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Naracoorte

Wednesday 22nd August

9.00am to 1.00pm

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Program

9:00 am	**Welcome**	***ORM***
9:05 am	**GRDC welcome and update**	***GRDC***
9:15 am	**Insects – resistance and control**	***James Maino,*** *cesar*
9:55 am	**Annual ryegrass control in the high rainfall zone**	***Peter Boutsalis,*** *The University of Adelaide*
10.35 am	***Morning tea***	
11:05 am	**Optimising yield and economic potential in the HRZ**	***Malcolm McCaskill,*** *Agriculture Victoria*
11.45 am	**Better pastures, better crops**	***Cam Nicholson,*** *Nicon Rural Services*
12:25 pm	**Canola – blackleg management update**	***Steve Marcroft,*** *Marcroft Grains Pathology*
1.05 pm	***Close and evaluation***	***ORM***
1.10 pm	***Lunch***	

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Insects, resistance and control

James L. Maino[1,2] Siobhan de Little[1,2], Lisa Kirkland[1,2], Elia Pirtle[1,2], Matthew Binns,[2] and Paul A. Umina[1,2].

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[Φ]Extra technical comment by Protech Consulting Pty Ltd

GRDC project codes: CES00003, UM00057, CES00004

Keywords

- redlegged earth mite, green peach aphid, Russian wheat aphid, insecticide resistance, neonicotinoids.

Take home messages

- Insecticide resistance issues continue to outpace novel control options.
- Redlegged earth mite (RLEM):
  - Insecticide resistance in RLEM has been detected for the first time in eastern Australia.
  - Synthetic pyrethroids (SPs) are completely ineffective against SP-resistant RLEM populations, while some efficacy remains for organophosphates (OPs) against OP-resistant RLEM populations.
- Aphids:
  - Green peach aphid (GPA) has acquired low level resistance to neonicotinoids.
  - Pirimicarb is now mostly ineffective against GPA due to resistance, but remains effective against other crop aphids, highlighting the importance of correct species identification.
  - A variety of insecticide seed treatments have been shown to control Russian wheat aphid (RWA), with the length of protection differing between products.
- The implementation of recently published resistance management strategies (RMS) is vital to maximising the long-term viability of chemical options for pest management.
- Looking to the future:
  - Growth in the use of neonicotinoids will likely see increased insecticide resistance issues and the disruption of beneficial insect services in Australia.
  - Cutting edge forecasting tools are helping to identify patterns in insecticide resistance outbreaks.

Background

Insecticide resistance issues in broad-acre cropping continue to outpace the expansion of novel control options. In this paper, the latest findings on two major pest species that have developed resistance to key chemical groups, the redlegged earth mite (*Halotydeus destructor,* RLEM) and the green peach aphid (*Myzus persicae*, GPA) are discussed.

New research on the efficacy of seed treatments against Russian wheat aphid (*Diuraphis noxia*, RWA) is also presented.

The paper concludes by discussing the future risks of increased reliance on neonicotinoid insecticides and the application of forecasting approaches managing insecticide resistance.

Resistance in redlegged earth mites spreads to eastern Australia

The redlegged earth mite (*Halotydeus destructor*, RLEM) is an important pest of germinating crops and pastures across southern Australia. Four chemical sub-groups are registered to control RLEM in grain crops: organophosphates (OPs) (Group 1B); synthetic pyrethroids (SPs) (Group 3A); phenylpyrazoles (Group 2B); and neonicotinoids (Group 4A). The latter two are registered only for use as seed treatments (Umina et al. 2016).

After remaining confined to Western Australia (WA) for a decade, in 2016, insecticide resistance in RLEM was detected for the first time in eastern Australia (Maino, Binns and Umina, 2017). In WA, resistance to SPs is widespread, while OP resistance is comparatively more restricted (Figure 1). In 2016, following reports of a field control failure in the Upper South East district in South Australia (SA), resistance testing determined this SA population was resistant to SPs and OPs (Figure 2). In 2017, two additional SP resistant populations were confirmed on the Fleurieu Peninsula (approx. 30km apart from each other, and approx. 200km from the 2016 detection).

All SP resistant populations tested to date have been found to possess a target site mutation on the para-sodium channel (Edwards et al. 2017). This mutation confers high level SP resistance (approximately 200 000 times the resistance of a susceptible population) leading to complete spray failures (Figure 2). In contrast, the mechanism conferring OP resistance has not yet been resolved, but resistance is comparatively less than SP resistance, such that OP efficacy will be reduced but not lost entirely.

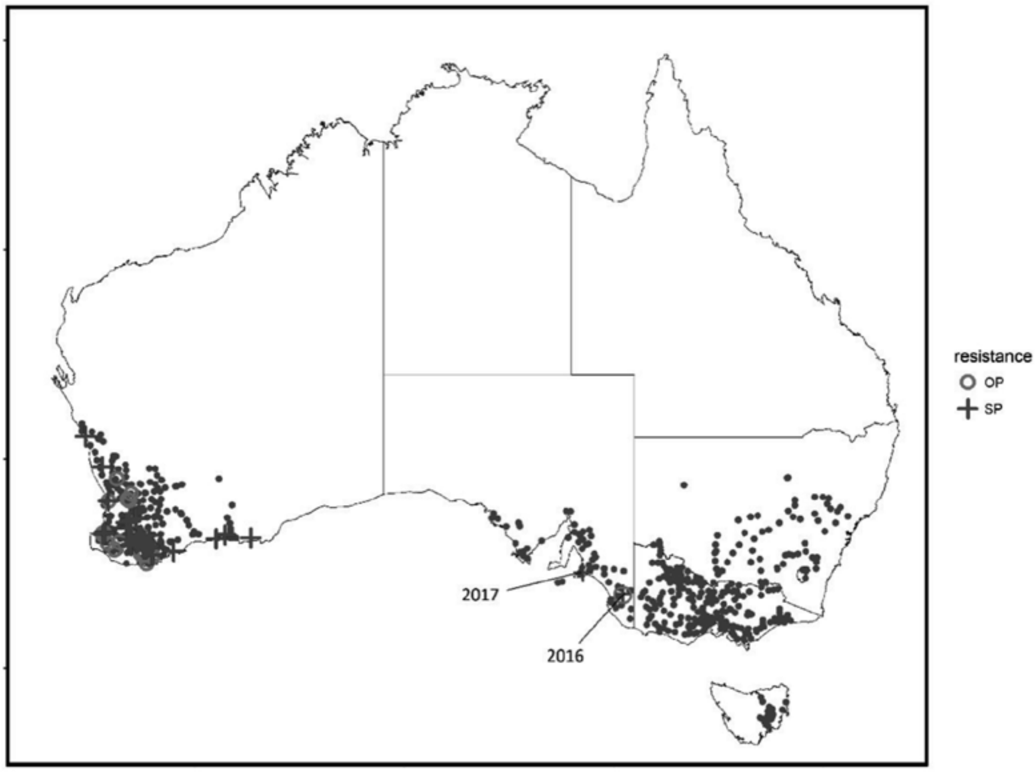

Figure 1. The current known distribution of *H. destructor* in Australia (adapted from Hill et al., 2012) shown as full circles, overlaid with the known distribution of SP and OP resistance across Australia at 2017.

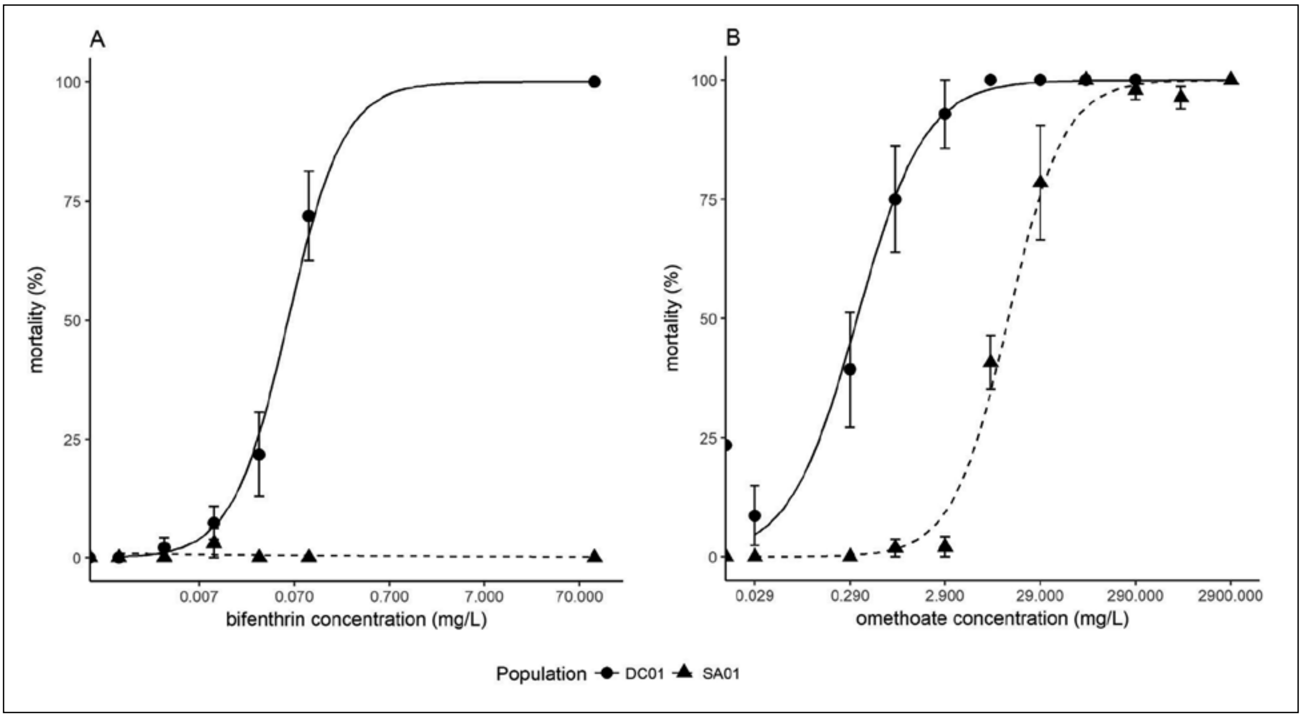

Figure 2. Concentration-mortality curves for redlegged earth mite from a susceptible (DC01) and resistant (SA01) populations when exposed to a synthetic pyrethroid — bifenthrin (A) — and an organophosphate — omethoate (B) — after 8 hrs exposure. Vertical bars denote standard errors. Lines represent fitted values from fitted logistic regression models.

To increase management options for RLEM populations with dual resistance to OPs and SPs, trials run by the University of Melbourne and **cesar** are testing the impact of different management regimes on mite abundance and chemical tolerance in a dual-resistant population. Preliminary results have shown that both foliar applied insecticide groups are largely ineffective on populations with SP and OP resistance, but that high rates of omethoate can still provide control in OP-resistant populations, though the long-term sustainability of this strategy is unlikely. A novel mode-of-action group was also tested as part of this trial and found to be highly effective at suppressing mite numbers, indicating no cross-resistance.

Green peach aphid acquires new resistances

Green peach aphid (GPA) is a widespread and damaging pest of canola and a range of pulse crops, causing damage by feeding and transmitting viruses. Five chemical subgroups are registered to control GPA in grain crops: carbamates (Group 1A); SPs (Group 3A); OPs (Group 1B); neonicotinoids (Group 4A); and sulfoxaflor (Group 4C). Paraffinic spray oils are also registered for suppression of GPA.

Together with CSIRO, **cesar** has been mapping the extent of insecticide resistance in GPA across Australia for the past few years. This ongoing resistance surveillance has continued to show high levels of resistance to carbamates and SPs that are widespread across Australia. Moderate levels of resistance to OPs have been observed in many populations, and there is evidence that resistance to neonicotinoids is spreading.

Despite widespread resistance to the aphid specific carbamate chemical pirimicarb[Φ] in GPA populations (Figure 4), this pesticide remains important to the control of other canola aphid species of similar appearance (e.g. cabbage aphid and turnip aphid). Thus, it is important to properly identify aphids before spray decisions are made. Figure 3 highlights some key features that can be used to distinguish GPA (with a hand lens) from other similar species found on canola. If a hand lens is unavailable, GPA will usually be found on the lowest, oldest leaves, typically in sparse family groups, while turnip aphid and cabbage aphid are more commonly found in large colonies on flower spikes.

[Φ]*Products containing pirimicarb are not registered for control of turnip aphid in canola. In commercial situations label specification must be adhered to at all times.*

Neonicotinoid resistance conferred by enhanced expression of the P450 CYP6CY3 gene was discovered in Australian GPA populations in 2016 by **cesar** and CSIRO researchers. Laboratory bioassays

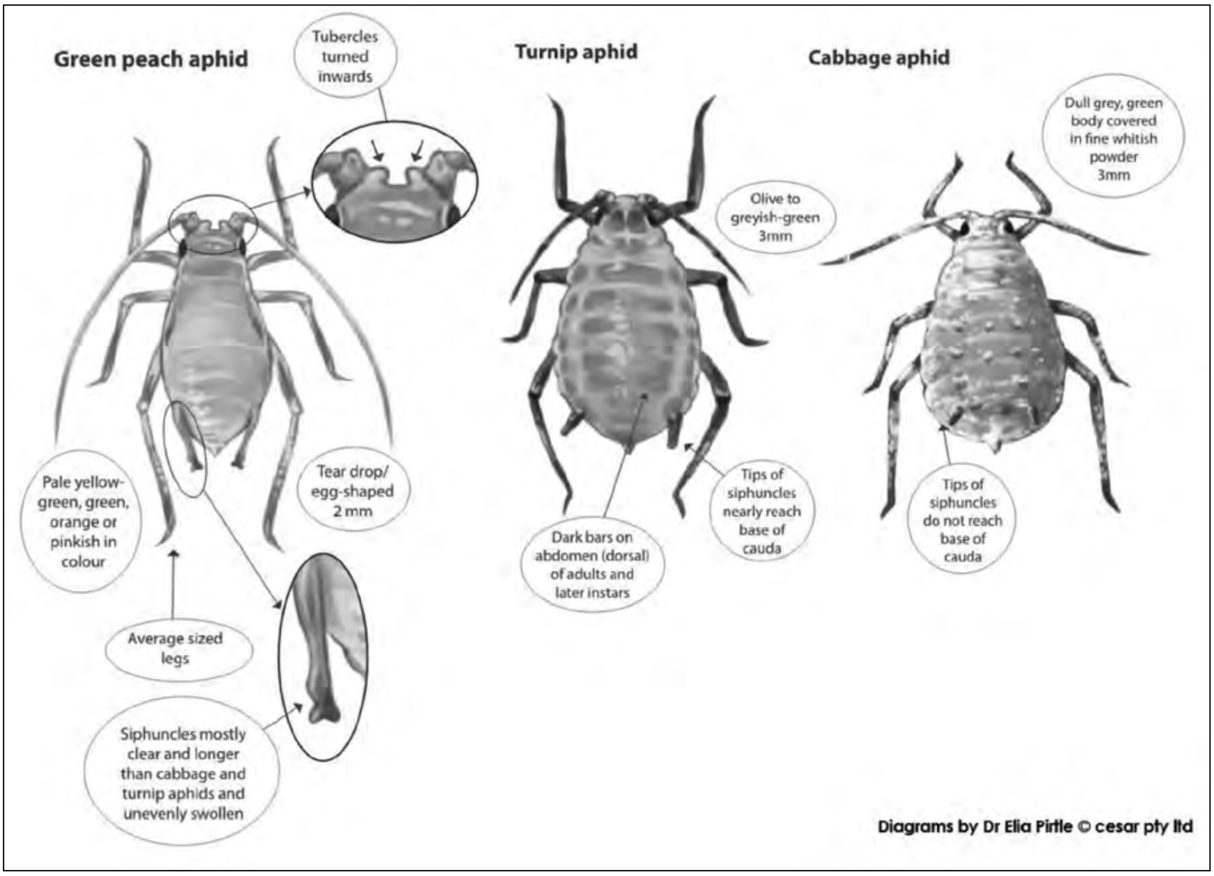

Figure 3. To assess the applicability of pirimicarb to other non-resistant aphid species of similar appearance, green peach aphid should be distinguished using diagnostic traits. If a hand lens is unavailable, green peach aphid will usually be found on lowest, oldest leaves, typically in sparse family groups, while turnip and cabbage aphid are more commonly found in large colonies on flower spikes

revealed these aphids to be approximately 10 times more resistant to a topical application of a neonicotinoid compared to a susceptible population. However, overseas GPA are known to carry an R81T gene mutation of the nicotinic acetylcholine receptor that confers approximately 1000 times resistance to neonicotinoids resulting in field control failures, as well as cross-resistance with group 4C chemicals such as sulfoxaflor. Australian GPA populations may acquire this high level neonicotinoid resistance if neonicotinoid selection pressures remain high, or if there is an incursion of overseas GPA carrying the R81T mutation.

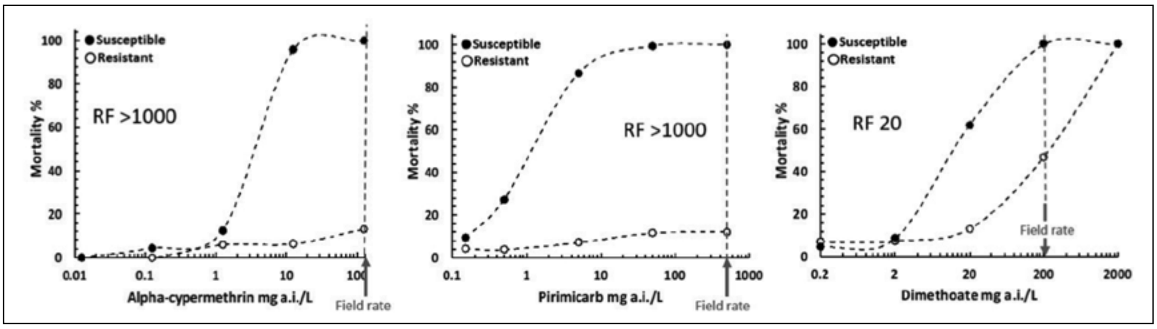

Figure 4. Sensitivity of a typical Australian susceptible and resistant green peach aphid population to the synthetic pyrethroid, alpha-cypermethrin (left panel), the carbamate, pirimicarb (middle panel) and the organophosphate, dimethoate (right panel). RF = Resistance Factor.

Resistance management strategies

With resistance evolution continuing to outpace the discovery of new chemistries with novel modes of action, resistance management strategies (RMS) are more than ever essential to maintain the viability of pest control tools.

RMS for major grains pests have been made available through the National Insecticide Resistance Management (NIRM) working group of the Grains Pest Advisory Committee, a GRDC funded project, which provides strategic advice to GRDC on pest issues. Across these strategies, there are both general and pest-specific practices that can help maintain the viability of chemistries into the future.

General RMS strategies include:

- If applying multiple insecticides within a season, rotate chemistry mode of action.
- Utilisation of non-chemical control options that suppress pest populations.
- Using economic spray thresholds to guide chemical applications.
- Using selective chemicals, if chemical application deemed necessary, in place of broad-spectrum options.
- if using broad spectrum chemicals, consider the secondary impacts to non-target pests and beneficials.
- Compliance with all directions for use on product labels and ensuring proper application coverage.

RMS strategies specific to GPA include:

- Managing the green bridge (in particular, the control of brassica weeds and volunteer crops) on which GPA may persist through summer.
- Stubble retention to decrease visual contrast between seedlings and soil (landing cue for GPA).

RMS strategies specific to RLEM include:

- Control of spring populations immediately before the production of over-summering (diapause) eggs through cultural control (grazing, broadleaf weed removal), or a Timerite® spray (if required) to reduce pest pressure at crop emergence/RLEM hatching the following autumn.

Testing control methods for Russian wheat aphid

Russian wheat aphid (*Diuraphis noxia*, RWA) was first detected in Australia in 2016. The host range of RWA includes more than 140 species of cultivated and wild plants within the family Gramineae (grasses). These include wheat, barley, triticale, rye, oats, pasture grasses and wild genera including *Poa, Bromus, Hordeum, Lolium, Phalaris* and others. Wheat and barley are most susceptible, while triticale, rye and oats are less susceptible.

Unlike other cereal aphids that damage plants by removing nutrients, RWA also injects salivary toxins during feeding that cause rapid, systemic phytotoxic effects on plants, resulting in acute plant symptoms and potentially significant yield losses. Even a few aphids can cause plant damage symptoms to appear as early as 7 days after infestation. These include:

- white and purple longitudinal streaks on leaves
- curled, rolled or hollow tube leaves
- stunted growth or flattened appearance
- discolored leaves
- hooked-shaped head growth from awns trapped in curling flag leaf
- bleached heads

Insecticide seed dressings$^{\Phi}$ can be effective to combat RWA infestations in establishing cereal crops. **cesar** have tested the relative efficacy and length of activity of various insecticide seed dressings in wheat against RWA, and compared this with another important cereal aphid pest, the oat aphid (*Rhopalosiphum padi*).

$^{\Phi}$None currently registered for use in Australia, but their use is permitted under the following permits: PER81133, PER82304 and PER83140.

All seed dressings tested provided effective aphid control up to five weeks after emergence, with higher rates generally providing several weeks extra protection over lower rates of the same product. Oat aphids generally persisted and reproduced on wheat at an earlier time-point than RWA, suggesting that RWA is less tolerant to the insecticide seed dressings tested. This suggests that management of cereal aphids in Australia using insecticide seed dressings is likely to achieve similar, if not better, control of RWA as oat aphid.

Balancing the scales of neonicotinoid seed treatment use

Neonicotinoids are currently the most used insecticide group globally. This over-reliance may be explained by the increased resistance issues surrounding older chemistries like the OPs and SPs. Also contributing to this trend is the convenience of neonicotinoids, in particular, as seed treatments, which are applied at the time of sowing at no extra application cost.

Despite the advantages of neonicotinoid seed treatments, their indiscriminate usage as commonly seen, carries some important costs. Continued wide-scale use of neonicotinoid seed treatments will select for resistance, as is currently being seen in GPA in Australia (de Little et al. 2017). Overseas, where neonicotinoids have been used for longer and more extensively, more cases of resistance have been documented (Sparks and Nauen, 2015). In addition to resistance concerns, widespread neonicotinoid use is likely to impair ecosystem services provided by some beneficial invertebrate and microbial communities, as has been shown in international studies. Industry stewardship and good resistance management are paramount to ensuring neonicotinoid usage is balanced against these issues, and remains a long-term viable control option for grains pests.

Before making a management decision, the question should be asked, is a neonicotinoid seed treatment warranted in this paddock, in this year?

- Wherever possible, assess the risk of damaging pest infestations (or virus risk), based on the prior paddock and seasonal history. In the case of RLEM, for example, a high-risk situation would be indicated by: (i) canola or lucerne to be sown, (ii) high mite numbers the previous year, and (iii) no Timerite® spray the previous spring.
- Unless the pest risk is deemed high, avoid using neonicotinoid seed treatments in consecutive years, preferably no more than one in three years in any given paddock.

With seed treatments, which are not applied in response to immediate pest pressure, the challenge, of course, is the ability to accurately forecast the timing and severity of pest (and virus) occurrences

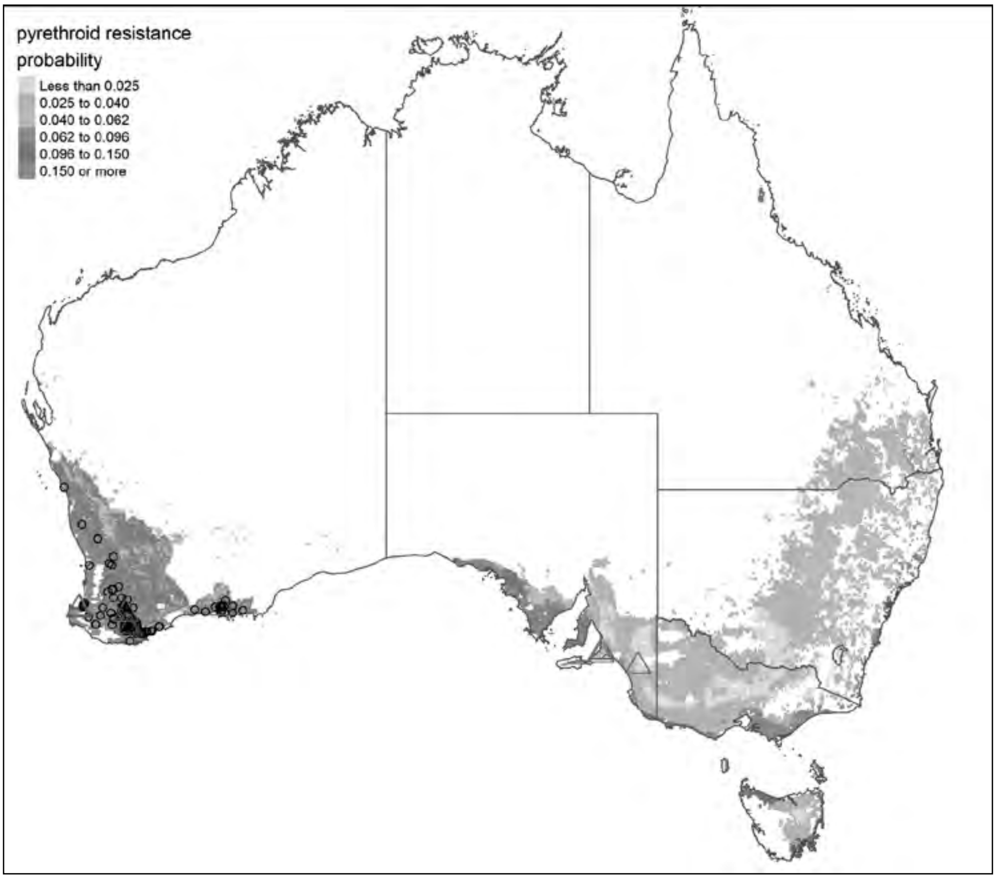

Figure 5. Predicted pyrethroid resistance risk (probability) for RLEM adapted from Maino et al. (*in press*). Known resistant populations used to calibrate the model (open circles) as well as newly detected populations (open triangles) are overlaid.

well ahead of time. Predictive tools may provide useful information here, but are currently not being used for such purposes, or simply do not exist for a particular species of interest.

Forecasting future resistance issues

To bring further focus to the resources directed to resistance management, researchers from **cesar** and the University of Melbourne have applied modern forecasting approaches to identify spatial relationships in the evolution of resistance. This novel approach synthesised large data sets on resistance, land usage, and environmental factors, and found that resistance in RLEM is related to chemical pressure (average number of chemicals used annually), but more surprisingly is also more likely to develop in regions with particular climatic properties (Figure 5). The study highlighted risks in eastern Australia before the recent detection of resistance in SA, and will be used to guide resistance management in the future.

Useful resources

https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/07/grdc-fs-greenpeachaphid

https://grdc.com.au/FS-RLEM-Resistance-strategy-West

https://grdc.com.au/FS-RLEM-Resistance-strategy-South

https://grdc.com.au/TT-RWA

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Umina, P. A. et al. (2016). 'Science behind the resistance management strategy for the redlegged earth mite in Australian grains and pasture'.

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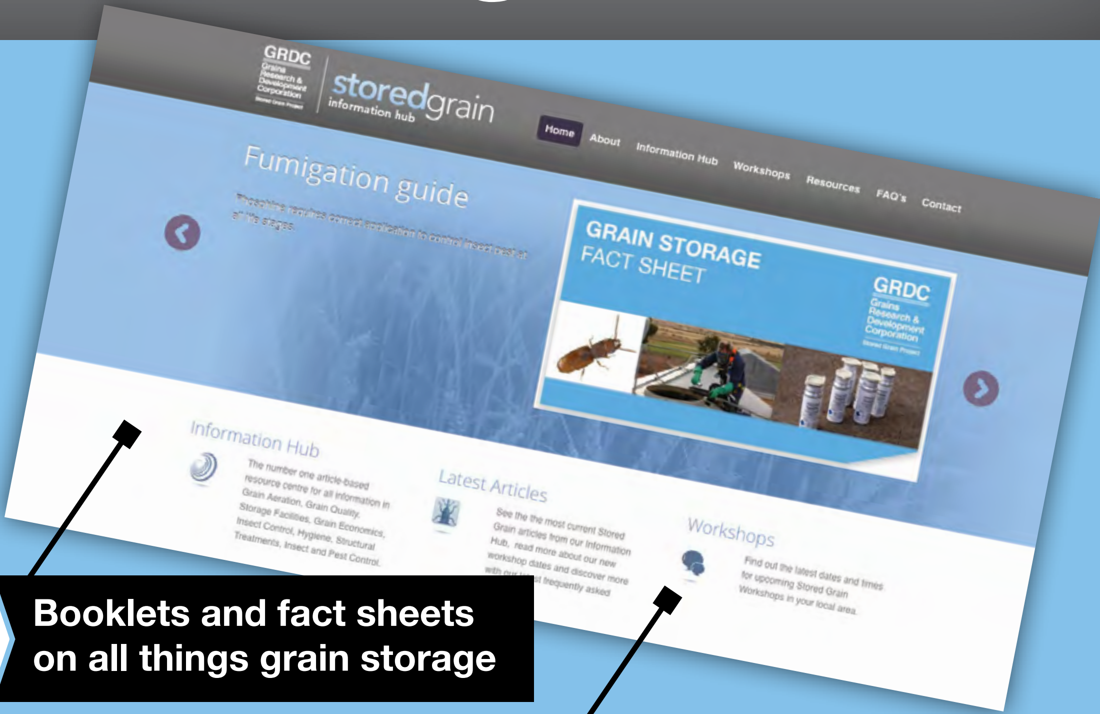

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Does glyphosate formulation affect the control of glyphosate resistant weeds?

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[1]Plant Science Consulting P/L; [2]School of Agriculture, Food & Wine, University of Adelaide.

[Φ]Extra technical comment by Protech Consulting Pty Ltd

GRDC project codes: UCS00020, UA00158

Keywords

- glyphosate resistance, annual ryegrass, herbicide formulations, weed survey.

Take home messages

- Glyphosate resistance has been detected in annual ryegrass and sowthistle.
- Initial trials suggest significant differences in efficacy between glyphosate products.
- Treating younger plants at lower temperatures can improve glyphosate efficacy on resistant biotypes.
- Crop topping with glyphosate is not effective on glyphosate resistant ryegrass.

Glyphosate resistance

The GRDC has invested in random weed surveys of cropping regions across WA, SA, VIC and NSW since 2005, to monitor for resistance levels in key weed species. In the latest round of weed surveys, glyphosate has been included in the suite of herbicides tested. The methodology involves collecting weed seeds from paddocks chosen randomly at pre-determined distances, at harvest. Weeds were tested in outdoor pot trials under natural growing conditions. The incidence of resistance to glyphosate identified in these surveys is presented in Figure 1.

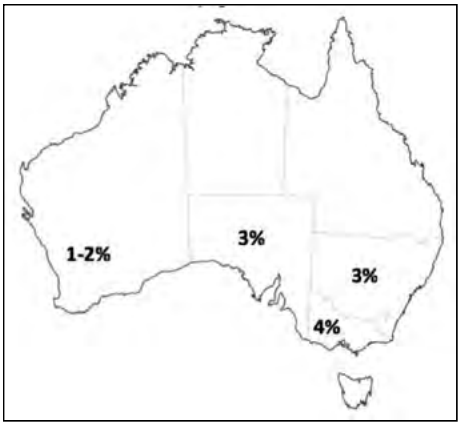

Figure 1. Incidence of paddocks containing glyphosate resistant ryegrass. Resistance is defined as a sample where more than 20% plant survival was detected in a pot trial. Paddocks surveyed in WA = 500, SA = 700, Vic = 450 and NSW = 600.

Glyphosate resistance in ryegrass has also been detected in grower samples sent to commercial resistance testing laboratories. In most cases, testing requests have been to identify effective herbicides or verify a herbicide failure. Requests to test with glyphosate due to poor performance is common. Figure 2 presents test results from Plant Science Consulting in the last 12 months. It highlights that the level of glyphosate resistance is similar across the southern states and is approximately 10-fold greater than the figures identified in the random weed surveys (Figure 1).

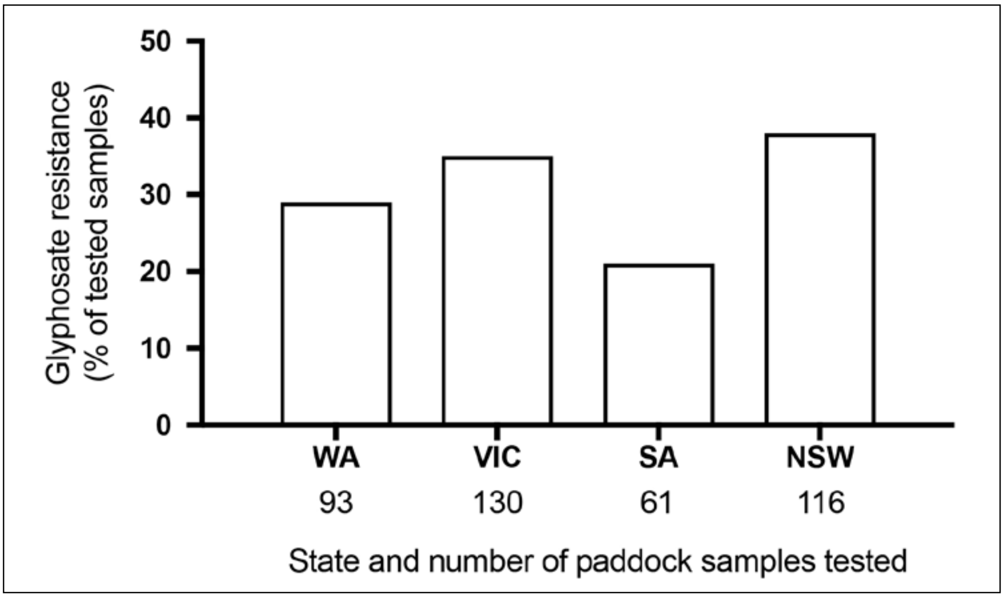

Figure 2. Resistance to 1.5L/ha Glyphosate 540 confirmed in grower ryegrass samples (Seed and Quick-Test) in the past 12 months by Plant Science Consulting.

Differences between glyphosate products

Significant differences between glyphosate products have been identified in outdoor pot trials conducted in winter and summer annual weed species. Three undisclosed registered glyphosate products were compared in initial trials, with significant differences in weed control. Herbicide products Gly 1 and Gly 3 gave consistently greater control than Gly 2 on susceptible and resistant ryegrass (Figure 3). Surfactant differences between glyphosate products is likely to be a major factor determining final control. In the field, using glyphosate products with quality surfactants could be the difference between controlling ryegrass individuals with lower levels of resistance or allowing them to survive, cross-pollinate and increase the levels of glyphosate resistance.

Differences in the level of control between glyphosate products in another key weed species such as glyphosate-resistant milkthistle (sowthistle) from NSW has also been confirmed (Figure 4). This information highlights that significant differences in control between glyphosate formulations occur, not only on glyphosate sensitive, but also on glyphosate resistant individuals.

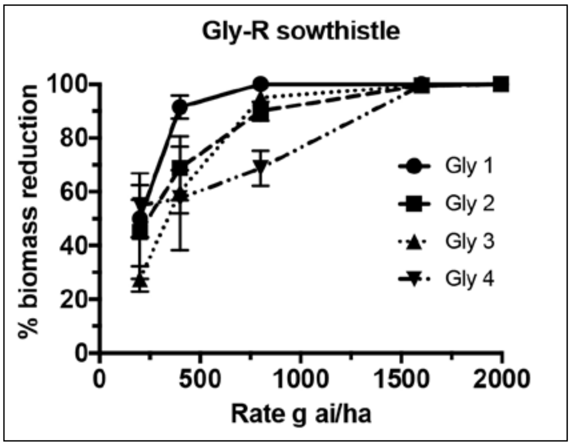

Figure 4. Efficacy of four glyphosate products on control of glyphosate resistant milkthistle as confirmed by outdoor pot trials by Plant Science Consulting.

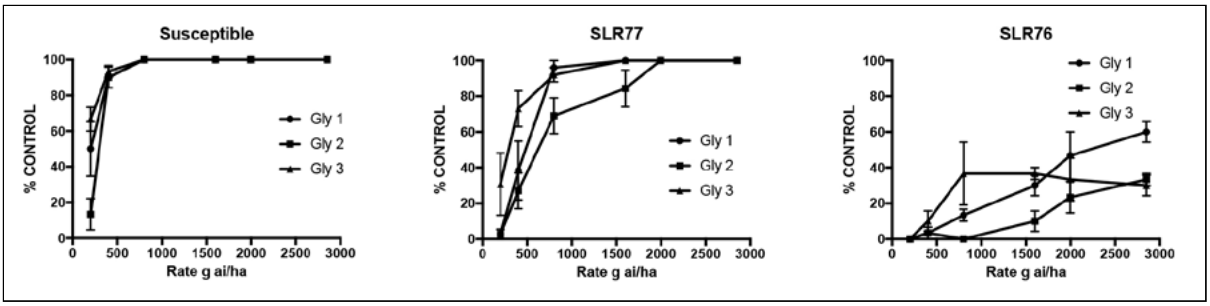

Figure 3: Efficacy of three glyphosate products on susceptible and glyphosate resistant ryegrass populations, SLR77 with weak glyphosate resistance and SLR76 with strong glyphosate resistance.

Growth stage and glyphosate rate

Plant growth stage can play an important role in weed control. Even in resistant populations, improved control can be achieved at younger growth stages. Younger plants tend to have thinner cuticles than older plants, and therefore, herbicide movement into younger plants is generally quicker. The effect of growth stage and glyphosate rate was investigated in a field trial in NSW on a susceptible and two glyphosate resistant sowthistle populations by Tony Cook, DPI Tamworth (Table 1). Increased control of glyphosate resistant sowthistle was observed at younger growth stages.

Weed seed sterilisation

Crop-topping is a procedure aimed at controlling weed seed set at pre-harvest timings with non-selective herbicides. One of the most commonly used practices is applying glyphosate pre-harvest to prevent seed set by flowering ryegrass. Only two glyphosate products (Nufarm Weedmaster DST® and Roundup Ultramax®[Φa]) are registered for this practice in wheat, barley[Φb], canola and some pulse crops. A field trial was conducted in 2016 to investigate the effect of crop-topping a glyphosate resistant ryegrass population with 2.8L/ha and 4.1L/ha of Weedmaster DST at two timings (flowering and milky dough). Additionally, laboratory testing confirmed that this population was not target site resistant, therefore resistance is due most likely to the reduced translocation mechanism. This is the most common glyphosate resistance mechanism identified in ryegrass. Viability testing of the seed after maturation revealed that the reduction in seed germination was between 9% to 22%, indicating that at least 80% of the seed remained viable. Glyphosate was therefore not effective in sterilising glyphosate resistant ryegrass. In addition, glyphosate resistance can increase if susceptible ryegrass is sterilised leaving only resistant individuals to cross-pollinate with each other.

[Φa] Roundup Ultramax is no longer registered but Pintobi Attack has these uses on its label; commercial applicators must use registered products. [Φb] Products listed are not registered for use in barley, their use is for research purposes only.

Effect of temperature

Temperature has been identified as playing a major role in glyphosate efficacy. Significant differences were identified in wild oat control with the same glyphosate product in plants sprayed in outdoor summer or winter pot trials in South Australia (Figure 6). Complete control of a wild oat population was not achieved in summer even at higher than label rates (1600g ai/ha glyphosate) whereas in winter trials 400g ai/ha glyphosate resulted in complete control. These large differences suggest that controlling wild oats in summer fallows can be affected by high temperatures.

Table 1. First cases of confirmed glyphosate resistant sowthistle from Liverpool plains. Data presented as percent biomass reduction at three growth stages. Fallow spray timings from early to late summer. Data courtesy of Tony Cooke, DPI, Tamworth.

Glyphosate rate (g ai/ha)	Growth Stage: Early rosette 10cm	Growth Stage: Early bolting	Growth Stage: Mid-flowering
Susceptible sowthistle- (% biomass reduction)			
360	79	76	0
720	100	81	33
1260	100	100	100
1800	100	100	100
Resistant sowthistle biotype “Yellow” - (% biomass reduction)			
360	55	27	0
720	97	0	0
1260	95	16	0
1800	97	63	4
Resistant sowthistle biotype “CRK” - (% biomass reduction)			
360	64	7	0
720	80	35	5
1260	91	71	58
1800	97	78	100

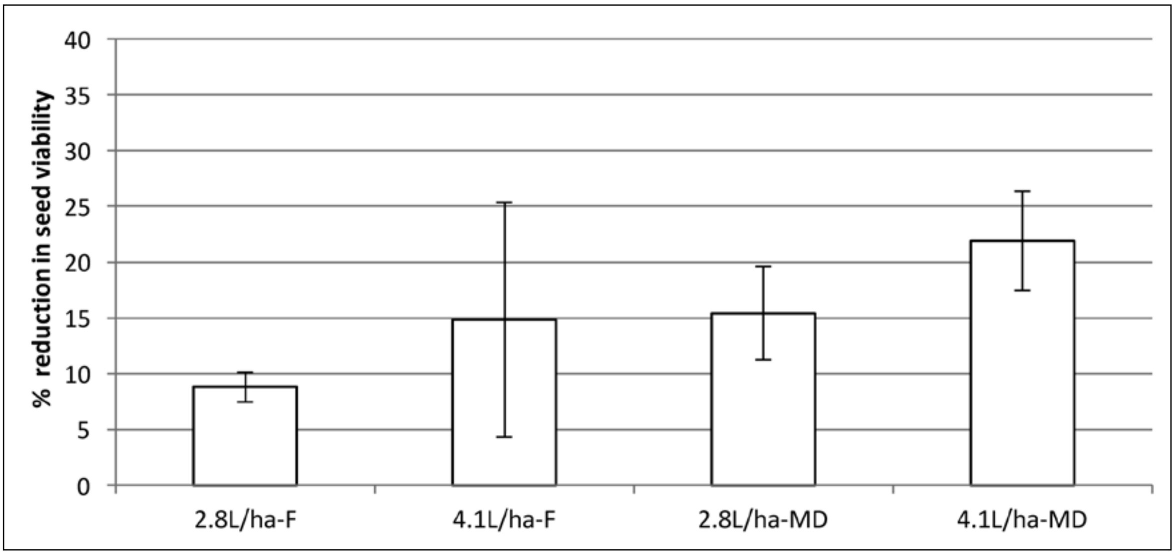

Figure 5. Reduction in viability of ryegrass seed after crop-topping with Weedmaster DST at two timings, F - flowering and MD = milky dough. Trial conducted at Roseworthy SA in 2016.

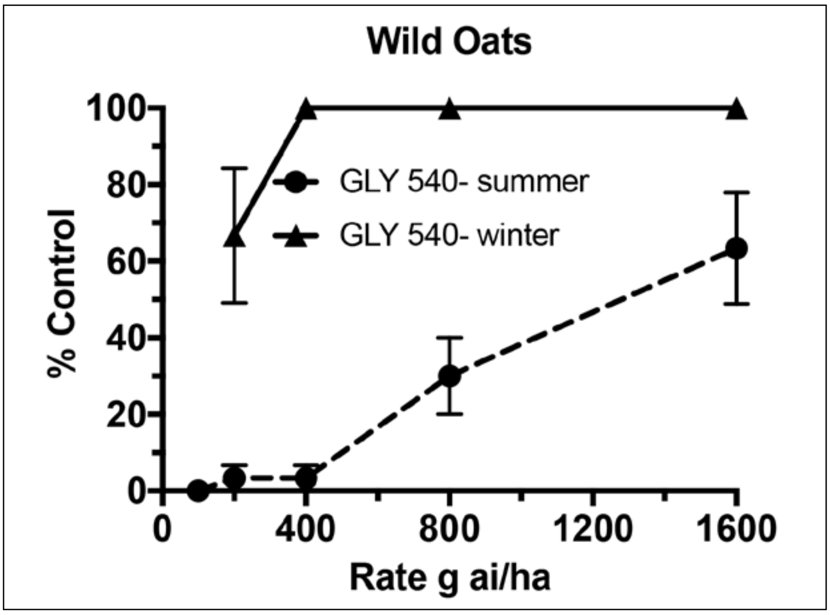

Figure 6. Control of wild oats with the same glyphosate product in outdoor summer and winter pot trials.

A current study is investigating the effect of temperature on control of glyphosate resistant sowthistle from NSW. Initial trials have confirmed greater control with glyphosate at lower temperatures, particularly of resistant biotypes (Table 2). These findings suggest that applying glyphosate at lower temperatures can improve control of glyphosate resistant sowthistle. At lower temperatures glyphosate remains in liquid form on plant surfaces longer leading to greater uptake, particularly at higher humidity. Maximising glyphosate uptake is therefore likely to improve weed control and factors such as lower temperature and higher humidity influence uptake.

Table 2. Effect of temperature in control of four biotypes of sowthistle with Glyphosate 540. Data is LD50= dose required to kill 50% of the population.

Biotypes	Resistance level	LD50 (g a.i/ha)	
		20°C	30°C
Yellow	strong	439	962
Crocket	strong	389	919
White	weak	132	389
GI	susceptible	135	152

Conclusion

In the southern cropping zone glyphosate resistance in ryegrass is becoming increasingly common. Significant differences between registered glyphosate products have been identified on several weed species with some products more effective than others. Differences in the control of glyphosate resistant ryegrass and sowthistle biotypes with different glyphosate products were observed. Products with quality surfactants can be expected to more effective than products with poor quality surfactants, particularly on stressed weeds. Treating younger plants under cooler temperatures using robust rates can improve weed control of susceptible and some glyphosate resistant individuals. These initial findings have identified that there are several factors that influence glyphosate efficacy including product choice. A better understanding of glyphosate formulations could improve weed control and delay glyphosate resistance. Further investigation of glyphosate products is recommended.

Acknowledgements

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Herbicide resistance testing

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Managing annual ryegrass in the high rainfall zone

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ΦExtra technical comment by Protech Consulting Pty Ltd

GRDC project codes: UCS00020, SFS00032, UOA1803-008RTX

Keywords

- herbicide resistance, annual ryegrass, crop competition, integrated weed management.

Take home messages

- Annual ryegrass has evolved resistance to most post-emergent herbicides in the high rainfall zone (HRZ).
- Individual pre-emergent herbicides tend to have variable efficacy making mixtures and sequences better.
- Crops mature later in the HRZ meaning that more than 50% of the annual ryegrass seed can shed prior to harvest. This makes harvest weed seed management practices less effective in the HRZ than other regions.
- Annual ryegrass can rapidly replenish the seed bank in the HRZ. This makes pre-sowing cultural tactics less effective unless they are coupled with stopping weed seed set.
- Double break crops in rotations are effective at reducing annual ryegrass population, due to the employment of crop topping.
- Moderate populations (less than 100 plants/m^2) of annual ryegrass do not greatly reduce crop yield, so strategies that drive annual ryegrass to low levels are not always the most profitable.

Herbicide resistance in Tasmania

Like most high rainfall cropping regions of Australia, resistance to the post-emergent herbicides is increasing in annual ryegrass in Tasmania. Random sampling shows resistance to Group A herbicides is common and resistance to Group B herbicides is increasing (Table 1). On the other hand, pre-emergent herbicides are mostly still effective. While the extent of herbicide resistance in annual ryegrass in Tasmania is lower than other high rainfall cropping regions on the mainland, increasingly pre-emergent herbicides will have to be relied on for annual ryegrass control with cereal production.

Table 1. Extent of resistance to herbicides in annual ryegrass in Tasmania from randomly collected samples in 2014 and 2019 (Data courtesy of Dr John Broster, Charles Sturt University).

Herbicide	Group	2014	2009
		Samples resistant (%)	
Diclofop	A	46	18
Clethodim (Select)	A	8	1
Sulfometuron (Oust)	B	16	24
Imazamox + Imazapyr (Intervix)	B	20	7
Trifluralin (TriflurX)	D	8	1
Prosulfocarb (Arcade)	J	0	-
Pyroxasulfone (Sakura)	K	0	-
Glyphosate	M	0	0

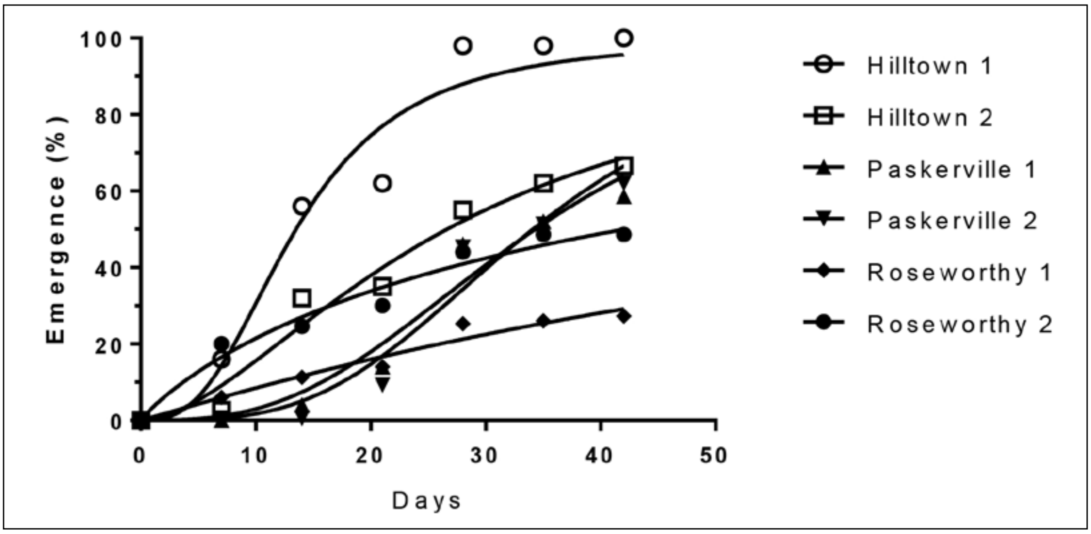

Figure 1. Emergence of annual ryegrass populations sourced from Hilltown (high rainfall), Paskerville (medium rainfall) or Roseworthy (medium rainfall) grown in the same environment.

Biology of annual ryegrass in the HRZ

There are anecdotal comments from growers and advisers that the ecology of annual ryegrass is different in the HRZ compared to other growing regions. Trial data from other regions suggests that annual ryegrass populations in continuously cropped regions have changed their emergence pattern to greater dormancy, with some of the population not emerging until after sowing. Where pre-emergent herbicides are the main control option, increased dormancy will reduce their efficacy. Some preliminary research from the University of Adelaide suggests that the changes in dormancy in annual ryegrass are less evident in higher rainfall regions than in medium rainfall regions (Figure 1).

Annual ryegrass populations tend to be larger in the HRZ and if seed dormancy has not changed, then later emergence of weeds is likely related to high weed seed banks and longer growing seasons. Rainfall tends to be higher in spring in the HRZ than in other growing regions and temperatures stay lower for longer. Both of these environmental conditions will encourage residual seeds in the seed bank to germinate. In addition, residual weeds in crops in the HRZ are able to take advantage of the extra moisture and cooler conditions to set more seed.

Pre-emergent herbicide performance in the HRZ

Trials and grower experience has consistently found that pre-emergent herbicide performance can decline quickly during the season in the HRZ. Activity of herbicides with short persistence in the environment, such as Boxer Gold® and Butisan®, can fall away quickly resulting in high weed populations later in the season. For this reason, products with longer residual activity are preferred.

Trial work conducted as part of GRDC project UA00113 examined the performance of various pre-emergent herbicide options for annual ryegrass control in 2011 and 2012 in six trials across higher rainfall districts of South Australia, Victoria and New South Wales. These trials showed that while all herbicides can perform adequately, single herbicide applications were more likely to fail than mixtures or sequences (Figure 2). The best performing options were mixtures of Avadex® Xtra with Sakura® and sequences of TriflurX® or Sakura® followed by Boxer Gold® early post. These are likely to be the best pre-emergent herbicide approaches for annual ryegrass control in wheat in the HRZ.

Harvest weed seed control in the HRZ

Harvest weed seed control (HWSC) is a set of practices that remove or destroy weed seeds that are collected by the harvesting operation. Some of these practices can be difficult to use in the HRZ because the biomass of cereal crops is often large, creating unacceptable fire risk for narrow windrow burning (form of HWSC). Frequently, the whole paddock will burn rather than just the windrows, producing a poor result.

Trial work conducted as part of GRDC project SFS00032 examined the applicability and use of HWSC in the HRZ. This work found that there were reductions in harvest efficiency with the Integrated Harrington Seed Destructor (iHSD) due to the amount of material going through the mill, resulting

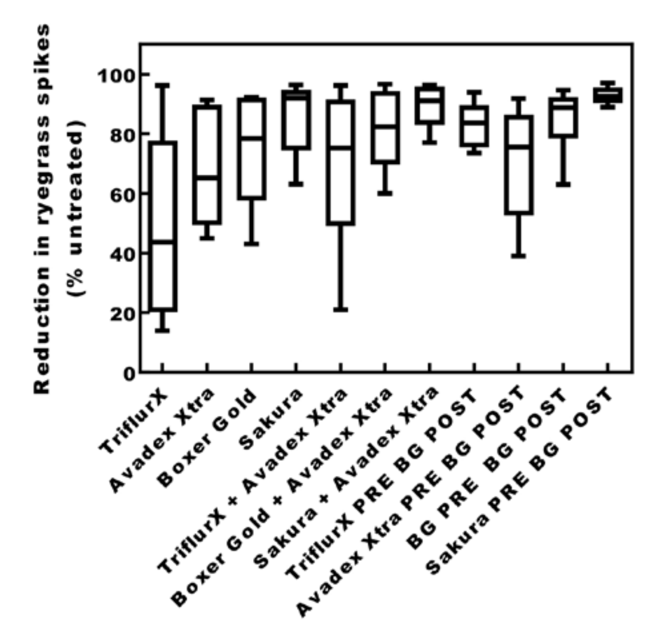

Figure 2. Performance of pre-emergent herbicides across six trials at Manoora, Yarrawonga and Wagga Wagga in 2011 and Saddleworth, Lake Bolac and Wagga Wagga in 2012. Data are presented as box and whisker plots. The line across the box is the mean of all trials. The top whisker is the best performing trial and the bottom whisker the worst performing trial. BG = Boxer Gold.

in greater fuel use. There was little impact of HWSC on annual ryegrass populations in fields with existing high annual ryegrass populations (Table 2). However, in these trials, annual ryegrass populations of about 100 plants/m^2 had little impact on crop yield.

Table 2. Annual ryegrass populations at 60 days after seeding/sowing (DAS) of the following crop after use of the iHSD at harvest in the previous crop.

Trial	Annual ryegrass at 60 DAS (plants/m^2)		
	2015	2016	2017
SFS Lake Bolac	145	115	
SFS Tasmania		259	
MFMG South Australia	218	144	74
FarmLink southern NSW		192	

In the HRZ annual ryegrass matures and substantial amounts of seed are shed before wheat maturity and this gets worse further south (Table 3). However, shedding of annual ryegrass seed can be reduced by later sowing and the amount of annual ryegrass seeds that are caught by HWSC can be increased by cutting lower. While still reducing weed numbers, the benefits of HWSC are not likely to be as great in the HRZ as they are in other regions.

Table 3. Amount of annual ryegrass seed shed in HWSC trials in the HRZ prior to harvest.

Trial	2015	2016	2017
Lake Bolac	50%	31%	0
Yarrawonga	-	57%	65%
Conmurra, SA		59%	65%

Crop competition for annual ryegrass management

Crop competition can help reduce seed set of annual ryegrass. There are several options for increasing crop competition against annual ryegrass. These include changing crop type, changing crop variety, reducing row spacing, increasing seeding rates, changing row orientation or changing planting times. Several of these tactics can vary greatly in efficacy in different environments.

Early sowing of wheat can reduce annual ryegrass seed production in medium rainfall zones; however, its value in the HRZ may be lower. A trial conducted at Lake Bolac in 2016 found no significant effect on annual ryegrass establishment in-crop or annual ryegrass seed head production between sowing times (Table 4). This demonstrates that competition practices effective in the medium and low rainfall zones may be less effective in the HRZ.

Table 4. Effect of time of sowing of wheat on annual ryegrass plant numbers and seed heads at Lake Bolac in 2016.

Time of sowing	Annual ryegrass plants (plants/m^2)	Annual ryegrass seed heads (spikes/m^2)
28 April	62	2418
15 May	53	1632
LSD	n.s.	n.s.

Long term Integrated Weed Management

A long-term trial at Lake Bolac has run since 2012. This trial initially examined the value of pre-sowing cultural tactics on annual ryegrass populations. These tactics were: retained stubble, burning stubble, incorporating stubble and a mouldboard plough operation followed by retained stubble. These were each followed by an in-crop treatment of either three different intensities of herbicide management (Table 5). The trial showed that the mouldboard plough operation reduced establishment of annual ryegrass by more than 95% in the year that it was implemented. However, in subsequent years the weed population continued to increase and by 2014 there was no difference in annual ryegrass populations between the pre-sowing cultural treatments.

Table 5. Herbicide and other treatments used as for the management strategies at Lake Bolac between 2012 and 2017.

Year and crop	Management strategy		
	MS 1 (low cost):	MS 2 (mid cost):	MS 3 (high cost)
2012 Wheat	Trifluralin 2L/ha + Dual Gold® 250mL/ha^{Φa} IBS	Boxer Gold® 2.5L/ha IBS	Sakura® 118g/ha + Avadex® Xtra 1L/ha^{Φa} IBS
2013 Barley	Trifluralin 2L/ha + Dual Gold® 250mL/ha^{Φa} IBS	Boxer Gold® 2.5L/ha IBS	Boxer Gold® 2.5L/ha IBS, Boxer Gold® 1.5L/ha^{Φa} @ GS11 ryegrass
2014 RT canola	Trifluralin 3L/ha IBS, Atrazine 900 2.2kg/ha^{Φa} + Select® 0.5L/ha @ 4 leaf canola	Trifluralin 3L/ha IBS, Roundup Ready® 0.9 kg/ha @ cotyledon, Roundup Ready® 0.9kg/ha + Atrazine 900 1.1kg/ha @ 6 leaf canola	Trifluralin 3L/ha IBS, Roundup Ready® 0.9kg/ha @ cotyledon, Roundup Ready® 0.9kg/ha + Atrazine 900 1.1kg/ha @ 6 leaf canola, Weedmaster® DST 3.5L/ha @ crop top
2015 Wheat	Trifluralin 3L/ha + Avadex® Xtra 1L/ha^{Φa} + Dual Gold 0.25L/ha^{Φa} IBS	Sakura® 118g/ha IBS	Sakura® 118g/ha + Avadex® Xtra 2L/ha^{Φa} IBS, Boxer Gold® 2.5L/ha^{Φa} GS 11
2016 Faba beans	Terbyne® Xtreme 1kg/ha^{Φa}, Boxer Gold® 2.5l/ha IBS. Clethodim^{Φb} 0.5l/ha, Factor® 0.18kg/ha @ GS13. Gramoxone® 0.8l/ha @ desiccation	Terbyne® Xtreme 1kg/ha^{Φa}, Boxer Gold® 2.5L/ha IBS. Clethodim^{Φb} 0.5L/ha, Factor® 0.18kg/ha @ GS13. Gramoxone® 0.8L/ha @ desiccation	Terbyne® Xtreme 1kg/ha^{Φa}, Propyzamide 1.11L/ha IBS. Clethodim^{Φb} 0.5L/ha, Factor 0.18kg/ha @ GS13. Gramoxone 0.8L/ha @ desiccation
2017 TT canola	Atrazine 900 1.1kg/ha IBS Atrazine 900 2.2kg/ha^{Φa} + Clethodim 0.5L/ha^{Φb} @ 4 leaf canola Weedmaster® DST 2.8L/ha crop top	Rustler® 500 mL/ha^{Φa} + Atrazine 900 1.1kg/ha IBS Atrazine 900 2.2kg/ha + Clethodim 0.5L/ha^{Φb} @ 4 leaf canola Weedmaster® DST 2.8L/ha crop top	Rustler® 500mL/ha^{Φa} + Atrazine 900 1.1kg/ha IBS Clethodim 0.25L/ha + Factor® 60g/ha^{Φa} @ 2 leaf canola Atrazine 900 2.2kg/ha + Clethodim 0.5L/ha^{Φb} @ 4 leaf canola Weedmaster® DST 2.8L/ha crop top

Note: IBS = incorporated before sowing; ^{Φa}Treatment listed are for trial purposes ONLY as rates and/or products are not as stated on the label for use within this crop, and therefore, are unregistered. For commercial use of products please adhere to label recommendations. ^{Φb}Unspecified concentration of active.

Annual ryegrass seed head numbers increased in all management strategies between 2012 and 2016. They increased less with the most intensive management (MS 3) than with the other management strategies (Figure 3). Following crop topping of faba beans for all strategies in 2016, weed numbers were greatly reduced during 2017. Despite this, annual ryegrass seed head production was still substantially higher under the low intensity management strategy compared to the other management strategies.

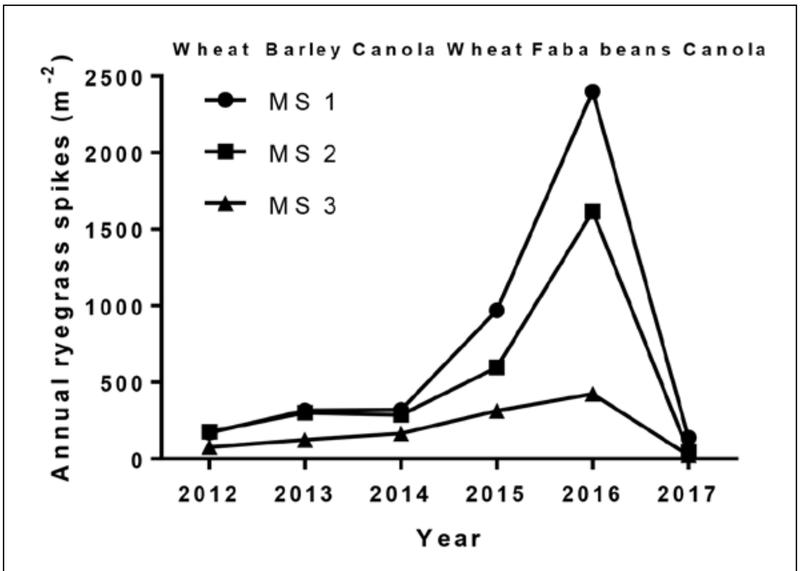

Figure 3. Annual ryegrass seed heads at harvest from 2012 to 2017 at Lake Bolac for the three different management strategies (MS1, MS2 and MS3) employed. See Table 5 for details of strategies.

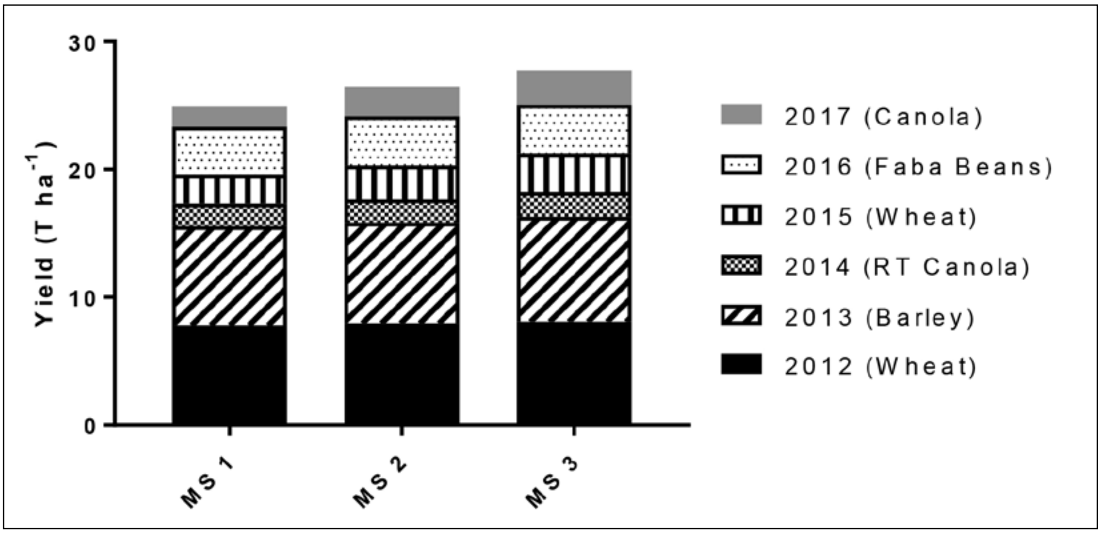

Figure 4. Effect of management strategy intensity on accumulated yield of crops at Lake Bolac between 2012 and 2017. MS1 was low intensity; MS2 medium intensity; and MS3 high intensity management.

Higher annual ryegrass populations in MS 1 resulted in lower crop yields at Lake Bolac (Figure 4). Yield over six years for MS 2 was 1.5t/ha more than MS 1 and for MS 3 was 2.8t/ha more than MS 1. These increases in yield were 6 to 12% of the yield of MS 1.

The GRDC has funded five demonstration trial sites across Victoria and South Australia in the HRZ to identify effective and profitable strategies for the management of annual ryegrass in the HRZ. Information about the trials and other information about management of herbicide resistant annual ryegrass in the HRZ can be found at: https://agwine.adelaide.edu.au/research/farming-systems/weed-science/hrz/

Useful resources

https://agwine.adelaide.edu.au/research/farming-systems/weed-science/hrz/

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www.blackdoginstitute.org.au The Black Dog Institute is a medical research institute that focuses on the identification, prevention and treatment of mental illness. Its website aims to lead you through the logical steps in seeking help for mood disorders, such as depression and bipolar disorder, and to provide you with information, resources and assessment tools.

www.crrmh.com.au The Centre for Rural & Remote Mental Health (CRRMH) provides leadership in rural and remote mental-health research, working closely with rural communities and partners to provide evidence-based service design, delivery and education.

Glove Box Guide to Mental Health
The *Glove Box Guide to Mental Health* includes stories, tips, and information about services to help connect rural communities and encourage conversations about mental health. Available online from CRRMH.

www.rrmh.com.au Rural & Remote Mental Health run workshops and training through its Rural Minds program, which is designed to raise mental health awareness and confidence, grow understanding and ensure information is embedded into agricultural and farming communities.

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Filling the yield gap – Optimising yield and economic potential of high input cropping systems in the HRZ

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GRDC project code: DAV00141

Keywords

- fertiliser, waterlogging, nitrogen (N), phosphorus (P), potassium (K), sulphur (S), economics, wheat, canola.

Take home messages

- Under-fertilising appears to be a major cause of yield gaps in cropping systems in the high rainfall zone (HRZ).
- Yield gaps need to take into account seasonal risk and relative crop and fertiliser prices.
- Soil test critical values should be higher than commonly used because of the higher yield potential of the HRZ.
- Return on investment in nitrogen (N) fertiliser is maximised if phosphorus (P), potassium (K) and sulphur (S) are non-limiting.
- The project has produced three Excel-based decision support tools to determine the economic optimum application rate of N, P, K and S under a range of conditions.

Background

In the HRZ of southern Australia, commercial wheat and canola yields are well below their water-limited potential (Yield Gap Australia 2018). The yield gap in this case was defined as the difference between actual yields reported by growers to the Australian Bureau of Statistics (ABS), and a potential yield calculated for each region and cropping year using the Agricultural Production Systems sIMulator (APSIM) model supplied with non-limiting nutrients. Since nutrient limitations are one of the most common causes of yield gaps, a plant nutrition component was incorporated into the DAV00141 project. One of the questions posed was whether the soil test interpretation guidelines developed in the low and medium rainfall areas were appropriate to the HRZ with its higher yield potential. The nutrition component comprised field experiments, crop modelling, economics, and the development of three Excel-based decision support tools to assist decision makers choose the most economic application rate of various nutrients for a given season.

Method

Experimentation

To determine which nutrients were responsible for crop responses, a series of nutrient omission experiments were conducted in the 2015 and 2016 growing seasons in the HRZ between Bool Lagoon in South Australia (SA) and Rutherglen in Victoria (VIC). At each site, one treatment was supplied with non-limiting rates of all the nutrients to which responses could be expected (P, K, S, copper (Cu), zinc (Zn)), while in other treatments, one or all of these nutrients was omitted. Nitrogen was applied at a minimal rate — 60% of estimated requirements or 100% of requirements. The experiments were conducted with either wheat (cv. Beaufort⁽ᵖ⁾) or canola (cv. Archer⁽ᵖ⁾) (Table 1). Soil samples were collected prior to sowing to develop yield relationships appropriate to the HRZ. These included soil N and available K to a depth of 1.4m, and Colwell, DGT-P and KCl-40 available S to 10cm. Further details are given by McCaskill et al. (2016) and Pearce et al. (2017).

In the 2017 season, the experimental program was modified to examine a range of application rates for nutrients to determine the economic optimum nutrient application rate. Results are presented here for a canola P response experiment conducted on the Hamilton Long-Term Phosphate Experiment at five starting fertility levels, and sufficient N applied for it to be non-limiting. Background fertility ranged from a Colwell P of 14mg/kg where virtually no P fertiliser had been applied over the previous 40 years, and to a Colwell P of 143mg/kg where the annual application rate had averaged 27kg/ha.

Data presented here have been analysed in Genstat (18th Edition) using the restricted maximum likelihood (REML) and standard curve procedures, and are reported at the 5% significance level. However, as some of the data are from incomplete data sets, the findings must be considered preliminary.

Decision support

Utilising the experimental findings of this and previous projects, a series of Excel-based decision support aids were developed. Firstly, we utilised grain yield response relationships to soil tests for P, K and S from this project and the database of Better Fertiliser Decisions for Cropping in Australia (BFDC). Secondly, these were embedded in the Catchment Analysis Toolkit (CAT) model (Christy et al. 2013) to derive a series of predicted yields for wheat and canola in response to a range of fertiliser application strategies across multiple sites and years. CAT is a biophysical model that operates on a daily time-step, and has a dynamic N model. Scenarios of starting soil conditions and fertiliser application were developed through discussion with commercial agronomists in south-western VIC and southeast SA. Starting soil conditions were based on soil samples collected at the nutrient omission experimental sites. Thirdly, these scenarios were summarised into a series of coefficients for response functions showing diminishing marginal returns and incorporated into Excel look-up tables within the decision support tools. The spreadsheet tools use conventional marginal investment and return economics to calculate the economic optimum application rate of N, P, K and S for a given set of input conditions, grain and fertiliser prices and the user's required benefit/cost ratio or rate of return on the marginal dollar invested in fertiliser. The key risk factor is seasonal outcomes and production functions were determined for four season types — 'very poor', 'poor', 'good' and 'very good'. Three spreadsheet tools were developed from a common base and these address different questions — (i) an **awareness** tool showing likely response to in-crop N based on the initial P, K and S fertility, (ii) a **planning** tool to assist with pre-sowing applications of N, P, K and S and in-crop decisions based on climate forecasts, and (iii) an **evaluation** tool, to check whether the crop was under fertilised or over fertilised, post crop.

Results and discussion

Field experiments

Could full nutrient application close the yield gap?

Grain yields for the 'all' treatments were close to or exceeded the water-limited yield potential in six of the twelve experiments (Table 1). In four experiments, yields below potential were associated with prolonged waterlogging (Bool Lagoon in 2016 and 2017, and Rutherglen in 2016). For example, wheat at Bool Lagoon in 2017 was inundated continuously mid July until mid November, and yielded 2.6t/ha compared with a region-wide yield potential calculated by APSIM of 6.0t/ha for a rainfall decile of 10. In two experiments, yields below potential were associated with an exceptionally dry finish (canola at Francis and Inverleigh in 2015).

Which nutrients were required and what are the critical soil test values?

Statistically significant grain yield responses were found to N, P, K and S, but not to the micronutrients Cu and Zn (Table 1). The magnitude of the P response was related to the Colwell soil test. The data set from this project was supplemented by four previous trials in the HRZ in the BFDC database. An exponential curve described 64% of the variation, with the 90% critical value at a Colwell P of 30mg/kg (±SE 23 to 44mg/kg) (Figure 1). There was no significant difference between wheat and canola (for comparison, 90% critical values from the BFDC database from all trials in Australia are 24mg/kg for wheat and 20mg/kg for canola). Unlike most relationships in the BFDC database, which plateau at 100% of maximal yield, this relationship plateaued at 88% of maximal yield. This is the 'starter P' effect, whereby P banded just below the seed assists early crop establishment.

There were insufficient responses to K and S to derive similar relationships from this project alone. However, from the information collected to date from trials and the experience of crop agronomists, we suggest that the K response relationship for pastures be used for HRZ cropping. The pasture relationship has a 90% critical level at a Colwell

Table 1. Summary of nutrient omission and response experiments conducted under the project, including the decile of growing season rainfall (April to November inclusive), measured grain yield of the all-nutrients treatment, the yield potential estimated by APSIM for seasons of the same rainfall decile from the Yield Gap Australia website, and the relative yield (%) where particular nutrients are omitted (only reported where responses were statistically significant).

Location	Year	Crop	Rainfall decile	Yield of 'all' (t/ha)	Yield potential (t/ha)	Relative yield if a nutrient is omitted
Hamilton	2017	Canola	7	6.3	4.3	P (6%), N (24%)
Bool Lagoon	2017	Wheat	10	2.6	6.0	P (83%)
Hamilton	2016	Canola	10	6.2	3.7	K (83%), N (17%)
Tarrington	2016	Canola	10	5.3	3.7	P (61%)
Inverleigh	2016	Wheat	8	10.9	5.3	
Rutherglen	2016	Canola	10	0.7	2.3	P (78%), N (33%), S (68%)
Bool Lagoon	2016	Wheat	10	4.6	6.0	P (76%), S (78%), N (41%)
Bool Lagoon	2016	Canola	10	1.4	3.4	P (62%), N (59%), S (70%)
Francis	2015	Canola	1	0.9	2.5	N (78%)
Bool Lagoon	2015	Wheat	1	3.6	5.1	
Chatsworth	2015	Wheat	1	4.4	4.6	
Inverleigh	2015	Canola	1	1.8	3.8	P (83%), N (80%)

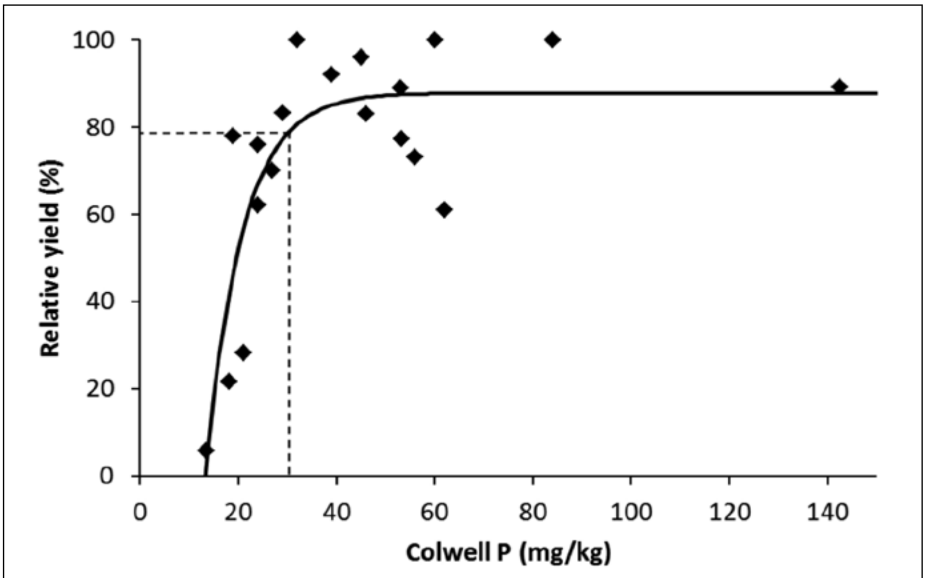

Figure 1. Relative grain yield response to Colwell P in wheat and canola for experiments in the HRZ in this project, and four previous trials in the BFDC database. Vertical line shows where fitted yield is 90% of the maximal value at a Colwell P of 30mg/kg. Note that because the relationship plateaued at 88% of the yield achievable when P is applied at sowing, the critical value is at 90% x 88% = 79%.

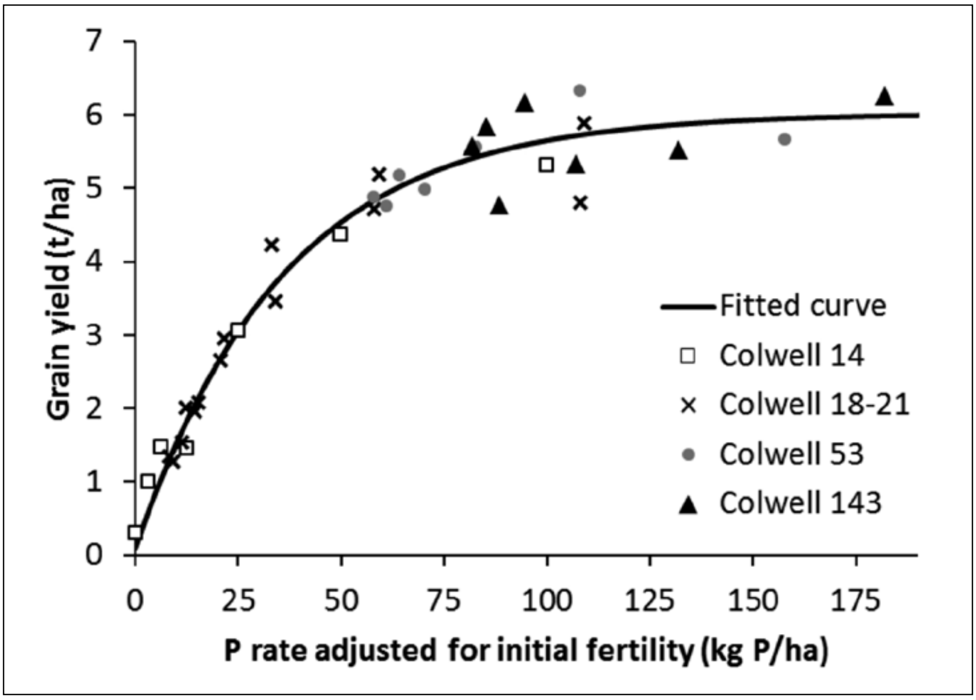

Figure 2. Canola grain yield response to applied P for a starting fertility of 14mg/kg Colwell, on the Hamilton Long-term Phosphate Experiment in 2017. Starting fertility ranged from 14mg/kg to 143mg/kg Colwell P, and P rates are adjusted so they are equivalent to the lowest starting fertility.

K of between 96mg/kg and 109mg/kg Colwell K depending on soil texture (Gourley et al. 2007) (this is much higher than 90% critical values from the BFDC database of 57mg/kg for wheat and 47mg/kg for canola based on trials in drier parts of Australia). For S using the KCl-40 extractant, a preliminary value of 8mg/kg appears to be more appropriate for both than the current BFDC values of 4.5mg/kg for wheat and 6.7mg/kg for canola.

A budgeting approach was used for N to determine application rates for the treatment where we aimed to provide 100% of N requirements. This approach involved calculating plant demand less soil N to a depth of 1m, less an allowance for mineralisation. The approach worked well for wheat but for canola it appeared much of the soil N was unavailable to the crop, despite the crop being highly responsive to fertiliser N. A parallel study (DAV00151 - Understanding how waterlogging affects water and nitrogen use by wheat) has shown that under waterlogged conditions, soil layers below approximately 5cm, become anaerobic. This would limit the capacity of roots to actively take up N and other nutrients, except where the roots have aerenchyma that allow oxygen diffusion. Wheat has aerenchyma in its adventitious roots, whereas canola lacks adventitious roots. This may explain why canola is much more dependent on fertiliser N application under waterlogged conditions than wheat.

How much nutrient was required?

While soil test response relationships describe the magnitude of response to a non-limiting amount of particular nutrient, they do not indicate the economic optimum amount to apply. This needs a fertiliser rate experiment such as that in Figure 2 (or equivalent model output such as from CAT). Here, seven rates of P were applied to fields with starting P fertility ranging from 14mg/kg to 143 mg/kg Colwell P. Canola grain yield followed a common relationship once adjustment was made for the starting fertility. For example, at a background P of 53mg/kg Colwell, yield of the nil P treatment was equivalent to a treatment receiving 58kg P/ha at a starting fertility of 14mg/kg Colwell.

Table 2. Background Colwell P of the response experiments on the Hamilton Long-term Phosphate Experiment, the long-term (40 year) annual P application that has produced the fertility level, the equivalent P application rate of the background P using the combined relationship in Figure 1, and the economic optimum P application rate at a 2:1 benefit cost ratio for canola at each background level.

Starting soil fertility P Colwell (mg/kg)	Economic optimum P application rate (kg P/ha)
14	88
18	79
21	80
53	30
143	6

Agricultural economists calculate the optimum fertiliser application rate as where $1 of extra grain is produced from $1 of extra fertiliser (Figure 3a), which is a 1:1 benefit cost ratio. A 1:1 benefit cost ratio is suitable if there is a high level of confidence in the response relationship, and no cost of capital. However, if there is some doubt whether a fertiliser investment will return sufficient additional yield despite seasonal variation and other possible crop growth constraints, a benefit cost ratio of 1.25:1 or 2:1 may be preferred, but the overall profits will be lower in the long term. In the example of P application to canola at Hamilton, the optimum P application rate at a 2:1 benefit cost ratio was 88kg P/ha less the allowance for background fertility (Table 2). Key factors that favour either high or low optimum application rates are:

Higher optimum fertiliser application rates	Lower optimum fertiliser application rates
High yields	Low yields
High crop prices	Low crop prices
Low fertiliser prices	High fertiliser prices
1:1 benefit cost ratio optimum	2:1 benefit cost ratio (or wider
Good seasons	Poor seasons

The yield factor is illustrated in Figure 3(b) by using the same curve as in Figure 2 scaled down to represent lower yield potentials in the Wimmera and Mallee. The 2:1 economic optimum occurs at 92% of yield potential in the HRZ, compared with 83% in the Wimmera and 66% in the Mallee. Soil tests are often interpreted in relation to a critical level at which 90% of maximum yield is achieved, whereas a higher threshold should be used in areas of greater yield potential.

The crop price factor is illustrated in Figure 3(c) by using the wheat price of $224/t in the canola yield response relationship, rather than the $495/t canola price. The economic optimum at a 2:1 benefit cost ratio declines to 55kg P/ha (from 88kg P/ha), less the allowance for background fertility.

It should be noted that this P response relationship was for a soil with a Phosphate Buffering Index (PBI) of 200, whereas the average PBI of commercial samples submitted in 2015 to the Nutrient Advantage laboratory from south-west VIC was only 108 (McCaskill et al. 2016 and unpublished). While a similar relationship would apply to all soils in the HRZ, the economic optimum application rate is likely to be lower than shown here.

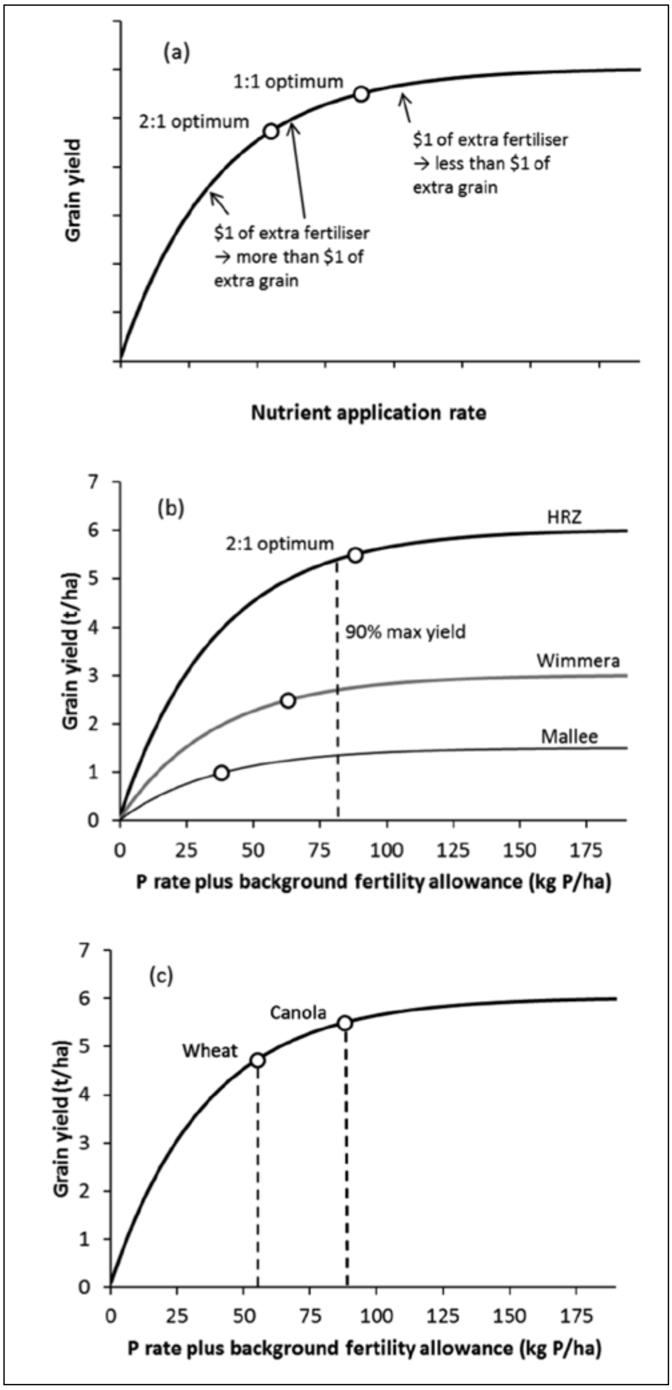

Figure 3. (a) Economic optimum nutrient application for a 1:1 and 2:1 benefit cost ratio; **(b)** economic optimum P application (circles) for a 2:1 benefit cost ratio for yield potentials representative of the HRZ, Wimmera and Mallee using the same curve as in Figure 2, and the fertility required for 90% of yield potential in all three environments; **(c)** economic optimum P application at a 2:1 benefit cost ratio for canola using the same curve as in Figure 2 and current prices, and for wheat if the yield response relationship also applied to wheat.

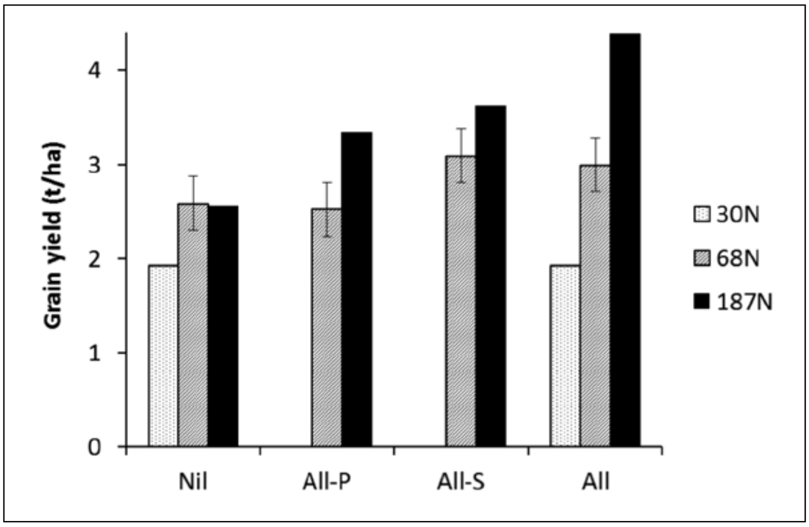

Figure 4. Wheat grain yield response to applied N at Bool Lagoon in 2016 as affected by the omission of all other nutrients at sowing, and the omission of P or S, at N application rates of 30kg, 68kg and 187kg N/ha. Error bars show the 5% least significant difference. Redrawn from Pearce et al. (2017).

What if two or more nutrients are limiting?

In the P rate experiment given above, non-limiting rates of N were applied, and N was not considered in the economic optimisation. In practice, most sites have an interaction between two or more limiting nutrients. This is illustrated from the 2016 wheat omission experiment at Bool Lagoon (Figure 4). There was a strong response to additional N where all the required other nutrients were applied, but there was a weaker response if P or S were omitted. Where both P and S were applied, each additional kilogram of N fertiliser between the mid and high rate of N produced 11.7kg of extra grain, compared with 6.8kg if P was omitted, 4.5kg if S was omitted and no additional yield if both were omitted. Correction of other nutrient limitations is the first step in obtaining a good response to applied N. Conversely, the P and S responses were only statistically significant at the high, but not the mid-rate of N. Similar findings were made from the other omission experiment sites. As cropping in the HRZ adopts varieties with higher potential yields and higher N rates are applied, we can expect more responses to P, K and S unless soil conditions are closely monitored.

4 YIELD POTENTIAL:

Expected yield quartile	Quartile 3 (good)	
Modelled/experimental yield potential with unlimited nutrients	7.9	t/ha
Yield adjustment for your paddock	-10%	%

5 CROP PRICE AT FARM GATE:

Price of crop at point of sale	260	$/t
Freight costs	15	$/t
Harvest costs	25	$/t

6 REQUIRED RETURN ON MARGINAL $ INVESTED IN FERTILISER:

B/C ratio	1.25	:1
Equivalent marginal rate of return	25	%

7 FERTILISER DELIVERY AND SPREADING COSTS:

Freight costs	15	$/t
Usual cost of fertiliser spreading, e.g. for ground application(s)	9	$/ha
Cost of topdressing final split application of N	9	$/ha

8 UREA COST (46-0-0-0) AT POINT OF SALE:	445	$/t

Putting it together — decision support

Since the economic optimum changes with input costs and product prices, economic information is better conveyed by calculation tools than static information. The tools combine well established production economics principles with relatively poorly developed (to-date) nutrient response relationships from the HRZ and are available on the eXtensionAUS website. The spreadsheet tools allow users to adjust prices for crops and inputs and reveal optimum nutrient ratios and fertilisation levels for the range of seasonal conditions. For limited capital and/or high risk situations, users are also able to specify their required benefit/cost ratio or rate of return on the marginal dollar invested in fertiliser. Simple graphs and tables were used to illustrate expected outcomes. A screen grab from the awareness tool (Figure 5) shows how limitations of P, K or S affect the optimal application rate of N.

The effect of season variability on the optimal fertiliser strategy is accommodated by a drop-down box of yield quartiles. At sowing, these yield outcomes have equal probability, and possible N, P, K and S fertiliser strategies can be tested under both good and poor seasonal conditions. As the season progresses, the probability of achieving a particular yield outcome becomes more certain because of rainfall received after sowing, and drought influences become apparent such as El Niño or a positive Indian Ocean Dipole (IOD). Much of this information is available in late August and can influence decisions on split N application in late winter and early spring. The planning tool allows users to test how these factors affect the probability of achieving a low or high final yield, and the economic optimum N application rate. We expect to conduct training and feedback sessions with the tools over the next year, leading to improved versions. Eventually the tools may be made available in other forms, through incorporation into existing decision support tools and possibly smartphone apps, but the current Excel form provides a way of prototyping in parallel with gathering more information on nutrient response relationships.

Conclusion

Through a series of nutrient response experiments, we have established that by providing sufficient nutrients, the yield of wheat and canola crops can be equal to or exceed the water-limited potential, except in cases of severe waterlogging or drought. The strongest responses were to P followed by N, S and K. The magnitude of these responses was related to soil tests, but with critical values at which 90% of maximal yield was achieved slightly higher than from previous trials in other parts of Australia. Economic analysis showed that the 90%

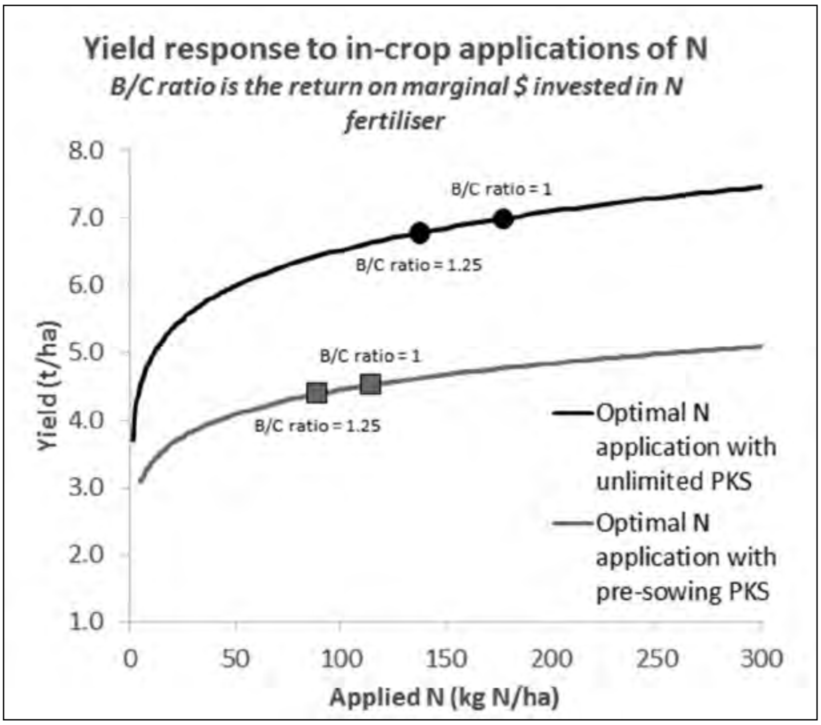

Figure 5. Screen grab from the awareness tool, showing some of the input data required, and a dynamic calculation of the economic optimum N application under conditions of limited P, K or S, and if these nutrients are fully supplied.

critical value underestimated the economic optimum because of the higher yield potential in the HRZ. Since the economic optimum fertiliser application rate is also dependent on input prices, product price and seasonal outlook, we have prepared three spreadsheets to calculate the optimum under a wide range of conditions. The spreadsheets are populated with yield and nutrient response data from a biophysical model, but allow modification to suit individual circumstances.

Useful resources

eXtensionAUS (http://extensionaus.com.au/)

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Notes

Better pastures, better crops

Cam Nicholson.

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GRDC project codes: SFS 00022, SFS00028

Keywords

- pastures, nitrogen, weeds, mixed farming.

Take home messages

- Grass fodders will generally grow more dry matter in a year than legumes and in the vegetative stage their feed quality is equivalent to legumes.
- Most common are the annual legume fodders (balansa, arrowleaf and persian clover) and they can produce significant amounts of high quality fodder under favourable growing conditions.
- Perennial fodders, especially lucerne, will dry the soil profile more than annual fodders. This may compromise subsequent crop yield if seasonal rainfall is below average
- Effective nodulation and husbandry of legumes is critical to achieve nitrogen (N) fixation. Just because a legume grows and looks healthy does not mean it is maximising N fixation
- Controlling seed set, especially in very late season weeds that germinate and grow outside the efficacy of in-crop herbicides is essential to achieve significant and sustained reduction in annual ryegrass.
- Crop yields after a fodder phase may be worse if growing season rainfall is below average because of potential lower starting soil moisture and inability to control the mineralisation of N rich organic matter that can 'cook' the crop.

Introduction

The inclusion of a pasture ley phase in a cropping system is not new. A simple computer search reveals pasture ley was at the forefront of farmers and scientists in the 1940s (Roe, 1956), with them grappling with the same issues as we are now around organic matter, fertility and soil structure decline and weeds. Since then new varieties and rotations, advances in chemicals (herbicides, fungicides and insecticides), the adoption of minimum or no till systems along with (until recently) depressed livestock commodity prices has resulted in widespread adoption of 'continuous cropping' on many farms. The pasture ley phase has largely been ignored. yet the issues of weeds, disease, fertility decline, especially N, and to a lesser extent soil structure remain. Data from the recent national soil carbon program (www.csiropedia.csiro.au/soil-carbon-research-program) through the Volcanic Plains of south west Victoria on similar soil types and rainfall shows a difference in soil carbon, especially the rapid turnover and humic portions of the organic carbon pool under different land uses (Table 1).

Table 1. Total organic carbon (TOC) and organic carbon fractions.

10 year land use	30 year AAR (mm)	TOC (%)	Organic carbon fraction (t/ha)		
			Particulate	Humic	Recalcitrant
Pasture - sheep beef	620	2.26	11.4	36.6	14.5
Crop-pasture rotation	611	1.79	8.8	33.0	14.1
Continuous cropping	579	1.41	6.0	25.7	12.1

In 2012 a GRDC funder project *Pastures in Crop Sequencing* (SFS00022) explored the opportunities of using a pasture phase in the high rainfall zone to improve crop performance. Fourteen trials and one demonstration were conducted in Victoria and South Australia. The Victorian trials were conducted by Southern Farming Systems and the South Australian trials by MacKillop Farm Management Group and Agriculture KI.

The project examined a range of fodders including variations in sowing rate, phase length and termination practices e.g. spraying, hay cutting, etc. Many parameters were measured including biomass, weed populations, N fixation and subsequent crop yields and quality. Results from individual trials have already been reported (GRDC Grains Research Update Bendigo 2017; Dubbo 2018; Paridaen et al, 2015; SFS final report on GRDC website). This paper aims to summarise the findings under five themes:

1. Dry matter production
2. Grain production after fodders
3. Soil nitrogen
4. Weed control
5. Changes to soil moisture

Results

Dry matter production from fodders

Several factors influenced the total amount of dry matter produced from the fodders sown. Seasonal conditions, species choice, time of sowing and perenniality all had an impact.

A range of fodders were grown across three years (2012 to 2014). During this period the growing season rainfall varied from well above average (decile 8 & 9), to around average (decile 4 & 5) to well below average (decile 1 & 2). As a consequence dry matter production also fluctuated dramatically, with growth more affected by the drier rather than the wetter growing season (Figure 1).

A 'typical' year was 2012 (roughly average rainfall) and yields were commonly around 7 to 10t/ha for 'grasses' (oats and ryegrass) and 1.5 to 6t/ha for legumes. Aerial seeding legumes (arrowleaf, balansa, Persian) were generally higher yielding than sub clover or lucerne.

In 2013 (an above average season), yields for crop varieties sown as a fodder (peas, beans, oats, wheat, vetch) were typically between 10 and 14.5t/ha.

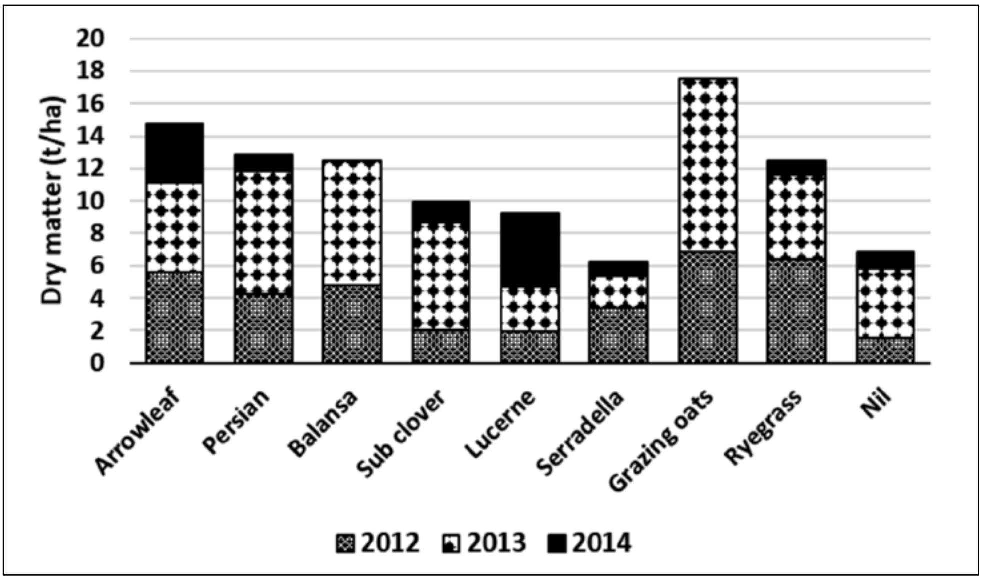

Figure 1. Annual drymatter (t/ha) for a range of fodder species from 2012 to 2014 at Inverleigh – common sowing rate.

Pasture grasses in the same year yielded between 3.3 to 11.1t/ha, but typically around 5 to 8t/ha and legumes between 1.2 and 8t/ha, typically around 5 to 6t/ha. Lucerne was commonly the lowest yielding legume even under favourable growing conditions.

A much drier year was encountered in 2014, resulting in some species failing to establish and lower dry matter production. Perennial grasses such as phalaris and soil seed burial legumes such as sub clover sown the previous year responded more favourably than the annual varieties that required resowing. Pasture grasses that established, commonly yielded between 4 to 9t/ha, with legumes between 1 to 6t/ha. The higher legume dry matter yields were recorded with sub clover and the poorest with established lucerne.

In one trial the 'weeds' or nil treatment were allowed to grow (with seed set controlled) and were compared to the dry matter produced by sowing a dedicated species. In 2012, yields from the nil treatment were approximately one third to one half as productive as sown species, however in 2013 (decile 8 or 9) dry matter production was half of the grasses but equal to most legumes.

These results illustrate the range in dry matter production possible from species across different growing conditions. Therefore, the choice of species will depend on the outcomes sought from the fodder phase. These can be summarised as follows:

- For maximum annual dry matter production and grazing consider annual grass species such as oats and annual ryegrass. If a longer fodder phase is sought, consider short-lived perennial ryegrass or phalaris.
- If a legume is required then consider annual aerial seeding varieties such as arrowleaf, balansa or persian clover. If a longer fodder phase is sought, consider subclover however, be prepared for lower growth in the first year.
- If maximum N fixation is required but no grazing, then consider peas or beans.
- Avoid using lucerne in short term rotations as dry matter production was lower than other legume species (and it does affect subsequent crop yields if rainfall is below average).

Fodder quality was consistently high, with digestibility for the legumes throughout the growing season commonly above 75% (10.8MJ ME/kg) and protein above 15%.

Grain production after fodders

An increase in grain production in subsequent crops is a common objective from using a fodder phase. The likelihood of achieving this results is highly dependent on in-season rainfall and the length of the fodder rotation.

One year of fodder

Results from only one year of winter legume (arrowleaf, balansa, Persian, sub clover, peas, beans) showed in most cases no difference in subsequent grain yield of canola or wheat, when the winter crop growing season was favourable (decile, 4, 8 or 9). The exceptions were higher yields at one site after balansa clover or peas. One year of grass fodder resulted in significantly lower yields and could be explained by lower soil N (refer to discussion on soil N).

The second year of crop showed no significant difference in yields from the one year of any species, with the exception of lower yields after oats and serradella. There was no impact on yield of the third crop after the fodder.

Two years of fodder

A two-year fodder phase had an impact on grain yield with most grass fodders (+/- companion legumes) and unsown treatments. Yields were considerably higher compared to treatments that had been fallowed or were in a continuous crop rotation (Table 2). There were no significant differences in protein or screenings.

Table 2. Canola yields in 2014 at Inverleigh after two years of a fodder phase.

Fodder	Yield (t/ha)	
Balansa	2.83	a*
Arrowleaf	2.69	b
Peas	2.52	c
Sub clover	2.51	c
Grazing oats	2.50	cd
Serradella	2.41	d
Ryegrass	2.40	de
Persian	2.40	e
NIL	2.37	e
Lucerne	1.59	f

**Significant differences as indicated by different letter*

Crops sown in 2015 after two years of legume fodder showed a significant reduction in grain yield at the location with decile 1 growing season rainfall but no significant yield loss at the site receiving decile 5 rainfall. This would suggest yield decline following two years of annual legume may occur in very low rainfall years. Both protein and screenings were higher suggesting moisture was limiting.

Three years of fodder

Three years of fodder followed by a crop was only tested with one trial and at two locations. Decile 1 growing season rainfall prevented successful crop establishment at one site (Inverleigh). There were no differences in yield at the other site (Lake Bolac), however yields were well below expectations (approximately 1.2t/ha for canola).

Soil nitrogen

Measuring changes in soil N was challenging, especially given the dry conditions, failed establishment and some crops being ensiled to manage weeds. Most testing was undertaken on a long-term trial, and the two sites at Inverleigh and Lake Bolac showed marked differences in N accumulation under various legumes.

Inverleigh 'responded' largely in line with accepted 'rules'. Total soil N was higher in the legume plots than the grasses and the highest was 17kg/ha of N fixed by Persian clover per tonne of dry matter grown. The accumulated N after two years of fodders resulted in marginally higher canola yields under legumes (except for lucerne) even though it was a decile 2 growing season rainfall. After three years of crop (only 1 year of fodder) there was no difference in barley yields or differences in grain protein, suggesting most of the accumulated N had been used or lost.

In contrast, Lake Bolac did not show increases in total soil N even after three years of legume fodder (Figure 2).

Canola yields in the following year from fodder were not significantly different from the common annual legumes such as Arrowleaf, Persian and sub clover compared to the ryegrass. Balansa clover was the exception with significantly greater canola yields after one or two years of fodder. No plant N fixation work was conducted at this site and the fodders appeared visually OK, however there may have been some nodulation issues at the Lake Bolac site that prevented adequate N fixation.

Ongoing work and reports by Belinda Hackney NSW DPI have identified poor nodulation as a major issue in pastures throughout NSW (Hackney et al, 2017) and studies have identified a number of contributing factors including low soil pH, low soil phosphorus (P) and sulphur (S) and already high levels of mineral N (so legumes become 'lazy'). Residues from herbicides may also be a contributing factor, especially with group B herbicides (Ballard, 2017), despite following the recommended plant back requirements (e.g. Hawthorne, 2007).

The dry conditions no doubt confounded some of the potential yield, and therefore, N response. While yield increases from the legume treatments were only recorded at one location, most showed no significant improvement in yield after the fodder phase. Significant grain protein responses were recorded after one year of legume at several sites but not at others, however screenings were commonly higher under the legume treatments, suggesting inadequate soil moisture limited potential yield.

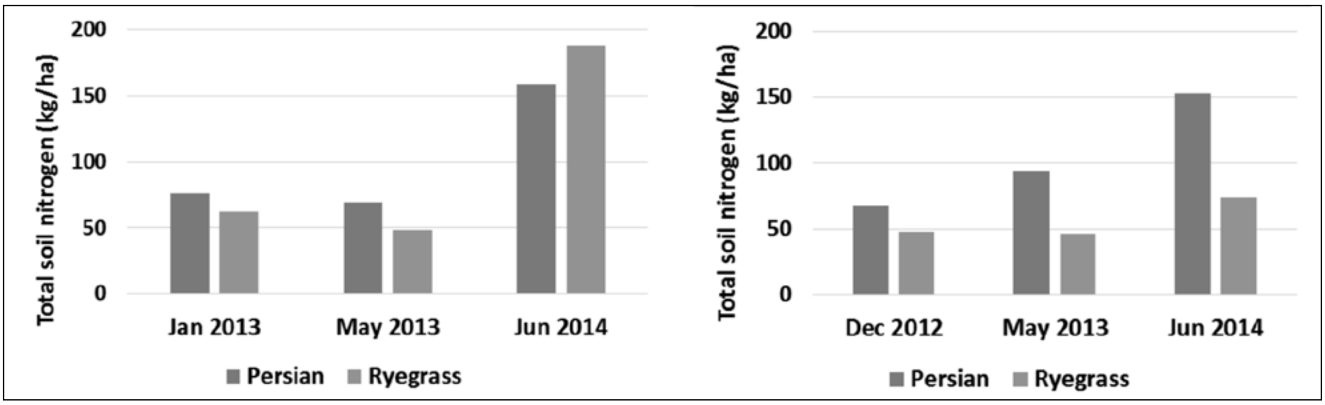

Figure 2. Total soil nitrogen (0-60cm) at Lake Bolac (left) and Inverleigh (right) after two years of Persian clover or annual ryegrass (fodder grown in 2012 and 2013).

Weeds

Annual ryegrass and wild radish were the two weeds studied in these trials. Initial weed counts were usually undertaken in July, however ongoing observations illustrate the problem with late germinating weeds, especially annual ryegrass. Mid-crop measurements were not providing an accurate understanding of carry-over weeds. More recent observations were also taken in October and November to pick up very late germinating weeds that had not been controlled by knockdown or in-crop herbicides.

Annual ryegrass

Results clearly show annual ryegrass populations can be dramatically reduced with only one year of a fodder; either a legume, grass or cereal fodder. Achieving adequate seed set control is the key. The only trial where annual ryegrass populations increased was the result of no spring intervention with the fodder treatments. To highlight the importance of seed set control, a canola treatment in the same trial that failed due to waterlogging was sprayed out in spring. This resulted in a dramatic reduction in annual ryegrass the next year compared to the untreated fodders. Increasing the fodder duration from one to two or three years generally had a continuing, albeit smaller benefit in lowering ryegrass populations in the fodders. This also appears to provide greater time with lower plant numbers in subsequent crops.

Other tactics such as increasing crop or fodder sowing rates above common practice and stubble burning proved ineffective in enhancing annual ryegrass control. Delaying sowing time was effective in gaining improved mid-winter weed control however the delay resulted in lower grain yield and no difference in end of season ryegrass numbers because of the late germinating weeds described previously. This confirms the issue of late germinating weeds that are beyond the effectiveness of in-crop herbicides.

Wild radish

Control of wild radish was largely ineffective. While a decline in numbers was observed in the first year of one trial, equivalent or even increased populations of wild radish were recorded, with different fodders or different treatments such as spray-grazing or stubble burning. In one trial the first year of canola after one year of fodder had to be abandoned (crop ensiled) because of very high wild radish numbers. This was irrespective of the treatment applied.

Wild radish was still present in considerable numbers in the first year of crop after three years of fodder. This is not surprising given the longevity of wild radish seed but does bring into question the long-term effectiveness of a short-term fodder phase as a tactic to control this weed.

Other tactics such as increasing crop or fodder sowing rates above common practice, stubble-burning and spray grazing proved ineffective in achieving long term weed control.

Changes to soil moisture

Apart from the lucerne treatment, most annual fodder species dried the soil profile by a similar amount. With adequate winter rainfall in 2013, the soil profile was full (sometimes waterlogged) by the end of winter and the water used by various fodders in that year was similar. Crops grown in the 2013 year showed no yield difference that could be related to differences in starting soil moisture created by the previous fodder.

2014 was a dry year and starting soil moisture after two years of fodder were the same between Persian clover, sown ryegrass and the nil treatment (% w/w of 39%, 38% and 42% respectively). There was no significant grain yield difference between treatments.

The exception was in 2015 at Frances in South Australia, where there were differences in starting soil moisture due to the treatments and a strong correlation with grain yield. In this trial the lowest soil moisture was under lucerne, followed by the grasses (perennial ryegrass and phalaris). Highest soil moisture was under crop fodders (oats for hay, peas for green manuring) and a fallow treatment and this correlated with higher grain yield.

Similar differences in soil moisture between fodder treatments were not measured at other sites.

This data shows that perennial fodders such as lucerne, phalaris and perennial ryegrass are likely to deplete soil moisture from the profile more than any of the annual fodders (annual clovers, annual ryegrass) but less than crop species such as oats or peas sown for fodder or green manuring and then terminated before the end of the growing season. Adequate growing season rain is required to avoid compromising subsequent grain yield because of the extra moisture depletion.

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Blackleg in canola - an update on resistance, Upper Canopy Infection and a new management App

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Keywords

- canola, phenology, flowering time, fungicide, disease control, resistance, Upper Canopy Infection (UCI).

Take home messages

- In 2017, blackleg leaf infection and resultant crown canker severity was low due to dry conditions in May and June during early seedling growth. Susceptible cultivars still had some level of disease but were well protected by fungicides applied at sowing which were highly effective due to the lower disease pressure. Application of foliar fungicides at the 4 to 6 leaf stage was generally not warranted.
- Upper Canopy Infection (UCI) is the collective term for blackleg flower, peduncle, pod, main stem and branch infection but does not include leaf lesions or crown canker.
- In 2016 and 2017, UCI caused large yield loss (up to 1t/ha) but the prevalent symptoms varied between years: pod lesions in 2016, stem and branch lesions in 2017.
- Delayed flowering after mid-August reduced severity of UCI in medium rainfall environments. Although flowering time is one important factor in the development of UCI, seasonal conditions relating to spore development and release, as well as infection events interact to produce UCI. Further research is required to understand and predict these interactions.
- Effective major gene resistance provides control of pod, branch and stem infection. Fungicides also control UCI however, further research is required to determine robust recommendations for foliar fungicide timing and determining the economic returns.
- The Blackleg Management App ('BlacklegCM' due for release February/March 2018) has been developed to provide growers and advisers with an interactive interface to explore the economic outcomes of different blackleg management strategies and their relative importance.

Blackleg resistance

There are two types of blackleg resistance genes in Australian canola cultivars; major and minor resistance genes. Major resistance genes stop the fungus from infecting the plant which results in complete protection against the blackleg pathogen. This is evidenced in the field by lack of leaf lesions and crown canker. A cultivar can have none, one or multiple major resistance genes. In Australia, all commercial canola cultivars are classified into Resistance Groups which describe the major genes present in the cultivar. For example, Group A cultivars have a single major resistance gene, Group ABDF cultivars have four major resistance genes. Blackleg is rapidly able to change and major gene resistance imposes strong selection for only those isolates of blackleg able to infect the plant. Therefore, major resistance genes can be overcome quickly in the field so cultivars dependant on major resistance genes tend to become more susceptible over time, sometimes becoming completely ineffective in as little as three years. Minor gene resistance (sometimes called quantitative, adult plant or crown canker resistance) reduces the severity of crown canker but does not inhibit leaf lesions and upper canopy infection. As the name suggests, each gene provides a minor level of crown canker resistance. However, the combined effect of a number of minor genes in the same cultivar can create very high levels of crown canker resistance. As blackleg is able to infect plants with minor gene resistance, selection of isolates able to overcome these genes isn't as strong, and therefore, can be robust for many years. At present, there is no rapid screening technique such as that used for major resistance genes, to identify the presence of minor resistance genes in cultivars. The Blackleg Rating classifies cultivars according to their overall level of resistance and includes both major and minor gene resistance. As major resistance genes inhibit infection of the plant, it is not until this resistance is overcome that it is then possible to determine the presence of minor resistance genes.

It is important to know the Resistance Group and also the Blackleg Rating when selecting a cultivar. In the field, cultivars with effective (not yet overcome) major gene resistance will be completely protected (no leaf lesions, crown canker or upper canopy infection). Crops with major gene resistance that has been overcome will be susceptible to leaf lesions and UCI but may still be resistant, or partially resistant to crown canker if minor resistance genes are present in the cultivar in combination with major resistance genes. An example of various levels of minor gene resistance is ATR Bonito$^{\phi}$ and ATR Mako$^{\phi}$. Both cultivars are in Resistance Group A, and therefore, have the same major resistance gene which in many locations has been overcome (Table 1). The Blackleg Rating of ATR Bonito$^{\phi}$ is moderately susceptible (MS) while ATR Mako$^{\phi}$ has a higher rating of moderately resistant (MR). As these cultivars are not completely susceptible to blackleg, this indicates that minor and major resistance genes are present in combination but ATR Mako$^{\phi}$ has better minor gene resistance.

In Australia, all cultivars classified in Resistance Group C have no effective major gene resistance and are therefore solely reliant on minor resistance genes with those with a higher Blackleg Rating more resistant to crown canker.

Periods of infection by blackleg for different plant parts

Blackleg is able to infect all parts of the canola plant. Figure 1 shows the relationship between the period of blackleg spore release and symptom development on different plant parts. Lesions form on leaves throughout the growing season however, severe crown canker is most likely to develop when plants are infected during the early seedling stage. The fungus grows from the cotyledons and leaves asymptomatically through the vascular tissues to the crown where it causes necrosis resulting in a crown canker at the base of the plant. Yield loss results from restricted water and nutrient uptake by the plant. Protection during the seedling stage is critical to reduce crown canker severity. Lesions can also develop on all other plant parts and these infections may go on to develop cankers as described further within this paper.

Winter is the main period in which conditions are generally most conducive for infection as rainfall triggers release of mature spores from crop residue and provides ideal conditions for the fungus to survive while it infects the crop (Figure 1). Once the plant has begun to flower, infection of flowers, peduncles, pods, main stem and branches of the plant has collectively been termed UCI (Figure 2). Any plant parts of susceptible cultivars exposed to spores during the winter period are likely to become infected and potentially cause yield loss. Upper canopy infection has become increasingly prevalent over recent years. Earlier flowering times and changes in farming systems with increased retention of stubble may contribute to higher disease severity. While the cost to yield and control of leaf lesions leading to crown canker is well understood, the factors contributing to UCI and possible control strategies are currently under investigation with current knowledge presented in this paper.

Blackleg crown canker in 2017 — seedling leaf lesions and crown canker severity

Crown cankers result from infection of plants while they are in the early seedling stage usually during May and June. Dry conditions in this period in 2017 resulted in generally low levels of leaf infection resulting in reduced crown canker severity. Predominant use of canola cultivars from the same resistance group (e.g. Group A resistance) in the same locality or region results in blackleg populations with a high frequency of isolates virulent towards that group. Since 2015, the Blackleg Rating of many of the Group A cultivars has fallen from MR to MS, indicating their increased

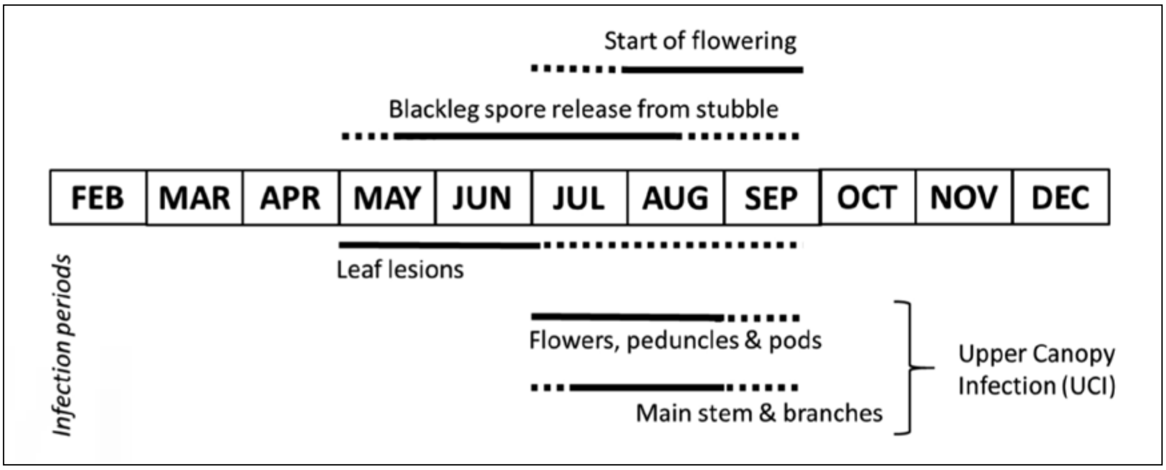

Figure 1. Periods of infection by blackleg for different parts of the canola plant in relation to the period of blackleg spore release and start of flowering in medium and high rainfall zones. Solid lines indicate main periods of infection and dashed lines indicate reduced risk from infection. For start of flowering, solid line indicates the optimal period in which yield is maximised while reducing disease risk.

susceptibility to disease. The severity of crown canker was assessed at 34 locations across the Australian canola-growing regions, and indicates the efficacy of different Resistance Groups (Table 1). Resistance Group H is not represented at these sites as winter cultivars are the only currently commercially available cultivars classified as Group H. At many locations, cultivars in multiple Resistance Groups had a high level of crown canker compared to the site mean. For example, Cootamundra in NSW had high levels of crown canker in Resistance Groups A, B, BF and AS. It should be noted that the cultivar used at these sites to represent Resistance Group C is ATR Stingray⁽ᴰ⁾ which has a good level of minor gene resistance with a Blackleg Rating of MR and hence low levels of crown canker (see preceding comments for further discussion). Increased intensification of canola plantings in the past few years has resulted in large areas of canola stubble that can release blackleg spores with the potential to cause significant yield losses in years where spore release coincides with environmental conditions conducive to infection, such as those experienced in 2016. Despite the low disease pressure in 2017, leaf lesions were present in susceptible cultivars but were adequately controlled by fungicide treatments applied to seed or fertiliser at sowing, with foliar fungicide application generally unwarranted. In contrast, wet winter conditions in 2016 produced extreme levels of leaf lesions which warranted the application of foliar fungicides at the 4 to 6 leaf stage to extend the efficacy of seed and fertiliser treatments.

Upper canopy infection

The infection by blackleg of flowers, peduncles, pods, stems and branches is termed UCI. In 2010, cankers on the upper stems and branches were observed in commercial canola paddocks (Figure 2). These cankers appeared to cause yield loss as the pods on affected branches senesced prematurely leading to early pod shatter. Stem/branch cankers are not correlated with the presence of crown cankers. In 2011, 2012 and 2013 stem/branch cankers were observed each year but symptoms were not generally severe and were not present in all regions. In 2014 and 2015, the symptoms were widespread and appeared to cause substantial yield loss. In 2016, research commenced investigating the causes and management of UCI. In contrast to previous years, severe stem/branch infection was not present at most sites in 2016. Data from 2016 clearly showed that flowering during the winter period where conditions for blackleg infection are optimal, consistently resulted in increased UCI. The data also clearly showed that UCI caused large yield losses (data not presented within paper).

UCI yield loss

Field experiments conducted in 2016 and 2017 show that in the absence of sclerotinia or blackleg crown canker, UCI caused yield loss of up to 1t/ha in southern NSW compared to where disease was fully controlled (Figure 3). In both seasons, delaying the onset of flowering after mid-August reduced yield loss. However, in 2016 crops starting to flower in early August had minimal yield loss compared to those in 2017 that had 0.7t/ha yield

Table 1. Blackleg crown canker severity in cultivars from different Blackleg Resistance Groups at monitoring sites in 2017. Disease severity is indicated as high, moderate or low compared to the site average.

Monitoring site	Resistance Group							
	Group A	Group B	Group C	Group AD	Group ABD	Group ABDF	Group BF	Group AS
NSW								
Beckom	High	High	Low	Low	Low	Low	High	High
Bellata	Low	Low	Low	Low	Low	Low	Low	Low
Cootamundra	High	High	Low	Low	Low	Low	High	High
Cudal	High	High	Low	Low	Low	Low	Low	Low
Gerogery	Mod	High	Low	Low	Low	Low	High	High
Grenfell	High	High	Low	Low	Low	Low	Low	Low
Lockhart	High	High	Mod	Low	Low	Low	High	Mod
Mullaley	Low	High	Low	Low	Low	Low	High	Low
Parkes	High	High	Low	Low	Low	Low	Low	Low
Tamworth	High	High	Low	Low	Low		Mod	Low
Wagga Wagga	High	High	Low	Low	Low	Low	Mod	Low
SA								
Arthurton	High	Low	Low	Low	Low	Mod	High	High
Bordertown	High	Low	Mod	High	Mod	Mod	High	High
Cummins	Low	Low	Low	High	Low	Low	Low	Low
Frances	High	Low	Low	Mod	Low	Mod	High	High
Mt Hope	High	Low	Mod	Mod	Low	Mod	High	Mod
Riverton	High	Low	Low	High	Low	Low	Low	Low
Spalding	High	Low	Low	High	Mod	Low	Low	High
Turretfield	Mod	Low	Low	Mod	Low	Low	High	High
Wangary	High	Low	Low	Mod	Low	Low	High	Low
Yeelanna	High	Mod	Mod	Low	Low	Mod	High	Mod
VIC								
Charlton	Low	High	Low	Low	Low	Low	High	Low
Diggora	High	High	Low	Mod	Mod	Low	High	High
Cavendish	Low	Low	Low	Low	Low	Low	Low	Mod
Kaniva	Mod	High	Low	Low	Low	Low	High	Mod
Minyip	High	Mod	Low	Low	Low	Low	Mod	High
Streatham	Mod	High	Low	High	Low	Low	Low	High
Yarrawonga	High	High	Mod	Low	Low	Low	High	Mod
WA								
Corrigin	Mod	High	Low	Low	Low	Low	High	Mod
Gibson	High	Mod	Mod	Low	Low	Low	Mod	Mod
Katanning	Mod	High	Low	Low	Low	Low	High	Low
Kendenup	High	Low	Low	Low	High	High	Low	High
Kojonup	Low	High	Low	Low	Low	Low	High	Low
Williams	High	Mod	Low	Low	Low	Low	Mod	Mod

Figure 2. Upper canopy infection includes blackleg infection of flowers, peduncles, pods, main stems and branches.

loss. This data indicates that although flowering time is one factor important in the development of UCI, seasonal conditions will determine the prevalence and severity of UCI. Spore development and release, as well as infection events interact with crop development stage to produce varying severity of UCI. Further research is required to understand and predict these interactions.

Infection of pods by blackleg can cause complete loss of pods as they break off the plant or shatter prematurely. Grain inside infected pods retained on the plant can also be affected (Table 2). Pods with increasing severity of blackleg lesions have reduced grain size and may have fewer seeds/pod. Severe blackleg lesions (>10mm) reduced grain size by up to 22% indicating that the effects of pod infection occur after seed number is set but that seeds may be aborted if directly infected. In addition, fully formed seed within infected pods and which is retained for future use is infected with blackleg. Plants growing from infected seed can have seedling blight resulting in poor crop establishment. Given the high level of pod infection by blackleg and alternaria (both of which can cause seedling blight) it is recommended that seed from crops with infected pods is not retained for sowing. If retaining seed, grade it for larger seed which is less likely to be infected with blackleg and ensure even and adequate treatment with an appropriate fungicide to control seedling blight.

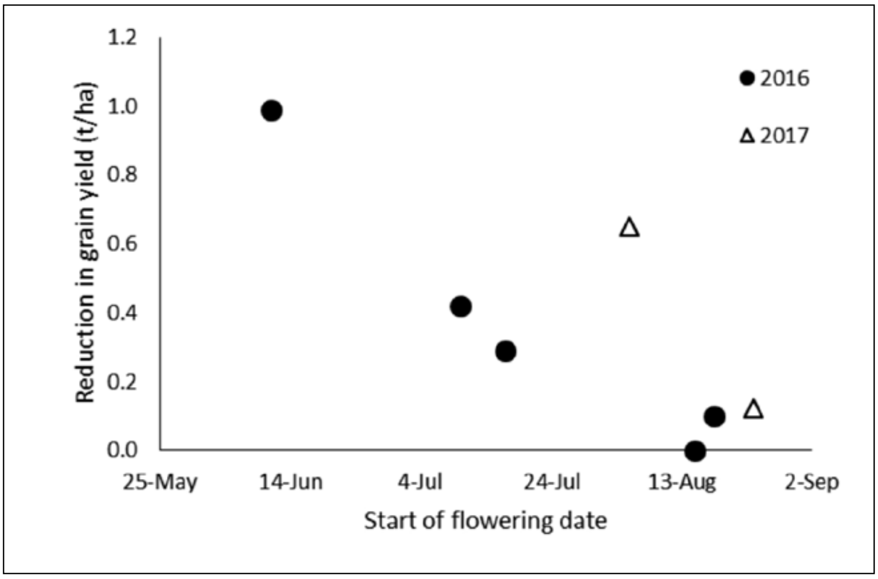

Figure 3. Yield loss caused by Blackleg UCI in cultivar Pioneer®44Y89CL differing in start of flowering date in southern NSW in 2016 and 2017. Yield reduction was the difference between treatments with none or full disease control.

Table 2. The yield components of individual pods with blackleg pod lesions at Canowindra and Wagga Wagga (cv 44Y89CL⁽ᴾ⁾), NSW in 2016 and Horsham (ATR-Stingray⁽ᴾ⁾), VIC in 2017. TGW = thousand grain weight. Values followed by the same letter within each column are not significantly different (P<0.05).

Pod blackleg lesion size	2016				Victoria 2017	
	Canowindra, NSW		Wagga Wagga, NSW		Horsham, VIC	
	TGW (g)	Seeds/pod	TGW (g)	Seeds/pod	TGW (g)	Seeds/pod
No lesions	3.69a	19.3a	3.43a	23.4a	2.98a	22.6a
<3mm	3.57b	19.8a	3.26ab	21.7b	3.23a	20.5a
3-5mm	3.45c	19.0a	3.26ab	21.4b	3.14a	19.9a
5-10mm	3.37cd	19.3a	3.20bc	20.4c	2.89a	21.3a
>10mm	3.17d	18.5a	3.06d	18.8d	2.33b	20.8a

Table 3. The yield components of pods harvested from the main raceme of plants with blackleg branch lesions at Wagga Wagga (cvs. Pioneer®44Y89CL, Nuseed Diamond and Archer) in 2017. Pods were collected above the lesions on each plant. The data are the mean of the cultivars as their response to disease was the same. TGW = thousand grain weight. Values followed by the same letter within each column are not significantly different (P<0.05).

Severity of blackleg branch lesion	TGW (g)	Seeds/pod
No lesion	3.73ab	12.63a
Moderate	3.92a	11.35b
Severe	3.59bc	9.70c

In contrast to pod lesions which directly affect the developing seed, branch lesions cause a disruption to the flow of nutrients to the developing pods and seeds. In 2017, branch lesions reduced the number of seeds/pod and also seed weight (Table 3). Consistent effects were found in three cultivars with different flowering times: Nuseed Diamond, Pioneer®44Y89CL and Archer.

Control of UCI — what we know and don't know

In 2017, experiments were conducted to confirm the effects of flowering time, cultivar resistance and fungicide use/timing. The results can be summarised as the following:

- Pod infection was the predominant symptom present in experiments in 2017. Later flowering reduced disease severity (Table 4).
- In 2016 levels of UCI infections were low in plants that flowered after July. However, in 2017 although symptoms were reduced in plants that flowered after July there was still some severe pod infection and UCI in late flowering plants (Table 4 and Table 6).
- Cultivars with effective major gene resistance do not get UCI symptoms, including pod infection (e.g. Group ABDF) (Table 4). Cultivars in Resistance Group C have no effective resistance to UCI in Australia. In these cultivars, the Blackleg Rating indicates resistance to crown canker only, not UCI. Although ATR-Stingray⍉ has higher levels of UCI than Archer, this is solely due to the earlier flowering time of ATR-Stingray⍉.
- Fungicides applied during the reproductive growth stages will reduce the severity of UCI. However, the economics of fungicide application at this stage are yet to be determined. The economic return will depend on the severity of symptoms and the timing of fungicide application. For example, ATR-Stingray⍉ sown in March will have a greater return from fungicide application compared to ATR-Stingray⍉ sown in June as it would flower outside the critical window for infection. Archer (later flowering cultivar) did not get enough UCI to warrant control regardless of sowing time. Hyola®350TT (Group ABDF) with effective major gene resistance did not get enough UCI to warrant control regardless of sowing time (Table 5 and Table 6).

Table 4. 2017 Effect of flowering date and cultivar resistance of upper canopy infection symptoms. Experiment undertaken in pots with canola stubble spread around the pots to ensure disease inoculation at Horsham, VIC.

Cultivar + date 1st flower	% flower infection	Stem infection 0-4	Branch infection 0-4	% head infection	% pod infection	% crown canker
ATR-Stingray⍉ MR + Group C ineffective major gene in this experiment						
9-Jul	2.8	0.2	0.5	0.3	33	0
30-Jul	1.5	0.1	0.7	0.2	27	1
25-Aug	1.5	0.1	0.7	0.1	3	8
10-Sep	0.8	0.1	0.2	0.0	1	12
Archer MS + Group C (ineffective major gene in this experiment)						
14-Aug	0.2	0.6	0.6	0.2	4	5
29-Aug	0.0	0.5	0.6	0.1	3	22
9-Sep	1.0	0.2	0.6	0.1	1	37
19-Sep	0.5	0.1	0.1	0.0	0	38
Nuseed Diamond R + Group ABF (partially effective major gene in this experiment)						
28-Jun	2.8	0.1	0.4	0.2	7	1
20-Jul	0.3	0.0	0.2	0.1	17	1
13-Aug	1.5	0.0	0.5	0.1	2	12
8-Sep	0.5	0.0	0.5	0.0	1	7
Nuseed GT42 Group ABDF (immune in this experiment)						
7-Jul	0.0	0.0	0.0	0.0	2	0
7-Aug	0.0	0.0	0.0	0.0	0	0
2-Sep	0.0	0.1	0.0	0.0	0	1
16-Sep	0.0	0.0	0.0	0.0	0	1
Hyola®350TT Group ABDF (immune in this experiment)						
7-Jul	0.0	0.0	0.0	0.0	2	0
27-Jul	0.2	0.0	0.0	0.0	0	0
25-Aug	0.7	0.0	0.0	0.0	0	2
9-Sep	0.3	0.0	0.0	0.0	0	1

The 0 to 4 scale: 0=no symptoms, 1=symptoms present, 2=symptoms common, 3=symptoms causing significant damage, 4=stem or branch death.

Table 5. Effect of flowering date and fungicide application on upper canopy infection symptoms and yield. Experiment undertaken in pots with canola stubble spread around the pots to ensure disease inoculation. UT = untreated, Full = full control. Cultivar ATR-Stingray⁽ᵇ.

Fungicide application timing	% flower infection	Stem infection 0-4	Branch infection 0-4	Head	% pod infection	% crown canker	Yield % of untreated
1st flower 9 July							
Untreated	1.7	0.6	0.2	0.58	34	0	100
30% bloom	0.8	0.2	0.0	0.30	34	0	116
Full	0.2	0.1	0.0	0.01	2	0	155
1st flower 25 August							
Untreated	3.7	0.9	0.2	0.10	4	4	100
30% bloom	1.7	0.3	0.0	0.02	2	5	97
Full	1.3	0.1	0.0	0.02	1	5	116

The 0 to 4 scale: 0=no symptoms, 1=symptoms present, 2=symptoms common, 3=symptoms causing significant damage, 4=stem or branch death.

Table 6. 2017 Effect of flowering date and fungicide application on upper canopy infection symptoms and yield. Experiment undertaken in the field at Longerenong, VIC, sown in plots exposed to natural blackleg inoculum. There were only very low levels of blackleg crown canker, no sclerotinia and no other diseases present.

Fungicide application timing	ATR-Stingray⁽ᵇ MR Group C Early flower	Cultivar ATR-Gem⁽ᵇ MS Group A Mid flower	ATR-Wahoo⁽ᵇ MS Group A Late flower
1st flower date			
Sown 14-April	17 Aug	13 Aug	28 Aug
% flowers infected			
Untreated	12	10	11
30% bloom	5	7	9
Full control	5	0	0
Stem infection (0-4 scale, 4 =stem death)			
Untreated	0.5	0.9	0.4
30% bloom	0.1	0.6	0.4
Full control	0.2	0.1	0.2
Branch infection (0-4 scale, 4 =branch death)			
Untreated	1.2	1.1	0.9
30% bloom	0.5	0.5	1.0
Full control	0.5	0.2	0.2
% pods infected			
Untreated	13	20	14
30% bloom	10	6	6
Full control	6	3	5
Yield (% of untreated control)			
Untreated	100	100	100
30% bloom	110	112	108
Full control	118	112	121

The 0 to 4 scale: 0=no symptoms, 1=symptoms present, 2=symptoms common, 3=symptoms causing significant damage, 4=stem or branch death.

- Data indicates that spraying at 30% bloom for sclerotinia control may reduce UCI symptoms if the season is conducive to disease development (Table 5 and Table 6).
- There is insufficient knowledge to recommend spraying solely for UCI control.
- In both 2016 and 2017 the yield responses to controlling UCI appear to be greater than the reduction in levels of visible symptoms of UCI. That is, small reductions in symptoms have resulted in significant yield increases. Infection by the blackleg fungus does not always produce visible symptoms. Symptomless infection of the crown can cause significant damage to the plant vascular tissue, and evidence suggests that branch and stem infection is similar. Further research is required to understand how UCI is causing yield losses (Table 5 and Table 6).

Blackleg management App — BlacklegCM

The current Blackleg Management Guide (https://grdc.com.au/__data/assets/pdf_file/0017/236051/blackleg-management-guide-2017-autumn-variety-ratings.pdf.pdf) contains information on the management factors that influence the severity of blackleg in your crop. It specifically lists cultural practices such as crop rotation and distances to canola stubble (inoculum source), the appropriate scenarios for fungicide application and presents the Blackleg Rating and Resistance Group for each cultivar. The Management Guide is updated twice yearly as the resistance status of individual cultivars can change as the blackleg fungus overcomes host resistance genes.

Although the Management Guide provides useful information, it has some limitations in its current form. Currently, it is difficult to consider complex interactions. For example, the use of cultivars with different Blackleg Ratings in high or low rainfall environments and the effect of fungicide use. Consequently, there has been a need to develop a management tool that can provide disease forecasting based on the management principles proposed by the manager of an individual paddock. This has led to the development of the new Blackleg Management App. 'BlacklegCM'.

BlacklegCM assists you to manage blackleg disease in Australian canola crops by integrating the information provided in the Blackleg Management Guide and producing a predicted economic outcome. BlacklegCM can be modified to account for some of the major factors that relate to risk of yield loss due to blackleg disease in your paddock. It allows you to compare the likely relative profitability of different disease management strategies including paddock selection, cultivar choice, seed dressing, banded fungicide and sprayed fungicide.

BlacklegCM takes account of costs, yield benefits and grain prices to give you best case, worst case and most likely estimates of economic return.

BlacklegCM accounts for the major factors that influence blackleg severity. The user has the option to change each parameter to tailor the output to their cropping circumstance. Consequently, the user can explore their options for disease control and understand the relative importance of each factor. For example, distance to one year old stubble has a large influence on disease severity, while two year old stubble has a minor influence. Foliar fungicide has a small influence if used in isolation but is very effective if used in combination with a seed dressing fungicide. Foliar fungicide on a one tonne crop is likely to cause an economic loss while fungicide on a three tonne crop is more likely to result in a large profit.

The strength of the App is that it allows the user to make as many comparisons as they wish in order to determine the best and most profitable way for them to reduce disease and increase profits.

The App is a result of 30 years of blackleg research. It has had input from all members of the GRDC investment 'National canola pathology program' and has been built by the 'National pathogen management modelling and decision support project'. The App has already been extensively tested by advisers and the interfaces were determined based on advisers' recommendations (Figures 4, 5, 6 and 7) .

BlacklegCM App loads with many options. The user can set these options to best match their circumstance (Figure 4).

Figure 4. Options available with use of BlacklegCM App.

Crop circumstances

The user puts in basic parameters such as target yield, production costs, grain price, and regional canola intensity (Figure 5).

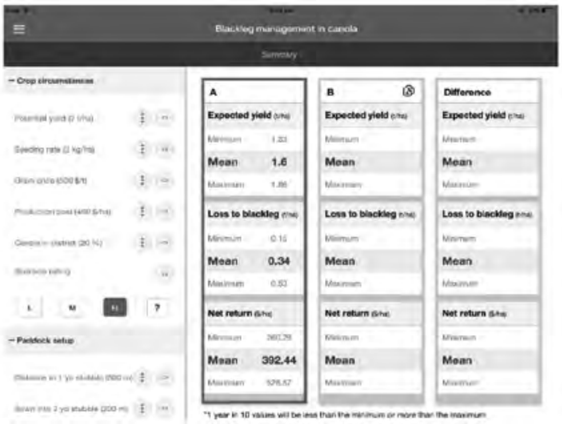

Figure 5. BlacklegCM App interface to collect information regarding crop circumstances.

Paddock set up

Within the paddock set up section, it's possible for the user to fill in distance to one and two year old stubble and whether the stubble has been left standing or has been knocked down (Figure 6).

Figure 6. BlacklegCM App interface to collect information regarding paddock set up.

Management options

Within the management options section the user is able to choose your cultivar, and indicate whether your cultivar has reduced resistance in your region. This can be determined from monitoring past crops, but if unknown the App will default to 'Not reduced'. If major resistance changes have occurred there will be published warnings, such as 'Group D resistance warning on the Eyre Peninsula in 2012'.The management options section also enables the user to add their fungicide plans, seed treatment, fertiliser amended or foliar application (Figure 7).

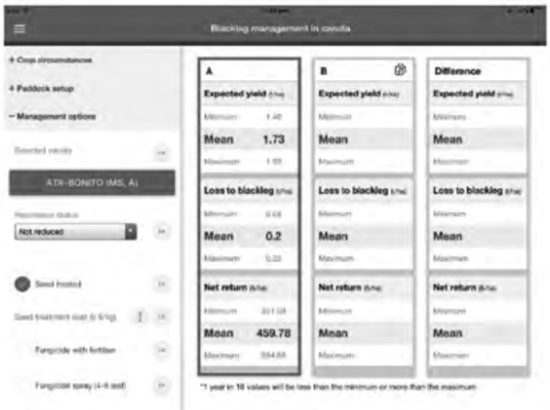

Figure 7. BlacklegCM App interface to collect information regarding management options.

Once all of the parameters have been entered, the real power of the App becomes apparent as it determines the likely blackleg severity, yield loss and economic return from the parameters that have been entered. But unlike the current paper management guide, the App can calculate an immense number of interactions. For instance, in a low rainfall environment the App will determine that most management options do not results in yield loss and fungicide use may even result in economic loss. Whereas in the high rainfall, high canola intensity regions even small changes in management may result in varying levels of disease. The App also enables the user to compare different management options.

Case study

In 2018 a grower has ATR-Bonito$^{\phi}$ seed which formerly had a blackleg rating of MR, however, it has fallen to Blackleg Rating MS. Should the grower use their ATR Bonito$^{\phi}$ seed as intended or get new seed of a more resistant cultivar?

The grower puts in their parameters:

Potential yield: 2t/ha

Seeding rate: 3kg/ha

Grain price: $500/t

Production cost: $400/ha

Canola in the district: 20%

Spore maturity risk: High

Distance to one year old stubble: 10metres

Distance to two year old stubble: 200meters

Two year old stubble: standing

Cultivar: ATR Bonito$^{\phi}$

Seed treatment: No

Fungicide with fertiliser: No

Fungicide spray: No

The predicted yield loss from blackleg is 20%.

The grower can now change parameters:

New cultivar with R rating = 20% yield loss reduced to 0% yield loss.

ATR Bonito⁽ᶲ⁾ with seed dressing and foliar fungicide = 20% yield loss reduced to 4% yield loss.

ATR Bonito⁽ᶲ⁾ sown with increased distance to one year old stubble = 20% yield loss reduced to 10% yield loss.

The App will also be updated continuously to ensure that it has all the current canola cultivars and their current blackleg rating. All new knowledge will also be incorporated; for instance, knowledge on UCI and different fungicide timings will be incorporated in the near future.

The App can also be used during the growing season, for instance in 2016 many growers planned for a 2t/ha crop but soon realised that yield potentials were much higher. Members of the canola pathology team then warned of a very high blackleg lesion severity. In this scenario in July, growers could have re-run the App with 3t/ha rather than 2t/ha yield target and compared plus or minus foliar fungicide.

It is envisaged that this App will continue to grow and evolve with the canola industry and become the mainstay for blackleg knowledge in Australia.

Useful resources

https://grdc.com.au/resources-and-publications/all-publications/publications/2017/09/blackleg-management-guide

www.nvtonline.com.au

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

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Notes

Notes

THE 2017-2019 GRDC SOUTHERN REGIONAL PANEL

JULY 2018

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHAIR - KEITH PENGILLEY

Keith was previously the general manager of a dryland and irrigated family farming operation at Conara (Tasmania), operating a 7000 hectare mixed-farming operation over three properties. Keith's role as chair of the Southern Region Panel finishes on 31 August 2018 at which time John Bennett will take up this role. The GRDC Southern Regional Panel identifies grower priorities and advises on the GRDC's research, development and extension investments in the southern grains region.

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DEPUTY CHAIR - MIKE MCLAUGHLIN

Mike is a researcher with the University of Adelaide, based at the Waite campus in South Australia. He specialises in soil fertility and crop nutrition, contaminants in fertilisers, wastes, soils and crops. Mike manages the Fertiliser Technology Research Centre at the University of Adelaide and has a wide network of contacts and collaborators nationally and internationally in the fertiliser industry and in soil fertility research.

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JOHN BENNETT

Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John, his wife Allison and family run a mixed farming operation across diverse soil types. The farming system is 70 to 80 percent cropping, with cereals, oilseeds, legumes and hay grown. John believes in the science-based research, new technologies and opportunities that the GRDC delivers to graingrowers. He wants to see RD&E investments promote resilient and sustainable farming systems that deliver more profit to growers and ultimately make agriculture an exciting career path for young people.

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PETER KUHLMANN

Peter is a farmer at Mudamuckla near Ceduna on South Australia's Western Eyre Peninsula. He uses liquid fertiliser, no-till and variable rate technology to assist in the challenge of dealing with low rainfall and subsoil constraints. Peter has been a board member of and chaired the Eyre Peninsula Agricultural Research Foundation and the South Australian Grain Industry Trust.

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FIONA MARSHALL

Fiona has been farming with her husband Craig for 21 years at Mulwala in the Southern Riverina. They are broadacre, dryland grain producers and also operate a sheep enterprise. Fiona has a background in applied science and education and is currently serving as a committee member of Riverine Plains Inc, an independent farming systems group. She is passionate about improving the profile and profitability of Australian grain growers.

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JON MIDWOOD

Jon has worked in agriculture for the past three decades, both in the UK and in Australia. In 2004 he moved to Geelong, Victoria, and managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high rainfall zone. In 2007, his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). In 2010 he became Chief Executive of SFS, which has five branches covering southern Victoria and Tasmania. In 2012, Jon became a member of the GRDC's HRZ Regional Cropping Solutions Network.

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ROHAN MOTT

A fourth generation grain grower at Turriff in the Victorian Mallee, Rohan has been farming for more than 25 years and is a director of Mott Ag. With significant on-farm storage investment, Mott Ag produces wheat, barley, lupins, field peas, lentils and vetch, including vetch hay. Rohan continually strives to improve productivity and profitability within Mott Ag through broadening his understanding and knowledge of agriculture. Rohan is passionate about agricultural sustainability, has a keen interest in new technology and is always seeking ways to improve on-farm practice.

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RICHARD MURDOCH

Richard along with wife Lee-Anne, son Will and staff, grow wheat, canola, lentils and faba beans on some challenging soil types at Warooka on South Australia's Yorke Peninsula. They also operate a self-replacing Murray Grey cattle herd and Merino sheep flock. Sharing knowledge and strategies with the next generation is important to Richard whose passion for agriculture has extended beyond the farm to include involvement in the Agricultural Bureau of SA, Advisory Board of Agriculture SA, Agribusiness Council of Australia SA, the YP Alkaline Soils Group and grain marketing groups.

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KATE WILSON

Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region. Kate and husband Grant are fourth generation farmers producing wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years, servicing clients throughout the Mallee and northern Wimmera. Having witnessed and implemented much change in farming practices over the past two decades, Kate is passionate about RD&E to bring about positive practice change to growers.

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BRONDWEN MACLEAN

Brondwen MacLean has spent the past 20 years working with the GRDC across a variety of roles and is currently serving as General Manager for the Applied R&D business group. She has primary accountability for managing all aspects of the GRDC's applied RD&E investments and aims to ensure that these investments generate the best possible return for Australian grain growers. Ms MacLean appreciates the issues growers face in their paddocks and businesses. She is committed to finding effective and practical solutions `from the ground-up'.

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2017–2019 SOUTHERN REGIONAL CROPPING SOLUTIONS NETWORK (RCSN)

The RCSN initiative was established to identify priority grains industry issues and desired outcomes and assist the GRDC in the development, delivery and review of targeted RD&E activities, creating enduring profitability for Australian grain growers. The composition and leadership of the RCSNs ensures constraints and opportunities are promptly identified, captured and effectively addressed. The initiative provides a transparent process that will guide the development of targeted investments aimed at delivering the knowledge, tools or technology required by growers now and in the future. Membership of the RCSN network comprises growers, researchers, advisers and agribusiness professionals. The three networks are focused on farming systems within a particular zone – low rainfall, medium rainfall and high rainfall – and comprise 38 RCSN members in total across these zones.

REGIONAL CROPPING SOLUTIONS NETWORK SUPPORT TEAM

SOUTHERN RCSN CO-ORDINATOR: JEN LILLECRAPP

Jen is an experienced extension consultant and partner in a diversified farm business, which includes sheep, cattle, cropping and viticultural enterprises. Based at Struan in South Australia, Jen has a comprehensive knowledge of farming systems and issues affecting the profitability of grains production, especially in the high rainfall zone. In her previous roles as a district agronomist and operations manager, she provided extension services and delivered a range of training programs for local growers. Jen was instrumental in establishing and building the MacKillop Farm Management Group and through validation trials and demonstrations extended the findings to support growers and advisers in adopting best management practices. She has provided facilitation and coordination services for the high and medium rainfall zone RCSNs since the initiative's inception.

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LOW RAINFALL ZONE CO-LEAD: BARRY MUDGE

Barry has been involved in the agricultural sector for more than 30 years. For 12 years he was a rural officer/regional manager in the Commonwealth Development Bank. He then managed a family farming property in the Upper North of SA for 15 years before becoming a consultant with Rural Solutions SA in 2007. He is now a private consultant and continues to run his family property at Port Germein. Barry has expert and applied knowledge and experience in agricultural economics. He believes variability in agriculture provides opportunities as well as challenges and should be harnessed as a driver of profitability within farming systems. Barry was a previous member of the Low Rainfall RCSN and is current chair of the Upper North Farming Systems group.

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LOW RAINFALL ZONE CO-LEAD: JOHN STUCHBERY

John is a highly experienced, business-minded consultant with a track record of converting evidence-based research into practical, profitable solutions for grain growers. Based at Donald in Victoria, John is well regarded as an applied researcher, project reviewer, strategic thinker and experienced facilitator. He is the founder and former owner of JSA Independent (formerly John Stuchbery and Associates) and is a member of the SA and Victorian Independent Consultants group, a former FM500 facilitator, a GRDC Weeds Investment Review Committee member, and technical consultant to BCG-GRDC funded 'Flexible Farming Systems and Water Use Efficiency' projects. He is currently a senior consultant with AGRIvision Consultants.

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HIGH RAINFALL ZONE LEAD: CAM NICHOLSON

Cam is an agricultural consultant and livestock producer on Victoria's Bellarine Peninsula. A consultant for more than 30 years, he has managed several research, development and extension programs for organisations including the GRDC (leading the Grain and Graze Programs), Meat and Livestock Australia and Dairy Australia. Cam specialises in whole-farm analysis and risk management. He is passionate about up-skilling growers and advisers to develop strategies and make better-informed decisions to manage risk – critical to the success of a farm business. Cam is the program manager of the Woady Yaloak Catchment Group and was highly commended in the 2015 Bob Hawke Landcare Awards.

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MEDIUM RAINFALL ZONE LEAD: KATE BURKE

An experienced trainer and facilitator, Kate is highly regarded across the southern region as a consultant, research project manager, public speaker and facilitator. Based at Echuca in Victoria, she is a skilled strategist with natural empathy for rural communities. Having held various roles from research to commercial management during 25 years in the grains sector, Kate is now the managing director of Think Agri Pty Ltd, which combines her expertise in corporate agriculture and family farming. Previously Kate spent 12 years as a cropping consultant with JSA Independent in the Victorian Mallee and Wimmera and three years as a commercial manager at Warakirri Cropping Trust.

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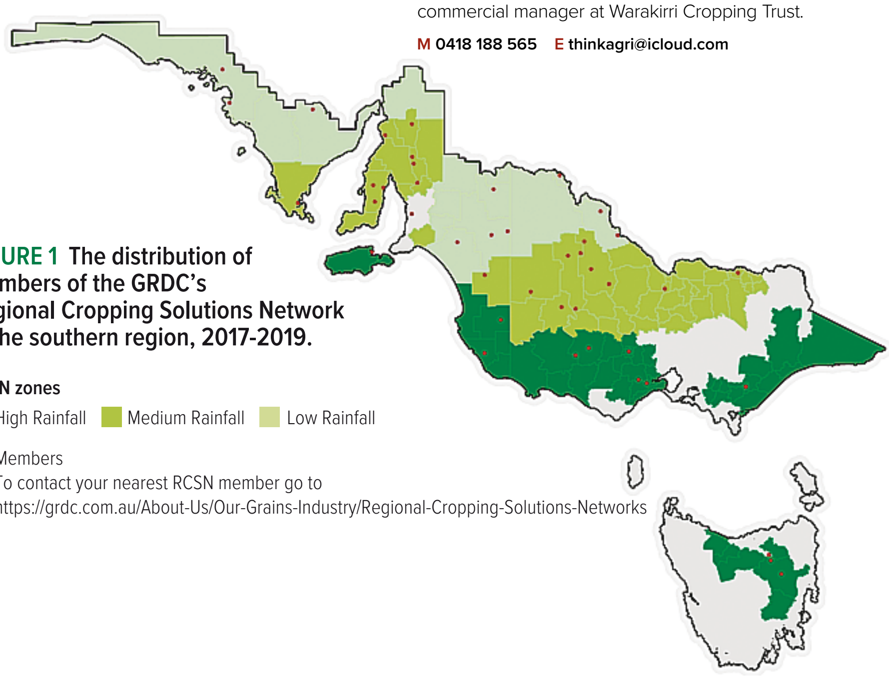

FIGURE 1 The distribution of members of the GRDC's Regional Cropping Solutions Network in the southern region, 2017-2019.

RCSN zones

High Rainfall | Medium Rainfall | Low Rainfall

Members

To contact your nearest RCSN member go to https://grdc.com.au/About-Us/Our-Grains-Industry/Regional-Cropping-Solutions-Networks

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

- Partnering organisation: MFMG

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& DEVELOPMENT
CORPORATION

You can now provide feedback electronically 'as you go'. An electronic evaluation form can be accessed by typing the URL address below into your internet browser.

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

- Complete the survey on one device (i.e. don't swap between your iPad and Smartphone devices. Information will be lost).
- One person per device (Once you start the survey, someone else cannot use your device to complete their survey).
- You can start and stop the survey whenever you choose, **just click 'Next' to save responses before exiting the survey**. For example, after a session you can complete the relevant questions and then re-access the survey following other sessions.

www.surveymonkey.com/r/Naracoorte-GRU

2018 Naracoorte GRDC Grains Research Update Evaluation

1. Name [ ]

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

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

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

Your feedback on the presentations

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

3. Insects, resistance and control: *James Maino*

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

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

4. Does glyphosate formulation affect the control of glyphosate resistant weeds? *Peter Boutsalis*

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

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

5. Filling the yield gap – optimising yield and economic potential of high input cropping systems in the HRZ: *Malcolm McCaskill*

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

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

6. Better pastures, better crops: *Cam Nicholson*

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

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

7. Blackleg in canola: an update on resistance, Upper Canopy Infection and a new management App: *Steve Marcroft*

Content relevance ☐ /10 Presentation quality ☐ /10

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

Your next steps

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

9. What are the first steps you will take?

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

Your feedback on the Update

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

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

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

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

Comments

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

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

Thank you for your feedback.