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Thursday 29 July

9.00am to 11.30 am ACST

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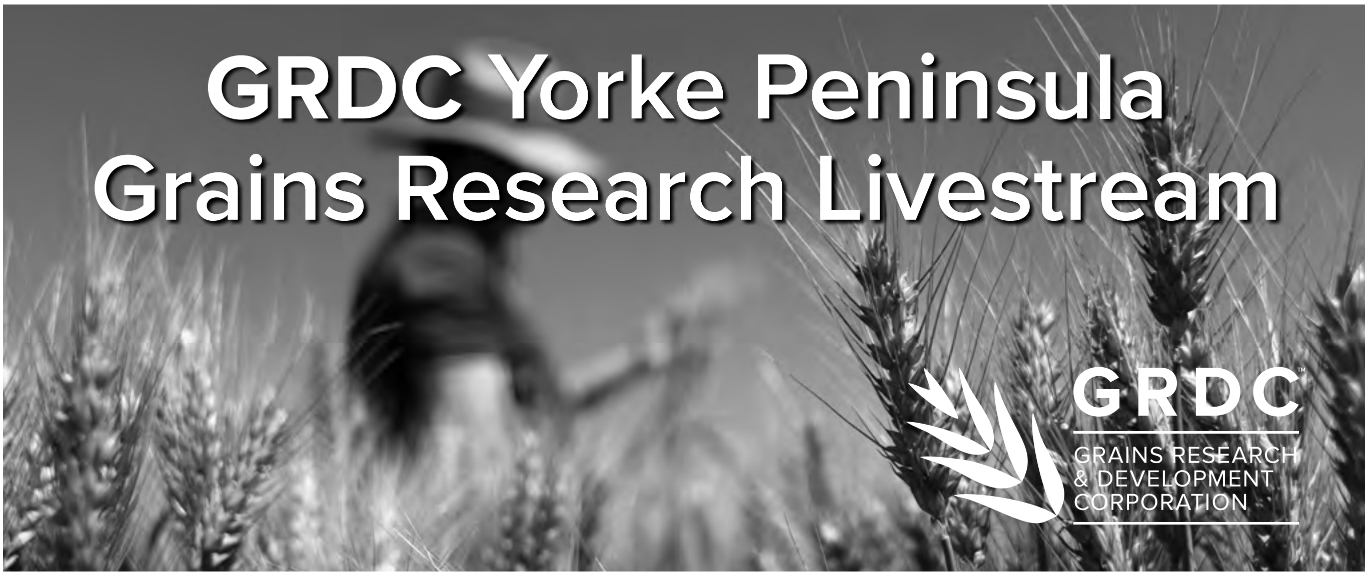

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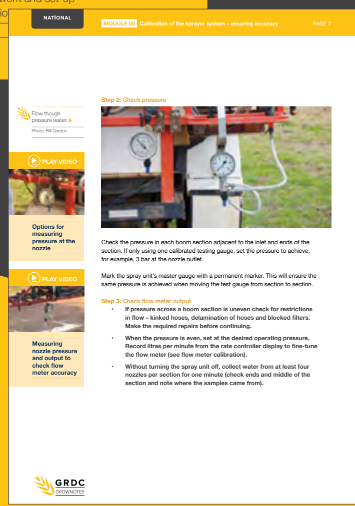

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Cereal disease update for Yorke Peninsula 2021

Hugh Wallwork and Tara Garrard.

South Australian Research & Development Institute.

GRDC project codes: UOA2003-008RTX, CUR00023

Keywords

- barley, net form net blotch, wheat, powdery mildew, fungicide resistance.

Take home messages

- Avoid growing barley on barley.
- Avoid reliance on fungicides by growing varieties with better resistance.
- Rotate and/or combine different classes of fungicides for control of net blotches and wheat powdery mildew.
- Avoid fluxapyroxad (Systiva®) for the time being.

Background, results and discussion

Barley net form net blotch

The net form net blotch (NFNB) fungus has been evolving rapidly in South Australia since the 1990s when it first showed up in the state after a lengthy absence. Initially it was observed with virulence on just a few key varieties including Franklin, Skiff and then Barque. Then in 2007 and 2008 it acquired virulence on Keel, then MaritimeⒹ and consequently spread dramatically across the state. Since 2012 we have been monitoring the virulence of the pathogen in SA each year using 24 key varieties. Results from this monitoring have shown a constant erosion of resistance over time with some varieties gradually losing resistance as minor genes have been overcome, whilst other varieties showed much larger, sudden increases in susceptibility. Until 2020 the older varieties Clipper, Schooner, SloopSA and ScopeⒹ showed good resistance to all isolates collected and so we identified these varieties as having durable resistance. Last year however one isolate from Bute and several from Western Australia showed virulence on all four varieties whilst a few other isolates showed virulence on one or more of them. The reason for this sudden shift is not apparent.

At the same time, the NFNB population has also been evolving resistance to some fungicides, notably the seed treatment Systiva®. In 2019 we observed 3 paddocks with a high degree of NFNB infection south of Minlaton. In each case SpartacusⒹwas sown with Systiva® seed treatment into stubbles of a SpartacusⒹ crop that had also been treated with Systiva® in 2018. This was clearly a situation where very high selection pressure was brought to favour any mutations towards increased virulence on SpartacusⒹ as well as resistance to Systiva®. Molecular tests conducted by Curtin University revealed the Systiva® resistance mutation in samples from each paddock. Further tests also revealed resistance mutations present across the lower Yorke Peninsula in 2019 (Figure 1) as well as in two isolated spots at Lock on the Eyre Peninsula and at Kybybolite in the South East. Interestingly samples from the latter two sites had quite different mutations to the Yorke Peninsula samples indicating quite separate evolution of resistance at each location.

In 2020 resistance to Systiva® was found to be commonplace on the West Coast of the Eyre Peninsula as well as being present at Avon on the Adelaide Plains. In June this year we have been advised that SpartacusⒹ treated with Systiva® is showing high levels of infection near Ouyen in Victoria. Again, this crop was sown into stubbles of SpartacusⒹ that had also been treated with Systiva® in 2020.

Table 1. Net form net blotch isolates from SA in 2018 tested on 24 barley varieties. A high number indicates high level of susceptibility.

Isolate	49/18	50/18	51/18	52/18	21/18	47/18	25/18a	69/18	70/18	71/18	75/18	73/18a	76/18	72/18a
Host	Keel	RGT Planet	Topstart	RGT Planet	RGT Planet	RGT Planet	Keel	Gairdner	La Trobe	Compass	Rosalind	Westminster	Oxford	Fatima
	Elliston	Elliston	Wanilla	Wanilla	Yeelanna	Yallunda Flat	Brentwood	Conmurra	Conmurra	Conmurra	Rendelsham	Rendelsham	Rendelsham	Rendelsham
Clipper	3	4	3	2	4	3	2	3	4	4	3	2	2	2
Schooner	4	3	2	3	4	2	2	3	2	4	2	2	3	2
Scope	2	2	2	2	2	2	2	2	2	3	2	2	2	2
SloopSA	2	2	2	2	5	2	2	2	2	2	3	2	2	2
Alestar	3	5	8	3	7	5	4	3	3	3	7	8	8	7
Banks	2	1	2	1	2	1	2	6	1	2	2	2	2	2
Commander	7	6	5	6	8	4	9	6	5	7	4	3	9	6
Compass	6	7	7	7	7	3	7	4	5	6	5	4	7	6
Fathom	6	7	7	8	7	4	8	7	3	7	7	5	8	5
Fleet	1	1	1	1	1	2	3	3	2	2	2	4	2	2
RGT Planet	3	4	7	3	9	5	4	3	3	6	7	7	8	8
Maritime	2	2	2	2	2	2	3	2	2	2	3	2	2	2
Navigator	7	7	8	7	7	5	6	7	5	8	8	7	8	8
Oxford	3	3	8	4	9	5	3	4	4	6	7	8	9	9
Rosalind	2	2	3	2	4	2	2	2	2	2	3	2	4	3
Spartacus	6	6	7	5	3	4	8	3	3	6	3	3	7	7
Traveller	2	3	7	3	5	6	2	1	2	4	7	7	6	8
Westminster	3	2	5	2	6	4	2	4	2	3	7	5	5	7
IGB1705T	5	4	7	4	3	3	4	2	2	3	3	5	4	4
WI4952	4	4	5	5	4	2	5	2	2	3	2	4	3	6
Leabrook	7	7	5	7	7	5	8	5	5	7	4	5	4	7
Biere	5	4	9	4	7	7	6	4	4	8	5	7	9	7
Charles	8	8	8	7	7	5	7	3	3	4	8	8	7	8
Sunshine	7	6	7	5	8	6	5	4	5	7	7	8	6	8

Table 2. Net form net blotch isolates from SA in 2020 tested on 24 barley varieties. A high number indicates high level of susceptibility.

	SA isolates													
Isolate	14/20	9/20	10/20	11/20	19/20	51/20	33/20	69/20	41/20	52/20	55/20	42/20	54/20	68/20
Variety	Spartacus	Spartacus	Barley	Rosalind	Compass	Compass	Spartacus	Maritime	Compass?	Spartacus	Spartacus	Spartacus	Spartacus	Commander
Location	Reeves Plains	Pt Kenny	Wauraltee	Minlaton	South Kilkerran	Mortana	Warnertown	Bute	NE Pt Kenny	Mt Hall	Mt Cooper	Pt Kenny	Elliston	Beetaloo Valley
Alestar	3	9	5	2	3	7	3	8	7	7	5	3	4	3
Banks	2	3	2	2	1	2	2	4	3	2	2	1	3	2
Beast								8	7	4	6	4	8	4
Bottler	1	3	3	2	2	3	2	6	4	3	2	3	2	3
Clipper	3	4	4	3	2	6	3	8	4	4	5	2	4	3
Commander	6	9	7	4	4	9	5	8	6	6	7	4	9	6
Compass	6	7	7	3	2	8	4	7	6	7	5	3	7	4
Fathom	7	9	9	4	7	9	5	9	7	7	6	5	8	5
Fleet	2	3	3	1	2	2	4	9	2	3	2	1	2	2
Kiwi	1	3	1	2	2	3	2	5	2	3	2	1	3	3
Laperouse	3	8	5	3	3	8	2	8	7	5	4	2	5	2
Leabrook	6	8	6	3	5	8	3	8	7	6	7	4	9	5
Maritime	3	3	3	2	3	3	2	9	3	3	2	2	3	2
Maximus	5	6	7	4	5	7	2	7	5	4	5	5	7	4
RGB Planet	3	4	4	2	2	5	2	5	4	4	5	4	2	3
Rosalind	5	4	6	2	2	3	2	3	2	4	3	2	3	2
Schooner	4	6	5	4	3	7	3	8	-	3	2	3	7	5
Scope	-	-	-	2	3	3	2	7	2	2	2	2	3	2
SloopSA	2	5	7	2	3	7	2	8	4	3	4	2	6	3
Spartacus	7	9	8	6	4	5	2	8	4	5	4	4	7	4
Traveller	3	4	3	1	2	3	1	4	3	3	3	1	2	3
Vlamingh	2	4	3	2	2	3	2	6	4	3	3	2	2	2
Westminster	2	3	3	2	2	7	3	6	2	3	3	2	6	3
WI4933	6	7	6	4	3	7	3	6	4	6	4	3	5	4
Biere	7	9	9	7	3	8	3	9	7	7	6	3	8	6

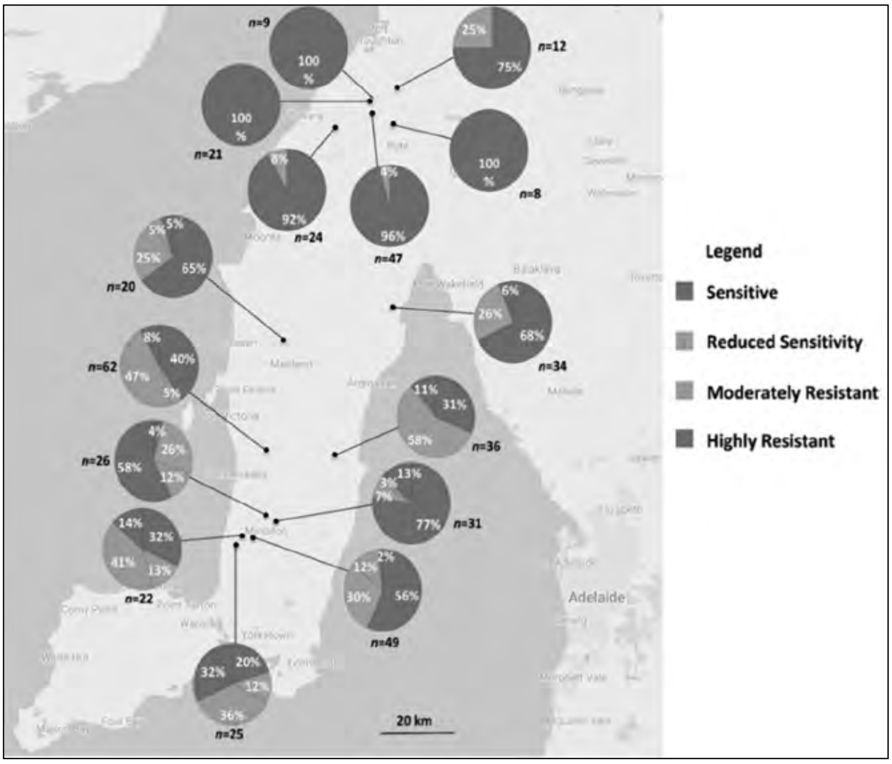

Figure 1. Incidence of resistance to Systiva (fluxapyroxad) in NFNB samples in 2019.

Wheat powdery mildew

Powdery mildew has become a significant problem in wheat crops on the Northern Yorke Peninsula over the past 3-4 years. The situation has arisen due to growers planting the very susceptible varieties Scepter⦸ and Chief CL Plus⦸ in close rotation and in neighbouring paddocks. This is reminiscent of the situation on the lower Eyre Peninsula around 2008-2010 when Wyalkatchem⦸ was grown intensively in close rotation. In the earlier situation the problem was largely overcome when Mace⦸ replaced Wyalkatchem⦸ and flutriafol treated fertiliser was widely used. Scepter⦸ and Chief CL Plus⦸ are similar to Wyalkatchem⦸ in their susceptibility to powdery mildew. Unfortunately, this time around the problem has been compounded by the development of resistance to the strobilurin fungicides as well as reduced sensitivity to some of the demethylase inhibitors (DMI) fungicides.

Trials run by Sam Trengrove and supported by SAGIT are investigating the relative efficacy of a range of fungicides around Bute. Their results have shown that flutriafol is providing good early control and should therefore be an effective management option for 2022. Foliar fungicides based on DMI chemistry also provided some good control, but the uneven distribution of disease in paddocks needs to be included in assessing the economic benefits of foliar sprays. It is worth noting that the efficacy of different foliar fungicide treatments is always under-rated where untreated or less effective treatments are included in plot trials since they provide a continuous supply of fresh inoculum that would not occur in a paddock situation. The trial data from Bute showed clearly that the best impact on disease control comes from variety resistance.

Powdery mildew will likely remain a significant problem whilst very susceptible varieties are grown in close rotations. Table 3 provides an indication of which varieties would be more suitable. Varieties rated MSS are much better than those rated SVS.

Table 3. Resistance rating of current wheat varieties to powdery mildew in South Australia.

Ballista⦸	SVS
Catapult⦸	S
Chief CL Plus⦸	SVS
Cutlass⦸	MSS
Grenade CL Plus⦸	MS
Hammer CL Plus⦸	MSS
Mace⦸	MSS
Razor CL Plus⦸	MSS
Rockstar⦸	S
Scepter⦸	SVS
Trojan⦸	S
Vixen⦸	SVS
Wyalkatchem⦸	SVS

Conclusion

The growing of very susceptible varieties as well as the use of close rotations, or no rotation, will often lead to increased disease problems. Reliance on chemical control can be a useful option at times but can also lead to worse outcomes over the longer term not only in individual paddocks but across whole regions for pathogens that have long distance dispersal mechanisms.

Acknowledgements

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

Fran Lopez and Fungicide Resistance team at Curtin University for molecular data to detect resistance mutations.

Useful resources

Cereal Variety Disease Guide 2021 https://www.pir.sa.gov.au/__data/assets/pdf_file/0005/384998/Cereal_Variety_Disease_Guide_2021.pdf

Cereal Seed Treatments 2021 https://www.pir.sa.gov.au/__data/assets/pdf_file/0005/237920/Cereal_Seed_Treatments_2021.pdf

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Notes

TOP 10 TIPS

FOR REDUCING SPRAY DRIFT

01 **Choose all products in the tank mix carefully**, which includes the choice of active ingredient, the formulation type and the adjuvant used.

02 **Understand** how product uptake and translocation may impact on coverage requirements for the target. Read the label and technical literature for guidance on spray quality, buffer (no-spray) zones and wind speed requirements.

03 **Select the coarsest** spray quality that will provide an acceptable level of control. Be prepared to increase application volumes when coarser spray qualities are used, or when the delta T value approaches 10 to 12. Use water-sensitive paper and the Snapcard app to assess the impact of coarser spray qualities on coverage at the target.

04 **Always expect** that surface temperature inversions will form later in the day, as sunset approaches, and that they are likely to persist overnight and beyond sunrise on many occasions. If the spray operator cannot determine that an inversion is not present, spraying should NOT occur.

05 **Use weather forecasting** information to plan the application. BoM meteograms and forecasting websites can provide information on likely wind speed and direction for 5 to 7 days in advance of the intended day of spraying. Indications of the likely presence of a hazardous surface inversion include: variation between maximum and minimum daily temperatures are greater than 5°C, delta T values are below 2 and low overnight wind speeds (less than 11km/h).

06 **Only start spraying** after the sun has risen more than 20 degrees above the horizon and the wind speed has been above 4 to 5km/h for more than 20 to 30 minutes, with a clear direction that is away from adjacent sensitive areas.

07 **Higher booms increase drift**. Set the boom height to achieve double overlap of the spray pattern, with a 110-degree nozzle using a 50cm nozzle spacing (this is 50cm above the top of the stubble or crop canopy). Boom height and stability are critical. Use height control systems for wider booms or reduce the spraying speed to maintain boom height. An increase in boom height from 50 to 70cm above the target can increase drift fourfold.

08 **Avoid high spraying speeds**, particularly when ground cover is minimal. Spraying speeds more than 16 to 18km/h with trailing rigs and more than 20 to 22km/h with self-propelled sprayers greatly increase losses due to effects at the nozzle and the aerodynamics of the machine.

09 **Be prepared** to leave unsprayed buffers when the label requires, or when the wind direction is towards sensitive areas. Always refer to the spray drift restraints on the product label.

10 **Continually monitor** the conditions at the site of application. Where wind direction is a concern move operations to another paddock. Always stop spraying if the weather conditions become unfavourable.
Always record the date, start and finish times, wind direction and speed, temperature and relative humidity, product(s) and rate(s), nozzle details and spray system pressure for every tank load. Plus any additional record keeping requirements according to the label.

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Increasing reliability of lentil production on sandy soils

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GRDC project codes: DAV168BA, CSP00203, DAS1905-011TRX, USA103-002RTX, DAV00150
SAGIT Project Codes: TC116 and TC119

Keywords

- Sandy soil, Lentil variety, herbicide tolerance.

Take home messages

- Four key steps to improving lentil productivity on underperforming sandy soils are: soil amelioration, variety selection, herbicide choice and nutrient management.
- Ameliorating soil constraints increased lentil grain yields up to 347%, with an average 0.31t/ha (85%) yield response to deep ripping.
- The highest yielding varieties on loamy soil types may not be the highest yielding on underperforming sandy soils.
- Weed control methods on sandy soil types should be carefully planned to minimise yield loss due to the heightened risk of herbicide damage from soil residual herbicides.
- Nutrient requirements on sandy soil types can vary across locations and seasons. Application of molybdenum on acidic sands were shown to increase grain yields.
- Lentil growth and biomass, as measured by NDVI, was positively correlated with grain yield on sandy soils.

Background

Lentil production in South Australia has expanded significantly over the last 20 years. It is valued for its agronomic rotational benefits and its ability to generate high economic returns. The expansion in lentil area now sees the crop produced on a diverse range of soil types across the state. Observations of lentil growth and productivity has indicated that on some sandy soils' performance has been sub optimal, with significant scope for improvement. This was particularly notable in the dune swale landscape of the northern Yorke Peninsula. Two SAGIT projects (TC116, TC119) have investigated opportunities for increasing lentil productivity on the sandy soil types of this region. These sands are typically red sandy dunes with low organic carbon (0.4-0.8%). Constraints on these sands can include compaction, non-wetting, pH (both acidic and alkaline), nutrition and low biological activity. The heavy reliance on herbicides with residual soil activity for broadleaf weed control in lentil also presents challenges on these soils. However, these sandy dune soil types are not typically constrained by the subsoil toxicities of sodicity, salinity or boron that limit production on many of the heavier textured soils in the region. Thus, significant production improvement in lentil is expected if these known constraints can be overcome. This paper details the results of SAGIT and GRDC funded amelioration, variety selection, herbicide choice and nutrition trials conducted on these sandy soils.

Methodology

General trial information

Yield data from specific treatments from a range of soil amelioration trials have been summarised for the purpose of this paper. For detailed methodology of each trial contact Trengove Consulting or refer to the relevant project listed.

Soil types – Trials occurred in 2015 and from 2017 to 2020 and were located on poor performing sandy soils across the upper northern Yorke Peninsula. Soils ranged from grey alkaline sands near Alford to red/orange sands around Bute and Port Broughton. Organic carbon level was typically low with 0.94% the highest, pH values ranged from acidic sites (0-10cm pH 5.3 $CaCl_2$) to highly alkaline (0-10cm pH 8.6 $CaCl_2$) and nutrition levels also varied with Colwell P values ranging from 26 – 44.

Trial sowing dates were typical for lentil crops in the region and were sown between May 11 and May 22. Standard seeding fertiliser was applied as MAP @ 60 – 80 kg/ha.

Herbicide treatments were applied using a 2m hand boom. Pre-emergent herbicides were applied pre seeding or split with 2/3 applied pre seeding and 1/3 post seeding pre-emergent. Plots were sown using knife points and press wheels on 250mm spacing and all plots were rolled using a steel roller, either pre-emergent or early post emergent. Early post emergent diflufenican herbicide treatments were applied (June 14 – July 28) approximately 10 days prior to Intercept® herbicide treatments (July 2 – August 8). Varieties for the herbicide tolerance and nutrition trials were either PBA Hurricane XT⁽ᴾ⁾ or PBA Hallmark XT⁽ᴾ⁾.

All trials in these projects were randomized complete block designs with three replicates and plot dimensions were 1.5 * 10m.

Early growing season rainfall during the herbicide trial years was generally, with the exception being one day in June 2019 where 47mm was recorded at Bute (Figure 1).

Results and Discussion

Amelioration

Compaction is a common physical constraint of crop growth on sandy soils in the northern YP region, it inhibits plant root exploration beyond compacted depths. Results from amelioration trials conducted in the northern YP and Mallee regions show an average lentil response to ripping of 0.31 t/ha, or 85% yield increase (Table 1). In some instances, the scale of response is much larger in lentil than for cereals at the same site. For example, a long-term trial site at Bute (Table 1, site 6) has averaged 0.51t/ha (109%) yield increase in lentil over two seasons, whereas cereal response has averaged 0.6t/ha (19%) over four seasons at the same site. The lentil responses, as measured by percent increase over the control treatment, are much greater than those measured in cereal due to the lower baseline yields in lentil. In this example the lentil response provides a much greater economic response when compared with cereals, due to their inherent higher grain price.

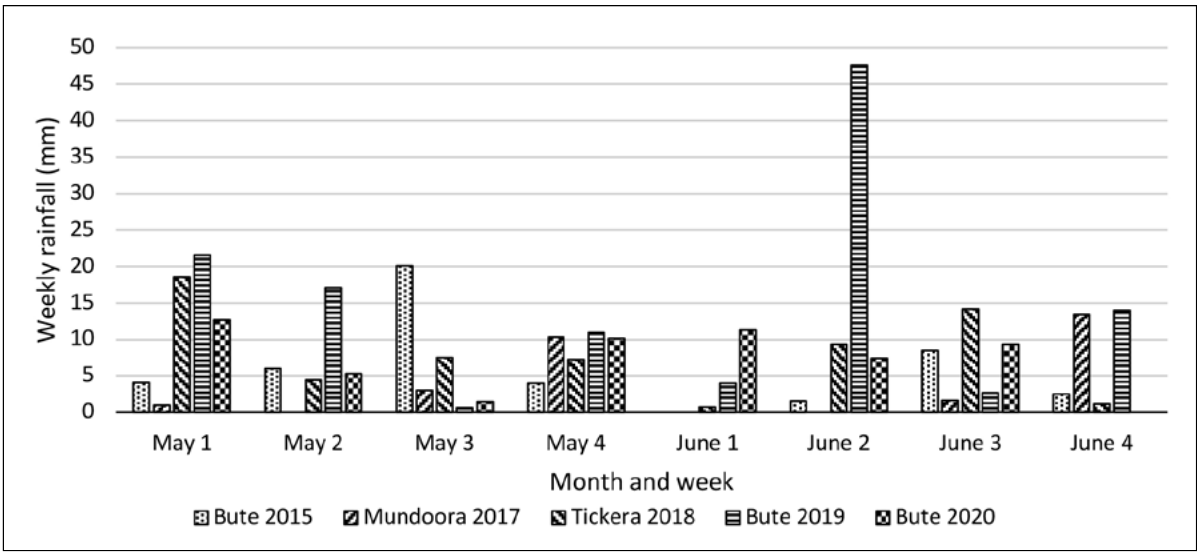

Figure 1. Weekly rainfall for the period leading up to seeding and early post emergent for all trials 2017 – 2020.

Penetrometer resistance measurements down the soil profile (data not shown) were characterised for sites five and six (Table 1). At site five soil resistance to a cone penetrometer never exceeded 2500kPa. However, at site six the untreated control exceeded 2500kPa from a depth of 17cm to the limit of measurement (at 60cm), with a peak of 4300kPa between 30-35cm. These differences help to explain the grain yield response to ripping at site six. It also highlights the need for diagnosing the presence of the constraint prior to undertaking soil amelioration works.

Other constraints identified include low fertility, low organic matter, and soil acidity. Four trials testing the response to chicken litter applied at rates of 5 or 7.5 t/ha as a once off application averaged 0.26 t/ha (41%) yield increase in lentil (Table 1). As found with the ripping response, at site six (Table 1) the application of 5 t/ha chicken litter has a greater effect in lentil than for cereals with the cereal yield increasing by an average 10.6% (0.32 t/ha) compared to 37% (0.18 t/ha) for lentil. Grain yield responses were measured six years after application in this trial. However, responses of this scale have not been observed in separate nutrition trials during the same period, where chicken litter has been included as a treatment at 5t/ha. The latter trials differ in that the chicken litter was applied to the surface immediately pre-seeding and incorporated by sowing, where in the amelioration trials the chicken litter was mostly incorporated in some way, either by ripping or offset disc, and was applied at least two years prior to lentils in three of the four trials. This method of incorporation and time period from application to lentil season may be important in explaining the differences in results observed. The findings suggest that earlier application and incorporation provided an improved environment for lentil plants to uptake mineralised nutrients from the chicken litter application than when applied and incorporated with the lentil crop.

Three trials assessing options for management of soil acidity on sandy soils in the Bute region were established recently in 2019. These trials were all lentil in 2020. Only small increases in grain yield were achieved in response to lime treatments averaging 0.08 t/ha, or 4% (Table2). Without the application of lime, soil acidity will continue to increase, and it is expected that these responses will increase over time. One trial included an elemental sulphur treatment applied to reduce soil pH to demonstrate effects of increased soil acidity. Plant biomass as measured by NDVI on September 15 was lowest in this treatment, with the best treatments (PenLime Plus and Spalding lime) having a 5% higher NDVI value (data not shown).

Varieties

Across a range of lentil agronomic trials, treatments that increased crop growth on sandy soils of the northern Yorke Peninsula also increased lentil grain yield. This finding was confirmed in variety trials, where varieties with higher NDVI values at the flowering growth stage produced higher grain yield (Figure 2A), even though no other site-specific constraints were addressed. This contrasts with results from trials conducted on more loamy soils (Figure 2B) where increasing biomass

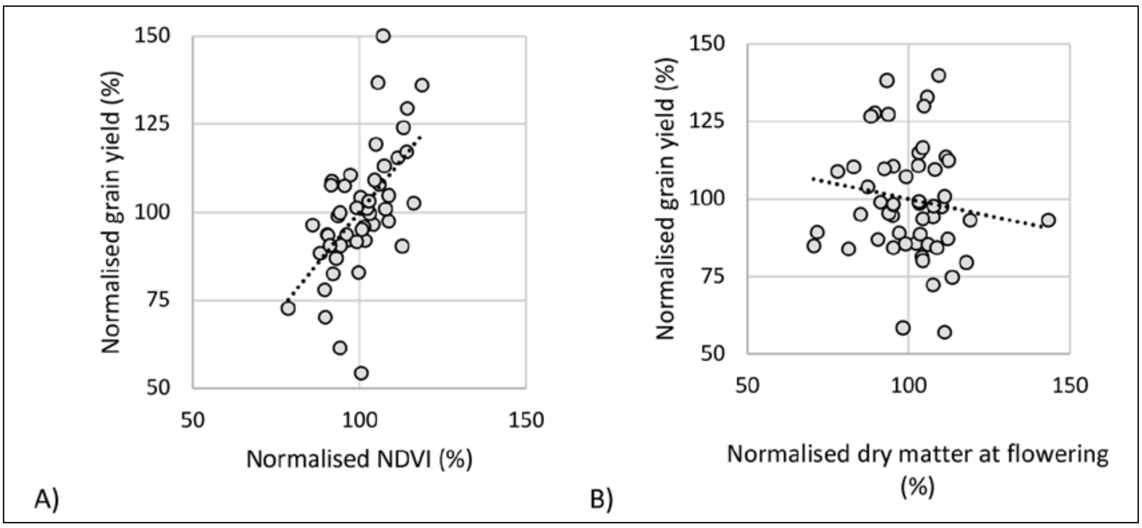

Figure 2. A) Normalised grain yield and NDVI at flowering data from lentil variety trials located on sandhills of the northern Yorke Peninsula from 2017-2020 ($y = 1.1674x - 16.642$, $R^2 = 0.329$). **B)** Normalised grain yield and biomass at flowering data from PBA breeding program located on loamy soils near Melton from 2012-2014 (source: PBA) ($y = 0.2176x + 121.82$, $R^2 = 0.0143$).

Table 1. Lentil grain yield response for a range of sandy soil amelioration trials.

Location	Project Code (GRDC or SAGIT)	Year trial established	Lentil crop year	Response to deep rip ~50cm	Response to spading ~30cm	Response to chicken litter in addition to district practice fertiliser
1. SARDI pulse agronomy –Bute	DAV00168BA: southern pulse agronomy	2019	2019	0.7t/ha (127%)	NA	5t/ha app 2019 = 0.19t/ha (63%) Nil background fertiliser applied.
2. Validation trial – Warnertown	CSP00203: southern region sandy soils	2019	2020	Rip: 0.06t/ha (7%) Rip + IP: 0.15t/ha (16%)	0.35t/ha (38%)	NA
3. Soil acidity lime incorporation trial – Bute	DAS 1905-011TRX: addressing soil acidity in SA	2019	2020	Rip: 0.53t/ha (29%) Rip + IP: 0.74t/ha (41%)	0.63t/ha (35%)	NA
4. Uni SA soil acidity fellowship trial – Bute	USA103-002RTX: mixing uniformity and crop response	2019	2020	0.07t/ha (8%)	2km/h (multi-pass): -0.09t/ha (-10%) 5km/h: 0.04t/ha (4%) 9km/h: -0.01t/ha (-2%)	NA
5. CSIRO soil amelioration –Bute Boundary Rd	CSP00203: southern region sandy soil	2018	2020	-0.05t/ha (-3%)	NA	7.5t/ha = 0.48t/ha (25%)
6. Long term soil amelioration –Bute	TC116: Increasing lentil productivity on dune and swale soils	2015	2017	0.58t/ha (149%)	NA	5t/ha app = 0.18t/ha (47%) 20t/ha app = 0.293t/ha (75%) 5t/ha app + rip = 0.84t/ha (216%)
6. Long term soil amelioration –Bute	CSP00203: southern region sandy soils	2015	2020	0.44t/ha (69%)	NA	5t/ha app = 0.17t/ha (27%) 20t/ha app = 0.22t/ha (35%) 5t/ha app + rip = 0.67t/ha (106%)
7. Lameroo 2020	SA MDBNRM	2020	2020	0.69t/ha (179%)	0.66t/ha (172%)	NA
8. Lameroo 2019		2019	2019	0.19t/ha (171%)	NA	NA
9. Kooloonong 2020	SPA (DAV00150)	2020	2020	0.71t/ha (97%)	NA	NA
10. Kooloonong 2019	SPA (DAV00150) / CSP00203	2019	2019	0.38t/ha (337%)	NA	NA
11. Carwarp	CSP00203: southern region sandy soil	2018	2018	-0.05t/ha (-12%)	NA	NA
		2018	2019	0.04t/ha (19%)	NA	NA
		2018	2020	0.09 (13%)	NA	NA

Table 2. Lentil grain yield response to lime application in a range of acidic sandy soil amelioration trials.

Location	GRDC Project	Year trial established	Lentil crop year	Starting pHca by depth increments of- 5cm from 0-30cm	Grain yield response to lime
Soil acidity lime product trial - Bute	DAS 1905-011TRX: addressing soil acidity in SA	2019	2020	6.1, 5.0, 4.8, 5.2, 5.6, 6.0	0.1 t/ha (4%)
Soil acidity lime incorporation trial - Bute	DAS 1905-011TRX: addressing soil acidity in SA	2019	2020	6.1, 5.0, 4.8, 5.2, 5.6, 6.0	0.14 t/ha (6%)
Uni SA soil acidity fellowship trial – Bute	USA103-002RTX: mixing uniformity and crop response	2019	2020	5.5, 5.0, 4.4, 4.6, 5.0, 5.6	0.02 t/ha (2%)

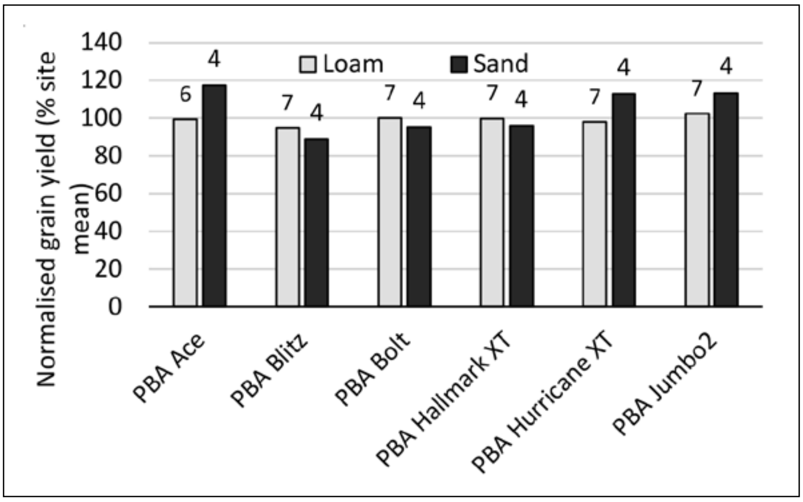

Figure 3. Average grain yield for selected commercial varieties as clustered by soil type for years 2017-2020 (Source: NVT Online, Willamulka NVT and Melton PBA yields used for loam cluster, sandy soil cluster yields from Trengove Consulting trials), number above bar shows number of trials variety is present.

was not correlated with increased grain yield. This finding suggests that the highest yielding variety on a heavier textured flat may be different to the highest yielding variety on a sand hill in the same paddock. The Willamulka NVT site is considered one of the lighter textured soil types within the suite of SA NVT lentil trials, yet by district standards it is a medium textured sandy loam flat. A four-year relative comparison of yield results from lentil variety trials on sandy soils across the northern Yorke Peninsula, to those from the Willamulka NVT and Melton PBA (loamy clay) lentil trials found that the highest yielding variety varies between the two groups (Figure 3). The high biomass later maturing variety PBA Ace⌽ was the highest yielding line from the sandy soils cluster of trials, some 4% higher than PBA Jumbo2⌽. Whereas in the loamy soil cluster, PBA Ace⌽ was 3% lower yielding than PBA Jumbo2⌽.

Herbicides

Herbicide tolerance

Yield losses associated with herbicide damage in lentil trials on these sandy soil types have ranged from 0 – 58% for individual products and up to 75% for herbicide combinations over 8 trials conducted in 2015 and from 2017 to 2020. This has been measured in the absence of weeds, with any weeds surviving the herbicide applications controlled by hand weeding from mid-winter onwards.

The herbicide products used in these trials all have different chemical properties. However, the residual soil applied herbicides were particularly sensitive to rainfall patterns post application (Table 3). The solubility value of each herbicide affects the way it moves in the soil profile with low solubility herbicides such as diuron requiring higher amounts of rainfall to move them through the soil. However, highly soluble herbicides such as metribuzin move rapidly through the soil profile after relatively smaller rainfall events. The adsorption coefficient (how tightly the herbicide binds to organic matter) and the DT50 value (days of time for 50% of the herbicide to dissipate) also have impacts on how these herbicides respond in each season and soil type. The herbicide diuron has a high adsorption coefficient and relatively low solubility and was found to often be the safest group C herbicide at the rates applied (Table 4). The seasons in which these trials were conducted generally did not have large rainfall events post seeding and in different seasons results may vary.

The products and ranges of rates that were used in these trials were selected as they were found to be representative of use patterns on sandy soils in the region, and typically at the low end of the rate range recommended for group C herbicides on sands (Table 4). Despite the low use rates crop damage and yield loss was still observed at these sandy soil trial sites in some seasons. Various group C herbicides were trialled in combination with other group B and F herbicides across different trials (Figure 4, Table 6). To summarise the effect of these group C interactions, results have been bulked across group C products and referred to as Group C plus companion herbicide. Chlorsulfuron was applied at 5g/ha IBS to simulate residual carryover from the previous season (Note: the label rate is 15-25 g/ha for application to wheat, barley, oats, triticale, and cereal rye). However, it still caused

Table 3. Pre-emergent herbicide properties for products used in the herbicide tolerance trials 2015 and 2017-2020. (Source: GRDC pre-emergent herbicide fact sheet).			
Herbicide	Solubility (mg/L @ 20C)	Adsorption coefficient, Koc value	DT50 value (range in reported value)
Diuron	36	680	90
Terbuthylazine	7	130	22 (6-149)
Metribuzin	1100	60	19 (14-28)
Chlorsulfuron	12500	40	36 (10-185)

Table 4. Herbicide products used and rate ranges used in trials in 2015 and 2017-2020.					
Product name	Herbicide active constituent	Herbicide group	Concentration	Rate range (mL or g/ha)	Application Timing
Chlorsulfuron	Chlorsulfuron	B	750g/kg	5[1]	IBS[1]
Intercept	Imazamox + imazapyr	B	33g/L + 15g/L	500	Post-emergent
Diuron	Diuron	C	900g/kg	550 - 825	IBS or PSPE
Metribuzin	Metribuzin	C	750g/kg	150 - 180[2]	IBS or PSPE
Terbyne	Terbuthylazine	C	750g/kg	500 – 750[3]	IBS
Brodal Options	Diflufenican	F	500g/L	150	Post-emergent

[1] *Chlorsulfuron was applied IBS at 5g/ha to simulate residual carryover from application in the previous season (Note: the label rates is 15-25 g/ha for application to wheat, barley, oats, triticale, and cereal rye).*
[2] *Note: the label rate for metribuzin is 180, 280 and 380 g/ha, dependent on soil type, and only applied as a post sowing – pre-emergent treatment.*
[3] *Note: the label rate for Terbyne is 1000-1400 g/ha and is not recommended for use on light soils with less than 40% clay.*

significant yield loss in XT lentil varieties at these sites (Figure 4), therefore it is important for growers to recognise the heightened risk of SU residue effects on these soil types and avoid this use.

Herbicide products applied individually generally only showed low levels of crop damage and associated grain yield loss. In this series of trials, average yield loss for individually applied products was 9% compared to the untreated control (Figure 4). However, when multiple products were applied, greater levels of crop damage were observed. This is particularly the case with the soil residual herbicide chlorsulfuron where the application of group C herbicides in conjunction increased the yield loss to 50% on average. Similarly, the

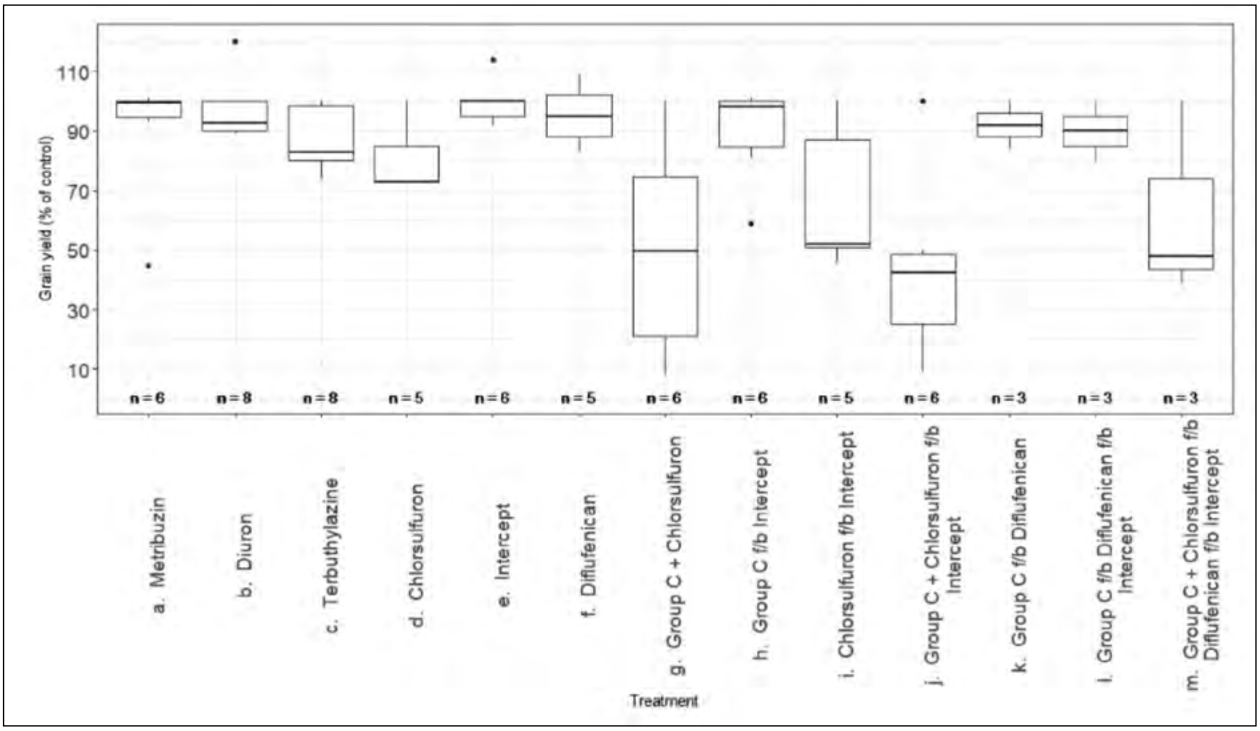

Figure 4. Grain yield presented as percent of control treatments for individual and product mixtures/sequences in the herbicide tolerance trials from 2015 and 2017-2020 on sandy soils.

additional effect of Intercept where chlorsulfuron residues were present significantly increased damage with yield loss averaging 50%, whereas on its own at the rates applied Intercept® did not reduce grain yield (Figure 4).

Weed control

Individual herbicides

- Metribuzin at the range of rates applied produced the poorest weed control of the group C herbicides across all weeds assessed (Table 5).
- Control of Indian Hedge Mustard (IHM) with Intercept® was highly variable, and likely represents the presence of imidazolinone herbicide resistance in some IHM populations across the region. Despite imidazolinone resistance now reported in sow thistle in the district, average control of 79% was seen as a relatively good result.
- Diflufenican (DFF) provided good control of the brassica weeds IHM and wild turnip.

Herbicide combinations

- Combinations of herbicides improved weed control compared to the same herbicides applied alone.
- Group C herbicides followed by DFF gave 100% control of IHM and wild turnip and good control of medic (82%) and sow thistle (94%).
- Group C herbicides followed by Intercept® provided 85% or better weed control of all four weed species.
- Group C herbicides followed by DFF followed by Intercept® averaged greater than 94% control of all weeds.

Nutrition

Chicken litter increased yield in four amelioration trial years (Table 1), as discussed previously. Tissue testing at site six (Table 1) in 2017 revealed elevated levels of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), copper (Cu), manganese (Mn) and molybdenum (Mo), in lentil whole tops compared with the control treatment, indicating chicken litter was supplying a broad range of nutrients. A trial with matched application rates of the macronutrients N, P, K, S and micronutrients Zn, Cu & Mn as synthetic fertiliser sources also elevated tissue test levels of P, K, S, Cu, and Mn but did not increase yields. Due to the differences in Mo levels between chicken litter and synthetic fertiliser treatments it was hypothesised that this may have been a significant deficiency on the acidic sand at this site (0-10cm pH 5.2 $CaCl_2$). Nutrition trials were run from 2017-2020 on both alkaline and acidic sands in the region. These trials included the addition and omission of a range of essential plant nutrients. While elevated levels of some nutrients were again measured in tissue tests, no unique nutrition constraints were identified that led to improved yield.

Molybdenum on acidic sands

In 2019 and 2020 post-emergent molybdenum trials on slightly acidic sands were conducted with pH of 5.8 $CaCl_2$ and 5.9 $CaCl_2$ 0-10cm, respectively. Nine treatments ranging from 0 – 400 g/ha sodium

Table 5. Weed control of Indian hedge mustard (*Sisymbrium orientale*), burr medic (*Medicago polymorpha*), common sow thistle (*Sonchus oleraceus*), and wild turnip (*Brassica tournefortii*) for different herbicide products and sequences in lentil herbicide trials on sandy soils across the northern Yorke Peninsula.

Herbicide product(s)	% weed control (# samples) range											
	IHM			Medic			Sow thistle			Wild turnip		
Metribuzin[1]	58	(4)	29-82	28	(5)	0-76	45	(6)	16-69	62	(5)	50-83
Diuron[2]	85	(4)	74-97	40	(5)	0-70	76	(6)	50-94	70	(5)	52-94
Terbuthylazine[3]	92	(4)	83-100	63	(5)	36-82	81	(5)	61-96	85	(5)	78-100
Intercept[4]	59	(3)	0-91	56*	(4)	0-88	79	(5)	61-88	96	(4)	88-100
Diflufenican[5] (DFF)	97	(2)	95-100	56	(2)	34-78	59	(3)	0-94	80	(2)	63-97
Group C f/b Intercept	85	(3)	62-97	86*	(4)	71-94	92	(5)	63-100	87	(4)	74-100
Group C f/b DFF	100	(2)	100-100	82	(2)	74-90	94	(3)	88-100	100	(2)	100-100
Group C f/b DFF f/b Intercept	99	(2)	99-100	94*	(2)	92-96	95	(3)	84-100	100	(2)	100-100

[1] *Note: metribuzin is not registered for medic control.*
[2] *Note: diuron is not registered to control Indian hedge mustard, medic, or sow thistle.*
[3] *Note: terbuthylazine is not registered to control Indian hedge mustard, medic, sow thistle or wild turnip.*
[4] *Note: Intercept is not registered to control medic or sow thistle.*
[5] *Note: diflufenican is not registered to control medic or sowthistle.*
* *In most cases surviving medic plants were severely stunted and not competitive.*

molybdate, applied over two timings, early July and mid-August were evaluated. In both seasons strong visual plant growth responses were observed within two weeks of treatment and resulted in increased NDVI values. This also resulted in increased grain yields of 43% and 21% for 2019 and 2020, respectively. In both seasons there was no benefit from increasing the rate of sodium molybdate above 25 g/ha and timing had no impact (data not presented).

Biomass and yield

Across a suite of 24 trials on sandy soils of the northern Yorke Peninsula a consistent positive linear relationship between biomass at flowering (using Greenseeker NDVI as a biomass surrogate) and grain yield has been established. This is consistent with work by Lake and Sadras (2021) experimenting with 20 lentil lines varying in seed type and phenology in eight environments. They found yield correlated with biomass and crop growth rate in more stressful conditions, where yields were less than 1.07t/ha. However, they also found this relationship decoupled in more favourable conditions where yields exceeded 1.7t/ha. In these favourable conditions' excessive vegetative growth can lead to self-shading, reduced pod and seed set, low harvest index and higher risk of disease and lodging (Lake and Sadras, 2021). The results presented in this update paper suggest the physical and chemical constrained sandy soils of the northern YP are also plant biomass constrained, where any treatment that overcomes some or all these constraints, increases both biomass and yield. However, it is also possible that this relationship decouples on the heavier textured soils within the same paddocks where biomass is not a constraint to yield.

Conclusion

There are four main steps and considerations when planning to increase the reliability of lentil production on sandy soils identified in this study. The first step is to identify and overcome any soil physical and chemical constraints that limit crop growth and biomass, through the use of soil amelioration techniques. The second step is selecting a suitable high biomass variety such as PBA Ace⫚, PBA Hurricane XT⫚ or PBA Jumbo2⫚. This decision needs to factor in the presence of any other soil types within the paddock. The third step is the selection of appropriate herbicides for the situation which should be based on the variety to be grown, soil types, soil moisture content and probable three day forecast at the time of application, the main weed targets and the level of escapes that are deemed acceptable as 100% control may come at a cost in yield reduction. The final step is correcting any nutritional deficiencies that may be present. Further gains on these soils are realistic through breeding improvements in varieties with higher plant biomass and improved Group C herbicide tolerance.

Acknowledgements

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

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Notes

The GRDC supports the mental wellbeing of Australian grain growers and their communities. Are you ok? If you or someone you know is experiencing mental health issues call *beyondblue* or Lifeline for 24/7 crisis support.

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Lifeline
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Looking for information on mental wellbeing? Information and support resources are available through:

www.ifarmwell.com.au An online toolkit specifically tailored to help growers cope with challenges, particularly things beyond their control (such as weather), and get the most out of every day.

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

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

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

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

www.cores.org.au CORES™ (Community Response to Eliminating Suicide) is a community-based program that educates members of a local community on how to intervene when they encounter a person they believe may be suicidal.

www.headsup.org.au Heads Up is all about giving individuals and businesses tools to create more mentally healthy workplaces. Heads Up provides a wide range of resources, information and advice for individuals and organisations – designed to offer simple, practical and, importantly, achievable guidance. You can also create an action plan that is tailored for your business.

www.farmerhealth.org.au The National Centre for Farmer Health provides leadership to improve the health, wellbeing and safety of farm workers, their families and communities across Australia and serves to increase knowledge transfer between farmers, medical professionals, academics and students.

www.ruralhealth.org.au The National Rural Health Alliance produces a range of communication materials, including fact sheets and infographics, media releases and its flagship magazine *Partyline*.

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The potential to increase the crop productivity by treating hostile subsoils

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GRDC project codes: DAV00149, DAS1905-011RTX

Keywords

- sodicity, hard pans, subsoil salinity, alkalinity or acidity.

Take home messages

- Subsoil limitations including poorly structured clay, hard pans, chemical toxicities and developing acidity can all restrict root growth and reduce yield potential. Issues can be soil type specific or occur on several soil types. Understanding where and which soils have these limitations is important for developing a treatment plan.
- Several GRDC projects are looking to address these issues and examine treatment options which include soil amendments, improved and tolerant varieties or improved management techniques to identify, manage or reduce the impact.
- The use of subsoil amendments including manures has increased yield by 20-50% over seven years at Stockport on a wet sodic sandy loam over clay, however these techniques have been unsuccessful in lower rainfall areas including the northern Yorke Peninsula (YP).
- Deep ripping has been providing good results on deeper silicious sands and sand over clays, but results have been inconsistent on other soil types. Inclusion plates may add value to deep ripping and provide longer lasting effects.
- Improvement to yield on soils affected by subsoil salinity, high exchangeable sodium percentage (ESP), boron, and high pH is likely to come from improved genetics and tolerance of multiple issues. High aluminium (Al) is another potential toxicity in these layers.
- Careful diagnosis of soil constraints to depth is critical before developing a soil amelioration strategy.

Background

Key subsoil limitations are present in many soils across the South Australian cropping zone and many of these are present across Yorke Peninsula's variable soils. Inherent issues include poorly structured clays (namely sodic clays), natural high salinity and/ or boron in subsoils, and induced subsoil issues such as hard pans, infertile A2 layers, and subsurface acidity or pH stratification.

Treatment options are diverse and at different stages of research, but include use of various amendments, soil modification techniques and breeding of more tolerant plants better adapted to these conditions, in addition to reducing constraints by modified crop management.

Key soil types on the Yorke Peninsula and observed subsoil issues are shown in Table 1.

Table 1. Key soil types on Yorke Peninsula (YP) and subsoil issues observed.		
Soil Type	Extent	Key subsurface and subsoil issues
Calcareous loams	widespread	Shallow laminar calcrete on some soils, deeper layers often contain high subsoil salts, high ESP*, high pH and boron
Deep silicious sand and sand over clay	Bute and Stansbury	Deeper sands often develop hardpans and subsoil infertility, while clay subsoils can be poorly drained, high strength impeding root growth, and high salt, pH and boron. Acidity is an emerging issue including on previously clayed areas in the A horizon.
Highly calcareous sandy loams and sands	Warooka south	Issues linked to highly calcareous nature and high pH include nutrient tie-up (esp. phosphorus), poor nutrient cycling, and disease. Subsoil salts and boron are occasionally an issue.
Sandy loams to loams over red and brown clays	Intermittent, mostly north Minlaton	Subsoil issues can be poor drainage through clay layers (sodic or poorly structured), subsoil salts and boron occasionally are an issue, acidity an emerging issue and common in the A horizon.

** exchangeable sodium percentage.*

When examined at a paddock level, many YP paddocks have a range of these soil types which lead to big variations in subsoil limitations, as well as surface pH and nutritional issues.

Method

Subsoil issues are being addressed in several GRDC projects including:

GRDC Subsoil – this includes a series of trials looking at addition of plant and animal products, gypsum and ripping onto sodic/ poorly structured subsoils. Key sites in SA are at Marrabel, Condowie, older sites at Bute and Stockport.

GRDC Sandy soils – includes a series of trials and demonstrations examining different limiting factors of sandy soils. Treatments include effectiveness of ripping, inclusion plates, claying, added organic matter, wetting agents and seeder strategies for repellent sands, etc.

GRDC Acidity – this project is focussing on emerging acidity and correction of sub-surface acidity including stratified profiles. Twelve trials have been established across SA including sites at Sandilands, Bute and Mallala.

GRDC/Soils CRC Calcareous Soils – Has just commenced with trials on highly calcareous soils on the Western Eyre Peninsula and a calcareous loam at Minnipa examining issues including nutrient tie up, poor biological activity and disease issues.

Common subsoil constraints are defined in table 2 below.

Results and discussion

Multiple subsoil constraints are present and vary with soil types across paddocks. Careful diagnosis of soil constraints to depth is critical before developing a soil amelioration strategy. Methods of detection include chemical and physical testing

Table 2. Definition of subsoil constraints.		
Subsoil constraint	Common Depth	Comment/ Test
Sub-surface acidity	5 to 20cm	pHCa < 5.0 in A horizon, $CaCl_2$ Al > 1-2 mg/kg
Hardpan/high strength	10 to 50cm	Weakly compacted sandy layer often with poor root growth in the A2 horizon. Penetration resistance > 2.5kPa
Sodic clay	10 to 60cm	Clay B horizon sometimes with columnar or massive structure. These slake and/or disperse when a ped is placed in water. ESP > 6-15 or high other ratios (e.g. CROSS Ratio)
Toxic layers- salt, boron, high pH.	40-100cm	Often where fine lime accumulates in the B horizon (Class 1 or 3A Wetherby carbonate class) EC1:5>0.5 or ECe>5 dS/M Boron >15 mg/kg pHw> 9.2
High Al on alkaline layers	40-100cm	High aluminate $Al(OH)_4^-$ > 0.8mg/l and pHw> 9.0
Rubbly broken calcrete	30-60cm	Wetherby class 3B/ 3C - often root growth is moderate through these layers apart from the rubble
Laminar impermeable calcrete	30-100cm	Wetherby class 2- difficult for roots to penetrate apart from cracks and solution pores

with precision approaches or soil type variation to understand paddock variability. Yield maps and NDVI measurements can also highlight areas of low or declining soil fertility.

Subsoil amendments

Mixed results have been seen across several subsoil amendment trials over the last seven years. At Stockport on a shallow sandy loam over a red-brown sodic clay which suffers some waterlogging, positive yield and plant dry matter responses have occurred each year since the amendments seven years ago. Chicken manure and mixed composts incorporated into the sodic B horizon at 25-30cm have given the best results, and recent sampling highlighted positive impacts on soil structure up to 15cm away from the where the amendment was originally placed. Dry matter production results for 2019 and 2020 are presented in Figures 1 and 2.

At the Marrabel site (established in 2018) some responses to surface applications of amendments and subsoil treatments including chicken manure,

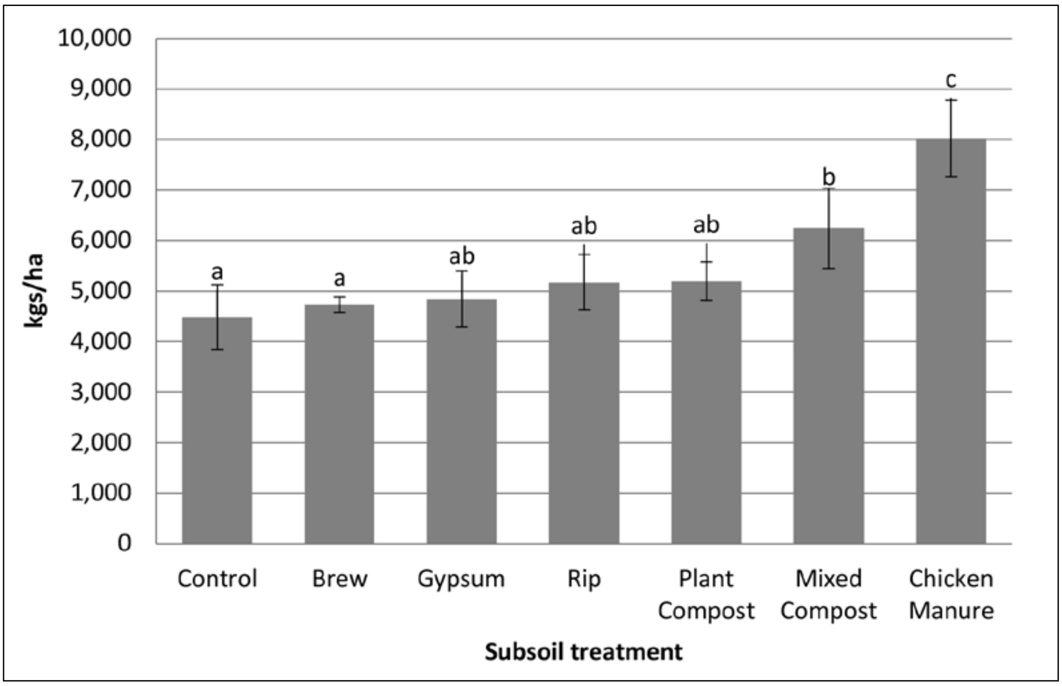

Figure 1. Dry matter of an oaten hay crop 6 years after application in 2019 (Stockport).

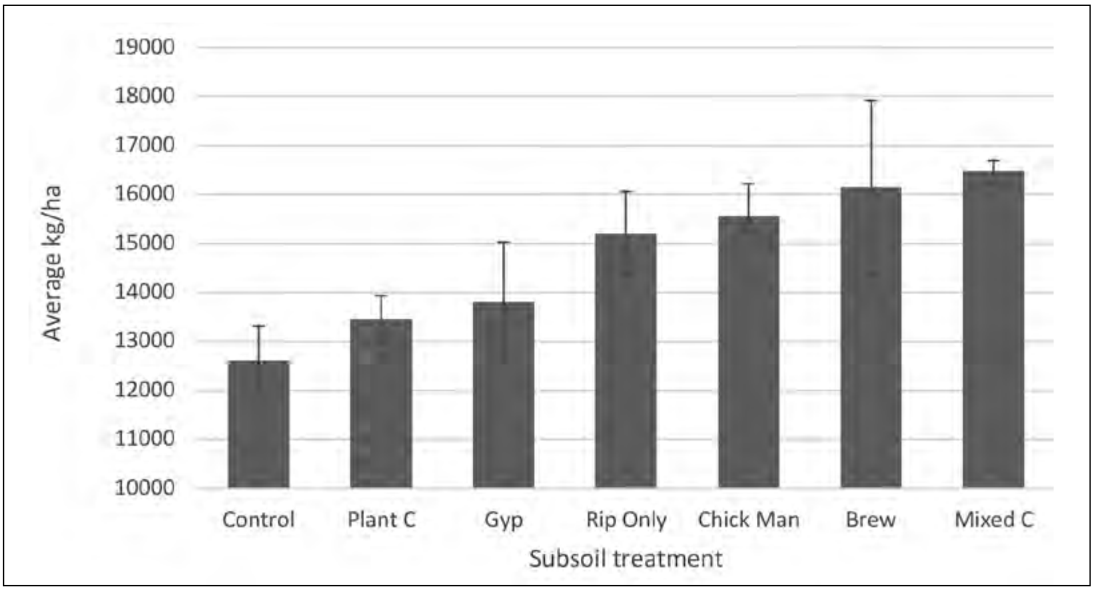

Figure 2. Dry matter of canola 7 years after application in 2020 (Stockport).

lucerne hay and wheat straw and nutrients have been recorded, although results have been variable, and returns are yet to be greater than the costs.

However, at the lower rainfall sites at Bute and Hart (on calcareous loams) and Condowie (on shallow sandy loam over sodic clay), no significant responses have been achieved over the last four years with some treatments producing negative impacts.

Deep ripping

Consistent responses to deep ripping have been seen on deeper silicious sands and thick sand over clays, however, results are variable on sandy loams over reddish clay and various calcareous soils. The use of inclusion plates may add value to the ripping by enabling less recompaction and longer benefits.

Work by Dzoma et al. (2020) has demonstrated the benefits of ripping compacted Mallee sands at Buckleboo and Peebinga over 2018-2020. Ripping was undertaken at five depths using two tyne spacings. The most economic result was from ripping to 70cm deep, and the 60cm tyne spacing of was equally effective as 30cm. Other constraints (e.g. water repellency, fertility, acidity) need to be considered whether considering soil amelioration of silicious sand as well as erosion risk.

At the Sandilands trial site on an acid brown loamy sand over reddish clay, un-replicated ripping and lime led to significant increases in wheat yield, while ripping on its own had a much smaller effect (Table 3).

Table 3. Lentil yield response to ripping treatments (Sandilands), mean of two reps only.

Treatment	Mean Yield (t/ha)
Control	0.828
Ripped to 30cms	0.856
Cultivated only control	0.890
4 T/ha lime + rip to 30cms	1.187

Sandy soil modification

In a trial established by Trengove Consulting at Bute on a sand over clay soil in 2019, deep ripping, ripping plus inclusion plates and spading gave lentil yield increases up to 0.75t/ha in 2020 (see Figure 3a). A lime product comparison trial showed a dry matter production response to Spalding and Angaston lime products, however, this response did not result in a significant yield increase (Figure 3b).

Overcoming subsoil salt, high pH and boron

Past research has examined genetic variability in the tolerance of crops to subsoil salinity and boron. In recent times screening has included high pH and a form of aluminium present on high pH soils (Schilling 2020). Table 3 below shows tolerant categories established for old commercial wheats to high boron, pH and Al.

In recent work the program examined over 200 breeding lines and has added sodicity, dispersion and hard pans to the soil constraints examined. Potential improvements in yield of around 10% have been observed where tolerance to multiple constraints was selected.

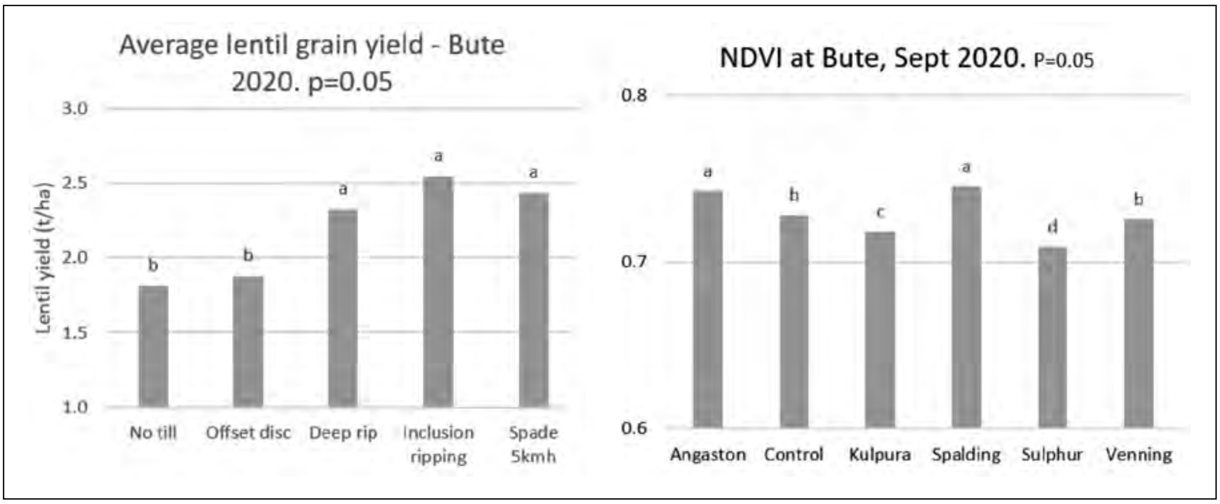

Figure 3. Grain yield of lentil following soil modification (left) and normalised difference vegetation index (NDVI) of lime source trial at Bute 2020 (right).

Table 4. Commercial wheats and their tolerance to high boron, high pH and high aluminium at high pH*(Schilling 2020).	
Tolerance category*	Variety
Tolerant	Emu Rock⁽ᴰ⁾, Gladius⁽ᴰ⁾, Mace⁽ᴰ⁾, Spitfire⁽ᴰ⁾, Zen⁽ᴰ⁾
Intermediate	Corack⁽ᴰ⁾, Scout⁽ᴰ⁾, Tammarin Rock⁽ᴰ⁾, Ventura⁽ᴰ⁾, Westonia, Wyalkatchem⁽ᴰ⁾, Yitpi⁽ᴰ⁾
Sensitive	Axe⁽ᴰ⁾, Cobra⁽ᴰ⁾, Gregory⁽ᴰ⁾, Hydra⁽ᴰ⁾, Janz, Magenta⁽ᴰ⁾, Trojan⁽ᴰ⁾

** Varieties were classified as tolerant if they were tolerant to at least two of the stresses and intermediate for the third; sensitive if they were sensitive to at least two of the stresses and intermediate to the third; and intermediate if they showed intermediate tolerance to at least two of the stresses and were either sensitive or tolerant to the third.*

Acidity on the Yorke Peninsula

Soil acidity is now quite common in the A horizon on non-calcareous soils on the YP. A patchy distribution is often observed, and pH mapping can be used to detect acidic areas in paddocks. Acidity has the potential to spread deeper into the profile particularly where the A horizon is thicker. In 2020 lentil dry matter production and yield (Figure 4) responded to lime applied the previous year were observed at Sandilands on a brown loamy sand over red clay. A combination of high-quality lime at a high rate with cultivation gave the best result, producing a 60% increase in dry matter and a 30% increase in grain yield.

Soil pH monitoring early in 2021 showed stratification and sub-surface pH issues even in treatments including tillage. All lime treatments had reduced toxic Aluminium levels in the surface (0-5cm) but issues were still evident deeper in the profile (5-15cm).

Conclusion

Multiple subsoil constraints are present and vary with soil types across paddocks. Careful diagnosis of soil constraints to depth is critical before developing a soil amelioration strategy.

Hard pans and deep ripping responses are common on silicious sands, but are less predictable on other soil types. High soil strength and water repellency on sandy soils can be overcome by using deep rippers, inclusion plates, spaders and delvers. The application of amendments including manures and composts into poorly structured subsoil clays have shown promise at Stockport, but have had limited response in drier areas.

Calcareous loams often have several subsoil toxicities, although calcareous sands are less affected. Toxic levels of boron, salinity and Al, along with high pH and sodicity are being examined across wheat varieties with the aim to provide multiple tolerance to these toxicities.

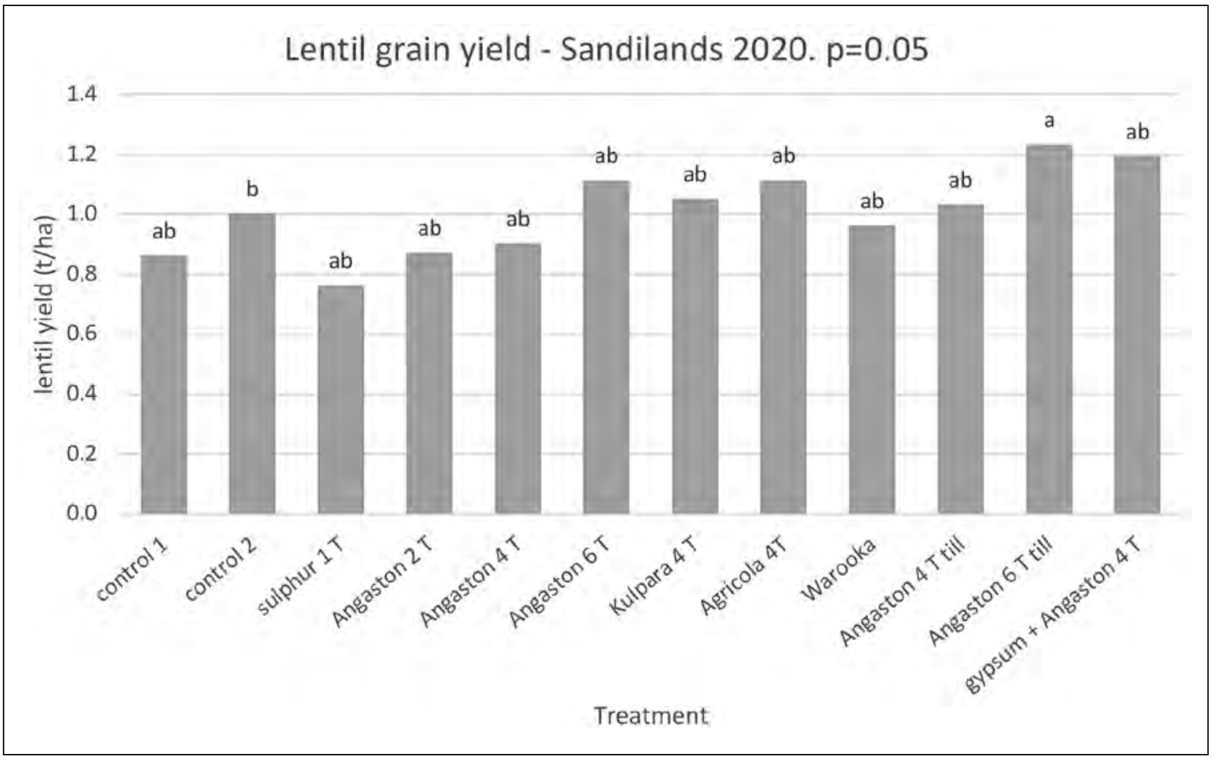

Figure 4. Mean grain yield of lentil at Sandilands in 2020.

Sub-surface acidity is becoming more common on soils with deep A horizons, and early detection and treatment with lime will prevent yield declines.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Additional support has been provided by PIRSA, DEW, SAGIT and Hills and Fleurieu Landscape Board to some components of the project.

Useful resources

SA soil acidity website: https://acidsoilssa.com.au/

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Notes

Herbicide MoA alignment: Stage 1

Herbicide Mode of Action (MoA) classifications have been updated internationally to capture new active constituents and ensure the MoA classification system is globally relevant.

The global MoA classification system is based on numerical codes which provides infinite capacity to accommodate new herbicide MoA coming to market, unlike the alphabetical codes currently used in Australia.

Farming is becoming increasingly global. Farmers, agronomists and academics around the world are now, more than ever, sharing and accessing information to assist them to grow crops, while managing sustainability issues such as herbicide resistant weeds.

It's important then that the herbicide MoA classification system utilised in Australia be aligned with the global classification system. This will ensure more efficient farming systems into the future and allow Australian farmers and advisors to access the most up-to-date information relating to managing herbicide resistance.

CropLife Australia is working with key herbicide resistance management experts, advisors and the APVMA to ensure farmers and agronomists are aware of the planned changes.

Growers can expect to start seeing herbicide labels with the new mode of action classification system from early 2022. There will be a transition period during which herbicide labels will exist in the supply chain, some bearing the legacy alphabetical MoA classifications, and others transitioned to the global numerical system.

The numerical classification system should be fully implemented by the end of 2024.

A mobile app compatible with Android and Apple systems is available via the **HRAC website** (hracglobal.com) at no cost to users. It will cross reference the herbicide active ingredient with its former MoA letter and new MoA number. Printed materials will also be made available to enable cross referencing of the changes.

CropLife Australia

Frequently asked questions

Q. Why change from letters to numbers?

A. A numerical code system is more globally relevant and sustainable, compared to the current alphabetic code used in Australia. Today there are 25 recognised MoAs. Over the next 10 years we anticipate up to four new modes of action to be commercialised, which will exceed the 26-letter maximum in the English alphabet.

Q. What is going to change?

A. The current alphabetical codes for herbicide active ingredients will change to numerical codes, in alignment with the global MoA classification system. For example, Group A herbicides will be labelled as Group 1 herbicides and Group M (glyphosate) will become Group 9.

Some new MoA will be introduced to accommodate some of the new chemistry being introduced world-wide. Some active ingredients will also be reclassified into different groups to better reflect their actual mode of action, not chemical structure.

A complete summary of the changes is available via the mobile app. More detailed information regarding the changes will be available in mid-2021.

Q. What are the main changes?

A. The main changes are outlined in the free mobile app, which you can download from the **HRAC website**. We are still working with industry experts to identify the consequences of these changes regarding how products fit into an integrated weed management program and will provide more specific guidance on the changes in mid-2021.

Q. How will the changes affect what we do?

A. The way growers use herbicides in the field will not change. The science hasn't changed and the mix and rotate messages remain correct. It is just the classification codes used on product labels and literature that will change from a letter to a number. Continue to follow your current IWM strategy and rotation plans.

Q. When will the changes take place?

A. There will be a transition period starting from July 2021, with growers likely to begin to see labels bearing the new MoA numbering system in the marketplace in early 2022.

Q. Does this mean the current MoA are wrong?

A. The science has not changed. Stick with your current IWM strategy and plans to rotate herbicides. In this era of multiple cross resistance, there is no magic bullet amongst the new modes of action.

Q. How will I know which products to rotate?

A. The science hasn't changed – stick with your current IWM strategy and plans to rotate herbicides. If in doubt, particularly with newer herbicides recently introduced, consult the manufacturer or your local agronomic advisor.

A summary of the changes is available via the mobile app. More detailed information regarding the changes will be available in mid-2021.

Q. Can I still use product on hand which has the old MoA printed on the label?

A. Yes. Legacy labels will be phased out over the next few years and will continue to be legally valid, although growers are encouraged to familiarise themselves with the new MoA classification system and corresponding resistance management strategies from 1 July 2021.

Q. Where can I find out more information?

A. You can find more information at the **CropLife website** and the free mobile app is available on the **HRAC website**.

Download the Global HRAC Herbicide MOA Classification app via Google Play or the App Store.

To find out more visit:
croplife.org.au/MoA

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Within-paddock nitrogen variability and the potential role of cereal grain protein mapping for site-specific N management

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EM Ag Consulting.

Keywords

- nitrogen, protein, GPC, wheat, variability, variable rate, VR, site-specific.

Take home messages

- Wheat grain protein concentrations of less than 11.5 % generally indicate that nitrogen (N) supply was insufficient for a crop to meet its water limited yield potential
- If this 'rule-of-thumb' is applied across a landscape, a spatially referenced wheat grain protein concentration map is analogous with an 'N adequacy' map
- This layer can be used in conjunction with targeted deep N soil sampling as a basis for site-specific N inputs to reduce both instances of yield loss due to N undersupply and adverse environmental/economic consequences associated with N oversupply.
- Research conducted in 2019/2020 across five paddocks (511.4 ha) in southern NSW supported the use of wheat protein mapping as a basis for site-specific N
- This approach may have a good fit for growers located on soils not prone to N losses that have variability in factors such as texture/CEC/OC%/PAWC, productivity (N removal) and/or management histories (e.g., amalgamated paddocks, variable N inputs).

Introduction

This paper will explore concepts around managing nitrogen (N) variability as part of a larger (whole system) approach to improving N management, with particular emphasis on the potential role of cereal grain protein mapping in site-specific N fertilisation. Results will be presented from paddock scale research conducted in 2019-20 that examined relationships between soil mineral nitrogen (SMN) levels and grain protein concentration across five paddocks in southern/central NSW.

The broader problem

Despite widespread knowledge of the importance of nitrogen (N) supply in broadacre cropping systems, N deficiency remains the most substantial contributor to the sizeable yield gap in Australian wheat production (Hochman and Horan, 2018). Furthermore, recent assessments have found that most Australian grain cropping systems are in negative N balance, that is, more N is being exported off-farm than is being applied as fertiliser or fixed from atmospheric N_2 (Angus and Grace 2017).

A major driver of N under-supply has been the naturally conservative approach of growers operating in highly variable rainfall environments, where adverse agronomic and environmental consequences of N oversupply have been experienced and/or are perceived. To this end, Australian growers have historically placed much reliance on mineralisation of organic N to meet crop demands (Angus et al., 2006), which has been desirable not only from an economic perspective, but also agronomically due to the positive relationship between both N supply and crop demand with soil moisture.

With resultant declining levels of soil organic matter (SOM; up to 60% under continuous cropping; Dalal & Chan, 2001) and the diminishing adaptive N supply ability of our soils, it is clear that a growing requirement exists for fertiliser N to maintain (or increase) productivity within the Australian grains industry.

For fertiliser rates to rise in a sustainable manner, it is also clear that there is considerable work to be done in improving the robustness of N fertiliser decision methods. In a 2015 survey of 132 commercial crop advisors in New South Wales, Schwenke et al. (2018) found that while most advisors regarded soil tests as moderately to very important for determining N fertiliser requirements, interviewed participants revealed that many of their clients either did not soil test, or of those that did, the number of paddocks tested was quite low. This supports findings by Lobry de Bruyn & Andrews (2016), who found that only 25-30% of Australian broadacre crop businesses conduct annual soil testing for nutrient levels.

One of the key barriers to N soil testing identified by Schwenke et al. (2018) is the view among growers that within-paddock spatial variability of N is high, which leads to distrust of whole-paddock bulked soil test results. Growers are instead more comfortable using 'rules-of-thumb' approaches based on paddock history and seasonal outlook. This suggests the lack of cost-effective, sound agronomic methods for quantifying and mapping spatial N variability is a substantial impediment to the overall improvement of N management in Australian cropping systems. This is supported by on-the-ground experience which would suggest that the lack of trusted variable rate (VR) N solutions available to growers presents a far greater impediment to the adoption of precision N practices than technological capacity or grower enthusiasm.

Supply and demand concepts

To better understand the challenges of successful site-specific N approaches, it is useful to examine the basic N dynamics at play in broadacre cropping systems. In simple terms, optimal N management refers to matching N supply to N demand – both parameters of which can be highly spatially variable in the Australian landscape.

For example, on the supply side of the equation – residual (carryover) N may vary according to previous crop and pasture productivity (influencing both N removal and N fixation), in-season mineralisation may vary according to soil type and management history (influencing SOM pools and moisture), N losses may vary according to factors such as soil texture and/or landscape position (influencing leaching and waterlogging/ denitrification) while a myriad of other less predictable factors and/or interactions may also be at play (e.g. uneven fertiliser/manure applications, uneven removal of hay, redistribution of N by livestock).

On the demand side of the equation, variability of yield potential in the Australian landscape can be substantial over very short distances, often driven by differences in plant available water-holding capacity (PAWC) resulting from variability of soil properties such as texture, bulk density and subsoil constraints (Rab et al., 2009).

This presents a highly complex situation where both supply and demand of N may be spatially variable due to entirely different (and often independent) driving factors. To further complicate the situation, many of these factors are temporally variable, making it difficult to correctly quantify whole season patterns of N deficit using data collected at any one snapshot in time. For example, the spatial patterns of start-of-season SMN may not match those of the full season N supply if there are considerable differences in mineralisation between different zones of the paddock.

Current approaches to site-specific N in Australia

There are two main approaches to sub-paddock scale N management currently in practice and/or commercially available in Australia.

The first is to divide a paddock into a number of sub-units or 'management zones', which are considered more-or-less homogenous in their N supply and/or demand attributes (Rab et al., 2009). Zones are generally developed based on either historic productivity (e.g., using yield and/ or remotely sensed imagery) or soil type (e.g., using apparent electrical conductivity (ECa), grid soil Cation Exchange Capacity (CEC) mapping and/ or aerial imagery). Each zone is then soil sampled separately and managed accordingly. While these approaches are generally considered to be an improvement on whole paddock testing, their main limitation is that the resolution of data collection is still quite low, therefore substantial reliance is placed on the accuracy of the zoning process. As moisture availability is generally the greatest yield constraining factor in Australian systems, it is likely that these methods do a reasonable job of differentiating areas of contrasting N demand, however, may not be as effective at detecting finer scale variability of N supply. To date, the majority of research around the accuracy of different zoning approaches has focused on crop responsiveness/N demand, with very little work assessing the homogeneity of N supply within zones (i.e., quantifying SMN variability).

The second approach is the use of remote or proximal sensing to directly develop site-specific N maps for mid-season N fertilisation. The most widely implemented spectral index used for this purpose is the Normalised Difference Vegetation Index (NDVI), which gives a representation of the amount of photosynthetically active biomass in a crop (Perry et al., 2014). These approaches have similar limitations to productivity-based management zone methods in that mid-season biomass is often correlated more closely with moisture availability (or other factors) than N nutrition per se. To address these limitations, work continues to identify alternative spectral indices that are more directly related to N nutritional status (e.g., CCCI, Basso et al., 2016; Red Edge, Richetti et al., 2020). In either case however, the successful implementation of these strategies generally requires the use of N-rich and N-poor calibration strips, ground-truthing and a good understanding of site-specific yield potentials relative to seasonal conditions. Indeed, a recent review by Colaço and Bramley (2018) of a large suite of globally published sensor evaluation studies found a lack of consistent evidence to confirm whether crop sensors in isolation can deliver benefits to N management. Instead, they suggest that future success will come in the way of more sophisticated algorithms that integrate spectral data with input from other sensors and data layers (e.g., moisture probes, weather forecasts, ECa mapping, etc.).

In addition to these two primary methods, there has also been limited use of 2-4 ha resolution grid deep N soil mapping for site-specific N in Australia, however this approach has generally been considered uneconomical due to the relatively expensive nature of deep sampling (Bramley and Janik, 2005).

Theoretical background to cereal grain protein based site-specific N

For many decades it has been recognised that a consistent relationship exists between cereal grain yield and cereal grain protein concentration according to N supply (e.g., Russell, 1963). This relationship consists of increasing grain yield and protein concentrations with greater N supply up to a certain point, after which grain yield begins to plateau while protein concentration continues to increase. At very high N levels, a decline in yield often occurs (Holford et al., 1992).

The point at which N supply has been optimised for maximum grain yield is termed the 'critical grain protein concentration' and has been found to be around 11.2–12.0% in most Australian hard white wheats through studies conducted in southern/central NSW (Brill et al., 2013, Sandral et al., 2018) and South Australia/Victoria (G. McDonald, review published in Unkovich et al., 2020).

While critical grain protein concentrations will vary between varieties and across seasonal conditions (Fowler, 2003), a simplified 'rule-of-thumb' interpretation under favourable (non-drought) conditions can be summarised as:

- Protein < 11.5% = insufficient N supply to meet yield potential
- Protein 11.5–12.5% = adequate/optimum N supply to achieve yield potential
- Protein > 12.5% = surplus N to crop requirement, possibly some yield penalty (Figure 1).

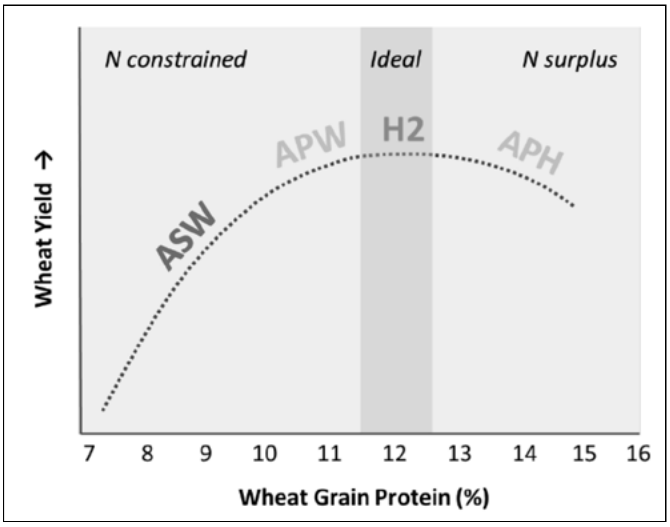

Figure 1. A generalised representation of the relationship between yield and grain protein concentration in wheat with increasing N supply. Labels refer to grades in the Australian wheat classification system.

If we apply this rule-of-thumb spatially across a management area grown to a single wheat variety, a georeferenced map of wheat protein concentration is analogous to an 'N adequacy' map – i.e., it serves to distinguish areas of the paddock that had insufficient, ideal or surplus N according to their site-specific yield potentials. Provided that crop demand wasn't very much higher than budgeted N supply (resulting in a full drawdown of soil mineral nitrogen (SMN) across the paddock), and that soils are not prone to N losses, it is likely that protein patterns will provide a good spatial representation of residual (carryover) SMN.

Ground-truth soil testing at the start of the following season can be used to test this assumption and quantify out-of-season mineralisation. A good approach to determining the placement of soil tests is to divide the paddock into zones based on combinations of yield and protein results from the previous harvest. This process provides useful insights into not only N dynamics but also where non-N related constraints may warrant further investigation. These concepts are summarised in Table 1.

A major advantage of a protein-based VR N approach over currently available alternatives is that it combines both the supply and demand elements of the N balance equation. For example, low protein areas within a paddock may occur either due to low N supply (i.e., differences in carryover N, mineralisation, fertiliser inputs, etc.) OR higher yield potential (i.e., due to the dilution of protein by higher yield; Simmonds, 1995). Regardless of which factor is responsible (or both), the management decision will involve increasing N rates in the following season.

In this sense, the protein layer is also accounting for temporal variability of N dynamics by providing a retrospective assessment of the *whole season*, net N balance, rather than a 'snapshot in time' as occurs with data layers such as spectral indices or grid soil mapping.

Another advantage is the benefit afforded by the plant providing an indication of N adequacy according to the conditions it experienced, i.e., the *plant available* N. This circumvents a limitation of soil testing where mineral N may be present within the profile however the plant may not be able to access it (e.g., if subsoil hostilities prevent root access). In a similar manner, if subsoil conditions are favourable and the plant is able to access deeper SMN, this will be reflected by the plant's protein concentration however may be missed by an arbitrary soil sampling depth cut-off.

Setting rates

Due to fluctuations that occur in critical grain protein concentrations between seasons and some varieties, start-of-season soil sampling will remain an

Table 1. Within-paddock combinations of cereal yield, protein attributes and their properties.

Classification	Interpretation	Residual N levels	Action
High Yield / High Protein	- Optimum scenario - Yield potential achieved, no major limitations - This area of the paddock may have higher mineralisation potential	Likely moderate to high, however soil test to confirm (particularly if crop N demand was higher than budgeted)	Determine rates based on soil test results and according to high yield potential
High Yield / Low Protein	- Sub-optimal N management - Yield could have been even higher - N deficiency likely occurred later in the season, as sufficient N was available to produce biomass/tillers - Could indicate 'tired' areas with lower mineralisation potential (e.g., historically high N removal/low SOM)	Likely low (assume post-harvest residual SMN was negligible, so levels are dependent on out-of-season mineralisation)	Increase N rates relative to paddock average in following season/s to support higher yields and build SMN
Low Yield / High Protein	- Non-N related problem - Further N additions would not have increased yield - If protein is *very* high, yield penalties from oversupply of N likely occurred - Most commonly related to lack of moisture supply (e.g., shallow or hostile subsoils, around trees), however may be another constraint such as pH, P	Likely high (mining of N may be advised to reduce yield penalties associated with N oversupply)	If the constraint cannot be amended, reduce N inputs relative to paddock average permanently to match lower yield potentials
Low Yield / Low Protein	- Sub-optimal N management - Yield potential was not met - It is unclear if other constraints exist that would continue to limit yield with higher N inputs - If N deficiency is the primary cause, SMN was likely low for the whole season	Likely low	Start by increasing N to determine the non-N constrained yield potential, then manage according to results

essential step to determining actual N rates. Soil sampling will also act as a ground-truthing s tep to test assumptions regarding patterns of carryover SMN and to test any unusual areas (e.g., if losses are suspected such as where waterlogging has occurred).

Where consistent protein zones are present, soil sampling should cover off on each of the major protein/yield combinations (see Table 1), aiming to get an idea of the paddock average and the spread (range) of SMN values. If protein data across the paddock is spatially noisy or does not have consistent zones, the paddock may not be a good candidate for VR N (i.e. SMN may not vary substantially, or variability might be on a sub-manageable scale). In this case, whole paddock testing and blanket rates may be more appropriate.

Once a paddock average has been determined, growers and advisors can use their preferred calculation method or decision support system (e.g. Yield Prophet®, 'N banks') to determine a 'base rate' which will act as the paddock average from which to vary N inputs (i.e. lower rates on high protein areas, higher rates on low protein areas). The increments of difference between rates will depend on; a) the spread of protein values, b) the spread of soil test results, and c) the grower's level of confidence/ conservatism. A more conservative approach (smaller increments) will afford a lower level of risk when moving from blanket rate applications, however there will likely be a longer lead time in reducing within-paddock N variability.

Over a number of seasons, implementing this strategy should reduce the spatial variability of protein concentrations, ideally converging around 11.5 - 12.5% if the base rates chosen have been appropriate. It is likely that the most 'bang for buck' to be gained implementing this strategy will occur in the early stages, by eliminating very low (highly constrained) and very high N zones.

It is important to remember that in paddocks where yield potential varies greatly due to factors other than N (e.g., relatively fixed factors such as PAWC), a successful outcome will not be where yield becomes even, but rather where yield is optimised in all areas according to their site-specific yield potentials. In these instances, N rates will need to continue to be varied to match N supply with variable N demand. One option for achieving this may be to transition to a VR N strategy based on N removal patterns.

In all cases, ongoing monitoring of cereal protein% results and annual deep soil sampling should serve as a constant feedback to ensure N decision-making approaches are performing well.

Getting started

A protein based site-specific N strategy might be a good approach for a grower if they:

a. Are predominantly located on soil types not prone to losses (i.e., free draining with good nutrient holding capacity such as occurs across most of southern NSW), and

b. Have within-paddock variability in factors such as texture/CEC/OC%/PAWC, productivity (N removal) and/or management histories (e.g., amalgamated paddocks, previous inputs).

At present, the cost of a harvester mounted grain analyser is around AUD $25,000 + GST including installation (Next Instruments 'CropScan 3300H' unit). This cost will be spread over a number of seasons. The unit can also be removed and reinstalled if a new harvester is purchased. There will also be costs related to data management and interpretation if the grower cannot or does not wish to do this themselves.

After completing the first harvest, a good strategy is to pick a few of the most variable paddocks to focus on. If a grower isn't comfortable implementing a VR application straight away, they may prefer to use N-rich and/or N-poor strips to test the impact of variable N rates on their soils. If doing so, strips should be designed so they pass through several zones (e.g., low/high protein, soil types, management histories, etc.). Paddocks being cropped to a second cereal crop (e.g., wheat on wheat) will be of most value for reviewing the results of strip trials and/or the success of VR N applications.

Research results

A 2019/2020 research project undertaken in southern NSW by FarmLink Research in conjunction with Precision Agriculture sought to examine within-paddock N variability patterns and test assumptions around the correlation of SMN with various parameters, including protein concentration. Selected findings are presented below. The full research report can be accessed at http://www.farmlink.com.au/project/nitrogen-variability (Moffitt, 2021).

Aims

- Quantify levels of within-paddock SMN variability across five cropping paddocks (511.4 ha).
- Examine correlations between 2020 start-of-season SMN and various other parameters including 2019 yield, protein and N removal, ECa (via EM38), soil texture and OC% (via MIR).
- Comment on the effectiveness of each layer to inform site-specific inputs, and
- Develop grower and advisor capacities for VR N decision making.

Methodology

Georeferenced yield and grain quality data was collected during harvest 2019 by eight late model Case IH harvesters equipped with standard yield monitors and retrofitted CropScan 3000H grain analysers. All CropScan 3000H units were calibrated prior to harvest using a single set of certified reference samples for wheat, barley and canola (protein%, moisture% ± oil%).

Five paddocks (four wheat, one barley) were subsequently selected on the basis of having complete yield/protein datasets and some level of protein variability. Paddocks were all located within 100 km of Temora in southern NSW on predominantly red to grey sandy loam to clay loam topsoils overlying clay loam to clay subsoils (chiefly Chromosols/Sodosols). Paddock management has consisted of continuous cropping of cereals (wheat/barley), canola and occasional pulses, with some paddocks having histories of lucerne/clover phases. Annual rainfall across the five sites averages around 480-600 mm however in 2019 rainfall was very low, ranging from 160-310 mm (annual) and 64-142 mm (April-October). As a result, none of the five paddocks had any additional N applied throughout the 2019 season apart from low levels in MAP/DAP fertilisers applied at seeding.

Grid soil sampling plans were designed at resolutions of 1.17 ha (108 m x 108x m; 4x paddocks) and 1.44 ha (140 m x 140 m; 1x paddock), depending on the width of top-dressing operations. A total area of 511.4 ha (425 grid sites) was soil sampled in late February/March 2020 at 0-30 cm/30-60 cm intervals and analysed for nitrate (NO_3), ammonium (NH_4), MIR texture and MIR Organic Carbon% (OC%). Soil sampling occurred after opening rainfall in 2020 following extremely dry conditions for many months prior. EM38 and elevation mapping was conducted during January 2020 at 18 m/24 m swaths. Weighted averages for each grid cell location were determined for EM38/elevation and yield/protein data through various interpolation methods. The strength of the relationship between SMN and other attributes was analysed via linear regression at the grid resolution.

Grower-led VR N applications and post-harvest grid soil mapping were also conducted in 2020. These results will not be discussed in detail below however can be obtained in the full report. http://www.farmlink.com.au/project/nitrogen-variability

Results and discussion

Considerable within-paddock variability of start-of-season (Feb/Mar 2020) SMN was observed at four of the five sites, where the range of values (max – min) was greater than 140 kg N/ha, and the standard deviation was greater than 20 kg N/ha (Table 2). At the fifth site (Ardlethan), where the average SMN was much lower (46 kg N/ha ± 11 kg N/ha SD), the range of SMN was 43 kg N/ha.

Table 2. Summary of 2020 start-of-season 0-60 cm SMN and 2019 harvest protein% results (grid n = 58 to 96).

		Ardlethan (83 ha)	Girral (103 ha)	Rannock (103 ha)	Temora (111 ha)	Thuddungra (112 ha)
Feb/Mar 2020 0-60 cm SMN (kg N/ha)	Mean	46	94	95	67	127
	Min	27	29	52	22	55
	Max	70	213	199	162	285
	SD	11	40	24	26	38
	CV	24%	43%	25%	39%	30%
2019 Protein %	Mean	8.3	17.4	11.7	13.4	15.3
	Min	6.7	15.9	10.0	10.1	14.0
	Max	11.9	18.4	13.5	15.4	16.8
	SD	1.2	0.7	0.8	1.3	0.6
	CV	14%	4%	7%	10%	4%

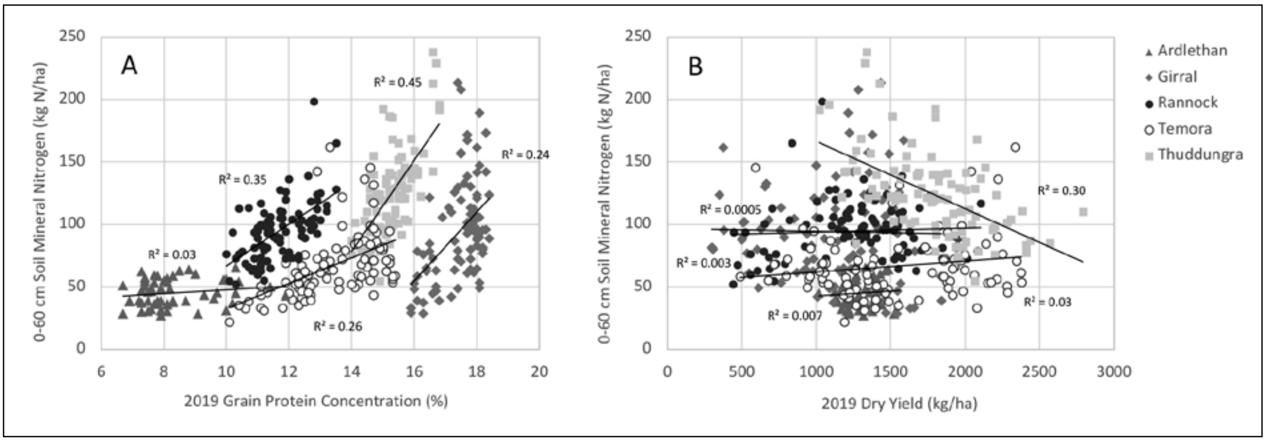

Figure 2. 0-60 cm Soil Mineral N (kg N/ha; sampled Feb-Mar 2020) versus 2019 cereal harvest results, **(a)** Grain Protein Concentration and **(b)** Dry Yield. (Girral = barley, rest = wheat). Each point represents one grid site (n = 425).

When examining the relationship between start-of-season (Feb/Mar 2020) SMN and various other attributes, 2019 grain protein% displayed the most consistent and strongest correlation compared to all other layers examined (Figure 2a; Table 3). This consistently positive relationship was significant at 4 out of 5 sites. The site that did not show a strong correlation (Ardlethan) was also the site of the lowest average SMN, lowest range of SMN and lowest average protein% levels (8.3%). Interestingly however, this site had one of the highest ranges of protein concentration (6.7% – 11.9%) in comparison to all others. This result will be discussed in more detail further below.

Importantly, at each of the four significantly correlating sites, areas of the paddock with the lowest protein% coincided reasonably well with areas of low SMN (e.g., see Figure 3 and Figure 4 examples). This occurred both in paddocks of lower overall protein% (Rannock, Temora) and in those with very high protein% levels (Thuddungra, Girral). On the other end of the spectrum, areas within each paddock with the highest protein concentrations did not necessarily always coincide with the highest SMN values (e.g., northern zone in Figure 4). In the two main instances this occurred, these zones were in low lying areas with at least average SMN levels and it is likely they were impacted by frost, which was noted across these sites in 2019. These localised effects demonstrate the importance of paddock and seasonal knowledge when interpreting protein and other data patterns.

When comparing 2019 dry yield and N removal to patterns of 2020 start-of-season SMN there was a very poor relationship (non-significant) at four out of five sites (Figure 2b; Table 3). This result is not unexpected given that moisture supply was by far the most limiting factor to yield in 2019 (not N supply). At the fifth site (Thuddungra), SMN and yield correlated negatively, i.e., higher SMN coincided with lower yields. This is likely explained by a VR chicken manure application which was undertaken

Table 3. Pearson correlation coefficients (r) for start-of-season (Feb/Mar 2020) 0-60 cm Soil Mineral N versus various attributes for each of the five trial paddocks. Values in bold are significant at P < 0.0001. *Variable rate chicken manure application performed pre-sowing 2019 at Thuddungra site only.

Feb/Mar 2020 SMN versus:	Ardlethan	Girral	Rannock	Temora	Thuddungra
2019 Protein%	0.17	**0.49**	**0.59**	**0.51**	**0.67**
2019 Dry Yield	0.09	-0.02	0.05	0.16	**-0.55**
2019 N removal	0.22	0.06	0.16	0.32	**-0.47**
Elevation	0.11	-0.36	0.28	0.19	**-0.46**
ECa (0.5)	-0.32	0.17	-0.07	0.33	0.19
ECa (1.0)	-0.34	0.19	0.19	**0.41**	0.24
0-60 cm sand%	0.18	**-0.40**	-0.12	**-0.42**	-0.09
0-60 cm clay%	-0.20	0.36	-0.03	**0.50**	0.02
0-30 cm OC%	0.23	**0.47**	**0.44**	0.32	0.39
Manure rate*	-	-	-	-	**0.66**

just prior to sowing in 2019, which increased the severity of 'haying off' where rates were highest. This interpretation is also supported by significant positive correlations found between manure rates and both 2020 start-of-season SMN (Table 3) and 2019 protein% (r = 0.69, P < 0.0001).

OC% consistently had a positive correlation with SMN, however the strength of the relationship was variable and not always significant (Table 3). It is possible that this relationship may have been stronger if soil sampling had been delayed until later in the season (following rainfall), however it is also worth considering that OC% is a bulked measurement of particulate, humus and recalcitrant (char-like) carbon fractionates, which vary in their ability to mineralise N (Baldock et al., 2013). Further research would ideally include the measurement of individual carbon fractionates and/or mineralisable N to better capture/understand the spatial patterns of mineralisation N supply.

Of the soil type proxy layers examined (ECa, sand%, clay%), there were no significant correlations with start-of-season SMN observed across all five sites, however two of the sites (Girral and Temora) had significant negative correlations between 0-60 cm sand% and SMN (i.e., sandier soils had lower SMN; Table 3). Along with Ardlethan, these sites were quite variable in soil type characteristics in comparison to Rannock and Thuddungra, where soil types were more consistent.

Previous management history also appeared to be a key driving factor of N variability for at least three sites, with noticeable differences observed between areas that were previously fenced separately, despite some of these changes being made up to 15 years prior.

These results suggest that in any one paddock there are a great number of variables that may potentially (but not always) influence spatial patterns of SMN. This highlights the difficulty of creating accurate management zones to predict patterns of N supply in the absence of higher resolution data to test assumptions around zone homogeneity.

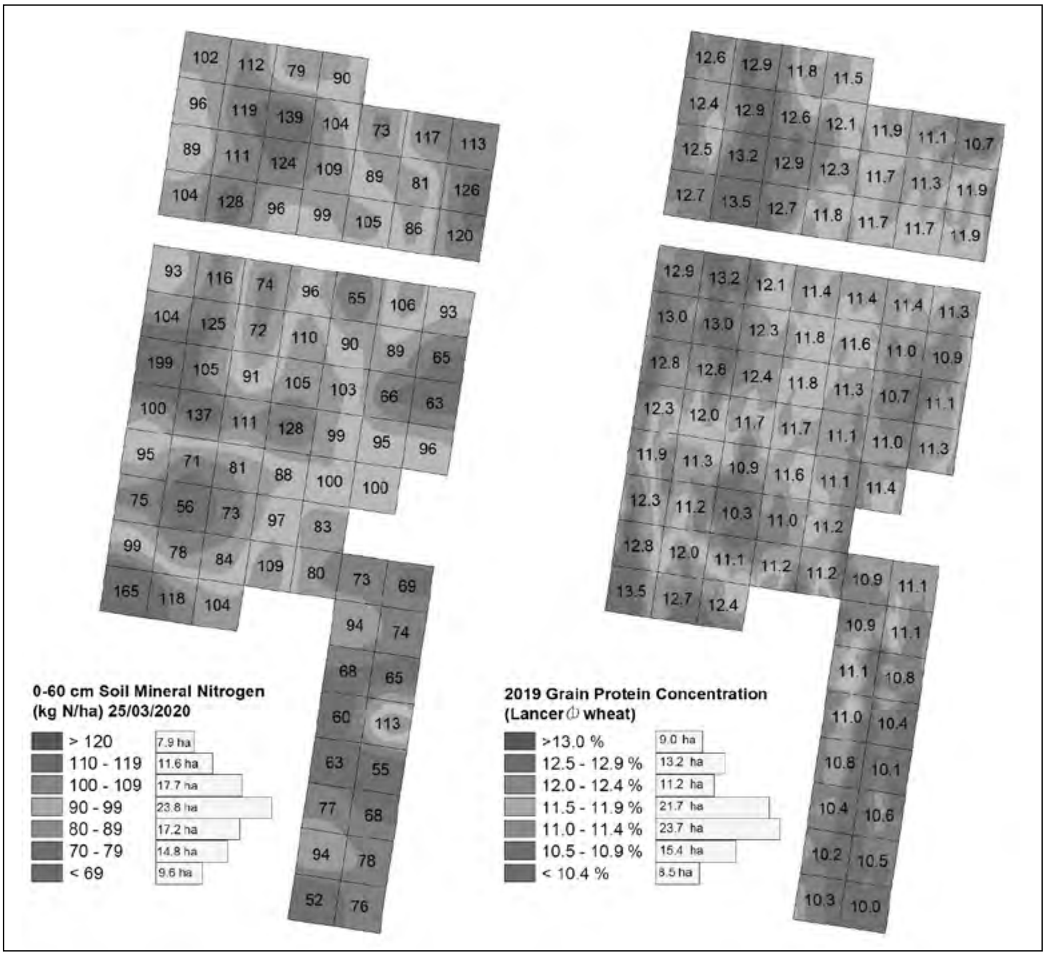

Figure 3. Rannock site 0-60 cm SMN (kg N/ha) sampled 25/03/2020 (left) and 2019 wheat protein% (right). Pearson correlation coefficient (r) = 0.59, P < 0.0001. The missing section between the two blocks is the location of an old fence line which was excluded from the sampling plan. Each cell size is 108 x 108 m, total area = 102.7 ha.

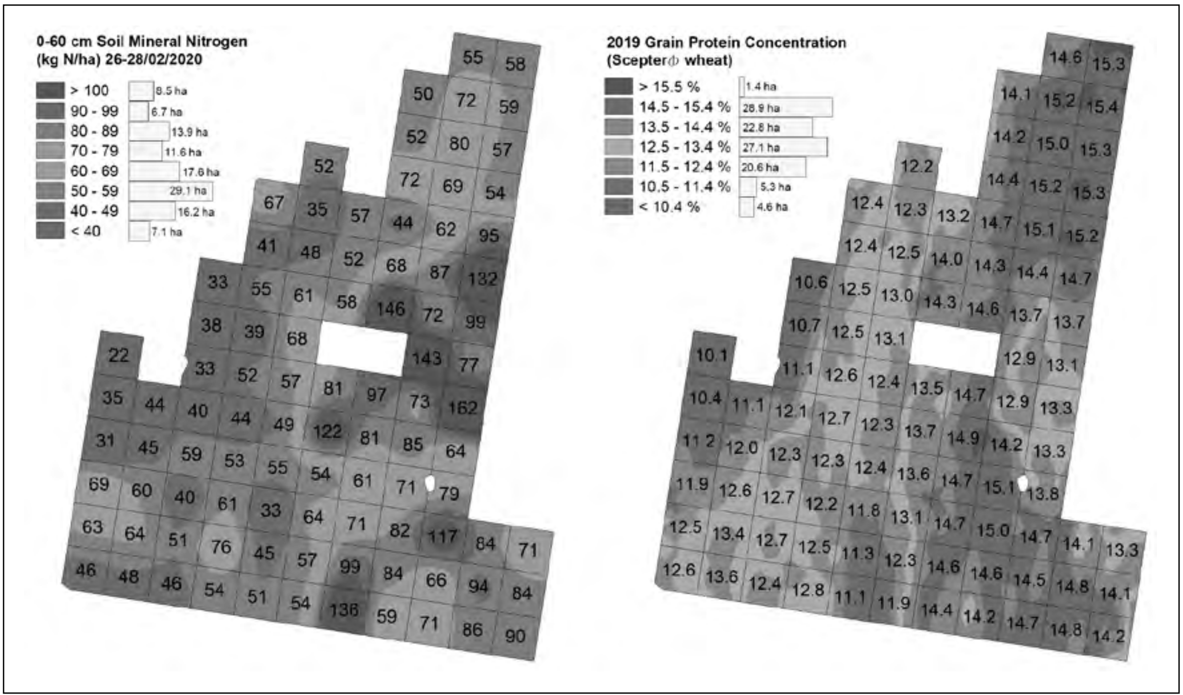

Figure 4. Temora site 0-60 cm SMN (kg N/ha) sampled 26-28/02/2020 (left) and 2019 wheat protein% (right). Pearson correlation coefficient (r) = 0.51, P < 0.0001. The far north of the paddock is a low-lying area that yielded poorly and was most likely severely impacted by both moisture stress and frost in 2019. Each cell size is 108 x 108 m, total area 110.7 ha.

Across the five sites, there was a general trend of increasing strength of correlation between SMN and protein% as the average SMN level increased. This may be explained by considering that N supply levels have to be high in comparison to N demand in order for there to be substantial residual (carryover) SMN. If crop demand is much higher than supply, SMN may be drawn down across the paddock and residual N will be correspondingly low. In this situation, protein% may still vary, as overall N supply may have differed spatially throughout the season. In this situation, it will be necessary to consider if the factors that caused variability in protein% are likely to be present in the following season or if they were a 'one-off'. For example, differences in mineralisation occurring due to soil type or long-term management practices are likely to reoccur while differences in carryover N patterns from the previous year may or may not reoccur.

This interpretation may explain the observations at the Ardlethan site, where 2019 protein variability was still quite high (6.7 – 11.9%) despite reasonably low 0-60 cm 2020 start-of-season SMN levels across the paddock (average 46 kg N/ha, Table 2). This suggests that N deficiency occurred across most of the paddock in 2019 (drawing SMN to very low levels), however the magnitude of N deficiency varied. When examining the patterns of protein variability, higher protein levels coincided with lighter textured soils on the eastern third of the paddock while lower protein levels coincided with heavier soils on the western two-thirds of the paddock. One possible explanation is that 2019 start-of-season (carryover) SMN levels differed between these two zones. This explanation is supported by a review of 2018 canola yields which were higher on the heavier soil type (i.e., more N removal occurred). A second explanation may be that additional N was accessed on the lighter soil type below 60 cm depth (i.e., below the depth of sampling). This may have occurred if sub 60 cm N reserves were variable OR if the less hostile subsoil conditions (lower CEC/EC/Cl/Na%) on the lighter soil type allowed greater root penetration during the very dry 2019 season.

Due to the uncertainty around this result, a strip trial experiment was implemented in 2020 to explore whether the grid soil mapping results or 2019 protein% layer would have been the best basis for site-specific N in 2020. The site was grown to a second season of wheat, with 80 kg/ha urea applied as a flat rate and two 160 kg/ha urea N-rich strips applied at 140 m width.

Results demonstrated a significant positive correlation between 2019 protein% and 2020 protein% for both the N-rich strip areas (n = 15, r = 0.81, P < 0.001) and non N-rich strip areas (n = 40, r = 0.73, P < 0.0001; Figure 5a). A significant

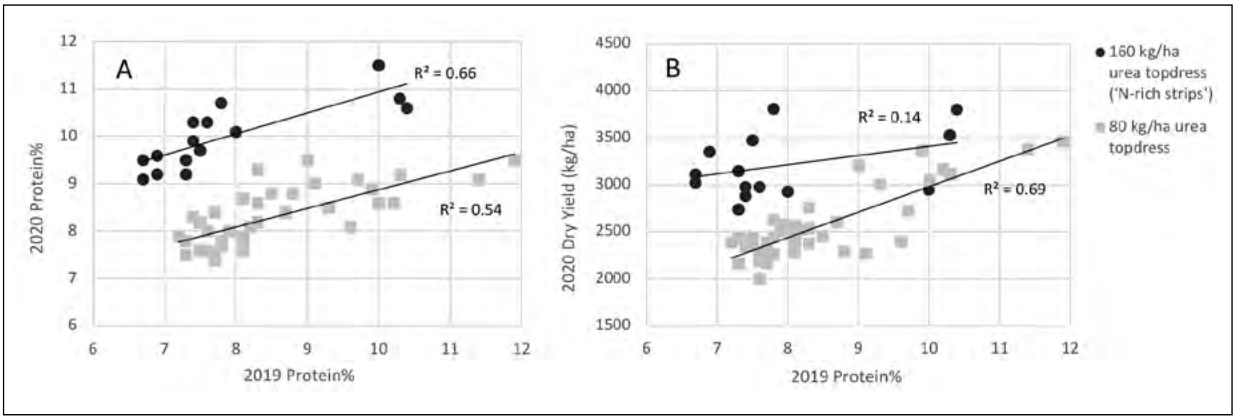

Figure 5. 2019 wheat (cv. Lancer) protein% versus 2020 wheat (cv. Spitfire) **a)** protein% and **b)** grain yield at the Ardlethan site. Each point represents one 120 x 120 m grid cell. N-rich strips n = 15, non N-rich strips n = 40.

positive correlation was also observed between 2019 protein% and 2020 yield for the non N-rich strip areas (r = 0.83, P < 0.0001; Figure 5b) while no significant correlations were observed between 2020 start-of-season SMN and 2020 yield or protein.

The consistency of protein patterns observed between the 2019 and 2020 seasons despite a lack of correlation with grid soil sampling results suggests there may be either differences in deeper SMN that has not been captured by 0-60 cm soil sampling, differences in the plant accessibility of N present below 60 cm or differences in mineralisation N supply between the two soil zones. The latter explanation appears less likely given that OC% levels were found to be lower on the lighter textured (high protein%) soil zone.

An average yield increase of 564 kg/ha and protein increase of 1.7% was observed for the N-rich strip cells when compared to their immediately adjacent non N-rich cells. A negative relationship was found between 2019 protein% and 2020 yield response, i.e., lower protein% areas had the largest yield response to additional N (r = -0.56, P < 0.01; Figure 5b, Figure 6). There was no significant relationship between yield response and start-of-season SMN (r = -0.04, ns).

These results suggest that given a fixed N budget, applying additional fertiliser to the lowest protein% areas of the paddock would have produced the greatest overall yield increase. Therefore, it appears that the adoption of a VR N strategy in 2020 based on the 2019 protein% pattern would likely have resulted in a more profitable outcome at this site

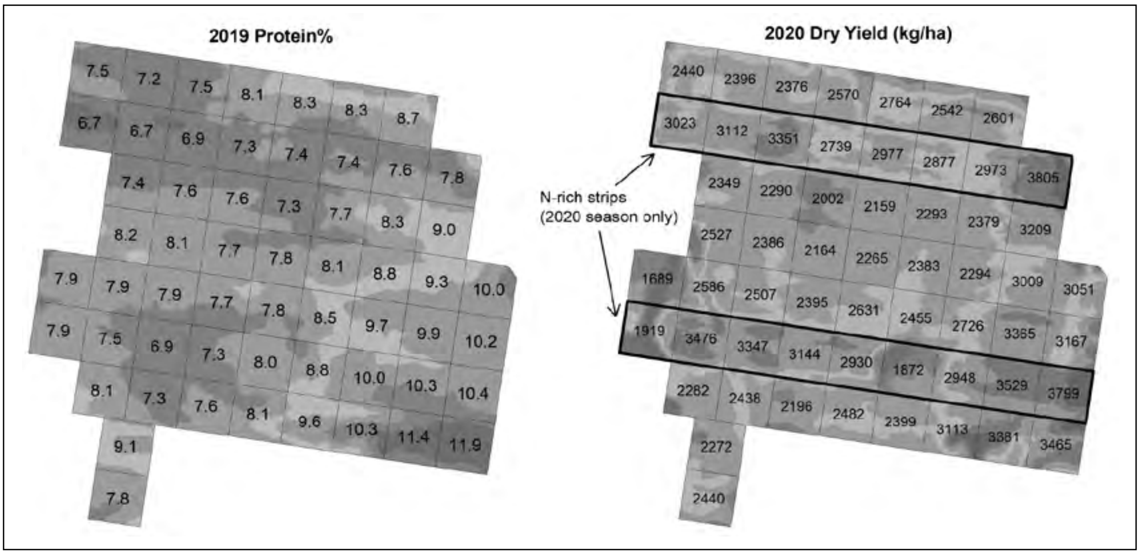

Figure 6. 2019 wheat (cv. Lancer) grain protein (left) and 2020 wheat (cv. Spitfire) dry yield at Ardlethan, with locations of N-rich strips shown. Note the greater yield response to additional N in areas of lower 2019 protein%.

than using grid soil mapping results or management zones where soil tests were used to directly determine rates.

Conclusions, challenges and further research required

The results of this project and experiences working with growers collecting and utilising harvester protein data have demonstrated that considerable potential exists for protein-based site-specific N strategies to drastically improve N management in our cropping systems, when used in conjunction with annual soil sampling and an appropriate N rate calculation method.

Research results suggested that at higher background SMN levels (where N supply is not drastically exceeded by demand), it is likely that a good relationship will exist between protein% and residual (carryover) N. Even at low (constraining) SMN levels, results showed that protein% patterns may still give a good indication of spatial patterns of N requirements. It is further worth considering that in these instances, considerably higher N rates are probably required in an overall sense, therefore any method that encourages more considered N management (e.g., through reviewing protein levels and undertaking basic ground-truth soil testing) is likely to have a positive impact on profitability.

The success of protein-based site-specific N strategies appears to be linked to the major advantage of this approach whereby the crop itself indicates the N adequacy it experienced over the sum of the whole season. This circumvents many of the challenges of site-specific N management which have either limited the quality/efficacy of some VR N approaches (that attempt to provide simple solutions to a complex problem) or have limited the uptake of other VR N approaches (that are too complex/laborious to be practical). The high spatial resolution of this data and relatively low cost when compared to alternative approaches (e.g., intensive soil sampling) is another major advantage.

While protein maps cannot be used to guide N management decisions in the season of their collection, this method should be considered more of a 'whole-system' approach to N management, with the aim of incrementally building (and/or mining) background SMN levels to match site-specific yield potentials across the farming operation over a number of seasons. This approach has considerable synergy with the concept of 'N banking' (Hunt et al., 2021; Meier et al., 2021) which aims to decouple N input decisions from seasonal demand by 'topping up' N levels each year to a pre-defined target that would be considered non-limiting in most seasons.

By using these two methods in conjunction (on soils that are not prone to losses), growers are armed with a simple, yet targeted strategy to both reduce/eliminate areas of yield loss due to N deficiency and reduce instances of N oversupply which are environmentally, agronomically and economically undesirable. This approach also has logistical benefits in that N rates and VR input maps can be determined/created quite early in the season (following the return of deep N soil test results). This has obvious benefits for financial budgeting and planning however also means that these decisions can be made well ahead of time rather than at a potentially stressful period before a rain event if relying on mid-season remotely sensed imagery, for example.

For this approach to be widely implemented, additional work is required to determine how to bridge the data gap that occurs in seasons where non-cereal crops are grown. Although not discussed in the current paper, results at the four project sites that grew canola in 2020 did not suggest that their protein patterns were as closely related to N supply as those observed in wheat. This may be due to the sensitivity of canola oil/protein concentrations to late seasonal climatic conditions (Walton et al., 1999; Uppal et al., 2019), however additional research is required to further explore this issue (see the full research report for 2020 trial results and a discussion around canola oil/protein drivers - http://www.farmlink.com.au/project/nitrogen-variability).

Another area for further research is examining the impact of frost during grain filling, which can result in elevated grain protein concentrations by curtailing the deposition of starch (Allen et al., 2001). While this may serve to 'artificially' elevate grain protein concentrations, it is possible that this effect is counteracted by reduced yields (N removal) and higher N concentrations of residues.

These challenges highlight that the most successful site-specific N management strategies will probably use a number of data layers and grower knowledge in conjunction with protein mapping and targeted deep N sampling to devise effective N input maps over the whole rotation. Such data layers that were identified by the current study to be potentially useful indicators of N variability included soil type parameters (e.g., ECa, CEC or texture mapping, subsoil health tests), long-term productivity (e.g., stacked yield or biomass maps), landscape features (e.g., elevation) and previous management history information (e.g., locations of amalgamated paddocks and their histories).

Given the immense potential productivity and environmental benefits of improved site-specific N management, considerable scope exists for follow up research to address the abovementioned challenges and explore the applicability of these methods in other regions and soil types.

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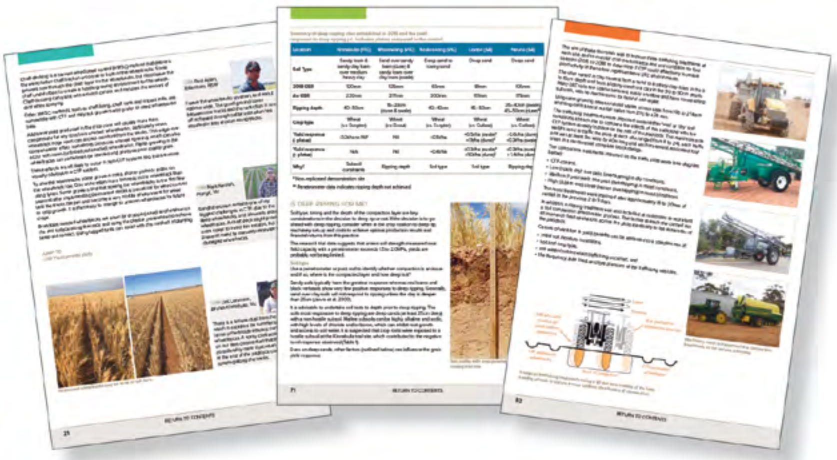

The rise of glyphosate resistance – management strategies to minimise its increase

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GRDC project code: UCS00020

Keywords

- glyphosate resistance, annual ryegrass, optimising control, herbicide testing, random weed survey, double knock.

Take home messages

- Glyphosate resistance in annual ryegrass has been detected in most states.
- There are ways to optimise glyphosate efficacy.
- The double-knock strategy can help combat glyphosate resistance.

Incidence of glyphosate resistance

The GRDC has invested in random weed surveys of cropping regions across Western Australia (WA), South Australia (SA), Victoria (VIC), New South Wales (NSW) and Tasmania (TAS) since 2005, to monitor for resistance levels in key weed species. Glyphosate has been included in the suite of herbicides tested. The methodology involves collecting weed seeds from paddocks chosen randomly at pre-determined distances, at harvest. Weeds were tested in outdoor pot trials under natural growing conditions. The incidence of resistance to glyphosate in annual ryegrass identified in these most recent surveys has been presented in Figure 1.

Commercial herbicide resistance testing

Between 2016 and 2020, almost 100 ryegrass samples were sent to Plant Science Consulting from the Yorke Peninsula for herbicide resistance testing. Most samples were collected by agronomists for their grower clients as seed samples. For 72 samples, at least one rate of glyphosate was selected. 52% of these samples exhibited glyphosate resistance ranging from 5% to 80% indicating significant levels of resistance on the Yorke Peninsula.

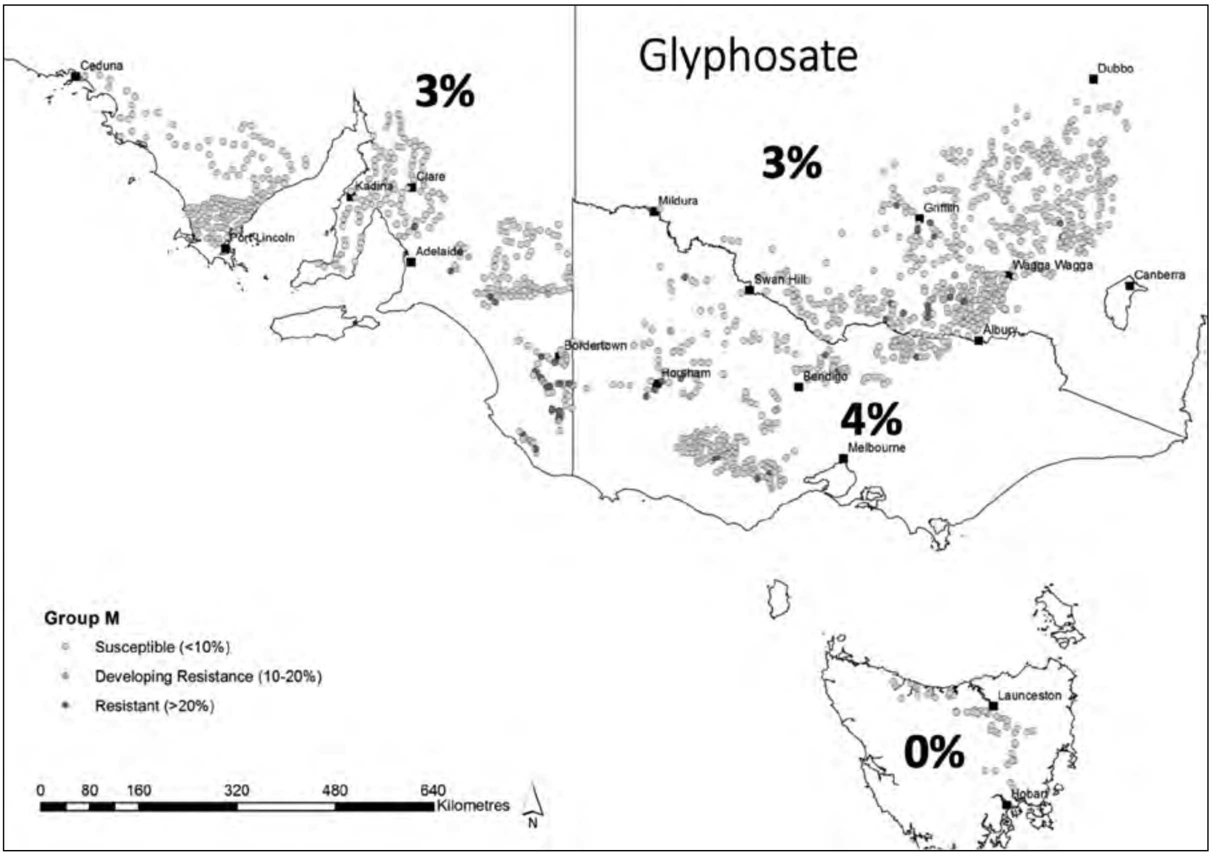

Figure 1. Incidence of paddocks containing glyphosate resistant ryegrass that were confirmed in the latest round of GRDC random weed surveys. Resistance is defined as a sample where ≥20% plant survival was detected in a pot trial. A figure of 3% indicates that of the ryegrass collected in the survey, 3% were confirmed as resistant to glyphosate in pot trials the following season.

2020 season

The early break in 2020 across most southern cropping regions resulted in an opportunity for knockdown weed control. Multiple applications of glyphosate and paraquat were possible targeting multiple flushes of weeds, in particular ryegrass from early autumn prior to sowing. Plants surviving glyphosate from WA, SA, Vic and NSW were sent to Plant Science Consulting for testing using the Quick-Test method to verify whether herbicide resistance had contributed to survival in the field. The data presented in Figure 2 indicates that 43%, 70% and 78% of ryegrass samples sent from SA, Vic and NSW in 2020 respectively, were confirmed resistant to glyphosate. This highlights that in the majority of cases, glyphosate resistance has contributed to reduced control in the paddock.

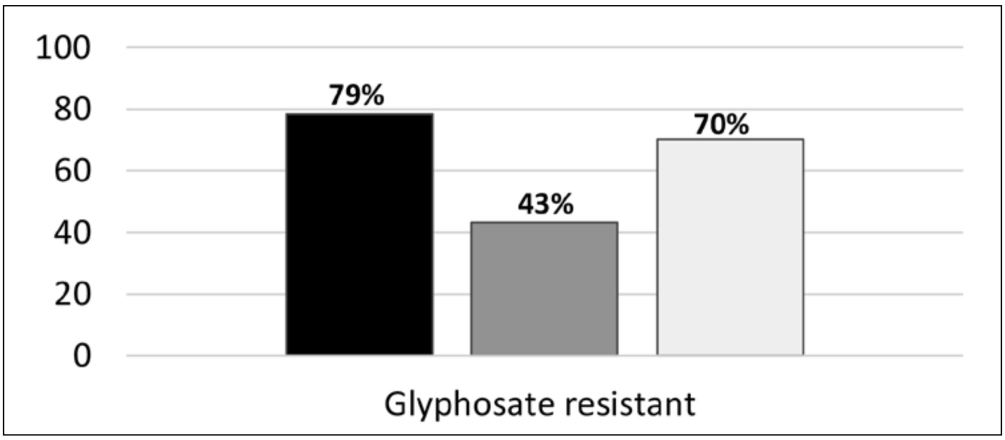

Figure 2. Percent (%) resistance to glyphosate confirmed in farmer ryegrass samples originating from 83 NSW, 37 SA and 74 Vic cropping paddocks treated with glyphosate in autumn 2020. Testing conducted by Plant Science Consulting using the Quick-Test.

Table 1. Percent survival (%) of 72 ryegrass samples received from the Yorke Peninsula between 2016-2020 and tested with 1, 1.5 or 2 L/ha Glyphosate 540. A resistance rating to indicate the effect of the herbicide on the survivors follows the survival data. 'R' indicates weak resistance (70-99% biomass reduction), 'RR' intermediate (41-69% biomass reduction) and 'RRR' strong (0-40% biomass reduction) resistance. S indicates susceptible. The samples were tested by Plant Science Consulting by seed or Quick-Testing. An empty cell indicates that rate of glyphosate was not selected.

	Glyphosate 540 (L/ha)				Glyphosate 540 (L/ha)		
Town	1	1.5	2	Town	1	1.5	2
Arthurton		0 S		Maitland			0 S
Arthurton		20 RR		Maitland	0 S		0 S
Arthurton		0 S		Maitland	45 R		0 S
Arthurton		5 R		Maitland		10 RR	
Arthurton		10 RR		Maitland		40 R	
Arthurton		0 S		Maitland		0 S	
Arthurton		55 RR		Maitland		0 S	
Arthurton		10 R		Maitland			0 S
Arthurton			80 RRR	Maitland			0 S
Arthurton		15 R		Maitland	10 R		0 S
Arthurton		15 RR		Maitland	25 R		0 S
Arthurton		5 R		Maitland		10 R	
Arthurton			0 S	Maitland	0 S		0 S
Arthurton			0 S	Maitland		20 R	
Arthurton		0 S		Minlaton		0 S	
Cunliffe	0 S		0 S	Minlaton		0 S	
Curramulka			15 RR	Minlaton		0 S	
Curramulka			10 R	Minlaton		0 S	
Curramulka			15 RR	Minlaton		0 S	
Curramulka			25 R	Moonta			0 S
Curramulka			20 R	Moonta			0 S
Curramulka			0 S	Port Broughton			0 S
Curramulka		60 RRR	45 RR	Port Vincent		40 R	
Curramulka	20 R			Port Vincent		0 S	
Curramulka	60 RR		15 R	Port Vincent		5 R	
Curramulka		45 RR		Stansbury		10 R	
Curramulka			0 S	Urania		80 RR	
Kulpara		15 R		Urania		35 RR	
Kulpara		0 S		Warooka		10 R	
Maitland	0 S		0 S	Warooka		0 S	
Maitland	10 RR		10 R	Yorketown		10 R	
Maitland	0 S		0 S	Yorketown		10 R	
Maitland			0 S	Yorketown		0 S	0 S
Maitland		10 R		Yorketown		0 S	
Maitland		15 R		Yorketown		0 S	
Maitland	0 S		0 S	Yorketown	30 R		0 S

Discrepancy between resistance testing and paddock failures to glyphosate

In some cases, plants that survived glyphosate in the paddock are not resistant. Reasons for the discrepancy between the paddock and a resistance test can include poor application or application onto stressed plants, incorrect timing, sampling plants that were not exposed to glyphosate or a combination of the above.

Evolution of glyphosate resistance

Glyphosate was first registered in the 1970s and rapidly became the benchmark herbicide for non-selective weed control. Resistance was not detected until 1996 in annual ryegrass in an orchard in southern NSW (Powles et al. 1998). Only a few cases of resistance were detected in the following decade. The fact that it required decades of repeated use before resistance was confirmed indicated that the natural frequency of glyphosate resistance was initially very low. At the current time there are over a dozen species that have developed resistance to glyphosate in Australia (https://www.croplife.org.au/resources/programs/resistance-management/herbicide-resistant-weeds-list-draft-3/). The most important weed species are annual ryegrass, sowthistle, awnless barnyard grass and feathertop Rhodes grass. Ryegrass and sowthistle will be discussed further in this paper.

There are several contributing factors for the increasing glyphosate resistance in ryegrass with generally more than one factor responsible. Reducing rates can increase the development of resistance particularly in an obligate outcrossing species such as ryegrass resulting in the accumulation of weak resistance mechanisms to create individuals capable of surviving higher rates. This has been confirmed by Dr Chris Preston where ryegrass hybrids possessing multiple resistance mechanisms were generated by crossing parent plants with different resistance mechanisms.

Other factors that can select for glyphosate resistance by reducing efficacy include:

1. Using low quality glyphosate products and surfactants.
2. Mixing glyphosate with too many other active ingredients resulting in antagonism, particularly in low water volumes.
3. Using low quality water, particularly hard water. Glyphosate is a weak acid and binds to positive cations (i.e. magnesium, calcium and bicarbonate) that are in high concentration in hard water (i.e., >200 ppm).
4. Applying glyphosate during periods of high temperature and low humidity, resulting in the rapid loss of glyphosate in solution from leaf surfaces thereby reducing absorption.
5. Translocation of glyphosate in stressed plants can be reduced. Maximum glyphosate efficacy relies on translocation to the root and shoot tips. While this occurs readily in small seedlings, in larger plants, glyphosate is required to translocate further to the root and shoot tips to provide high levels of control.
6. Shading effects reducing leaf coverage resulting in sub-lethal effects.
7. As glyphosate strongly binds to soil particles application onto dust covered leaves can reduce efficacy.
8. Application factors such as speed and nozzle selection, boom height can reduce the amount of glyphosate coverage.
9. A combination of the above factors can reduce control thereby increasing the selection for resistance.

Optimising Glyphosate Performance

The selection of glyphosate resistance can be reduced by considering the points mentioned previously Additionally, there are a number of important pathways to improve glyphosate performance include:

1. Avoid applying glyphosate under hot conditions. A trial spraying ryegrass during the end of a hot period and a following cool change was conducted in October 2019. Ryegrass growing in pots was sprayed at 8am, 1pm and 8pm with temperature and Delta T recorded prior to each application. Control of well hydrated plants ranged between 0% and 40% when glyphosate was applied during hot weather (30 to 32.5°C) and high Delta T (14 to 16.7) with the lowest control when glyphosate was applied at midday (Figure 3). In contrast, glyphosate applied under cool conditions just after a hot spell resulted in significantly greater control (65%-80%), indicating that plants can rapidly recover from temperature stress provided moisture is not limiting, e.g. after rainfall.

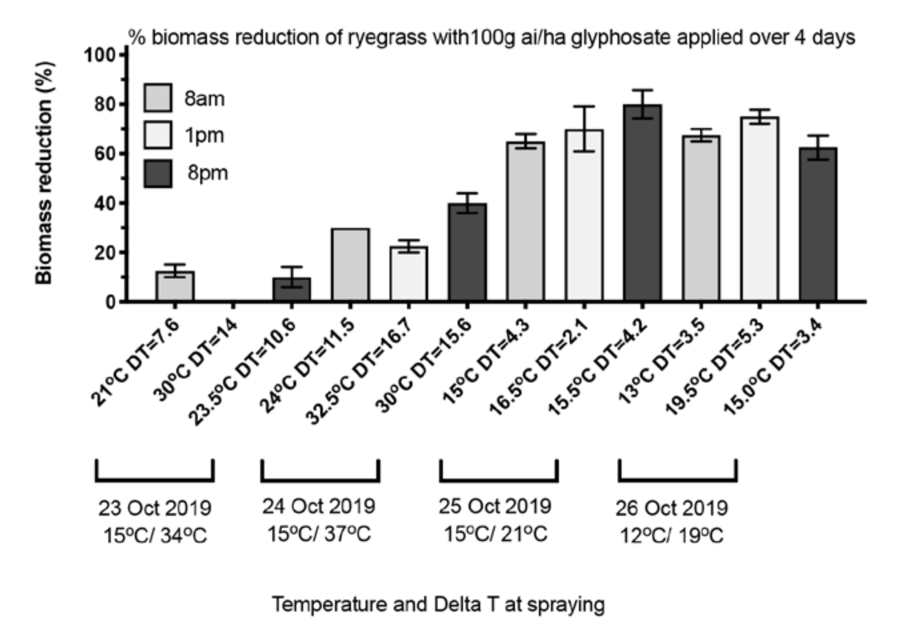

Figure 3. Effect of temperature & Delta T on glyphosate for ryegrass control. A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions.

2. Improving water quality and glyphosate activity by using ammonium sulfate (AMS). The addition of AMS has several functions. One is to soften water by combining to positively charged ions such as magnesium and calcium common in hard water. The negative charged sulphate ions combine with the positive cations preventing them from interacting with glyphosate and reducing its solubility and leaf penetration. Additionally, AMS has been shown to independently improve glyphosate performance, as the ammonium ions can work with glyphosate to increase leaf uptake. In a pot trial conducted with soft water, AMS was shown to significantly improve control of ryegrass with 222ml/ha (100g ai/ha) of glyphosate 450 (Figure 4). As a general rule, growers using rainwater (soft) should consider 1% AMS, if using hardwater (i.e., bore, dam) 2% AMS. The addition of a wetter resulted in a further improvement in control.

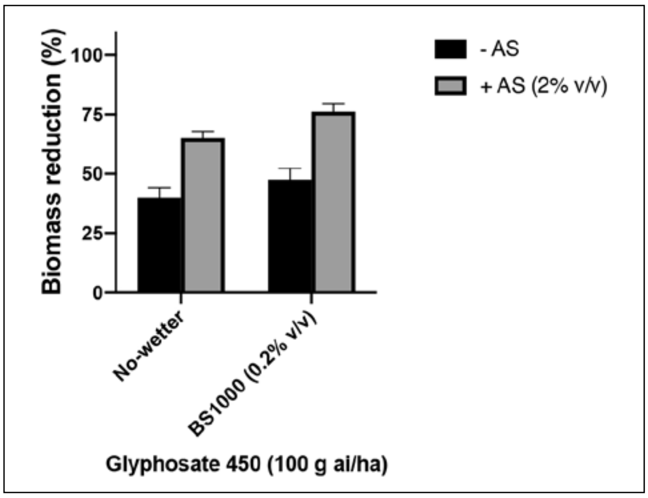

Figure 4. Effect of ammonium sulfate and wetter on glyphosate for ryegrass control. A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions.

3. Herbicide activity can vary at different growth stages. In a pot trial investigating the effect of glyphosate at four ryegrass growth stages (1-leaf to 4-tiller), good control was achieved at the three older growth stages but not on 1-leaf ryegrass (Figure 5). Most glyphosate labels do not recommend application of glyphosate on 1-leaf ryegrass seedlings because they are still relying on seed reserves for growth. Consequently, very little glyphosate moves towards the roots.

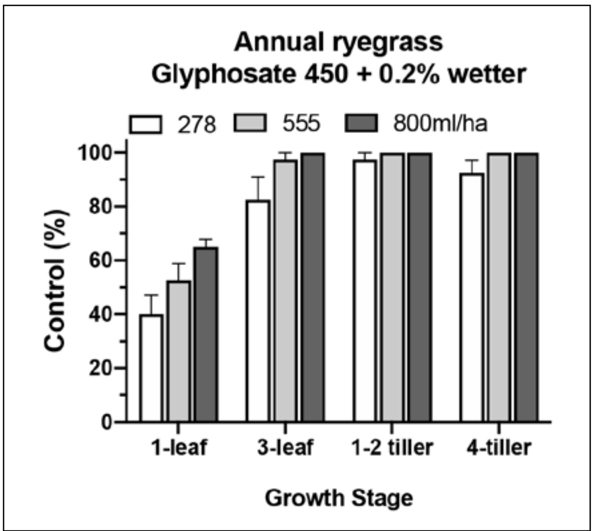

Figure 5. Effect of ryegrass growth stage on glyphosate activity. A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions.

A double knock strategy is defined as the sequential application of two weed control tactics to combat the same weed population. The most common double knock strategy is glyphosate followed by paraquat. It has been widely adopted to prevent or combat glyphosate resistance particularly for ryegrass. The first 'knock' with glyphosate is aimed to control the majority of the population with the second 'knock' (paraquat) intended to kill any individuals that have survived glyphosate. In the presence of glyphosate resistance, paraquat applied one to five days following glyphosate was shown to provide optimum control in trial work conducted by Dr Christopher Preston (Figure 6). The timing depends on weed size and growing conditions with three to five days required to maximise glyphosate activity. After a week (depending on environmental conditions) glyphosate resistant plants treated with glyphosate can stress resulting in the absorption of less paraquat thereby reducing control with the second tactic. If growing conditions are poor or plants large, the stress imposed by glyphosate maybe further delayed.

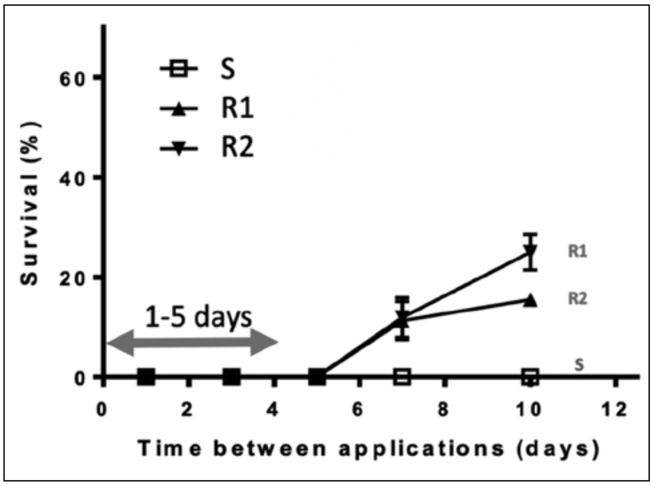

Figure 6. Double knock timing. Glyphosate applied onto a susceptible (S) and two glyphosate resistant ryegrass biotypes (R1 & R2) followed by paraquat 1, 3, 5, 7 and 10 DAA. (Source: Trial work conducted by Dr Christopher Preston (The University of Adelaide)).

Summary

In the southern cropping zone glyphosate resistance in ryegrass continues to increase as indicated by random weed surveys across the region and the Bayer Resistance Tracker database. The early break in autumn 2020 resulted in the targeted testing of about 200 ryegrass populations prior to sowing with over half confirmed resistant to glyphosate. Although it took about 20 years after the registration of glyphosate for the first case of resistance to be confirmed, in the past 10 years there has been an exponential rise in the number of confirmed cases. Decades of strong selection pressure resulting from repeated use coupled with application under suboptimum conditions has played a major role. More efficient use of glyphosate combined with effective integrated weed management (IWM) strategies is required to reduce further increases in resistance.

Acknowledgements

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Notes

Notes

THE 2020-2022 GRDC SOUTHERN REGIONAL PANEL

May 2021

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CHAIR - JOHN BENNETT

Lawloit, VIC

Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John and his family run a mixed farming operation across diverse soil types. The farming system is 70 to 80 per cent cropping, with cereals, oilseeds, legumes and hay grown. He wants to see RD&E investments promote resilient and sustainable farming systems that deliver more profit to growers and ultimately make agriculture an exciting career path for young people.

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DEPUTY CHAIR - KATE WILSON

Hopetoun, VIC

Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region and produces wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years servicing the Mallee and northern Wimmera. Kate is passionate about producing high quality grain, whilst enhancing the natural ability of the soil. Kate is passionate about research and the extension of that research to bring about positive practice change to growers.

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Andrew is Managing Director and a shareholder of Lilliput AG, and a Director and shareholder of the affiliated Baker Seed Co, a family-owned farming and seed cleaning business. He manages a 2500ha mixed cropping enterprise south of Rutherglen. Lilliput AG produces wheat, canola, lupin, faba bean, triticale, oats and sub clover for seed and hay. Andrew served on the GRDC's medium rainfall zone RCSN (now National Grower Network) and has held many leadership roles. He holds a Diploma of Rural Business Management and an Advanced Diploma of Agriculture.

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Jon has worked in agriculture for the past three decades, both in the UK and in Australia. He has managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high rainfall zone, and his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). Jon was a member of the GRDC's HRZ (RCSN (now National Grower Network) and became a GRDC Southern Panel member in 2015. In 2020 Jon set up an independent consultancy, TechnCrop Services.

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LOU FLOHR

Lameroo, SA

Lou is a farmer based at Lameroo in the Southern Mallee of South Australia. With her parents and partner, she runs a mixed farming enterprise which includes export oaten hay, wheat, barley, a variety of legumes and a self-replacing Merino flock. Prior to returning to the family farm, Lou had a 10-year agronomy career, servicing the Upper South East and Mallee. She is passionate about her industry, particularly in recognising the role that women play in the industry and on the land.

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Andrew is a research agronomist, based at Port Lincoln on SA's Eyre Peninsula. He started his career with the South Australian Research and Development Institute (SARDI) at the Minnipa Agriculture Centre, and then spent time at CSIRO in Adelaide. Andrew managed the family farm on Lower Eyre Peninsula for 10 years before returning to SARDI in late 2009. In 2019, Andrew started his own research company EPAG Research, delivering applied research across Eyre Peninsula. Andrew received the GRDC Southern Panel's Emerging Leader award in 2018, and prior to joining the Panel he served on the GRDC's low rainfall zone RCSN (now National Grower Network).

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Dimboola, VIC

Pru was raised on a mixed farm at Diapur in Victoria's Wimmera region. She has worked at the Victorian Department of Primary Industries and GRDC, where she implemented GRDC's first social media strategy. She then worked at Birchip Cropping Group, managing and supporting extension projects. She has recently started her own business focusing on extension, project development and management.

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MICHAEL TRELOAR

Cummins, SA

Michael is a third-generation grain grower based at Cummins on South Australia's Eyre Peninsula, where he grows wheat, barley, canola, beans, lupins and lentils on a range of soil types. He has been involved in the South Australian Grains Industry Trust, the Lower Eyre Agricultural Development Association and the South Australian No Till Farmers Association. He believes research and development underpins profitability in Australian farming systems and the GRDC is pivotal in delivering research outcomes that support growers.

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MICHELLE WATT

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In February 2020 Professor Michelle Watt was appointed the Adrienne Clarke Chair of Botany at the University of Melbourne. From 2015 to 2019, she was Director of the Plant Sciences Institute at the Helmholtz Centre and Professor of Crop Root Physiology at the University of Bonn in Germany. Prior to 2015 Michelle was at CSIRO. She has been in multi-partner projects with Australia, the USA, India, the Philippines, UK and Germany in the under-studied but critical area of plant roots. She is President of the International Society of Root Research and Co-Chair of the Root Phenotyping.

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DR NICOLE JENSEN

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Nicole is general manager of GRDC's Genetic and Enabling Technologies business group. She brings a wealth of experience in digital agriculture, plant breeding and genetics from roles she has held in Australia and internationally in the seed industry.

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- Intolerant cereal varieties grown on stored moisture
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- Stem nematode
- Blackspot (field peas)
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- Common root rot
- Pythium clade f
- Charcoal rot
- Ascochyta blight of chickpea
- White grain disorder
- Sclerotinia stem rot

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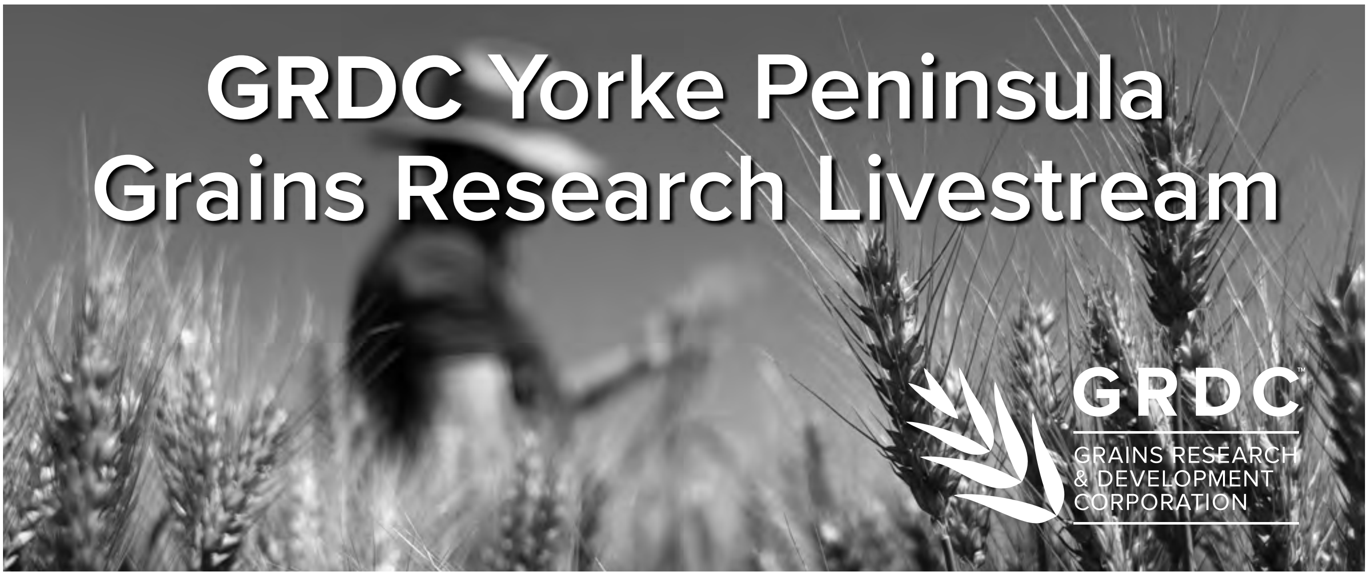

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- The local GRDC Grains Research Update planning committee that includes growers, advisers and GRDC representatives.

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