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GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC 2020 Grains Research Update Welcome

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

Welcome.

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

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

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

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

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

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

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

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

Regards,
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Farming systems: profit, water, nutritional and disease implications of different crop sequences and system intensities in SNSW

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Take home message

- Southern NSW growers and consultants were consulted for 12 months (2017) to establish four state-of-the-art farming systems research sites targeting the next step changes in WUE and farm profit
- For the first time, interactions of crop sequence, early sowing systems (with and without grazing) and nitrogen fertiliser strategies were established and monitored for WUE, production and profit
- Results to date from two consecutive decile 1 seasons (2018 and 2019) have shown that the 2-year average annual earnings before interest and taxes (EBIT) ranged from -$50 to $1000/ha across the sites, and at all sites there were options that outperformed the Baseline (canola-wheat sequences) by $200 to $500/ha
- Under the dry conditions, grazing crops and barley were highly profitable at all sites, but there were also legume options at all sites that outperformed baseline wheat and canola sequences
- Legacy effects of water and N generated by both crop choice (legumes) or fertiliser strategy increased profit in subsequent crops by $200-$300/ha due to increased grazing, hay or grain.

Background – changing the WUE paradigm from crop to crop sequence

Australian farmers have been enthusiastic adopters of crop benchmarking tools (such as French and Schultz or Yield Prophet®) to compare the performance of individual crops to water-limited potential. However, in dryland farming systems, it makes sense to consider the efficiency of water use across the crop sequence, to account for the inevitable legacy effects of one crop to the next (i.e. carry over effects on water, N, weeds and disease). Recent analysis in southern QLD and northern NSW revealed only 30% of paddocks had crop sequences that were achieving >75% of predicted potential, much lower than for individual crops. No similar study has been conducted in southern NSW, but recent crop sequence studies have shown the value of diversifying the crop sequence to maintain profit and manage biotic constraints. The average annual gross margins of the best 3 to 4-year sequences was often $400/ha higher than the worst, and $150 to $200/ha better than common sequences, even when individual crops were well managed (see Further Reading).

In addition to improved crop sequences, new early sowing systems are proving efficient and profitable for individual wheat and canola crops (including grazed crops), but the legacy of dry soils left by these higher-yielding crops across the sequence may affect following crops. Preliminary simulation studies in southern NSW suggest earlier sowing strategies can provide benefits across the crop sequence, but this is influenced by rainfall, crop sequence and modified by N management.

No previous study has investigated the interactions of crop sequence choices, sowing time and N supply on efficiency and profitability across a whole sequence. Our project, now in its third year, is investigating these interactions to develop strategies to convert annual rainfall into more profit across a crop sequence while managing costs, risk, soil fertility, weeds and diseases.

The Southern Farming Systems Project

This project builds on recent GRDC projects in southern NSW and on a sister project that commenced earlier in northern NSW and QLD (Zull et al., 2020). During 2017, we reviewed the existing literature, conducted a comprehensive survey of growers and agronomists and established sites with sequence, sowing date and N treatments relevant to local growers and advisors.

To cover the range of soil and climate in southern NSW, sites were established at Wagga Wagga (core site), Greenethorpe (higher rainfall), Condobolin (lower rainfall) and Urana (different soil type). A range of different sequences were established to compare with the common baseline of canola-wheat sequences (Table 1). These included more intensive cereal sequences (wheat and barley), a range of high (lentil, chickpea) and low-value (lupin, faba) legume options as well as grazing and forage options. These treatments generate different water and N-use patterns as well as weed, disease and cover legacies monitored by the team.

In addition, for some sequences, we included interactions of early sowing (March-early April) and timely sowing (mid-April-mid May) of wheat and canola options (grazed and ungrazed), and different N management strategies based on either Decile 2 or 7 outlooks for spring. These treatments, developed with local advisers generated a range of different management and sequence decisions to influence the pattern of water and N use as well as the cost, risk and ultimately the efficiency of the system ($/ha/mm). In addition to the planned and phased sequences, we included "flexible" treatments managed by local advisors, where they nominated the crops and their management.

Together with the experimental measurements we are running APSIM simulations to extrapolate the results across more sites and seasons, and to update pre-experimental modelling predictions with validated data. This combination of multi-site experiments and simulation will provide powerful insights to the drivers of higher systems efficiency.

Table 1. Treatment summary - including crop sequence, time of sowing and N strategy from the Wagga Wagga core experimental site. A subset of these treatments relevant to the other sites were established according to local grower and consultant advice. Common treatments at all sites are shown in grey.

Treatment description	Sequence	Sowing time	N strategy (Decile 2 or 7)	Grazing
Baseline	Canola-wheat-barley	Timely	2, 7	
Intense Baseline	Canola-wheat	Early, timely	2, 7	Yes
Diverse high value 1	Lentil-canola-wheat	Early, timely	2, 7	
Diverse high value 2	chickpea-wheat	Timely	2	
Diverse low value	(Faba/lupin)-canola-wheat	Timely	2	
Diverse (mix)	HDL*-canola-wheat	Early, timely	2, 7	Yes
Continuous wheat	Wheat-wheat-wheat	Timely	2, 7	
Fallow	Fallow-canola-wheat	Early, timely	7	
Intercrop	Mixed species#-wheat	Timely	2	
Ley phase	Biserrula-wheat	Timely	2	Yes
Flexible	e.g. Safflower-barley-chickpea	Flexible	Flexible	
Intense baseline + organic matter (OM)	Canola-wheat	Timely	2	

*HDL= high density legume mix (vetch, arrowleaf clover, balansa clover)
Intercrop mixed species = 2018, 2019 (mix of faba bean/canola); 2020 (mix of linseed/chickpea)

Key outcomes to date

The context – dry conditions in 2018-2019

As most sequences involve 3-year phases, a full statistical analysis of the sequences is not yet possible. In addition, the 2018 and 2019 seasons have been consecutive decile 1 seasons, so that most of the responses measured to date are relevant to the context of very dry, low rainfall seasons. In 2018, early sown options received small amounts of supplementary irrigation (<10mm) to establish crops, while at Condobolin in 2019, irrigation was required to keep the experiment viable. The amount of rainfall at each site across the two seasons and the long-term mean are shown in Table 1.

Table 2. Rainfall (irrigation in brackets) at the experiment sites in 2018 and 2019 and the long-term median rainfall.

Site	2018	2019	LTM
Greenethorpe	359	353	579
Wagga Wagga	286	320	526
Urana	276	222	449
Condobolin	218 (120)	162 (118)	434

Despite the consecutive decile 1 seasons, all planned treatments were successfully established in both years, and given that context, some general observations across the sites, as well as some more specific observations emerging from the sites are presented here.

Annual profits (EBITs) varied widely - some options made good profits despite the conditions

Despite the decile 1 conditions, the annual earnings before interest and taxes (EBITs) for different crop options varied from -$500 to $1700/ha in 2018, and -$500 to $1200/ha in 2019, with the 2yr average annual EBITs varying from $-50 to $1000/ha across the sites (Figures 1, 2, 3, 4). The high profits overall were underpinned by good fallow management to preserve the summer rain that fell (strict weed control and stubble retention), and the timely and successful establishment of good plant populations across the sites.

Grazed crops were highly profitable

Early-sown grazed treatments (dual-purpose canola and wheat in Intense Baseline) were among the most profitable treatments at Greenethorpe and Wagga Wagga where they were included. (Figure 1, 2). This was the case in both years at Greenethorpe, while at Wagga Wagga in 2019, the earlier onset of stress limited biomass for grazing and regrowth after grazing (Table 3). However, at both sites, the early-sown dual-purpose wheat and canola crops were significantly more profitable than either early or timely-sown grain-only crops (un-grazed Intensive Baseline, Baseline), as the grazing provided significant income in these dry years where grain production was limited, and livestock prices were high.

The success of the dual purpose (DP) crops largely depended on an early sowing opportunity, and on deep stored water from either summer rainfall and good fallow management, or sequences with legumes (e.g. Diverse Mixed) which left legacies of water and N. At Greenethorpe, consecutive early-sown DP crops were able to capitalise on higher amounts of stored water to produce more than 3 times the profit achieved by the grain only (or hay) system **($1122/ha vs $334/ha)** (Figure 2, Table 3). At Wagga Wagga under drier conditions, income for the same DP crops declined in the second year (2019) due to legacies of drier soil, but still had higher profit than the grain-hay system ($379/ha vs $172/ha) (Figure 1, Table 3). More information on the DP crops can be found in Kirkegaard et al., (2020 a,b).

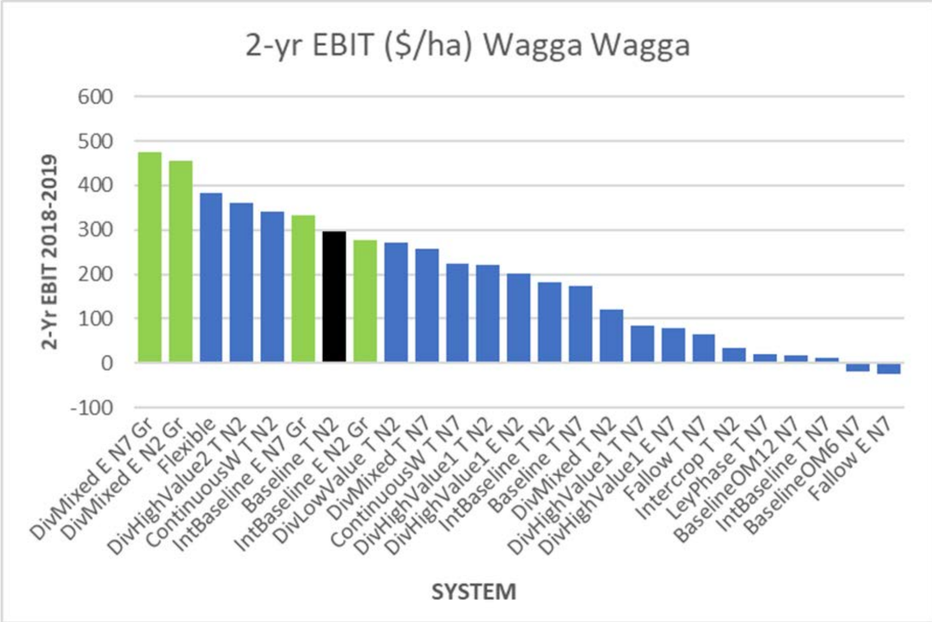

Figure 1. Two-year average annual EBIT for different treatments at Wagga Wagga. The Baseline treatment [canola-wheat-barley; timely sown; decile 2 N] is shown in black. Early sown grazed treatments are shown in green and were among the most profitable for the 2018-2019 seasons. Grazed sequences involving legumes (Diverse; Div) were more profitable than Intense Baseline (C-W only) as the legume was grazed, and also left legacies of water and N for the early-sown canola and wheat (see Table 1 for treatment descriptions). (T=Timely. N2 and N7 refers to nitrogen strategy for a decile 2 or 7 season. Gr=grazed. Div=Diverse. Int=Intense.)

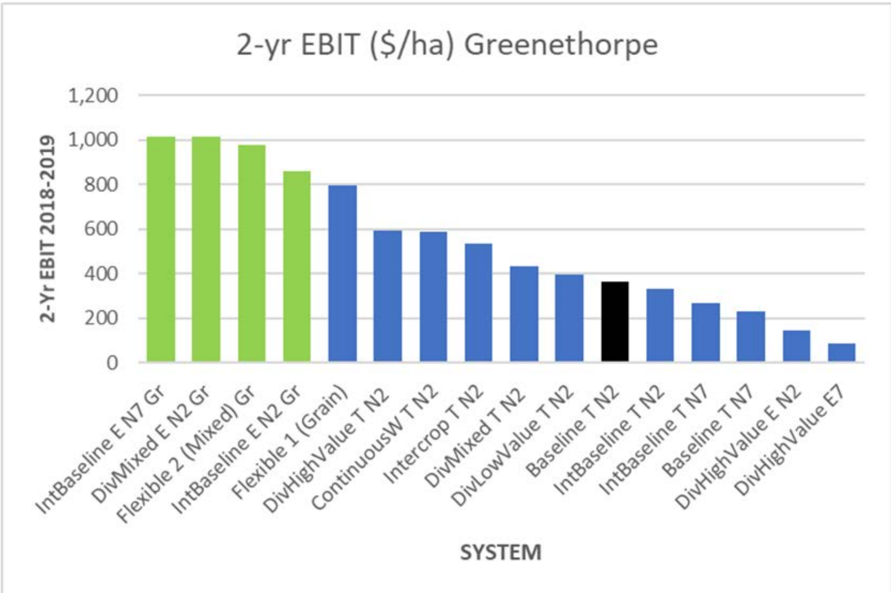

Figure 2. Two-year average annual EBIT for different treatments at Greenethorpe. The Baseline treatment [Canola-Wheat-Wheat; timely sown; Decile 2 N] is shown in black. Early sown grazed treatments are shown in green and were the most profitable for the 2018-2019 seasons. Numerous treatments were more profitable than the Baseline during 2018 and 2019. In general, the decile 2 N strategy was more profitable due to the drought (see Table 1 for treatment descriptions). T=Timely. N2 and N7 refers to nitrogen strategy for a decile 2 or 7 season. Gr=grazed. Div=Diverse. Int=Intense.)

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

Site/Crop	Dual-purpose system				Grain only system		
	Variety (sowing date)	Graze (t/ha)	Grain (t/ha)	EBIT ($/ha)	Variety (sowing date)	Grain/ (Hay) (t/ha)	EBIT ($/ha)
Greenethorpe							
2018 Wheat	LRPB Kittyhawkⓓ (5/4)	1.5	1.9	$862	Coolahⓓ (7/5)	2.7	$619
2019 Canola	Hyola®970 (23/3)	5.0	0	$1,414	HyTTec Trophy® (1/5)	(3.1)	$96
Ave 2-Yr EBIT				***$1,138***			***$358***
2018 Canola	Hyola970 (3/4)	3.5	0.9	$1,251	HyTTec Trophy (7/5)	1.1	$79
2019 Wheat	DS Bennettⓓ (26/3)	3.5	0	$960	Coolahⓓ (1/5)	(4.8)	$538
Ave 2-Yr EBIT				***$1106***			***$309***
Average 2-yr system EBIT				**$1122**			**$334**
Wagga Wagga							
2018 Wheat	LRPB Kittyhawkⓓ (3/4)	2.0	1.9	$974	Beckomⓓ (2/5)	2.1	$333
2019 Canola	Hyola970 (8/4)	2.7	0	$78	Pioneer 43Y92 CL (26/4)	1.1	$124
Ave 2-Yr EBIT				***$526***			***$229***
2018 Canola	Hyola970 (3/4)	3.1	0	$347	Pioneer 43Y92 CL (3/4)	1.2	$34
2019 Wheat	LRPB Kittyhawkⓓ (8/4)	2.8	0	$114	Beckomⓓ (6/5)	(3.5)	$198
Ave 2-Yr EBIT				***$231***			***$116***
Average 2-yr system EBIT				**$379**			**$172**

Grain legumes performed well at most sites

Grain legumes (fababean, lentil, lupin, pea and chickpea) and pasture legumes (vetch) performed well across the sites in both years and were never the least profitable crop option (Table 4). In 2018, they produced the highest non-grazed EBITs which were at or above $1,000/ha at 3 of the 4 sites. In 2019, the fababean at Urana and pea at Condobolin performed very well (among the most profitable options), while lentil and chickpea did not perform as well in 2019, but they generated moderate EBITs. In all cases there were legume options that outperformed canola and wheat at the sites. Diverse sequences (i.e. those that included a legume) also made higher 2-year profit then the Baseline treatments at all sites and were among the most profitable even when not grazed (Figures 1 to 4).

The grain legumes also left legacies of higher water and N in the soil at harvest. Compared to early-sown wheat or canola, there was 20mm more water and 50 kg/ha more N in 2018, and up to 60mm more water and 50-100 kg/ha more N in 2019. These legacy effects of the 2018 grain legumes on 2019 crops are discussed in the next section.

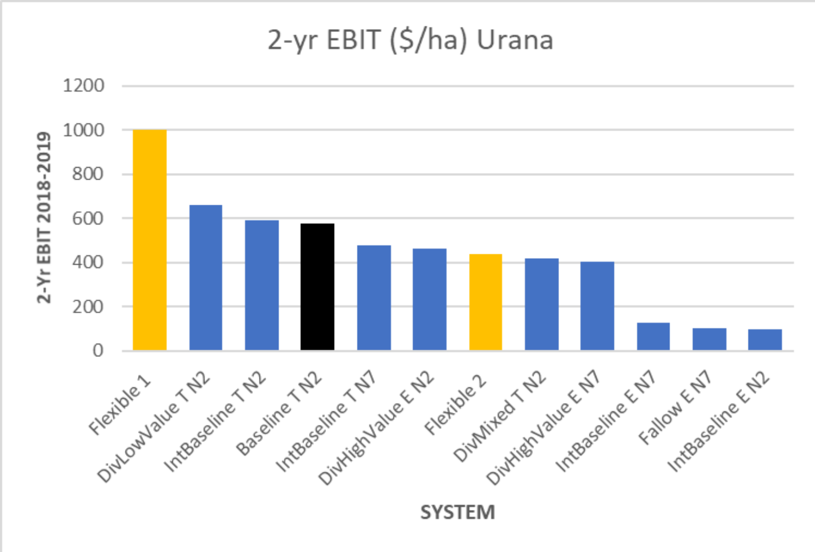

Figure 3. Two-year average annual EBITs for different treatments at Urana. The Baseline treatment [Canola-Wheat-Barley; timely sown; Decile 2 N] is shown in black. The highly profitable "Flexible" treatment was a safflower-barley sequence nominated by the grower. Early sown un-grazed treatments, and treatments including fallow had low profit. The Diverse treatment with low value legume (fababean-canola-wheat) was more profitable than the Baseline. (See Table 1 for treatment descriptions). (T=Timely. N2 and N7 refers to nitrogen strategy for a decile 2 or 7 season. Gr=grazed. Div=Diverse. Int=Intense.)

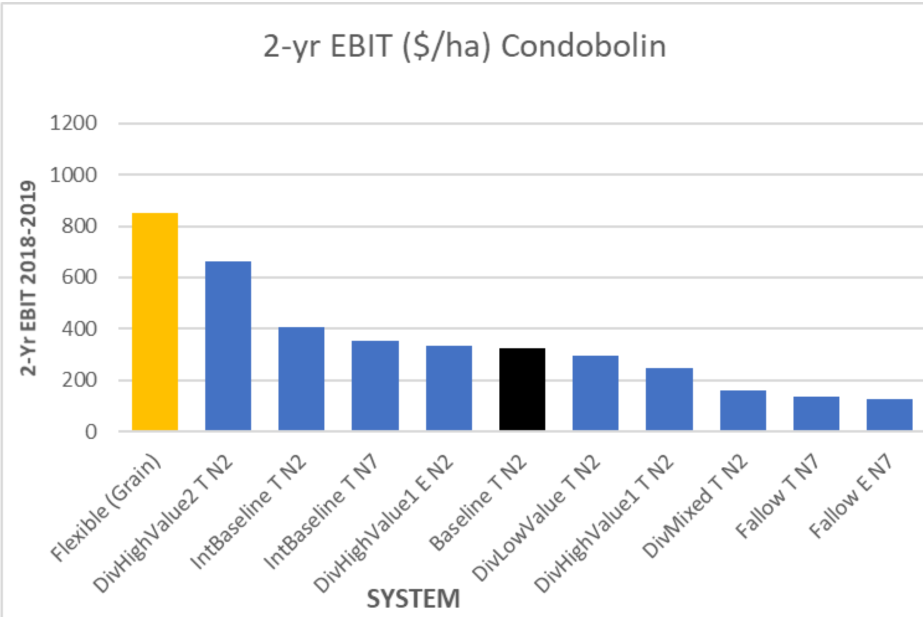

Figure 4. Two-year average annual EBIT for different treatments at Condobolin. The Baseline treatment [canola-wheat-barley; timely sown; decile 2 N] is shown in black. The highly profitable "Flexible" treatment was a barley-fieldpea sequence nominated by the consultant. The Diverse high value sequence (chickpea-wheat) was also highly profitable while the Fallow sequence (fallow-canola-wheat) had low profit as the low rainfall over both seasons meant poor fallow efficiency. (See Table 1 for treatment descriptions). (T=Timely. N2 and N7 refers to nitrogen strategy for a decile 2 or 7 season. Gr=grazed. Div=Diverse. Int=Intense.).

Table 4. Yield and profit achieved by different legume options across the sites in 2018 and 2019 compared to timely-sown wheat and canola crops (decile 2N) in Baseline treatments (grey). Legume options that are more profitable than both wheat and canola in each case are shown in bold.

Site/crop	Year 1 - 2018			Year 2 - 2019		
	Variety (Sow date)	Yield (t/ha)	EBIT $/ha	Variety (Sow date)	Yield (t/ha)	EBIT $/ha
Wagga Wagga						
Chickpea	PBA Slasherⓓ (10/5)	1.3	**$499**	PBA Slasherⓓ (13/5)	0.5	$87
Lentil	PBA HallmarkXTⓓ (10/5)	1.4	$313	PBA HallmarkXTⓓ (13/5)	0.7	$120
Lupin	Batemanⓓ (10/5)	1.6	**$338**	Batemanⓓ (13/5)	1.3	**$353**
Canola	*43Y92 CL (2/5)*	*1.2*	*$34*	*43Y92 CL (26/4)*	*1.3*	*$203*
Wheat	*Beckomⓓ (2/5)*	*2.1*	*$333*	*Beckomⓓ (6/5)*	*1.3*	*-$6*
Greenethorpe						
Chickpea	PBA Slasherⓓ (8/5)	1.9	**$996**	PBA Slasherⓓ (14/5)	1.2	$278
Lentil	PBA HallmarkXTⓓ (8/5)	1.7	$589	PBA HallmarkXTⓓ (14/5)	0.9	-$51
Fababean	PBA Samiraⓓ CL (9/5)	2.1	**$1029**	PBA Samiraⓓ (15/5)	2.3	**$406**
Canola	*InVigor® T4510 (7/5)*	*1.1*	*$43*	*HyTTec® Trophy (1/5)*	*1.2*	*$34*
Wheat	*Coolahⓓ (8/5)*	*2.7*	*$650*	*Coolahⓓ (1/5)*	*2.4*	*$337*
Urana						
Chickpea	-	-	-	PBA Slasherⓓ (16/5)	(2.4 hay)	$185
Lentil	PBA HallmarkXTⓓ (8/5)	2.2	**$992**	PBA HallmarkXTⓓ (16/5)	1.3	$371
Fababean	PBA Samiraⓓ (8/5)	1.8	**$970**	PBA Samiraⓓ (16/5)	2.0	**$987**
Canola	*43Y92 CL (30/4)*	*1.9*	*$573*	*43Y92 CL (30/4)*	*1.1*	*$201*
Wheat	*Beckomⓓ (30/4)*	*2.1*	*$558*	*Beckomⓓ (30/4)*	*2.7*	*$735*
Condobolin						
Chickpea	PBA Slasherⓓ (22/5)	2.0	**$1328**	PBA Slasherⓓ (22/5)	0.9	**$235**
Lentil	PBA HallmarkXTⓓ (22/5)	1.3	$349	PBA HurricaneXTⓓ (22/5)	0.9	$92
Lupin	Batemanⓓ (22/5)	2.0	**$863**	Batemanⓓ (22/5)	0.4	-$187
Fieldpea	-	-	-	Ouraⓓ (22/5)	1.8	**$459**
Canola	*InVigorT 4510 (2/5)*	*1.2*	*$151*	*HyTTec Trophy (22/5)*	*0.8*	*$19*
Wheat	*Beckomⓓ (1/5)*	*2.4*	*$681*	*Beckomⓓ (22/5)*	*1.6*	*$144*

Legacy effects of legumes and their impacts

The legacy effects of the 2018 legumes on 2019 crops were in some cases quite significant and related to the carryover of N, water or both, which influenced the yield and profit of the 2019 crops (Table 5). Evidence for significant legacy effects were obvious at all sites, often generating increases in subsequent EBITs of up to $200-$300/ha due to either increased grazing, hay or grain yield.

For example, at Greenethorpe in 2019, the early-sown dual-purpose canola produced 4.0 t/ha of forage for grazing when sown after high density grazed legume (vetch), compared to 3.6 t/ha after grazed wheat. This was presumably due to more water (59mm *vs* 31mm) and nitrogen (82 kg N/ha *vs* 41 kg N/ha) left in the profile at harvest in 2018. Similarly, at Wagga Wagga, the yield of timely canola after wheat (decile 2 N) was 1.1 t/ha, compared to 1.7 t/ha after lentils with an associated increase in EBIT from $124/ha to $389/ha. The decile 7 timely canola had an intermediate yield of 1.4 t/ha and EBIT of $210, suggesting at least some of the difference between the legume and canola pre-crops could be related to N, but more likely to water, as lentils are known to be shallower rooted and leave more residual water than canola. At Urana, the timely canola with decile 2 N yielded 1.0 t/ha after wheat compared to 1.5 t/ha after lentil, with the EBIT increasing from $187 to $443 as a result. A higher N level on the 2019 canola did not increase the yield or EBIT, suggesting residual water after the lentils rather than N was the primary driver. At Condobolin, the timely wheat (decile 2 N) in 2019 yielded 1.7 t/ha after canola but 2.2 t/ha after chickpea, with EBIT increasing from $165/ha to $354/ha. The timely wheat decile 7N yielded 1.9 t/ha and EBIT was $238.

Table 5. Some of the yield and profit increases in 2019 crops related to legume pre-crops in 2018 and the residual plant available water (PAW) and N left at harvest.

Site	2018 Crop			2019 Crop		
	Crop Type	Residual N (kg/ha)	Residual PAW (mm)	Crop	Yield (t/ha)	EBIT ($/ha
Greenethorpe	HDL (vetch)	82	59	Hyola970	4.0 (forage)	$1,073
	Wheat - Manning⚲	24	31	Hyola970	3.6 (forage)	$1,015
Wagga Wagga	Lentil - HallmarkXT⚲	-	24	43Y92 CL	1.7	$389
	Wheat - Beckom⚲	-	16	43Y92 CL	1.1	$124
Urana	Lentil - HallmarkXT⚲	-	-	43Y92 CL	1.5	$443
	Wheat - Beckom⚲	-	-	43Y92 CL	1.0	$187
Condobolin	Chickpea - Slasher⚲	70	19	Beckom⚲	2.2	$354
	Canola – 43Y92	33	18	Beckom⚲	1.7	$165

Responses to nitrogen fertiliser strategies

There were few yield responses to the higher N treatment (decile 7 *vs* decile 2) in 2018, and in some cases yield reductions, presumably due to haying off. However, soil tests revealed higher levels of post-harvest N carryover in the decile 7 treatments and these had impacts on the biomass, hay and in some cases grain yields of the 2019 crops, despite the dry conditions. Positive responses to higher N were generally in grazed biomass or hay (e.g. at Greenethorpe the Intensive baseline early-grazed canola provided 5.0 t/ha at 7N but only 3.6 t/ha at 2N; and in the un-grazed Intensive baseline wheat, the hay cut was 5.1 t/ha vs 4.8 t/ha). For grain-only crops there was either no response or a negative response to higher N (e.g. Greenethorpe Baseline timely sown decile 2N produced 2.4 t/ha while decile 7 N produced 2.1 t/ha). At Condobolin, the early-sown wheat after canola hayed-off in the decile 7 N treatment, producing only 0.8 t/ha grain yield compared to 1.8 t/ha in Decile 2 N treatment. Haying off with higher N reduced the EBIT from +$226/ha to -$150/ha. In general, across the 2-year EBITS, the decile 2 N tended to be more profitable than the decile 7 (Figures 1-4), due to the increased cost of N with little or no responses to the additional added fertiliser in the N decile 7 treatments in these dry years.

Barley outperformed wheat in both years

In both 2018 and 2019 barley outperformed wheat as a grain-only option. In 2018, timely-sown barley yielded 3.0 to 3.5 t/ha compared with wheat at 2.0 to 2.5 t/ha, and in 2019 barley doubled the yield of wheat at Greenethorpe (4.7 t/ha vs 2.0 to 2.5 t/ha) and Wagga (3.2 t/ha compared to 1.3 t/ha). At Urana, emus attacked the barley during grain fill, but based on biomass at anthesis the estimated yield was 5.0 t/ha compared to 3.1 t/ha for wheat. The decision to ensure all sites were adequately limed for successful growth of pulses may have benefited the barley along with excellent performance of recent varieties. Wheat was generally more profitable than canola and hay was often a more profitable option than grain, especially for canola.

Hay was a good option for some crops

For un-grazed crops, hay became a very good option due to the significant early biomass accumulated as a result of good stored summer rainfall, combined with the poor winter and spring rainfall and the high prices for hay. A comparison of hay and grain options was presented at the Wagga Wagga Update by Graeme Sandral (see further reading).

Impacts of management decisions on cover levels

During these consecutive dry seasons, the value of summer ground cover on water conservation and especially the opportunity for successful early sowing became evident. Decisions that influence the level of cover include crop choice (cereals>canola>legumes); the level of grazing and lock-up times - especially where crops are 'grazed out'; and the decision to cut hay. The impact of cover on the amount of water stored near the surface and the rate of surface drying during the dry autumns in 2018 and 2019 was stark. We measured the levels of cover on the soil in March 2020 across the sites, and at Greenethorpe. Levels of cover varied from 0.9 t/ha up to 9 t/ha depending upon the management choices made in the preceding two years. Happily, the autumn rainfall in 2020 came early and regularly and was not a significant issue for crop establishment, but the increasing incidence of dry autumn periods and the clear benefits of the earlier-sown grazed treatments, suggests that maintaining adequate cover to facilitate early sowing opportunities may be a wise management decision in southern NSW.

Conclusion

We have completed two years (both decile 1) of the first three-year phase of selected crop sequences combined with different sowing dates and N strategies. Different options have generated results that varied from losses of $500/ha to profits above $1200/ha depending upon management choices. The 2-year annual average EBITs also showed that many options over the first two years have outperformed the Baseline strategies nominated at each site by $200 to $600/ha and EBITS were up to $1000/ha despite the two dry seasons. Legacy effects could also be worth $200 to $500/ha driven by crop choices and N management strategies.

The 2020 season has been very different to date, with good levels of stored water and above average summer, autumn and winter rainfall, so that the full-3-year analysis will provide a more balanced view as nitrogen and not water may become limiting, and the additional costs of disease control become a more significant part of the economics. Our results indicate that sound management strategies in very dry conditions can still provide good profits to allow a more rapid recovery for businesses when conditions improve.

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Further reading

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

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

A. Expenditure

1. All herbicides/fungicides/insecticides, seed dressings, fertilisers, GRDC levies and crop insurance costs were obtained from the annual NSW winter cropping guide or the annual SAGIT farm gross margin and enterprise planning guides with links at:
    i. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops
    ii. https://grdc.com.au/resources-and-publications/all-publications/publications/2019/farm-gross-margin-and-enterprise-planning-guide
2. All seed was priced according to purchasing as pure treated seed from seed companies. i.e. In 2019, prices used were wheat seed at $1/kg, faba bean seed at $1.20/kg, chickpea seed at $1.80/kg and canola seed ranging between $23-30/kg.

3. All operations costs (sowing, spraying, spreading, haymaking, harvest) were based on the principal that a contractor performed the task. These costs were extracted from the yearly SAGIT Farm gross margin and enterprise planning guides. i.e. In 2019 prices used included sowing at $50/ha, ground spraying at $10/ha, cereal harvest at $70-85/ha, cut/rake/bale hay at $115/ha, with links at: https://grdc.com.au/resources-and-publications/all-publications/publications/2019/farm-gross-margin-and-enterprise-planning-guide
4. All variety levies for all crops and varieties were determined from the variety central website at: (e.g. for pulses) http://www.varietycentral.com.au/varieties-and-rates/201920-harvest/pulse/

B. Income

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

Appendix 2: Determining grazing value

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

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

Dressed weight and value:

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

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

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

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Brown manures, cover crops and long fallows – how decreasing crop intensity can reduce costs and risk, while increasing profit – Case study

Chris Minehan, RMS Farm Business Consultants

Key words

brown manure, fallow, weeds, risk, profit, fertility, PAW

Take home messages

- Reducing crop intensity can reduce variable costs and risk, while increasing profit
- Use a long-term, systems approach when considering a brown manure, cover crop or long fallow. Many of the benefits from this appear two to three years later
- 'Problem' paddocks with weed or soil fertility issues are the best place to start, as these are often unprofitable when cropped, so opportunity cost is minimal.

Why reduce cropping intensity?

Long term continuous cropping systems can be very profitable when managed well, however continuous cropping is prone to several key issues which decrease profitability and increase risk; including soil fertility decline, increasing grass weed pressure and herbicide resistance, soil and foliar disease build up in single crop systems. Many of these issues cannot be adequately addressed in a single year break cropping situation. A trend of declining spring rainfall in southern NSW is also expected to increase the risk of all-crop systems.

To improve the sustainability and profitability of cropping systems in southern NSW, many growers have chosen to replace their usual grain crop in lower performing crop paddocks with an alternative 'non-grain' crop, forage or pasture for one year, as a way of addressing some of the issues outlined above. The choice between brown manure, long fallow, sacrifice crop, mixed-species cover crop or other alternative is based on variables including financial considerations, location, climate, soil type, access to livestock and suitable livestock infrastructure.

The factors common to each of the mentioned cropping tactics are:

- Crop is terminated in spring, to ensure complete weed control, often incorporating double knock applications or non-herbicide control measures
- Timing of termination is aimed at maximising accumulation of plant available water (PAW) and organic nitrogen for the following crop.

Benefits of non-crops?

There are benefits of replacing a grain cash crop with a non-grain crop accrue, both at the paddock level and at the broader farm business level, especially when a system is adopted across a portion of farm area each year. Benefits may compound by following a brown manure or non-grain crop option with another break crop, such as canola. This 'double-break' is extremely effective at managing grass weeds and cereal root diseases. Positioning canola after a brown manure or long fallow also decreases risk for canola by providing additional nitrogen and PAW, ensuring canola is more likely to be established at the correct time.

Potential benefits at the paddock level:

- Improved weed control
- PAW accumulation

- Increased soil fertility (with legumes)
- Increased diversity (when multiple plant species are used together).

Follow on benefits identified for the farm business:

- Reduced input costs, especially grass herbicides in cereals and urea following legumes
- Increased productivity from planted area - Similar crop income, from less area, with less cost
- Reduction in risk, resulting from lower spend on input costs
- Ability to effectively manage herbicide resistance, through multiple and varied weed control tactics
- Improvements in labour and machinery efficiency
    - Wider sowing window
    - Less paddocks require urea
    - Less pre-emergent herbicides used.

Limitations?

There can be logistical issues involved with 'non grain' options, including sourcing of seed, or trouble sowing through heavy pulse stubbles. These will vary between farms based on location, machinery and management priorities. History suggests that once growers are convinced a practice is worthwhile, a solution will soon to be found to the technical and logistical issues.

Many of the cited limitations to adopting a brown manure (or similar) system are associated with FOMO (the fear of missing out). The most commonly cited reasons not to brown manure a paddock are cash flow constraints or the opportunity cost of not cropping that paddock in the current year.

Cashflow Implications?

Cash is critical to business. While it may seem that a paddock not producing grain is negative to cashflow, brown manure crops tend to have much lower input costs compared to cash crops, especially when those crops require expensive grass herbicides or urea to achieve their yield potential. A typical brown manure crop might cost $100/ha from sowing until termination, compared to a cereal crop targeting 2.5 t/ha which could cost between $200 and $300/ha up to harvest. The first year with decreased grain area is certainly the hardest. From the second year onwards, the benefits from previous brown manure crops generally outweighs initial decreased harvested area resulting in greater returns/ha over time.

Many vetch growers use hay as a strategic cashflow tool. In dry years, when other grain yields are likely to be lower and cashflow tight, vetch is made into hay, capitalising on higher hay prices in those years. In better years, when there is adequate income generated from other crops, the vetch is brown manured, reducing nutrient removal, leaving more nitrogen, more PAW and better groundcover.

For those with livestock of their own, or access to agistment, mixed species forage crops can provide many of the same benefits as straight brown manures, with cashflow from livestock. This is heavily dependant on location and individual situation.

Opportunity cost

"I could grow a four-tonne barley crop there". Typically, this argument over-estimates the yield and the price, underestimates the cost of growing a cash crop and does not account for any future yield increases or cost savings associated with the brown manure. Rather than using a farm average grain yield, or aspirational yield target, the analysis should be done using the worst paddock on the farm. Typically, the lowest performing paddock on any farm will have a very low profit margin in most years and may possibly be costing the business money. By starting with a poor performing paddock first, the opportunity cost is minimised. This allows the brown manure program to commence with less impact on cashflow.

Example

A group of paddocks in 2016, all sown to barley, except the two least productive paddocks (due to grass weed populations), which were sown to field peas and brown manured ($100/ha cost).

Barley results 2016	
3.0 t/ha @ $170/tonne average	
Income:	$510/ha
Waterlogging, grass weeds and disease	
Boxer Gold® + Axial® in-crop, urea spread by plane	
Variable costs:	$280/ha
Gross margin:	$230/ha

- All paddocks were sown to Canola in 2017.
    - The yield map is shown in Figure 1
    - Canola in paddocks following barley averaged: 0.8 t/ha
    - Canola in paddocks following brown manure (BM) peas averaged 1.9 t/ha (60% higher yield)

Calculating the benefit of BM field peas in 2016	
Extra canola yield 2017 (1.1 t/ha @ $550 /tonne) in 2017	$605/ha
Less the cost of growing peas in 2016	- $100/ha
Less the opportunity cost of Barley in 2016	- $230/ha
Net benefit of BM field peas (over 2 years)	**$275/ha**

- Cumulative rotational benefits identified from 2016 to 2019

Calculating the benefit of BM field peas in 2016	
Extra canola yield 2017 (1.1 t/ha @ $550 /tonne) in 2017	$605/ha
No Sakura® on BM paddocks 2018	+ $40/ha
No urea on BM paddocks 2019 (vs 100kg urea on all others)	+ $55/ha
Less the cost of growing peas in 2016	- $100/ha
Less the opportunity cost of barley in 2016	- $230/ha
Net benefit of BM field peas (over 4 years)	**$365/ha**

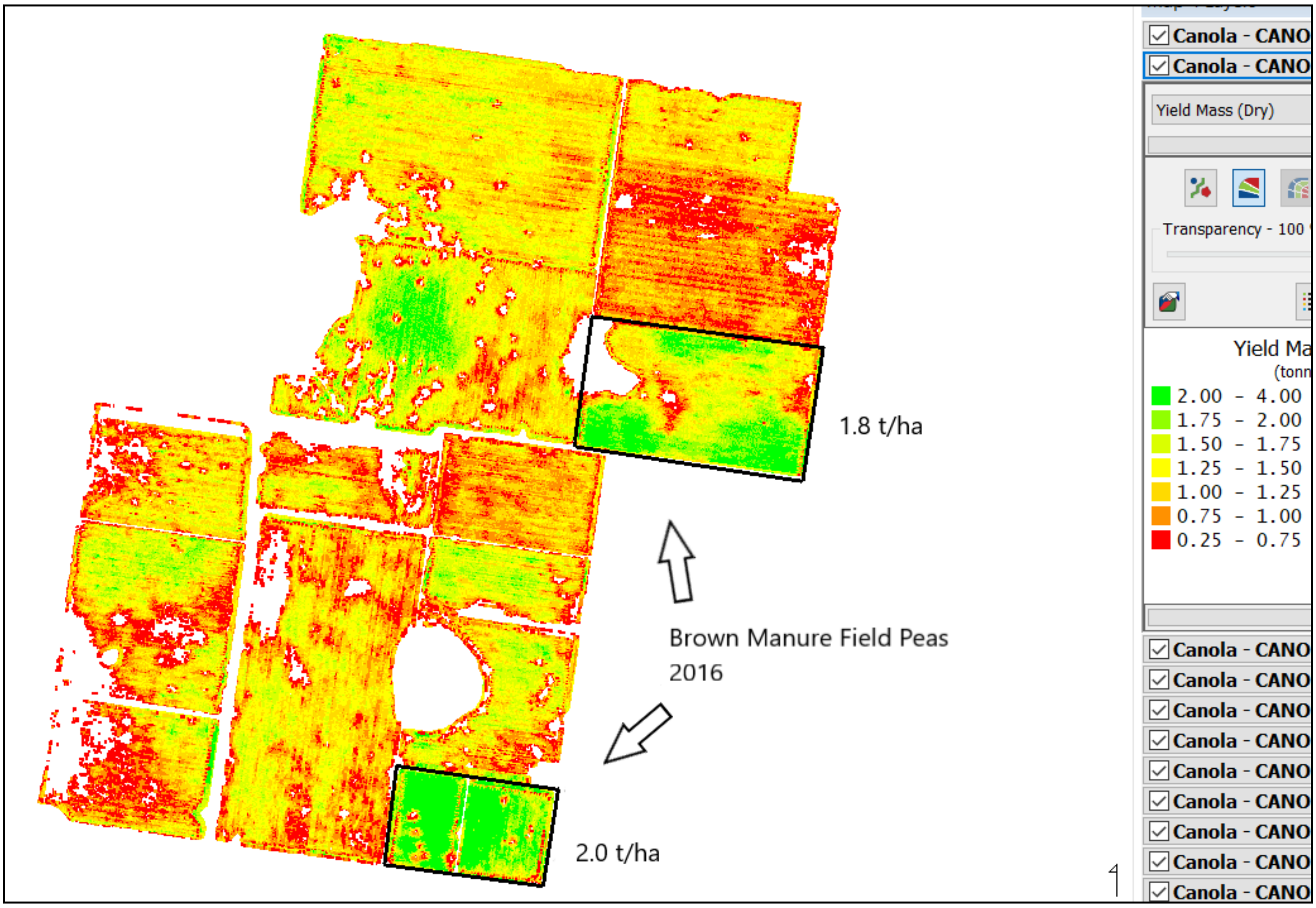

Figure 1. Yield map of paddocks highlighting difference in yield between brown manure fields and rest of the property.

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Pathogen burden in NSW winter cereal cropping

Andrew Milgate and Steven Simpfendorfer, NSW DPI

Key words

disease survey, rotation, PREDICTA® B

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership - *A strategic partnership between GRDC and NSWDPI.* Projects BLG207 and BLG208

Take home message

- Disease surveys are important to stay abreast of developing issues within farming systems
- Fusarium crown rot was widespread in cereal crops in 2019
- The yellow spot fungus was detected in 52% wheat crops surveyed and surprisingly also in 53% of the barley crops.
- qPCR assays (PREDICTA® B platform) are a valuable tool to rapidly quantify a wide range of fungal pathogens, nematode pests and beneficial fungi within wheat and barley crops
- Restoring rotations to include breaks in winter cereal are necessary to reduce pathogen burdens within paddocks.

Introduction

Reducing disease burden in winter cereal crops begins with measurement of what pathogens are present and their severity. This allows for decisions to be made about the need for rotation with alternative crop species and or integration of other control strategies.

The lack of good seasonal planting conditions has put pressure on rotation choices for growers across NSW in recent years. Prolonged periods of drought not only affect yield in a particular season but can also impact on the survival and build-up of many pathogens across seasons. This creates greater risk for losses in subsequent years and may take several seasons to return pathogen populations to acceptable levels.

Healthy cropping systems rely on using alternate hosts in a cropping sequence to reduce the frequency a pathogen encounters susceptible material and keeps population levels below economic thresholds for control. This approach is very old and forms the basis of sustainable farming practices around the globe by reducing the need for fungicides and other agrochemical inputs. However, in some regions there is limited alternative crops to plant in rotation with winter cereals. This may be because of a lack of agronomic fitness such as chilling tolerance in chickpeas, perceived lack of marketing options for some pulse crops or high establishment costs for crops such as canola. The most common rotations involve at least two consecutive cereals either as wheat - wheat or wheat – barley sequences. This is increasing the disease burden in our region.

The widespread adoption of stubble retention for improving moisture capture and retention has also led to increased impact from pathogens that survive from one crop to the next on stubble. These stubble-borne pathogens survive on dead plant material and form fruiting structures which produce spores or mycelium to infect the next crop. Examples of these are including *F. pseudograminearum* (cause of crown rot), *Rhizoctonia solani* (cause of Rhizoctonia bare patch) and *Pyrenophora tritici repentis* (cause of yellow leaf spot).

This paper will discuss the latest survey results for four key winter cereal pathogens across the northern region.

What we did

In 2019 the NSW DPI undertook an extensive survey of winter cereal crops in the northern region to determine current disease levels across the region as part of the Grains Agronomy Pathology Partnership. In collaboration with locally based agronomists, 264 winter cereal crops were surveyed between the start and end of grain filling. The GPS location and background information for each paddock were recorded, but to maintain confidentiality, data is presented here based on broad boundaries and distribution maps (Table 1 and Figure 1). Northern NSW sites were located at latitudes north of Tamworth, central NSW sites were situated at latitudes between Tamworth and West Wyalong, and southern NSW sites were latitudes south of West Wyalong. East and west locations were defined by the Newell Highway. The Liverpool Plains is included with NE NSW in the tables with Sth QLD and NW NSW grouped together. Durum and bread wheat data were also combined for simplicity in the tables. In 2019, survey sites and numbers were affected by crop availability in a drought affected season, particularly in central and northern NSW.

Table 1. The regional sampling of winter cereal crops in the northern region for 2019

Region	Barley	Durum	Wheat	Total
CE NSW	8		17	25
CW NSW	22	1	52	75
N Coast	3		4	7
NE NSW	24	9	34	67
NW NSW	2		20	22
SE NSW	13		26	39
Sth QLD	6		12	18
SW NSW	4		7	11
Total	***82***	***10***	***172***	***264***

Within each crop, a diagonal transect (~500 m) was created starting at least 50 m in from a road or fence line and avoiding obvious barriers such as trees or dams. Five consecutive whole plants (roots with adhering soil, stems and heads) were collected along the planting row from ten separate sampling points across the diagonal transect (i.e. total of 50 plants/crop). Samples were transported to Tamworth or Wagga Wagga and stored at 4°C before processing;

- 100 random tillers (i.e. two/plant) were assessed for incidence of basal browning (crown rot), leaf diseases (e.g. yellow spot or net blotch) and head infections (e.g. bunt, smut or Fusarium head blight (FHB)
- Fifty crown and stem bases (one/plant) were rated for the severity of basal browning and scored for root health prior to plating on laboratory media to determine the incidence of *Fusarium* (crown rot) and *Bipolaris sorokiniaina* (common root rot) infection.

The 100 tillers used for visual assessments were further separated into plant base (root, crowns and stems and leaves below the base of the flag-2 leaf) and plant top (stem, leaves above and including the flag-2 leaf and heads) samples. The aim was to determine pathogen loads in the lower section of the cereal plants in comparison to levels in the top three leaves (plus head) which are the main yield contributing leaves in cereal plants. It is expected that leaf pathogen levels in the top three leaves will have a stronger relationship with yield loss from leaf diseases (e.g. yellow spot and net blotches). All samples were dried at 40°C for 48h, put through a fine grinder and then couriered to SARDI to assess fungal DNA concentrations using a range of existing qPCR assays (available through PREDICTA B). A 20g subsample of ground plant material was mixed with 180g of sterile sand before extraction of total DNA and qPCR B analysis. All DNA data, picograms (pg) or 1000 DNA copies (kDNA) were then converted to 'per gram of dry plant tissue weight' units.

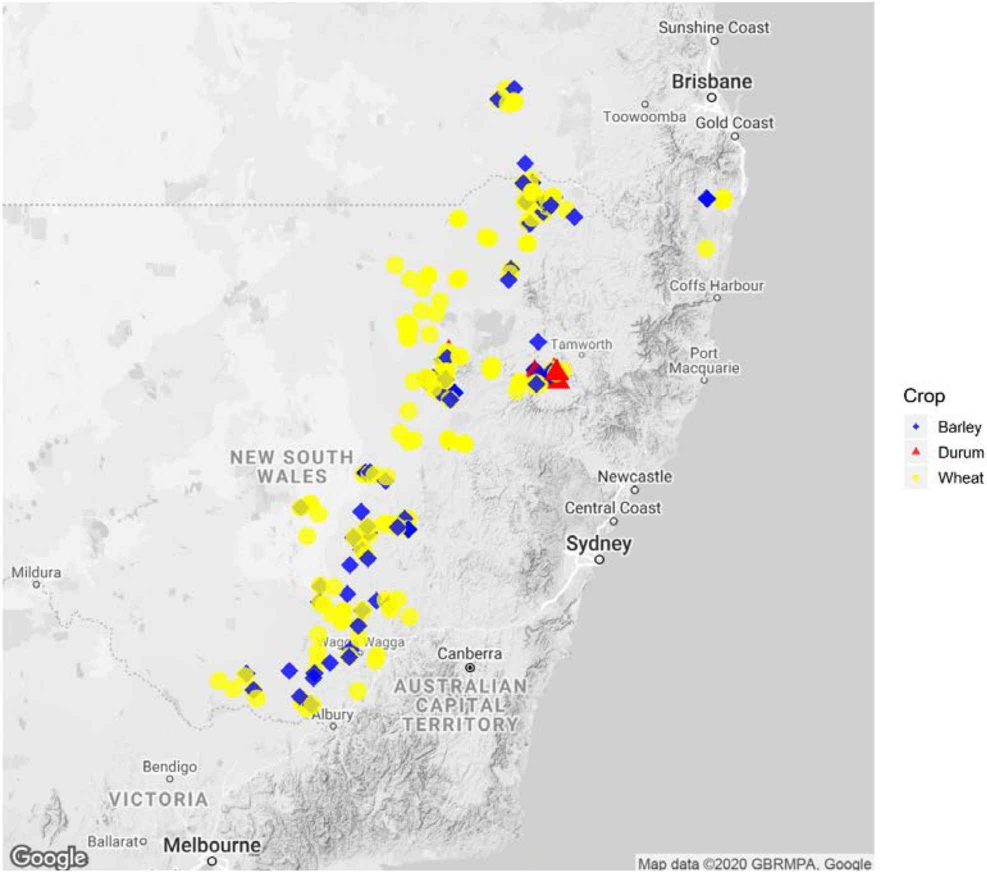

Figure 1. Distribution of winter cereal survey sites across the northern region in 2019

What did we find?

It is important to understand qPCR DNA assays are extremely sensitive with specificity to the target fungal pathogen or plant parasitic nematode of interest. Hence, we expect there to be high levels of pathogen found when infections occur. The approach used in this survey differs from traditional PREDICTA B soil testing where calibrations have been developed to determine the relative risk of infection prior to sowing. Traditional PREDICTA B tests quantify the amount of target pathogen DNA in the soil, old plant roots and stubble residues. This approach helps define the risk of infection developing within a season.

In this survey, plant samples were collected during grain filling and washed to remove soil and old stubble residues. Hence, the DNA tests in this context, determine the level of pathogen burden within either the base or top of the plant at a specified growth stage and do not measure contamination from previous crop residues.

The key point being the DNA values presented in the following tables and figures should ***not*** be compared with current PREDICTA B pre-sowing risk levels or population densities for the different pathogens. Furthermore, the DNA values within plant tops or bases have been assigned to a purely arbitrary low, medium or high category based on the spread of data across sites in 2018 and 2019. They should ***not*** necessarily be interpreted as low, medium or high infection levels.

For example, the 2018 and 2019 seasons were generally dry which was not conducive to the development of leaf diseases such as yellow spot in wheat and net blotches in barley. Hence, even though DNA of the causal fungal pathogens was detected in both seasons, these levels are probably considerably lower than what is likely to be detected in a wetter year. However, DNA concentrations did correlate with visual assessments of disease incidence e.g. crops with higher incidence and severity of basal browning had elevated *Fusarium* DNA levels. DNA data at this stage should be considered for comparative purposes only with continued surveys and research, hopefully developing relationships between pathogen burden in plant bases and/or tops with disease severity and yield loss. Enough of the caveats. What was actually interesting using this new approach with PREDICTA B qPCR assays?

Fusarium crown rot (Fusarium spp.)

Two DNA assays were used to detect *Fusarium pseudograminearum,* with separate tests detecting *F. culmorum* or *F. graminearum*. All three *Fusarium* species can cause basal infection of cereal stems resulting in crown rot and the expression of whiteheads when heat and/or moisture stress occurs during grain fill. When wet weather occurs during flowering, these species, especially *F. graminearum* and *F. culmorum* can also infect heads causing Fusarium head blight (FHB). Due to dry conditions, FHB was not visually recorded in 2019. DNA data for all four tests were combined for this interpretation to provide an overall level of *Fusarium* spp. DNA.

The incidence of crown rot, based on basal browning and laboratory plating, was high across much of the surveyed area in 2019 (data not shown) which reflects the qPCR data (Table 2 and Figure 2). The dry and hot finish to the 2019 season was conducive to the development of Fusarium crown rot, with *Fusarium* DNA detected in the bases of all 264 cereal crops randomly surveyed in 2019 (Table 2, Figure 2). Fusarium crown rot appeared to be particularly severe in cereal crops in central-east, central-west and south-western NSW with 80%, 68% and 64% of wheat and barley crops respectively having high levels of *Fusarium* DNA in the base of plants (Table 2). Fusarium crown rot appears to have also become a significant issue in central and southern NSW especially compared with northern NSW where this disease has traditionally been considered to be more prevalent.

As noted previously, *F. pseudograminearum* is primarily considered a crown and lower stem pathogen, but interestingly low levels of *Fusarium* DNA were also detected in the top section of 65% of samples across regions, indicating the extent of vertical fungal growth up infected tillers under conducive conditions in 2019. In some crops the DNA levels were in the medium to high range in the tops of infected plants (Table 2, Figure 2).

Table 2. Proportion of paddocks (%) with varying levels of *Fusarium* spp. (crown rot) DNA detected in wheat and barley bases or tops in 2019

Fusarium spp. (pg DNA/g)	Bases				Tops			
Region (no. paddocks)	Nil	Low (<1000)	Medium (<10000)	High (>10000)	Nil	Low (<1000)	Medium (<10000)	High (>10000)
Sth QLD/NW NSW (40)	0	72	15	13	33	64	0	3
NE NSW (67)	0	36	21	43	36	57	6	1
N Coast (7)	0	71	29	0	43	43	14	0
CW NSW (75)	0	24	8	68	11	73	13	3
CE NSW (25)	0	12	8	80	20	80	0	0
SW NSW (11)	0	18	18	64	40	60	0	0
SE NSW (39)	0	44	15	41	38	62	0	0
Total (264)	***0***	***38***	***14***	***48***	***27***	***65***	***6***	***2***

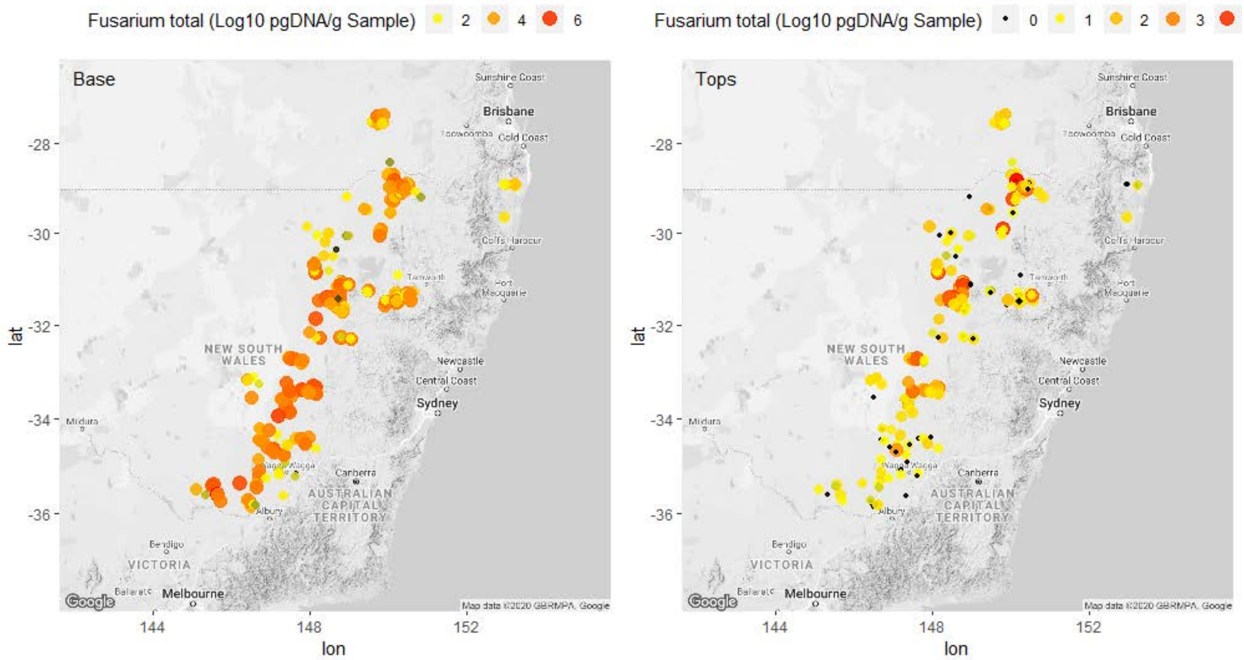

Figure 2. Distribution and intensity of Fusarium crown rot in winter cereal crops across the northern grains region in 2019. 264 paddocks sampled and qPCR used to quantify the presence of Fusarium spp. in the base of wheat and barley plants below the Flag-2 leaf (base; left) and in the plant parts from the Flag-2 leaf up including the heads (tops; right).

Yellow spot (*Pyrenophora tritici-repentis*)

Yellow spot is a stubble-borne disease of durum and bread wheat caused by the fungus *Pyrenophora tritici-repentis* (*Ptr*). Wet weather favours infection and production of tan lesions with a yellow margin on the leaves of susceptible wheat varieties. Repeated rainfall events during the season are required for infection to progress up the canopy of a wheat plant. Given the generally dry conditions in 2019, the visual incidence of yellow spot lesions on the top three leaves during grain filling was low. However, in many crops the presence of yellow spot lesions on the lower leaves was noted (data not shown). Although *Ptr* is a leaf pathogen of wheat, it is also an effective saprophyte (feeds on dead tissue) and can colonise dead leaves and stubble of barley late in the season under wet conditions as observed in northern NSW in the 2018 survey. Hence, both wheat and barley base and top samples were assayed for *Ptr* DNA levels.

Ptr DNA was detected in the bases of 52% of wheat crops and surprisingly also in 53% of barley crops surveyed in 2019 (Table 3, Figure 3). Medium to high *Ptr* DNA levels were measured in the base of wheat crops across all regions with the exception of north-west NSW and southern Qld. High *Ptr* levels were especially evident in wheat crops in central-east and south-eastern NSW (Table 3, Figure 3).

The proportion of barley crops with medium to high *Ptr* DNA in plant bases was lower compared to wheat and only occurred in central-east, south-eastern NSW and north Coast (Table 3). Underlying differences in rotation sequences or rainfall patterns in 2019 between regions may explain this situation, but this has not yet been explored. Consistent with the 2018 survey, the results for 2019 highlight that barley should not necessarily be considered a break crop for yellow leaf spot in wheat. Recent publications suggest *Ptr* is capable of infecting live barley without causing significant disease symptoms. However, the lifecycle of *Ptr* may also allow it to grow as a saprophyte on dead barley tissue. Further investigation is needed on this issue.

Table 3. Proportion of paddocks (%) with varying levels of *Pyrenophora tritici-repentis* (yellow spot) DNA detected in wheat and barley bases in 2019

Yellow spot (kDNA/g)	Wheat				Barley			
Region (no. paddocks wheat, barley)	Nil	Low (<1000)	Medium (<10000)	High (>10000)	Nil	Low (<1000)	Medium (<10000)	High (>10000)
Sth Qld/NW NSW (29, 8)	69	31	0	0	75	25	0	0
NE NSW (38, 20)	63	29	5	3	75	25	0	0
N Coast (4, 3)	0	50	0	50	0	33	67	0
CW NSW (52, 22)	63	31	6	0	45	55	0	0
CE NSW (16, 8)	6	63	19	13	25	50	25	0
SW NSW (7, 4)	29	29	43	0	25	75	0	0
SE NSW (26, 13)	4	35	42	19	8	62	15	15
Total (172, 78)	***48***	***34***	***13***	***5***	***47***	***45***	***5***	***3***

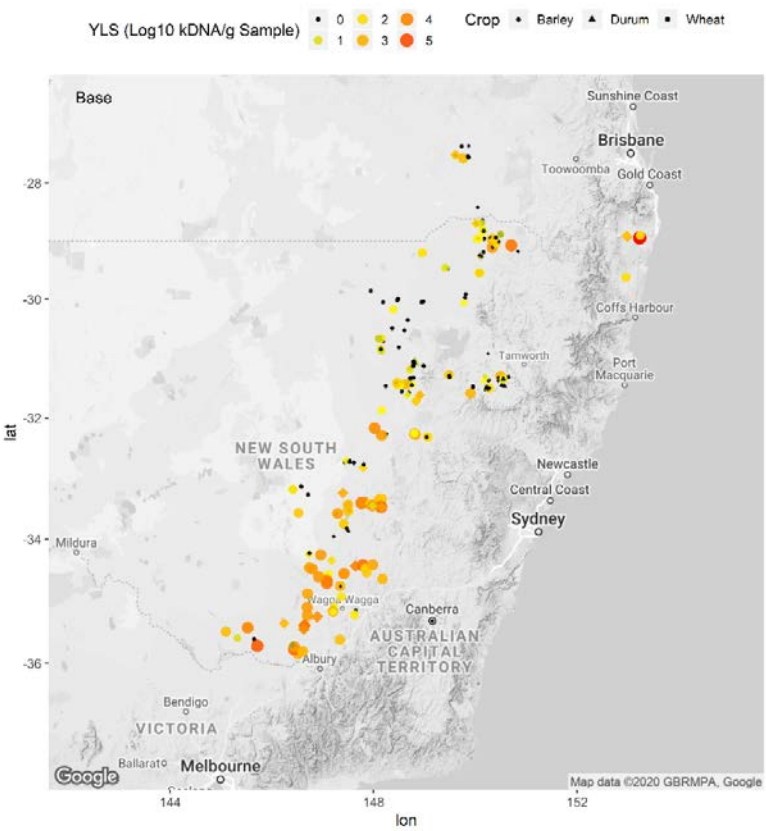

Figure 3. Distribution and intensity of yellow spot in winter cereal crops across the northern grains region in 2019. 264 paddocks sampled and qPCR used to quantify the presence of *Pyrenophora tritici-repentis* in the base of plant below the flag-2 leaf.

Rhizoctonia and Pythium

Rhizoctonia solani (AG8) DNA was only detected on average in 5% of surveyed crops across the northern region in 2019 (Table 4). Prevalence was higher in southern NSW (18% to 25%) than in northern NSW (0%). This is consistent with the known distribution of *Rhizoctonia solani* which is not adapted to survival in the heavier self-mulching alkaline soils which predominate in northern NSW.

Pythium clade f DNA, a pathogen usually associated with seedling blight in wet soils, was detected at low levels in plant bases in 39% of cereal crops surveyed in 2019 (Table 4). Higher detection occurred in southern NSW, followed by central NSW and the north coast with lowest detection in northern NSW in 2019. Medium *Pythium* DNA levels were recorded in 9% of crops in south-west NSW and 8% in south-east NSW in 2019 (Table 4).

Table 4. Proportion of paddocks (%) with varying levels of *Pythium* or *Rhizoctonia solani* AG8 DNA detected in wheat and barley bases in 2019

	Rhizoctonia solani AG8 (*Pg DNA/g*)				*Pythium (Pg DNA/g)*			
Region (no. paddocks)	Nil	Low (<1000)	Medium (<10000)	High (>10000)	Nil	Low (<1000)	Medium (<10000)	High (>10000)
Sth QLD/NW NSW (40)	100	0	0	0	97	3	0	0
NE NSW (67)	100	0	0	0	84	16	0	0
N Coast (7)	100	0	0	0	57	43	0	0
CW NSW (75)	99	1	0	0	52	47	1	0
CE NSW (25)	96	0	4	0	52	48	0	0
SW NSW (11)	82	9	9	0	27	64	9	0
SE NSW (39)	74	10	15	0	21	72	8	0
Total (264)	***95***	***2***	***3***	***0***	***61***	***37***	***2***	***0***

Conclusion

Molecular testing, such as PREDICTA® B qPCR assays used in this survey are a powerful tool for quantifying levels of fungal pathogens, nematode pests or beneficial fungi (AMF) within crop tissue. Dividing plant samples into base (root, crown, stem, leaf below flag-2) and tops (stem, heads and leaves above flag-2) prior to DNA testing, allows an additional level of interpretation. At present DNA concentrations within base or top tissue can only be used for comparative purposes between regions, crops, seasons, rotation sequences, climatic conditions etc. Continuing surveys and associated research are required to understand what impact different DNA concentrations within base or top tissue has on crop yield.

Collectively these survey results show that southern NSW faces a different complex of pathogens compared to northern NSW. Measuring the pathogen burden as this survey has done, highlights the importance for growers in southern NSW to review current rotations and strongly consider including the use of single or double break crops to reduce pathogen burden over time.

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Dual-purpose crops – direct and indirect contribution to profit

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Key words

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

GRDC code

CSP00160, CSP00132, CFF00011

Take home messages

- Dual-purpose (DP) crops can increase farm profit on the Tablelands, Slopes and Plains of southern NSW
- Higher whole-farm profit relies on attention to detail with crop and livestock management. Establishing the right crop early and correct lock-up time are key to increase profit and reduce risk
- Tough 2017-2019 years (good livestock prices) demonstrate profitable and flexible 'exit' options
- Ongoing refinement to deal with new and emerging issues with DP systems are discussed.

Introduction

In southern NSW, outputs from experimental research and grower experience over two decades has firmly established dual-purpose (DP) crops (both cereals and canola) into mixed farming systems. Experienced growers have undoubtedly increased profit, flexibility and reduced risks in their businesses with appropriate integration of dual-purpose crops. Numerous previous papers have reported on that success across a range of different environments, which I urge readers to revisit for more of the finer detail (see reference list). Some of the main messages are worth repeating here, and more recent experiences and data that reinforce some of those messages are worth reflecting upon. Inevitably new issues have also emerged as the farming system continues to evolve in the face of a changing climate.

In view of the special COVID19 circumstances in 2020, this paper is designed to consider relevant information on dual-purpose crops according to the broad regions represented in southern NSW, from the Tablelands (Feb-March sown winter crops), Slopes (a mix of winter and spring varieties in sown in March and April) and the Plains (opportunistic grazing of April-sown spring crops). The majority of the recent research has been carried out in the medium rainfall Slopes area, where all of the options listed above are possible depending upon seasonal conditions – and indeed many mixed farmers in that area consider that almost all crops are potential grazing options.

First - a few universal guidelines

Early establishment with the right variety is the key to success

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

Lock-up time is a crucial decision to maximise profit

Grain yield penalties occur when grazing too late (i.e. removing reproductive parts) and too hard (leaving insufficient biomass to reach target yield). Rules of thumb have been published previously (see reading list). The decision is significantly influenced by the crop yield outlook and the relative prices for livestock and grain. These different 'exit options' depending on circumstances provide significant flexibility.

Tablelands and higher rainfall areas east of the Olympic Way – winter wheat and winter canola

In the higher elevation, eastern areas of southern NSW, the length of season and extended frost windows mean that 'winter types' of both cereals and canola are well-adapted to capitalise on early sowing opportunities, as their vernalisation requirement (need for cold temperatures) delays flowering until after the main frost period. This provides a very long potential vegetative period (increasing grazing potential of 3+ months) for early-sown crops as well as a later and safer flowering window to avoid frost risk (even if crops are not grazed). The longer growth duration of the crops also increases yield potential to take advantage of the higher annual rainfall.

The area spanning Delegate-Canberra-Goulburn provides an excellent case study area where a transformation in farming systems and business profit has been possible in the last decade with the steady integration of both dual-purpose wheat and canola crops into traditional grazing areas.

The system changes

Dual-purpose winter wheats were grown in the area prior to 2010 with some success, and the availability of milling varieties such as Wedgetail⫽ was also popular. Managing grass weeds and diseases became problematic with continuous cereals, and dual-purpose winter canola varieties were first trialled in 2004 and commercialised in 2011. They demonstrated potential for early sowing, very high early (autumn) biomass production and safe grazing with sheep, with some issues for cattle. The dual-purpose canola provided an excellent break crop for the dual-purpose wheat (increasing both early biomass and yield), and when integrated on-farm, the crops extended the sowing and grazing windows providing operational flexibility, and a longer period of winter grazing to spell pastures and increase summer feed. In general, if the DP crops replaced perennial pastures, the autumn and winter feed gaps diminished. The cropping phase also paid for lime, fertiliser, and weed control which provided greater success in establishing perennial pastures. It has also allowed for improvement of native pastures, lifting stocking rates from 4-5 DSE to 12 DSE with associated increases in land value. In order to capitalise on the higher levels of autumn and winter feed, meat enterprises and livestock trading often diversified self-replacing flocks. Rather than sell weaners as store animals, they can be value-added to grow out to prime stock. As a result, some farms that 10 years ago produced only wool, now produce a range of cereals, oilseed, hay and silage as well as cattle or sheep enterprises for meat and wool. Stores of feed, silage, hay or grain provide further insurance in dry times.

Direct and indirect impacts on profit

Systems experiments, simulation and the early adopters in the district have demonstrated that the benefits to whole-farm businesses can **increase in profit by more than $100/ farm ha**. The gross margins on individual paddocks which can provide 2500-3,500 DSE.grazing days/ha (3 months) and then yield 3 t/ha of canola and 6 t/ha of cereal, are often in excess of $2,000/ha and the most profitable enterprises on farm. As the crops are often replacing perennial pastures on some farms where arable areas are low, we have previously estimated that the benefits of DP crops will peak at around 20% of the farm area. Allocating 10-20% of the farm to a combination of dual-purpose wheat and canola could increase whole-farm sheep grazing days by 10-15%, increase farm output by >25% and increase farm profit margin by more than $150/ha compared to pasture-only livestock systems.

Where DP crops are being used as a tool to improve areas of native pastures, the area may grow to 40% for some farms.

Emerging issues

Sowing just gets earlier….
Improved, longer-season winter wheats (e.g. Revenue, Bennett) and canola variety choices along with better summer fallow management has moved sowing dates back into February or even late January. The early availability and amount of feed produced requires serious re-evaluation of stock numbers and approaches to capitalise on the extra feed.

At these livestock prices why risk grain?
At current livestock prices, and where spring rainfall is uncertain, grazing out DP crops and terminating them in October can be cost effective, and can set up the paddock with good weed control and stored water and N for an early sowing opportunity in the subsequent season. Windrow, harvest and storage costs are saved.

Keeping up the N supply
Early-sown and high yielding crops especially down the rotation (several years after a pasture ley) can have substantial N requirements. For example, we recommend that soil N be at least 150kg/ha at sowing to maximise forage production, and the seasonal N requirements for grain yield are 80 kg N/tonne for canola and 40 kg N/tonne for wheat. The fate and recovery of the N in grazed crops is not well understood.

Managing disease
Fungal disease such as Blackleg and *Sclerotinia* in canola, and *Septoria tritici* and leaf and stripe rusts in wheat are more prevalent with higher intensity of cropping, higher rainfall and higher biomass. Resilient disease management plans using resistant varieties, cultural methods (sequence and residue management) as well as targeted fungicide use will be required. Of particular concern is the over-reliance on flutriafol which is applied in both the wheat and canola year, and foliar fungicides which may require at least 2 sprays.

Medium rainfall slopes area – winter and long-season spring varieties (Olympic to Newell Highways)

The medium rainfall area between the Olympic Way and Newell Highway has been the area of the earliest and longest adoption of dual-purpose cropping and the associated research activities of many agencies (Grain'n'Graze, DP wheat and DP canola research). A range of both winter and spring cereal and canola varieties provide potential grazing opportunities across this zone. The opportunity to sow 'true winter types' in March still presents across this region and in the eastern Slopes, the season is often still long enough for successful grain harvests with true winter types. However, as you move west, while early sowing and excellent grazing opportunities persist, flowering and grain filling often falls outside the optimum period limiting grain yield recovery in some seasons. Under those circumstances the faster winter wheat types and slow developing spring canola types tend to provide safer dual-purpose options and may be better suited to farms with a greater focus on grain than livestock, but where autumn and winter feed gaps can still limit whole-farm profit.

The system changes

Dual-purpose winter cereals have been part of the system in this region for decades, with breeding programs devoted to them since the 1960s. During the 1990s when the profitability of crops exceeded livestock, many farms intensified cropping at the expense of pastures and livestock numbers and interest in DP crops waned. The large impetus to further adoption came with the development of the higher protein milling wheat varieties in the late 1990s – early 2000s (Whistler, Wylah and Wedgetail). The combined value of the early-sown grazing forage and higher protein grain revitalised interest and increased adoption significantly, especially as research outlined grazing strategies that avoided yield penalties. The arrival of dual-purpose canola as an option in the late-2000's was timely as Wheat Streak Mosaic Virus temporarily discouraged early sowing of DP wheat, while early-sown hybrid canola varieties were shown to provide high value grazing potential similar to wheat. By 2010, dual-purpose canola had become an established part of the feed base and together with grazing cereals provided the opportunity to increase livestock production through increased winter carrying capacity, while increasing the cropped area on farm. More recently the move to strict summer fallow management and earlier sowing opportunities offered by DP crops provides indirect benefits to the whole farm by moving the whole sowing program earlier. This together with buoyant livestock prices has meant that dual-purpose crops have become an important adaptation to increasingly unreliable autumn and spring rainfall and increasing spring temperatures. The practice of grazing any crop with excess early biomass is now widely used and whole-farm benefits (spreading workload, resting pastures, increasing winter stocking rates, flexible exit options) apply.

Direct and indirect impacts on profit

In general, in these medium rainfall areas, dual-purpose crops are likely to be replacing grain-only crops on farms that are more crop-focussed, and this presents a somewhat different picture for whole-farm profit impacts. A summary of over 10 years of experiments, simulation studies and collaborative on-farm validation has demonstrated an increase in net crop returns by up to $600/ha (Table 1) with a range of other benefits including widening the sowing window, reducing crop height, filling critical feed gaps, spelling pastures and importantly providing flexible options in dry years.

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

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

Emerging issues

Exceptional performance in drought but legacies must be managed Early-sown DP wheat and canola options have been highly profitable at GRDC farming systems sites at Greenethorpe and Wagga in two recent decile 1 seasons in comparison with timely-sown grain only crops (Table 2). However, the success largely depended on deep stored water from either summer rainfall and good fallow management, or sequences with legumes which left legacies of water and N. At Greenethorpe consecutive early-sown dual-purpose crops (phased canola and wheat) were able to capitalise on higher amounts of stored water to produce more than 3 times the profit achieved by a grain-only (or hay) system **($1122/ha *vs* $334/ha)**. At Wagga Wagga under drier conditions, income for the same DP crops declined in the second year in 2019 due to the legacy of drier soil from 2018, but the DP system still had higher profit than the grain-hay system **($379/ha *vs* $172/ha**). In medium rainfall areas, selecting the paddocks and seasons to go for early-sown winter options can maximise profits.

Companions and forages

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

Managing N budgets in DP crops

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

Utilising the feed in good seasons

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

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

Site/Crop	**Dual-purpose system**				**Grain only system**		
	Variety/Sowing date	**Graze (t/ha)**	**Grain (t/ha)**	**EBIT ($/ha)**	**Variety/Sowing date**	**Grain/ (Hay) (t/ha)**	**EBIT ($/ha)**
Greenethorpe							
2018 Wheat	Kittyhawk (5/4)	1.5	1.9	$862	Coolah (7/5)	2.7	$619
2019 Canola	Hyola®970 (23/3)	5.0	0	$1,414	HyTTec®TT (1/5)	(3.1)	$96
Ave 2-Yr EBIT				***$1,138***			***$358***
2018 Canola	Hyola970 (3/4)	3.5	0.9	$1,251	HyTTecTT (7/5)	1.1	$79
2019 Wheat	Bennett (26/3)	3.5	0	$960	Coolah (1/5)	(4.8)	$538
Ave 2-Yr EBIT				***$1106***			***$309***
Average 2-yr system EBIT				**$1122**			**$334**
Wagga Wagga							
2018 Wheat	Kittyhawk (3/4)	2.0	1.9	$974	Beckom (2/5)	2.1	$333
2019 Canola	Hyola970 (8/4)	2.7	0	$78	43Y92 (26/4)	1.1	$124
Ave 2-Yr EBIT				***$526***			***$229***
2018 Canola	Hyola970 (3/4)	3.1	0	$347	43Y92 (3/4)	1.2	$34
2019 Wheat	Kittyhawk (8/4)	2.8	0	$114	Beckom (6/5)	(3.5)	$198
Ave 2-Yr EBIT				***$231***			***$116***
Average 2-yr system EBIT				**$379**			**$172**

Lower rainfall plains – opportunistic grazing of early-sown spring crops

The system changes

On mixed, crop-focussed farms in the drier western areas, the swing towards earlier sowing systems with appropriate wheat and canola varieties has trended towards grain-only with the availability of new varieties (e.g. Longsword⍉). Cereals are likely to be a larger focus here than canola due to the greater risks with canola, although in early starts with good soil water, grazing opportunities can still arise. Fewer early sowing opportunities and the higher likelihood of drier conditions during the recovery phase also means that closer attention to lock-up times and residual biomass is necessary, and larger paddock sizes and generally lower stocking rates can provide further challenges for even grazing. These areas may also have a higher frequency of 'sacrificial grazing' where value from failed grain crops can be salvaged. As livestock numbers increase, areas prone to frost or otherwise risky for grain are being sown to dedicated vetch or oat crops to be grazed out and fallowed. Smaller areas of these dedicated forages combined with more focussed grain-only crops has become a trend. The dry seasons in 2018 and 2019 highlighted missed potential income from livestock which has encouraged some trading and agistment in order for farms with no livestock to capitalise on good prices and available forage.

Direct and indirect impacts on profit

Much less research work has been conducted in the drier western areas, but some of the research in drier seasons on the eastern edge of the zone near Temora between 2010 and 2014 has suggested around 0.3 to 1.0 t/ha of biomass providing 200-600 DSE grazing days/ha can be achieved with early-sown spring wheat or canola with limited impact on grain yield. In drier areas further north, Bell suggested long-season cultivars could provide grazing value of ~$400/ha in seasons where early sowing was possible, while opportunistic grazing of spring wheat varieties was generally limited to $200/ha. Critical yields to trigger sacrificial grazing of wheat are predicted to be around 1.2 to 1.5 t/ha, but this can be difficult to forecast without good information on soil water.

Table 3. Effect of winter grazing on yield of canola and wheat varieties grown at Temora between 2009 and 2014. Crops were grazed with sheep prior to stem elongation.

Crop year	Cultivar type - sowing date	GSR (summer rainfall)	Grazing			Yield (t/ha)	
			Start graze	Start graze dry matter (t/ha)	Sheep grazing days/ha	Ungrazed	Grazed
Canola							
2010	OP-TT – 15 Apr	460	29 June	0.3	240	4.0	4.1
2011	HybridCL – 15 Apr	200	24 June	0.8	1000	3.5	3.1
2013	HybridCL – 1/5	227 (135)	1 Aug	1.3	1470	1.0*	1.3*
2014	TT – 1 May	238 (158)	8 July	0.5	n/a	2.2	1.6
Wheat							
2009	Gregory⍉ – 30 Apr	182	18 June + 7 July	0.5	570	1.7	1.3
2010	Bolac⍉ – 15 Apr	460	25 June	0.3	140	7.0	7.5
2011	Bolac⍉ – 15 Apr	200	22 June	0.8	520	4.3	4.8
2012	Wedgetail⍉ – 18 Apr	175 (462)	20 June	0.3	680	4.8	4.8

*Severely affected by frost.

Emerging issues

Even grazing on variable soils
The capacity to apply sufficient stocking rates to utilise the forage on large paddocks evenly in the narrow ‘safe’ grazing window can be problematic, especially as stock numbers decline. Around 25 DSE or > 8 adult cattle per ha may be required to evenly graze rapidly growing cereals.

Grain-only and forage only crops may provide less risky options
The increasing options in both cereals and canola for earlier grain-only crops are becoming attractive and narrow grazing windows make safe grazing more difficult. Dedicating problematic paddocks that are riskier for grain production (e.g. frost-prone, lighter or variable soils) to dedicated forage crops to graze out (vetch, oats) may provide better options.

Safe early establishment opportunities
At Condobolin, March rainfall in the last decade has tended to be above average while April and May below average. Taking opportunities to get some of the farm sown on opportunities in March improves timeliness for the rest of the farm. Planning for this exposes more possibilities to make money, provided successful establishment can be achieved.

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Further reading

https://grdc.com.au/data/assets/pdf_file/0033/377493/Combined-papers-Coolah-2019-no-adds.pdf

https://www.grdc.com.au/uploads/documents/GRDC_Dual-PurposeCrops.pdf

http://www.ausgrain.com.au/Back%20Issues/241mjgrn14/Match%20flowering.pdf

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

Wire, water and grazing management in dual purpose crops

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Key words

Paddock layout, fencing, water, dual purpose crops

Take home messages

- Paddock size, or available grazing area, is key to maximise grazing efficiency
- Strip fencing may be necessary to 'create' the required stock density
- Water sources must be of good quality and well located within each paddock
- Identify the class of stock and their indicative weight and consumption needs before sowing to determine the likely area of grazing crop needed (use regional dry matter crop growth rates to assist)
- Increased profitability per hectare gross margin by comparison to crop only situations.

Introduction

Dual-purpose crops offer great opportunities for farmers with livestock in their system (their own or via potential agistment income) to utilise early-season sowing opportunities, spread risk, and increase per hectare (ha) returns. Critical to gaining the most from these opportunities, is getting much of the logistics right, and applying sound grazing management. Cropping machinery (in general) over the last 20 – 30 years has been getting larger and more efficient. As a consequence, livestock infrastructure has been reduced, and in many cases, removed. So, what does this mean for dual purpose crops? In short, many paddocks are now too large to graze efficiently. Water points are often minimal and of lesser quality and quantity, or the number of stock required to provide efficient grazing can be very large - creating its own sub-set of management issues.

Kirkegaard et al. (2016) reported that with good management, the period of grazing can increase net crop returns by up to $600/ha and have a range of system benefits including widening sowing windows, reducing crop height, filling critical feed gaps and spelling pastures. However, achieving this grazing return relies heavily on 'good management', with time of sowing, stock number, grazing management, crop growth (both pre grazing and recovery), water supply and other factors all critical to a successful outcome. The indicative stock density used to achieve the above profit was approximately 2000 dry sheep equivalent (dse) grazing days/ha. Put simply, it may be 40 dse/ha for 50 days of grazing.

Paddock infrastructure

There is no 'ideal' paddock size, or available grazing area. My experience is that smaller paddocks/areas (<40 – 50 ha) are likely to be far easier to manage and have more manageable water points than much larger paddocks. Getting the most from the grazing dry matter (DM) requires eating more of what is on offer, over a shorter period of time, and leaving a critical residual biomass to allow significant crop regrowth before the second (and potentially third) grazing. Understanding crop growth rates, and what drives them, from planting to first graze (autumn) and into winter, enables farmers and advisors to predict likely stock numbers and DM production. Stock number and predicted consumption determines how long a set amount of DM will last. Using the grazing day information from Kirkegaard et al (2016), a 40 ha paddock would require approximately 1600 dse (potentially 2000 lambs (or 230 - 250 weaner steers depending on size)) for two 25 day grazings. A paddock larger than this will proportionately increase the stock number needed to optimise grazing efficiency.

A significant limitation to larger paddocks (and by default mob size) is water. This is usually the most difficult infrastructure to accommodate in the dual purpose crop system. Many issues surround good stock water supply. Distance to, temperature and cleanliness of water, dam vs trough, and other factors all impact on animal intake and performance.

The Dept. of Primary Industries and Regional Development WA (2020) publication ‘Water quality for livestock’, guides farmers in the water needs of livestock. Stock avoid warm water, so deeper or shaded water sources will generally be preferred. Pipes carrying water above ground to moveable troughs may deliver hot and undrinkable water (pending time of the year and location). Similar outcomes can also occur in shallow troughs in full sun. While trough systems have many benefits, if mob size is too large or inflow rates too low, stock will walk off with less (and sometimes nil) water intake. Allowing at least one metre of trough per 130 sheep is their advice. Further, sheep not used to water troughs, and particularly young sheep, may take time to learn to drink from them, so always push them onto water in a new paddock.

Dams are still very valuable, and often the only option for many. If there has been a benefit of the recent drought and dry dam situation, it is the opportunity provided to clean out those dams that farmers will benefit from most into the future. Stock will always decrease the quality of dam water, often by urine and faeces contamination and most commonly just by mud and foot disturbance. If water quality is poor, livestock may drink less than they need, or rarely, may stop drinking altogether. Lower water intake decreases DM intake, thus resulting in decreased animal performance. Many experiments have demonstrated the benefits of cleaner trough water over dam water, but it is not available to all. Lardner et al (2005), in their study of cattle performance, showed that by improving water quality with pumping and aeration to a trough, weight gains of 9 – 10% were achieved over the control mob over a 90 day grazing period in most years.

Dry matter, grazing management and stock density – the numbers

Kirkegaard et al. (2016) expressed DM production in terms of dse days/ha. They write that “early-sown, slower-maturing crops have the longest vegetative period and provide the most grazing potential, but typical grain-only spring crop varieties can also be sown early and provide useful grazing without significant yield loss following the same principles – but the potential grazing is much reduced, and closer management of lock-up timing is required”. Further, when it comes to planning, preparation and sowing (i.e. all key management activities), they quote that “each week delay in sowing wheat after early March, reduces grazing potential by 200-250 dse.days/ha and yield by 0.45 t/ha”.

So, the challenge is to convert this DM into red meat as best we can, without penalising ourselves in grain yield. Again, I refer you to Kirkegaard et al. (2016) for a very explicit description of that critical time to destock, or “shut the gate” so that little or no grain penalty occurs. You will note that this decision is driven by the plant, through its stage of growth and critical residual biomass needs and not by a date on a calendar. If maximising grain yield is a key target, it is imperative to get this destocking decision right.

Understanding plant growth, time to first graze and regrowth rates enables us to predict how many stock, of what class, will be required during the season. In the late 2000’s, working with a grower at Cumnock (Central West Slopes), we aimed to get 60 – 75 days grazing from the early sown cereals. This was usually achieved in two or three grazings but required good estimations of DM prior to and during grazing, and what growth rate could be expected during the ‘rest or recovery period’. Figure 1 provides DM growth rates for the Central West Slopes (NSW DPI – Prograze, 2000), for a range of pastures species, with oats included as a reference. The oat growth curve line is ‘indicative’ of a cereal crop's daily growth rate (kg DM/ha/day) in this region, and while I accept that wheat may be slightly lower or it may be sown slightly later, it can be used to estimate a potential grazing situation. There are good data sets of DM rates available from more recent NSW DPI/GRDC trials should you wish to fine tune your future DM estimates for areas closer to home.

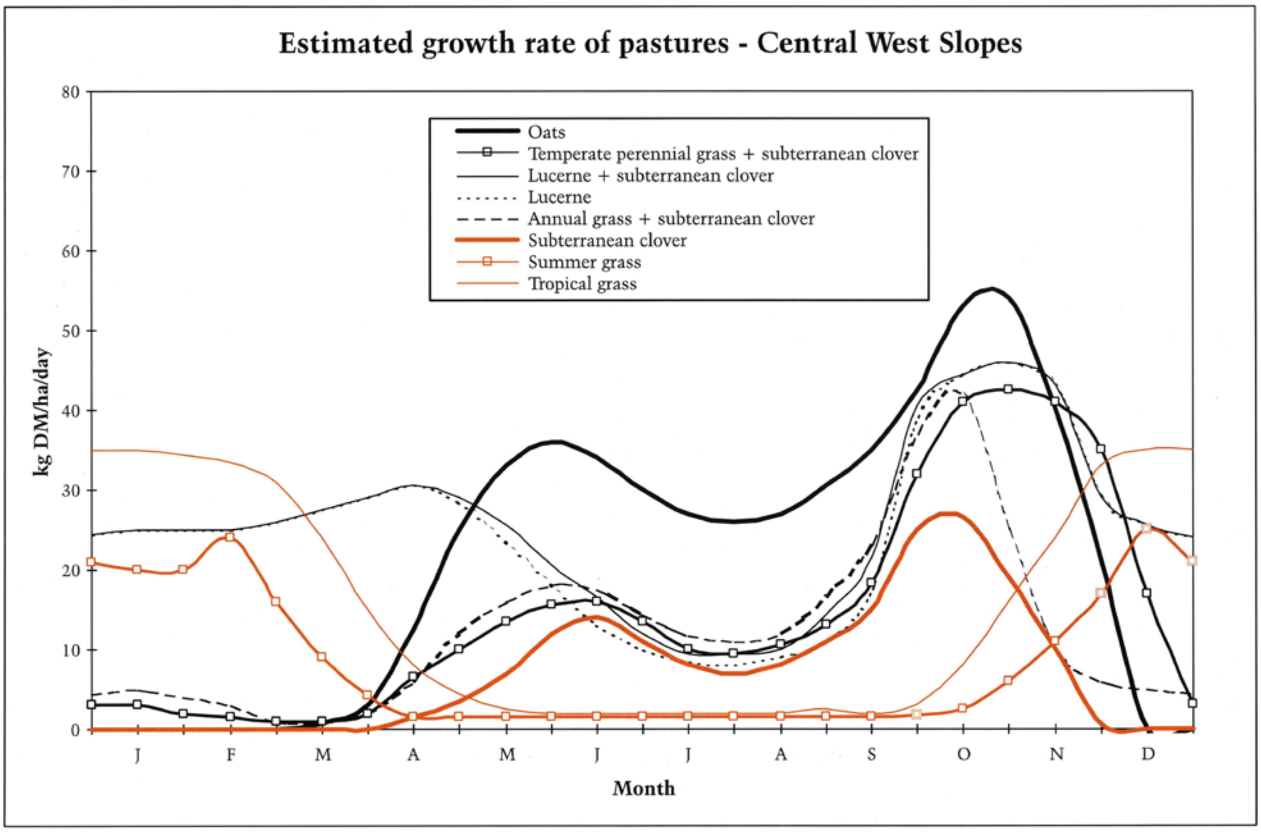

Figure 1. Estimated growth rate (kg Dry Matter/ha/day) of pasture species on the Central West Slopes of NSW (Source NSW DPI - Prograze)

By providing a working example of DM utilisation, it may make the following numbers more understandable. Using the oat growth rate line (the top thick black line from May to October) from Figure 1 as a guide (and knowledge of more recent wheat DM growth rates from various locations), one can estimate how much DM could be on hand by a certain point in the growth cycle. By sowing early (March 1) into a well prepared and planned paddock, one could estimate DM by mid-May to range from 1800–3000 kg DM/ha pending species/varieties/growing conditions. If sowing date was a month later (April 1st), this same DM is likely to be achieved by mid to late June. So how do we use it?

DM utilisation is the amount of DM consumed by the animal as a % of total on offer. For cereals, I estimate 60 – 70% utilisation pending row spacing, and I am aware of data showing higher utilisation rates in canola. The caution here is not to over-estimate potential DM on offer, as running out of crop DM is far worse than having more left in the paddock than first planned. It takes experience, and lots of it, as no two seasons are the same, and growth rates can change rapidly in response to dry spells, frosts and nutrient deficiencies to list a few. The second variable to consider before stocking is how much residual DM to aim for to enable speedy recovery/regrowth. Best regrowth occurs when there is 1000 – 1400 kg DM remaining (typically 10 – 12 cm high in cereals). Eating below this range restricts regrowth rates for a period, thus decreasing overall DM available for consumption during the season. As Kirkegaard et al. highlight, "not leaving enough residual biomass after the last grazing is very damaging in terms of grain recovery".

So, for the first grazing, if we average possible DM on hand (2400 kg/ha), and likewise average what residual DM we want left (1200 kg/ha), we can determine there to be 1200 kg DM/ha that we have available to eat. If this is consumed at 65% utilisation, then we eat 780 kg DM. Now the stock class and size and continued crop growth comes into play. Using a 35 kg lamb (0.8 dse), one estimates they will consume 3-4% of their body weight a day (1.05 – 1.4 kg DM/day, average 1.2 kg DM/day), while from figure 1, growth rate of the crop will continue at say 30 kg DM/day. So just to "hold" the crop where it is, one needs to eat the daily growth (30 kg DM @ 65% = 19.5 kg) which will require 16 lambs/ha. Should we wish to eat the available 780 kg DM over the next 3 weeks, then 780 kg DM /21 days = 37 kg DM/day is further required to be eaten. Again at 1.2 kg DM/day eaten by each lamb, this existing DM needs another 31 lambs/ha. Multiply this by grazable crop area, and this is where paddock size and water source(s) become critical to total stock number required. This above example indicates more than 45 lambs per ha (at a point in time) could be required to get the best grazing efficiency, and thus productivity and profit.

The balancing act of having this amount of quality feed on offer for an extended period means that usually three paddocks or areas of similar size will be required so a 21 day rotation as indicated in the above example can be practiced. This allows approximately 42 days between grazings, enough for significant DM growth if good grazing management principles are applied, and minimum DM limits obeyed.

Similar calculations can be run for grazing crop situations, it just requires DM estimates and predicted DM growth rates, keeping in mind that when the crops near 'lock up' time, these stock, if not ready for sale, need to go somewhere else! As noted earlier in this paper, additional gross margin returns of $600/ha are quite achievable in the current livestock market, with a significant range, pending crop season length, from $300/ha to more than $1000/ha.

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Soil and management impacts on potential legume production: results of a survey of 300 commercial paddocks in the GRDC northern region

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Key words

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Take home message

- Soil acidity is a widespread issue across the growing regions surveyed and is likely to be impeding optimal performance of grain and pasture legumes with respect to plant growth and nitrogen fixation
- Phosphorus levels are generally above, and often well in excess of critical levels required for grain and pasture legume production but there is an uneven distribution of phosphorus availability within the soil profile
- Sulphur levels are generally adequate in cropping paddocks, but frequently inadequate in pasture paddocks which may impact legume performance
- Soil organic carbon levels vary significantly with region, and within some regions as a result of land use (crop vs pasture)
- Reallocation of input expenditure to ameliorate soil acidity and the use of strategic cultivation may assist in alleviating some soil constraints to legume production across these regions.

Background

There is increasing opportunity and options for the use of legumes in rotation systems in the mixed farming zone. Both grain and pastures legumes offer greater flexibility in rotation systems by providing a disease break and allowing the use of a different spectrum of herbicides to control weeds that impact cereals and canola thus prolonging the useful life of herbicides. In the case of pasture legumes, grazing can also be used strategically with herbicides to control weeds. Central to the use of legumes in rotations is their capacity to contribute significant quantities of biologically fixed nitrogen for use by following crops. The capacity of legumes to supply nitrogen can considerably reduce fertiliser input costs. However, harnessing nitrogen fixation capacity requires legumes and their rhizobia to achieve an effective symbiosis (that is, form effective nodules). If effectively nodulated, the quantity of nitrogen fixed is then a function of how much biomass (herbage) the plant produces. Soil factors and management strategies imposed prior to sowing legumes and in years when they are grown in the rotation can have a significant impact on their capacity to form an effective symbiosis and reach nitrogen fixation targets of 20-40 kg N/t dry matter (DM). In 2019, a survey of 300 commercial paddocks across 150 farms was undertaken across four GRDC growing northern region to quantify soil chemical characteristics and assess likely regional limitations to legume growth. Concurrently, the participating growers completed a management survey providing information on the management of each paddock over the previous five years. The management survey included collection of information on paddock use over the past five years, herbicide and fertiliser inputs, grazing management and intended future use of the paddock. Additional information collected included botanical composition and ground cover at time of sampling. In this paper, preliminary results of some soil chemical characteristics and key management findings impacting legume growth and nitrogen fixation are presented.

Methodology

Farms included in the field survey were selected using farming system groups, advisors, local land services and by drawing on previous databases held by the project team. Growers were asked to provide two paddocks for sampling, with our preference being one paddock in crop and one in pasture on each farm.

A representative area of the paddock measuring 50m x 50m was selected for sampling. A minimum of 16 cores to a depth of at least 30cm were collected from within the sampling area. The soil cores were divided into segments of 0-5, 5-10, 10-20 and 20-30cm with each depth bulked together for analysis. All chemical analyses were undertaken by Nutrient Advantage laboratories (Werribee Victoria). Analyses included pH_{Ca}, total carbon and nitrogen (LECO) and available sulphur (all depths) and available phosphorus (Colwell) and cation exchange capacity (0-5 and 5-10cm depths only). In this paper we report; pH_{Ca}, total carbon, available P and available S results and key findings of the management survey.

Results and discussion

Paddocks sampled

There was a slightly higher prevalence of cropping paddocks sampled in the central west and south west growing regions, whereas there was a higher prevalence of pasture paddocks sampled in the central east and south east growing regions (Table 1). These differences are reflective of variance in land use across the regions.

Table 1. The number of crop and pasture paddocks where soil was collected for analysis and management history collected in the central east, central west, south east and south west GRDC northern region growing regions.

	Central east	Central west	South east	South west
Crop	26	47	31	30
Pasture	62	42	40	22
Total	88	89	71	52

Soil pH_{Ca}

There were differences in soil pH_{Ca} associated with land use (crop or pasture), soil depth and between regions, but these were not always statistically significant (Figure 1). For example, in the central west growing region, the pH_{Ca} of the soil profile was greater at all depths beyond 5cm in cropping paddocks compared to pasture paddocks. However, there were no significant differences between crop and pasture paddocks in the other regions. Similarly, there were differences in soil pH_{Ca} associated with soil depth but these differences varied within and between regions. For example, the pH_{Ca} of the 5-10cm soil layer was significantly lower than the 0-5cm layer in the south east growing region, but not in any other region. The pH_{Ca} of the 5-10cm layer was significantly lower than the 10-20cm layer in the south west growing region. The pH_{Ca} of the surface 10cm of soil was significantly lower in the south east growing region compared to the central west, while both eastern regions had a lower pH_{Ca} in the 20-30cm layer than either of the western growing regions.

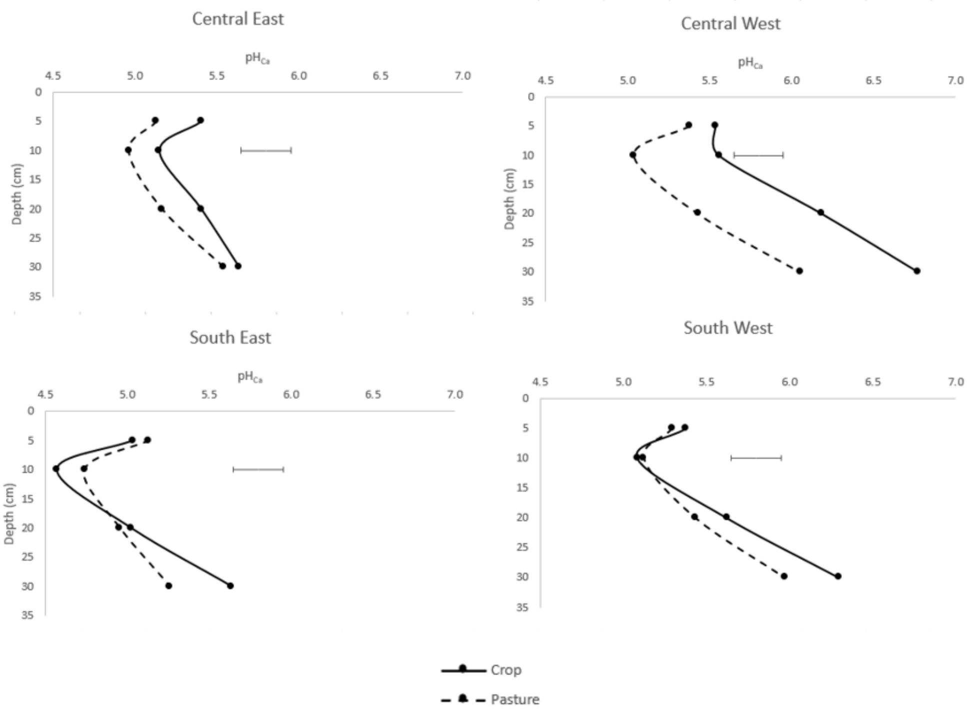

Figure 1. Soil pH_{Ca} for crop and pasture paddocks in the central east, central west, south east and south west GRDC northern growing regions for 300 paddocks sampled in 2019. LSD at $P<0.05$ indicated.

Implications of soil pH for legume growth

The host legume plant and its associated rhizobia have specific tolerances to soil pH. For most grain and pasture legumes, growth of the host plant will not be compromised at soil $pH_{Ca} \geq 5.0$. However, for the rhizobia associated with many of these plants, their survival and effectiveness generally begin to suffer some decline when $pH_{Ca} < 5.5$. Thus, there is a discrepancy in tolerance between the host plant and its rhizobia. As the effectiveness of rhizobia begins to decline, the host plant relies increasingly on soil nitrogen to satisfy its nutritional requirements. As pH_{Ca} declines below 5.0, plants may utilise more soil nitrogen than they contribute via nitrogen fixation.

For all the regions surveyed, soil pH_{Ca} was less than 5.5 in the top 10cm meaning there is likely to be some impediment to the optimisation of nitrogen fixation. The surface 10cm of the south east cropping paddocks and the 5-10cm layers of the pasture paddocks in the central east and south east were less than 5.0 (and as low as 4.6 and 4.7 in the crop and pasture paddocks of the south east growing regions, respectively) indicating nitrogen fixation may be severely constrained in these soils.

Management of soil acidity

Approximately one-third of growers surveyed had applied lime in the last five years to one or both paddocks sampled on their farm. Forty-five percent of growers surveyed indicated they had a specific target soil pH for one or both of their sampled paddocks with 80% nominating a target $pH_{Ca} \geq$

5.5. Where lime was used, the application rates varied from 1000-3000kg/ha. Less than 20% of growers who applied lime practised full incorporation to a depth of 10cm. The majority relied on incorporation of applied lime at sowing or use of a speed tiller for incorporation.

Improving management of soil acidity

It is clear from the survey results that soil acidity is a significant issue across the growing regions sampled. There is a moderate level of awareness of target pH for optimising legume growth. Of those growers who nominate a target soil pH, most aim to achieve a soil pH that is suitable to achieve nitrogen fixation. Of the paddocks tested, most would generally benefit from an increase in soil pH in the surface 10cm of the profile to improve legume growth and nitrogen fixation. Where possible and practicable, greater use of full incorporation when liming would assist growers in reaching their soil pH targets in the surface 10cm. In the most part, below a depth of 10cm, soil pH_{Ca} was 5.5 or greater.

Available phosphorus

Phosphorus availability varied between regions, soil depth and in some regions (central east and south west) between land use (Figure 2). Phosphorus availability was above critical in all regions and for all land uses in the 0-5cm soil layer. While phosphorus availability was significantly lower at 5-10cm than at 0-5cm, it was above critical in all cropping paddocks (except in the central west) and in pasture paddocks in the south east growing region. Overall, when averaged over the 0-10cm soil layer, the available phosphorus level was above critical in all except for the central west cropping paddocks where phosphorus availability was 95% of the critical level.

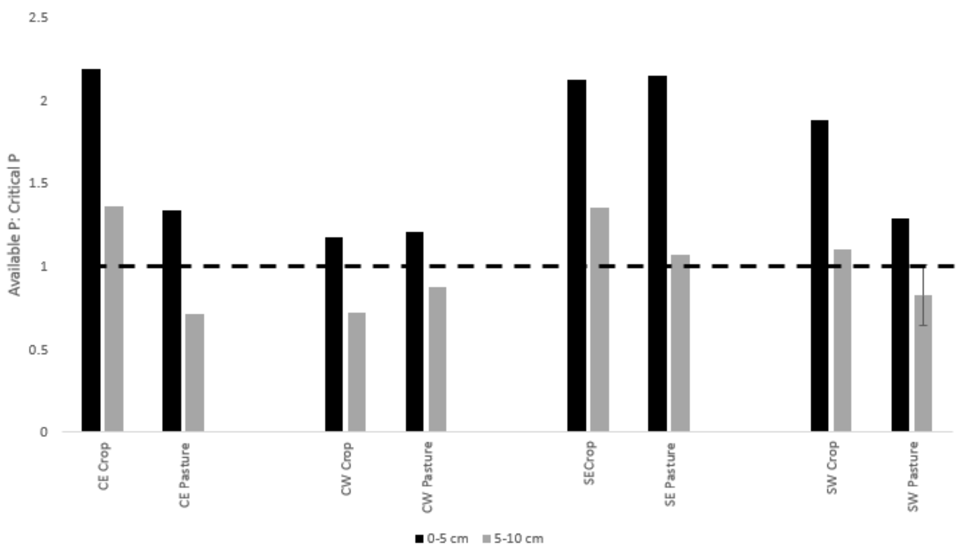

Figure 2. The ratio of available phosphorus (P; Colwell) and critical phosphorus based on phosphorus buffering index for crop and pasture paddocks in the 0-5 and 5-10cm soil layers of the central east, central west, south east and south west growing regions.

Implications of phosphorus availability for legume growth

Phosphorus is critical to drive plant growth and for the formation and maintenance of an effective symbiosis. Therefore, ensuring sufficient phosphorus is available is critical in achieving nitrogen fixation targets. However, it must be remembered that there are other macro and micronutrients that are also essential in supporting legume growth and nitrogen fixation. Surplus phosphorus does not compensate for deficiencies in other nutrients essential for plant growth and rhizobia survival and function.

Phosphorus management

Averaged across all cropping paddocks surveyed (except in the central west growing region), phosphorus levels averaged over the 0-10cm soil layer were 50-75% above the level considered critical to support optimal production. All pasture paddocks had at least critical phosphorus levels available in the surface 10cm of soil with pasture paddocks in the south east growing region having levels 50% above critical.

For pasture paddocks, there is unlikely to be any production benefit attributable to increasing soil phosphorus levels given the current levels whilst they remain under pasture. For cropping paddocks, phosphorus is generally well in excess of requirements, but high concentrations in the surface 5cm of the profile pose some production implications for grain legumes when sown at depths of 5cm or greater. This may also apply to pasture paddocks coming back into crop.

While deeper banding of phosphorus fertiliser may overcome shortages of phosphorus for deeply drilled seed, long term efficiencies also require consideration. It is clear from the survey results that there is generally luxury availability of phosphorus in the surface 5cm. Further, in the majority of paddocks sampled, soil acidity was an issue in the surface 10 cm. Rapid amelioration of soil acidity to 10cm requires full incorporation of lime to 10cm. This practice would also redistribute phosphorus throughout that section of the profile, overcoming any phosphorus and soil pH stratification issues.

Available sulphur

Sulphur availability varied with depth, and in the central west and south west growing regions between land use, with pastures having significantly lower levels of available sulphur than crop paddocks (Figure 3). On average, cropping paddocks had sufficient availability of sulphur in the surface 10cm (≥ 8mg/kg). However, for pastures, sulphur was deficient in the surface 10cm in all regions except the south east. There was no evidence of sulphur accumulation in any section of the soil profiles sampled (that is, to 30cm).

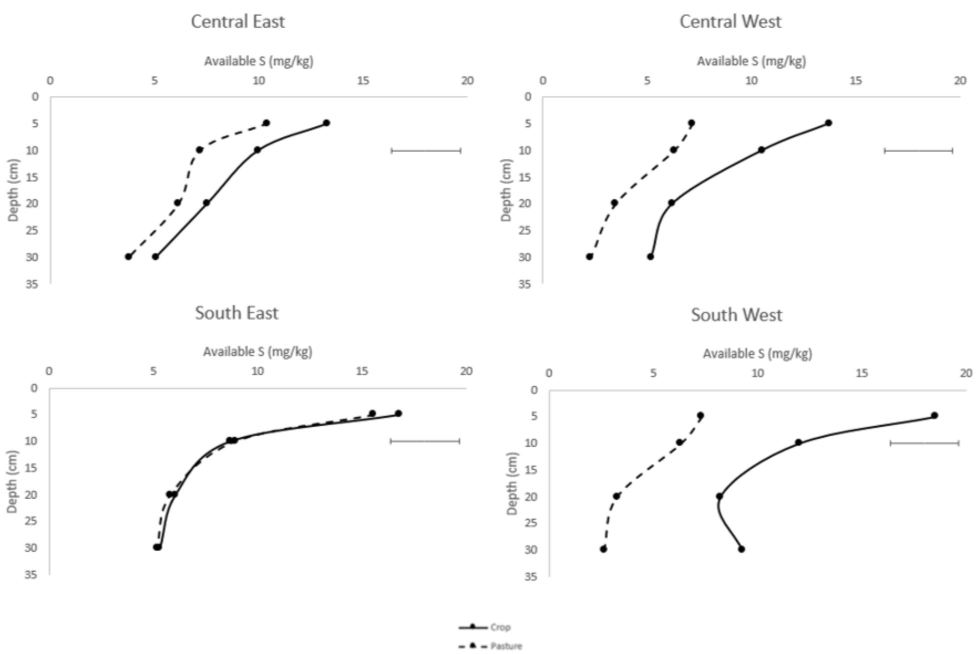

Figure 3. Available sulphur (S mg/kg; KCl-40) for crop and pasture paddocks sampled in the central east, central west, south east and south west northern GRDC growing regions. LSD at P<0.05 indicated.

Implications of sulphur availability for legume growth

Sulphur is a key nutrient required by legumes and rhizobia and is involved in the formation of an effective symbiosis and the conversion of atmospheric nitrogen to 'fixed' nitrogen. The survey results suggest that sulphur deficiency is unlikely to be limiting in paddocks currently used for cropping. However, for pastures, soil sulphur levels were generally much lower than in cropping paddocks which may impact on legume growth and nitrogen fixation.

Sulphur management

Monoammonium phosphate (MAP) was the most commonly used fertiliser on cropping paddocks (≥ 85% of respondents). However, more than 50% of cropping paddocks had also received an application of some source of sulphur over the past four years which may account for the relatively high sulphur availability in paddocks currently in crop. In contrast, for pasture paddocks in the central east, central west and the south west, fertiliser use was much more sporadic. In some regions, up to 75% of pastures had received no fertiliser in the three years prior to sampling. Where pastures were fertilised, it was predominately with MAP. Reduced fertiliser input and use of low sulphur fertilisers would explain the differences in sulphur levels between crop and pasture paddocks in these regions.

Potassium

Less than 5% of paddocks surveyed had potassium levels less than that considered adequate for the given soil type in the paddock.

Organic carbon

Soil organic carbon concentrations decreased significantly with depth and were significantly different between regions. However, with the exception of the south east, there was little difference between crop and pasture paddocks within regions (Figure 4). Soil organic carbon concentrations in the surface 10cm were lower in the central west than in other regions. In the south east, soil organic carbon concentrations in the 0-5 and -10cm soil layers were significantly higher in pasture compared to crop paddocks. Soil organic carbon concentrations were generally lower in the lower rainfall (central west and south west) regions for each respective land use than in the higher rainfall regions.

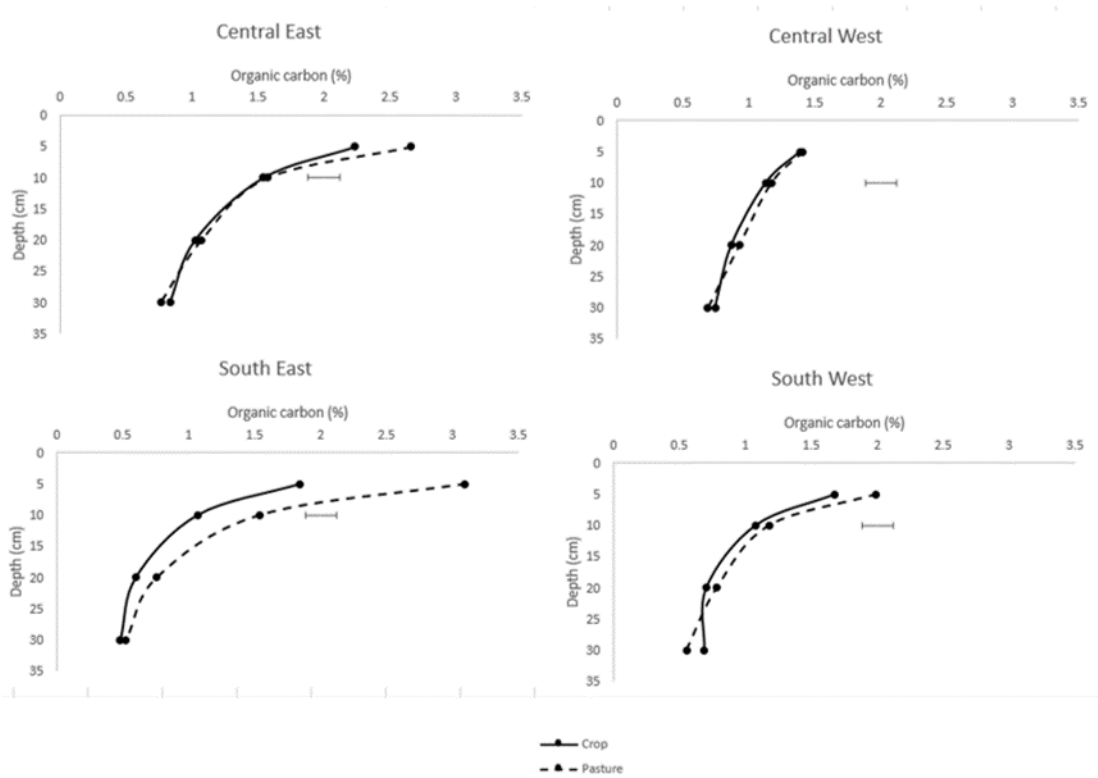

Figure 4. Soil organic carbon (%) for crop and pasture paddocks in the central east, central west, south east and south west GRDC northern growing regions. LSD at P<0.05 indicated.

Organic carbon implications for legume growth

Soil organic carbon concentration is an indicator of soil health; specifically, the soils ability to store, cycle and supply plant available nutrients. It is also correlated to soil structural properties including water holding capacity and infiltration. Increasing soil organic carbon concentration underpins plant and rhizobia growth and function, and can mitigate issues such as surface crusting that impedes emergence of newly sown crops and pastures.

Organic carbon management

Approximately 40% of growers surveyed nominated targeting organic carbon levels on 1.2-2.5% for their soils with a similar percentage of growers actively monitoring their soil organic carbon levels. The vast majority of growers (>80%) maintained stubble over summer and where pastures were part of their farming system, aimed to maintain at least 70% ground cover year round.

Herbicides

Herbicides and herbicide residues can have a significant impact on grain and pasture legume performance and their capacity to nodulate and fix nitrogen. The analysis of the survey data on herbicide use is in its preliminary stages. However, from the analysis so far, up to 40% of crop paddocks included in the survey were at risk of having residues that would impact the performance of legumes sown in the year following the crop based on herbicide application rates, timing of application and requirements required (e.g. time, rainfall, soil moisture) for plant back. In pasture paddocks, more than 20% of paddocks had herbicides applied during the pasture phase that would likely have a detrimental impact on legume function.

Conclusions

There are soil and management issues likely to constrain growth and nitrogen fixation of grain and pasture legumes throughout the four GRDC northern region growing zones surveyed. Soil acidity is widespread and likely to be placing restrictions on host legume growth and/or the development and maintenance of an effective symbiosis. The issue appears most severe in the south east growing region. While around 35% of growers have a specified soil pH_{Ca} target of >5.5, the way that strategies to manage soil acidity are applied requires change to rapidly ameliorate soil acidity in the surface 10cm of soil. Specifically, growers need to consider full incorporation of lime rather than incorporation by sowing or topdressing alone which is currently the most widespread practice. Strategic incorporation would also assist in alleviating the discrepancy in phosphorus availability between the 0-5 and 5-10cm soil layers which may currently limit performance of grain legumes when sown at > 5cm. Overall, phosphorus levels are generally above critical levels required for optimum production. Sulphur levels in cropping paddocks were generally adequate but deficient in pasture paddocks in the majority of regions, which reflects fertiliser forms used in pastures. While management surveys are only partially analysed, it is clear that herbicide residues pose a risk in a large proportion of paddocks and for established pastures, herbicides are used within the growing season that are likely to impact legume growth and nitrogen fixation. In summary, it appears there is scope to consider reapportioning management inputs to address issues that may be constraining legume productivity, specifically allocation of some expenditure to address soil acidity given soil phosphorus levels are generally at or well beyond critical levels.

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Maintaining wheat yield under high temperatures - how do current cultivars compare with what's coming?

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Keywords

Wheat, heat tolerance, genomic selection, phenotyping, pre-breeding

GRDC code

US00081

Take home message

- Recent Australian wheat cultivars are heat tolerant. However, new materials developed from diverse genetic backgrounds using field-based phenotyping and genomic selection suggest that levels of heat tolerance can be substantially improved.

Introduction

Periods of extreme high-temperature, particularly short periods of heat shock are a major threat to wheat yield and grain quality throughout much of the Australian wheat belt. Current projections of Australian climate change indicate that heat waves and temperature variability will become more frequent and more intense in the coming decades (CSIRO 2011, Climate Change in Australia. http://climatechangeinaustralia.com.au). It is vital that new wheat germplasm with improved high-temperature tolerance and molecular tags linked to this tolerance are developed and introduced into commercial breeding programs.

Genomic selection is a breeding method that requires a reference population of wheat lines that are phenotyped for the trait of interest and genotyped using many DNA markers distributed across the whole genome. Statistical methods are then used to estimate the effect of each DNA marker on the phenotype; the collection of all these DNA marker effects provides a prediction of genomic breeding value. This information can then be used to predict the phenotype of new plants that have known genotypes but not phenotypes. This allows early selection of plants/lines without phenotyping which decreases the breeding cycle leading to increased genetic gain.

Methods

A highly diverse set of agronomically adapted materials were assembled for phenotyping. These included thousands of new lines developed by the University of Sydney, including crosses with synthetic wheat, emmer wheat collected in warm areas, landraces, adapted germplasm with putative tolerance identified in hot wheat growing areas globally, Australian wheat cultivars and other sources of heat tolerance developed by others.

These materials were phenotyped for various traits; including yield, using a three-tiered strategy. Firstly, thousands of lines were evaluated in the field in replicated yield plots at Narrabri in northwestern NSW at different times of sowing. Later, sown materials were exposed to greater heat stress. Subsets of materials, based on performance in the previous year and estimated genetic values, were sown at sites in Western Australia (WA) and Victoria (Vic) to assess the transferability of traits. Each year, high performing lines were retained from the previous year, intolerant materials removed, and new materials added. Materials identified as heat tolerant in the times of sowing experiments were subsequently evaluated in the field during reproductive development using heat chambers to induce heat shock to confirm heat tolerance. Finally, those lines that maintained heat tolerance in the heat chambers were screened in temperature-controlled greenhouses to assess pollen viability under heat stress. Materials surviving all three stages of testing were considered highly heat tolerant.

All materials (>2000 lines) phenotyped in times of sowing experiments were genotyped using a 90K Single Nucleotide Polymorphism (SNP) platform and these formed the reference population for genomic selection from which all DNA marker effects were estimated. A prediction equation was developed and used to calculate genomic estimated breeding values (GEBVs) on selection candidates which were genotyped but not phenotyped. A genomic selection model that incorporated environmental covariates (for example; temperature, radiation and rainfall) directly was developed. This allowed the prediction of line performance under high temperature conditions. Environmental covariates were defined for each plot and growth development phase (vegetative, flowering and grain fill). An in-field validation of GEBV selected lines was then conducted by correlating GEBVs with field trial phenotypes. Various cycles of crosses were made among diverse lines with high GEBVs and progeny subsequently selected for high GEBV. These form the basis of our new elite heat tolerant materials.

Results

Extensive field-based phenotyping over a six-year period identified lines with superior adaptation to terminal heat stress (Figure 1). The tolerance of these materials was then confirmed in field-based heat chambers. The heat chambers were calibrated over a three-year period in replicated, triplicate plots (Table 1). Heat shock at anthesis significantly reduced yield compared to an ambient chamber and the uncovered plot. The ambient and uncovered plot were not significantly different from each other, and therefore, all future screening was conducted as paired plots (with and without heat chambers). The developed genotype-by-environment interaction genomic selection model increased genomic prediction accuracy for yield by up to 19%.

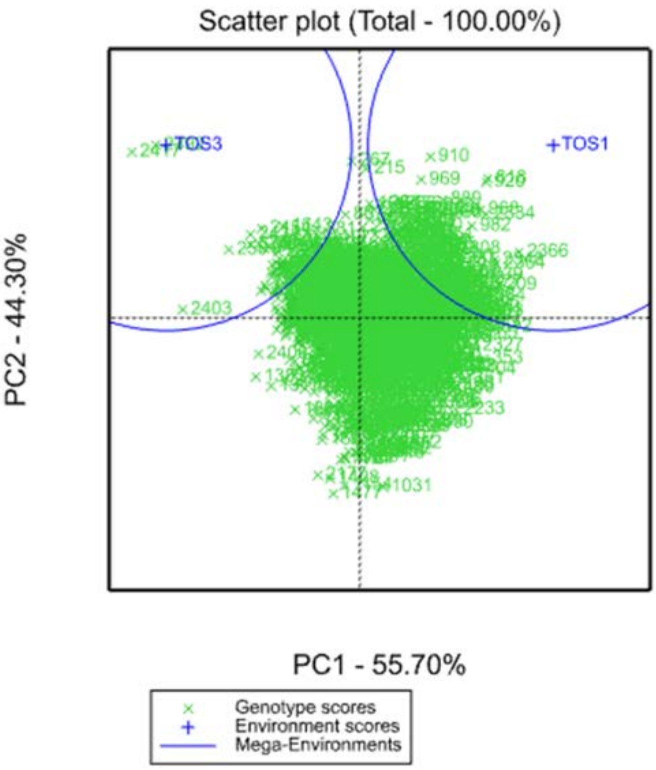


Figure 1. Genotype-by-environment interaction (GGE) biplot of yield in optimal (TOS1) and late (TOS3) sowing at Narrabri, 2013 to 2018.

Table 1. The impact of heat chambers on yield, kernel weight, kernel number and other traits, 2013 to 2015.

	Treatment			
	Ambient	Heated	No Chamber	Prob.
Yield (kg/ha)	2775 a	2248 b	2849 a	<0.001
TKW (g)	32.5	32.4	32	ns
Height (cm)	82.1	85.5	82.8	ns
Screenings%	4.09	4.89	5.13	ns
Grain number/10 spikes	49.3 a	43.8 b	48.74 a	<0.002

n.b. Means in the same row followed by different letters are significantly different.

The most heat tolerant Australian cultivars evaluated between 2013 to 2018 were the older varieties; Sunco, Annuello, Scout⟮PBR⟯, Sunstate and Lang⟮PBR⟯. These cultivars showed little difference in yield between times of sowing over years (Figure 2) but tended to have relatively low yield potential. However, the higher yielding, more recent varieties; EGA Gregory⟮PBR⟯, Suntop⟮PBR⟯ and Spitfire⟮PBR⟯ tended to have reduced heat tolerance. Several recently derived pre-breeding lines (PBI09C034-BC-DH38, PBI09C028-BC-DH56, PBI09C026-BC-DH5) have combined both high yield and heat tolerance.

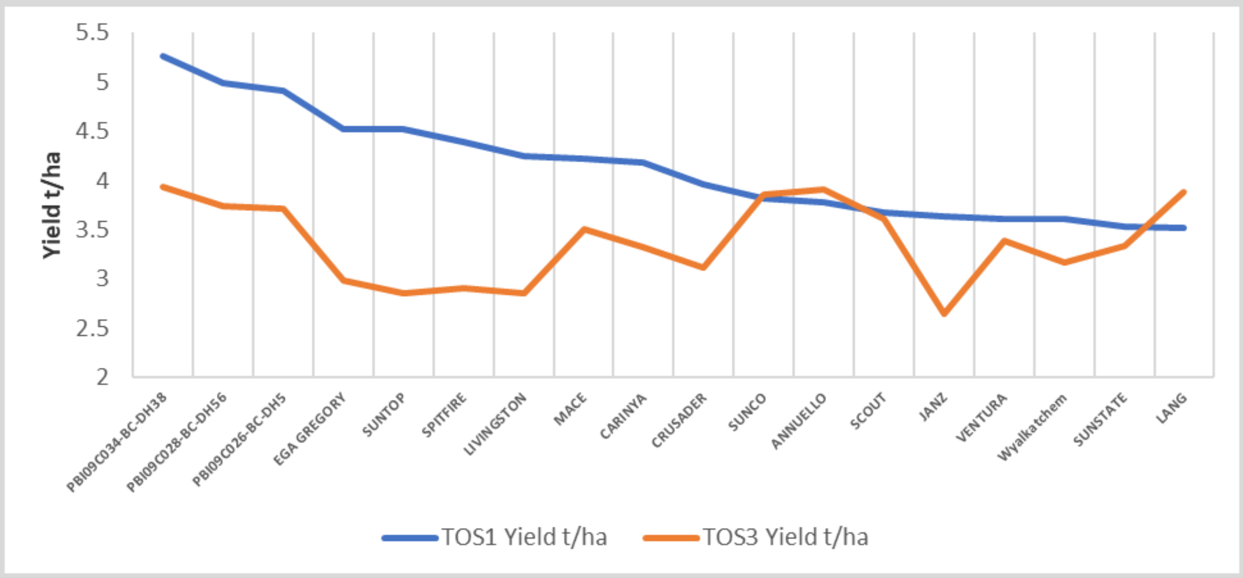


Figure 2. Yield at Narrabri (2013 to 2018) for heat tolerant lines and Australian cultivars for two different times of sowing (TOS1 and TOS2 are optimal and late sowing, respectively).

A wider range of Australia cultivars, including many recent releases, was included in 2019 (Figure 3). Mustang, Scepter, Mace, Sunmate and Borlaug all showed relatively high levels of heat tolerance. Mustang and Scepter combined this with high yield. The pre-breeding lines PBIC15020-0C-60N-010N and PBIC15022-0C-6N-010N, developed using genomic selection, also combined high yield with heat tolerance. Unlike Mustang, these materials flowered later and did not escape the high temperatures during grain fill.

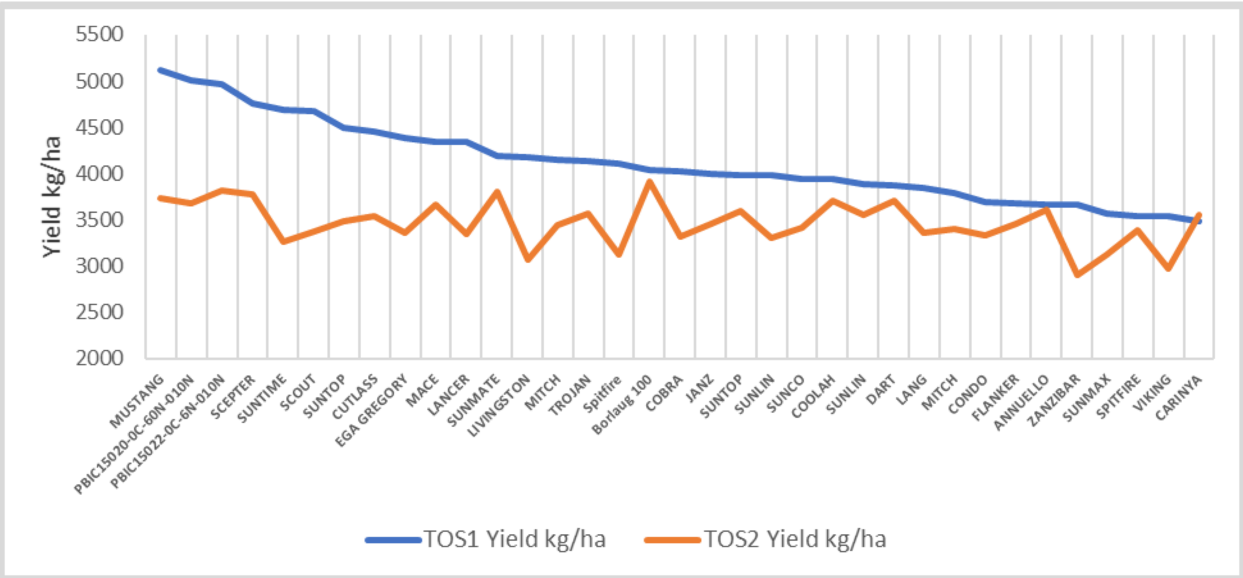
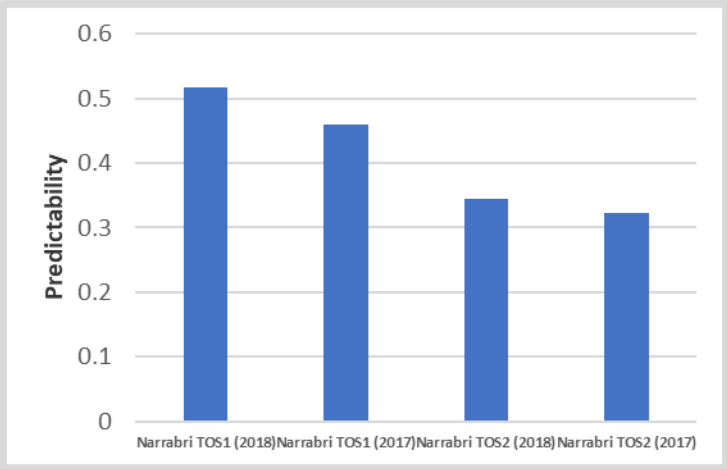


Figure 3. Yield of Australian cultivars and new heat tolerant lines at Narrabri, 2019 for two different times of sowing (TOS1 and TOS2 are optimal and late sowing, respectively).

An important aspect of this work was the transferability of the Narrabri results to other regions of Australia. Subsets of 200 lines, selected for high GEBV, were evaluated at Merredin and Horsham to validate the strategy. A training population was necessary to allow genomic prediction models to calculate GEBVs without the need for phenotyping at other sites. The accuracy of genomic prediction for yield, trained at Narrabri, was evaluated in 2017 and again in 2018 (Figure 4). When the 2018 data were included in the estimations of GEBVs, the predictability exceeded 0.5 for both early and late times of sowing.

A. Merredin



B. Horsham

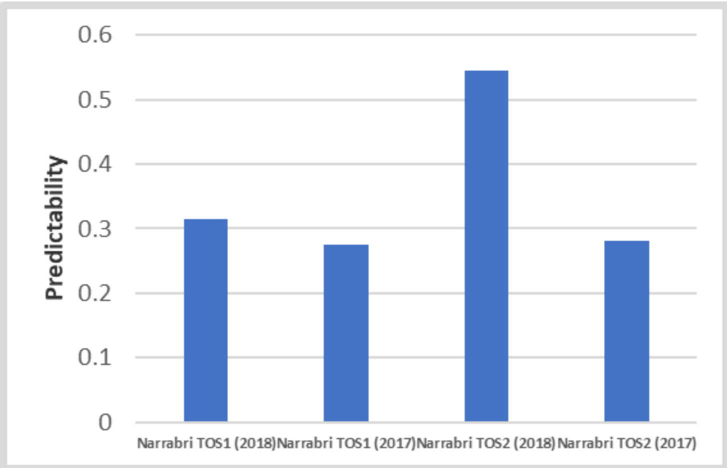


Figure 4. Accuracy of genomic prediction for yield trained at Narrabri (GEBVs calculated from five and six years of data) and validated at Merredin and Horsham in 2017 and 2018. TOS1 and TOS2 are optimal and late sowing, respectively.

Conclusion

Some recently released Australian cultivars have both the genetics of high yield and the genetics for heat tolerance. However, new pre-breeding materials developed using genomic selection offer commercial wheat breeders' new sources of diversity for both yield and heat tolerance that can be used to mitigate the effects of a warming environment. The strategy of selecting for heat tolerance at Narrabri for other regions of Australia was validated by the relatively high correlations between GEBVs and yield under heat stress at Merredin and Horsham.

Acknowledgements

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

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

Assessing natural enemy impacts in canola

Jo Holloway, NSW DPI

Key words

natural enemies, aphids, canola, IPM, biological control

GRDC code

CSE00059

Take home messages

- Natural enemies play an important role in reducing aphid populations
- Selective insecticides should be used whenever possible to preserve natural enemies
- Economic thresholds involving natural enemies are complicated: best advice is to monitor pest number trends to inform spray decisions.

Background

Invertebrate pest management is often seen as a low priority, particularly compared to weeds, with a recent survey finding only 0-1% of respondents regard pest control as a concern for maximising yield (Zhang et al. 2019). This may be due to the sporadic nature of pest outbreaks (economically threatening pest situations do not occur every year), as well as the relative ease and low cost of using broad-spectrum insecticides. This begs the question: why are so many prophylactic insecticide treatments (e.g. seed treatments or 'just in case' inclusion of insecticide with another spray treatment) used?

Alarm bells only seem to start ringing when there is a new pest incursion such as the wheat curl mite/wheat streak mosaic virus, Russian wheat aphid and the current fall armyworm. However, even this anxiety generally only extends for one to two seasons after which it is realised that an outbreak does not occur every year. In fact, it is highly probable that the 'new' pest may have already been present for a season or two prior to the outbreak and it was only that favourable environmental conditions and/or a disruption to natural enemies that led to excessive population growth and spread. Another driver for management change can be insecticide resistance. Currently, organophosphate resistance in red legged earth mite is present in south-eastern Australia and spreading, while green peach aphid (GPA), corn earworm and diamondback moth have all developed resistance to a range of insecticide formulations (McDonald et al. 2019).

Integrated pest management (IPM) is a method of pest control that uses a range of practices, including chemical control, but relies heavily on natural enemies (predators, parasitoids and disease). However, with the exception of grain regions strongly influenced by cotton production, implementation of IPM is relatively low in broadacre cropping, with lack of knowledge and low confidence in its efficacy often cited as reasons. The aim of this work was to increase the knowledge base and confidence in IPM by assessing the impact natural enemies have on aphid populations in canola. In addition, it was hoped that this data could be used to inform economic thresholds to include natural enemies.

Methods

Cage trials were conducted in canola paddocks in NSW, VIC, SA and WA to assess the efficacy of natural enemies on green peach aphid (GPA) during September-October 2018 and July-September 2019. In 2018, up to five predators, either sourced from the surrounding paddocks ('local' and differed in each state) or purchased ('reared' green lacewing nymphs (GLW)) were added to canola plants that had previously been caged, cleaned of any other invertebrates and inoculated with 50 aphids. To ensure insecticide seed treatments did not interfere with aphid establishment, aphid inoculations were delayed until at least 8 weeks post-sowing. Aphid numbers were assessed at various times over 15 days. In 2019, using a similar set up with the cages, three parasitoid wasps were assessed against varying densities (20, 100, 200 or 500) of GPA. Assessments were made on aphid abundance over time as well as the number of aphid mummies (aphids that have been parasitised by wasps) that developed over the 42 days.

In both trials, control plants were left open to the environment after aphid establishment to determine the effect of the local natural enemies within the paddock. In addition to sweep net samples of the surrounding crop on Days 0 and 2 at all sites, funnel traps were placed within the NSW paddock and checked every 4 weeks from post-sowing to preharvest to assess the local presence of natural enemies throughout the season.

Results and discussion

Despite some large variations in aphid numbers between cage replicates and regions, similar trends were found at each of the four cage trial sites. Local predators appeared to have some initial impact but were unable to control GPA by the end of the two weeks. However, in those cages with the five GLW nymphs added, as well as the open control cages which were exposed to all predators and parasitoids in the paddock, aphid numbers either decreased or were at least maintained close to the initial population. Unfortunately, poor environmental conditions and stressed canola plants appeared to hamper aphid population growth in the eastern states which resulted in low overall densities of aphids in all trial cages at those sites, but in Western Australia significant differences were found between the treatments (Figure 1).

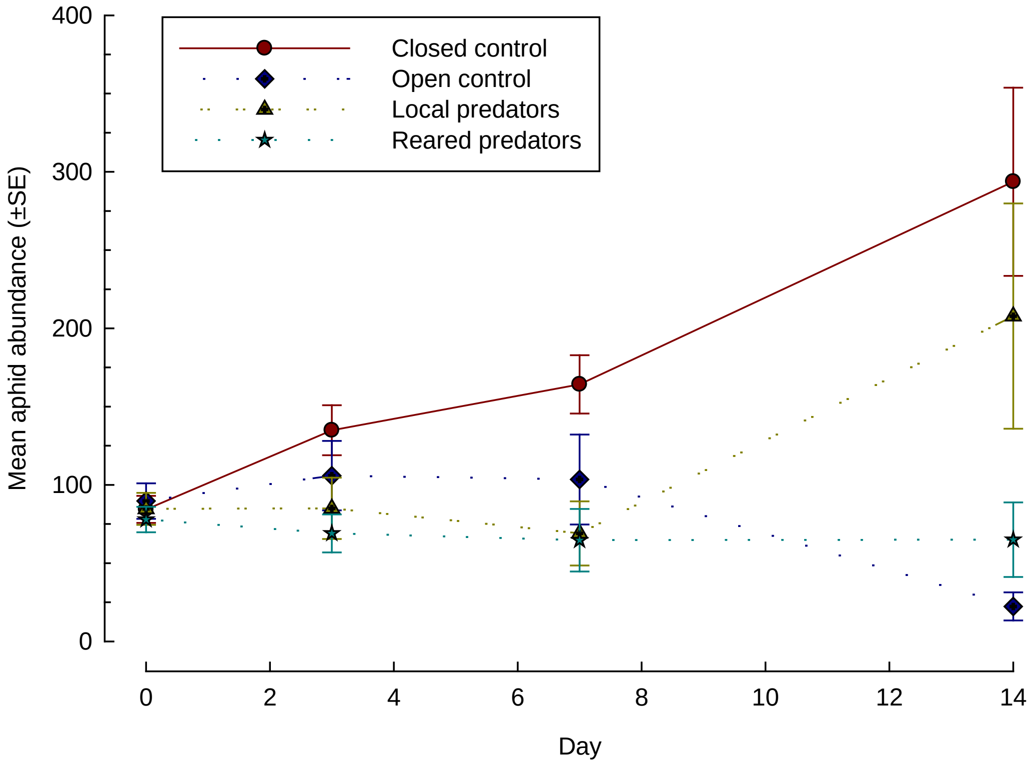

Figure. 1. Impacts of local (2 ladybeetles) and laboratory reared (5 second instar green lacewing nymphs) on green peach aphid in cage trials in canola.
(Data from Western Australia: Dusty Severtsen)

With the cage trials using parasitoid wasps the following year, results were again highly varied between cage replicates and regions. In hindsight, more conclusive results may have been found if a higher number of wasps had been added to each cage, but we were unable to repeat these trials due to issues with the equipment. However, while no significant GPA control was seen within the cages, significantly lower numbers of aphids were found on those open control plants (those plants exposed to the natural environment) inoculated with 100 GPA (Fig. 2), indicating that a combination of parasitoids and predators were able to exert some control of aphids at certain population levels. Despite closed cages being relatively open to the environment, it is possible that weather conditions (rain, wind) also contributed to the observed reduction in aphid numbers compared to the closed cages.

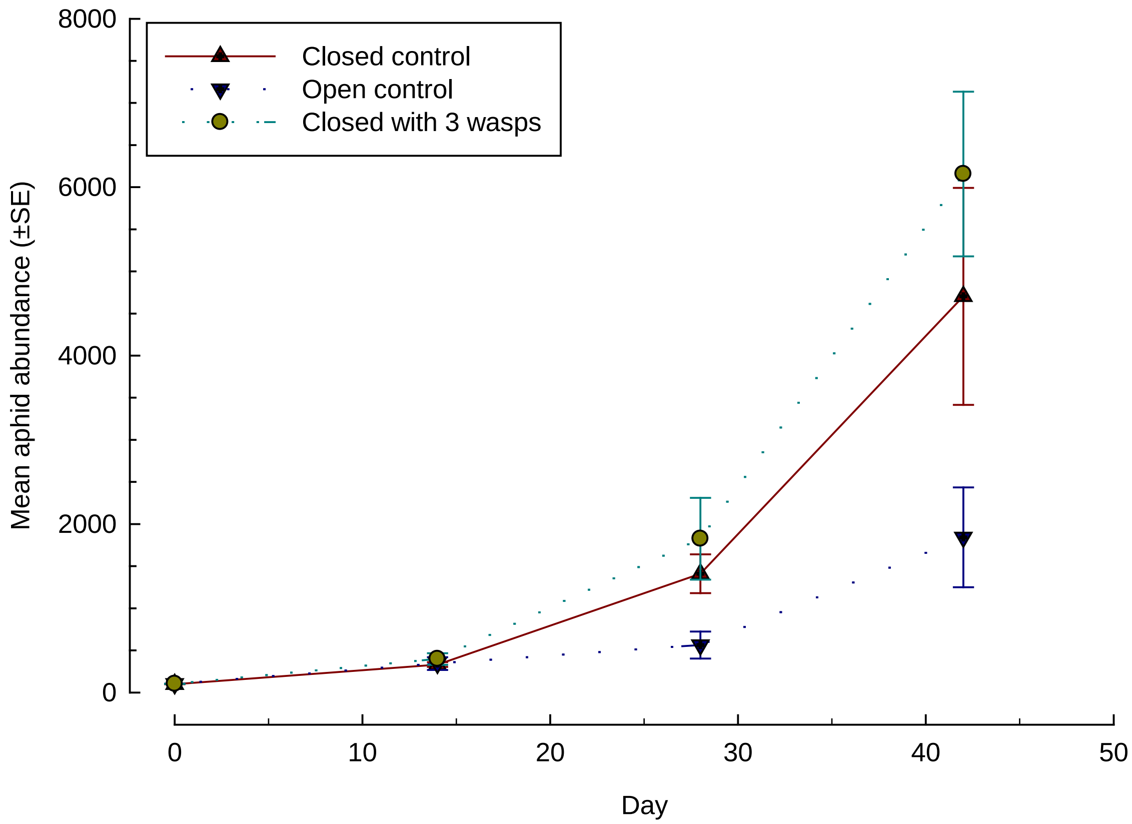

Figure 2. Comparison of the impacts of parasitoid wasps alone and local natural enemies (predators and parasitoids: "open control") on canola plants inoculated with 100 aphids in July. (Data from NSW: Jo Holloway)

Mummified aphids were not found in any of the treatments until Day 28 indicating that estimates of parasitism in the field may be underestimated due to undiscernible parasitism. Generally, numbers of aphid mummies increased exponentially in the closed cages, with higher number of aphids producing higher numbers of mummies, although numbers were similar between the medium (100 aphids) and high (200 aphids) cages (Figure 3). The number of aphid mummies produced in the open cages were lower than the corresponding closed cage treatments (but again similar between high and medium), which may be due to a number of reasons such as lower parasitoid wasp activity in the field, environmental conditions or removal by predators.

Although numbers were much lower than those in spring, predators and parasitoids were present throughout the entire growing season, with small rove beetles (Staphylinidae) the most common predators during the winter. Also present were spiders and predatory mites. However, in response to an escalation in aphid numbers, as well as increasing temperatures, numbers of brown lacewings and parasitoid wasps also increased and became the most dominant natural enemy groups.

The number and proportion of natural enemies present in the paddock varied over both growing seasons (Figure 4). This was probably as a response to the differences in aphid populations between the two years. In 2019, aphid numbers showed an earlier escalation, reached a peak twice as high and had a marked decline in population prior to windrowing compared to 2018. This resulted in natural enemies, particularly brown lacewings, increasing their numbers earlier and to a larger degree. Interestingly, aphid parasitoid wasps had a corresponding decrease in numbers that coincided with the decrease in aphids.

These results emphasise the need to use selective rather than broad-spectrum insecticides whenever possible. While natural enemy populations tend to lag behind those of aphids, use of selective insecticides allows these populations to be retained, while decreasing aphid numbers, resulting in a higher proportion of natural enemies to pests. This increases the likelihood of maintaining aphid populations below the economic threshold for the remainder of the season and reduces the potential requirement of any additional insecticide sprays.

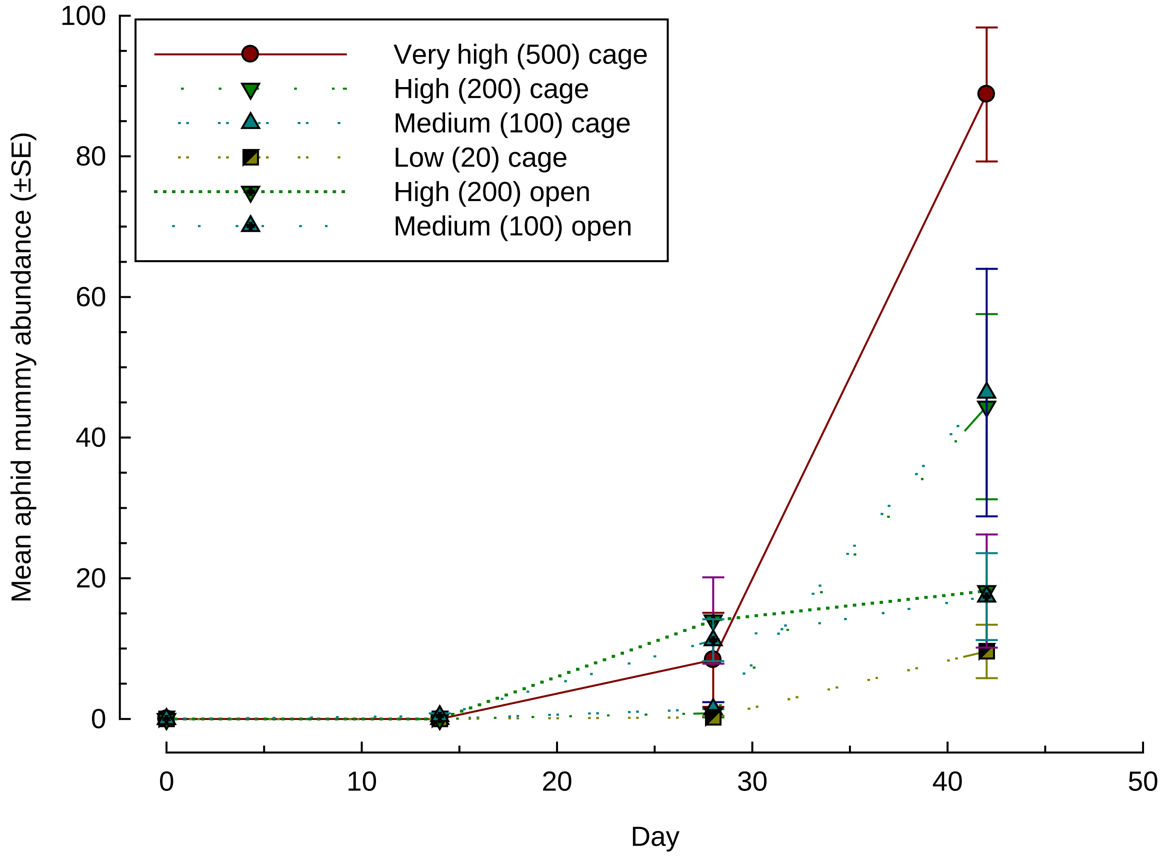

Figure 3. Number of parasitised mummies located over 42 days on caged and open canola plants inoculated with green peach aphids and three parasitoid wasps (*Aphidius colemani*).
(Data from NSW: Jo Holloway)

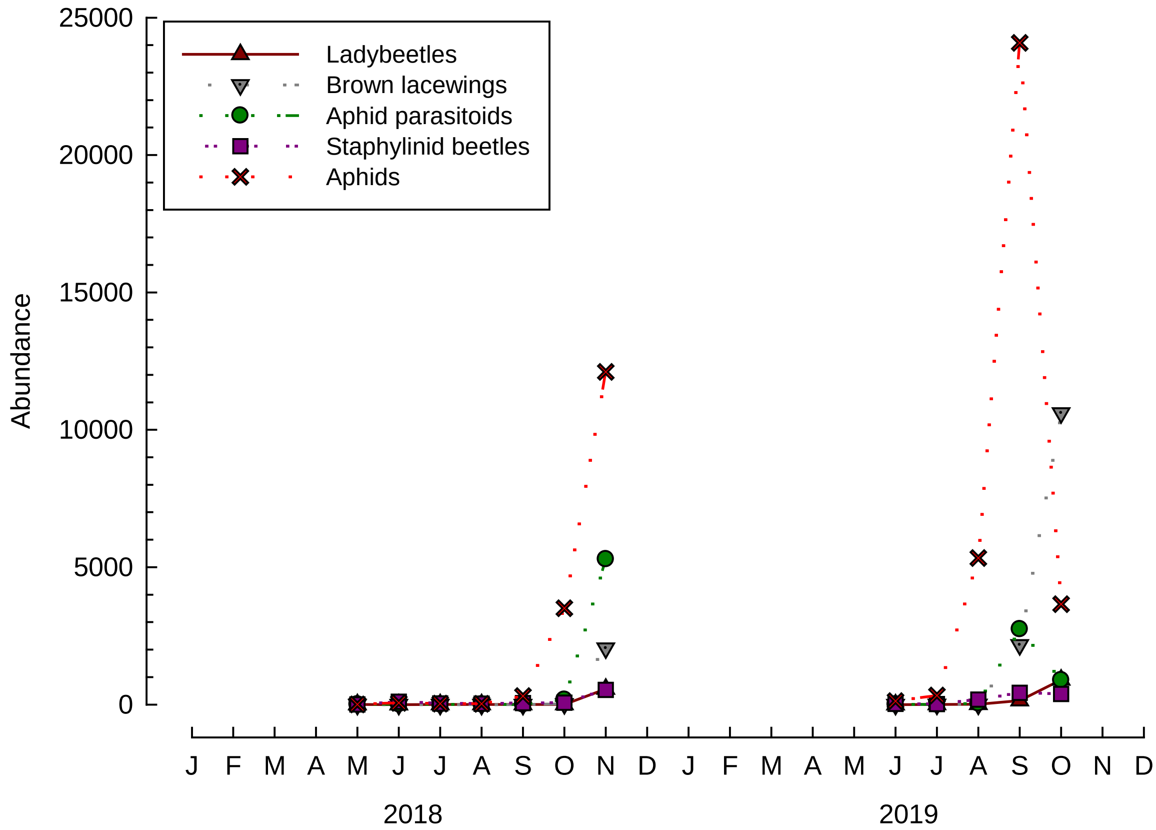

Figure 4. Abundance (total number of insects (or invertebrates) per 20 funnel traps) of aphid and natural enemy groups captured in funnel traps during cage trials. (Data from NSW: Jo Holloway)

The results also highlight the complexities of trying to include natural enemies in economic thresholds. While often dealing with only one or two pests that require control at a time, there are a whole suite of natural enemies that may need to be considered such as predatory beetles, spiders, lacewings, predatory bugs, parasitoid wasps. All of these contribute, to differing degrees, to pest control, and many factors (e.g. life stage, temperature, species, prey preference, season, geography) influence their efficacy. Further, little information is known about many and trapping and identifying some for assessment may be difficult. These factors make it very difficult to include natural enemies into economic threshold calculations and provide 'rule of thumb' advice. Therefore, to inform spray decisions, it is probably more important to concentrate on monitoring pest abundance over time to determine the overall trends. At the same time be aware of the presence of natural enemies as these will contribute to pest control. If pest numbers are remaining stable or only increasing slowly, delay spraying. Naturally, if pest populations are increasing at a high rate, it may be necessary to spray. In these cases, use a selective insecticide wherever possible to conserve the natural enemies and allow their populations to grow.

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Feathertop Rhodes grass ecology and management. What strategies are working best?

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Key words

feathertop Rhodes grass, *Chloris virgata*, ecology, management

GRDC code

NGA00003 and NGA00004, DAN1912-034RTX, ICN1912-002SAX

Take home message

Feathertop Rhodes grass is well adapted to colonise bare ground (fallows, roadsides)

Commitment to two summers of 100% control of feathertop Rhodes grass should deplete the seed bank in the soil

Control strategies require an integrated approach that includes tillage, crop selection, maximising crop competition, residual herbicides and selective use of double knock applications in fallow.

Feathertop Rhodes grass (*Chloris virgata*) (FTR) continues to be a major problem weed in zero till farming systems in the northern grains region, with populations continuing to expand further south, particularly along road corridors.

Biological factors that influence control strategies

Feathertop Rhodes grass is a prolific seed producer which can produce up to 40 000 seeds per plant under optimal conditions. However, when plants are under moisture stress, they will quickly begin setting viable seed, even when the plant is small/young.

It appears to have a short dormancy period, with poor germination for the first few months after shedding.

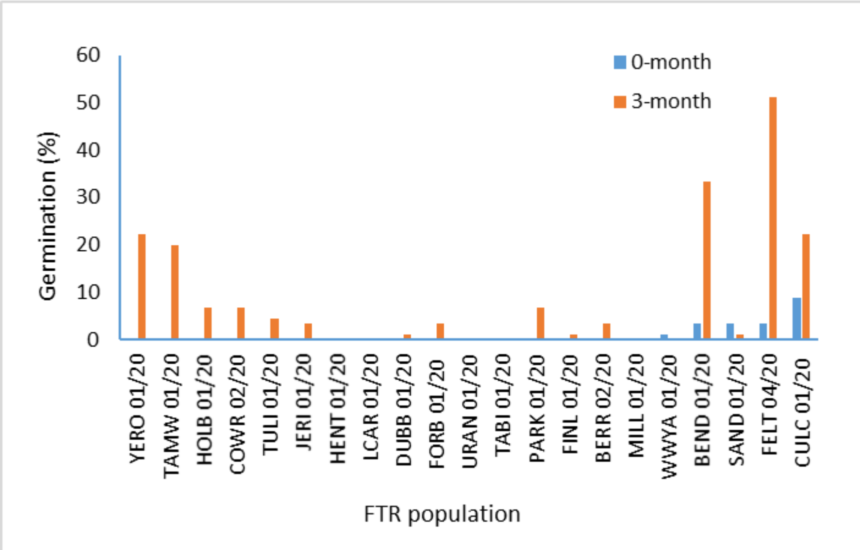


Figure 1. Germination percentage of different FTR collections soon after shedding (Hanwen Wu. NSW DPI)

FTR is often the first weed to establish on bare ground following a rainfall event in spring/summer, although it can germinate at all times of the year (including winter).

Glasshouse studies by Queensland Department of Agriculture and Fisheries (Werth 2017) showed that FTR will emerge following as little as a 10mm simulated rainfall event (Figure 2) however larger rainfall events resulted in increased emergence.

Awnless barnyard grass, common sowthistle and flaxleaf fleabane were also included in this study (data not shown). The rainfall requirement for emergence of FTR was less than for awnless barnyard grass, especially at the lower temperature tested, while rainfall >20mm was required to provide significant emergence of sowthistle and fleabane. This ability for FTR to establish on lower rainfall highlights one of the reasons that FTR is often the first weed to establish following spring rainfall.

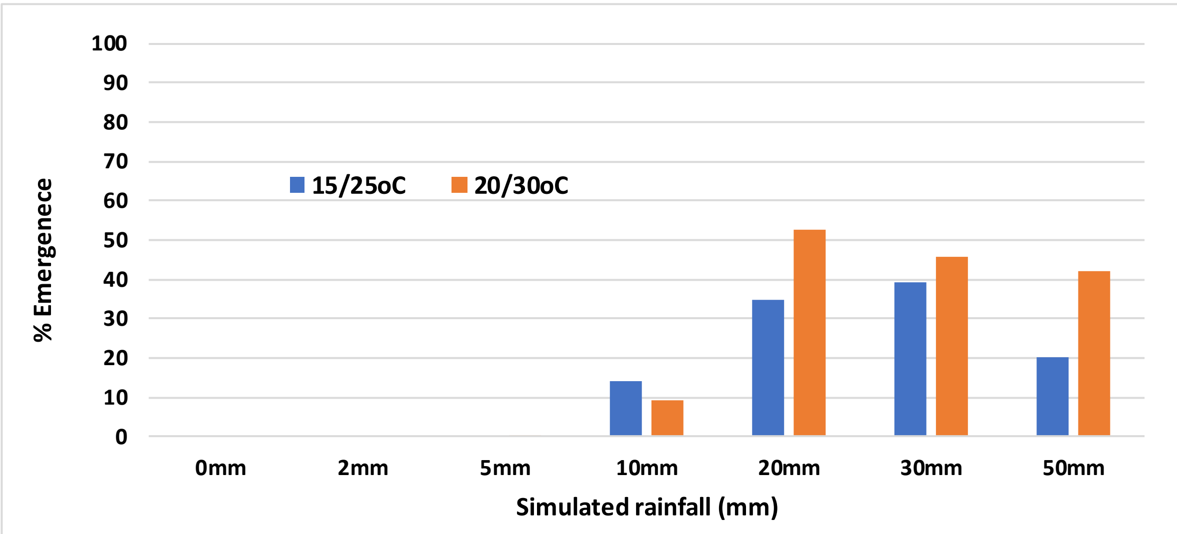


Figure 2. Percentage FTR emergence with respect to temperature and rainfall

In a second trial in the same study, different amounts of rainfall were simulated over consecutive days (Figure 3). Keeping the soil surface moist for a longer period typically increased the percentage emergence compared to a single application of the same total amount of rainfall.

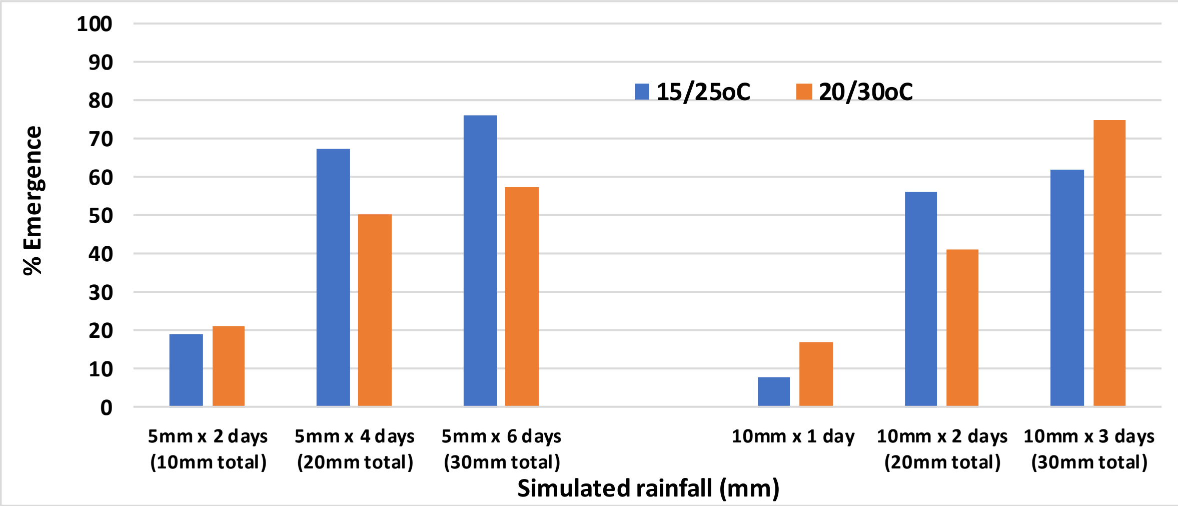


Figure 3. Percentage FTR emergence with multiple rainfall events

Feathertop Rhodes grass is predominantly a surface germinator, with minimal germination occurring from seed below the top 2cm in the soil (Figure 4).

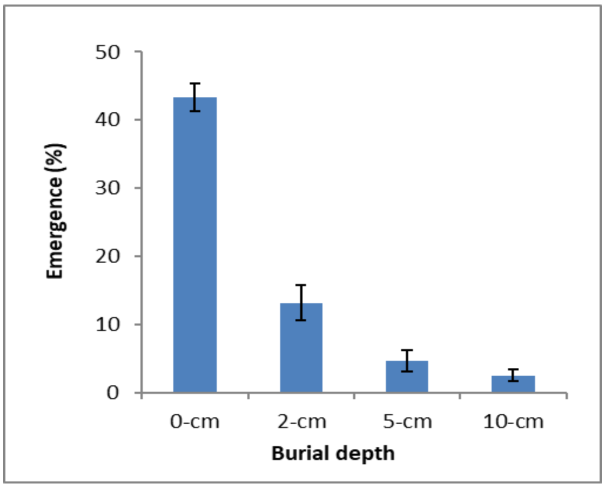


Figure 4. Effect on emergence of FTR seed burial (Hanwen Wu, NSW DPI)
Pot trial -duplex red Kandosol soil, pH 5.4 and organic carbon 0.6%.

The combination of surface germination and germinating on less rainfall than competitor weeds means that FTR is well adapted to zero till fallows and other bare areas (such as roadsides sprayed with glyphosate).

Seed persistence is short. Viability of seed declines rapidly and almost no seed remains viable 12-18 months after shedding (Figure 5). Unlike most other weeds, studies have shown that burying seed does not significantly increase persistence.

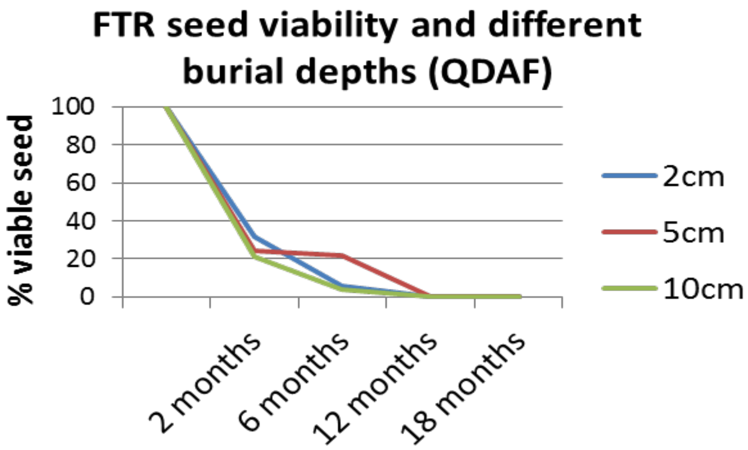


Figure 5. FTR persistence over time
Adapted from QDAF (2014) Integrated weed management of feathertop Rhodes Grass

This lack of seedbank persistence can be utilised as the proverbial boxer's 'glass jaw' in management of FTR – a concerted effort over two consecutive summers to completely stop seed set and any further recruitment into the paddock can see paddocks rapidly go from infested to effectively clear of FTR in a couple of years.

Feathertop Rhodes grass does not compete well with existing crops or pasture. However, it often is the dominant species in any bare areas (eg. roads, fallow) right up against the edge of the crop or pasture paddocks.

These factors see FTR quickly dominate bare earth roadsides or zero till paddocks, especially following wet summers where control programs have not been able to stop seed set and recruitment into the seed bank.

Outside of the cropping paddock, residual control can be achieved by the use of imazapyr based herbicides (e.g. Arsenal®) in non-crop areas. The flumioxazin based herbicides Terrain® and Valor® have recently obtained registrations for residual control along fencelines and irrigation channels respectively.

The first punch – prevention is better than cure

Control of established populations of large FTR is difficult, extremely costly and most likely to be incompatible with zero till farming. Therefore, growers should aim to keep FTR out of farming paddocks wherever possible, and urgently seek to remove individual plants before they have a chance to set seed.

Where glyphosate has been used on roadways and fence lines and FTR has then become established, seed can be blown into adjacent paddocks. Alternatively, seeds may be deposited in the paddock via livestock and kangaroos; from machinery or in flood water.

Typically, a single plant in year 1 will result in a small clump covering maybe 2-3m^2 in year two. Over coming years these patches will continue to expand, potentially seeing the whole paddock infested if nothing is done to stop seed set.

Growers should be continually on the lookout for individual plants and act quickly to manually remove or spot spray these before they are allowed to set seed. Small patches should be chipped, burnt or cultivated to prevent spread. Ideally these should be GPS mapped for future monitoring with a residual herbicide applied prior to the commencement of spring rainfall events.

The second punch – knockdown herbicides

Glyphosate alone is not registered for control of FTR and cannot be expected to achieve control (Widderick 2014, Douglas 2019). Even when using a double knock of glyphosate followed by paraquat under ideal conditions and targeting seedlings before they start tillering, control is variable and rarely provides a commercially acceptable result.

Targeting larger weeds that have commenced tillering, or are under any stress, will typically achieve less than 50% control as a double knock, and often not significantly better than using paraquat alone as a single application.

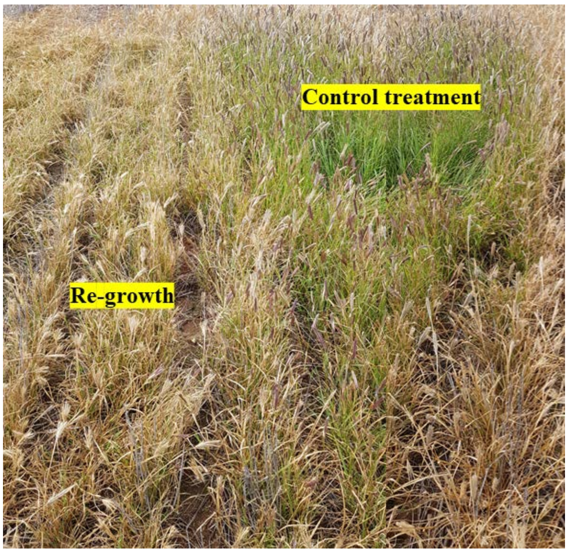


Figure 6. Re-growth (left) with single knock of glyphosate (540g ai/L) at 1.44L/ha (not registered for FTR) (Photo: Hanwen Wu)

Research trials and commercial experience have shown that Group A herbicides can be effective in providing useful control.

Shogun® (propaquizafop) is registered for the control of feathertop Rhodes grass in fallow and in cotton, peanuts and sunflower. In fallow, Shogun must be applied to weeds at the 3-leaf to early tillering growth stage and followed with an application of paraquat within 7-14 days (double knock).

Firepower 900 (haloxyfop) has recently been registered for control of FTR in fallow. (Note: this is the only haloxyfop formulation approved for use on FTR in NSW). Weed size is restricted to 2 leaf to early tillering (Z12 to Z22) and for FTR, this should always be followed by a paraquat double knock.

The APVMA has also recently approved an emergency permit that supports the use of clethodim formulations for control of FTR in fallow (PER89322 – Expires 31 August 2021, for NSW and Queensland only). This must also be followed by a paraquat double knock application within 7-14 days. While there is no weed size recommended on the permit, it should be noted that trial work has consistently shown that clethodim is generally slightly less effective than 'fops' on FTR, so limiting application to seedlings or very early tillering is strongly advised.

The importance of weed growth stage is critical for the performance of Group A herbicides (Figure 7 & 8). As weed size increases, translocation of the herbicide reduces throughout the plant. Once plants move from vegetative production to reproductive growth, production of the enzyme targeted by the Group A herbicide reduces in the plant. Further information explaining this can be found in the GRDC Fact Sheet 'Group A Herbicides in Fallow'. http://www.grdc.com.au/GRDC-FS-GroupAinFallow

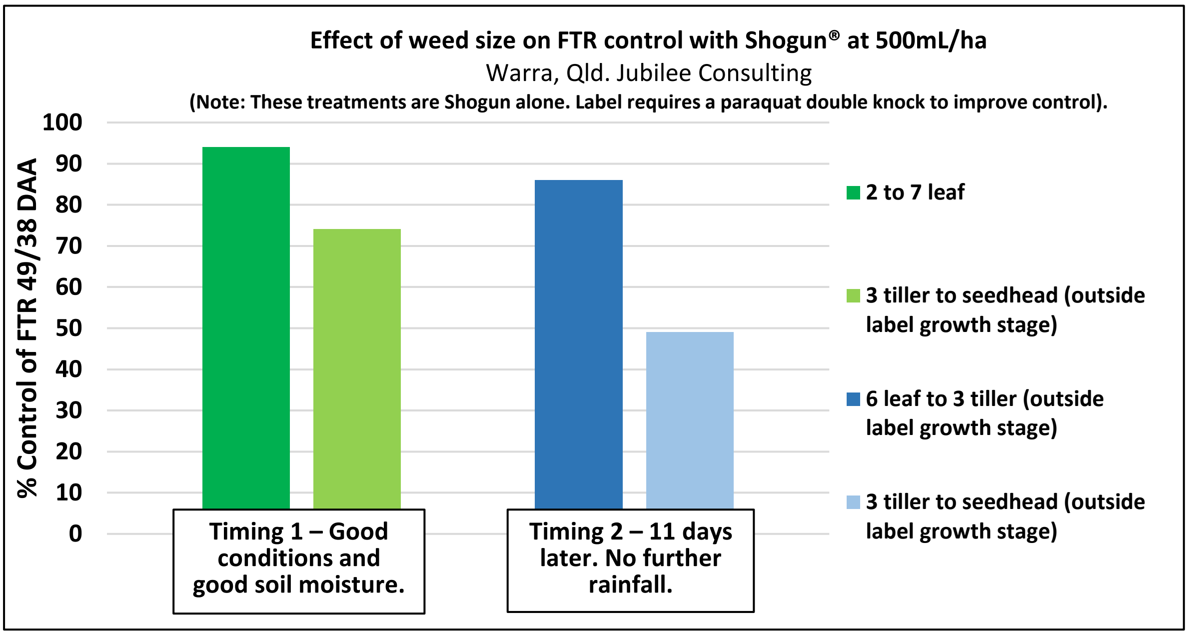


Figure 7. Effect of weed size and timing of Shogun on FTR (Adama, unpublished)

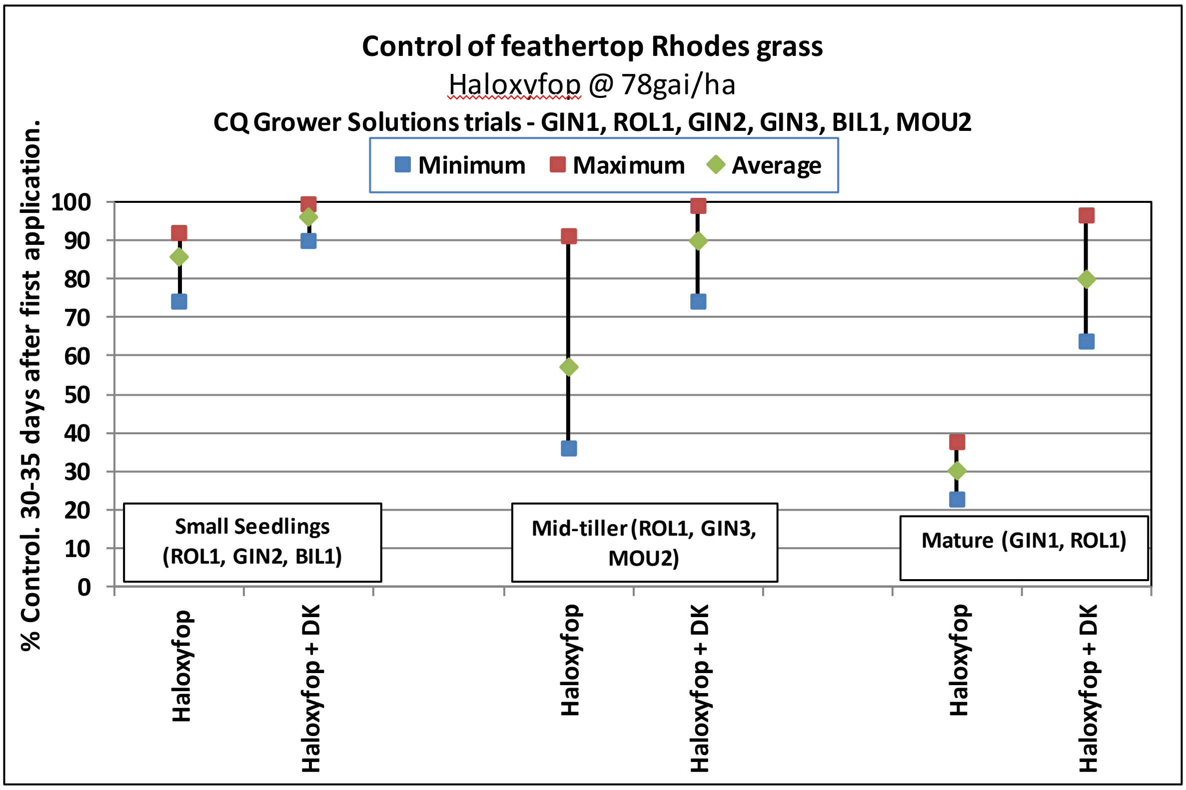


Figure 8. Effect of weed size +/- double knock of haloxyfop on FTR
(Central Queensland Grower Solutions Project 2011-15)

When applying Group A herbicides, ensure the correct adjuvant is used and application set up is optimised for coverage. Typically, this will be a medium-coarse spray quality, with water rates of 80 to 100 L/ha.

Avoid tank-mixing other herbicides which may reduce the performance of Group A herbicides (Figure 9).

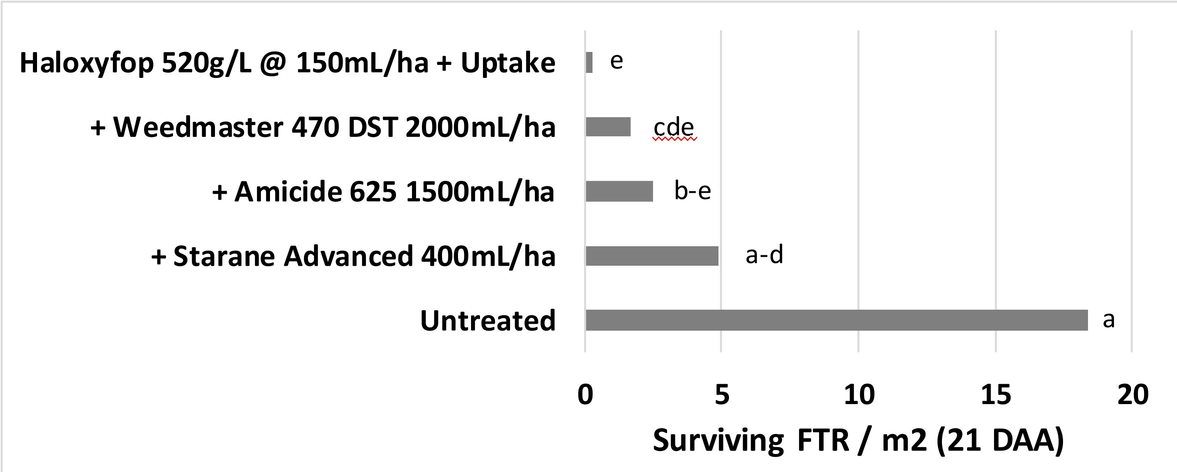


Figure 9. Haloxyfop tank mixes against FTR (NGA, Crooble 2014. RN1433)

Experience in other grass weed species has shown that Group A herbicides are one of the quickest modes of action to select for resistance as there is typically a high frequency of resistant individuals in the natural population.

For this reason, all Group A applications in fallow must be followed by a double knock; they should only be targeted at small weeds; and should not be used more than once per season.

It is essential that this mode of action is protected from resistance selection. Group A herbicides are the mainstay of post-emergent grass weed control in summer broadleaf crops.

The third punch – tactical cultivation

Where FTR has got out of hand and established plants are present, it is likely that tillage will be needed to remove existing weeds.

It is unlikely that any herbicide treatment will provide consistent cost-effective control of mature plants. Where old, established plants remain from last summer they can frequently shade herbicide application, thus leading to unsatisfactory results from subsequent knockdown or residual herbicide applications.

Removing mature plants via cultivation can be very effective. Burial of seed below 5cm can also reduce emergence and this seed will lose viability within about 12 months (providing it is not subsequently returned to the soil surface by further tillage).

While an effective cultivation may bury the vast majority of seed, there is always a small percent of seed remaining at the soil surface in the preferred germination zone. If something is not done to prevent these seeds from germinating and establishing, then the cycle recommences.

A plan should be in place to manage these subsequent germinations via either tillage, knockdown or residual herbicides.

The knockout blow – residual herbicides

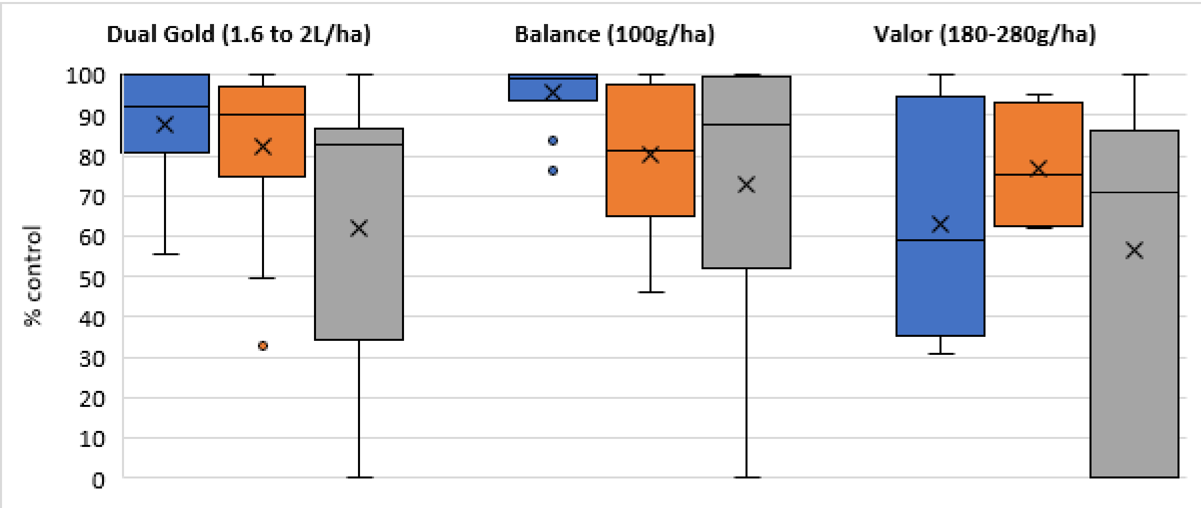
The most successful strategies employed by growers for managing FTR have included the use of residual herbicides. Either directly targeted at known FTR problem paddocks, or more broadly, by keeping FTR at bay when targeting other grass weed problems on the farm. The viability of most other grass weed seeds in the soil is much longer than for FTR, so where growers are incorporating residual herbicides into their program to manage grass weeds such as awnless barnyard grass, FTR is often also controlled or suppressed.

Balance® can be a particularly effective option for fallow management. In addition to residual control of FTR, it will also control flaxleaf fleabane and common sowthistle with suppression of awnless barnyard grass, however significant plantback periods apply for many summer crop options.

Dual® Gold is registered for residual control of FTR prior to planting a wide range of summer crops and also in fallow situations, with minimal plantback constraints. A new use pattern also allows for a top-up application in sorghum after crop emergence.

Valor, applied at rates for residual control, is also an option prior to planting selected summer crops. Plantback periods apply for some summer crops when using Valor, so always check the label. In addition to control of FTR, Valor can also provide residual control of a range of difficult to control broadleaf weeds such as fleabane, sowthistle, red pigweed, caltrop, bladder ketmia and the *Ipomea* species such as bell vine and morning glory.

Most residual 'grass' herbicides are active on FTR however the length of residual control is a function of environment at the site; the soil type and stubble; and the individual properties of the herbicides. Chose the 'grass' residual herbicide that fits the farming system within that paddock.



12 10 9 13 10 12 6 4 7 Data points*

Figure 10. Summary of 22 residual herbicide trials (2007-2016) (NGA, QDAF, GOA, NSW DPI)
Blue 14-48 DAA Orange 58-77 DAA Grey 81-147 DAA
*Not all treatments in all trials. Some trials had more than one rate. Some trials had two ratings within the same time grouping.

Screening of residual herbicides registered for use in winter cereal or pulses is showing a promising range of options that can suppress FTR emergence for periods of three to four months. These may be options to consider in areas where spring temperatures are warmer and FTR is establishing in-crop during spring.

Going the full ten rounds – pulling it all together

Where there has been a 'blow out' and a paddock has become infested with FTR, it is likely that a management strategy will look something like the following:

- Cultivation of established plants (before seed has been shed)
- Residual herbicide applied if there is still the possibility of further germination before winter
- Aggressive crop competition (and pre-emergent herbicides) in the winter crop

- Decide on your strategy for summer before the first spring rainfall event, and potential weed germination
    - If fallowing over summer, apply a residual herbicide before spring rainfall. Monitor frequently for any escapes or breakdown of the residual herbicide. Access to an optical (camera) sprayer can be beneficial in cost effectively treating isolated escapes. Once the residual treatment has broken down, a double knock application will be required, with consideration given to including another residual application with the second knock
    - Where soil moisture is adequate, consider a summer broadleaf crop (or cotton where suitable). Use a pre-emergent herbicide effective on grass weeds; keep row spacing narrow and plant population high to increase the benefit of crop competition; and utilise a selective Group A ‘fop‘ herbicide in-crop to control any escapes. Inter-row tillage is also a valid strategy in wide row summer crops.
- Do not plant sorghum or maize into paddocks with a high FTR seed bank population. Pre-emergent herbicide options such as Dual Gold are unlikely to provide full season residual control, even at the highest application rate – especially in wet seasons. Late season germinations can establish after the pre-emergent herbicide has broken down
- If FTR is not allowed to set seed, then seed bank viability should be low the following year. Continue vigilant management for another season to ensure depletion of the seed bank.

Unfortunately, the best management strategies for this difficult to manage weed place great reliance on herbicides; and therefore, selection of resistant individuals. Glyphosate is ineffective and Group A herbicides are known to be of significant risk of rapid selection for resistance. While there is currently negligible resistance in the northern grains region to many of the pre-emergent herbicides with efficacy on this weed, one thing we have learnt from history is that if we over-rely on a particular herbicide or herbicide group and don’t stop weed seed set of survivors, then we will break it.

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