very good hosts for the disease and can quickly build up levels of soil borne sclerotia
- Foliar fungicides for management of the disease are best applied at 20 – 30% bloom (15-20 flowers off the main stem) for main stem protection
- In low to medium rainfall regions outbreaks of sclerotinia stem rot are sporadic and the returns from foliar fungicide applications must be considered carefully.

How does the disease develop?

The complexity of the disease cycle of sclerotinia stem rot results in disease outbreaks being sporadic compared to other diseases. Several key stages must be synchronised and completed for plant infection to occur. Weather conditions must be suitable for the pathogen at each stage. These stages of development include:

1. Softening and germination of soil borne sclerotia
2. Apothecia development and release of ascospores
3. Infection of petals by air-borne ascospores
4. Senescence of infected petals in the presence of moisture and subsequent stem infection.

Weather conditions during flowering play a major role in determining the development of the disease. The presence of moisture during flowering and petal fall will determine if sclerotinia stem rot develops. Dry conditions during this time can quickly prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development.

What factors drive the development of sclerotinia stem rot?

- **Frequency of sclerotinia outbreaks.** The past frequency of sclerotinia stem rot outbreaks in the district can be used as a guide to the likelihood of sclerotinia developing this season.

Paddocks with a recent history (last 5 years) of sclerotinia outbreaks are an indicator of potential risk, as well as those paddocks that are adjacent. The frequency of canola and lupin in the paddock can also increase disease risk. Canola and lupin are very effective hosts for the disease and can quickly build up levels of soil-borne sclerotia.

- **Commencement of flowering.** The commencement of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. **Canola crops which flower earlier in winter (late June - July) are more prone to disease development and exposure to multiple infection events.**
- **Spring rainfall**. Epidemics of sclerotinia stem rot occur in districts with reliable late winter and spring rainfall with long flowering periods for canola. These provide long periods of canopy wetness necessary for the disease to develop, at least 48 hours or more. Overnight dews generally don't trigger epidemics.

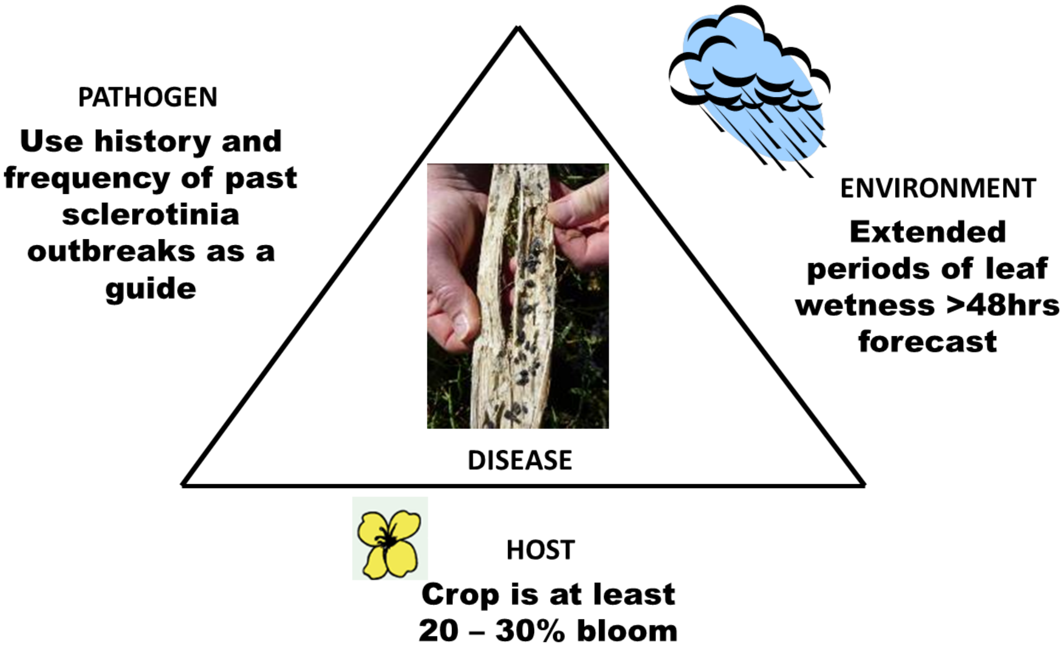

Figure 1. Factors that drive the development of sclerotinia stem rot

Key points for low-medium rainfall districts

- Compared to high rainfall districts, serious outbreaks of sclerotinia stem rot will be highly sporadic, once in very 5 – 7 years, often only in years of above average rainfall
- Background levels of sclerotia are likely to be much lower, due to less frequent outbreaks of the disease, reducing disease pressure
- Shorter flowering periods for canola reduces the opportunity for the disease to develop to damaging levels and crops canopies are less bulky
- The intensity of canola in the system is often less, reducing high disease risk situations from high inoculum loads.

Pre-sowing sclerotinia management

Crop rotation

- Rotate canola once in every 4 to 5 years to reduce build-up of sclerotia
- Incorporate lower-risk crops into the crop rotation e.g. cereals, field pea and faba bean
- Separate last year's canola stubble and new seasons' crops by at least 500m
- Ascospores spread within 100m to 400m of the apothecia.

Burning

- Burning of stubbles and windrows will kill some sclerotia, but will not significantly reduce the risk of disease.

Clean seed

- Always use seed free of sclerotia where possible
- Grade retained seed for sowing to remove sclerotia if in doubt
- Grain receival standards allow a maximum of 0.5 per cent sclerotes in the sample.

Variety selection

- There are no Australian canola varieties with known resistance to sclerotinia. Some differences may be observed in the level of stem rot in some seasons. This is likely to be related to the timing of flowering and infection events.

Crop management

- Always follow the recommended sowing time and seeding rate for your region
- Early maturing varieties sown early can be prone to developing stem infection due to the earlier commencement of flowering when conditions are wet for prolonged periods
- Once flowering starts, the crop becomes susceptible to infection and prolonged exposure to infested senescent petals means greater chance of stem infection
- Bulky crop canopies can retain more moisture and are conducive for the development of stem infections
- Wider row spacing or reduced seeding rates can increase air-flow through the canopy, reducing moisture retention and potential for infection.

Use SclerotiniaCM app (see useful resources) to determine the most appropriate management strategies for your district.

Post sowing sclerotinia management - fungicide application

- Use foliar fungicides to prevent early stem infection via infested petals
- Always use fungicide products that are currently registered in Australia, there are several new products registered for use in 2022
- Timing of foliar fungicide application is more important than choice of fungicide product in reducing potential levels of stem infection

- Foliar fungicide application is most effective before an infection event
- Application of foliar fungicide at 20-30% bloom stage is most essential in reducing main stem infection and most yield loss by protecting early petals from infection. Penetration of fungicide into the crop canopy is needed to protect potential infection sites from falling petals
- Multiple foliar fungicide applications may be needed in high-risk-disease districts with a high yield potential. Applications at both 10 -20% and 50% bloom provide critical early and follow up protection from multiple infection events
- Use high water rates (at least 100 litres per hectare) to achieve adequate coverage and penetration into the canopy
- Foliar fungicides generally have an active life of two to three weeks. The protection provided may wear off during the critical infection period or where crops have an extended flowering period. A single fungicide application too early may not be effective
- Foliar fungicides will have no effect on managing basal infections, as this occurs below the soil surface and beyond the activity of foliar fungicides.

Always

- Determine disease risk as your crop enters the flowering period
- Assess bloom stage, seasonal conditions and weather forecasts to identify the potential risk to your crop
- Identify how many consecutive wet days are forecast as the crop commences flowering and the week ahead, especially consecutive wet days of 48 hours or more
- Monitor crops for disease development and identify the types of infection. Basal and main stem infections cause the most yield loss

Useful resources

- NSW DPI Winter Crop Variety Sowing Guide (Disease updates, variety resistance, fungicide products).

- SclerotiniaCM App for iPad and android tablets

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Hyper yielding crops lifts canola yield above 6 t/ha

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[1] BrillAg
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Key words

canola, hybrid, nutrition, manure, fungicide

GRDC code

FAR2004-002SAX

Take home messages

- Grain yield reached well over 6 t/ha at Millicent and Wallendbeen in 2021, 1 t/ha above the highest yields observed in 2020
- Yield plateaued from nitrogen application either below or up to 150 kg/ha applied N
- The application of animal manure lifted yield by a further 11-18% above the maximum yield from applied N
- Variety choice has a major impact on achieving hyper yields, with 45Y95 CL being the standout variety in 2021.
- Further research will determine the mechanisms behind the strong yield response from animal manure and how nutrition can drive hyper yields of canola.

Background information

The canola component of the GRDC and FAR Australia Hyperyielding Crops project commenced in 2020 with sites at Gnarwarre, Victoria; Millicent, South Australia; and Wallendbeen NSW. The focus has been on determining the management factors including variety choice, nutrition, fungicide and canopy management required to achieve a canola yield of 5 t/ha. Variety choice and nutrition were the two most important factors driving canola yield in these high yielding environments in 2020, with fungicide and seeding rate less important. Highest yields were at Wallendbeen with 5.6 t/ha of 45Y28 RR with 225 kg/ha N applied. At Gnarwarre, highest yield was 4.8 t/ha of 45Y28 RR with 106 kg/ha N applied with 5 t/ha pig manure. At Millicent highest yield was 4.6 t/ha of 45Y93 CL. All results from 2020 are available at: https://faraustralia.com.au/wp-content/uploads/2021/04/210325-HYC-Project-2020-Results-Canola-Final.pdf .

2021 hyper yielding canola trials

Trials with a similar focus were conducted in 2021 in the same environments as 2020. Yields were higher in 2021 at all sites, with two of the three sites achieving a grain yield of 6 t/ha, well above the target yield of 5 t/ha (Figure 1). This paper outlines the key management strategies to achieve these very high yields at each site.

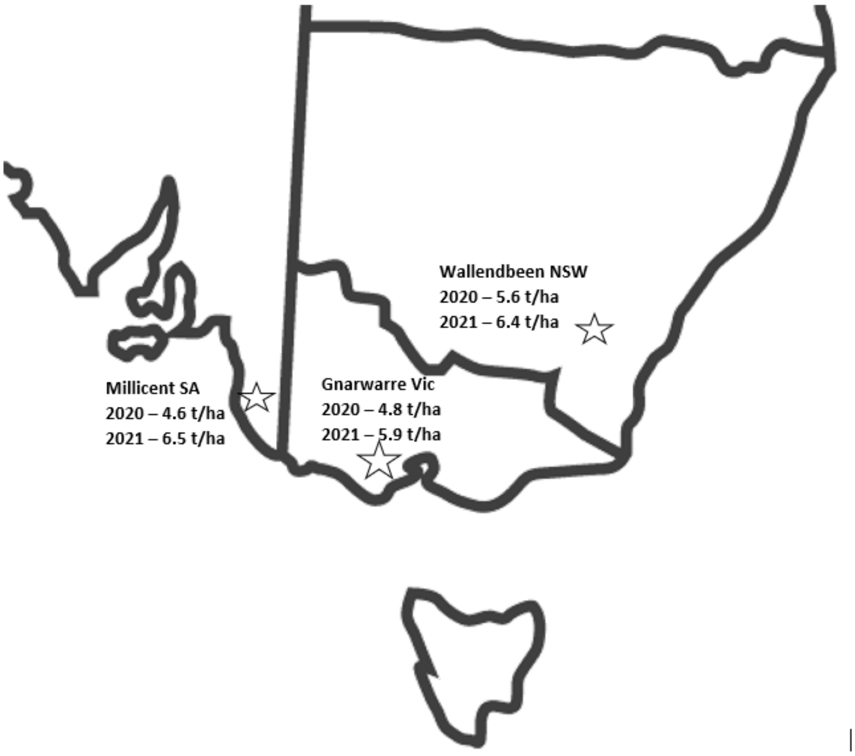

Figure 1. Grain yield of the highest yielding canola treatments at three sites in 2020 and 2021.

Methodology

This paper reports on two key trial series (Table 1), the first a genotype x environment x management (GEM) trial which were split into separate winter and spring trials with three management strategies (low, medium and high input) applied to each variety (blocked by herbicide tolerance) at three locations; Gnarwarre, Millicent and Wallendbeen (Site descriptions in Table 2). The second trial series was a nutrition trial again split into separate spring and winter trials with six nutrition treatments, focusing on nitrogen management and the addition of animal manure.

There were separate fungicide, seeding rate and variety screen trials conducted at each site. Results from these will be presented at GRDC Updates and available on the FAR Australia website on completion of reports.

Table 1. Variety entries and treatments in a canola G x E x M trial and canola nutrition trial, conducted at three sites in 2021.

GEM trial series			**Nutrition trial**		
Spring varieties	**Winter varieties**	**Treatments**	**Spring variety**	**Winter variety**	**Treatments**
ATR Wahoo	Hyola 970CL	Low input: Seed = Maxim® XL 20% Bloom = Aviator® Xpro® 0.8 L/ha N = 150 kg/ha	45Y28 RR	Hyola Feast CL	0 kg/ha N
HyTTec® Trifecta					75 kg/ha N
45Y93 CL		Medium input: Seed = Maxim XL 20% Bloom = Aviator Xpro 0.8 L/ha N = 225 kg/ha			150 kg/ha N
45Y95 CL	Hyola Feast CL				225 kg/ha N
45Y28 RR		High input: Seed = Saltro® Duo 6-Leaf = Prosaro® 0.45 L/ha 20% Bloom = Aviator Xpro 0.8 L/ha 50% Bloom = Prosaro 0.45 L/ha N = 225 kg/ha			300 kg/ha N
Condor TF					225 kg/ha N + Animal Manure*

*Manure applied – 6.7 t/ha pig manure at Gnarwarre and Millicent (2.7% N, 1.3%P) and 3 t/ha chicken manure at Wallendbeen (3.3% N and 0.7% P).

Table 2. Site description for three hyper yielding canola sites in 2021.

Location	Region	Average rainfall	Elevation	Soil type	Available N at sowing	Organic Carbon	Colwell P	Applied P	Applied S
Gnarwarre	Southern Victoria	600 mm	190 m	Sodic Vertosol	70 kg/ha (0-100 cm)	1.4%	34 mg/kg	22 kg/ha	30 kg/ha
Millicent	South-East SA	710 mm	20 m	Organosol	173 kg/ha (0-10 cm)	9.7%	56 mg/kg	22 kg/ha	30 kg/ha
Wallendbeen	South-West Slopes NSW	680 mm	540 m	Red Ferrosol	340 kg/ha (0-90 cm)	2.0%	63 mg/kg	30 kg/ha	30 kg/ha

Results and discussion

Nutrition trials

In the spring nutrition trials, yield from the application of N alone (as urea) plateaued at 150 kg/ha at Gnarwarre and 75 kg/ha at Millicent (Table 3), with no yield increase from applied N at Wallendbeen which had a starting nitrogen of 340 kg/ha in the top 90 cm. In the winter nutrition trials, there was no yield response from applied N (urea) at either Gnarwarre or Wallendbeen (winter results not yet available for Millicent) (Table 4).

Despite high starting fertility levels and saturated N responses, there were still strong responses to applied animal manure over and above high rates of applied N. This response was observed in all spring trials and one winter trial, Gnarwarre. The yield response from manure in the spring trials ranged from 11% at Wallendbeen to 18% at Gnarwarre and in the winter trials from not significant to 17.5%.

It is exciting to see such strong yield responses from nutrition above the response from applied N (urea) alone, especially to yield levels above 6 t/ha. The challenge for the project team is to better understand the reason for the strong yield response from animal manure and how that can be cost-effectively implemented across the wider grains industry.

Table 3. Effect of nutrition (applied N and animal manure) on 45Y28 RR canola at three hyper yielding canola sites in 2021. Shaded cells denote highest yield in trial.

Treatment (kg/ha N)	**Gnarwarre, Vic**	**Millicent, SA**	**Wallendbeen, NSW**
0	4.0	4.9	4.5
75	4.5	5.6	4.4
150	4.9	5.8	4.6
225	5.1	6.1	4.5
300	5.0	5.8	4.5
225 + Manure	5.9	6.5	5.0
l.s.d. ($p<0.05$)	0.36	0.56	0.32

Table 4. Effect of nutrition (applied N and animal manure) on Hyola Feast CL canola at two hyper yielding canola sites in 2021. Shaded cells denote highest yields in the trial.

Treatment (kg/ha N)	**Gnarwarre, Vic**	**Wallendbeen, NSW**
0	3.8	3.8
75	3.9	3.7
150	4.1	3.6
225	4.1	3.8
300	4.0	3.7
225 + Manure	4.7	3.5
l.s.d. ($p<0.05$)	0.51	n.s.

GEM trials

There were large differences between varieties in the spring GEM trial, with a small response from management at Gnarwarre and Wallendbeen and no management response at Millicent. At Wallendbeen there was an average yield response of 0.3 t/ha in the high input versus medium and low input management. At Gnarwarre there was 0.3 t/ha higher yield in the high input compared to low input management.

At Millicent and Wallendbeen, 45Y95 CL was the standout variety with yield of 6.4 t/ha (averaged across management levels) (Table 5). This yield is 28% higher than the target yield of 5 t/ha and highlights what can be achieved with canola when seasons, variety choice and management all align. The addition of manure to improve crop nutrition may raise the bar even higher for canola and this will be tested in the GEM trial in future years. Further sample processing and data analysis will help understand the reasons behind the standout yield of 45Y95 CL at these two sites.

45Y28 RR was the highest yielding variety in the GEM trials at Gnarwarre where Clearfield varieties were not included. However, 45Y95 CL was the highest yielding variety in the adjacent spring screen trial.

In the winter GEM trials, Hyola Feast CL yielded higher than Hyola 970CL at Wallendbeen, but there was no yield difference between the two at Gnarwarre (Table 6). There was no yield difference between the management levels in the winter GEM trial at either site.

Table 5. Effect of variety choice on grain yield (averaged across three input levels) in Spring G x E x M trial at Gnarwarre, Millicent and Wallendbeen in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	**Millicent SA**	**Wallendbeen NSW**
ATR Wahooᶲ	3.5	3.3	3.6
HyTTec Trifecta	3.9	4.4	5.2
45Y95 CL	*	6.4	6.4
45Y93 CL	*	5.7	5.6
45Y28 RR	4.5	5.1	4.9
Condor XT	3.9	5.1	5.2
l.s.d. (*p*<0.05)	0.21	0.34	0.36

Table 6. Effect of variety choice on grain yield (averaged across three input levels) in Winter G x E x M trial at Gnarwarre, Millicent and Wallendbeen in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	**Wallendbeen NSW**
Hyola Feast CL	4.3	3.8
Hyola 970 CL	4.0	3.4
l.s.d. (*p*<0.05)	n.s.	0.34

Discussion and conclusion

There were three major stories to emerge from 2021 hyper yielding canola trials:

1. Yield levels were above even the most optimistic forecasts for canola. 6 t/ha should be a commercial target for industry and 7 t/ha will be the next frontier for research in these environments.
2. Nutrition is not just about applied urea. Strong responses from animal manure showed the importance of nutrition to push yields to new levels. This needs to be further investigated by the project team to determine if the yield response from manure is due to its slow-release nature or from nutrients such as phosphorus and potassium that are applied along with nitrogen in animal manure.
3. Like 2020, variety choice had a large impact on grain yield outcomes. 45Y95 CL was the standout variety across the three sites in 2021.

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Friday 25 February 2022
Chickpeas

Impact and timely control of ascochyta blight of chickpea

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Key words

chickpea, ascochyta, management, foliar fungicides

GRDC code

GAPP, Grains Agronomy & Pathology Partnership – A strategic alliance between GRDC and NSW DPI (DAN00213): BLG206 IDM for Broadleaf Crops in southern and central NSW

Take home messages

- Ascochyta blight is the most damaging disease of chickpea in Australia
- In southern NSW outbreaks of the disease are usually less severe due to the reduced occurrence of chickpea within cropping rotations
- An Integrated Disease Management approach should be taken when managing this disease and not rely on fungicides alone
- Foliar fungicides are an important component of disease management and should be used strategically at critical crop development stages
- Manage ascochyta blight early and grow chickpea varieties with the best resistance to minimise disease impact.

Introduction

Ascochyta blight (ascochyta) is the most serious disease of chickpea in Australia and can cause 100% yield loss in years favourable to the disease. In northern NSW, chickpea producers contend with outbreaks of the disease every year, with the high frequency of chickpea within cropping rotations driving disease development. Whereas chickpea is not widely grown in southern NSW, and many producers are still in the early stages of learning to manage the crop and understand the behaviour of ascochyta outbreaks.

Chickpea is sold into human consumption markets and as such requires a higher level of disease management compared to other grain legumes such as lupin or field pea. Ascochyta can not only reduce yield potential, but also reduce grain quality, so effective management of disease is required for the life of the crop. Taking an integrated approach, there is a range of strategies that can be used to effectively manage ascochyta.

This paper will outline critical considerations when managing ascochyta in southern NSW and key disease management strategies that should be considered. This includes key findings and observations from disease management experiments and commercial chickpea crop surveys in southern NSW.

Early stages of disease development – germination to vegetative

Paddock selection: The fungus that causes ascochyta survives on old chickpea trash; it does not survive in soil. In northern NSW, the high frequency of chickpea in cropping rotations makes separation of last year's stubble from this season's crop often difficult and significantly increases disease pressure. The same also applies to the frequency of chickpea in the rotation, once every four years is ideal.

In southern NSW, separation of last year's chickpea stubble from new season's crops is far easier to achieve and should be a high priority. Also consider the logistics of multiple fungicide applications when selecting paddocks to be sown to chickpea. This also includes the possibility of using aircraft to apply fungicides if conditions are too wet for a ground rig.

Seed**:** The fungus that causes ascochyta can survive within infected chickpea seed if the infection occurs during formation of the seed within the pod. Often though infection occurs late during seed development and the fungus is restricted to the seed coat. Infestation of seed can also occur during harvest where small particles of infected seed pod or stubble can mix with harvested seed and contaminate the seedlot.

Sowing of infected or infested seed is a significant source of introduction of the disease into new seasons crops in southern NSW. Often seed for sowing is sourced from northern NSW or the Wimmera region of Victoria, where ascochyta is far more prevalent. Treating chickpea seed with a fungicide for sowing will significantly reduce, but not eliminate ascochyta. This includes commercially sourced seed. Following emergence, seedlings grown from fungicide treated seed will have limited systemic protection from ascochyta and may be prone to infection.

Transmission and spread of ascochyta can still occur from chickpea seed treated with a seed-applied fungicide.

Seedling – vegetative**:** Symptoms of ascochyta are not always easily seen at early stages of crop establishment. In southern NSW, chickpea is often slow to emerge and slow for crops to establish due to cold temperatures in late autumn and winter. During this time Ascochyta can develop in random hotspots and may go largely undiagnosed. Frequent rainfall events and cool temperatures favour the spread and establishment of ascochyta during this time. Often by the time the disease is noticeable within crops, significant levels of infection have occurred.

Recent field experiments conducted by NSW DPI at Wagga Wagga and grower experience have indicated this period of crop development can provide significant opportunities to effectively manage ascochyta and reduce disease pressure later in the season. The application of a foliar fungicide at this stage can be very effective at reducing the initial establishment and spread of the pathogen, given the ability to attain excellent plant coverage. This suggests that the combination of a fungicide seed dressing and early application of a foliar fungicide are highly complementary in reducing levels of ascochyta within chickpea crops. This approach becomes even more effective if growing chickpea varieties that have reduced levels of resistance.

Scouting for disease during the growing season is important at all growth stages. The susceptibility of chickpea varieties to ascochyta and the ability of ascochyta to spread quickly requires commercial crops to be inspected at regular intervals (every 7 – 14 days). Effective scouting for disease requires crops to be inspected on-foot, at several locations. Inspect crops making note of possible disease symptoms, changes in disease symptoms and development of ascochyta hotspots within crops. Use pegs to mark inspection points within crops or the location of ascochyta hotspots.

Ascochyta is largely splash dispersed during the growing season. Pycnidiospores produced within leaf and stem lesions are dispersed short distances by rain droplets and can be blown further by wind-blown rain. Every rainfall event that occurs during the growing season is an opportunity for ascochyta to spread further and cause infection if crops are not adequately protected.

With warmer temperatures the rate of crop growth will increase. Canopy closure is a significant crop development stage with the foliage in adjacent rows closing over. Within the canopy humidity increases and potential infection periods also increase. The ability of foliar fungicides to penetrate the canopy significantly decreases at the same time, which makes early fungicide applications important.

Vegetative – late podding: Ascochyta has the potential to develop and spread quickly in late winter and spring. Following canopy closure, the ability for moisture to remain within the crop canopy to initiate infections increases considerably. Warmer temperatures also decrease generation times for ascochyta to approximately 5-7 days, allowing infections to spread quickly with frequent rainfall events.

Infections that develop during this period are more difficult to manage. This is due to a combination of reduced fungicide penetration into the canopy and shorter generation times from the ascochyta fungus.

Rapid crop growth during this period is often very 'soft' and susceptible to infection. Flowers and developing pods are also very susceptible to ascochyta. Continue to scout crops for symptom development.

Ascochyta prevention is important during the reproductive stage as the disease on pods causes seed abortion, seed infection and seed defects, and may not be suitable as planting seed for the following season or can be downgraded at delivery.

Foliar fungicide applications during this period aim to maintain protection of newly emerging growth and protect developing pods from infection. Spring rainfall patterns will dictate the number of fungicide applications required.

Late podding – maturity: Management of ascochyta during this period continues to focus on protecting pods. Be aware that late rains around maturity can result in some late seed infection and seed discolouration.

Using foliar fungicides

Begin monitoring as soon as the crop has emerged. If ascochyta is detected, apply a registered fungicide as close to the next rainfall event as practical. Fungicide use should focus on prevention of new infections and spread of the disease **NOT** curing old infections. Currently fungicides fall into two categories, older fungicides and new fungicides.

Older fungicides (active ingredients such as chlorothalonil and mancozeb):

- Preferred products in-crop, being the most reliable and cost effective. They provide excellent protection when applied before rain with thorough coverage and high-water volumes.
- Chlorothalonil and mancozeb are persistent and rain fast (up to 50 mm rain in 10 minutes).
- Expect several weeks control on plant tissue sprayed (14-20 days) with chlorothalonil and mancozeb, but no protection of new growth as they have no systemic movement through the plant.
- Refer to fungicide labels for maximum amount of chlorothalonil that can be applied per season.

Newly released fungicides (products include Aviator® Xpro® (prothioconazole + bixafen), Amistar® Xtra (azoxystrobin + cyproconazole) and Veritas® (tebuconazole + azoxystrobin).

Points to note:

- These chemicals offer protection via different chemical groups, which is important in an integrated disease management program to prevent resistance
- These fungicides are more expensive than chlorothalonil with equivalent efficacy as preventive fungicides
- Post-infection or salvage applications should not be considered part of a standard management program
- Aviator Xpro has limited curative activity as well as residual control.
- Veritas, Amistar Xtra and Aviator Xpro labels state a maximum of two applications of each in any one season. Aviator Xpro cannot be applied after late flowering. Veritas can be applied at any growth stage but has a harvest withholding period (WHP) of four weeks, while Amistar Xtra has a harvest WHP of eight weeks
- Expect several weeks control on sprayed plant tissue (up to 21 days), but new growth will not be protected as they have little systemic activity.

What to do if disease found in the paddock

Monitoring your chickpea crop for ascochyta regularly is the most effective means of managing the disease. The appearance of the disease or spread of the disease will be most easily seen 7 -10 days after a rainfall event.

If the disease is detected for the first time, apply a registered foliar fungicide. Movement of the disease will be limited while conditions are dry, so focus on managing the disease between rainfall events and periods of protection from the fungicide. Continue to regularly monitor for disease and check for lesion development and spread within the crop. This is very important for susceptible varieties (e.g. Kyabra⊕).

Summary

Ascochyta blight is the most important disease of chickpea in Australia.

In southern NSW the area sown to chickpea is still small, compared to northern NSW, so pressure from this disease within cropping rotations is low. The fungus that causes ascochyta blight is transmitted between seasons on old, infected crop trash and infected seed.

Management of ascochyta commences with the use of clean seed that is treated with an appropriate fungicide seed treatment. Once the crop has emerged, regular crop inspections are key to applying foliar fungicides at the right time, with prophylactic use before rainfall events essential in high risk situations and when using varieties that do not have good genetic resistance.

In addition to using treated seed, the critical timings for foliar fungicide applications are:

Critical period 1: **4- 6 weeks post emergence**; apply a foliar fungicide to contain or eliminate any seed-borne infections.

Critical period 2: **Just prior to canopy closure**; apply a foliar fungicide to the crop to obtain adequate coverage of the lower canopy before the crop canopy closes. It is important to ensure coverage of the lower canopy and potential infection sites.

Critical period 3: Podding; continue to monitor the crop during podding to protect pods from infection.

Continue to monitor the crop regularly throughout the growing season and time foliar fungicide applications according to the period of protection offered by the fungicide product applied and rainfall events.

Other resources

NSW DPI – Winter Crop Variety Sowing Guide

NSW DPI - Managing ascochyta blight in chickpeas in 2021 (Penny Heuston and Kevin Moore)

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The impact of Ascochyta on chickpea yield and economics when infection occurs at three different growth stages

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Key words

disease severity, management, gross margin, chickpea, Ascochyta blight

GRDC code

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

Take home message

Variety choice remains a critical management tool under high disease pressure (gross margin loss of $300/ha in Kyabraᶲ compared to gains of up to $1000 in PBA Seamerᶲ when no fungicide applied)

Preventative application of fungicide before seedling infection has the greatest impact in reducing severity of disease

Salvage application of fungicide to seedling infection in susceptible varieties is insufficient in preventing yield loss

Seasonal conditions in 2021 were not conducive to determine if infection during the vegetative growth stage impacts yield

Application of fungicide during early podding growth stage may reduce yield loss if Ascochyta blight is present and a wet-season finish is predicted.

Introduction: why was this research done?

*Ascochyta blight (*AB) management in chickpea across southern Queensland and north-central New South Wales regions is based on controlling early season infection. This strategy has been developed through agronomist feedback and past Tamworth Agricultural Institute (TAI) experiments where infection is simulated after the first post emergent rain event. However, dependant on varietal resistance, chickpeas are also known to be susceptible to AB infection later in the season during flowering and podding. Limited studies have been conducted on the impact of AB management when infection occurs during flowering and podding stages of chickpea in Australia.

In 2020 an experiment was conducted at Trangie Agricultural Research Centre (TARC). This established that early disease management and higher AB varietal resistance continues to be the most profitable management strategy when compared to uncontrolled infection with susceptible varieties. However, the 2020 results raised further questions about what would occur if fungicide application was reactive after the first post emergent rainfall event, or if no fungicide was applied until pod infection. These treatments were added to the 2021 experiments conducted both at TARC and TAI to assess the economic impact of AB infection at three separate growth stages on chickpea varieties with different levels of AB resistance.

Methods

Variety and AB resistance

- **Kyabra**ᶲ VS = Very susceptible
- **PBA HatTrick**ᶲ MS = Moderately susceptible
- **PBA Seamer**ᶲ MS = Moderately susceptible

Treatments applied per variety

- **No disease (LOW):** Plots un-inoculated with AB and any potential disease controlled using foliar chlorothalonil fungicide applied before rain or irrigation events
- **High disease (HGH):** Plots inoculated with disease twice at seedling (3-4 nodes) and vegetative (7-8 nodes) growth stage with no fungicide applied
- **Seedling 1 (SDG1):** Plots inoculated with AB at seedling stage (3-4 nodes), with one prior (preventative) fungicide treatment at 2-3 node stage. Allow disease to progress for 2-3 rain events, then control for remainder of season with foliar fungicide as with LOW treatment
- **Seedling 2 (SDG2):** Plots inoculated with AB at seedling stage (3-4 nodes), with no prior (preventative) fungicide treatment. Allow disease to progress for 2-3 rain events, then control for remainder of season with foliar fungicide as with LOW treatment
- **Vegetative (VEG):** Plots protected with foliar fungicide from emergence to vegetative growth stage then inoculate with AB. Allow disease to progress for 2-3 rain events or to first pod, then control again with foliar fungicide for remainder of season
- **Podding 1 (POD1):** Plots are protected with foliar fungicide from emergence to first pod then inoculated with AB, disease allowed to progress through to harvest
- **Podding 2 (POD2):** Plots progress to the podding stage without foliar fungicide protection then inoculated with AB, disease allowed to progress through to harvest

Fungicide application and infection events

All fungicide treatments were chlorothalonil (720 g/L) @ 1 L/ha with up to 6 treatments applied to LOW disease plots. Inoculation was completed with AB conidial suspension @ 400,000 – 300,000 conidia/mL. Additionally, two AB-infected spreader plants per inoculated plot were planted at each end of the treatment plots at each growth stage timing for infection. Treatments were applied at each site according to predicted rainfall that would sustain 6-12 hours of leaf wetness (Figure 1 and 2).

Field experimental design and operations

Field experiments were conducted at TARC and TAI on grey and light clay soil respectively. The experiments were sown in a randomised block design on 16 and 29 of May at TAI and TARC respectively. All chickpea varieties were sown at 35 plants/m^2 on 30 cm row spacing with Pulse starter Z fertiliser and rhizobia group N. All experimental seed was treated with P-Pickel T® pre sowing. Field experiments were managed according to best practice weed and insect management. Pre-harvest desiccation was applied using Reglone® (200 g/L diquat) @ 2 L/ha at TAI; and Roundup Ultra®MAX (570 g/L glyphosate) @ 1.7 L/ha plus Sharpen® (700 g/kg saflufenacil) @ 34 g/ha at TARC. The experiments were harvested to assess grain yield response on 13 December at TARC and 19 December at TAI.

Data collection and analysis

Severity of AB was assessed on a 1 – 9 scale (Table 1). Treatment HGH represented the positive control for each variety (high disease – no fungicide applied) and LOW represented the negative control (low disease – multiple fungicides applied) in comparison to all other treatments. The TAI trial was scored on August 17, September 29 and October 25. The TARC trial was scored on September 13, September 28 and October 27. Gross margin was calculated based on the PIRSA gross margin for chickpeas.

Table 1. Summary of *Ascochyta blight* disease scale

No. score	**Definition**
1	Disease symptoms not detected
2	Leaf lesions on the lower canopy are rare, no leaf lesions on the upper canopy
3	Leaf lesions on the lower canopy are rare, leaf lesions on the upper canopy rare
4	Leaf lesions on the upper canopy common
5	Stem lesion rare, leaf lesions on upper canopy common
6	Stem lesions uncommon, leaf lesions on upper canopy common
7	Stem lesions common, leaf lesions on upper canopy common, stumps uncommon
8	Stem lesions common, leaf lesions on upper canopy common, stumps common
9	All plants are dead

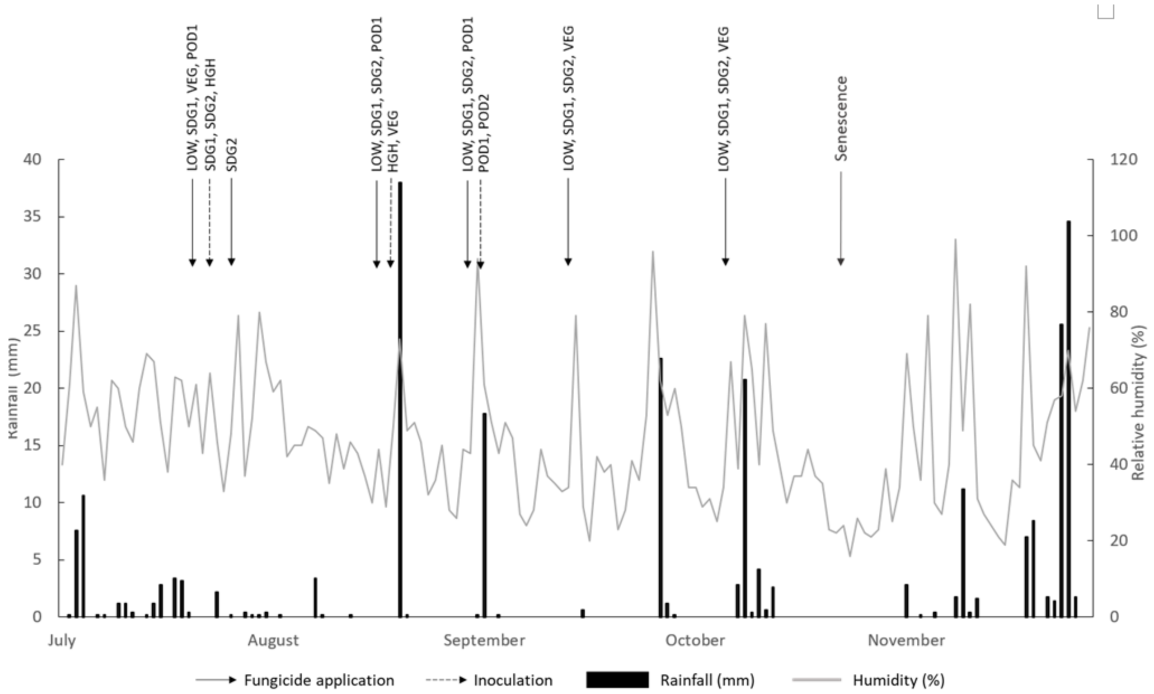


Figure 1. Timing of seedling, vegetative and podding Ascochyta blight inoculation and fungicide treatments as triggered by rainfall (mm) events of sustained 6-12-hour leaf wetness at Trangie Agricultural Research Centre in 2021.

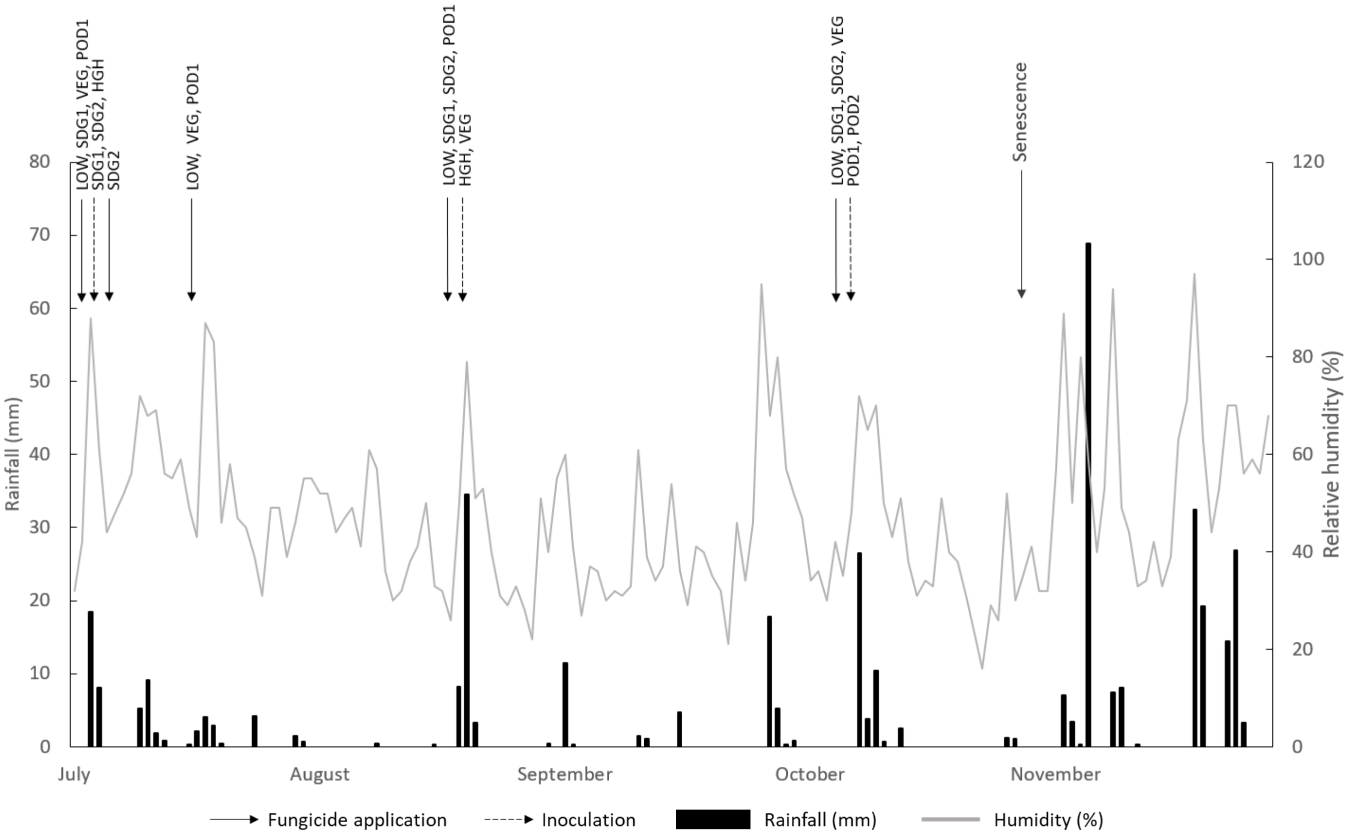


Figure 2. Timing of seedling, vegetative and podding *Ascochyta blight* inoculation and fungicide treatments as triggered by rainfall (mm) events of sustained 6–12-hour leaf wetness at Tamworth Agricultural Institute in 2021.

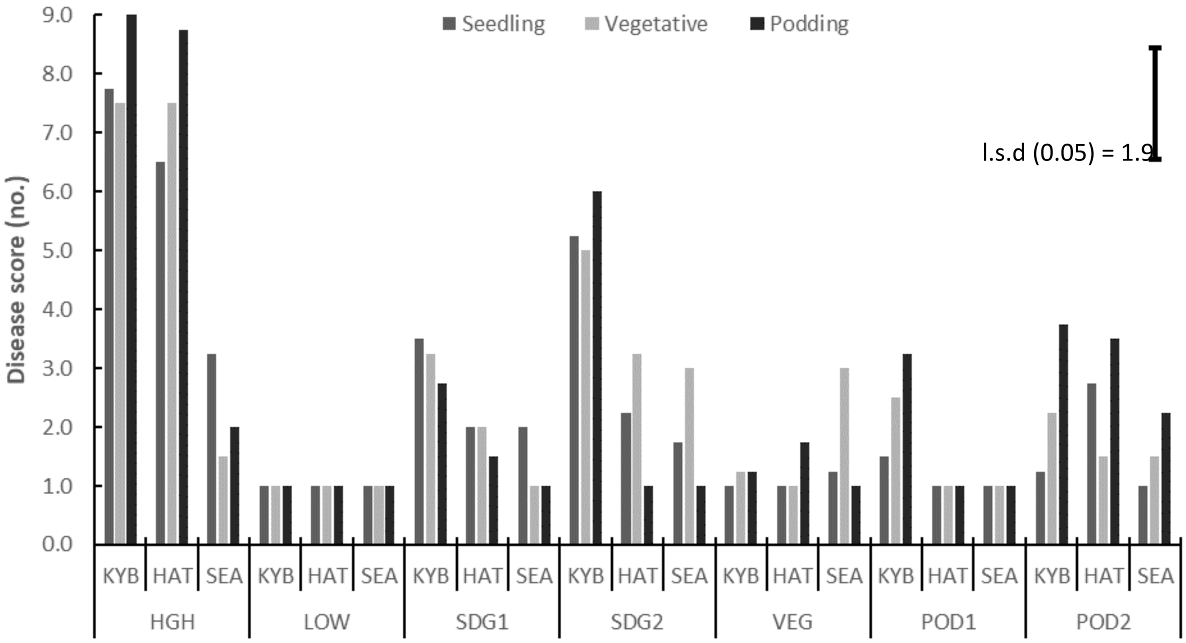
Results

Disease severity

Disease assessments were taken at least two weeks after disease inoculation and application of corresponding fungicide management treatments. The no fungicide (positive control (HGH)) treatments for susceptible variety Kyabraᶲ scored highest for disease severity at both TARC and TAI. For moderately susceptible varieties PBA HatTrickᶲ and PBA Seamerᶲ at TARC the highest scores were ≥ 8 and ≥ 3 respectively. The same varieties at TAI scored ≥ 4 and ≥3 respectively. At both TARC and TAI there was little to no disease for the full fungicide (negative control (LOW)) treatments (Figure 3). Overall, TARC appeared to have consistently higher disease scores than TAI.

Across fungicide management treatments at both TARC and TAI Kyabraᶲ plots with seedling infection and no early fungicide (SDG2) had the highest disease scores with significant increases in disease severity compared to the full fungicide (negative control (LOW)) treatment. At both TARC and TAI, there was a significant difference between the Kyabraᶲ SDG1 and SDG2 treatments at all assessment timings with lower disease severity in the SDG1 treatment which had a fungicide applied at the 2-3 node stage prior to inoculation at 3-4 nodes. All treatments had significantly decreased disease severity compared with the no fungicide treatments with except for TAI SDG2 which retained high severity and all PBA Seamerᶲ which remained low regardless of treatment. In comparison to the negative control (LOW), disease severity was significantly higher with the SDG1 treatment at both locations and SDG2 and VEG at TAI. In addition, disease severity was significantly different at both locations between both the negative control (LOW), POD1 and POD2, as well as between POD1 and POD2 at TARC (Figure 3).

(a). TARC



(b). TAI

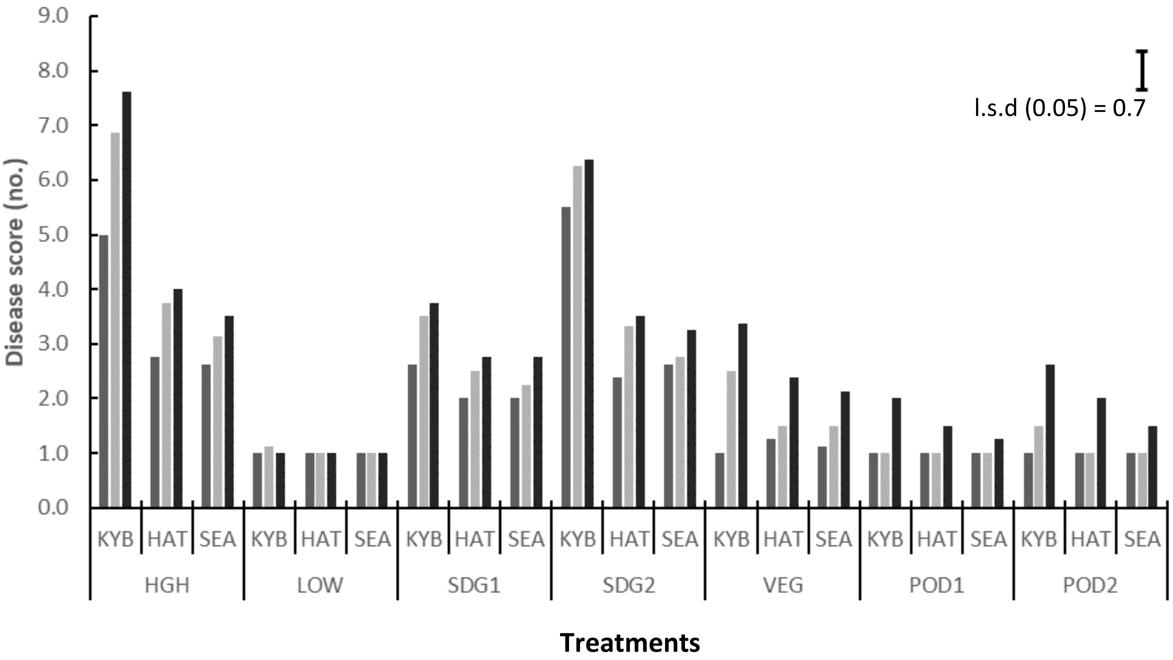


Figure 3. *Ascochyta blight* disease scores taken at least 2 weeks post seedling, vegetative and podding infection timings at TARC (a) and TAI (b) in 2021. (KYB= Kyabra⍉, HAT=PBA HatTrick⍉, SEA= Seamer⍉)

Yield

Significant yield differences were recorded between treatments at both TARC and TAI. In the no fungicide (positive control (HGH)) treatments, there was a yield loss for Kyabraⓓ, PBA HatTrickⓓ and PBA Seamerⓓ of 97, 51 and 18 % respectively at TARC. Losses were similar at TAI with Kyabraⓓ, PBA HatTrickⓓ and PBA Seamerⓓ at 97, 60 and 18% when no fungicide was applied. When SDG1 and SDG2 treatments were compared to the negative control (LOW) where disease was not present, the greatest loss was 35% and 90% for Kyabraⓓ at TARC and TAI respectively. This is compared to moderately susceptible varieties PBA HatTrickⓓ and PBA Seamerⓓ that lost 3-8% yield at TARC and 37% and 0% at TAI. There were no differences in yield loss between the negative control (LOW) and VEG treatments. However, at TARC there was significant difference observed between the negative control, POD1 PBA Seamerⓓ, and POD2 for all varieties with losses of up to 18% (Table 2).

Table 2. Effect of *Ascochyta blight* infection timing on grain yield (t/ha) at TARC and TAI in 2021.

Treatment	Fungicide management strategy	Variety	TARC Yield (t/ha)	TAI Yield (t/ha)
HGH	No fungicide	Kyabraⓓ	0.10	0.08
		PBA HatTrickⓓ	1.60	0.86
		Seamerⓓ	2.80	1.22
LOW	Every rainfall	Kyabraⓓ	3.50	2.51
		PBA HatTrickⓓ	3.30	2.17
		Seamerⓓ	3.40	1.92
SDG1	Before infection	Kyabraⓓ	3.40	1.45
		PBA HatTrickⓓ	3.00	1.90
		Seamerⓓ	3.10	2.21
SDG2	After infection	Kyabraⓓ	2.30	0.25
		PBA HatTrickⓓ	3.20	1.38
		Seamerⓓ	3.10	1.93
VEG	Before & after infection	Kyabraⓓ	3.50	2.01
		PBA HatTrickⓓ	3.10	1.80
		Seamerⓓ	3.10	1.85
POD1	Before pod infection	Kyabraⓓ	3.60	1.86
		PBA HatTrickⓓ	3.10	2.17
		Seamerⓓ	3.00	1.50
POD2	No fungicide	Kyabraⓓ	3.10	1.76
		PBA HatTrickⓓ	2.70	1.66
		Seamerⓓ	3.00	1.78
p-value			<0.001	0.005
l.s.d (P = 0.05)			0.361	0.759

Gross margin

The greatest economic loss occurred at both locations when AB was not controlled at any growth stage (HGH) in the susceptible variety Kyabraⓓ (> $300 loss) (Table 3). The highest gross margin was calculated to be for the Kyabraᶲ POD1 treatment ($1,365) at TARC where disease was controlled until podding infection. The greatest discrepancies at both locations in gross margin between non-control treatments occurred when susceptible varieties were subjected to early season infection and fungicide management strategies with a > $500 difference between Kyabraᶲ SDG1 and SDG2.

Table 3. Collective effect of *Ascochyta blight* on gross margin across 2020 and 2021 at TARC and TAI.

Treatment	Variety	Gross margin $/ha*		
		TARC 2020	TARC 2021	TAI 2021
HGH	Kyabraᶲ	-300	-334	-348
	PBA HatTrickᶲ	-160	413	42
	Seamerᶲ	842	1010	221
LOW	Kyabraᶲ	701	1287	822
	PBA HatTrickᶲ	678	1187	653
	Seamerᶲ	857	1237	527
SDG1	Kyabraᶲ	-	1237	292
	PBA HatTrickᶲ	-	1038	516
	Seamerᶲ	-	1087	673
SDG2	Kyabraᶲ	-399	689	-305
	PBA HatTrickᶲ	174	1137	258
	Seamerᶲ	843	1087	534
VEG	Kyabraᶲ	506	1301	690
	PBA HatTrickᶲ	518	1102	585
	Seamerᶲ	934	1102	608
POD1	Kyabraᶲ	862	1365	496
	PBA HatTrickᶲ	765	1116	651
	Seamerᶲ	898	1066	318
POD2	Kyabraᶲ	-	1159	490
	PBA HatTrickᶲ	-	959	440
	Seamerᶲ	-	1109	500

* Gross margin based on December 2021 chickpea price of $498 per tonne, fungicide application cost of $14.25 per ha and other contributing production costs of $385.15 per ha; based on 2021 PIRSA gross margin calculator for chickpea crops.

Discussion

This experiment demonstrated that early seedling AB infection had the greatest impact on disease severity but was reduced by fungicide application before the initial rainfall event for susceptible varieties. However, where early seedling infection did occur it did not translate to significant yield loss in varieties with a moderately susceptible disease rating. The benefits of using varieties with increased resistance is their ability to recover yield regardless of disease severity earlier in the season once fungicide is applied as shown by the PBA HatTrickᶲ (37%) SDG2 treatment. This recovery of PBA HatTrickᶲ yield at TARC, contrary to higher disease scores, may also be in response to mild spring conditions and additional rainfall in September (Figure 1). This recovery was also mirrored by the PBA Seamerᶲ positive control (HGH) treatment (Figure 3). Both these results indicate that varieties with a higher AB resistance rating are more likely to recover yield once AB is controlled after a seedling infection event provided seasonal conditions are conducive for grain yield recovery.

Unfortunately, no conclusion can be made regarding AB management at the vegetative stage. Firstly, the infection events for the VEG treatments did not have sufficient rainfall and spreading events post infection (Figure 1) to result in a yield loss. Secondly, during the vegetative stage of growth there is increased vigour in plant growth making chickpeas less susceptible to infection at this time. Reduced AB disease severity with infection at the vegetative growth stage has been found in a similar Indian study (Basandrai *et al.,* 2007). This indicates that a missed fungicide application during the vegetative stage of chickpea growth is not as likely to cause yield damage as with seedling AB infection. Further testing of infection at this growth stage is required across more locations and years to clarify this under Australian chickpea growing conditions.

Anecdotal evidence suggests that podding infection is likely to have yield and seed quality impacts as plant resistance plateaus during this growth stage. However, under Australian conditions, podding normally occurs during mid to late spring when rainfall generally declines after the winter growing season. Hence, if AB has been adequately controlled in-crop throughout the winter growing season, then economic return from late season podding control is likely to be dependent on the continuing seasonal weather forecast. For example, in the experiment at TARC in 2020, the gross margin for protecting against AB at podding had minimal economic benefits under dry spring conditions which were unfavourable for AB infection (Moore et al., 2021). In contrast the experiment at TARC in 2021 showed plants which were protected from AB at podding during the wet finish displayed increased yield response and justifiable economic benefit from fungicide application.

Variation in gross margin between sites and years is important to note. Indicating strongly that input of fungicide and varietal choice will have returns dependent upon site location and weather conditions. Therefore, seasonal planning to maximise predicted income according to long range weather forecasts through variety, paddock location and fungicide regime choice is recommended.

Conclusion

The choice of a variety with improved AB resistance remains the most important tool for protection against yield loss in chickpea. The application of a fungicide prior to the initial rainfall event at the seedling stage will have the greatest impact on reducing disease severity However, moderately susceptible varieties are able to maintain yield potential if that initial seedling fungicide application is missed for some reason. No conclusions can yet be made regarding AB infection at the vegetative growth stage. Fungicide application may be required at early podding if AB is detected at this growth stage and wet seasonal conditions are predicted to protect against yield and economic loss.

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Phytophthora root rot and waterlogging in chickpeas – minimising risk and management options

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Take home messages

- Waterlogging had a greater impact on chickpea yield compared to mild Phytophthora root rot (PRR) infection
- Chickpeas such as PBA HatTrick⍬ are affected more by waterlogging at a late vegetative growth stage (83% yield loss) than waterlogging at an early vegetative growth stage (26% yield loss)
- Late waterlogging plus PRR results in plant death and even greater yield losses (98%)
- Rainfall and irrigation volumes can be used to predict PRR yield losses, PBA Seamer⍬ with 250 mm of plant available water that received > 135 mm in-crop rainfall by flowering had yield losses of at least 40% and losses reached over 50% with pre flowering irrigation of 185 mm
- PRR yield loss information based on rainfall and irrigation volume can be used by growers to support decisions for forecasting yield loss when in-crop rainfall drives PRR infection.

Introduction

Phytophthora root rot (PRR) (*P. medicaginis*) causes significant yield losses in chickpea grown in the northern grain region being estimated to cost $8.2 million per year in wetter than normal seasons or following periods of soil saturation in normal seasons (Murray and Brennan, 2012). Although moderate field resistance is available in some chickpea varieties such as PBA HatTrick⍬ and PBA Seamer⍬ (MS resistance), substantial yield losses (up to 70%) can still occur under conditions highly favourable to disease development (high inoculum loads, poorly drained soils and high rainfall).

Environmental conditions are a major factor affecting *Phytophthora* epidemics, in particular the duration of free water in the soil influences the production and germination of sporangia by *P. medicaginis* (Pfender *et al.*, 1977, Duniway, 1983). Soil-borne *Phytophthora spp.* produce sporangia under high soil moisture conditions, which release motile zoospores that infect roots causing severe disease. *Phytophthora* spp. require oxygen and during periods of soil saturation in many circumstances it is difficult to determine if crop damage is from PRR, waterlogging or a combination of both due to the effect of oxygen deprivation on both plant and pathogen (Erwin *et al.*, 1983, Dron *et al.*, 2022).

In order to understand when integrated disease management (IDM) practices may be successful or unsuccessful, we need to understand the scale of effects of waterlogging and PRR separately and as a combined effect. The ability to predict PRR induced yield loss could be used to reduce late season in-crop inputs, however, to achieve this objective the rainfall dependent PRR yield and economic loss relationship needs to be defined for PRR of chickpea. For PRR of chickpea we have no information quantifying rainfall volume and timing effects on the extent of yield loss.

Our research objective was to support in-crop management decisions by defining

1. The scale of effects of waterlogging and PRR separately and as a combined effect on chickpea grain production; and
2. The PRR yield and economic losses for volume effects of irrigation (as a surrogate for rainfall) on PRR epidemics.

How does early and late growth stage waterlogging and *Phytophthora medicaginis* affect chickpea root health and yield?

A shade house trial in Tamworth used 100 L bins as deep pots filled with potting media to capture the effects of early and late growth stage waterlogging in the presence and absence of PRR. The trial was sown on June 29, 2020. The bins were irrigated to provide 80% field capacity at a depth of 20 cm and were fertilised fortnightly. Experimental treatments were: chickpea lines ($n = 4$), waterlogging treatments ($n = 3$), and Phytophthora inoculation treatments ($n = 2$). Chickpea lines included the moderately resistant 04067 (*Cicer echinospermum* backcross breeding line), the moderately susceptible Yorker and PBA HatTrickⓓ, and the susceptible Rupali. The three waterlogging treatments were: non-waterlogged (media maintained at 80% field capacity); early vegetative growth stage waterlogging; and late vegetative growth stage waterlogging. The two PRR treatments were uninoculated or *P. medicaginis* (*Pm*) inoculated. A total of 4 replicates of each treatment combination were included in the experiment, with bins arranged according to a randomised complete block design (RCBD).

Following in furrow *Pm* inoculation (PBA HatTrickⓓ at 5 node stage) early waterlogging treatments were applied for five weeks during the early vegetative phase (PBA HatTrickⓓ at 6 node stage) and late waterlogging at the late vegetative phase (PBA HatTrickⓓ at 13 node stage). Once the control treatment had senesced, the experiment was then desiccated with glyphosate. Harvest measurements on 19 Oct., 2020 included: root health score (1 healthy – 9 dead) and grain weights.

The traits root health score and grain weight were analysed using linear mixed model in R statistical software. Significance testing was based on $P < 0.05\%$ and 95% confidence intervals calculated for treatment means.

Results showed that the waterlogging treatments had the largest effect on root health in the experiment ($F = 33.2$, $P < 0.001$) compared to Phytophthora ($F = 10$, $P < 0.01$) and chickpea line ($F = 3$, $P < 0.01$), with the three factors providing a significant interaction ($P < 0.05$). Root health score was significantly worse in PBA HatTrickⓓ following early waterlogging *pm* inoculated (4.8); late waterlogging uninoculated (5) and late waterlogging *Pm* inoculated (6.8), compared to the non-waterlogged uninoculated control (1) (Figure 1).

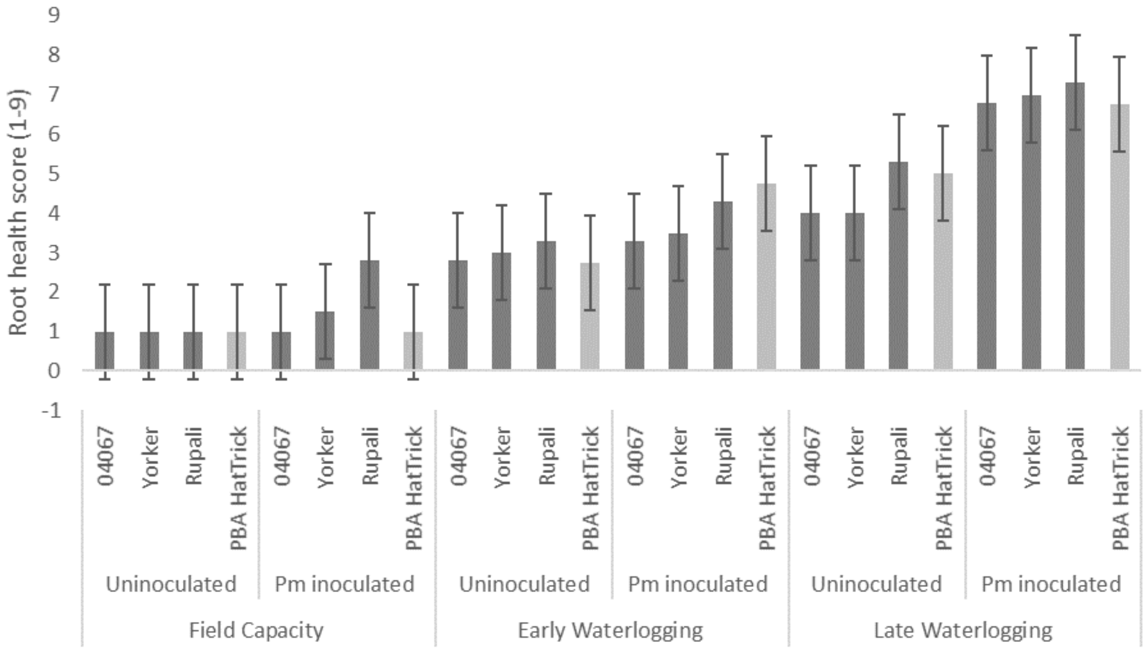

Figure 1. Root health score results presented as means and 95% confidence intervals for treatments: Field capacity (FC) or early and late vegetative waterlogging, uninoculated or *Phytophthora medicaginis* (Pm) inoculated; for four chickpea lines (PRR moderately resistant 04067, moderately susceptible Yorker and PBA HatTrickⓓ, and susceptible Rupali). P value for the three-way interaction is <0.05

Waterlogging treatments also had a greater effect on grain weights in the experiment (F = 305, $P < 0.001$), followed by chickpea line (F = 32.7, $P < 0.01$) and *Phytophthora* (F =10, $P < 0.01$), with the three factors providing a significant interaction ($P < 0.001$). Grain weight of PBA HatTrickⓓ reduced from 0.8 g / plant in the control to 0.6 g / plant and 0.1 g / plant in the early waterlogging and late waterlogging, respectively (Figure 2). PBA HatTrickⓓ with waterlogging in combination with *Pm* resulted in further reductions with early waterlogging having 0.2 g / plant and later waterlogging 0.01 g / plant grain weight. None of the four lines examined were able to recover grain weight following either waterlogging treatment and the loss of grain weight was worse in the presence of *Pm*. Yield loss observed in the early waterlogging treatments was caused by plant stunting, whereas the late waterlogging lead to early senescence and plant death.

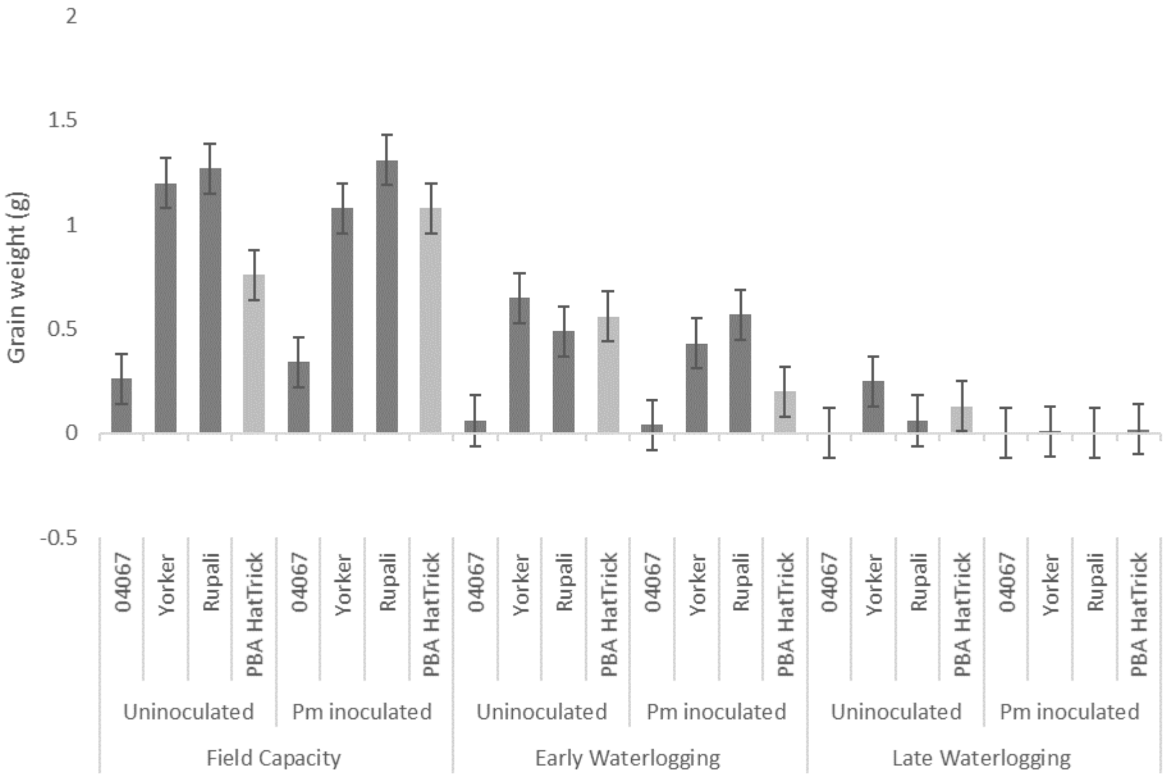

Figure 2. Grain weight per plant presented as means and 95% confidence intervals for treatments: Field capacity (FC) or early and late vegetative waterlogging, uninoculated or *Phytophthora medicaginis* (*Pm*) inoculated; for four chickpea lines (PRR moderately resistant 04067, moderately susceptible Yorker and PBA HatTrickⓓ, and susceptible Rupali). P value for the three-way interaction is <0.001.

PBA HatTrickⓓ *Pm* inoculated in the absence of waterlogging had an unusually higher grain weight (1.1 g / plant) when compared to the control (0.8 g / plant) (Figure 2). The mild PRR infection in this experiment, in treatments without waterlogging, resulted in lines not performing as expected. Greater grain weight reductions are likely to be observed in the moderately susceptible Yorker, PBA HatTrickⓓ and susceptible Rupali under environments with greater *Pm* disease pressure. The reduced *Pm* disease pressure in the absence of waterlogging may have been attributed to the poor water holding capacity of the light soil media used within this experiment, which resulted in low levels of PRR infection. If moisture levels were higher for a longer duration following irrigation, we would expect to have caused greater root disease and grain reductions in *Pm* inoculated non-waterlogged treatments, particularly in the susceptible lines.

Chickpea plants will senesce and die following a severe late waterlogging event particularly during flowering as observed during the 2021 growing season in the northern grains region and as described previously by Cowie *et al.* (1996). Similarly in our experiment, for both waterlogging and *Pm* in combination with waterlogging, disease severity was worse in the late waterlogging treatments. This can be attributed to the physiological growth stage and increased requirements of the chickpea plants at higher temperatures later in the growing season. The final redox measures (indicator of waterlogging severity) were similar between early and late waterlogging treatments. However, the soil temperature and ambient temperature were 12.1°C and 7.8°C warmer during the late waterlogging treatment compared to the early waterlogging treatment, respectively (Figure 3). The warmer conditions with high moisture can favour rapid pathogen development and high respiration rates in the plant leading to rapid plant death.

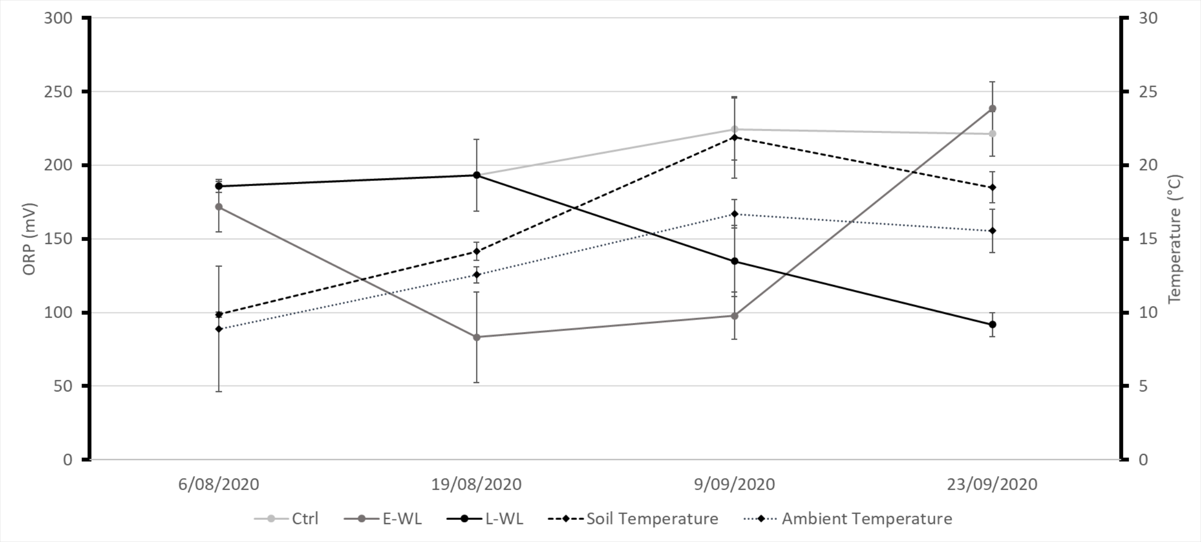

Figure 3. Soil redox (Oxidation reduction potential, ORP) an indicator of oxygen availability, ambient and soil temperatures during early and late waterlogging treatments. E-WL: Early waterlogging, L-WL: late waterlogging, Ctrl: control.

How does rainfall (field irrigation) affect yield loss in chickpea across two soil types?

Field experiments in 15 m^2 plots were conducted in 2018 and 2019 at the Hermitage Research Facility, Warwick. There were two non-irrigated control treatments with +/– *Phytophthora* inoculation (*P. medicaginis* oospores applied in-furrow at sowing) and nine irrigation treatments (ranging from 0-150 mm). Irrigation treatments were imposed at a single time point across all plus irrigation treatments plots (70 days after sowing in 2018 and 77 days after sowing in 2019). To prevent waterlogging, the delivery of irrigation occurred over a 72-hour period for both experiments. There were two desi chickpea genotypes; the PRR moderately susceptible PBA Seamer⁽ᴾ⁾ and the provisionally moderately resistant advanced breeding line, CICA1328. Both experiments contained four replicates of each treatment combination, arranged according to a randomised complete block design. Assessments included plant emergence, disease incidence, grain yield, and 100 seed weight.

In 2018, the experiment was conducted on a well-drained grey vertosol soil type of 90 cm depth which had a full sub-soil moisture profile at planting. In 2019, the experiment was performed on a moderately well drained black vertosol soil type with a depth of 120+cm with drought conditions dictating that only a partial sub-soil moisture profile was available at sowing.

Traits were analysed across both experiments using a linear mixed model framework, whereby treatments were included as fixed effects (irrigation volume treated as a continuous covariate) and terms to describe the experimental design structure were included as random effects. Additionally, random cubic smoothing spline effects were included to model the nonlinearity in trait response to irrigation volume. Models were fitted using the asreml-R package in the R statistical computing environment. Significance testing was based on $P < 0.05\%$ probability level.

In the *P. medicaginis* inoculated treatments, significant yield losses resulted as a result of increasing irrigation volumes in both seasons, for both chickpea genotypes (Figure 4). In 2018 the two genotypes differed in yield by approximately 0.4 t/ha whenever equivalent irrigation volumes were above 70 mm. Yield differences of 1 t/ha were observed, in favour of the more resistant genotype, CICA1328, with irrigation volumes from 70 mm to 150 mm. In 2019 the two genotypes consistently differed for yield by approximately 0.4-0.6 t/ha across all irrigation volumes.

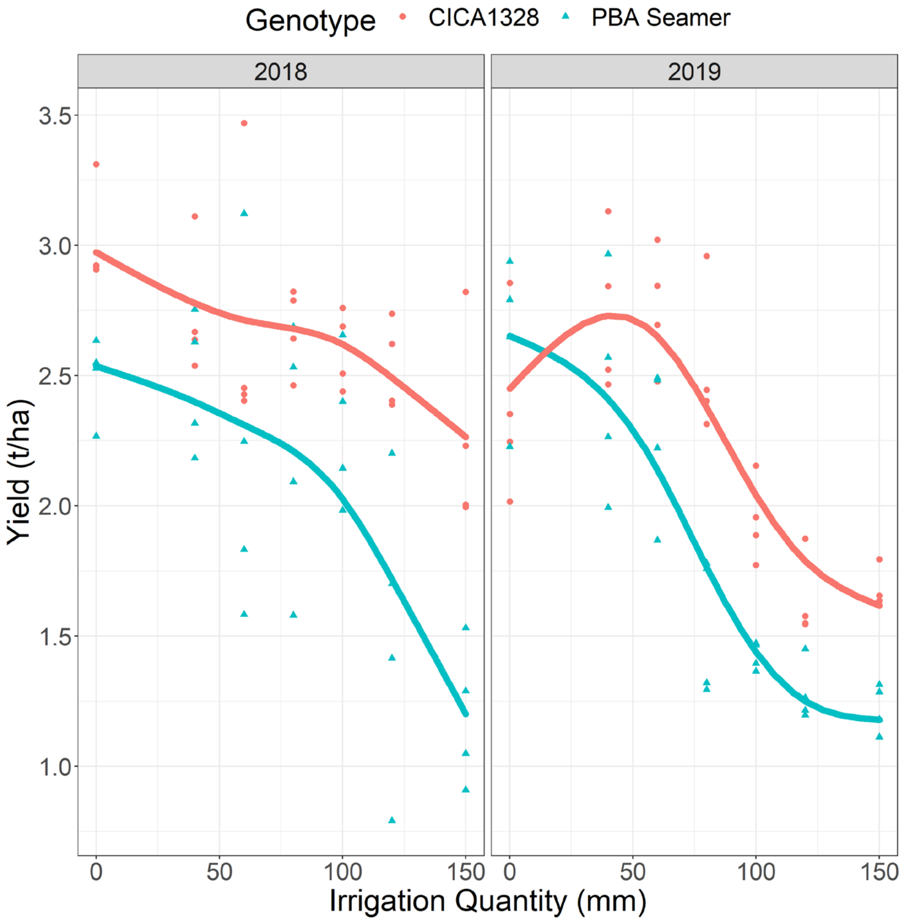

Figure 4. Yield response of PBA Seamer⟑ and CICA1328 to increasing irrigation volumes for *Phytophthora medicaginis* inoculated treatments in experiments in 2018 and 2019.

The *Phytophthora* irrigation yield loss relationships provided the ability to predict yield losses, with this information being useful to understand the extent of yield losses possible from seasonal weather conditions. Results from these experiments provide growers with a decision support tool regarding yield loss thresholds that can be expected when in-crop rainfall drives PRR infection (Figure 4). Findings also show that varieties with high levels of PRR resistance will yield more than susceptible varieties when in-crop rainfall is conducive to PRR.

Phytophthora yield loss outcomes were predicted for three rainfall plus irrigation volume scenarios from the two experiments (Table 1). The rainfall plus irrigation totals of >250 mm were realistic of wet winter seasons possible in the northern chickpea growing region of Australia. Predicted yield losses were greater than 50% in both years for PBA Seamer⟑ for the 150 mm maximum irrigation volume treatment, for CICA1328 a maximum yield loss of 34% was predicted for this treatment. A consistent finding for the three presented irrigation volumes was that CICA1328 required an approximate additional 50 mm of rainfall for yield losses to equal that of PBA Seamer⟑.

Table 1. Predicted yields (t/ha) for two chickpea genotypes in *Phytophthora medicaginis* inoculated (+PRR) irrigation (I) volume experiments for three single irrigation treatments of 50, 100 or 150 mm in 2018 and 2019 at Hermitage Research Facility, Warwick. Rainfall plus irrigation (R +I) values provided to represent total water delivery for each experiment and treatment combination.

Year	**Soil type**	**Genotype**	**Control Yield 0 mm I + PRR**	**Yield 50 mm I + PRR (% yield loss[2])**	**Yield 100 mm I +PRR (% yield loss)**	**Yield 150 mm I +PRR (% yield loss)**
2018	Grey vertisol	PBA Seamerⓓ	2.54	2.36 (7%)	2.03 (20%)*	1.2 (53%)*
		CICA1328	2.97	2.74 (8%)	2.62 (12%)	2.26 (24%)*
2018		In-crop R + I[1]	185mm	235mm	285mm	335mm
2019	Black vertisol	PBA Seamerⓓ	2.65	2.29 (14%)*	1.44 (46%)*	1.18 (56%)*
		CICA1328	2.45	2.71 (11% gain)	2.04 (17%)*	1.62 (34%)*
2019		In-crop R + I[1]	100 mm	150 mm	200 mm	250 mm

[1] In-crop rainfall was 185mm in 2018, and 100mm in 2019. The in-crop rainfall is then combined with irrigation volumes applied 70 days after sowing in 2018 and 77 days after sowing in 2019 to determine In-crop R + I values.

[2] Yield losses are % yield differences from the predicted control yield 0mm I + PRR

*Yield loss is significantly ($P< 0.05$) different from the predicted control yield for the 0mm I + PRR at the 5% probability level

Target yield groups are used by industry for profit forecasting. To assist with *Phytophthora* disease loss forecasting exercises, we predicted the rainfall plus irrigation volumes for yield groups of 1.5, 2 and 2.5 t/ha (Table 2). Different rainfall volumes were experienced during the two years of experimentation, with 2018 commencing with a wetter profile and experiencing an extra 85 mm of in-crop rainfall when compared to 2019. Depending on the yield group targeted, CICA1328 with improved PRR resistance could experience 36-106 mm more rainfall and still achieve the same yield group as PBA Seamerⓓ. As such, the improved PRR resistance of CICA1328 was worth more in the wetter year of 2018. These forecasts may be used to assist with critical in-season decisions in wet years, around whether to continue or abandon a crop when PRR infection is present, or to reduce late season crop inputs where appropriate.

Table 2. Predicted rainfall plus irrigation volumes (mm) for three yield (t/ha) groups for the two chickpea genotypes in *Phytophthora medicaginis* inoculated experiments in 2018 and 2019.

Year	**Soil type**	**Genotype**	**Yield group**		
			2.5 t/ha	**2.0 t /ha**	**1.5 t /ha**
2018	Grey vertisol	PBA Seamerⓓ	198 mm	287 mm	317 mm
		CICA1328	304 mm	>335 mm[1]	>335 mm[1]
2019	Black vertisol	PBA Seamerⓓ	130 mm	167 mm	195 mm
		CICA1328	172 mm	203 mm	>250 mm[1]

[1] Yields <=2.0t/ha not observed for CICA1328

What does it mean for growers?

We showed that with a large pot experiment waterlogging alone can cause major losses in yield with the timing of waterlogging also having a major effect. Yield of PBA HatTrick⌽ was reduced by 26% and 83% following early waterlogging and late waterlogging, respectively. Our experiment also showed that in a scenario where both waterlogging and *Pm* inoculum is present in combination, further yield reductions will occur with 74% and 98% losses observed in PBA HatTrick⌽ after early and late vegetative waterlogging, respectively. Our findings are supported by waterlogging results of other crop species where waterlogging causes both physical root damage and physiological constraint reducing water and nutrient uptake, which in turn reduces the plant's ability to overcome stress resulting in plant death (Colmer and Voesenek, 2009; Palta *et al.*, 2010). In terms of understanding waterlogging effects in cropping paddocks, our findings show that the likelihood of plant survival and recovery is higher when waterlogging occurs during early growth stages in the absence of *Pm* inoculum.

Our field experiments using irrigation as a surrogate for rainfall showed fairly consistent genotype responses in two differing seasons on different soil types, although yield losses were higher on the black vertosol in the second season. These irrigation plus rainfall PRR disease yield loss responses can be used to predict potential yield losses on the basis of forecasted rainfall and may assist with either yield forecasting or determining when to cease further crop inputs in heavily PRR affected areas of paddocks. The yield loss prediction and yield group rainfall values may also assist with calculating the yield benefits from selecting varieties with improved PRR resistance for use in future seasons.

The field experiments were not able to include waterlogging treatments. If substantial waterlogging occurs in fields with high PRR inoculum risk, we expect that the level of grain yield losses will be more substantial than those reported here for PRR in the absence of waterlogging.

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Timing of flowering and pod initiation influences yield potential in chickpeas

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Key words

chickpea, early flowering, yield, phase development, chilling tolerance

GRDC code

BLG111

Take home messages

- Chickpeas are sensitive to average temperatures of less than 15°C during flowering, which causes flower abortion
- Early flowering does not equal early pod set or increased grain yield
- Sow within the recommended cultivar window to ensure that the majority of flowering occurs when temperature conditions are optimal
- Understanding developmental phase changes can improve productivity by aligning flowering and podding with optimal temperatures for a given environment.

The story so far

Chickpeas are suited to environmental conditions of many grain growing regions of Australia and are an important winter pulse crop for farming systems. Despite this, in northern NSW and southern Queensland, abiotic and biotic factors are estimated to cause yield reductions of 1.7 – 2.7 t/ha (Yield Gap Australia, 2018). In 2016, cool spring weather was estimated, to have resulted in yield losses of 0.5 – 0.7 t/ha in northwest NSW (K. Hobson, *pers. com.*).

Under ideal environmental conditions, chickpea will produce pods within a couple of days of flowering (Clarke & Siddique, 1998). However, if temperatures stay below optimal levels the length of time between the beginning of flowering and the commencement of podding can be more than two months (Berger *et al.*, 2005). Furthermore, if average daily temperatures are below 15°C during flowering, there is reduced pollen viability, delayed stigma development and flower drop as reported by Siddique and Sedgley (1986) and Srinivasan *et al.* (1999). They observed that average temperatures during flowering significantly influenced flower abortion. Siddique and Sedgley (1986) found that when chickpeas were sown early and experienced average temperatures of 12.5°C during flowering there was 800 aborted flowers/m^2, compared to 0 aborted flowers/m^2 from a later sowing date where the average temperature was 16.8°C during flowering.

How did we get here?

In 2020, detailed phenology experiments were conducted at Tamworth in northern NSW and Wagga Wagga in southern NSW. In this series of experiments, sowing time was used to assess the capacity of a range of genotypes to produce pods and seeds under cool temperatures. These experiments included a set of 12 diverse genotypes, both released cultivars and advanced breeding lines, and targeted three sowing windows, with an early (late April to early May), main (mid-May to early June) and late season (mid to late June) sowing. Plant phasic development stages, between late vegetative and pod initiation were defined and dates were recorded. Changes in phase development that are important for pod and seed development under suboptimal environmental conditions included; the date when plants become reproductive, the date when 50 % of plants have one open flower and the date of pod initiation.

What did we find?

Phenology responses – flowering and pod initiation

Sowing date and location were found to influence the timing of phasic development of individual genotypes. At Tamworth, from the early sowing, in late April (Figure 1), the early flower CBA line had at least one flower on 50% of plants by 28 July, 22 days earlier than the next cultivar, CBA Captainᶲ and 35 days earlier than the slowest variety Kyabraᶲ. When sown in late April, Kyabraᶲ flowered on 1 September, 2 days before the average air temperature rose above 15°C on 3 September (Figure 1). In contrast, when the cultivars were sown in the optimal/main sowing window in late May, the early flower CBA line commenced flowering on 29 August, with CBA Captainᶲ and PBA Strikerᶲ achieving 50 % flowering on 5 September, and Kyabraᶲ and PBA Seamerᶲ flowering on 8 September (Figure 1).

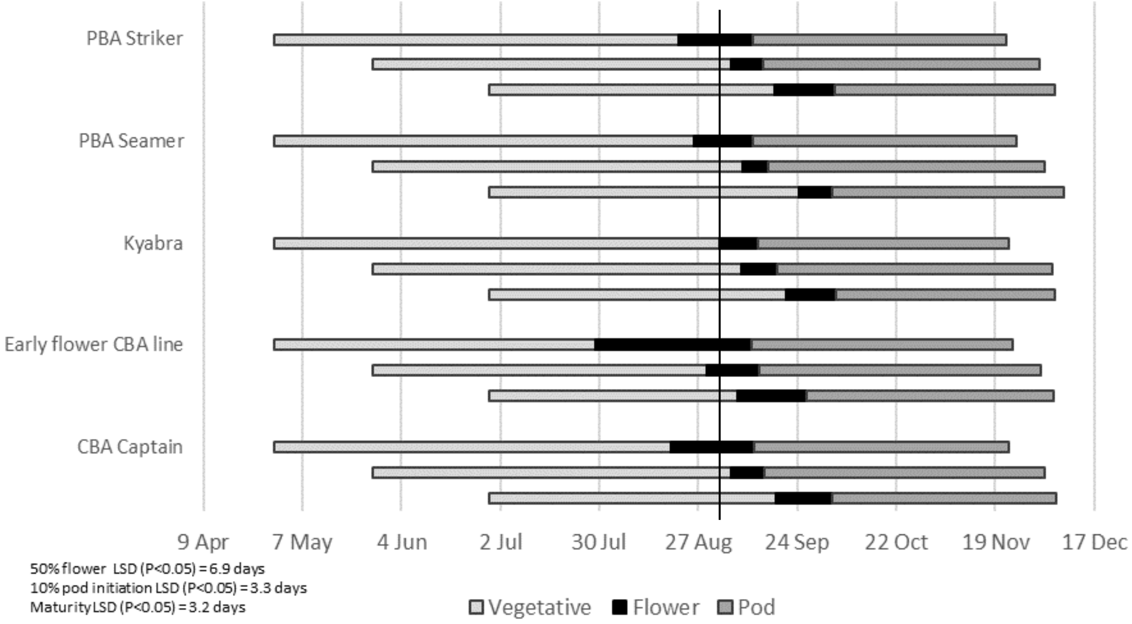

Figure 1. Phase development of four commercially released cultivars and an early flowering genotype at Tamworth in 2020 for three sowing dates. Vertical line represents the date at which average air temperature rose above 15°C on 3 September.

In contrast to the Tamworth findings, flowering did not commence at Wagga Wagga until 6 September, the day the average air temperature rose above 15°C for the first time (Figure 2). The first line to flower from the main sowing in mid-May was the early flower CBA line. Time to flowering was condensed over the three sowing dates (Figure 2 and Figure 3). Date of pod initiation at Wagga Wagga was also condensed, with a small but significant delay in pod initiation for Kyabraᶲ when compared to the early flower CBA line at each of the sowings (Figure 2).

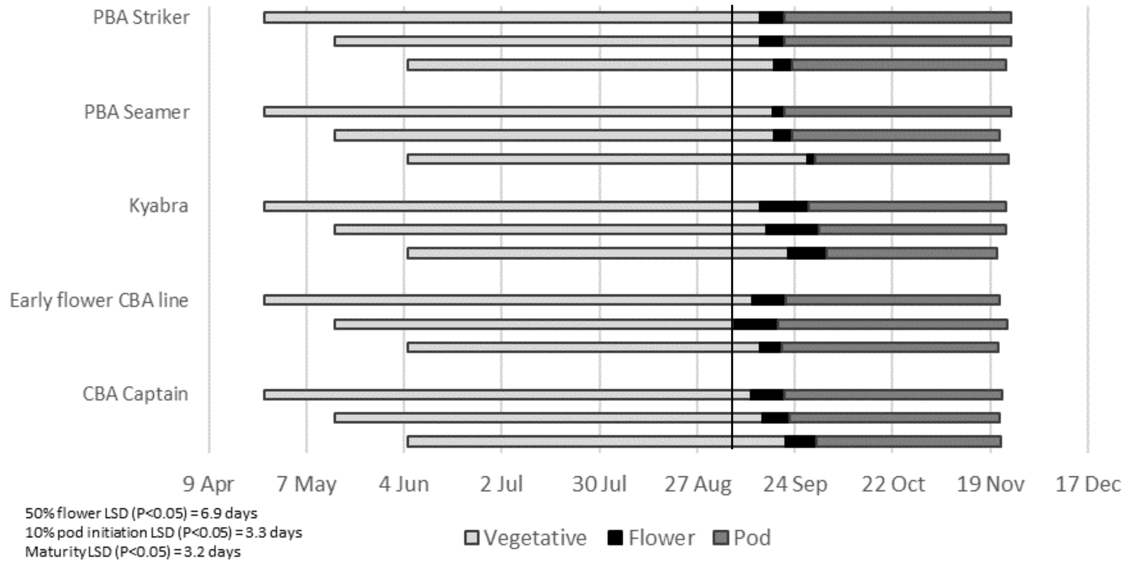

Figure 2. Phase development of four commercially released cultivars and an early flowering genotype at Wagga Wagga in 2020 at three sowing dates. Vertical line represents the date at which average air temperature rose above 15°C on 6 September.

Pod initiation, averaged over all genotypes at Tamworth for late April, late May and late June sowing dates, respectively, occurred 10, 13 and 32 days after average air temperature became optimal (3 September) (Figure 1). The delay in pod initiation, for the late June sowing at Tamworth, reflected the dry spring and depleted soil moisture in dryland cropping systems in northern NSW in 2020.

In contrast, when averaged over all genotypes, at Wagga Wagga, pod initiation for the late April, mid-May and early June sowings, respectively occurred 16, 18 and 25 days, after optimal average air temperature was achieved on 6 September, (Figure 2). Pod initiation at Wagga Wagga was in part delayed due to the higher level of temperature fluctuation in September, when temperatures rose and fell, above and below the optimal average air temperature of 15°C.

The relationships between date of 50 % flowering and date of pod initiation varied between the two sites (Figure 3). Genotypes sown early at Tamworth, had a spread of dates for the time to 50% flowering between 19 July to 9 September (52 days), while pod initiation occurred quickly, from 9 September to 13 September (4 days) (Figure 3). In comparison, the second and third sowing dates both had a variation in the time to 50% flowering of 17 days and 20 days, while pod initiation was spread over 9 days and 12 days, respectively (Figure 3).

The relationships between date to 50 % flowering and date of pod initiation, were compressed at Wagga Wagga when compared to Tamworth (Figure 3). There was overlap of both the date to 50% flower and the date of pod initiation between the three sowing times (Figure 3). Early and main sowing had similar dates to 50 % flowering from 7 September to 18 September and pod initiation from 14 September to 6 October. It is surmised, that this compression of dates for these phenological stages, may have been due to the greater variation in spring temperatures observed at Wagga Wagga, when compared to Tamworth.

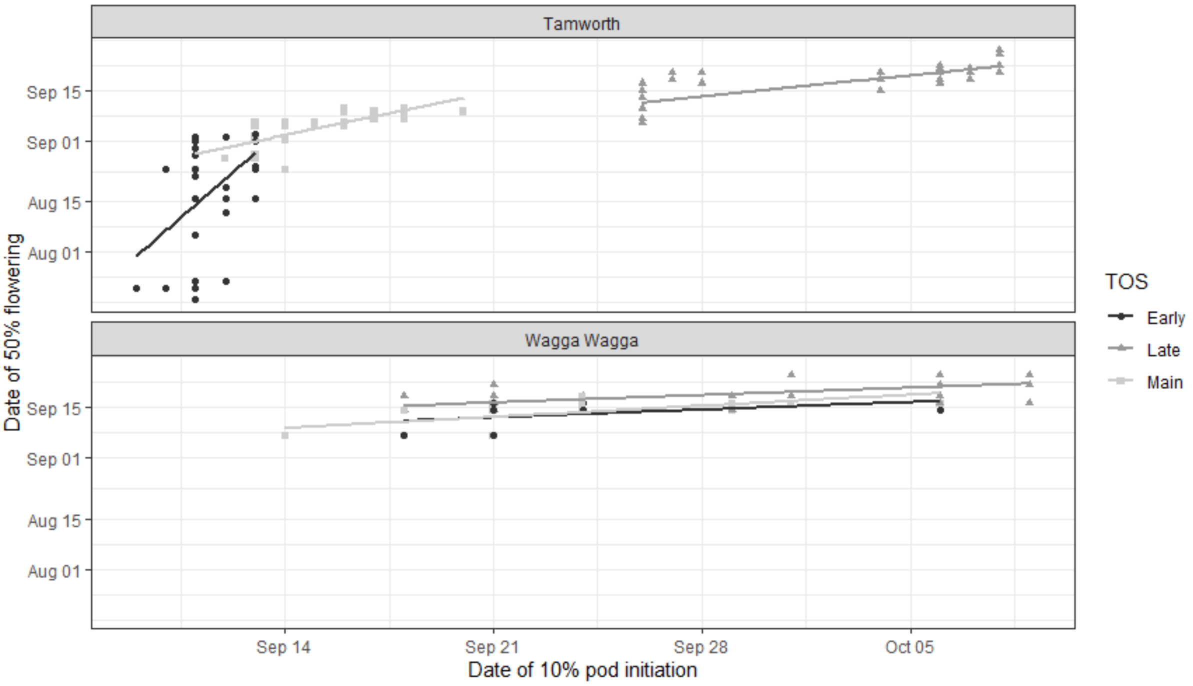

Figure 3. Relationship between date of 50% flowering and the date of pod initiation at Tamworth and Wagga Wagga in 2020.

Indictive yield response

When pooled across all genotypes, highest grain yield was observed when crops were sown between mid to late May, yielding 2.5 t/ha at Tamworth and 2.7 t/ha at Wagga Wagga (Figure 4). Sowing earlier than mid-May caused a yield loss of approximately 7 % at Tamworth and 18 % at Wagga Wagga (Figure 4). In part, the lower grain yield associated with early sowing, may be due to the longer time spent during the reproductive period in suboptimal temperatures.

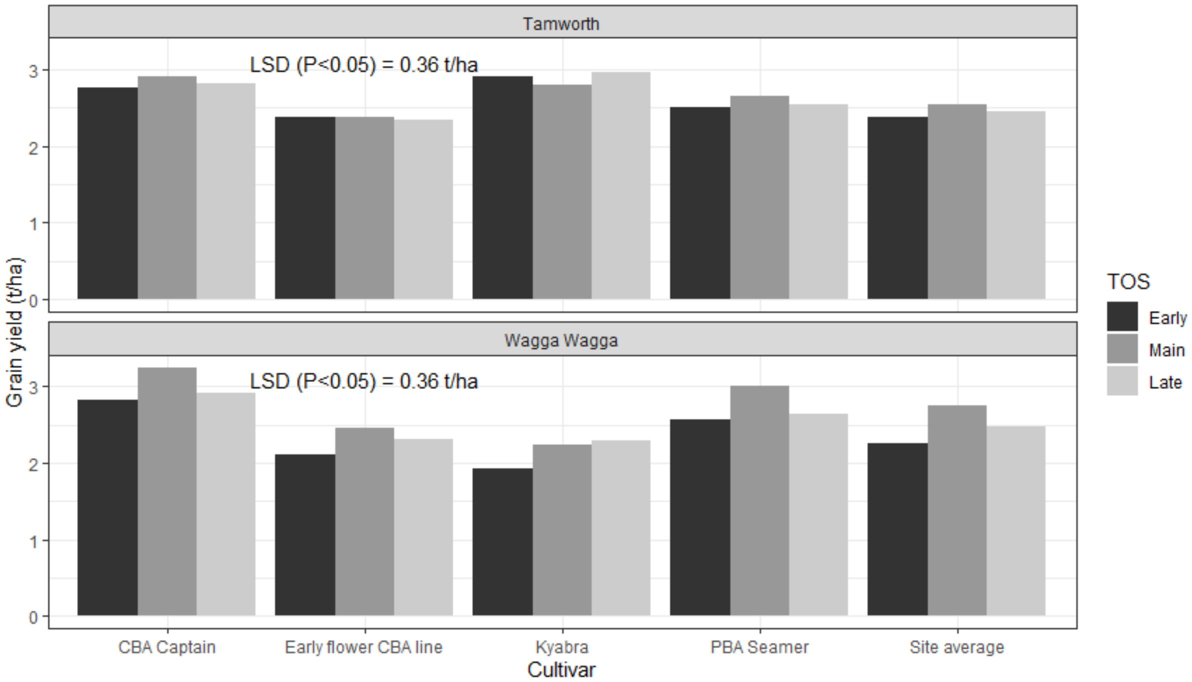

Figure 4. Grain yield (t/ha) for selected varieties and site average at Wagga Wagga and Tamworth for the three sowing dates in 2020.

Individual varieties showed different patterns of yield rankings over the three sowing dates at both Wagga Wagga and Tamworth. Differences in yields between the three sowing dates for four genotypes, CBA Captain⦶, early flower CBA line, Kyabra⦶ and PBA Seamer⦶, at Wagga Wagga were significant, whilst at Tamworth they were not. When each of the four genotypes were sown early at Wagga Wagga there was a reduction in yield of between 12 % to 14 %, when compared to their main season sowing yields (Figure 4).

This loss in grain yield when crops were sown earlier than optimal can be partially explained by plants developing flowers that do not form pods or pods with seeds when temperatures are suboptimal. Current research, within this project, aims to look at the level of lost flowering opportunities and potential pods and seeds, when crops flower under suboptimal conditions, through measuring the conversion of reproductive nodes into pods and pods that contain seeds.

Summary

Matching developmental phases, in particular flowering and pod initiation to optimal environmental conditions increases the yield potential of chickpea cultivars. Importantly, results from these experiments show that early flowering does not translate to earlier pod initiation. This was particularly highlighted when comparing genotypes from an early sowing date at Tamworth in 2020.

The results from these experiments do however indicate that there is greater variation in pod initiation between genotypes from main and late season sowings, with earlier flowering genotypes initiating pods earlier than later flowering lines.

It can be seen from these experiments that early flowering does not equal early pod initiation or increased grain yield.

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Mapping *Ascochyta rabiei* aggressiveness and understanding the pathogen adaptation to disease management strategies

Ido Bar, Griffith University

Key words

Ascochyta blight, chickpea, disease management, fungal pathogen

GRDC code

GRI2007-001RTX

Take home message

Ascochyta rabiei isolates are getting more aggressive in recent years and are able to overcome some of the `resistant` chickpea varieties used by the industry.

Unique clusters of highly aggressive isolates have been identified that potentially pose a major and ongoing risk to the industry.

The risk from local micro-evolution of highly aggressive isolates becomes even greater when combined with cross-region gene flow that is likely driven by human activities.

To be able to offer the most accurate and up-to-date information on the spread of Ascochyta blight and provide early warning of the emergence of highly aggressive *A. rabiei* isolates, industry action is needed. Action needed is in the form of; adherence to the use of clean seed, machinery hygiene practices and maximum frequencies for chickpeas in the rotation to be established and adhered to.

Engage with pathologists when Ascochyta blight symptoms are seen to assist in sample collection and pathogen monitoring.

Introduction

Research on the Australian *Ascochyta rabiei* population over the past eight years has established a comprehensive isolate database, provided insights into the population structure and identified trends in adaptation and possible modes of evolution across all chickpea growing regions. A subset of the collected isolates in each year are phenotyped against a differential host set of chickpea genotypes (ICC3996, Genesis™ 090, PBA HatTrick, PBA Seamer and Kyabra) to determine their potential aggressiveness (classified as Pathogenicity Group 0-5, from the least aggressive to the most aggressive). The phenotyped isolates are further characterised molecularly and genotyped to determine their mating type, genetic relatedness and the population structure.

Ascochyta rabiei in Australia appears to be clonal (which means the offspring are identical to their parent), with detection to date of a single mating type (MAT1-2). Despite this form of reproduction, which is suggested to limit new genetic diversity, it seems that the population contains sufficient existing diversity to undergo spontaneous mutation events to adapt to and overcome host resistance sources. This is evident by the detection of severe disease symptoms on the formerly released 'resistant' hosts, such as Genesis™ 090, PBA Seamer and ICC3996 (the resistance source for many commercial varieties, see Figure 1).

Since 2015 there has been an increase in the frequency of collected isolates that can cause severe disease on 'resistant' cultivars. In particular, the proportion of isolates highly aggressive on PBA HatTrick rose from 18% in 2013 to 51% in 2020 (Figure 1). Similarly, a higher frequency of isolates able to cause severe disease on Genesis™ 090 was observed (up from 11% in 2016 to 36% in 2020).

This is particularly concerning since PBA HatTrickⒹ and Genesis 090 are broadly sown cultivars in northern and southern chickpea regions, respectively. Of most concern for northern growers is the growing number of highly aggressive isolates on PBA SeamerⒹ (up from 4% in 2016 to 48% in 2020, Figure 1) (Sambasivam *et al.,* 2020).

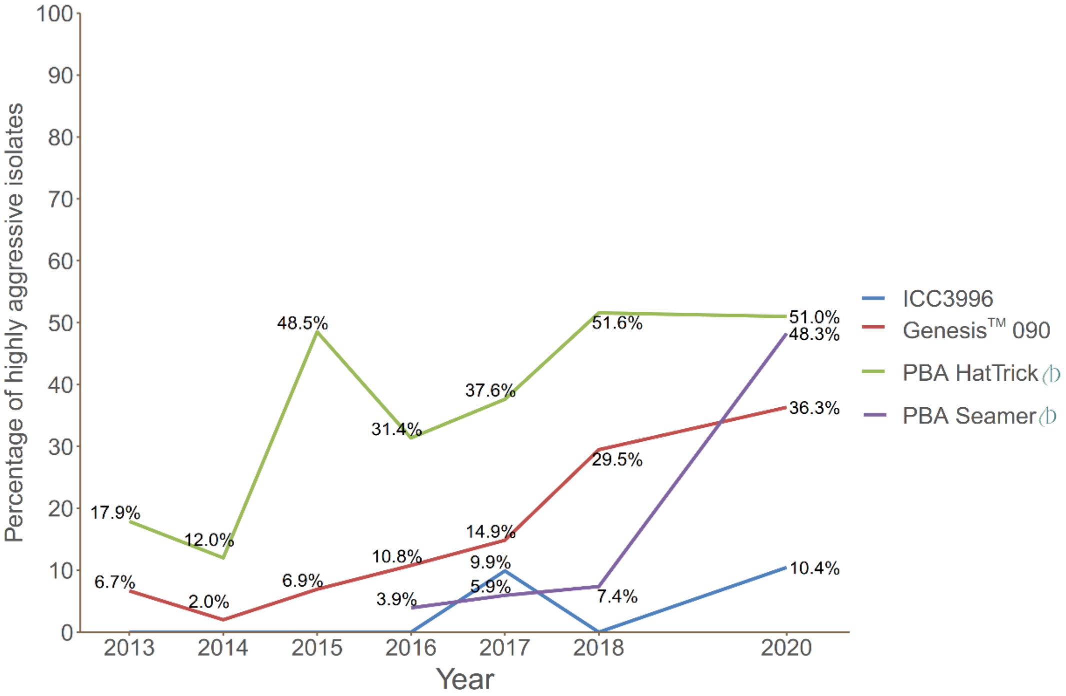

Figure 1. Percentages of *Ascochyta rabiei* isolates screened in controlled environment bioassays able to cause severe disease on the four chickpea hosts assessed (95-200 isolates screened per year)

A high-resolution genetic analysis of 193 isolates collected from all growing regions in 2020 discovered unique genetic clusters of highly aggressive isolates within specific locations that potentially pose a major and ongoing risk to the industry. Isolates in these clusters are 10-13 times more likely to be highly aggressive than other isolates. Based on the genetic relatedness of the isolates we identified two likely sources that contribute to the emergence of new isolates: either local micro-evolution of isolates that can lead to adaptation of highly aggressive isolates or cross-region gene flow likely driven by human activities. Both mechanisms pose a major and ongoing risk to the industry. Identifying the source of new genetic material in an event of an outbreak is crucial to be able to manage the risk and control the disease effectively (Bar *et al.,* 2021).

To support informed disease management strategies and identify trends and patterns affecting the emergence of highly aggressive isolates, an online dashboard was developed and deployed as a live web application to enable interactive interrogation of *A. rabiei* isolates collected within the current (and previous) GRDC investments. The dashboard provides a spatio-temporal overview of 437 isolates that were collected in 2020-2021, along with specific details of their collection metadata. It also details the phenotypic assessment and summary plots of 806 isolates that were phenotyped between 2013-2020. The dashboard was developed with an interactive and user-friendly interface and is available at http://bit.ly/asco-dashboard

These findings and further advances in the understanding of the pathogen populations have significant implications for development of accurate diagnostics tools and informed disease management strategies at a regional and national scale to assist Australian scientists, breeders, farmers and government agencies in managing and reducing the chickpea Ascochyta blight risk for sustainable production of chickpea.

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

A new diagnostic tool for botrytis in chickpeas – in-paddock biosensors - progress towards development of an in-paddock diagnostic device that is cheap, reliable, and accurate

Dr. Ido Bar, Griffith University

Key words

Botrytis, chickpea, biosensor, fungal pathogen, diagnostics

GRDC code

UOA2007-002RTX

Take home message

A novel, specific and highly sensitive molecular probe-based nano biosensor device and diagnostics protocol were validated for both *Botrytis cinerea* and *B. fabae* on field host crop samples.

The diagnosis of the *Botrytis* spp. was sensitive, specific, quantitative, fast and low cost and allowed the detection of inoculum prior to the visible appearance of disease symptoms.

The tools developed and protocols validated within this work may be applied to many other pathosystems, dependant on the development of target-specific probes and protocol optimisation.

Additional research is required to perform broader *in field* and *in industry* validation and to simplify sample preparation and DNA extraction to develop this prototype into a compact and portable device that can inform on the presence, distribution and quantity (inoculum load) of crop pathogens. If done, this would provide significant power to disease management decision making, more targeted (and potentially reduced) chemical usage and potentially improved grower returns.

Botrytis grey mould (BGM), caused by *Botrytis cinerea* and *B. fabae*, separately or within a complex, substantially reduces grain legume yield during environmentally conducive seasons. Fast, accurate and cost-effective diagnosis and quantification of the causal pathogen(s) can lead to greater success in application of integrated disease management approaches to reduce yield and profit losses.

Biosensors that use functionalised magnetic gold nanoparticles for molecular target enrichment have been recently developed to detect cancer biomarkers with extreme specificity, sensitivity and accuracy (Islam *et al.*, 2018). In this project we have partnered with experts from the Queensland Micro- and Nanotechnology Centre at Griffith University to adopt this diagnostics approach for the detection of plant pathogens, using *Botrytis spp.* as a case study.

To achieve this, biotinylated capture probes were developed based on the MRR1 and NEP1 genes *B. cinerea* and *B. fabae*, respectively. The probes were assessed for their specificity and sensitivity to detect the pathogens from field collected faba bean leaf samples using a functionalised magnetic gold nanoparticles biosensor assay (Bilkiss *et al.*, 2020).

Sampling of faba bean leaf samples was performed at four field sites in south-eastern South Australia (Millicent, Bool Lagoon, Frances and Mundulla) in October 2020 in a replicated manner. Foliar samples were collected at each site from symptomatic and asymptomatic tissues to provide robust quantifiable levels of target pathogens. Genomic DNA was extracted from five symptomatic and five asymptomatic samples from each site and was used for the biosensor assay.

The target DNA was directly adsorbed onto the electrode surface *via* gold-affinity interaction, and the amount of adsorbed DNA of each target species DNA was robustly and reproducibly quantified via chronocoulometric (CC) charge density change (Figure 1).

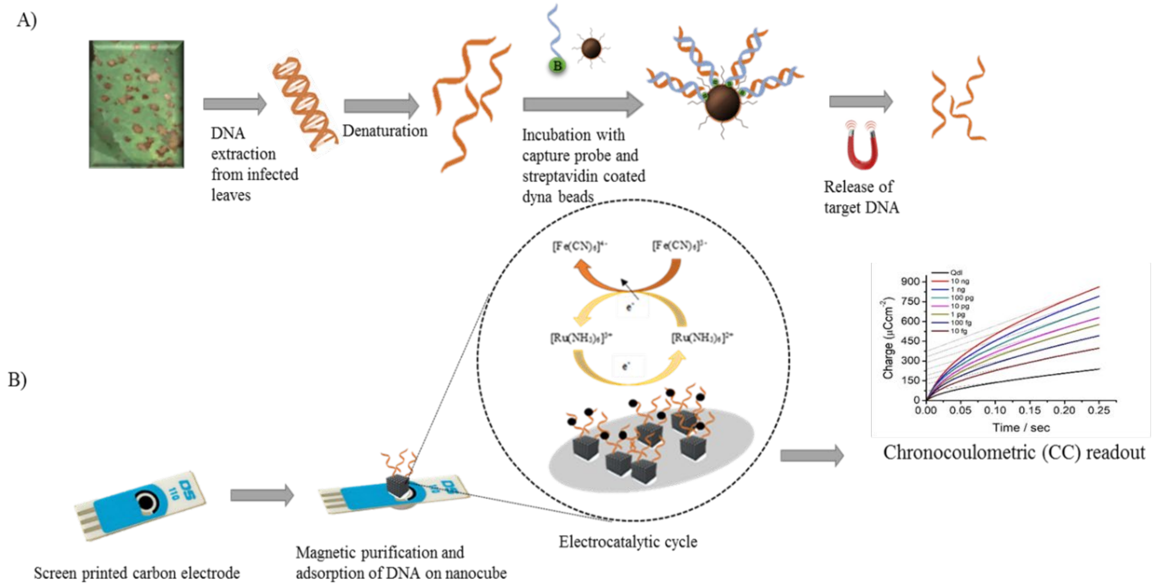

Figure 1. The two-step process for the electrochemical detection of *Botrytis* spp. from leaf samples. Where A = Magnetic isolation and purification of target *Botrytis* spp. DNA and B = Electrochemical detection and quantification of the adsorbed target ssDNA (Source: Marzia Bilkiss PhD thesis).

Based on the charge density changes observed, the capture probes were shown to be species-specific to either *B. cinerea* or *B. fabae*. The biosensor assay was able to detect single spores of *B. cinerea* and *B. fabae* from symptomatic and asymptomatic leaves, thus demonstrating its ability to detect and quantify the causative organisms prior to the visible appearance of the disease on plants and proving to be more sensitive than other published diagnostic methods for both species (Bilkiss *et al.,* 2019). This provides a diagnostic tool for *B. cinerea* and *B. fabae* that is highly sensitive, quantifiable, species-specific to each of *B. cinerea* or *B. fabae* and fast. The process from sample collection to result is ~45 mins and low cost at <$2 per sample.

The tools developed and protocols validated within this work are open for commercialization partnering through investor engagement. Further investment may be required to perform broader *in field* and *in industry* validation and to simplify sample preparation and DNA extraction to develop this prototype into a compact and portable device that provides an accurate and calibrated readout of pathogen loads.

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Farming systems - dual purpose crops in the medium rainfall zone of central/southern NSW and summer sown pasture legumes

Dual-purpose crops – roles, impact and performance in the medium rainfall farming systems

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Key words

mixed farming, grazing wheat, grazing canola, feed gaps, lock-up

GRDC code

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Take home messages

- Dual-purpose (DP) crops can increase farm profit in the medium rainfall areas of southern NSW
- True winter cereal and canola varieties have a better fit in the eastern slopes, while fast winter and slow spring varieties are safer dual-purpose options in the lower rainfall western areas
- At the paddock-scale, high profit relies on attention to detail with crop and livestock management. Establish the right crop early, and correct lock-up times are key to increase profit and reduce risk
- Recent variable seasons (very dry and very wet) demonstrate the many flexible ‘exit’ options for dual-purpose crops (graze out, graze-silage, graze-hay, graze-grain, grain only)
- Ongoing refinement to deal with new and emerging issues with DP systems are discussed.

Introduction

The medium rainfall area between the Olympic Way and Newell Highway in southern NSW has been the area of the earliest and longest adoption of dual-purpose (DP) cropping and the associated research activities of GRDC and other agencies (Grain’n’Graze, DP wheat and DP canola research). Outputs from experimental research and grower experience over two decades has firmly established dual-purpose crops (both cereals and canola) into mixed farming systems. Experienced growers have undoubtedly increased profit, flexibility and reduced risks in their businesses with appropriate integration of dual-purpose crops. Numerous previous papers have reported on that success and readers are urged to revisit these for more of the finer detail (see reference list).

A range of both winter and spring cereal and canola varieties provide potential grazing opportunities across this zone. The opportunity to sow ‘true winter types’ in March still presents across this region, but especially in the eastern slopes (Cootamundra, Harden, Greenethorpe) the season is long enough for early March sowing, an extended grazing period (May-July) and successful grain harvests (2 - 3 t/ha) with true winter types.

As you move west to the Newell highway, the frequency of early March sowing opportunities declines, and while excellent grazing opportunities still exist in some seasons, flowering and grain filling for true winter types often falls outside the optimum period, limiting grain yield recovery. In these areas, the fast winter wheat types and slow developing spring canola types tend to provide more frequent and reliable dual-purpose options. In this area farms often have a greater focus on grain than livestock, but autumn and winter feed gaps in the livestock enterprise can still limit whole-farm profit.

Most of the research on dual-purpose crops reflect the potential performance in individual paddocks compared to grain-only crops, assuming highly efficient forage utilisation. Flow-on benefits at the farm-scale (e.g., benefits for earlier sowing, reduced supplementary feeding) have been observed, but the impact on profit at the farm-scale depends on many enterprise-level factors which are the focus of subsequent papers.

Background to current use of winter and long-season spring varieties

DP winter cereals have been part of the system in this region for decades with breeding programs devoted to them since the 1960s. During the 1990s the profitability of crops exceeded livestock. As a result, farms intensified cropping, with livestock numbers and interest in DP crops waning. The large impetus to further adoption of DP crops, came with the development of higher protein milling wheat varieties in the late 1990s – early 2000s (e.g., Whistler, Wylah and EGA Wedgetail⦶). The combined value of the early-sown grazing forage and higher protein grain revitalised interest and increased adoption significantly, with research outlining grazing strategies to avoid grain yield penalties.

DP canola was developed as an option in the late-2000s and was timely as wheat streak mosaic virus temporarily discouraged early sowing of DP wheat, and early-sown hybrid canola varieties could provide high value grazing potential similar to wheat. By 2010, DP canola had become an established part of the feed base and along with grazing cereals, provided the opportunity to increase winter livestock carrying capacity, while maintaining or increasing crop production. New varieties of wheat and canola suitable for DP use have been released in recent years. A significant gap remains in canola where no intermediate winter-spring types with ‘fast-winter’ - ‘slow-spring’ phenology are currently available. These would be better suited to sow in late March - early April to increase grazing potential, but mature earlier than current winter types to maintain grain yield.

Research outcomes establish the profit potential

The research results represent what is possible when the forage produced is grazed carefully and very efficiently, and the value is often estimated assuming high-value (meat) livestock enterprise. Establishing that aspiration potential of dual-purpose crops, and the management factors to achieve it, remains a useful benchmark for improvement - even though many seasonal, economic or enterprise-level factors will determine what can be achieved on different farms.

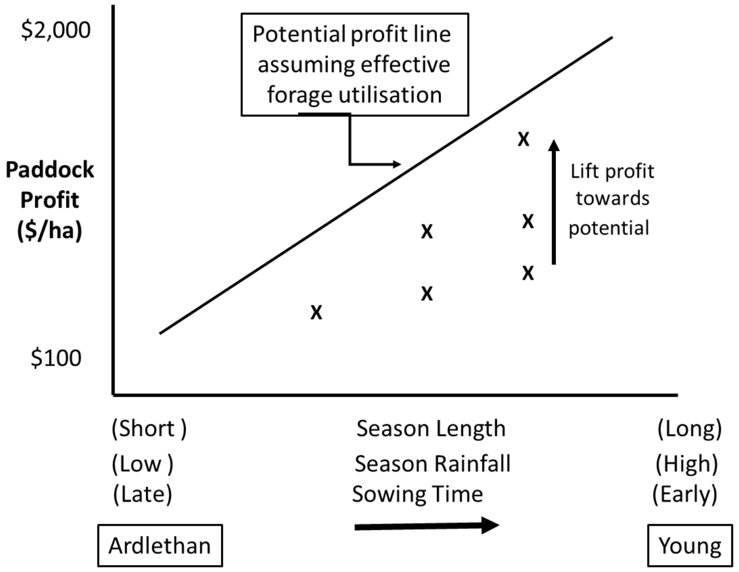

Figure 1. The potential paddock-scale profit from dual-purpose crops assuming effective forage utilisation (solid line) increases with longer seasons, more rain and early sowing. Improved crop and livestock management can improve profit at any potential level (crosses).

Getting it right at the paddock scale - a few universal guidelines

Early establishment with the right variety is the key to success.

Successful establishment in the earliest window with the right variety to flower at the optimum time provides maximum grazing potential. Grazing potential **declines by 200-250 dry sheep equivalent (DSE).days/ha for every week's delay after March 1.**

Lock-up time and residual biomass are crucial decisions to maximise profit

Grain yield penalties occur when grazing too late (i.e., removing reproductive parts) and too hard (leaving insufficient biomass to reach target yield). Rules of thumb have been published widely previously (see reading list). The decision is significantly influenced by the crop yield outlook and the relative prices for livestock and grain. These different 'exit options' (graze out, graze-hay, graze-silage, graze-grain) depend on specific circumstances and can provide significant management flexibility in response to variable seasonal or price outlooks.

Direct and indirect impacts on profit

In general, in these medium rainfall areas, dual-purpose crops are likely to be replacing grain-only crops on farms that are more crop-focussed. A summary of over 10 years of experiments, simulation studies and collaborative on-farm validation has demonstrated an increase in net crop returns at the paddock scale in the range of $300 to $1000/ha (Table 1). In general, the potential profit/ha is higher with earlier-sown winter types in the higher rainfall, longer-season areas and decreases as rainfall, season length and early-sowing opportunities decline moving west (Figure 1, Table 1). This is because the period for forage production, the time for crop recovery, and the grain-yield potential all decline with later sowing – but opportunistic grazing is still possible.

At farm scale, DP crops provide a range of other benefits such as widening the sowing window, filling critical feed gaps for earlier turn-off at higher weight or price, reduced supplementary feeding, spelling pastures and providing flexible options in dry years. The recent move to strict summer weed control and earlier sowing in cropping programs means early-sown DP crops provide indirect benefits to the whole farm by moving the whole sowing program earlier. This effect, together with buoyant livestock prices has meant that dual-purpose crops have become an important adaptation to increasingly unreliable autumn and spring rainfall and increasing spring temperatures.

Table 1. Typical examples of forage, grain yield and gross margins achieved from well-managed dual-purpose crops by collaborating growers in southern NSW

Crop type	Grazing achieved (DSE.days/ha)	Grain yield (t/ha)	Paddock gross margin (GM) $ increase above grain only
Winter wheat	1600 - 2700	4.5 – 6.5	+$600 - $1000
Spring wheat	400 - 800	3.0 - 5.0	+$300 - $500
Winter canola	750 - 2500	2.0 – 4.0	+$600 - $1000
Spring canola	300 - 700	1.5 – 2.5	+$300 - $500

Recent performance of winter types across the medium rainfall zone

Recent farming systems experiments have investigated the performance and profitability of grazing early-sown (March) winter canola and wheat systems at Greenethorpe and Wagga Wagga which span the medium rainfall zone. The economic performance of grazed canola-wheat systems has been compared with later-sown, grain-only spring wheat and canola systems (both systems managed with optimal agronomy). The grazing value was estimated by measuring the biomass removed by the livestock (usually heavily grazed for short periods), assuming 70% use efficiency and using feed conversion ratio and average long-term meat prices to establish the potential value of the grazing (see summary at end). The annual and average 3-year profit (earnings before interest and taxes (EBIT)) was calculated and compared using real input and production costs for the years 2018-2020 (Table 2).

Profit was higher at Greenethorpe than at Wagga for both the dual-purpose system and the grain-only systems as a result of higher forage and grain yields in most years. But at both sites, the dual-purpose systems were significantly more profitable in all years (except 2018 at Wagga where the winter canola crop failed to recover from grazing in the drought). In the consecutive dry years of 2018 and 2019 at both sites, the grazed forage was an important part of the increased profitability as grain yields were relatively low. In the wet year of 2020 the un-grazed spring crops outyielded the grazed winter crops, but this was more than compensated by the value of the grazed forage.

Table 2. Annual and 3-Year profit (EBIT) at Greenethorpe and Wagga Wagga for early-sown (March) dual- purpose canola-wheat systems compared with timely sown (April) canola-wheat grain-hay systems in 2018 and 2019. Systems were phased (both crops were grown in each year).

Site/Crop	Dual-purpose system				Grain only system		
	Variety (date sown)	Graze (t/ha)	Grain/ (hay) (t/ha)	EBIT ($/ha)	Variety(date sown)	Grain/ (hay) (t/ha)	EBIT ($/ha)
Greenethorpe							
2018 Wheat	Kittyhawk⦶ (5/4)	1.6	1.8	$799	Coolah⦶ (7/5)	2.5	$619
2019 Canola	Hyola970 (23/3)	4.9	0	$1,419	HyTTec® TT (1/5)	(3.1)	$96
2020 Wheat	Bennett⦶ (18/3)	2.1	6.2	$1699	Coolah⦶ (5/5)	7.8	$1269
Ave 3-Yr EBIT				*$1305*			*$661*
2018 Canola	Hyola970 (3/4)	3.2	0.7	$1,251	HyTTec TT (7/5)	1.1	$79
2019 Wheat	Bennett⦶ (26/3)	3.4	0	$960	Coolah⦶ (1/5)	(4.8)	$538
2020 Canola	Hyola970 (17/3)	3.5	3.9	$2759	HyTTec TT (5/5)	4.6	$1958
Ave 3-Yr EBIT				$1536			$859
Average 3-Yr System EBIT				$1420			$760
Wagga Wagga							
2018 Wheat	Kittyhawk⦶ (3/4)	0.7	2.4	$649	Beckom⦶ (2/5)	2.2	$323
2019 Canola	Hyola970 (8/4)	4.5	(1.7)	$996	43Y92 (26/4)	1.4	$113
2020 Wheat	Bennett⦶ (10/3)	2.5	6.0	$1370	Beckom⦶ (12/5)	6.9	$917
Ave 3-Yr EBIT				*$1005*			*$451*
2018 Canola	Hyola970 (3/4)	1.8	0	-$79	43Y92 (3/4)	1.3	$93
2019 Wheat	Kittyhawk⦶ (8/4)	0.8	(3.0)	$229	Beckom⦶ (6/5)	(3.8)	$50
2020 Canola	Hyola970 (10/3)	2.4	2.8	$1505	43Y92 (23/4)	4.0	$1440
Ave 3-Yr EBIT				*$552*			*$528*
Average 3-Yr System EBIT				$778			$489

Our expectation was that successive seasons of early-sown winter crops at Wagga would generate legacies of dry soils that would reduce yield and profit compared with later sown grain-only crops. While the relative advantage of the grazed crops at Wagga was lower (59%) compared to Greenethorpe (85%) it remained significant, and in only 1 case out of 6, was the profit lower than the grain only option.

In almost all cases, grazing reduced grain yield compared to grain only crops (except wheat at Wagga in 2018), which means the value ascribed to the grazed forage is an important driver of the profits reported. The biomass removed in grazed winter crops averaged 3.1 t/ha (1.6 to 4.9 t/ha) at Greenethorpe and 2.1 t/ha (0.7 to 4.5 t/ha) at Wagga Wagga. The value of this forage will differ depending on how effectively it is utilised and the value of the livestock enterprise. Our assumptions are detailed at the end of this article and can be modified to suit each enterprise.

Performance of spring types for grazing

A long-term experiment at Temora from 2009-2017 investigated the effect of grazing sheep on no-till, controlled-traffic, spring wheat and canola crops sown from mid-April to early May (Table 3). The crops were managed to **maximise grain yield** in no-till, interrow sowing systems on 30cm row spacing, and were **grazed opportunistically** with animals removed prior to Z31. The data reflect the potential for the opportunistic grazing of spring crops and the impacts on grain recovery.

The amount of biomass available for grazing is significantly less than for winter crops due to later sowing and more rapid development to Z30 and bud visible. The total biomass available at the start of grazing averaged 0.8 t/ha for canola (0.3 to 1.3 t/ha) and 0.8 t/ha (0.3-1.7 t/ha) for wheat. A maximum of ~1 t/ha was removed by livestock. In most cases the effects on grain yield were relatively small, (<0.2 t/ha), but tended to be higher with heavy (e.g., canola 2014) or late (e.g., wheat 2015) grazing.

Table 3. Effect of winter grazing on yield of canola and wheat varieties grown in C-W-W system at Temora between 2009 and 2016. Crops were crash grazed by sheep prior to stem elongation. Long-term average growing season rainfall (GSR) is 300 mm

Crop/year	Cultivar type & sowing date	GSR (April-October) (mm)	Grazing			Yield (t/ha)	
			Period	Start graze dry matter (t/ha)	Biomass removed (t/ha)	Ungrazed	Grazed
Canola							
2010	Tawriffic TT – 15/4	318	29-30/6	0.3	0.2	4.2	4.0
2011	45Y82CL – 15/4	198	24-25/6	0.8	0.5	3.3	3.1
2013	Hyola575CL – 1/5	230	2-4/8	1.3	1.0	1.0*	0.7*
2014	Stingrayⓟ TT – 1/5	313	8-9/7	0.5	n/a	2.1	1.6
2016	Hyola650TT - 27/4	590	14-16/7	1.1	0.7	3.3	3.2
Wheat							
2009	Gregoryⓟ – 30/4	225	18/6-7/7	0.4	0.4	1.7	1.3
2010	Bolacⓟ – 15/4	318	25/6	0.3	0.1	7.0	7.5
2011	Bolacⓟ – 15/4	198	22-26/6	0.8	0.6	4.3	4.8
2012	Wedgetailⓟ – 18/4	186	20-21/6	0.3	-	4.8	4.8
2013	Gauntletⓟ – 1/5	230	24-25/7	0.8	-	3.8	3.0*
2014	Lancerⓟ – 1/5	313	-	-	-	4.0	3.9
2015	Lancerⓟ - 24/4	279	13-20/7	1.3	0.7	5.3	3.8
2015	Lancerⓟ – 24/4	279	18-19/7	1.7	0.9	5.7	3.8
2016	Lancerⓟ - 28/4	590	18-19/7	-	-	5.7	5.1

*Severely affected by frost.

Emerging issues and farm-level considerations

Exceptional performance in drought but legacies must be managed

Early-sown DP wheat and canola options have been highly profitable at GRDC farming systems sites at Greenethorpe and Wagga in two recent decile 1 seasons in comparison with timely-sown grain only crops (Table 2). However, the success largely depended on deep stored water from either summer rainfall and good fallow management, or sequences with legumes which left legacies of water and N. At Greenethorpe, consecutive early-sown dual-purpose crops (phased canola and wheat) were able to capitalise on higher amounts of stored water to produce twice the profit achieved by a grain-only (or hay) system across the 3-year sequence **($1420/ha *vs* $760/ha)**. At Wagga Wagga under drier conditions, income for the same DP crops declined in the second year in 2019 due to the legacy of drier soil from 2018, but the DP system still had higher profit than the grain-hay system (**$778/ha *vs* $489/ha**). In medium rainfall areas, selecting the paddocks and seasons in which to use early-sown winter options can maximise profits.

Companions and forages

Some new options are being used on farms in the area including companion mixes which include a mix of cereal, oilseed and legume options, where after grazing the companions are terminated and the main crop harvested, or all may be grazed out. The mixture can increase the amount and quality of the forage while some benefits (soil improvements, pest or insect repellence, weed competition, N-fixation) are sought. In other cases, winter and summer crops may be sown exclusively for forage.

Managing N budgets in DP crops

Early-sown grazing crops require robust N levels at or near sowing to maximise biomass production (100-150 kg N /ha available in soil or fertiliser). But the uncertain fate of N in the consumed forage that is recycled onto the soil makes top-dressing decisions difficult. Though sheep remove very little N from the paddock (~5%), the timing and availability of the grazed and recycled N is uncertain – our best estimates suggest only 50% of the N taken up by the crop will be recycled and available to current crops, so adjusting topdressing accordingly to yield potential on this basis is advised.

Utilising the feed in good seasons

The large amount of feed made available in autumn especially in seasons like 2020 and 2021 (following prolonged drought) meant that thought must be given to effective and profitable utilisation of this feed. How to match the stock with the opportunity? Join more ewes for early autumn lamb? Retain more lambs from previous spring to target export weights? Trade sheep? These all carry risks for overstocking if dry conditions persist.

Farm-level impacts

Capitalising on the potential forage generated by dual-purpose crops at the farm-scale to lift profit towards the **potential profit** as predicted from forage production in plot-scale research requires careful planning of the livestock enterprise at the whole-farm scale. Dual-purpose crops will generally comprise only a portion of the cropping program, and numerous farm-scale considerations are required to determine how the grazing enterprise can be adjusted to make the most of the additional forage. These considerations are discussed in the paper by John Francis: 'Practicalities and economics of integrating dual purpose crops into the whole of farming operation in the medium rainfall zone'

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Further reading

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/past-update-proceedings/2019/grdc-grains-research-update-coolah-2019 https://www.grdc.com.au/uploads/documents/GRDC_Dual-PurposeCrops.pdf

Appendix 1: Determining earnings before interest and tax (EBIT)

To calculate the annual EBIT for all treatments, we have initially used the following assumptions/prices.

A. Expenditure

1. All herbicides/fungicides/insecticides, seed dressings, fertilisers, GRDC levies and crop insurance costs were obtained from the annual NSW winter cropping guide or the annual SAGIT farm gross margin and enterprise planning guides with links at:
    - i. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops
    - ii. https://grdc.com.au/resources-and-publications/all-publications/publications/2019/farm-gross-margin-and-enterprise-planning-guide
2. All seed was priced according to purchasing as pure treated seed from seed companies. i.e. In 2019, prices used were wheat seed at $1/kg, faba bean seed at $1.20/kg, chickpea seed at $1.80/kg and canola seed ranging between $23-30/kg
3. All operations costs (sowing, spraying, spreading, haymaking, harvest) were based on the principal that a contractor performed the task. These costs were extracted from the yearly SAGIT Farm gross margin and enterprise planning guides. i.e. In 2019 prices used included sowing at $50/ha, ground spraying at $10/ha, cereal harvest at $70-85/ha, cut/rake/bale hay at $115/ha, with links at: https://grdc.com.au/resources-and-publications/all-publications/publications/2019/farm-gross-margin-and-enterprise-planning-guide
4. All variety levies for all crops and varieties were determined from the variety central website at: (e.g. for pulses) http://www.varietycentral.com.au/varieties-and-rates/201920-harvest/pulse/

B. Income

1. Wheat, barley and canola grain prices were obtained on the day of harvest from the AWB daily contract sheet for specific regions relating to trial location at: https://www.awb.com.au/daily-grain-prices
2. Pulse grain prices were obtained on the day of harvest from Del AGT Horsham and confirmed with local seed merchants.
3. Hay prices were obtained in the week of baling from a combination of sources including The Land newspaper and local sellers.

Appendix 2: Determining grazing value

To determine the estimated value of grazing the early sown crops, we have used the following formulae:

Winter grazing value ($/ha) = Plant dry matter (kg) removed x Liveweight dressed weight (c/kg) x Feed conversion efficiency (0.12) x Dressing % (lambs) x Feed utilisation efficiency (0.75)

Dressed weight and value:

- Lambs = 22.9kg (3-year average of light, heavy and trade lambs)
- Dressed weight = $6.25/kg (3-year average NSW)
- Dressing percentage = 50%

An example of 45kg lambs grazing winter Hyola 970 canola:

3800kg plant DM removed x $6.25 x 0.12 x 50% x 0.75 = $1069/ha

Note:

- These calculations assume a “trading margin” of zero – i.e. animals are bought and sold for the same price/kg
- We have not deducted a cost associated with the grazing livestock – this must be estimated and deducted for relevant enterprises (breeding, trading, etc)

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Practicalities and economics of integrating dual purpose crops into the whole of farming operation in the medium rainfall zone

John Francis, Agrista

Key words

dual-purpose crops, grazing crops, whole farm profitability

GRDC code

CFF00011

Take home message

- There is no one size fits all approach to the integration of dual-purpose crops into a farming system. The value of the integration will depend on several factors including the existing system and the existing skill base. Following are some tips that may assist in successful implementation to ensure that dual purpose crops are an enduring part of the farming system
- Extracting value from dual purpose crops at a whole farm level requires optimising not only the grazing crop but also the other parts of the farming system
- Don't underestimate the investment in skills required to make some of the changes. Start small to build confidence as this will minimise risk and build skill over time
- Whole farm feed budgeting prior to making systems changes will assist in understanding the extent of the capital requirements for the additional livestock and the stocking rates necessary to deliver profitability improvements
- If feed budgeting skills can be learned and perfected through exposure to dual purpose crops and then applied to other parts of the farm, then there is the potential for improvement in whole farm profit.

Introduction

The GRDC farming systems project has compared the performance of crop sequences over the 2018 to 2020 growing seasons to account for legacy effects of one crop to the next. This has helped to move thinking beyond individual crop performance within any year to rotation performance across years. Further insights will be delivered with GRDC's investment into the second three-year phase which will run from 2021 to 2023.

The introduction of dual-purpose crops has the potential to increase whole farm profitability where the per hectare returns exceed those of the existing enterprises and their introduction doesn't erode the profits of the existing system. The aim of this paper is to demonstrate some of the factors that will influence the financial performance of dual-purpose crops. Dual purpose crops will have a greater chance of being an enduring part of the system if there is general understanding of the success factors prior to implementing change.

This paper will take a theoretical approach and combine it with case studies to demonstrate some of the practical issues associated with integrating dual purpose crops into the whole farm system. The value created, or destroyed, as a result of the integration of dual-purpose crops into the system is dependent on a range of factors including skills, management, the existing system and the extent to which it is already optimised.

This paper will also address the methodology for assigning a value to the grazing component of dual-purpose crops and consider some of the issues associated when scaling up from experimental components to an integrated whole farm system.

Play to your strengths

Decisions around farming systems changes should have some element of weighting on financial performance however there are a range of other factors that are also important. The financial performance resulting from production delivered in farming systems experiments is highly dependent on the management applied to the plots. This is entirely appropriate as the aim of these experiments is to measure the effect of an experimental treatment or test a hypothesis which is usually easier if all other management factors are optimised.

Not all farm business managers have the same level of skill across their enterprise mix. Farm performance analysis often shows that in mixed enterprise farms some business operators consistently perform better in one enterprise than another irrespective of commodity price differences. There is little data showing why this occurs, but the speculation is that passion or natural preference for one enterprise over another plays a role in this outcome. This passion leads to a greater skill development in the preferred enterprise at the cost of skill development in another enterprise and that just exacerbates the relative difference in performance.

A case in point is a producer in a 600-millimetre mixed farming area of southern NSW with 15 years of farm production and financial performance data. The highest return and best use for their farmland is dryland cropping with livestock enterprise returns being the next most appropriate use based on the resource base. Despite this, the farm manager has exceptional livestock performance due the skills built in this enterprise, the desire to manage livestock and his implementation of a livestock system that matches feed supply with feed demand and the timing of offtake of trading livestock coinciding with the decline in feed quality.

For this particular producer, over the last 15 years the per hectare financial returns of dual-purpose crops, inclusive of the value of grazing income, have rarely exceeded those of the chosen livestock enterprise. While farm performance data suggests this is not reflective of similar farms in the area, it reflects the management and skill sets of this individual manager. Despite these results, the manager was an early adopter of dual-purpose crops and continues to grow them for the role they play in reducing the weed seedbank prior to sowing long term perennial pasture.

For every manager with strengths in livestock management skills and weaknesses in crop management skills there will be another with strengths in crop management skills and weaknesses in livestock management skills. There is real value in identifying the weakness and establishing the cost of that weakness prior to executing a change in system, as the investment in a system change requires appropriate skill sets. Capital investment without the necessary skill sets is likely to be insufficient.

The key point here is that some farm managers have strengths and skills that need consideration when deciding about which farming system to implement. The financial performance delivered in a research trial may never be achieved on some farms because the effort and discipline required to build the management skills to deliver the same results exceeds the marginal reward when compared to the alternative.

What do you give up and what do you gain?

Studies of human behaviour, psychology and mental processes have shown that we value a loss and a gain of the same magnitude differently. The value that we place on loss is far higher and has a far greater impact than the value we place on gain. In fact, some studies have shown that we fear loss nearly twice as much as we value gain. Given this, it is important to quantify the value of any potential downside as well as the frequency of occurrence of that downside.

The vast weight of research data involving dual purpose crops suggest that, provided a few simple grazing rules are followed, there is no marginal cost of foregone grain yield of moving from a grain only system to a dual-purpose cropping system. In other words, yields of grazed crops are not significantly dissimilar to yields of ungrazed or grain only crops. This suggests that there is little risk from the grain income side of introducing a dual purpose crop, but there may be perceived risk on the grazing side.

The risks in introducing a grazing enterprise to a system where there was previously no livestock include:

1. Biosecurity risk. The introduction of weed seeds in the livestock themselves.
2. Labour risk. The time taken to manage the grazing livestock erodes some value elsewhere on the farm.
3. Management risk. The skills haven't been developed so there are unknown elements that could induce cost.
4. Capital risk. There is more capital required for the outlay of the livestock however this needs to be tempered with the extremely low probability that it would be completely lost.
5. Production and price risk due to a lack of skill. The combination of these doesn't combine to deliver the outcome necessary to generate an adequate return.

These risks need to be considered against the reward which is the additional income that can be generated from the grazing. It is also worth noting that many of these risks can be dealt with by taking a pro-active management approach to minimise their impact.

What base are you coming from?

An important step in establishing the value of any systems change is to first consider the status quo or base case. This is important because the value of a change in system depends in part on the existing system and its performance. When assessing the integration of dual-purpose crops into an existing farming system, there will be several factors that require consideration which are outside of the production and financial performance demonstrated in research trials.

These include, but are not limited to:

- Skills
- Human resources
- Capital requirements
- Land class suitability.

The extent of the change in technical skills, labour requirements and capital investment when integrating dual purpose crops into a farming system, previously devoid of this enterprise will differ depending on the existing enterprise mix. Table 1 shows that a mixed grain and livestock business will experience only small changes in skills, labour and capital investment when integrating dual purpose crops into the system. By comparison, the changes are large if moving from a livestock or grain only enterprise mix.

Table 1. The extent of the change in skills, labour and capital investment to integrate grazing of dual-purpose crops will differ depending on the existing enterprise mix.

Current enterprise	Change in skills, labour & capital investment
Mixed grain and livestock enterprise	Small
Livestock only enterprise	Large
Grain only enterprise	Large

Allocating grazing value to crops

The allocation of the value of grazing to a dual-purpose crop is necessary to account for the multiple streams of income (grain and grazing) that can be provided by the crop. There can be complexity associated with the allocation of the net value of grazing to dual purpose crops. Simplification sometimes results in miscalculation of the true value of the grazing resulting in erroneous values that can influence decision making. This can have major consequences where implementation is heavily dependent on financial performance.

Market value of feed

To assess performance at an enterprise level it is necessary to place a market value on the production generated by the dual-purpose crop. The market value of the grain is easily estimated as it is a simple calculation of yield by price. There is more complexity associated with the calculation of the value of grazing biomass because the value differs depending on how that biomass is used. The biomass can be used for trading livestock, creating value internally through utilisation in existing livestock enterprises or by agisting external livestock.

The value of a livestock trade allocated to a dual-purpose crop can be calculated as the net value or proportion of net value created by the trade. This is calculated as sales less purchases less all associated enterprise costs. If the trade occurs over a period which is longer than the dual-purpose crop grazing period, then the appropriate proportion of net earnings generated by the crop should be allocated.

The value of external agistment allocated to a dual-purpose crop is dictated by the price paid by the market. When feed is abundant the value may be low and when feed is in short supply the value increases. The range is usually around $0.50 cents to $2.00 per DSE per week.

The value to existing livestock enterprises of using a dual-purpose crop can be allocated in one of two ways. The first is to assign the market value of agistment as if the feed were to be sold as external agistment. The second is to establish the value generated from the use of the feed internally. The latter is far more difficult to calculate because splitting the costs and benefits of different components of a breeding unit is not straightforward.

In any livestock breeding enterprise, there are usually several income streams. These include trading livestock sales, cull and surplus female sales, bull, ram or wether sales and wool sales. The largest of the livestock income streams is usually the livestock trading component typically made up of young livestock such as lambs, hoggets, steers or heifers. In a breeding enterprise, the production of these trading livestock is dependent on a female breeding animal. This breeding animal incurs most of the enterprise cost and consumes around 75 percent of the total feed of the breeding and trading unit combined. Allocation of the trading income to the dual-purpose crop without either attribution of the cost of carrying the breeder or allocation of a purchase price of the lamb therefore results in unrealistically high values accrued against the dual-purpose crop.

Allocating a livestock trading enterprise value to a grazing crop

Where feed utilisation levels of fifty percent or above are achieved on pastures in the farming system then the inclusion of a livestock trading enterprise can be an effective means of utilising the additional feed supplied by the dual-purpose crop. To achieve feed utilisation levels of fifty percent or above, it is necessary to manage a livestock system that matches feed supply with demand. Typically, in a breeding operation, this means timing operational activities with high energy demand such as lambing, calving to coincide with the highest energy supply and ensuring trading livestock are sold as energy supply declines rapidly.

Where a trading enterprise is introduced for the sole purpose of generating revenue from the grazing crop, then the allocation of trading enterprise net earnings to the crop is relatively straight forward. The net earnings, or margin on the trade consists of sales less purchases less operational costs. It is generally not necessary to allocate any overhead costs to this trade unless it consumes a large proportion of the total labour use on farm. If a portion of the time spent by the trading livestock occurs off the crop, then the net earnings can be allocated on a pro-rata basis.

It appears to be a reasonably common industry practice to allocate the income of a livestock trading enterprise to the dual-purpose crop irrespective of the way the crop feed is utilised. This can be problematic as it may result in skewed results that aren’t truly reflective of the value at a whole farm level.

Industry practice appears to involve an estimation of grazing income, based on the estimation or measurement of weight gained on the crop by livestock, multiplied by a sales value per unit of weight gained. Some potential issues associated with the use of this methodology follow.

1. If the business is a breeding business and doesn’t have a trading enterprise, then it is possible that this method will overestimate the value of income.
2. There is no allocation of the value of any enterprise costs associated with the trade. If the trade was conducted purely for the consumption of the crop-supplied feed then the costs will include freight to farm, induction costs (animal health treatments including drench and vaccine), shearing and crutching costs and transaction costs including commissions, transaction levies and freight costs.
3. There is no allocation of the financial impact of mortality rate on income. At a financial level, mortality is accrued as foregone income by multiplying only those livestock sold by the value per head. Per hectare calculations derived from per head performance multiplied by stocking rate will need to account for mortality. This means that some per hectare calculations will be based on the number of livestock purchased and some on the number of livestock sold with the difference between the two being mortality.
4. Trading gains or trading losses are not allocated where income is calculated as sales value per unit of weight multiplied by weight gained.

Two components to a livestock trade

There are two components in a livestock trade that contribute to the margin net of costs. An explanation of these components follows.

1. The trading margin – calculated as the difference between buy and sell price.
2. The weight gain margin. The value of every unit of liveweight gain multiplied by the price per unit of liveweight gain at the point of sale. This must account for mortality as dead livestock tend not to put on a lot of weight.

The trading margin (difference in the buy and sell price) only applies to the weight purchased. When there is a positive price differential between the sell and buy price (i.e., the sell price exceeds the buy price) every kilogram purchased makes money. When there is a negative differential between the sell and buy price (i.e., the sell price is lower than the buy price) every kilogram purchased loses money. The weight gain margin is the value of every kilogram added after purchase.

It is the sum of the two that matters (i.e., makes the net income) – not one or the other in isolation. Some high-profile livestock producers have self-promoted their grazing and trading results on social media showing only the value of total weight at sale. In a livestock trading enterprise this gives an incomplete picture as it doesn't declare the value at purchase or the enterprise cost.

Many livestock trading enterprise managers conduct their risk analysis and trade margin calculations based on there being an adequate margin over the volume traded rather than ensuring the buy and sell price being the same. That is, they tend to accept that the sell price might be lower than the buy price because they think that the value of the weight that they gain at a lower price (than the buy price) will more than compensate for the lower price at sale. This mentality is not captured where trading income is calculated as sales price by weight gained.

The assignment to grazing crops of the value of livestock weight gain multiplied by the sales value per kilogram is only appropriate if the buy and sell price in a trade is exactly the same and mortality rate equates to zero. This however only accounts for the income in the trade and without the cost associated with the trade it overestimates the net margin associated with crop grazing.

Tables 2 and 3 provide examples of the calculations that are used to estimate grazing income on dual purpose crop. The methodology used in Table 1 potentially overestimates the value of the grazing contribution as it doesn't account for costs or trading gains or losses. The methodology in Table 3 more accurately values the grazing contribution to the crop as it accounts not only for the value of the weight gain but also for trading gains or losses, mortality and operating costs. The examples apply to a lamb trade however the principles apply equally to any livestock enterprise.

Table 2. Weight gain margin approach to valuation – does not account for costs or trading gain/loss

Biomass available for grazing (kg DM/ha)	3,800
Utilisation	75%
Feed conversion efficiency (kg DM/kg lwt)	8.3
Yield (cwt:lwt)	50%
Sale price ($/kg cwt)	$6.25
Carcase weight gained (kg cwt/ha)	171
Gross value of weight gain ($/ha)	$1,069

Table 3. Net margin approach to valuation – accounts for costs trading gain/loss and mortality

Buy to sell price disparity	**0%**
Gross value of weight gain ($/ha)	$1,069
Mortality adjusted value of weight gain ($/ha)	$1,035
Trading gain/loss ($/ha)	$0
Enterprise & transaction costs ($/ha)	$436
Net margin on trade ($/ha)	$599
Bottom line relative to headline	56%

Table 4 shows the assumptions that drive the outputs shown in Tables 2 and 3.

Table 4. Assumptions driving production and financial outputs.

Assumption	Metric
Mortality rate for period	1%
Induction & enterprise costs ($/head)	$8
Sales costs (commissions/fees/freight)	7%
Buy to sell disparity	0%
Yield (lwt to cwt)	50%
Sale price ($/kg cwt)	$6.25
Feed conversion efficiency	8.3
Crop area	250
Target sale weight (kg cwt/head)	22

Figure 1 shows that the weight gain margin method for valuing grazing to crops is insensitive to price disparity. This results in over estimations of net grazing value except where sell to buy price disparity exceeds 10 percent. The magnitude of the outcome of this analysis differs based on the selling price which in this example is $6.25 per kilogram carcase weight (lamb).

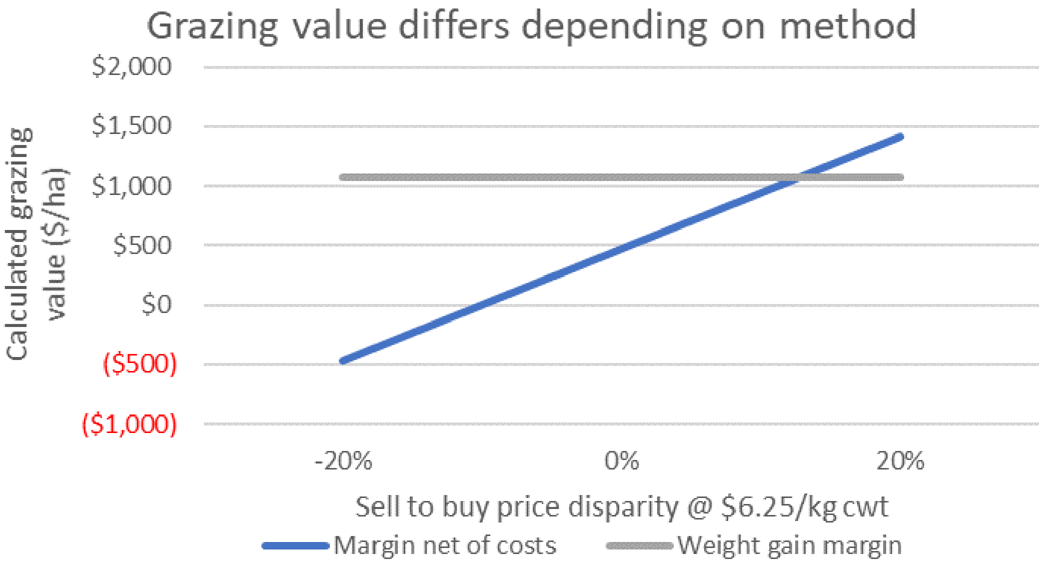

Figure 1. The weight gain margin method of grazing valuation is insensitive to trading gains or losses and ignores costs.

Shuffling the deck chairs or capturing the value? A case study demonstrating the difference

Farming systems trials have shown that dual purpose crop profits are highest where grain yield is optimised and vegetative crop biomass is well-utilised. Several research studies have concluded that the additional value generated through the inclusion of dual-purpose crops to the farming system adds considerably to whole farm profitability.

While farm benchmarking data shows that there are individuals who are able to capture the benefits of including dual purpose crops into their systems there are as many who generate no additional value. Individual farm benchmarking data sets have been examined to explore these issues and gain some understanding of why the additional return from dual purpose crop inclusion is not being delivered across the farm.

Table 5 shows two farming systems. The first three columns represent a livestock only system while the next three represent a system with 80% of the total farm area as pasture with the remaining 20 percent as dual-purpose crop (DP crop). The type of livestock enterprise, the time of lambing and calving and the time of turnoff of trading livestock are all important but they are not drivers of the outcome in the context of this analysis.

Table 5. Biomass production calculations for two systems – one livestock only, the other includes 20 percent dual purpose crop

	Livestock 100% Dual purpose crop 0%			**Livestock 80% Dual purpose crop 20%**		
	Pasture	**DP crop**	**Total**	**Pasture**	**DP crop**	**Total**
Enterprise (% total area)	100%	0%		80%	20%	
Area (ha)	1000	0	1,000	800	200	1,000
Biomass grown (kg DM/ha)	7,366	0	7,366	7,366	3,980	6,689

Figure 2 shows the stocking rate by systems component of the two farming systems. The grey line represents the monthly stocking rate, expressed in DSE per hectare, on pasture of the livestock only system. The dark blue bars represent the monthly stocking rate on the 80-pasture area while the light blue bars represent the monthly stocking rate on the 20 percent dual purpose crop area.

Figure 2 Shows the value of dual purpose crops is short duration grazing during Autumn and mid winter.

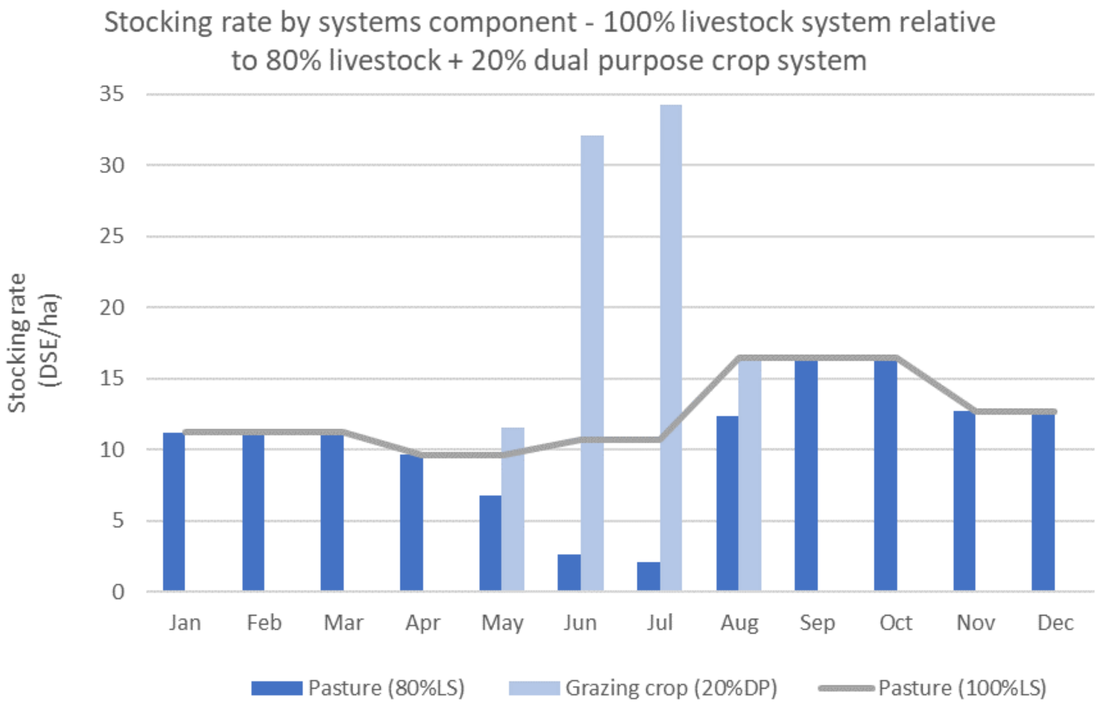

Figure 2. Stocking rate by month for a 100% livestock system vs an 80% livestock + 20% dual purpose crop system.

Table 6 shows stocking rate per hectare by component (pasture and crop) and by farming system. It also shows opening and closing annual biomass per hectare as well as feed utilisation levels. Feed utilisation is calculated as intake divided by feed grown. The closing crop biomass and the utilisation levels in the crop demonstrate that the additional feed supplied by the dual-purpose crop has been very well utilised. The issue however is that the lower mid-winter stocking rate in the pasture, shown as the dark blue bars in Figure 2, has reduced the average annual stocking rate on the pasture.

This reduction in average annual pasture stocking rate in the mixed livestock crop system has led to a reduction in feed utilisation demonstrated by the utilisation rate and the lower average annual stocking rate when compared with the livestock only system. If the pasture system was achieving a stocking rate of 12.5 DSE per hectare prior to introducing dual purpose crop it should be achieving the same stocking rate afterwards. Instead, the stocking rate on pasture declined.

At a whole farm level this means that the 9,980 DSE managed in the pasture and dual-purpose crop system represent 80 percent of the 12,430 DSE managed in the livestock only system. Given the pasture area in the pasture crop system represents 80% of the pasture area in the livestock only system this stocking rate should have been achieved in the absence of the dual-purpose crop and the 1,580 DSE in the dual-purpose crop should have been additional livestock. In other words, the grazing crop has added no marginal grazing value at a whole farm level.

This doesn't mean that the dual-purpose crop hasn't paid for itself, but it does mean that there is no additional grazing value added as a result of dual-purpose crop inclusion. The contribution of grain typically dwarfs the contribution of grazing to dual purpose crop income so there may still be value in adding dual purpose crops to the enterprise mix but their value isn't optimised. This is covered in more detail in Table 6.

Why is it so? For those that don't keep good livestock production records or differentiate pasture stocking rates from crop or whole farm stocking rates then it is possible that this issue isn't even known. It is plausible that the extremely high stocking rates on the crop, where the majority of livestock graze during a period that is conventionally difficult to manage and which accounts only for the minority of total grazed area, are causing misjudgements about the whole farm stocking rate. This is why recording stocking rate by area grazed is particularly important.

Dual purpose crops can provide potential benefits beyond production and its value. In cases where dual purpose crops are grazed with trading livestock, producers have been forced to become more skilled at feed budgeting. Many managers, because of growing dual purpose crops, are very attuned to crop growth rates, wastage rates, livestock intake and the factors that influence these.

In some cases, these feed budgeting skills have delivered improvements in feed utilisation in pasture systems as these managers become more confident in their ability to manage the livestock pasture interface. In some cases, the value of the improvements to the other parts of the farming system, depending on its scale may be greater than the value of the introduction of the dual-purpose crops to the system.

Table 6. Stocking rate per hectare by component (pasture and crop) and by farming system and opening and closing annual biomass per hectare as well as feed utilisation levels for 100% livestock system vs. an 80% livestock and 20% dual-purpose crop system. Dual purpose crop biomass is well utilised but pasture utilisation decreases.

	Livestock 100% Dual purpose crop 0%			**Livestock 80% Dual purpose crop 20%**		
	Pasture	**DP crop**	**Total**	**Pasture**	**DP crop**	**Total**
Opening biomass (kg DM/ha)	2,500			2,500	1,230	
Closing biomass (kg DM/ha)	2,526			2,884	508	
Average annual stocking rate	12.43		12.43	10.5	7.9	10.0
Utilisation rate	49%			42%	58%	
Farm stocking rate DSE	12,430		12,430	8,400	1,580	9,980

The impact on financial performance of two systems and three scenarios is presented in Table 7. The first column represents an efficient livestock only business (LS OPT). The next three columns represent the enterprise components of an 80% pasture base and 20% dual purpose crop system (LSC SUB) with pasture utilisation compromised or sub optimally stocked. The rightmost three) columns represent the enterprise components of an 80% pasture base and 20% dual purpose crop system (LSC OPT) with pasture utilisation and stocking rate optimised.

The value of the biomass in a dual-purpose crop represents only a small proportion of the total value of the crop. The majority of the total enterprise earnings are in grain production.

Table 7, which is an extension of Table 6, shows the difference in financial performance between enterprise components and between systems with sub optimal and optimal feed utilisation. In the system with sub optimal pasture utilisation the livestock (August lambing wool flock) are agisted onto the crop at a value of $1 per DSE per week. This is shown as crop grazing income at a gross level or Agistment/grazing margin at a per hectare level. This equates to $68 per hectare.

This agistment income is then seen as an expense in the livestock enterprise. When spread over all the livestock it equates to approximately $1.40 per DSE. The gross overhead costs allocated to the livestock enterprise decline from $310,000 to $250,000 but this equates to no net change on a per DSE basis. This is demonstrated in the cost per DSE which is $25 for the LS OPT and LSC SUB systems. Profits per DSE decline from $45 per DSE in the LS OPT system to $44 per DSE in the LSC SUB system due to the additional cost of the agistment onto the crop.

In the system with optimal pasture utilisation (LSC OPT), crop biomass is utilised with a livestock trade rather than the existing wool flock. The average annual stocking rate on the crop equates to 7.9 DSE per hectare but unlike the pasture, which is grazed year-round, it has been derived from short duration high intensity grazing for only a proportion of the year.

The number of livestock grazed on pasture increases relative to the LSC SUB system to reflect the per hectare stocking rate of the LS OPT system. This equates to 9,980 DSE. All of the expenses associated with the trade have been deducted so the net earnings of the trade are what is shown as the grazing margin. This means that there is no cost to be accrued against the existing livestock enterprise. The overhead cost base of the existing livestock enterprise is maintained at $25 per DSE which delivers the same profit per DSE.

The assumptions for the trade are shown in Table 8. The margin for the livestock trade ($308 per hectare) compared with the agistment income reflects the higher risk in this enterprise.

The grain income is assumed to be $1,238 per hectare which is higher than the average of the three-year grain income in the farming systems trial to attempt to reflect less volatility. The outcome of the analysis is highly sensitive to the value of the grain income per hectare. This reinforces the message around the importance of skills. Croppers know how much timeliness and management skill contributes to attaining the production while others may be less aware.

Per hectare comparisons

Livestock/pasture enterprise returns

The LS OPT system delivers operating profit or EBIT of $560 per hectare. The LSC SUB system delivers EBIT of $544 per hectare from the livestock due to additional agistment costs associated with grazing the dual-purpose crop. The LSC SUB system has maintained the 12.4 DSE per hectare stocking rate on the pasture by agisting on the crop which adds no value at a whole farm level.

The LSC OPT system generates the same return as the LS OPT system per hectare as the stocking rate per hectare on pasture has remained the same, but the additional feed produced by the crop is consumed using a livestock trading enterprise. At a gross level, profits have declined but only by the proportion of area sown to crop.

This means that there is no marginal cost associated with the crop as it has been grazed with trading livestock.

Crop enterprise returns

The LSC SUB system generates operating profit or EBIT of $555 per hectare in profit primarily due to low agistment income of only $68 per hectare when compared to the LSC OPT system. The LSC OPT system has higher grazing income because the net returns of trading (after costs) in this example are higher than the value attributed to agistment. The LSC OPT system generates $796 in EBIT per hectare which weights the whole farm EBIT per hectare up. This demonstrates that the value of the dual-purpose crop comes from creating additional value from the crop grazing.

Bottom line

The bottom line (EBIT) is demonstrated by the column titled ‘Whole farm.’ This is the aggregation of the enterprise contribution of income, expenses and profits within each system and scenario. The LSC SUB system generates less return to the whole business relative to the LS OPT system not because the grazing crop didn’t deliver solid production and financial performance but because that performance came at the cost of optimising the performance in the livestock system.

The LSC OPT system generated more profit across the whole farm because the stocking rate in the pasture system was maintained and the crop profits were higher than the livestock only system.

The returns of both the LS SUB system and the LS OPT system are highly sensitive to grain production, pasture feed utilisation (stocking rate) and agistment or grazing returns.

In this case study the livestock system generates the majority of the whole farm profit so it is critical that per hectare performance is maintained in this enterprise to ensure that whole farm profit isn’t eroded with the inclusion of a dual purpose cropping system.

The key message associated with this whole farm analysis is that without good records it is difficult to establish the value contributed by dual purpose crops at a whole farm level. Without recording whole farm stocking rate and taking it further to understand stocking rate per pasture and crop hectare it is impossible to establish the contribution of different enterprises to the whole farm performance. A good starting point for those looking to compare the value of dual purpose crops with alternative enterprises is to have good farm records to allow for the analyses to be conducted.

Table 7. Where whole farm grazing is optimised there is a greater business case to introduce dual purpose grazing crops. The difference in financial performance between enterprise components and between systems with sub optimal and optimal feed utilisation

System	**LS OPT Livestock Optimal SR**	**LSC SUB Internal agistment onto crop Sub optimal pasture stocking rate**			**LSC OPT Trade livestock onto crop Optimal pasture stocking rate**		
	Pasture	**Pasture**	**Crop**	**Whole farm**	**Pasture**	**Crop**	**Whole farm**
Stocking rate (AADSE)	12,425	8,400	1,580	9,980	9,980	1,580	11,560
Area (ha)	1,000	800	200	1,000	800	200	1,000
Gross profit ($/DSE)	$95	$95			$95		
Enterprise expenses ($/DSE)	$25	$25			$25		
Agistment expenses ($/DSE)		$1					
Overhead expenses ($/DSE)	$25	$25			$25		
EBIT ($/DSE)	**$45**	**$44**			**$45**		
Gross profit grain ($/ha)			$1,238			$1,238	
Agistment/grazing margin ($/ha)			$68			$308	
Gross profit ($/ha)	$1,180	$1,185	$1,305	$948	$1,185	$1,546	$1,257
Enterprise expenses ($/ha)	$311	$329	$450	$340	$312	$450	$340
Overhead expenses ($/ha)	$311	$312	$300	$310	$312	$300	$310
EBIT ($/HA)	**$559**	**$544**	**$555**	**$547**	**$561**	**$796**	**$608**
Gross profit livestock ($)	$1,180,419	$948,100		$948,100	$948,100		$948,100
Gross profit grain ($)			$247,500	$247,000		$247,500	$247,500
Crop grazing income ($)			$13,543	$13,543		$61,650	$61,650
Component gross profit ($)	**$1,180,419**	**$948,100**	**$261,043**	**$1,209,143**	**$948,100**	**$309,150**	**$1,257,250**
Enterprise expenses ($)	$310,637	$249,500	$90,000	$339,500	$249,500	$90,000	$339,500
Agistment grazing expense ($)		$13,543		$13,543			
Overhead expenses (4)	$310,637	$249,500	$60,000	$309,500	$249,500	$60,000	$309,500
Total operating costs ($)	**$621,273**	**$512,543**	**$150,000**	**$662,543**	**$499,000**	**$150,000**	**$649,000**
EBIT ($)	**$559,146**	**$435,557**	**$111,043**	**$546,600**	**$449,100**	**$159,150**	**$608,250**

It is possible to calculate the minimum per hectare profits from the dual-purpose crop enterprise required to break even with the LS OPT system. Deduct the whole farm livestock enterprise EBIT in the LSC SUB and LSC OPT systems from the LS OPT system and dividing that figure by the crop area.

For example, the LSC SUB system compared to the LS OPT system: $559,146-$435,557 = $123,589 ÷ 200 = $617 per hectare.

For example, the LSC OPT system compared to the LS OPT system: $559,146-$449 100 = $110,046 ÷ 200 = $550 per hectare.

This approach can be used in forecast budgets to assist in decisions.

Table 8 Livestock (lamb) trading assumptions

Livestock trade assumptions	
Weight gain (kg/head/day)	0.275
Yield (cwt to lwt %)	46%
Feed adjustment period (days)	10
Sale weight (kg cwt/head)	21
Sale weight (kg lwt/head)	45.7
Purchase weight (kg lwt/head)	29.2
Price in ($/kg cwt)	$8.00
Price in ($/head)	$107.28
Price out ($/kg cwt)	$8.50
Price out ($/head)	$178.50
Sales cost ($/head)	$12.50
Enterprise costs ($/head)	$8.00
Total cost ($/head)	$20.50
Net margin ($/head)	$50.73
Net margin ($/ha)	$398
Net margin ($ gross)	$61,650

What this means to you

There is no one size fits all approach to the integration of dual-purpose crops into a farming system. The value of the integration will depend on several factors including the existing system and the existing skill base. Following are some tips that may assist in successful implementation to ensure that dual purpose crops are an enduring part of the farming system.

1. Extracting value from dual purpose crops at a whole farm level requires optimising not only of the grazing crop but also the other parts of the farming system.
2. Don't underestimate the investment in skills required to make some of the changes. Start small to build confidence as this will minimise risk and build skill over time.
3. Whole farm feed budgeting prior to making systems changes will assist in understanding the extent of the capital requirements for the additional livestock and the stocking rates necessary to deliver profitability improvements.
4. Where there is opportunity for feed budgeting skills learned as a result of exposure to dual purpose crops to be implemented to other parts of the farm there is massive opportunity for improvements in whole farm profitability.

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Dual purpose crops - a growers perspective

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Notes

Cranking up crop yields and livestock production using summer sown pasture legumes – revisiting fundamental soil and agronomy with new technologies to increase production and rotation flexibility

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Take home message

- Summer sowing of hardseeded legumes is a robust and effective way to establish pastures well adapted to climatic variability and acidic soils
- Once a seedbank is established, hardseeded legumes can add flexibility to pasture-crop rotation systems enabling growers to capitalise on crop and livestock market opportunities
- Hardseeded legumes can support high yields in following grain crops even when they were grown in a poor season. Considerable savings in nitrogen fertiliser are possible
- Growers should focus on what they should grow, considering soil, climatic and pasture-crop rotation systems used in order to maximise the potential of hardseeded legumes in their farming systems.

Introduction

Maintaining crop areas and profitability is facing considerable pressure as a result of rising input costs, particularly fertilisers, and competition from currently lucrative livestock enterprises. Increasingly, this is leading growers to explore opportunities to better integrate crop and livestock production in a way that allows for more fluid transition between enterprises in response to market opportunities, input cost pressures and climatic conditions. A component of building flexibility in to mixed farming systems is via consideration of the pasture component of the farming unit.

Pastures in mixed farming systems of eastern Australia have generally been used as phases of 3-10 years in a cropping rotation. While such pastures systems can provide stability in terms of productivity, they are also relatively inflexible in terms of allowing for rapid transition of total farming land area between crop and livestock production enterprises. Additionally, these pastures often require relatively lengthy periods to adequately establish (i.e. lenient grazing in the first 12 months) and require resowing after each cropping phase. For traditional pastures, sowing also coincides with peak labour demand, with ideal sowing time generally coinciding with the winter crop sowing window. Labour competition frequently results in pasture sowing occurring after the winter cropping program is completed, which can lead to poor pasture growth and seed production with impacts on long term persistence and performance.

However, astute pasture legume breeding programs and development of intuitive pasture establishment techniques such as summer sowing, have resulted in the development of highly productive and flexible legume-based pastures. Such pastures can be integrated into farming systems to increase productivity of crop and livestock systems. Legume species used in these pastures have also proven to be very tolerant of highly variable seasonal conditions, including extreme drought.

What is summer sowing and what legume species is it applicable to?

Summer sowing was developed by Dr Brad Nutt and colleagues at Murdoch University and the Department of Primary Industries and Regional Development in Western Australia (see Nutt et al. 2021). Summer sowing eventuated after the same team had previously developed range of robust pasture legume species including bladder clover, biserrula and gland clover, along with the first cultivars of hardseeded French serradella and new cultivars of arrowleaf clover and yellow serradella. All of these species produce their seed aerially, as opposed to subterranean clover which buries a proportion of its seed. Aerial seed production meant that it was possible to harvest seed of the legumes using conventional headers. This alone was a significant achievement as it allowed seed to be harvested quickly, efficiently and at relatively low cost.

When the aerial seeded legumes are harvested with a header, very minimal damage is caused to the seed coat (or the pod in the case of serradella), meaning that the seed retains a very high hard seed level. Such seed could be sent for further processing (i.e. scarification) and then subsequently sown in mid to late autumn like a traditional pasture sowing. However, early experiments showed that if the unprocessed seed was sown in mid to late summer, then a proportion of it would soften due to fluctuations in temperature and moisture and be capable of germinating on opening autumn rainfall. This meant that pasture sowing could be completed well ahead of the winter crop sowing program. The legume species suited to summer sowing also had attributes such as deep root systems and/or capacity for improved control of transpiration losses, which meant they could survive periods of high temperature and/or moisture stress that would normally result in high mortality of early sown traditional pasture legumes such as subterranean clover and annual medics. Additionally, as the pasture emerged early while temperatures were warm, more biomass could be produced than for conventionally sown pastures.

The early experiments in Western Australia found that bladder clover and hardseeded cultivars of French serradella were reliable for summer sowing in that environment. Later experiments found that arrowleaf clover, biserrula and gland clover in addition to bladder clover, hardseeded French serradella cultivars and some cultivars of yellow serradella were options for summer sowing in the central and southern regions of NSW. Higher soil moisture throughout summer and its interaction with temperature fluctuations appears to have increased hard seed breakdown rates in NSW (Nutt *et al.,* 2021).

How effective is summer sowing?

To date, in NSW, we have completed 18 replicated field trials (2012-2021) comparing summer sowing to conventional sowing across areas receiving long-term average annual rainfall of 380- 650 mm. Average annual rainfall over that period has ranged from 70% below to 50% above average across sites, with growing season rainfall varying by a similar magnitude. Across year and seasonal conditions, summer sowing has resulted in production of 4-10 t dry matter (DM)/ha, considerably higher than that achieved when pastures were conventionally sown (Table 1). Under drought conditions summer sowing maintained a similar level of production to the overall average and showed capacity for elasticity in response to improved conditions in wetter than average years.

Table 1. Total herbage production for annual legumes established via summer sowing (t DM/ha) as unprocessed seed in February or via conventional sowing of scarified seed in late May averaged over all years, in drought years or in higher than average rainfall years for 18 experimental sites between 2012 and 2021 in central and southern NSW. The herbage production for subterranean clover established via conventional sowing is also shown.

	Overall average (t DM/ha)	**Drought year (t DM/ha)**	**Wet year (t DM/ha)**
Summer sowing[1]	4-10 (av 4.8)	4-6 (av 4.1)	4-20 (av 8.6)
Conventional sowing[1]	0.3-4 (av 0.9)	0.3-1.8 (av 0.6)	2-5.5 (av 2.4)
Subterranean clover	0.8	0.3	2.0

[1] Species included were arrowleaf clover, biserrula, bladder clover, gland clover, French serradella and yellow serradella

With the exception of arrowleaf clover, all hardseeded legumes when established via summer sowing in extreme drought (2019), produced at least 80% of average herbage yield for all years (Figure 1). Capacity to maintain high levels of productivity in drought provides useful feed for livestock as well as building soil nitrogen for following crops. All species except bladder clover were also highly responsive to improvements in seasonal conditions producing 20-30% more herbage than the average across all years.

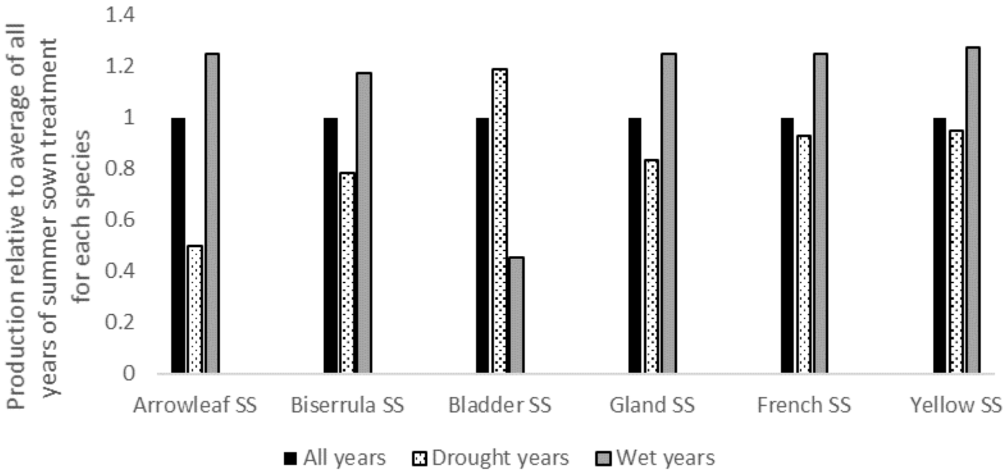

Figure 1. The herbage production of a range of hardseeded annual pasture legumes established via summer sowing relative to the overall average herbage production within each species averaged over 18 sites in NSW in the period 2012-2021.

N supply for following crops

The capacity of hardseeded legumes to support following crop production has been under evaluation at a number of sites in NSW. Near Ungarie in 2019, a number of annual legumes were grown under severe drought conditions in a replicated experiment with wheat included as a control. In 2020, the site was sown to wheat with the plots split for nitrogen treatment. Nitrogen treatments were either nil nitrogen, nitrogen applied at sowing only (as MAP) or nitrogen applied at sowing plus topdressing with urea at GS31.

Despite the severe drought of 2019, all hardseeded legumes provided sufficient nitrogen to support grain yields in 2020 of >3.8 t/ha without addition of nitrogen (Figure 2). Application of nitrogen at sowing or at sowing and then at GS31 did not increase the grain yield above that achieved by the nitrogen provided by the legumes alone. In contrast, both the continuous cereal and subterranean clover treatments showed significant response to addition of nitrogen at sowing with a further significant increase if nitrogen was also applied again at GS31. Further, the continuous cereal and subterranean clover treatments, application of nitrogen at sowing and at GS31 was required to produce an equivalent grain yield to the hardseeded legumes where no nitrogen was applied. Results for grain protein followed a similar pattern with wheat grown after hardseeded legumes achieving 12-14% protein without addition of any nitrogen compared to 8-9% wheat grown in the continuous cereal rotation or after subterranean clover. Application of nitrogen as sowing and GS31 was required to lift grain protein to 11% in the continuous cereal rotation.

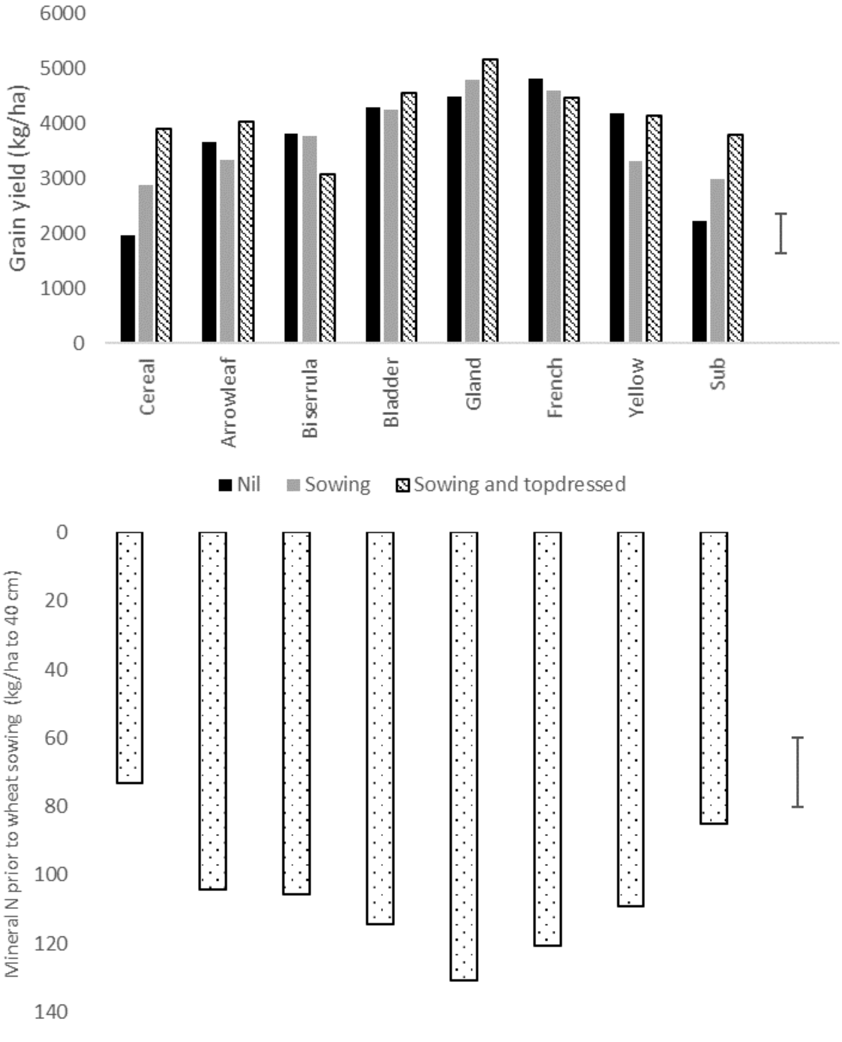

Figure 2. The grain yield of wheat (kg/ha) where no nitrogen, nitrogen at sowing only or nitrogen at sowing and at GS31 was applied in 2020 grown after a range of hardseeded annual legumes, wheat or subterranean clover in 2019. Soil mineral nitrogen prior to wheat sowing in 2020 is also shown.

Feed quality for livestock

Previous research has shown that at the same stage of growth, the feed quality of hardseeded legumes is similar to that of traditional legumes such as subterranean clover (Hackney *et al.*, 2021a). Therefore, when utilised directly via grazing, it would be expected that similar liveweight gains would be achieved if intake is not restricted by herbage availability.

However, capacity for increased production from hardseeded legumes due to better tolerance of variable growing conditions or because of suitability to summer sowing, means that there is potential for greater levels of livestock production to be achieved. Such increases in livestock production may be achieved through utilising the forage produced directly by grazing (i.e. increasing stocking rate) or via strategic fodder conservation when seasonal conditions allow.

In terms of fodder conservation, it is important to consider the timing of cutting. The quantity of herbage available and its quality can change rapidly throughout spring, which has a significant impact on the potential liveweight gain that might be achieved later in feeding the conserved fodder. At a site near Condobolin in 2021, the quantity of herbage available for fodder conservation from hardseeded legumes established via summer sowing was monitored over the growing season (Figure 3). If we consider the probable times for making silage (15 September) and hay (16 October), it can be seen that the quantity of herbage available at each time was reasonably stable, but the stem, leaf and reproductive plant material ratio varied considerably. We are still awaiting plant quality analysis for these data. However, based on our previous research, we know that in mid-September at the late vegetative-early reproductive stage of growth, the digestibility and protein of the herbage of hardseeded legumes would range between 65-69% and 21-29%, respectively. By mid-October, given the plants stage of growth, digestibility would be in the order of 59-62% and protein 13-20% (Hackney *et al.*, 2021a). From a livestock production perspective, delaying harvest from mid-September to mid-October, the likely decline in feed quality would see the potential liveweight gain of weaner steers decline from 2.5 kg/hd/d to 1.6 kg/hd/d (Grazfeed version 32). In this scenario, the potential liveweight gain declines from 1.1-3.1 t/harvested ha as silage to 0.75-2.3 t/harvested ha for hay, depending on legume species. In some situations there may be an increase in herbage availability between probable silage and hay cutting times, however, the inevitable decline in plant quality over that time almost always means that there will be a reduction in potential liveweight gain on a per head basis (Note: these calculations include factoring in of 20% loss due to residual herbage below cutting height and losses during the fodder conservation process).

Whether the increase in herbage availability makes up for the decline in feed quality will determine what the absolute livestock production per harvested hectare will be. Clearly, however, summer sowing of suitable species offers scope for increasing livestock production either directly via grazing or indirectly via conservation as compared to the conventional sowing of traditional legume species such as subterranean clover or annual medics (Figure 3).

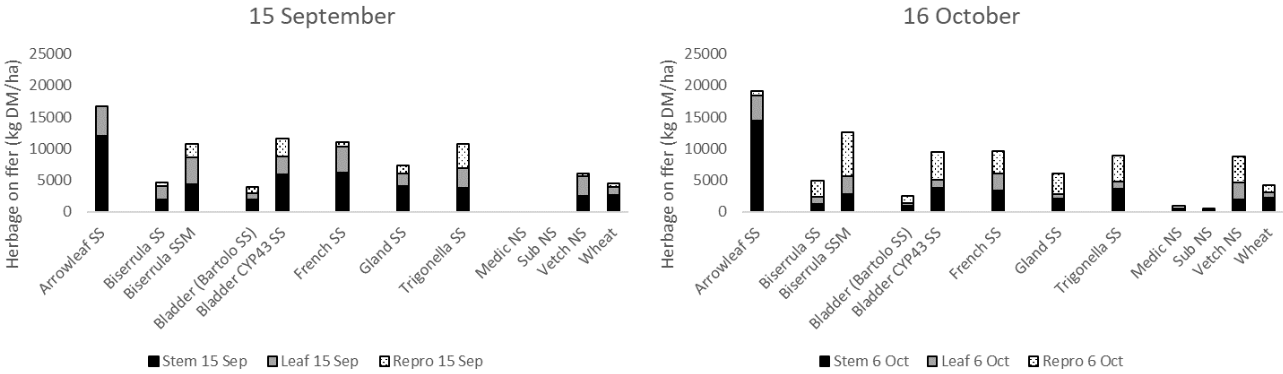

Figure 3. Herbage on offer (kg DM/ha) of stem, leaf or reproductive plant components for a range of hardseeded legumes established via summer sowing (SS) or for annual medic, subterranean clover and vetch established via conventional sowing and wheat at probable silage (15 September) or hay (16 October) cutting times at Condobolin in 2021.

Considerations when using hardseeded legumes in rotations and specific considerations for summer sowing

Hardseeded annual legumes can be highly successful when used in rotation with crops. However, there are certain fundamental management requirements that must be satisfied in order to ensure success in growing them. Many of these principles are common to traditional legumes but some are specific to the hardseeded legumes.

Paddock preparation

All plants have four fundamental requirements for growth; space, light, moisture and nutrients. Paddock preparation is key in setting a foundation for satisfying these requirements when sowing any new pasture. Running down the weed seedbank in the years leading up to sowing a new pasture is critical to establishment success. Competition from weeds is the leading cause of establishment failure in newly sown pastures. A minimum of two, but preferably three years of absolute weed control leading up to pasture sowing are essential to minimise weed competition in newly established pastures. For many weed species providing there is no topping up of the seedbank (e.g. wind borne seed, seed from weed escapes, seed transported by water, machinery or livestock), populations within the weed seed bank can be drastically reduced in a two to three year period (Figure 4). However, it is important to consider the absolute number of weed seeds that main remain in the seedbank rather than just the percentage. For example, a 3% survival of a weed seed after three years with an initial seedbank population of 300 seeds/m^2 gives a vastly different competition scenario to 3% survival from an initial seedbank population of 10 000 seeds/m^2. Populations of the same weed can also exhibit differences in how quickly seed will decline in number within the seedbank with locality. Local climate and soil conditions (e.g. temperature, temperature variation, moisture) can influence factors such as germination, dormancy and emergence of weed seeds. Similarly, management can influence population dynamics of a weed population. For example, development of herbicide resistance can result in changes in seed behaviour of resistant weed populations within the seedbank or regular use of specific herbicides may see plants develop escape mechanisms such as later emergence. Such factors can result in changes in the weed competition risk profile when sowing new pastures. The key point is to plan well ahead when considering sowing any new pasture to minimise potential weed competition.

Some weeds such as wild radish and spiny emex can persist at low levels in the seedbank over an extended period of time and for species such as these, survival of the seed is aided if the seed is buried at depth. The population density of these species can rapidly rebound from low levels due to their ability to produce large quantities of seed per plant. However, significant reductions in seedbank populations can still be achieved over a three-year period. As with any weed, strategies for selective control once a pasture is established must be considered in advance to prevent weeds rapidly increasing in density. Carefully considering herbicide tolerances of pasture species to be sown is an important in the planning process to maximise options for selective weed control. Similarly, thought should be given to other tactical options that can be used to control weed seed set leading up and following pasture sowing. This may include use of tactical grazing, spray-grazing or strategic fodder conservation. Research in Victoria demonstrated an 80% reduction in the wild radish seedbank population through instigating silage cutting in one year (Henne and Sale 2014).

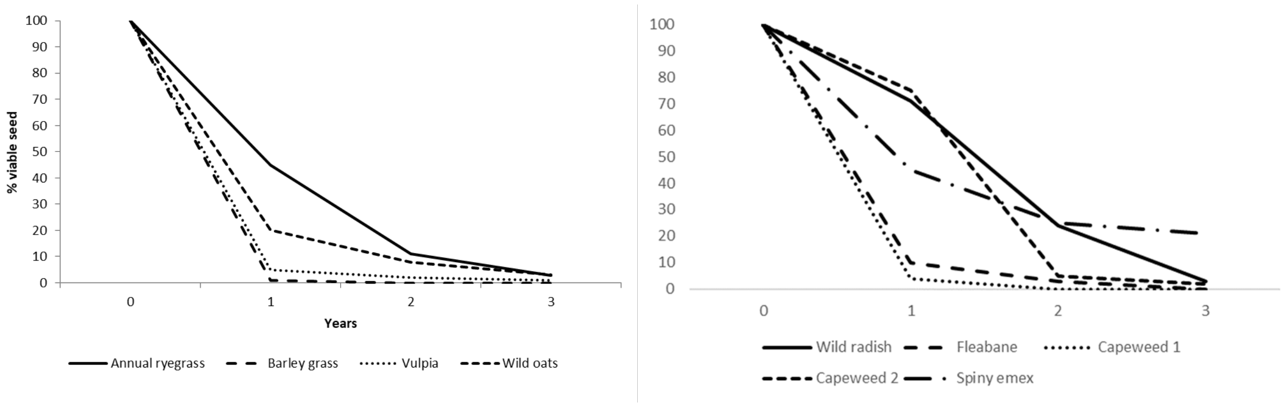

Figure 4. The percentage of seed in the soil seedbank remaining viable over a three year period for a range of grass and broadleaf weed species. Source: Cheam (1987), Dowling (1996), Peltzer et al. (2002), Dunbabbin and Cocks (1999), Green et al. (2010).

Herbicide residues

Ensure, when sowing new pastures, that all plant back requirements have been met prior to sowing. Carefully check the herbicide label. Herbicides can have time, rainfall and/or specific soil moisture requirements for breakdown. Additionally, some herbicides present different risks for residues associated with soil pH or texture. The rate of application also needs to be considered for some herbicides. It is critical to have accurate records of what herbicides have been used in previous crops and to make sure all requirements for safe plant back have been met. Remember, if you are undertaking summer sowing, this will occur some 3-4 months earlier than traditional pasture sowing meaning that plant back requirements need to have been satisfied at the time of sowing so that seed, inoculant and early germinating pastures are not exposed to residues.

It is also critical to be mindful of herbicides used in the maintenance of summer fallow following harvest of the previous years crop. It is not uncommon to see poor establishment in newly sown pastures due to a forgotten herbicide used in the summer fallow. A recent survey (n=155 farming businesses) found that more than half had used at least one herbicide in the fallow that would present a risk for pasture legumes they intended to sow that year, either via summer or conventional sowing (Hackney et al. 2021b)

Species selection

When choosing which hardseeded legume(s) to grow, it is important to determine if what you want to grow aligns with what you should grow. What you should grow is determined by your climate, soils and the type of pasture-crop rotation system you intend to run.

Most of the hardseeded legumes will grow well in soils with good drainage where soil pHCa is in the range of 5.0-7.0 (Table 2). Species such as serradella and biserrula have good tolerance to more acidic soils. All species in Table 2 have good tolerance to drought conditions. However, arrowleaf clover tends to produce seed later in the season than other hardseeded legume species and so under severe drought conditions, its seed production may be compromised.

Residual hard seed levels are an important consideration in species selection for inclusion in crop rotations. Residual hard seed is a measure of how much of the seed produced in a given season that remains hard by the following autumn. Higher levels of residual hard seed mean that the legume will be more persistent in the seed bank over time and has the capacity to withstand a longer cropping interval and regenerate without the need for resowing.

Generally, cultivars of legume species with residual hard seed of 40-60% are well suited to 1:1 rotations (that is alternating years of pasture and crop). Occasional two-year crop intervals may also work well with such cultivars once a couple of years of legume seed set have occurred. For cultivars of legume species that have higher hard seed levels (>70%), cropping phases of 2-4 years are feasible.

Table 2. Preferred soil $\mathrm{pH_{Ca}}$ for hardseeded annual legumes and their rhizobia, suitable soil texture and soil drainage characteristics, drought tolerance and residual hard seed percentage in the autumn following seed set.

	$\mathrm{pH_{Ca}}$ (Plant)	**$\mathrm{pH_{Ca}}$ (Rhizobia)**	**Soil texture**	**Soil drainage**	**Drought tolerance**	**Residual hard seed[2] (%)**
Arrowleaf clover	4.8-8.0	5.5-7.5	Sandy loam to medium clay	Good drainage	Good	40-60
Biserrula	4.2-7.5	4.8-7.0	Sandy loam to loam	Good drainage	Excellent	70-90
Bladder clover	5.0-8.0	5.5-7.5	Sandy loam to loam	Good drainage	Very good	40-60
Gland clover	4.8-8.0	5.5-7.5	Sandy loam to clay	Good to poorly drained	Very good	40-60
French serradella[1]	4.0-7.0	4.5-7.0	Sand to loam	Good drainage	Very good to excellent	40-60
Yellow serradella	4.0-7.0	4.5-7.0	Sand to loam	Good drainage	Very good to excellent	40-80

[1] This information refers to the hardseeded French serradella cultivars Fran2o, Margurita and Erica.

[2] The hard seed remaining in the autumn following seed set

Which cultivars of the hardseeded legume species are suitable for summer sowing?

There are a limited number of commercially available cultivars of most of the hardseeded legume species. As an example, there is only one cultivar each of gland clover and bladder clover and these have proven to be successful for use in summer sowing. For both French and yellow serradella, a number of cultivars are available. For French serradella, the cultivars Fran₂o, Margurita and Erica are suitable for summer sowing. For yellow serradella, we have had success with Avila and a soon to be released cultivar. It should be noted that Avila is not well suited to areas receiving less than 500 mm average annual rainfall.

For biserrula, we have had good success in sowing unprocessed seed for summer sowing. However, in cases where summer is extremely dry, hard seed breakdown can be restricted and therefore plant density may be lower than desirable. In the past two years we have been experimenting with seed that has been lightly scarified (25% germination). Use of partially processed biserrula seed in summer sowing has resulted in a significant increase in plant density and biomass production (Figure 5).

It is critical to check local trial results in determining which species/cultivars are suited to summer sowing in your area. As stated earlier in this paper, initial field trials in WA suggested bladder clover and the hardseeded French serradella cultivars were suitable for summer sowing in their hot, summer-dry conditions. However, in NSW, where many areas receive more summer rain and/or retain higher levels of soil moisture due to the higher clay content of soils, use of other species/cultivars are possible. Remember to carefully assess your particular situation with regard to summer rainfall, soil and temperature conditions and seek advice if you are unsure.

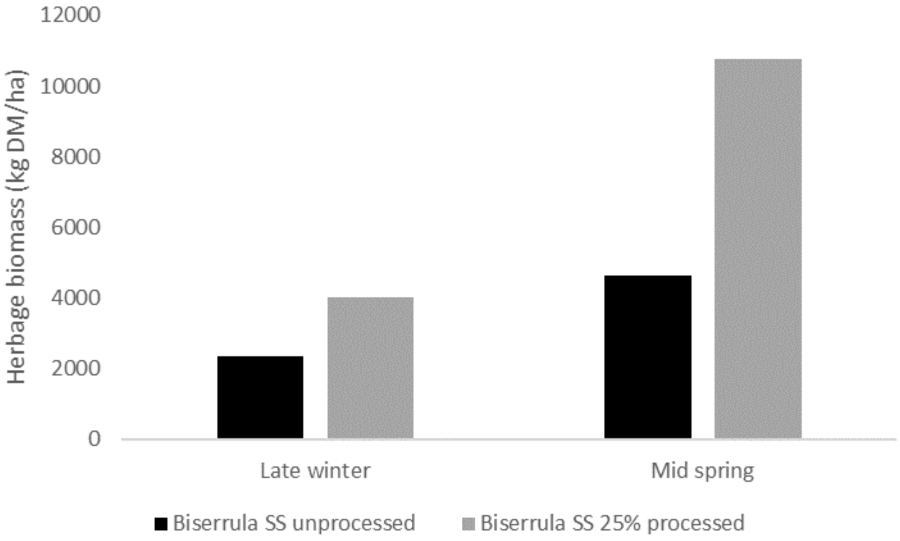

Figure 5. Herbage biomass (kg DM/ha) of summer sown biserrula where seed was either unprocessed or where a mix of 75% unprocessed and 25% scarified seed was sown.

Sowing time

For summer sowing, unprocessed seed is used. For the clover species and biserrula, this means seed that has not been scarified, while for serradella, pod segments are used. Adequate time is required for a proportion of the hard seed to break down for germination. Summer sowing is generally best undertaken from mid January to late February. However, successful establishment has occurred where sowing has occurred as early as December or as late as mid March. However, it is important to note that sowing beyond late February may result in reduced hard seed breakdown and lower plant density.

Sowing rate

Summer sowing requires a source of unprocessed seed. Generally, growers will have a nursery paddock from which they harvest seed and then use this to sow other areas of the farm. Use of nurseries can be a useful way to evaluate which species might work best for your farm. We frequently advise growers who have not previously grown hardseeded legumes to grow nursery blocks of 5-20 ha of a range of species (using purchased scarified seed sown in autumn). Growers can then harvest species that work best for them and use this unprocessed seed in summer sowing operations.

When summer sowing the hardseeded clovers or biserrula, the minimum suggested sowing rate is 12 kg unprocessed seed/ha. For serradella pod segments, a minimum rate of 20 kg/ha is used.

Inoculants

It is critical to ensure the correct inoculant group is used for each legume sown. Additionally, sowing in summer presents additional challenges of high temperature and often limited soil moisture, both of which can adversely impact rhizobia survival. Low moisture clay granular inoculant has proven to be an effective form of inoculant delivery in our summer sown field trials since 2012.

Fertiliser at sowing

Adequate nutrition is critical for both the legume plant and for rhizobia. Recent surveys have shown that phosphorus deficiency prevalence is relatively low (<30%) compared to sulphur deficiency (>75%) in soils of central and southern NSW (Hackney et al. 2021b). However, most growers (70%) use MAP or DAP when sowing new pastures. Ensure that soils are analysed from paddocks to be sown to new pastures and that appropriate fertilisers are used to address deficiencies that may be present.

Management following the establishment year

Our field trials have shown that hardseeded legumes produce 4-10 t DM/ha within the growing season. This represents potential nitrogen fixation of 80-250 kg N/ha (Table 1). We often find that growers want to allow legume pastures to regenerate in the second year. However, growers need to consider the value of nitrogen for supporting production of following crops. As shown in Figure 2, the use of hardseeded legumes in rotation with crops can significantly reduce the expenditure required on N-fertiliser to support crop production. Further, large quantities of unutilised nitrogen present an opportunity for weed proliferation.

Flexible rotations

Once a seedbank of hardseeded legumes is established, there is opportunity to alter how pasture-crop rotations are managed in response to seasonal conditions and commodity prices. With an on-demand seedbank in place, growers have the opportunity to flex and change their pasture to crop ratios and hence livestock to crop ratios within short timeframes. As an example, if seasonal conditions are predicted to be poor and high risk for cropping, then paddocks with a seedbank of hardseeded legumes can be allowed to regenerate and the herbage utilised for livestock and/or to build soil nitrogen for subsequent crops. Alternatively, if returns from cropping are high, then paddocks can be put to crop knowing that there is sufficient seed in the seedbank to allow for regeneration after the crop.

The crop phase length that can be imposed without needing to resow depends on residual hard seed levels of the legumes. For species with very high residual hard seed levels such as biserrula and some cultivars of yellow serradella, it is possible to crop over paddocks where there has been high initial seed set for 3-5 years and have strong regeneration of the legume. For species such as arrowleaf clover, bladder clover, gland clover and hardseeded cultivars of French serradella, rotations of one year crop, one year pasture are suggested, although once the legume has set seed a number of times, the seedbank will support occasional two-year cropping phases without needing to be resown.

Ultimately, the length of the crop phase imposed over the legumes will involve balancing out nitrogen supply provided by the legumes relative to requirements of the crop as well as considering the relative value of cropping and livestock to the overall farming system within and between years.

Conclusions

Over the last decade, summer sowing of hardseeded legumes has proven to be an effective means of establishing highly productive pastures. Summer sowing has been robust in the face of seasonal variation including extreme drought providing feed for livestock and nitrogen for subsequent crops. From a cropping perspective, hardseeded legumes have supported high levels of grain production in the year following their growth without requiring additional N-fertiliser; a significant cost and risk mitigation strategy that can be incorporated into contemporary farming systems. The ability of hardseeded legumes to maintain productivity in drought conditions, yet exhibit elasticity in response to improved seasonal conditions and provide additional options for use such as fodder conservation can only be beneficial in achievement of crop and livestock production goals. Perhaps though, one of the greatest advantages of hardseeded legumes is the capacity for growers to flex and change their crop and pasture ratios over short time periods once a seedbank is established in response to seasonal and commodity price conditions.

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