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P Level 4 | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 **T** +61 2 6166 4500 **F** +61 2 6166 4599
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Lameroo, South Australia

19th August 2020

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GRDC Grains Research & Development Corporation

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T 03 5441 6176
E admin@orm.com.au
W orm.com.au

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CONTACT:
Russell Burns
russell.burns@sa.gov.au
0401 122 115

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Seeder-based approaches to reduce the impact of water repellence on crop productivity

Jack Desbiolles[1], Nigel Wilhelm[2], Melissa Fraser[3], Lynne Macdonald[4], Therese McBeath[4] and James Barr[1].

[1]University of South Australia; [2]South Australian Research and Development Institute; [3]Primary Industries and Regions South Australia; [4]CSIRO Agriculture and Food.

GRDC project code: CSP00203

Keywords

- hydrophobic sands, soil wetter, on-row sowing, moisture delving, deep furrow till.

Take home messages

- Low-cost, low risk seeder-based strategies produced valuable benefits to wheat/barley establishment and grain yield in a severely water repellent sand in two below-average rainfall seasons.
- Several products and application strategies provided consistent and large crop establishment benefits over two years at the same site, while also producing up to 0.22t/ha (Year 1, wheat) and 1.07t/ha (Year 2, barley) extra grain yield.
- Edge-row/on-row sowing achieved the greatest benefits by exploiting existing in-furrow moisture via guided sowing, while 230mm deep furrow tillage produced similar benefits from the opener lifting moist soil deeper in the profile.
- A soil wetter provided grain yield benefits with both edge-row and inter-row seeding over the respective control, while combining the soil wetter with paired-row seeding on the row maximised the grain yield response in the trial (for example; +1.82 t/ha gain over a 0.6 t/ha control).
- Challenges remain in selecting the most effective wetting agents for a particular sand environment due to performance variability.

Introduction

An estimated 12.5 million hectares of sandy soils in southern and Western Australia are deemed at moderate and high risks of water repellence (Roper et al. 2015). These 'non-wetting' sands have low fertility and suffer from delayed and uneven wetting, which leads to erratic crop establishment, staggered weed germination and generally poor crop productivity due to low plant densities, low nutrient access, poor weed control and crop damage in areas prone to wind erosion.

A research project supported by GRDC investment (CSP00203) and led by CSIRO is investigating techniques of amelioration and mitigation of sandy soil constraints. A range of field trials are investigating management options available at seeding time to mitigate the impacts of water repellence. During 2018 and 2019, two trials were conducted in a 270mm growing season rainfall (GSR) zone at Murlong on the Eyre Peninsula (EP), namely a soil wetter evaluation trial and a seeder strategy evaluation trial, aiming to compare a number of seeding strategies.

The soil at the site (-33.691295S, +135.944050E) was classified as severely repellent (molarity of ethanol test results were 2.8 at 0-5cm and 3.0 at 5-10cm). In Year 1, a water repellency profile was estimated at seeding using a Water Drop Penetration Test with de-ionised water (Leelamanie et al. 2008), as follows: severe to extreme water repellency (0-10cm), 'strong' (10-15cm), 'slight' (15-20cm), and non-repellent below 20cm depth.

Soil wetter evaluation trial (2018-19)

Background

Soil wetter chemistries are varied and complex, and little is known of their individual suitability to local water repellence which appears to vary in nature depending up on the soil. Modern soil wetters typically have both surfactant and humectant properties. Surfactants lower the surface tension between water and the soil particles, which allows rainfall to more readily infiltrate into the water-repellent soil. These are penetrant-type products, promoting entry and drainage through the topsoil. Humectants are designed to counter excessive leaching in a low 'surface area' sands and aid moisture retention. Humectant co-polymers promote a horizontal spread of water within the sandy soil and increase moisture retained within the furrow seed zone. The benefits of applying soil wetters at seeding time have been evaluated in Western Australia (WA) over the past 10 years (Davies et al. 2019), and this work recently concluded that:

- Banded wetters are most beneficial for dry sown cereals on repellent forest gravels of the south-west with less reliable benefits for break-crops.
- Benefits of banded wetters are minimal, or at best sporadic, for dry sown crops on deep sands and there is no benefit with sowing into moist soil for any crop or soil type.
- Benefits are larger in seasons with low and sporadic germinating rains in autumn.

South Australian (SA) research at Wharminda on EP conducted from 2015 to 2017 found that the two soil wetting agents evaluated could significantly improve wheat, barley and lupin establishment and also have a positive impact on grain yield, in two years out of three (Ward et al. 2019).

Building on these results, the soil wetter trial instigated at Murlong aimed to broaden the range of soil wetter types and combinations evaluated under contrasting furrow placement scenarios.

Experimental design

The impacts of 13 different wetting agents (both surfactants and humectants), in single and dual placement configurations (furrow surface and/or seed zone) were tested over two years (2018 and 2019 seasons). The treatment costs ranged between $12 and $41 per ha (Table 1).

The range of commercial soil wetters evaluated included pure surfactants, surfactant/humectant (S/H) blends, and S/H blends enriched with organics/nutrients. Six treatments consisted of split applications and included single products split-applied at 50:50 rate or combined products applied at full rate in their recommended furrow delivery locations. All suppliers were consulted to ascertain the recommended application rates and locations of each product.

Table 1. Soil wetter treatments evaluated at the Eyre Peninsula, Murlong site over 2018 and 2019.

Product names (commercial supplier)	Treatment key	Rate (L/ha)	Placement zone*	$/ha (2018)
SE14® (SACOA)	T1	3	SZ	21
RainDrover (SACOA)	T4	2	SZ	12
Aquaforce (SST Australia)	T2	2.5	FS	20
H2Flo™ (ICL Specialty Fertilizers)	T5	2	FS	16
SeedWet (SST Australia)	T7	2	FS	17
H2Pro® TriSmart (ICL Specialty Fertilisers)	T8	2	FS	15
Soak-n-Wet (Victorian Chemicals)	T9	4	FS	14
Bi-Agra Band (SST Australia)	T10	1.5+1.5	FS+SZ	22
Divine® Integrate/Agri mix (BASF)	T11	1+1	FS+SZ	20
Aquaboost AG30 FB + AG30NWS (BioCentral Lab)	T12	2+2	FS+SZ	24
Precision Wetter + Nutri-Wet (Chemsol GLE)	T13	2+2	FS+SZ	21
Aquaforce (SST Australia) + SE14® (SACOA)	T3	2+3	FS+SZ	41
H2Flo™ (ICL Specialty Fertilisers) + RainDrover (SACOA)	T6	2+2	FS+SZ	28

Key: SZ=Seed Zone; FS=Furrow Surface

Wetting agents have variable effects in different soil types depending on the site-specific nature of repellence. Treatments were initially pre-tested on the Murlong soil under laboratory conditions showing a de-ionised water control penetration time of more than 120 minutes, whereby the soil wetters at recommended rates resulted in penetration times ranging from 2-3 seconds to 82 minutes.

Plots were 25m long by six crop rows at 0.28m spacings, and were sown at 6km/h using a deep banding knife point operating at 110mm depth, followed by twin seeding discs and a furrow stabilising V press wheel, 140mm wide. A stable consolidated furrow surface is often critical to the efficacy of surface applied soil wetters, working best on a firm settled soil, rather than mixed into loose backfill. Soil wetter treatments were applied in 100L/ha volume of rainwater with foam suppressant at 0.05% v/v, using a Teejet® TPU1501 low angle flat fan nozzle behind press-wheels to produce a 25-30mm wide band on the furrow surface (FS). In contrast, seed zone (SZ) applications were delivered with a *Keeton* in-furrow seed firmer to achieve accurate co-location with the seeds.

The trial had four replications organised into a randomised complete block design. In Year 1, the plots were sown with wheat into a grazed barley stubble, while in Year 2, all plots were inter-row sown with barley into the standing wheat stubble. The 2018 treatments were re-applied to the same plots in 2019.

Some aspects of seeding agronomy are summarised in Table 2. Uniform® fungicide at 400mL/ha and Intake® Hi-Load Gold fungicide at 250mL/ha were also applied in furrow in 80L/ha volume to address medium/high risks of rhizoctonia or yellow leaf spot and take-all, respectively.

Seeding depth in both years was targeted in the range of 3-5cm as a preferred strategy for non-wetting sands.

Crop establishment results (2018-19)

Wheat and barley crop establishment rates at five weeks after sowing are shown in Figure 1. The inter-row control established at 24% and 12% of seeds sown (48 and 27 plants/m^2, respectively), indicating very unfavourable conditions for crop establishment in this severely water repellent sand.

In 2018, the soil wetter treatments increased wheat crop establishment by 25 plants/m^2 on average, with a range of 0 to 58 plants/m^2. In 2019, the same treatments increased barley crop establishment by 17 plants/m^2 on average, with a similar range of 0-56 plants/m^2. The impact of soil wetter treatments on crop establishment was similar in both years, as confirmed by a strongly positive correlation between results in each year ($r = +0.849$, $P<0.001$, Figure 2). No correlation was found between product performance and $/ha cost, indicating that cost is not a useful indicator of performance.

Interestingly, all furrow surface applied wetters performed poorly at Murlong, while the two seed zone applied (humectant) products performed better. Combining a surfactant on the furrow surface (FS) with a humectant in the seed zone (SZ) provided a synergistic response in 2019 for one combination, greater than the cumulative benefits of each single product (i.e. T1+T2 < T3), but not for another (i.e. T4+T5 ≥ T6), which did not improve benefits beyond the seed zone wetter response, in both years. Overall, five out of the six seed zone+furrow surface wetter combinations provided a benefit.

Table 2. Soil wetter trial seeding agronomy and season overview.

Year	Seeding date and crop seed rate	Nutrition (kg/ha)	Rainfall pattern
2018	21-23 June 2018 Razor CL Plus WHEAT at 63kg/ha (32.3g/1000 grains, 99% germination), Rancona® C + Imidacloprid 600 treated	26N+11P+6S+0.5Zn in-furrow (of which 20N+4S deep banded at furrow depth), foliar application of ZnCuMn trace elements at late tillering	16mm opening (early-mid June), 26mm post-sowing over 5 weeks, 193mm GSR, (296mm annual)
2019	15-17 May 2019 Scope CL BARLEY at 68kg/ha (30.5 g/1000 grains, 96% germination), Vibrance® + Cruiser®350 treated	28N+12P+6S+1.5Zn deep banded at furrow depth, foliar application of ZnCuMn trace elements at tillering	20mm opening (early May), 35mm post-sowing over 5 weeks, 174mm GSR, (185mm annual)

(Key: N=nitrogen; P=phosphorus; S=sulphur; Zn=zinc; Cu=copper; Mn=manganese)

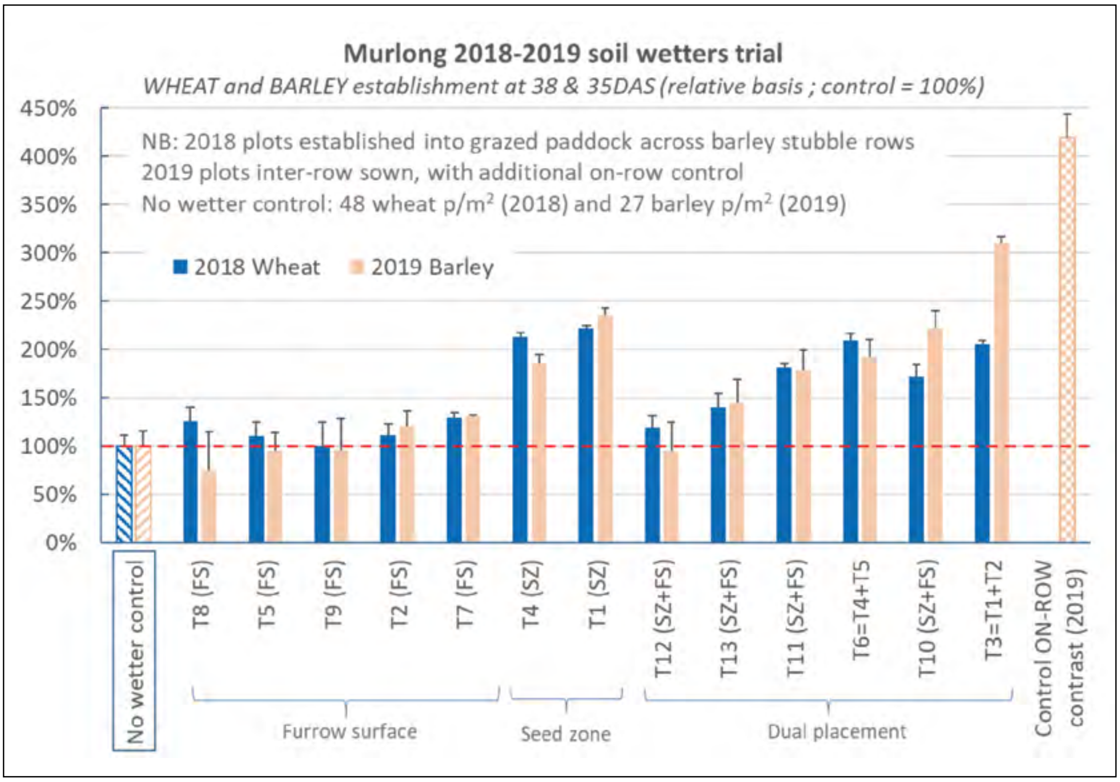

Figure 1. Effect of 13 soil wetter treatments on inter-row sown wheat in 2018 (left bar within treatment) and barley in 2019 (right bar within treatment) crop establishment at five weeks after sowing, relative to a no-wetter control (NB: error bar = 1 standard error of the mean)

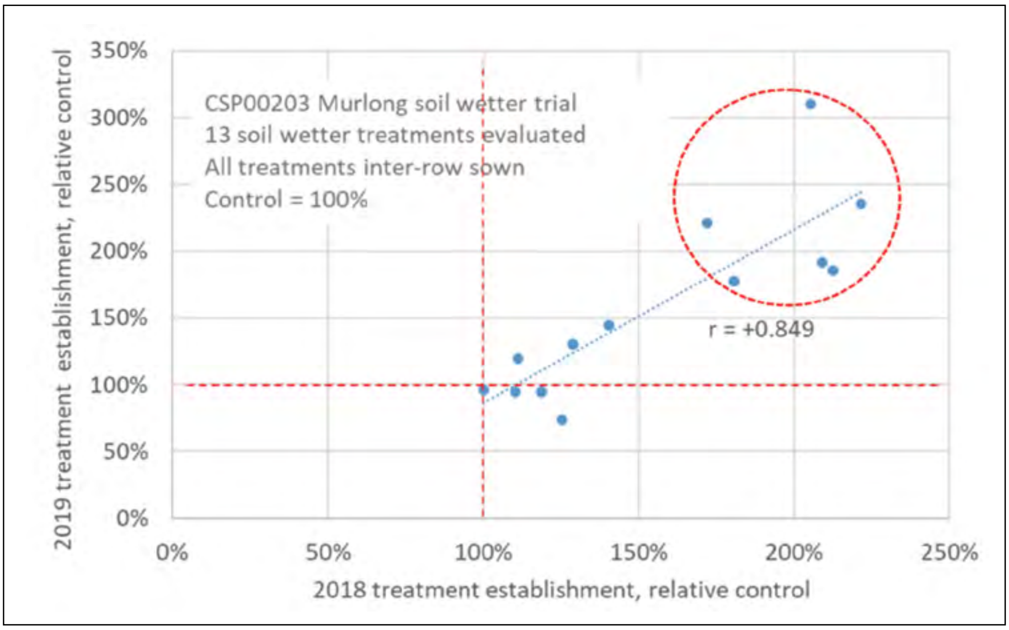

Figure 2. Correlation between 2018 and 2019 soil wetter treatment effect on crop establishment benefits relative to a 100% control (The data suggest a cluster of six products or mixes which consistently performed well at the Murlong site - details in Table 3 within this paper).

Table 3. Synopsis of top six soil wetter treatment* performances: (Snapshot crop establishment ranking at five weeks and grain yield ranking at harvest).

Ranking**	2018		2019	
	Establishment 36DAS	Grain yield	Establishment 35DAS	Grain yield
1st	T1(SZ)	T3=T1(SZ)+T2(FS)	T3=T1(SZ)+T2(FS)	T3=T1(SZ)+T2(FS)
2nd	T4(SZ)	T10(SZ+FS)	T1(SZ)	T1(SZ)
3rd	T6=T4(SZ)+T5(FS)	T4(SZ)	T10(SZ+FS)	T10(SZ+FS)
4th	T3=T1(SZ)+T2(FS)	T1(SZ)	T6=T4(SZ)+T5(FS)	T11(SZ+FS)
5th	T11(SZ+FS)	T11(SZ+FS)	T4(SZ)	T4(SZ)
6th	T10(SZ+FS)	T13(SZ+FS)	T11(SZ+FS)	T6=T4(SZ)+T5(FS)
Range relative control: (control reference)	172-222% (48 p/m^2)	109-121% (1.02 t/ha)	178-310% (27 p/m^2)	145-197% (1.10 t/ha)

**Product details shown in Table 1*

SZ: Seed Zone ; FS: Furrow Surface (30mm wide band spray)

***Some treatments may not be significantly different from others in the ranking*

In 2019, the additional on-row sowing control resulted in crop establishment well above the best soil wetter treatment (+85 plants/m^2), which indicates that access to soil moisture under the stubble row is critical in achieving uniform and fast germination in this non-wetting sand. This trial did not combine on-row sowing + soil wetter, but this was done in a second trial at the same site (see the seeder strategy trial).

Table 3 ranks the top six soil wetter treatments used at Murlong, which were consistent across both years. This indicates these products may prove reliable over many seasons on this particular soil type. Anecdotal evidence suggests that some of the other wetting agents not in the top six at this site have performed well in other areas of the state, so a broad evaluation across other types of water repellent sands is advisable.

Grain yield results (2018-19)

Figure 3 shows the grain yield results for both years. In 2018 (decile 2 GSR), the untreated control had an average wheat grain yield of 1.02t/ha. In the first year, grain yield responses to soil wetter treatments ranged from 0 to 21%, with a maximum response of 0.22t/ha. There was a significant positive correlation ($r = +0.76$, $P<0.01$) between grain yield and plant density at 38 days after sowing (DAS).

The earlier break of the season and slightly drier season in 2019 saw larger barley crop responses to soil wetters, with the grain yield of the inter-row sown control averaging 1.10t/ha. Yield responses to the wetter treatments ranged from +23 to +97%, with a maximum increase of 1.07t/ha. In comparison, the on-row control introduced in 2019 yielded the highest (2.15 times more than the inter-row control), providing a 1.26t/ha grain yield benefit. A strong positive correlation ($r = +0.883$, $P<0.01$) was obtained between grain yield and plant density at 36DAS. The greater yield responses to soil wetters in 2019 may have been influenced by the stability of the water harvesting furrows produced by the seeding system (Figure 4), compared to 2018 when the challenging post-seeding period resulted in early backfilling of the furrows.

Overall, the grain yield responses across all treatments were similar for both years, with a strong positive correlation ($r = +0.815$, $P<0.01$) between the two data sets (Figure 5). This is encouraging and suggests the better treatments may be recommended to growers in this environment.

Table 3 provides a synopsis identifying the top six performers overall for both crop establishment and grain yield for this site. This evaluation was conducted using a precise split seeding system (knife point + independent dual seeding discs) where co-location of the wetter and seed was assured, and a stable wide furrow was created for the surface wetters applied in a 30mm wide band (Figure 4). The lower performance of a less accurate seeding system used in Trial 2 (see seeder strategy trial) suggests seeding system accuracy had a likely impact on securing these results.

Seeder strategy evaluation trial (2019)

Background

In 2019 a dry 11-12cm thick repellent top layer was present in the inter-row zone at seeding, but with consistent moisture below 16-17cm, which was separated by a patchy transition zone. This situation was similar to conditions seen at sowing in 2018.

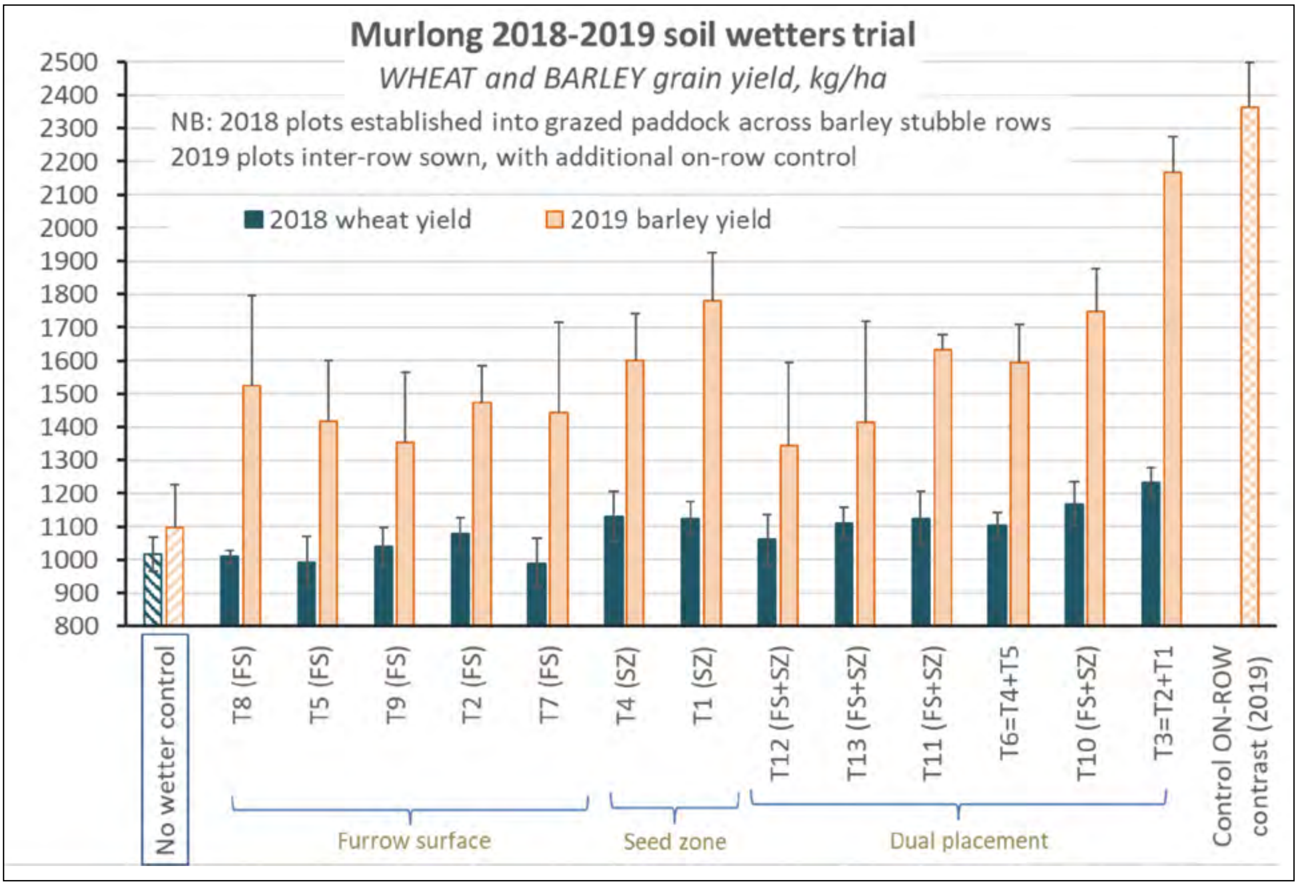

Figure 3. Effect of thirteen soil wetter treatments on grain yield (kg/ha), relative to a no-wetter control (NB: error bar = 1 standard error of the mean).

Figure 4. Left: Precision tine-disc seeding system used in the soil wetter evaluation trial; Right: Stable water-harvesting furrows still apparent at 54 days after sowing during 2019.

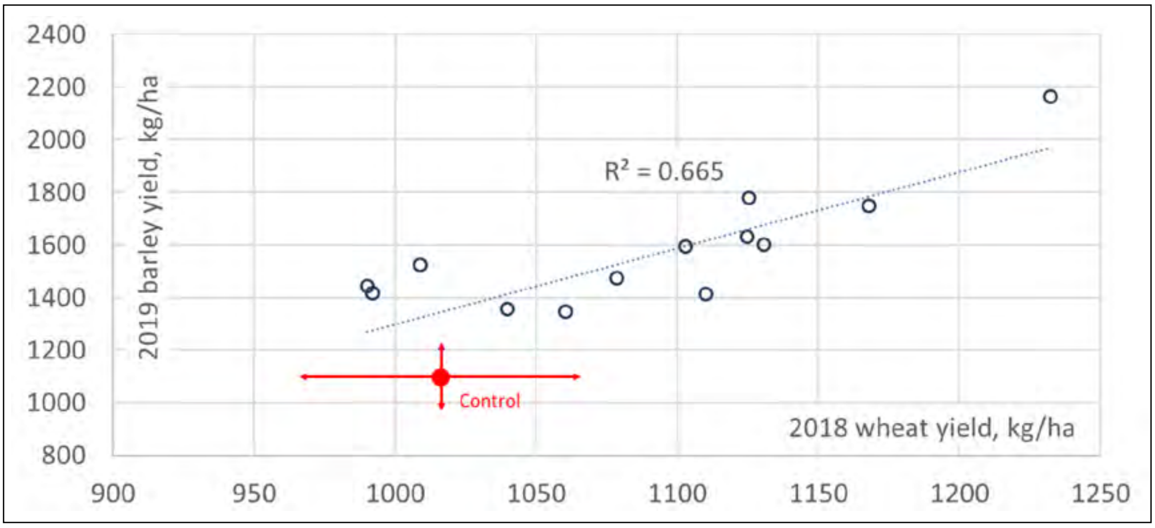

Figure 5. Soil wetter treatment grain yield correlation, relative to control during 2018 and 2019 (NB: arrows indicate ±1 std error of the mean control for both years).

However, there was good moisture 4-5cm below the existing stubble rows in 2019. Measurements quantified 9mm more water stored in the 0-40cm layer in the stubble row zone compared to the inter-row zone, with the majority in the top 25cm layer. This additional soil moisture under the stubble row at sowing was consistent with observations made in a water repellent sand at Lameroo, where 7-9mm of extra water was measured in the 0-40cm layer under the row in 2018 and 2019.

Experimental design

This trial was sown to barley in 2019 into wheat stubble plots established in 2018. Real-Time Kinetic (RTK) AB-line technology ensured high accuracy when sowing row-guided treatments (Table 2). Plot dimensions, sowing and wetter application techniques were the same as the soil wetter evaluation trial, but this trial was sown five days l ater (20 to 22 May 2019). Eleven experimental treatments with four replications were organised in a randomised complete block design, and consisted of:

- Six treatments assessing the impact of a selected seed-zone soil wetter (SACOA SE14® at 3L/ha) under inter-row, edge-row and on-row sowing configurations, at a common 110mm depth of furrow. Different seeding systems were used to achieve edge-row, inter-row and on-row sowing, as shown in Figure 6.
- Two soil wetter treatments assessing the additional impact of a 230mm deep furrow till under inter-row and edge-row sowing.
- Two soil wetter treatments contrasting the impact of an inverted T opener (95mm wide) and of paired-row sowing (75mm spread) at the common 110mm depth of furrow and under on-row sowing configuration.
- One additional contrast to the no-wetter control under inter-row sowing, assessing the impact of a proportion of in-furrow fertiliser; nitrogen (N) and phosphorus (P) (6N+12P) applied with the seeds.

Barley crop establishment

On-row sowing alone increased barley plant density by 39 plants/m^2 over edge-row sowing and by 95 plants/m^2 over inter-row sowing (Figure 7). Edge-row sowing was much more variable than on-row, indicating the sensitivity of this strategy to optimum position which may be a barrier to adoption. Crop establishment with inter-row sowing was 21 plants/m^2 less than the inter-row control in the 2019 soil wetter evaluation trial, which had used a more accurate seeding system (Figure 5 left). The placement of 6N+12P fertiliser with the seed created a small additional loss to an already poor crop establishment in the control (NB: 0.28m row spacing, approximately 10% seedbed utilisation).

The addition of soil wetter increased plant density by 22 and 29 plants/m^2 in the inter-row and edge-row sowing treatments, respectively. In contrast, soil wetters provided no benefits with on-row sowing, where the stubble row soil was already sufficiently moist to achieve good germination. This stands in contrast with a single plot unreplicated

Figure 6. Seeder strategies evaluation trial: Left: Baseline double shoot seeding system used for inter-row and on-row sowing; Right: Side banding double shoot seeding system used for edge-row sowing.

test conducted in the soil wetter evaluation trial combining treatment (T10) with on-row sowing, which produced a total 119 plants/m^2 more than the control, also resulting in the most vigorous and uniform crop growth during the season.

In this case the benefit of the soil wetter (SACOA SE14®) with inter-row sowing was slightly less than that measured in the soil wetter evaluation trial (22 plants/m^2 compared with 36 plants/m^2), which may be due to better seed placement and water harvesting by the better furrows obtained in the soil wetter evaluation trial. This perhaps emphasises the importance of considering a range of furrow management issues when looking at the suitability of soil wetters as a mitigation approach.

Deep furrow till to 230mm had a major positive impact (extra +74 plants/m^2) under inter-row sowing with a soil wetter, whereby the associated deep moisture delving strongly benefited an otherwise dry seed zone. No corresponding benefit occurred with edge-row sowing, where a 26 plants/m^2 decrease was recorded. This may be due to the differences with the side-banding seeding system using a long steep knife point to reach 230mm depth which was probably less effective at lifting moisture up and the extra disturbance may have also reduced the uniformity of seed placement.

Deep furrow till was not evaluated with on-row sowing. However, a positive response to the inverted T opener (+20 plants/m^2) was measured, indicating that the extra quantity of moist furrow from soil lifting and mixing benefited seed germination.

Under on-row sowing with the soil wetter, the paired row system (T25) did not improve crop establishment over the single row equivalent (T27), both using a knife point opener.

Barley grain yield (2019)

Barley grain yields ranged from 0.5t/ha to 2.42t/ha, with inter-row, edge-row and on-row sowing controls yielded 0.59, 1.45 and 2.0t/ha, respectively (Figure 8). All on-row treatments yielded 2t/ha or more, with paired row sowing (T25) yielding 2.42t/ha. The edge-row sowing treatment benefited from the soil wetter (+0.22t/ha) and the 230mm deep-furrow till (+0.24t/ha). Inter-row sowing also benefited from the soil wetter (+0.37t/ha), and considerably more from the 230mm deep furrow till (+1.16 t/ha). The soil wetter had no effect on grain yield when applied on-row where furrow moisture was sufficient to achieve good germination, while a minor grain yield benefit from the inverted T opener was measured (+0.1t/ha).

Overall, grain yield responses to treatments were very highly correlated ($r = +0.950$; $P<0.01$) with plant densities established early in the season, indicating higher plant populations was a key factor driving barley grain yield under the trial conditions. The inter-row control in the soil wetter evaluation trial yielded significantly more (+0.5t/ha) than in this trial, which may be explained by the combined benefits of five days earlier sowing, greater water harvesting and stable furrows, more precise seed placement and soil wetter co-location achieved by the tine-disc seeding system.

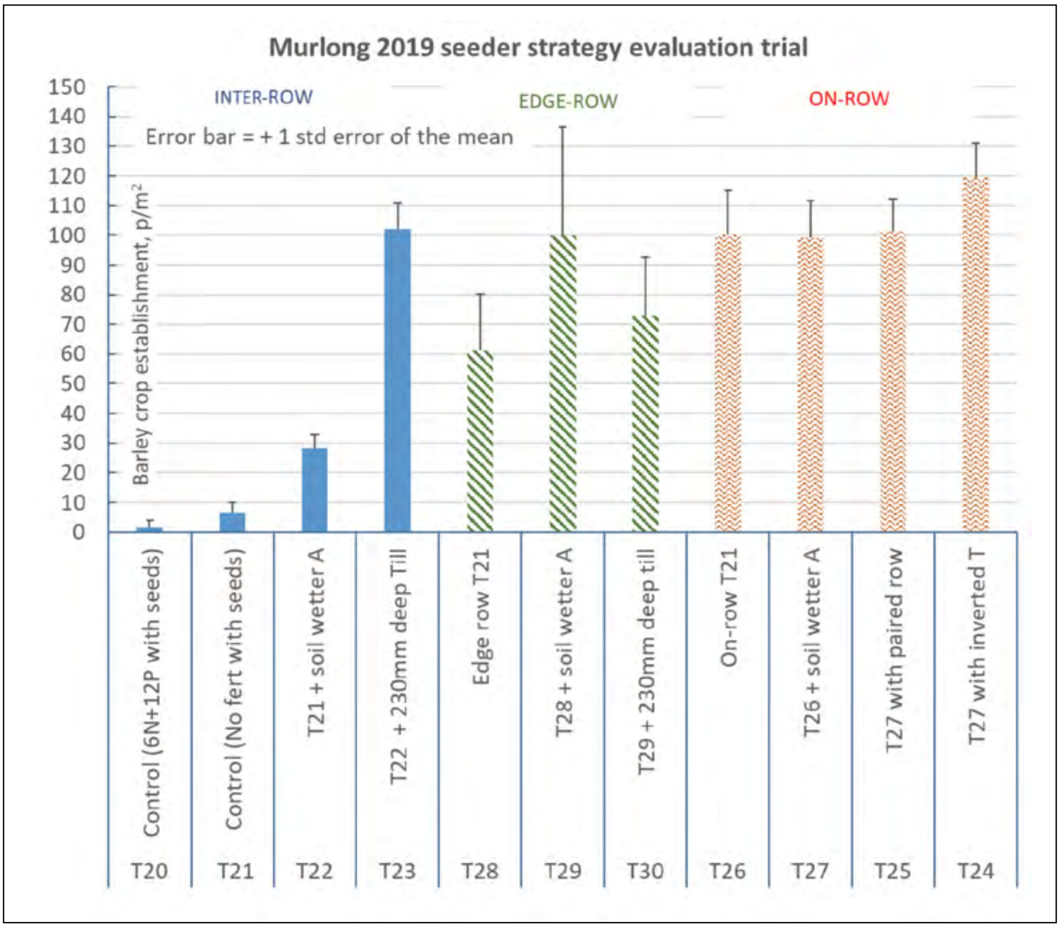

Figure 7. Impacts of various inter-row, edge-row and on-row sowing strategies on crop establishment at five weeks after sowing in barley at Murlong in 2019.

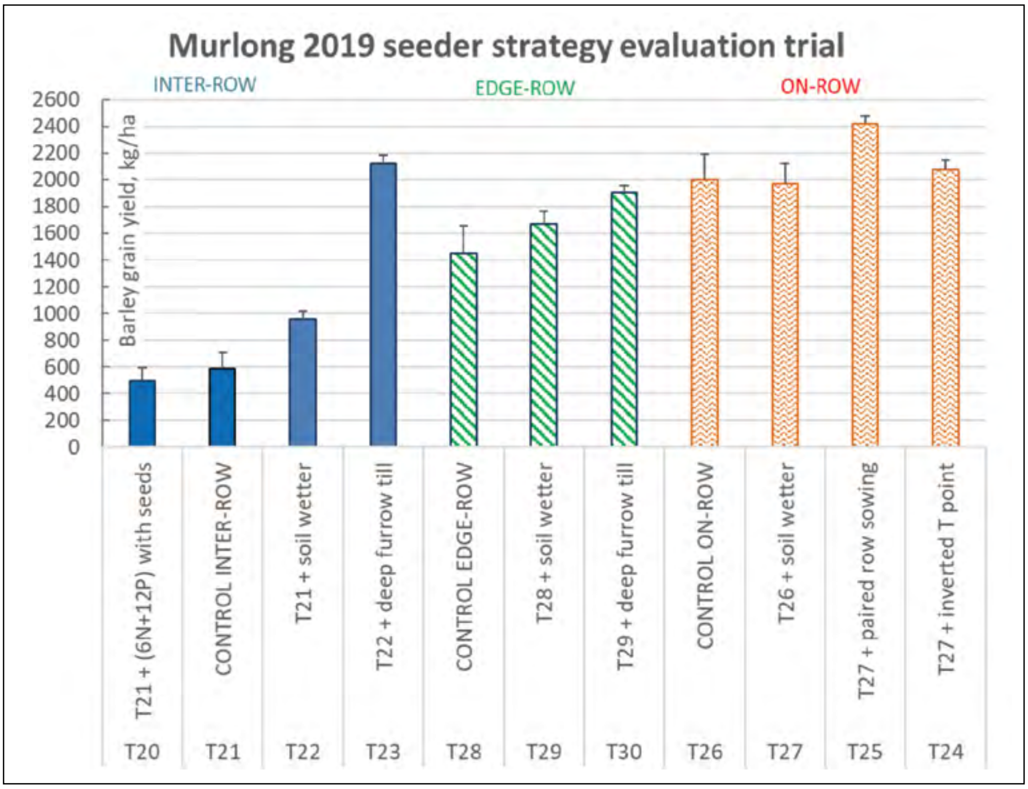

Figure 8. Impacts of various inter-row, edge-row and on-row sowing strategies on barley grain yield at Murlong in 2019.

It is worth noting that, in another project trial conducted in a non-wetting deep sand at Lameroo during 2017-2019, significant benefits of edge-row and on-row sowing on wheat and barley crop establishment and grain yield were also obtained, and significant biomass and grain yield responses to 230mm deep furrow till were also measured (Desbiolles et al., 2019). These reinforce the findings of the trials at Murlong.

Conclusions

Two trials conducted over 2018 and 2019 in a highly water repellent sand and under well below-average rainfall conditions at Murlong SA demonstrated:

- Seeder-based strategies for reducing the impact of water repellence can deliver large benefits on crop establishment and grain yield. The strategies evaluated focussed on accessing stored moisture under existing stubble rows, the deeper moisture found below a dry non-wetting topsoil and maximising in-season rainfall infiltration and use.
- Specific technologies were required to implement these strategies, such as: precision guidance (on-row, edge-row sowing), liquid dispensing (soil wetters), seeding system attributes (adjustable depth of furrow till, stable water-harvesting furrows, precision placement of seed and liquids (in-furrow, paired-row seeding, seed-fertiliser separation).
- Combining technologies can deliver additive benefits to crop establishment and grain yield, thus have the potential to form the basis of best practice. However, adoption of some strategies is likely to be limited if major investments are required by the grain grower. Other complications include the fact that water repellent sands usually occupy a part of large paddocks, and variable tracking accuracy with commercial scale machinery.
- Some of the benefits summarised could be achieved with low-technology options such as upgrading seeders with capability for deep moisture delving and seeding at a small angle to existing stubble rows (without RTK guidance) to maximise the benefits of furrow moisture.
- Additional factors that may influence the cost-effectiveness of a soil wetter include optimising-its furrow location, application rate and water volume per ha. These factors may require further experimentation on a product by product basis.
- Project validation activities in 2020 will work with growers to evaluate which seeder-based strategies can be effectively implemented at farmer scale in different sand environments.

Acknowledgements:

The research undertaken as part of this project has been made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC; the authors would like to thank them for their continued support. The authors would also like to acknowledge the technical assistance from Dean Thiele (UniSA) and Ian Richter (SARDI) for trial implementation data sampling and site management, and also support from the soil wetter suppliers listed in Table 1; Syngenta Australia, Nufarm/CropCare, Incitec Pivot Fertilisers and Wengfu Fertilisers. The broader CSP00203 project team input is also gratefully acknowledged.

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Contact details

Dr Jack Desbiolles
Agricultural Machinery Research and Design Centre,
University of South Australia,
jack.desbiolles@unisa.edu.au
0419 752 295

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Soaks are seeping across the Mallee – what can be done about it?

Chris McDonough.

Insight Extension for Agriculture.

GRDC project code: 9176969

Keywords

- Mallee seeps, normalised difference vegetation index (NDVI), seep management strategies.

Take home messages

- Seeps are rapidly growing as a result of modern farming systems, landscape and seasonal factors.
- Early identification and action are imperative and can be assisted through satellite NDVI imaging.
- Specific management strategies must be applied within recharge, discharge and interception zones to prevent the initial problem of unused freshwater developing into large unproductive saline scalds.

Background

Seeps resulting from localised, perched water tables have become a degradation issue across the cropping zones of SA and Victoria over the last 20 years and have rapidly increased over the last decade. This was highlighted in a recent survey involving 80 landholders across the Mallee region (McDonough, C. 2017). Their emergence is due to a combination of landscape, seasonal and farming system factors, leading to the waterlogging, scalding and salinisation of productive cropping ground in swales, a reduction in paddock efficiencies, and increased machinery risks.

Modern farming improvements toward no-till and continuous cropping have led to near total control of the previously dominant deep-rooted/perennial summer weeds like skeleton weed. This is leading to a greater storage of summer rainfall, which passes through the sandy rises with very low water-holding capacity. Figure 1 demonstrates the resulting formation of perched water tables above areas of impervious clay layers, (such as Blanchetown Clays). Water moves laterally toward lower-lying areas of the paddock and reaches the soil surface where the clay comes close to the surface in mid-slopes, or at the base of swales. This results in waterlogging, capillary rise, evaporation and salinisation over time at the discharge site.

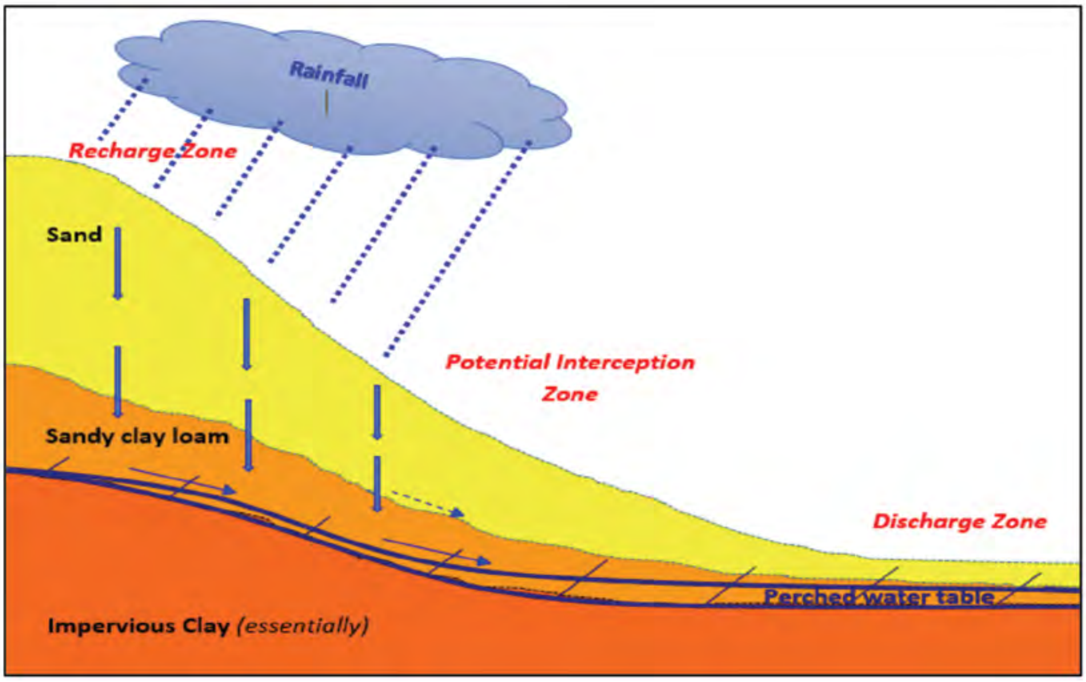

Figure 1. The formation of Mallee dune seeps near Karoonda, SA, (adapted from Hall, J. (2017) pp. 31).

Seeps generally begin as areas inundated with excess fresh water, which will lead to permanent salinisation and land degradation usually within three to four years if no remediation occurs. However, some perched water tables emerge and become quite saline over a longer period of six to ten years. These have only recently displayed surface expression due to changes in agronomic practices during recent years e.g. summer weed management. The key to managing seeps is to identify the problem early, assess and apply appropriate management into the three key zones; recharge, intercept and discharge areas (see Figure 1):

- recharge zones – where most of the excess water is entering the system
- discharge zones – where the problems are developing at the soil surface (often in mid-slope or lower-lying areas)

  potential interception zones – where higher water use strategies can utilise the excess water before it reaches the discharge zones.

This paper presents findings and strategies resulting from several seep monitoring projects conducted over the last five years involving seven sites over six farms. Each site involves the use of moisture probes, piezometers and rain gauges with continuous data loggers. In addition, detailed landscape soil testing and treatment monitoring was used to more accurately assess the dynamics of the catchments, impacts of rainfall events and various management strategies. Growers were directly involved in developing and applying practical strategies to remediate the problems.

This research addresses many important understandings, outcomes and strategies for growers and advisors in dealing with this growing, land-degradation issue. Further results and new approaches will continue to develop as part of a collaborative project between Mallee Sustainable Farming (MSF), the GRDC, the Australian Government's National Landcare Program — Smart Farming Initiative and the SA Murray Darling Basin NRM Board.

Results and discussion

Identifying the problem

There are several key indicators that a seep area may be forming. Initially the crop below a sandy rise, or lower in a catchment area, may produce substantially higher growth or yield, due to accessing the extra moisture from the beginnings of a perched, fresh-water table. This is often more evident through drought years. It is not uncommon to find a distinct saturated layer of soil within the top 1m (sometimes slightly deeper) where this is happening. Ideally, this is the time to commence remedial action, well before it grows into a degraded soil area.

Large crop growth or yield in the developing seep is usually succeeded by ryegrass becoming thick and dominant through a cereal or pasture phase.

Ryegrass tends to be more tolerant and responsive to seep conditions, persisting well into summer with a large seed set which is likely to contain a high percentage of hard seed.

As the seep areas grow it is common to find tractors suddenly sinking to their axels and causing major operational disruptions around these sites. The perched water table gets closer to the surface and bare, scalded areas will start to emerge due to anaerobic soil conditions that are detrimental to most plant growth. Depending on rainfall and landscape factors, surface ponding may occur for periods after rainfall events. This is a critical phase as, particularly over the heat of summer, as bare soil conditions will lead to capillary rise of moisture, evaporation and accumulation of salt at the surface to toxic levels for crop growth.

In recent years it has become evident that whilst wet years (such as 2010/11 and 2016) have resulted in seeps developing in these catchments, it is the drier years, with less plant growth and longer periods of heat and evaporation, that greatly exacerbate the accumulation of surface salt.

Normalised Difference Vegetation Index (NDVI) mapping has grown in prominence in recent years as a way of monitoring crop and pasture growth in precision agricultural management. NDVI images can be obtained from both drones and satellites, and essentially indicate areas of good or poor vegetative growth through spatial colour images. In 2017 a NR SAMDB project (McDonough, C. 2018a) found that strategic use of NDVI imaging can be used to identify both the formation of Mallee seep areas, as well as the potential threat to surrounding areas becoming degraded.

Consultants and growers are using numerous NDVI satellite use programs such as DataFarming and Decipher to identify areas of poor crop growth. The satellite images are convenient, free to access for the levels required, and are becoming a vital tool for seep management. A guide to the use of an NDVI mapping program is available on the MSF Mallee Seeps Website at http://www.malleeseeps.msfp.org.au/.

The key principle to reading NDVI images is to look at cloud free images over multiple dates through October to December. Soils remain wetter-for-longer in perched water table areas, resulting in extended periods of plant growth in spring. This is particularly evident in annual species, which show up clearly in contrast with normal crop areas that have already matured. Sites can then be analysed to assess the impact of seeps on the landscape.

The main advantage of NDVI imagery is that it shows the extent to which bare seep areas are likely to spread if nothing is done. In many cases it has been revealed that an easily visible bare patch of 0.2ha has the potential to quickly impact 5ha or more, due to a clear indication of excessive water and growth in the surrounding area. This provides a strong incentive for growers to take immediate remedial action, rather than observing degradation develop over time.

Viewing images throughout the growing season may also identify areas of poor crop growth which may contribute directly to recharge after rainfall.

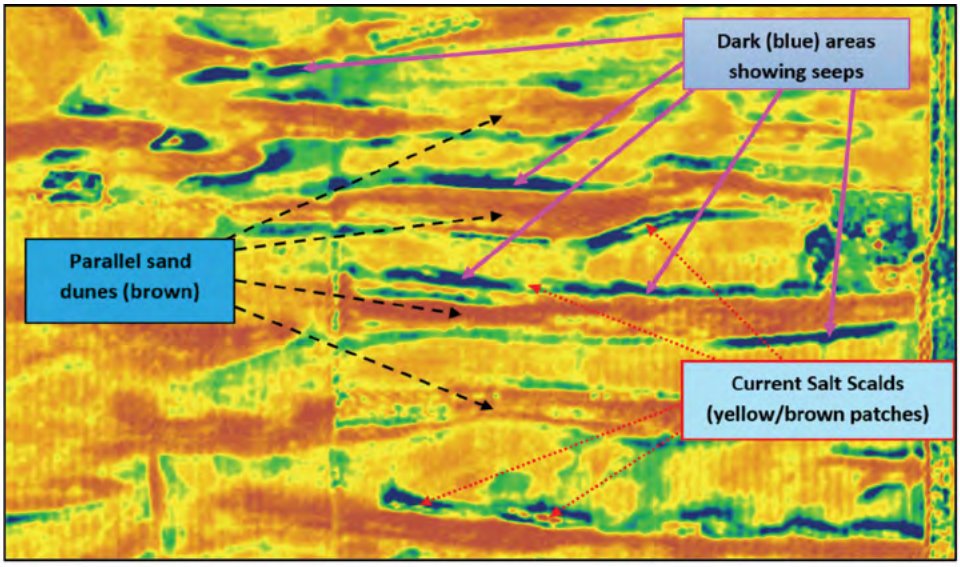

Figure 2. Normalised difference vegetation index (NDVI) map 16 October 2017 showing large areas under threat from seep degradation (dark (blue) shading).

These areas can then be targeted for specific management options. Ground truthing of images, along with local grower knowledge, is vital in ensuring an accurate mapping of potential seep areas and identification of other unrelated factors influencing growth. For example, frost events can lead to crops reshooting late in the season and staying greener, for longer, in low lying areas. Also, summer crops or uncontrolled summer weeds may also present as similar NDVI image colours as seeps, as can trees or other perennial vegetation. Cloud cover and cloud shadows can cause distortions and misinterpretations, which is why it is important to view multiple images over a timeframe.

Management zone strategies

Once seeps and surrounding areas at risk have been identified, it is important to implement management strategies as soon as possible. Ideally, these should be designed to best fit within the grower's systems, with minimal disturbance to normal paddock activities. Some strategies may even lead to higher paddock productivity. However, some 'less convenient' changes may be necessary to protect a greater area of productive land heading towards total degradation and problems.

It is generally a combination of management strategies targeted in each of the recharge, discharge and interception zones is required to stop the spread of seeps and possibly bring the damaged area back into profitable production.

Recharge zone

Site monitoring shows that deep sands (often non-wetting) are the main source of excessive recharge water entering the system. Deep sands have very low water holding capacity and soil fertility and often suffer from compaction that restricts rooting depth. This means that even relatively small rainfall events can quickly pass through the root zones to contribute to the perched water table below.

Figure 3 illustrates the rises in water table at the mid-slope piezometer site between November 2015 and May 2018 at Wynarka, including the wet spring of 2016. The perched water table at this site is below the crop root zone, so any level rise is a direct impact of rainfall contributing recharge from the 60m of sandhill slope above the piezometer. Any fall in levels is likely due to discharge, evaporation or transpiration of the water lower in the system (particularly in the hotter summer periods), or in some cases, a bulge of water moving down the slope after a larger rainfall event. It reveals that a 40mm rainfall event raised the mid-slope water table by over 40cm. Smaller events of 12mm and 15mm during the 2017 growing season led to rises of 15-20cm. Even a sudden 7mm rainfall event in December 2016 caused a rise in water table of 10-15cm.

The key principles for managing the recharge areas is firstly to break any soil compaction, effectively increasing the plant root zone from

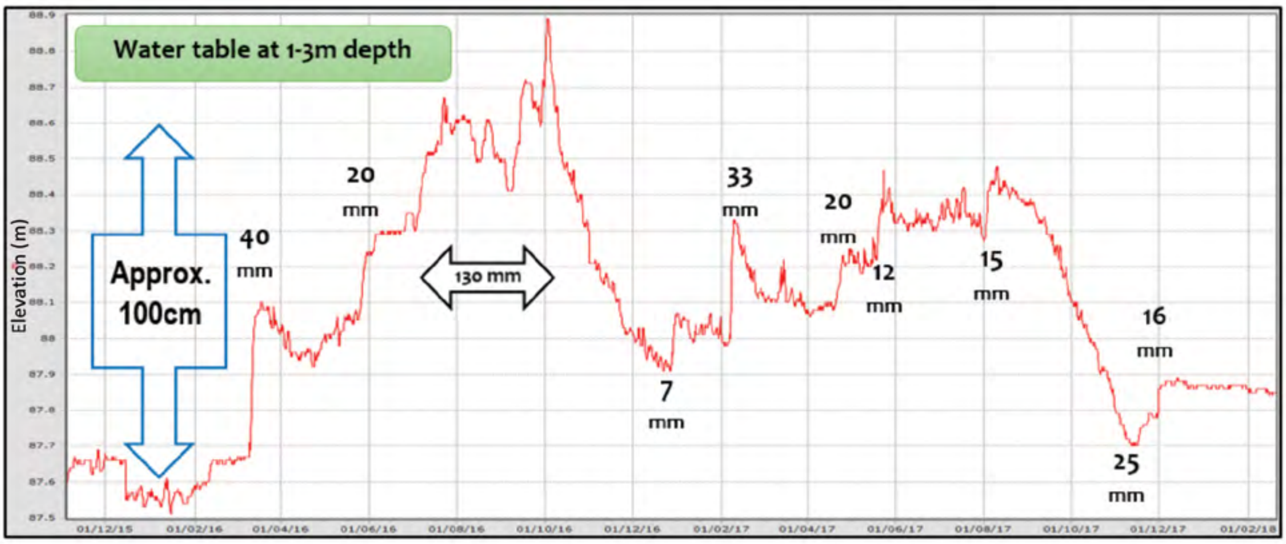

Figure 3. Midslope (RO2 piezometer) water table rises after specific rainfall events (November 2015 to May 2018).

around 20cm depth to down to 150cm (as observed at one site). This allows crops to dry out new rootzones to wilting point with benefits to crop growth and yield, while also creating a larger 'bucket' to fill before it starts contributing to recharge.

Soil amelioration that incorporates clay or nutritious forms of organic matter such as manures into the top 40cm often improves soil water holding capacity within this rooting zone. This was clearly evident at a Karoonda seep monitoring site, where spading in chicken manure more than doubled crop yield over a four-year period. Soil moisture probes showed excellent soil water retention within the 40cm spading depth which was utilised by the crop. This was in direct contrast to the untreated control plot which produced low yields, very little soil moisture used by crops below 30cm depth, and numerous rainfall events contributing to recharge (McDonough 2018b).

Any practical, effective and safe method of achieving soil amelioration through deep ripping, delving, spading, clay-spreading or manure/organic matter/nutrition incorporation will be beneficial in increasing crop water extraction and remediation of sandy recharge zones. Current research is developing more options for growers in this pursuit.

Some growers have decided their deep sands aren't worth cropping and have chosen to establish permanent perennial, deep rooted pasture options such as lucerne or veldt grass. This becomes a viable option for growers with livestock in their systems, providing valuable feed options at critical times. However, care is needed in establishing pastures into adequate soil cover within favourable seasons to reduce the risk of wind erosion. In 2019, a grower at one site chemically fallowed their sandhill until sowing lucerne in August. This avoided a dry period from May to June which coincided with high winds and achieved an excellent stand as the soil warmed up in spring.

Discharge zones

The main principle for discharge zones is to try and maintain living soil cover all year around if possible. This greatly reduces capillary rise of moisture to the surface, and evaporation leading to surface salt accumulation, due to plant roots drawing moisture from deeper in the profile. Bare soil over the summer months and dry seasons, will lead to a rapid deterioration of soils into unproductive, saline scalds. The strategies to best manage this will depend on the development stage of the seep.

When a perched water table is in its early stages when crop yields are often increased, it is important to try and maintain cropping through these areas, without getting machinery bogged. As soon as practical after harvest, sow a summer crop in these zones to dry them out. A mixture of sorghum and millet has been successfully used over three seasons by growers near Mannum. With very little summer rainfall in this period the summer crops grew well where excess moisture was accumulating, but soon died out in the dry sandy soils surrounding the seeps. Summer crops are either cut for hay or harvested prior to seeding the winter crop.

Despite the growth of the summer crop in the discharge area, this did not lead to any yield loss in the following winter crop, as the soil continued to be recharged from higher parts of the landscape. While summer crops do not address the problem at its source, they greatly reduce soil degradation, with minimal impact on the grower within their normal cropping program. This method will only be effective long term if management strategies are also employed to address the excess water emanating from the recharge and interception zones.

For an established scald with high surface salinity or waterlogging affecting crop growth, a perennial salt tolerant pasture such as puccinellia or tall wheat grass should be considered. Ideally these can be sown with airseeders, but where heavy machinery cannot access the seep site, salt tolerant pastures can be established by spreading seed through a rabbit baitlayer and dragging harrows behind a quadbike. It has been reported that puccinellia is suitable for areas with moderately-high to very-high salinity (8 to >32dS/m), and tall wheat grass tolerates low to moderate levels (0-8dS/m, Liddicoat and McFarlane, 2007).

Current demonstrations resulted in good establishment at a variety of salinity levels, including excellent puccinellia establishment on a crystalline salt-covered scald at Wynarka. In some cases, tall wheat grass has established later in the season where puccinellia has not grown, even though they were sown together in the same seed mixture. The salt tolerant annual legume variety Messina has also been tried, but generally struggled on bare scalded sites. In addition, saltbush has been grown and grazed successfully in some seep areas, however it has not survived well in areas with periodic water inundation.

The successful establishment of pastures appears to depend on seasonal factors and more specific soil parameters not considered in previous work at more saline sites. Even slight rises in surface soil levels (i.e. raised beds????) or additions of organic matter have improved survival. Saline seeps are extremely alkaline with soil pH approaching 11 in many cases, which is toxic to most plant growth. This also needs to be considered when selecting salt tolerant species.

The MSF seeps project aims to gain a better understanding of the various mechanisms leading to saline seeps and better management decisions, by measuring soil parameters at different times throughout the seasons across different management practices. Initial success has been shown using a front-end loader to introduce a 10cm layer of sand, straw and manure to bare scalds, which improved establishment of salt tolerant grasses, and even a cereal crop at one site. These sites are being monitored over coming seasons to see if they will deteriorate over time or continue towards greater improvements.

In seep areas that have salt-scalded centres too toxic for crop growth, it is still important to employ these strategies on the less toxic edges to restrict the spread of these scalds.

Interception zone

Below the recharge zone there is a lateral subsoil flow of excess water above the impervious clay layers before it hits the discharge area (Figure 1). This area provides an opportunity to intercept and use this water before it causes problems lower in the landscape. At all monitoring sites the most successful strategy applied within this interception zone has been the strategic establishment of lucerne, with roots that penetrate deep into the perched water table to produce hay or pasture throughout the year. Lucerne effectively exploits large summer rainfall events that normally cause water recharge and is a versatile option that is familiar to growers. Figure 4 shows that each major rainfall event in the lucerne site area was quickly utilised with no evidence of recharge. This contrasts with the continuously cropped side which regularly had 60-70mm more water in the top 100cm soil passing beyond the rootzone. In the extremely wet season of 2016, the midslope lucerne was the only site to experience a reduction in the water table.

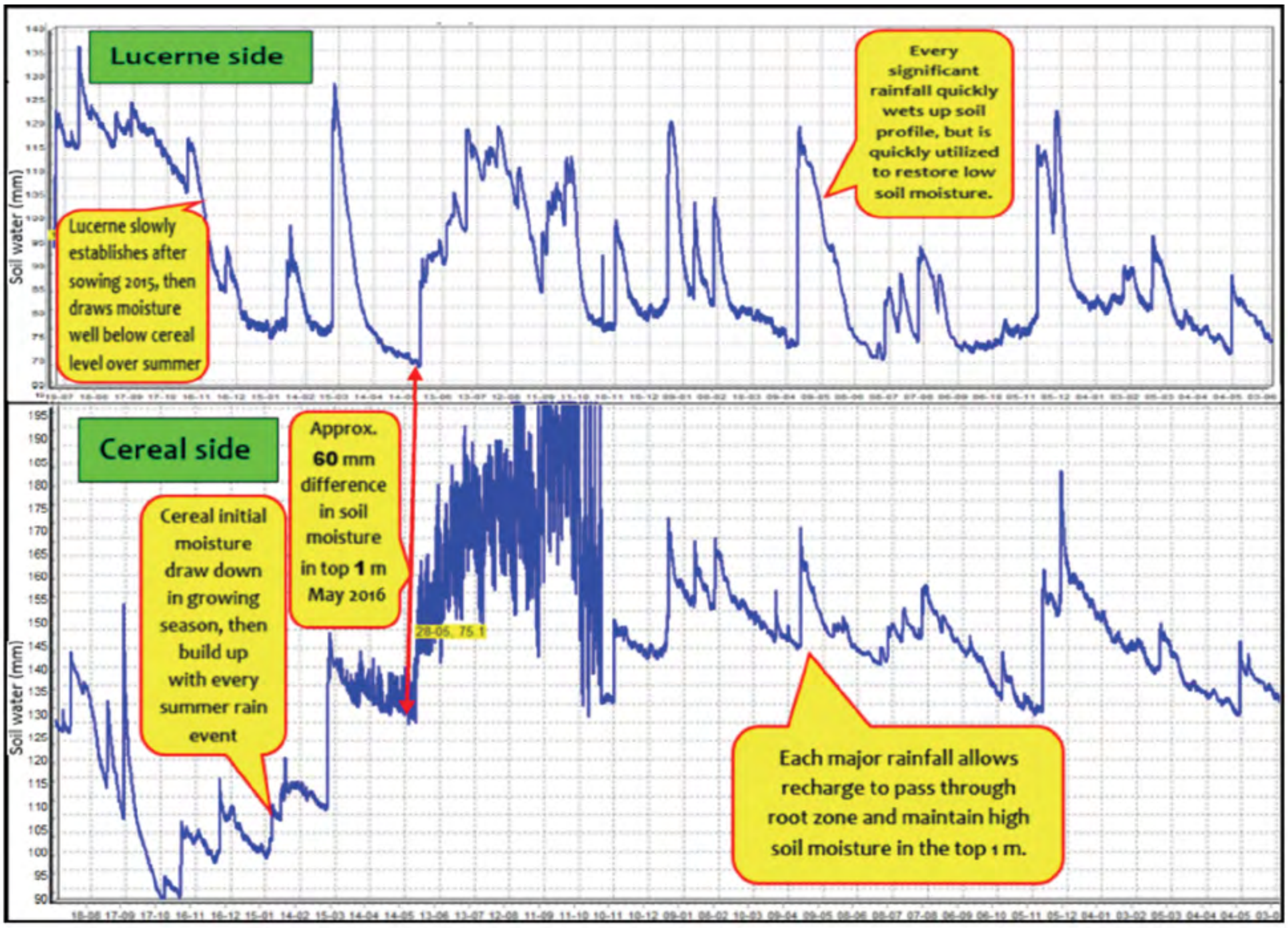

Figure 4. Comparisons of top 1m soil moisture levels in lucerne and cereal treatment areas (July 2015 to May 2018).

Growers are now targeting strips of lucerne (often 30-50m wide) above seep areas to intercept the lateral water flows and benefit from the productive fodder production. Even growers without livestock can boost their profits by selling lucerne hay produced off these areas. Crops can be sown through these lucerne strips, so establishing lucerne in the same direction as cereal sowing may be worthwhile, even if it takes more initial effort. While encompassing these lucerne strips within cropping paddocks may require some compromises, it is still better than losing expanding areas of highly productive land to seeps.

While growers may not wish to plant trees in the middle of cropping paddocks, these may worth considering, particularly where a fence line or laneway already exists. If planting trees close to seeps, it may be worth testing water quality to assess the level of salt tolerance required. Tree guards to protect seedlings from vermin and some early watering to ensure summer survival on deeper non-wetting sandy soils are recommended.

Innovative strategies

The MSF seeps project is currently conducting several trials and demonstrations of innovative management options, including the use of a subsoil extruder to apply organic amendments on deep sands above a seep at Alawoona. This machine applies a manure slurry behind deep ripping tines with minimal increases in erosion risk, unlike spading. Initial improvements in crop production and water use are promising.

Other trials are assessing other subsoil amelioration techniques, alternative pasture species and use of long season varieties to extend the growth period. One site is assessing the practicality of an in-ground sump and pump, just above a seep scald area, to extract water for spraying, livestock or liquid fertiliser application, however, poor water quality is presenting some challenges.

Conclusions

Localised seeps are a growing land degradation issue across cropping zones of southern Australia, due to a combination of landscape and seasonal factors as well as changes associated with modern farming systems. Early detection and treatment is vital to avoid rapid expansion of seep areas.

Various projects in the SA Murray Mallee have identified a number of strategies that provide practical options for growers to apply into the three critical areas of recharge, discharge and intercept zones. New technologies such as NDVI satellite imaging are providing important resources for early detection of developing seeps and the potential threat to grower's paddocks if left unmanaged. Ongoing work is refining these strategies through the MSF Mallee Seeps project to improve water use efficiencies and remediation of these issues.

Acknowledgements

The current research is a collaborative project between Mallee Sustainable Farming, the GRDC, the Australian Government's National Landcare Program — Smart Farming Initiative and the South Australian Murray Darling Basin Natural Resource Management Board. The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

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Contact details

Dr Chris McDonough
Insight Extension for Agriculture
0408 085 393
cmcd.insight@gmail.com

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New pasture opportunities to boost productivity of mixed farms in low/medium rainfall areas

Ross Ballard[1], David Peck[1], Bonnie Flohr[2], Rick Llewellyn[2], Jeff Hill[1], Naomi Scholz[1], Fiona Tomney[1], Jessica Gunn[1], Ian Richter[1], Therese McBeath[2], Bill Davoren[2], Willie Shoobridge[2], Belinda Hackney[3], Michael Moodie[4] and Jake Howie[5].

[1]South Australian Research and Development Institute (SARDI); [2]CSIRO Agriculture and Food, Adelaide; [3]NSW Department of Primary Industries, Wagga Wagga; [4]Frontier Farming Systems, Mildura; [5]formerly SARDI

GRDC project code: 9175959

Keywords

- medic, clover, serradella, biserrula, vetch, nitrogen (N2)-fixation, pasture ley.

Take home messages

- A critical assessment of the regional performance of existing and new pasture legumes over two years has shown that annual medics continue to provide the best pasture option for neutral/ alkaline sandy soils in the Mallee. Common vetch is an alternative option where a sown legume ley of one-year duration is preferred.
- PM-250 strand medic will be released in 2021. For the first time, it combines resistance to the foliar fungal pathogen, powdery mildew, and tolerance to sulfonylurea herbicide residues.
- Aim to maximise pasture legume seed set in the establishment year. Legumes with very high hard seed levels (>90%) are best cropped in the year following establishment.
- Differences in legume production and N_2-fixation have been measured and impacts on wheat production will be measured at multiple sites in 2020.
- Alternative pasture establishment methods (for example; summer sowing) are viable in the Mallee, however, are not suitable for all legume species. Further investigation is needed to define the conditions where summer sowing and twin sowing practices are reliable.

Background

A project, informally known as the Dryland Legume Pasture Systems (DLPS) project, is evaluating a diverse range of annual pasture legumes on mixed farms in the low to medium rainfall zone (<450mm). The DLPS project aims to:

- Provide a critical assessment of the regional performance of existing and new pasture lines.
- Determine if pasture legumes can be established more efficiently.
- Quantify the benefits provided by pasture legumes to crops and livestock.

Legumes close to commercial release, including strand medic line, PM-250⁽ᵇ⁾, existing legumes not widely utilised in south-eastern Australia (for example; serradella, bladder clover and biserrula) as well as undomesticated legumes (for example; Trigonella and Astragalus spp.) are being compared with traditionally grown medics and vetch. Commercial legume species options are shown in Table 1. Legume production, N_2 fixation, nutritive value and ability to regenerate after cropping phases is being measured to understand different legume species adaptation to soil type, so that growers can be confident in their performance and benefits for the crops that follow.

A significant obstacle to the adoption of new pastures legumes is the high cost of pasture seed and difficulty in establishment, particularly in low to medium rainfall areas. A feature of some legumes under investigation is their aerial seeded habit and retention of seed, allowing seed to be grower harvested and re-sown with standard cropping equipment. The project is examining the potential of different pasture legume species to be established more efficiently.

Table 1. Annual pasture legumes. Cultivars (release date and key traits) and indicative adaptation.

Legume and rhizobia	Preferred soil texture	Preferred soil pH_{CaCl}	Cultivars and key traits
Strand medic Group AL inoculant (strain RRI-128)	Sandy loams & loams	>5.8	PM-250ⓓ (2021; PM, HT, BGA, ¥Early, ¥HS70) *Jaguarⓓ (2004; PH, BGA, SAA, Early, HS80) Angel (2000; HT, BGA, SAA, Early, HS80) Herald (1994; BGA, SAA, Early, HS80) Harbinger (1959; Early, HS80)
Disc medic Group AL inoculant (strain RRI-128)	Sands & sandy loams	>5.8	Toreador (2000; BGA, SAA, Early, HS75) Tornafield (1969; Early, HS75)
Barrel medic Group AM inoculant (strain WSM-1115)	Loams & clays	>5.8	*Sultan SU (2015, HT, BGA, Early, HS85) *Cheetahⓓ (2007, PH, BGA, SAA, Early, HS>90) *Jesterⓓ (1998, BGA, SAA, Mid, HS80) *Caliph (1993, BGA, SAA, Early, HS>90)
Spineless burr medic Group AM inoculant (strain WSM-1115)	Loams & clays	>5.2	*Scimitarⓓ (2000; BGA, Mid, HS70) *Cavalierⓓ (2000, Mid, HS80) *Santiago (1988; Early, HS85)
Pink (French) serradella Group S or G inoculant (strain WU425 or WSM471)	Deep sands & sandy loams	4.0 to 7.0	Frano (2021: PH, Mid-late) *Marguritaⓓ (2002, PH, Mid, HS60)
Yellow serradella Group S or G inoculant (strain WU425 or WSM471)	Deep sands & sandy loams	4.0 to 7.0	*Santorini (1995; PH, Mid-late, HS>90)
Biserrula Biserrula 'special' inoculant (strain WSM1497)	Loams	4.5 to 8.0	*Casbah (1997; PH, Early-mid, HS>90)
Sub clover (ssp. subterranean) Group C inoculant (strain WSM1325)	Sandy loams & loams	4.5 to 6.5	Tamminⓓ (2021, Early, HS60)
Rose clover Group C inoculant (strain WSM1325)	Sandy loams & loams	4.5 to 7.0	SARDI Rose (2005; SH, Mid, HS80)
Bladder clover Group C inoculant (strain WSM1325)	Sandy loams & clay loams	5.0 to 8.0	*Bartolo (2007, SH, Mid, HS80)
Vetch Group E or F inoculant (strain SU303 or WSM1455)	Sandy loams & clay loams	5.5 to 8.5	Studenicaⓓ (2021; Early, SH, HS<1) *Volgaⓓ (2013, Early, SH, HS3)

¥ This table provides general information for hard seed levels and maturity time. Environment can significantly affect these traits.
**Seed available through Australian seed marketers. Other cultivars may still be grown and traded between farms.*
Key for traits
PM: resistant to powdery mildew
PH or SH: pod holding or seed able to be collected with cereal harvester
HT: bred to be tolerant of SU herbicide residues; is tolerant of Intervix® residues
BGA: tolerance to blue-green aphids
SAA: tolerance to spotted alfalfa aphids
HS%: approximate level of hard-seed remaining at break of season
Early, mid or late maturity

Results and discussion

A new strand medic

A new strand medic (*Medicago littoralis*) cultivar is scheduled for release in 2021. Currently known as PM-250⦷, it provides a significant advantage over the cultivar Angel, which it will replace. PM-250⦷ combines for the first time, resistance to the foliar fungal pathogen, powdery mildew (Erysiphe trifolii), and tolerance to sulfonylurea (SU) herbicide residues. It is suited to neutral and alkaline sandy loams receiving 275 to 400mm rainfall.

The commercialisation of PM-250⦷ is based on the assessment of its performance at 10 field sites. Across these sites, 34 assessments of dry matter (DM) production and 12 assessments of seed yield were completed. Overall, PM-250⦷ produced 16% more DM than Angel medic and similar high seed yields (Figure 1). Production increases are likely to be greatest, but not limited to, where powdery mildew occurs. Increases of up to 49% and reduced levels of the phytoestrogen, coumestrol have been measured in the presence of powdery mildew. PM-250⦷ is being further assessed in the DLPS project described below.

Casting the net to identify the next opportunity

On 15 June 2018, 30 annual pasture legumes (12 medics, 10 clovers, two serradellas, two lotus, two trigonella, biserrula and astragalus) and two vetches were established at the earliest opportunity after late opening rains in a small plot trial at Lameroo, SA. A similar trial sown at Minnipa SA (27 June 2018) contained an extra vetch, but only seven clovers (Table 2). The Lameroo trial was located on a sandy soil, on the lower-mid dune (pHCa 5.8). The Minnipa trial was located on a uniform area of sandy loam (pH_{Ca} 7.8). Seed was inoculated with the appropriate rhizobia strain and sown at 5, 7.5, 10 or 40kg/ha germinable seed for the small, small-medium, medium and large seeded legumes, respectively. Plots were un-grazed and managed to maximise seed set. In 2019, the legume plots were allowed to regenerate. Plant DM production (2018 and 2019), seed set (2018) and plant regeneration (2019) were measured.

Growing season rainfall was 48% in 2018 and 71% in 2019 of the long-term average at Lameroo (269mm), and 62% in 2018 and 89% in 2019 of the long-term average at Minnipa (242mm).

Performance of commercial legume species

Production in 2018 was limited to less than 1,500kg/ha by seasonal conditions. Even so, differences in the production and seed set of the commercially available legumes were measured (Figure 2). Vetch was most productive (1,098kg DM/ha), followed by barrel medic (820kg DM/ha) and strand medic (688kg DM/ha). Barrel medic was the most productive pasture species at Minnipa, consistent with the recommendation for use on alkaline loam soils. Legumes developed for acidic sands in WA (bladder clover, serradella and biserrula) were less productive.

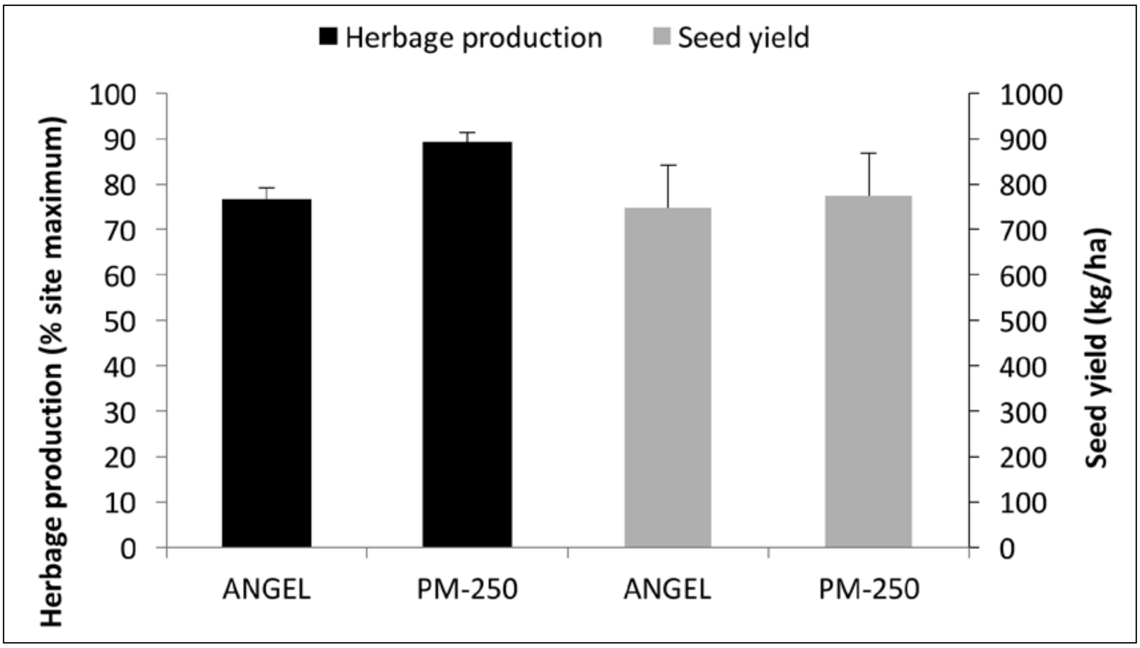

Figure 1. Relative mean herbage production (% site maximum) and seed yield (kg/ha) of PM-250⦷ and Angel strand medics across ten field sites. Includes 34 assessments of dry matter production and 12 seed yield assessments. Bars above columns indicate standard error.

Seed set of the commercial legume species generally exceeded 200kg/ha, with the exception Margurita⁽ᵇ⁾ serradella (129 and 47kg/ha) and vetch at Minnipa (55kg/ha) (Figure 2). The later flowering time of the French serradella likely contributed to its low seed production.

There were large differences in legume regeneration in 2019. Strand and barrel medics regenerated adequately (>200plants/m^2) at both sites, as did rose clover at Lameroo. This provided some flexibility to extend the pasture phase into a second year and consolidate the seed bank (Figure 2). Although biserrula produced a reasonable seed yield in 2018, it regenerated at <20plants/m^2 in 2019. This is due to its high hard seed level (Table 1) and is consistent with the recommendation that this legume be cropped the year following its establishment, to enable some breakdown of hard seed. Vetch, which has been selected to have <5% hard seed to prevent it becoming an in-crop weed, did not regenerate.

DM production of the commercial legumes in 2019 was generally consistent with the results for 2018. The annual medics (developed for alkaline soils) generally produced most winter DM. Rose clover performed better on the sandy loam soil at Lameroo. The WA bred legumes produced less DM, the result of poor regeneration (for example; Casbah) and sub-optimal adaptation to soil type.

Performance of other pasture legume species, cultivars and lines

Ranked performance of all legumes sown at Lameroo and Minnipa is shown in Table 2.

In 2018 when growing season rainfall was less than 200mm, vetches and barrel medics were consistently the most productive species. In the absence of powdery mildew, PM-250⁽ᵇ⁾ strand medic ranked 11th, achieving about 65% of the best legume lines, namely Studenica⁽ᵇ⁾ vetch at Lameroo and Caliph barrel medic at Minnipa. Rose clover and astragalus were the most productive alternative species, even though astragalus is known to have been constrained by poor nodulation.

In 2019, strand medics (Herald, Harbinger, Jaguar⁽ᵇ⁾, PM-250⁽ᵇ⁾ and Pildappa) and the strand

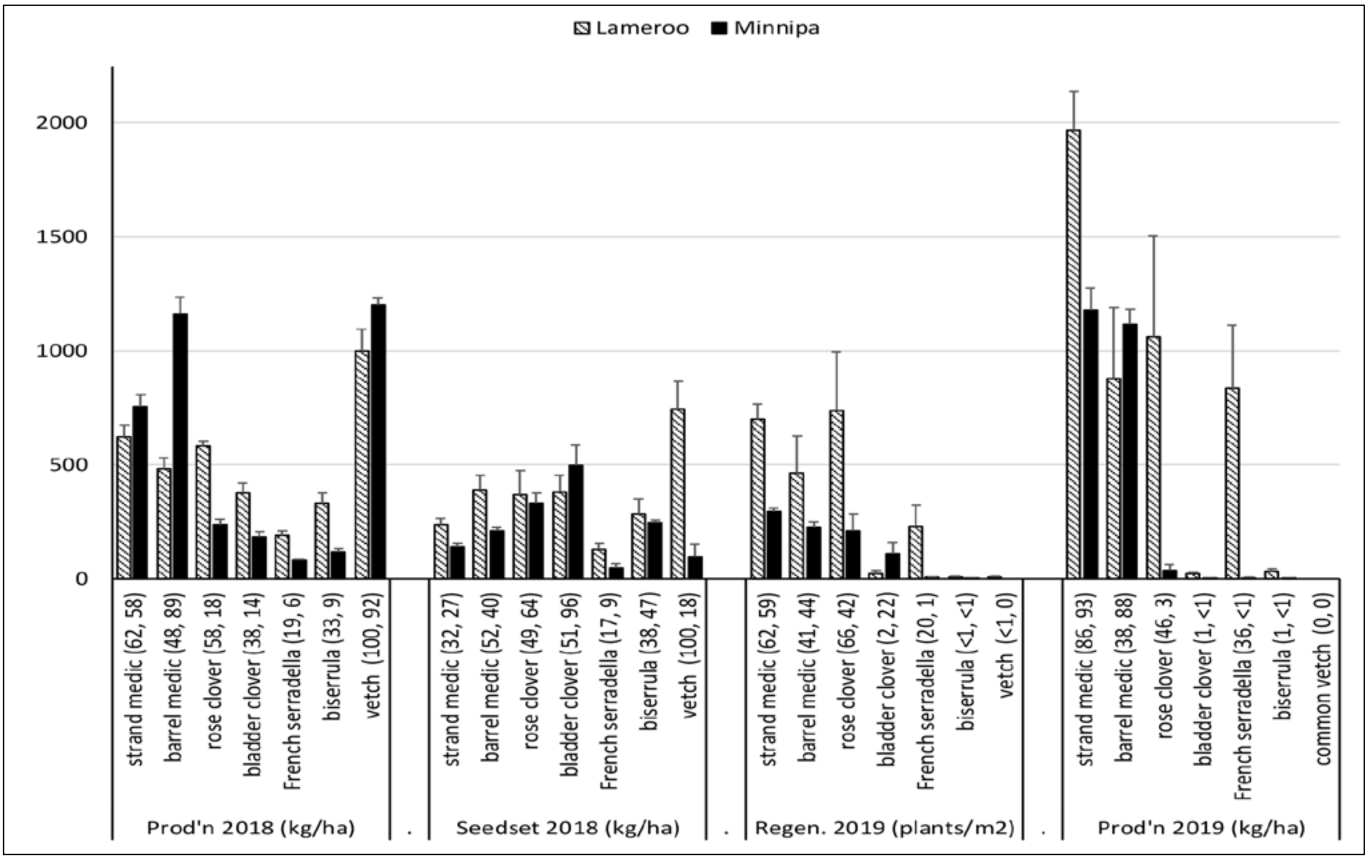

Figure 2. Dry matter production, seed set and regeneration of strand medic (multiple cultivars), barrel medic (multiple cultivars), bladder clover (cv. Bartolo), rose clover (cv. SARDI Rose), French serradella (cv. Margurita⁽ᵇ⁾), biserrula (cv. Casbah) and vetch (cv. Studenicia⁽ᵇ⁾) at Lameroo and Minnipa, SA. Numbers in parentheses accompanying the legume name (e.g. 62, 58) indicate % performance relative to the best legume entry at Lameroo and Minnipa, respectively. Bars above columns indicate standard error.

medic hybrid (Toreador) occupied six of the top ten ranked positions. They established and grew well at both sites, regenerating at >250plants/m^2 and producing more than 1,100kg/ha biomass. Sultan SU was the best barrel medic (rank 9th). Caliph and Cheetah⦶ (best two pasture legumes in 2018), performed less well in 2019, falling to ranks 17 and 20. The best alternative legumes were the early flowering selection of trigonella, burr medic with putative boron tolerance, rose clover and two lotus species. These legumes performed best on the loam soil at Minnipa. Astragalus fell to rank 27 in 2019, due to high hard seed levels.

Legume performance in other environments

A sub-set of the legumes in Table 2 is being tested in other low rainfall environments.

Table 2. Ranked performance by mean of measures and sites, of 33 legumes in 2018 (establishment year) and 2019 (regenerating year). Parentheses show % performance relative to the best legume at Lameroo and Minnipa respectively.

Legume	2018 performance ranking and (% of site maximum)		2019 performance ranking and (% of site maximum)	
Studenica⦶ vetch	1	(100, 95)	30	(06, 14)
Capello⦶ woolly pod vetch	2	(88, 78)	31	(06, 00)
Caliph Barrel medic	3	(65, 100)	17	(26, 80)
Cheetah⦶ barrel medic	4	(63, 87)	20	(13, 75)
Sultan SU barrel medic	5	(74, 74)	9	(50, 86)
Toreador strand × disc hybrid medic	6	(78, 67)	1	(92, 99)
Scimitar⦶ burr medic	7	(63, 78)	5	(58,96)
Harbinger strand medic	8	(68, 70)	3	(86, 87)
Astragalus	9	(58, 76)	27	(03, 59)
Pildappa strand medic	10	(74, 60)	7	(61, 83)
PM-250⦶ strand medic	11	(68, 64)	6	(62, 90)
Volga⦶ vetch*	12	(---, 65)	33	(---, 00)
Boron tolerant line of burr medic	13	(65, 64)	11	(29, 92)
Herald strand medic	14	(68, 54)	2	(100, 86)
SARDI Rose clover	15	(70, 51)	15	(56, 53)
Frontier balansa clover**	16	(58, ---)	23	(34, ---)
Jaguar⦶ strand medic	17	(58, 53)	4	(84, 86)
Zulu arrowleaf clover	18	(59, 50)	26	(01, 66)
Bartolo bladder clover	19	(60, 48)	28	(03, 45)
Helmet clover APG2970**	20	(48, ---)	32	(03, ---)
Sand clover APG83821**	21	(47, ---)	21	(39, ---)
Prima gland clover	22	(61, 30)	19	(29, 71)
Early rose clover APG35623	23	(58, 33)	12	(48, 70)
Early trigonella balansae APG37928	24	(42, 46)	10	(24, 100)
Casbah biserrula	25	(56, 32)	29	(02, 39)
Santorini yellow serradella	26	(48, 30)	25	(07, 62)
Trigonella balansae APG5045	27	(33, 43)	18	(20, 85)
Balansa x nigrescens clover	28	(50, 24)	16	(27, 81)
Lotus arenarius APG37667	29	(39, 31)	13	(29, 85)
Minima⦶ spineless burr medic	30	(38, 31)	8	(43, 95)
Lotus ornithopodioides APG33729	31	(35, 34)	14	(21, 93)
Tammin⦶ sub-clover	32	(44, 12)	22	(31, 44)
Margurita⦶ French serradella	33	(39, 15)	24	(30, 40)

*Only at Minnipa**

*Only at Lameroo***

APG = Australian Pasture Gene-bank number

On a neutral (pHC$_{aCl}$ 7.4) sandy soil in Piangil, Victoria, the production of several legumes established in 2019 exceeded 4,000kg/ha, more than double that measured at the SA sites. Even so, relative legume production at Piangil was significantly correlated (n=19, P<0.01, R^2 = 0.57) with production in the establishment year (2018) at Minnipa (Table 2). Studenica$^{\phi}$ vetch (4,880kg/ha) and the barrel medics (Caliph, Sultan SU and Cheetah$^{\phi}$) were most productive (≥3 500kg/ha). Margurita$^{\phi}$, Santorini serradellas and biserrula produced less than 1 ,000kg/ha DM at Piangil.

In NSW, legume performance has been different on the acidic red loams at Kikoira (pH$_{CaCl}$ 4.9) and Condobolin (pH$_{CaCl}$ 5.1). In trials established in 2018, biserrula was the outstanding species across both sites. It was the only legume to survive extreme drought conditions at Condobolin. Biserrula produced more than 120kg/ha seed at Kikoira with approximately one-third of that produced prior to the end of October. Other species including Margurita$^{\phi}$, Santorini serradella and arrowleaf clover also produced useful quantities of herbage (around 1,200kg/ha) under severe drought at Kikoira but had not commenced reproductive growth by late October. Whilst they managed some seed set after 53mm rain in November, had this not occurred, these later maturing species may have failed to produce seed. Both Casbah biserrula and Lotus ornithopodioides regenerated well in 2019.

Pastures in rotations

A cropping systems experiment at Lameroo is evaluating the duration of pasture benefits and pasture regeneration after cropping, using a range of legume species grown for two years, (PM-250$^{\phi}$ medic, Margurita$^{\phi}$ serradella, SARDI rose clover and Trigonella balansae), or one year (PM-250$^{\phi}$ medic, and Margurita$^{\phi}$ serradella). Crop benefits will be measured in 2020 after the one or two-year pasture phase, when the pasture systems will be compared against three control treatments; vetch-cereal, pea-cereal and continuous cereal. Similar experiments (not reported here) are being undertaken at Piangil in Victoria, and at Harden and Uranquinty in NSW.

Growing season rainfall at Lameroo in 2018 was 140mm. In 2018 pastures were established primarily to set seed for regeneration in 2019. Seed set was adequate for each species and was estimated to range between 190-320kg/ha. PM-250$^{\phi}$ medic produced the greatest DM up until late September (1.8t/ha, Table 3), however late rains in October/November (33mm) may have supported some further growth and seed set of the later flowering species, particularly serradella.

After the first season, soil mineral nitrogen was the parameter that varied most. Measured in early 2019 it reflected N fixed by the pasture species in 2018 (Table 3), medic>rose clover>trigonella>serradella>wheat. Some serradella plants were pale yellow and because nodulation in adjacent plots was observed to be less than ideal, we speculate that sub-optimal nodulation was probably limiting in the system experiment. While there were significant differences in nutritive values of metabolisable energy (ME), digestibility and crude protein, they were not large.

In 2019, regenerating pasture treatments had higher plant establishment than plots sown in autumn, namely PM-250$^{\phi}$ and Margurita$^{\phi}$. PM-250$^{\phi}$ density in the regenerating plots was five times (232 versus 38plants/m^2) and Margurita$^{\phi}$ density seven times (373 versus 47plants/m^2) levels in the sown plots. Rose clover and trigonella regenerated at 304 and 151plants/m^2, respectively. These differences affected production (Figure 3).

Table 3. Summary of N_2 fixation and biomass production, metabolisable energy (ME), digestibility and crude protein at peak biomass from 2018 sampling, and soil mineral nitrogen and moisture from 0-100cm from soil cores taken in May 2019 at Lameroo, SA.

Treatment 2018	N_2 fixation (kg/ha)	Dry matter at peak biomass (t/ha)	ME (MJ)	Digestibility (%)	Crude protein (%)	Soil moisture (mm)	Soil mineral N kg/ha (0-100 cm)
Wheat	--	3.2	--	--	--	105	49
Serradella (Margurita$^{\phi}$)	6	1.2	8.8	61	12	96	54
Trigonella balansae (5045)	14	0.8	9.4	65	14	108	55
Rose Clover (SARDI)	20	1.1	9.2	63	13	93	65
Medic (PM250$^{\phi}$)	24	1.8	9.1	63	13	108	70
P-value	<.001	<.001	<.001	<.001	<.001	NS	0.006
LSD (5%)	5	0.57	0.1	0.8	0.6	--	12

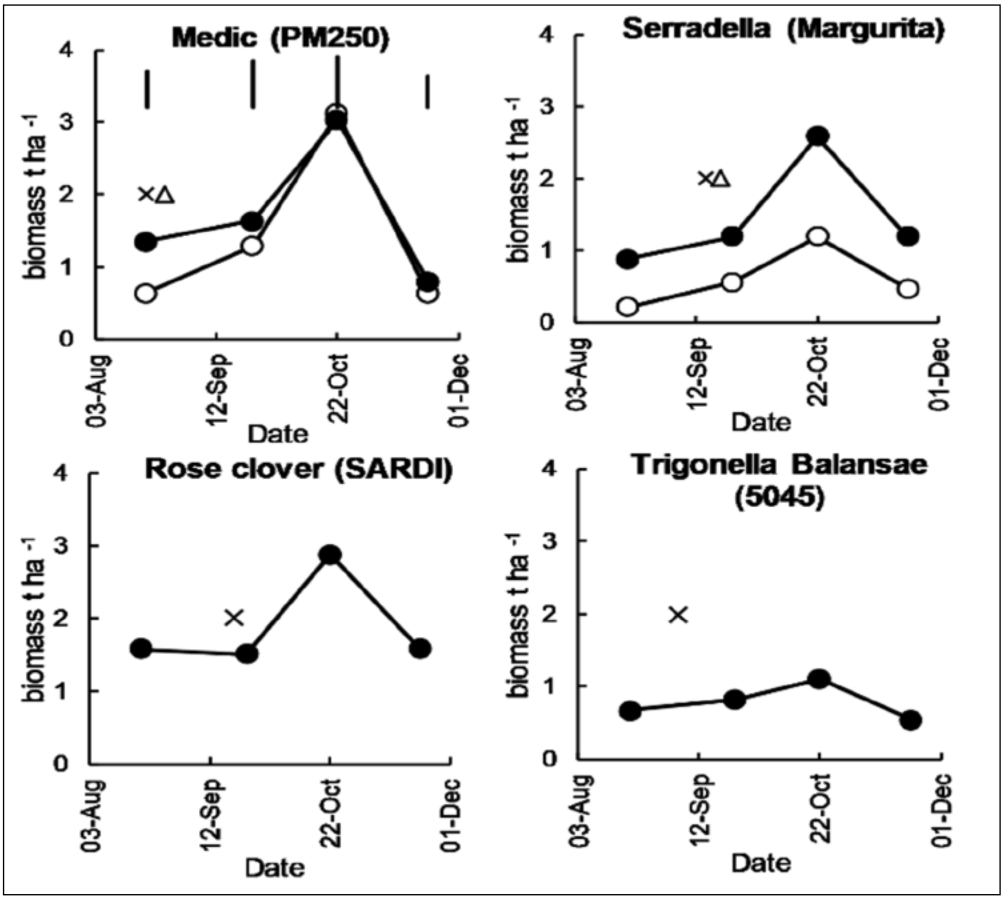

Figure 3. Biomass in Lameroo 2019 for pasture species either sown on 14 May 2019 (O) or regeneration from seed set in 2018 (●). Solid vertical line in the Medic figure is LSD (5%) at each biomass measurement, and markers are the date that first flowers were observed in autumn sown treatments (Δ) and regenerating treatments (×).

Growing season rainfall (April to October) in 2019 at Lameroo was 205mm. All treatments produced most DM in mid-October when all species were podding (Figure 3). There was no significant difference at the mid-October cut between autumn sown medic, regenerating medic, regenerating rose clover and regenerating serradella. The extent to which lower production of trigonella and autumn sown serradella effect crop production, will be measured in 2020.

Pasture establishment in the Mallee

Alternative pasture establishment methods were evaluated at Waikerie, SA, and Piangil, Vic, in 2019 using a range of annual pasture legumes, including some not commonly grown in the Mallee region. Indicative sowing rates are shown in Table 4. Establishment methods evaluated were:

- Twin-sown, where 'hard' pasture seed/pod was sown with wheat seed in 2018 for pasture establishment in 2019.
- Summer-sown (February), where 'hard' seed/pod was sown in summer and softens to establish on the autumn break.
- Autumn-sown (control treatment), where 'soft' germinable seed is sown on the break of the season.

In 2019 at Waikerie, the seasonal break occurred on 9 May with 20mm rainfall. Rainfall prior to 9 May was 22mm. In Piangil, the seasonal break occurred on 2 May with 19mm rainfall, and rainfall prior to 2 May of 17mm. At both sites, all establishment treatments emerged within two weeks of each other. Sowing method had a significant effect on plant density at both sites (Figures 4A and 4B). The targeted population for sown pastures is typically 150-200plants/m^2.

Seedling establishment

At Waikerie, mean plant density across all legumes were; autumn-sown 132plants/m^2, twin-sown 64plants/m^2 and summer-sown 159plants m^2

Table 4. Indicative rates of sown pod or seed (kg/ha) and equivalent amount (kg/ha) of viable hard seed sown in twin- and summer-sown treatments; and rate of germinable seed (kg/ha) in the autumn sown treatment.		
Legume	Twin and summer-sown treatments (kg/ha)	Autumn sown treatment (kg/ha)
PM-250⁽ᵇ⁾ medic	28 as pod; providing 7kg/ha viable hard seed	5
Trigonella balansae	12 as seed; providing 6kg/ha viable hard seed	4
Bladder clover	18 as seed; providing 16kg/ha viable hard seed	7
Rose clover	44 as seed; providing 11kg/ha viable hard seed	6
Biserrula	8 as seed; providing 4kg/ha viable hard seed	5
French serradella	30 as pod; providing 8kg/ha viable hard seed	6
Gland clover	10 as seed, hard seed not measured	5

(Figure 4). In Piangil, mean plant density across all legumes were; autumn-sown 73plants/m^2, twin-sown 42plants/m^2 and summer-sown 60plants/m^2. An observation relevant to the lower establishment in twin-sown plots, is that seed may have been buried too deep as a result of collapse of furrows and sand movement over the 2018/19 summer period.

At both sites, serradella had the highest establishment for all twin- and summer-sown treatments compared to other species but established best when summer-sown. Medic densities were greatest when autumn sown.

Production

Treatment differences in dry matter production were measured at Waikerie, despite production being limited by low rainfall (Figure 5). Production was greatest for summer and autumn-sown PM-250⁽ᵇ⁾ medic. Although serradella and rose clover produced more DM when summer-sown, their overall production was lower, suggesting they are less well adapted to Mallee soils. Dry matter was lowest in the twin-sown treatment, consistent with lower plant numbers.

At Piangil, twin-sown treatments performed better than at Waikerie (Figure 6). Higher plant density did not necessarily result in higher biomass production. For example, there was higher plant density in summer-sown serradella, but twin-sown treatments produced more biomass. Medic produced similar biomass in the autumn- and twin-sown treatments. Production of trigonella and gland clover was generally low, indicating they are less adapted to the soil type.

Results from 2019 indicate that twin and summer-sowing may be a viable establishment method for the Mallee region, however it is not suitable for all legume species. In both environments, Margurita⁽ᵇ⁾ serradella gained the most advantage from the alternative establishment methods. Results for PM-250⁽ᵇ⁾ medic were inconsistent, with twin-sowing inferior at Waikerie and summer-sowing inferior at Piangil. Given that all treatments emerged on similar

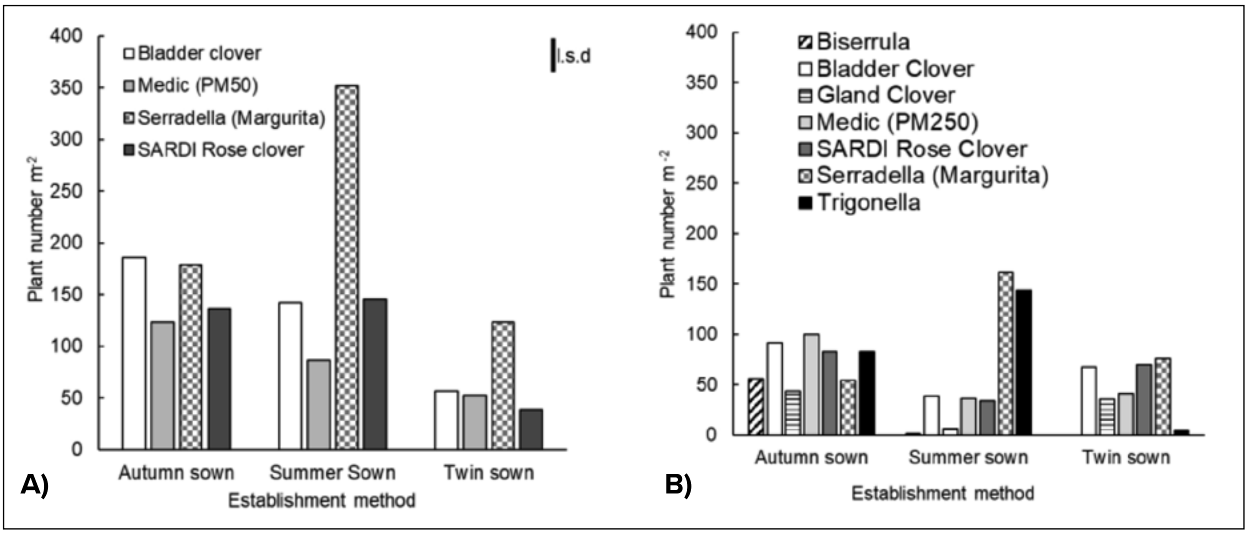

Figure 4. Plant establishment resulting from different establishment methods at A) Waikerie on 25 June 2019 and B) Piangil on 5 June 2019.

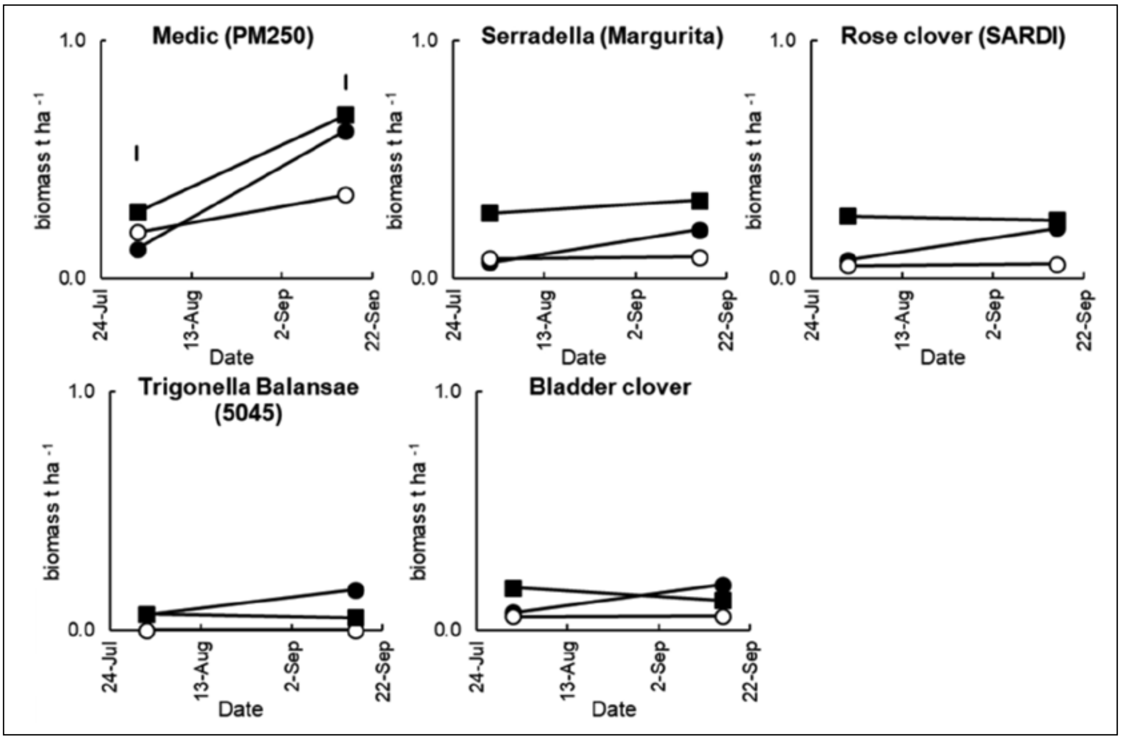

Figure 5. Biomass production in 2019 at Waikerie in the establishment treatments; autumn-sowing (●), twin-sowing (O) and summer-sowing (■).

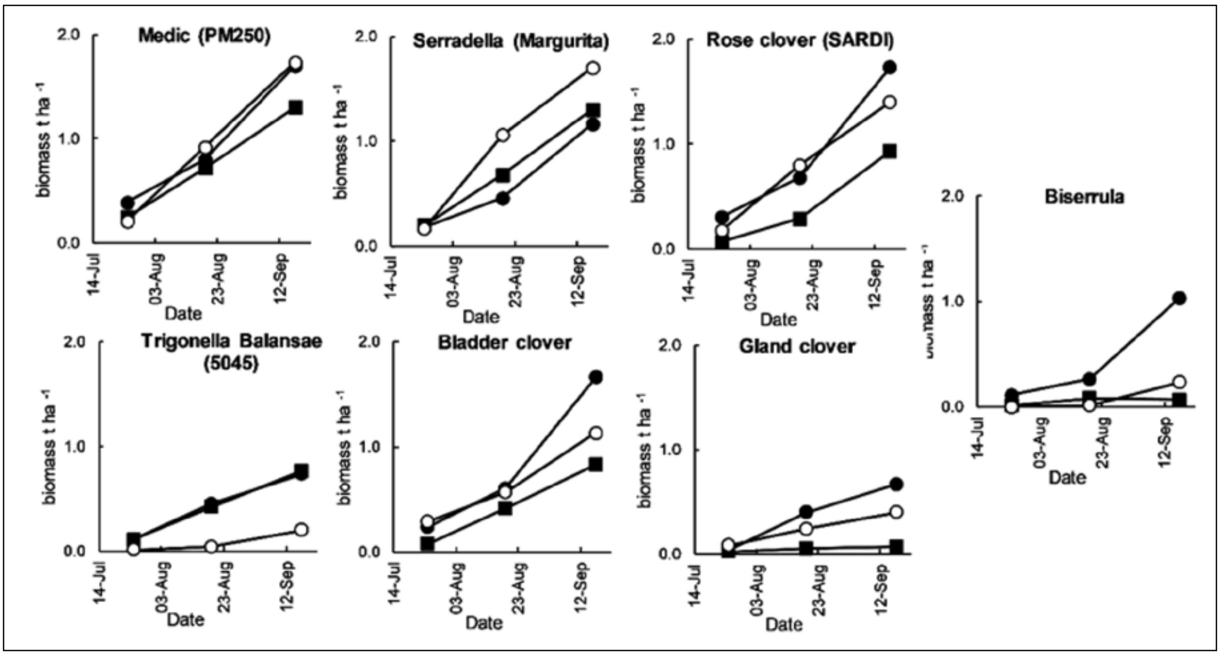

Figure 6. Biomass production in 2019 at Piangil in the establishment treatments; autumn-sowing (●), twin-sowing (O) and summer-sowing (■).

dates, and there was very little summer rainfall in 2019, further exploration of the methods are required under a range of growing seasons such that risks and/or benefits associated with earlier seasonal or false breaks can be evaluated.

Weed management

Weed control is an important consideration with twin and summer-sowing. At Waikerie there were significantly greater numbers of broad leaf weeds in the twin and summer-sown plots, compared to autumn-sown plots. Weed DM for the treatments was; twin-sowing 500kg/ha, summer-sowing 440kg/ha and autumn-sowing 360kg/ha (P<.001). Autumn-sown plots received a knock-down spray at sowing, while twin and summer-sown plots did not. Twin and summer-sowing methods should only be considered for paddocks with low weed levels.

Seasonal analysis

To understand the likely suitability of summer and twin-sowing in other low rainfall environments, historic climate records (1970 to 2018) were analysed to reveal 25th to 75th percentiles of when the seasonal break occurred. Using the APSIM model (version 7.10) and historic weather records, the approach of Unkovich (2010) was used to estimate the mean break of a season, that is, when over a seven-day period, accumulated rainfall exceeds accumulated pan evaporation. An additional rule was added, which was that soil temperature should be below 20°C. Figure 7 shows 'box and whisker' plots for six locations, and the probability of a break occurring on 25 April.

The analysis revealed that Lameroo and Condobolin have the earliest median break, and higher probability of a break occurring before 25 April, while Minnipa and Waikerie typically have the latest seasonal break. In environments with a greater probability of an early seasonal break, summer-sowing will likely be more beneficial — soil conditions are warmer, and a longer growing season can be exploited more often. In environments where the seasonal break is often later, there is greater risk of seed losses or burial, rhizobia death and exposure to pathogens. Establishment following autumn, summer and twin-sowing methods will also be measured in Lameroo in 2020.

Conclusion

Pasture legume production, regeneration and persistence is determined by multiple factors (Nichols et al. 2012), including adaptation to soil type (texture and pH), capacity to set seed (early flowering desirable in low rainfall areas) and hard seed levels that allow regeneration and persistence through the cropping sequence.

On neutral/alkaline soils in the low rainfall regions, annual medics continue to provide the best option where a self-regenerating pasture is preferred. The SA trials reported in this paper, reiterate strand and disc medics as the best pasture legume choice for the lighter sands and barrel medics for the heavier loams in the Mallee. PM-250⁽ᴰ⁾ strand medic is scheduled for release in 2021 and has demonstrated a production benefit of 16% over the cultivar Angel which it will replace. In addition, larger benefits are expected where powdery mildew and herbicide residues are present. Cohorts of disc, strand and burr medic have been developed and are being assessed by the DLPS project.

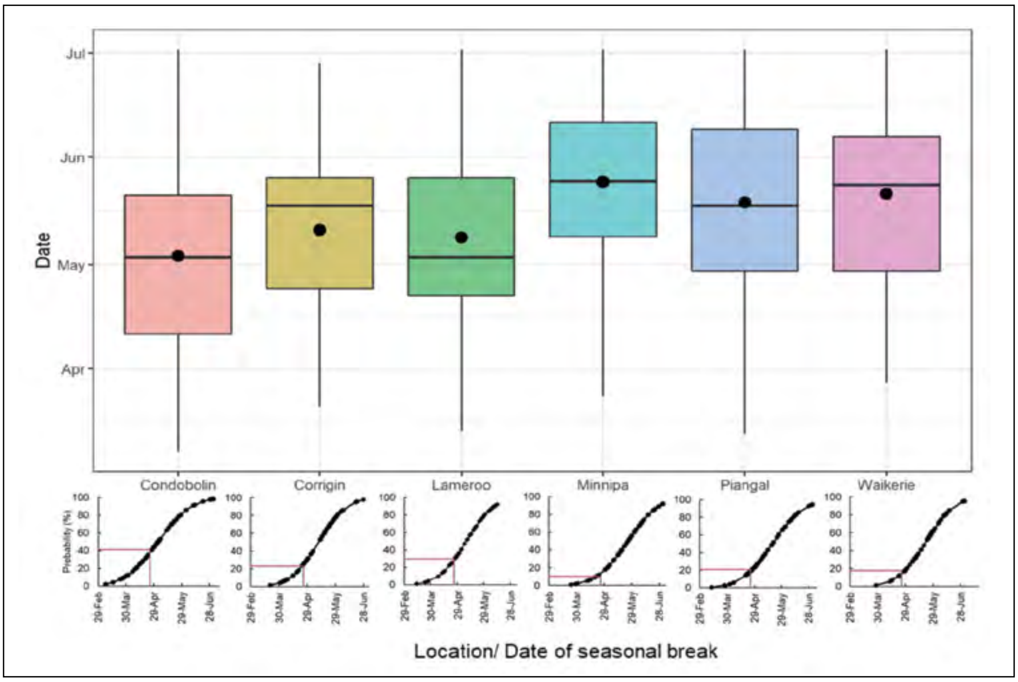

Figure 7. 'Box and whisker' plots showing 25th to 75th percentiles of when the autumn break occurred in historic data set 1970-2018, using Unkovich (2010), and the probability of the seasonal break occurring on 25 April.

Legumes developed for WA soils and farming systems (biserrula, serradella and bladder clover) have so far performed less well on Mallee soils in SA but have performed well on other soil types. Specifically, biserrula has grown and regenerated well on acidic red sands in NSW. Pasture legume species other than medics have on occasion shown promise in the Mallee but have neither been outstanding or consistent. If trialling the 'alternative' species, it suggested that small areas are initially sown. Common vetch may be a better option where a sown legume ley of one year is preferred, because of its ability to provide early production and options for late weed control. A new vetch cultivar (Studenica⁽ᵗʰ⁾), scheduled for release in 2021, has performed well in the DLPS trials.

The aim in the establishment year of legume pastures should be to maximise seed set, and if done well the resultant seed bank (25 times what is sown) will support pasture regeneration for many years. Alternative establishment methods have demonstrated potential in the Mallee but are not suitable for all legume species. Margurita⁽ᵗʰ⁾ serradella gained greatest advantage from the alternative establishment methods. Results for PM-250⁽ᵗʰ⁾ medic were inconsistent but showed some promise and are worthy of further investigation given their potential to provide growers with greater sowing flexibility and reduce seed costs. Differences in N_2 fixation by the different legumes have been measured. The impact of this and other pasture impacts on wheat production will be measured in 2020.

The studies reported in this paper have focussed on legume monocultures. Legume mixtures such as medic and vetch in the establishment year may be useful to achieving more consistent production through the season and across variable soils.

Acknowledgements

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We thank the Pocock and Schmidt families for hosting trials at Lameroo and Waikerie, SA.

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Contact details

Ross Ballard
SARDI Soil Biology and Diagnostics
GPO Box 397, Adelaide SA 5001
+61 8 8429 2217
ross.ballard@sa.gov.au

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Notes

TOP 10 TIPS

FOR REDUCING SPRAY DRIFT

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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.

THE 2017-2020 GRDC SOUTHERN REGIONAL PANEL

JANUARY 2020

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CHAIR - JOHN BENNETT

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

M 0429 919 223 **E** john.bennett5@bigpond.com

DEPUTY CHAIR - MIKE MCLAUGHLIN

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

M 0434 765 574
E michael.mclaughlin@adelaide.edu.au

PETER KUHLMANN

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

M 0428 258 032 **E** mudabie@bigpond.com

JON MIDWOOD

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

M 0400 666 434 **E** jmidwood@sfs.org.au

FIONA MARSHALL

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

M 0427 324 123 **E** redbank615@bigpond.com

LOUISE FLOHR

Lou is a farmer based at Lameroo in the Southern Mallee of South Australia. Along with her parents and partner, she runs a mixed farming enterprise including export oaten hay, wheat, barley a variety of legumes and a self-replacing Merino flock. After graduating Lou spent 3 years as a sales agronomist where she gained valuable on-farm experience about the retail industry and then returned to her home town of Lameroo. She started her own consultancy business three years ago and is passionate about upskilling women working on farms.

M 0429 083 927 **E** flohrlouise@gmail.com

RICHARD MURDOCH

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

M 0419 842 419 **E** tuckokcowie@internode.on.net

MICHAEL CHILVERS

Michael runs a collaborative family farming enterprise at Nile in the Northern Midlands of Tasmania (with property also in northern NSW) having transitioned the business from a dryland grazing enterprise to an intensive mixed farming enterprise. He has a broad range of experience from resource management, strategic planning and risk profiling to human resource management and operational logistics, and has served as a member of the the High Rainfall Zone Regional Cropping Solutions Network for the past seven years.

M 0409 974 556 **E** fchilvers@bigpond.com

KATE WILSON

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

M 0427 571 360 **E** kate.wilson@agrivision.net.au

ANDREW RUSSELL

Andrew is a forth generation grain grower and is currently the Managing Director and 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 the family farm in the Rutherglen area, a 2,500 ha mixed cropping enterprise and also runs 2000 cross bred ewes. Lilliput AG consists of wheat, canola, lupin, faba bean, triticale and oats and clover for seed, along with hay cropping operations. Andrew has been a member of GRDC's Medium Rainfall Zone Regional Cropping Solutions Network and has a passion for rural communities, sustainable and profitable agriculture and small business resilience.

M 0417 401 004 **E** arussell@lilliput-ag.com.au

DR NICOLE JENSEN

Nicole Jensen is GRDC General Manager for the newly created Genetics and Enabling Technologies business group. Nicole brings a wealth of experience in plant breeding and related activities arising from several roles she has held in Australia and internationally in the seed industry including positions as Supply Innovation Lead with the Climate Corporation - Monsanto's digital agricultural flagship, Global Trait Integration Breeding Lead for Monsanto.

T 02 6166 4500 **E** Nicole.Jensen@grdc.com.au

T +61 8 8198 8407
P Grains Research and Development Corporation (GRDC) | Level 1 | 187 Fullarton Road, Dulwich 5065, South Australia

KEY CONTACTS

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

SOUTHERN REGION

ADELAIDE
Level 1
187 Fullarton Road
DULWICH SA 5065

P: +61 8 8198 8400
southern@grdc.com.au

OPERATIONS GROUP

SENIOR REGIONAL MANAGER
Craig Ruchs
Craig.Ruchs@grdc.com.au
M: +61 4 7771 0813

BUSINESS SUPPORT TEAM LEADER
Amanda Kendall
Amanda.Kendall@grdc.com.au
P: +61 8 8198 8402

CONTRACT AND TEAM ADMINISTRATOR
Claire West
Claire.West@grdc.com.au
P: +61 8 8198 8401

CONTRACT ADMINISTRATOR
Mark Waterhouse
Mark.Waterhouse@grdc.com.au
P: +61 8 8198 8406

APPLIED RESEARCH AND DEVELOPMENT GROUP

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS
Stephen Loss
Stephen.Loss@grdc.com.au
M: +61 4 0841 2453

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS
Allison Pearson
Allison.Pearson@grdc.com.au
M: +61 4 1887 4748

MANAGER WEEDS (NATIONAL)
Jason Emms
Jason.Emms@grdc.com.au
M: +61 4 3954 9950

CROP PROTECTION MANAGER SOUTH
Ruth Peek
Ruth.Peek@grdc.com.au
M: +61 4 5553 4040

GENETICS AND ENABLING TECHNOLOGIES GROUP

SENIOR MANAGER ENABLING TECHNOLOGIES
Tom Giles
Tom.Giles@grdc.com.au
M: +61 4 1788 9860

SENIOR MANAGER NATIONAL VARIETY TRIALS
Sean Coffey
Sean.Coffey@grdc.com.au
M: +61 4 2865 2226

MANAGER NATIONAL VARIETY TRIALS SOUTH
Rob Wheeler
Rob.Wheeler@grdc.com.au
M: +61 4 0114 8935

MANAGER NATIONAL VARIETY TRIALS SYSTEMS
Neale Sutton
Neale.Sutton@grdc.com.au
M: +61 4 3857 9992

MANAGER RESEARCH PLATFORMS
Trevor Garnett
Trevor.Garnett@grdc.com.au
M: +61 4 5790 6770

NATIONAL VARIETY TRIALS OFFICER
Ben O'Connor
Ben.O'Connor@grdc.com.au
M: +61 4 9988 7749

CONTRACT ADMINISTRATOR
Cindy Hall
Cindy.Hall@grdc.com.au
P: +61 8 8198 8407

GROWER EXTENSION AND COMMUNICATIONS GROUP

GROWER RELATIONS MANAGER
Courtney Ramsey
Courtney.Ramsey@grdc.com.au
M: +61 4 2827 4018

GROWER RELATIONS MANAGER
Randall Wilksch
Randall.Wilksch@grdc.com.au
M: +61 4 3776 9098

GROWER RELATIONS MANAGER
Tom Blake
Tom.Blake@grdc.com.au
M: +61 4 1889 3186

COMMUNICATIONS MANAGER
Sharon Watt
Sharon.Watt@grdc.com.au
M: +61 4 0967 5100

BUSINESS AND COMMERCIAL GROUP

ACTING GM – BUSINESS DEVELOPMENT AND ECONOMICS GROUP
Ron Osmond
Ron.Osmond@grdc.com.au
M: +61 4 000 2640

MANAGER COMMERCIALISATION
Fernando Felquer
Fernando.Felquer@grdc.com.au
M: +61 4 1351 1412

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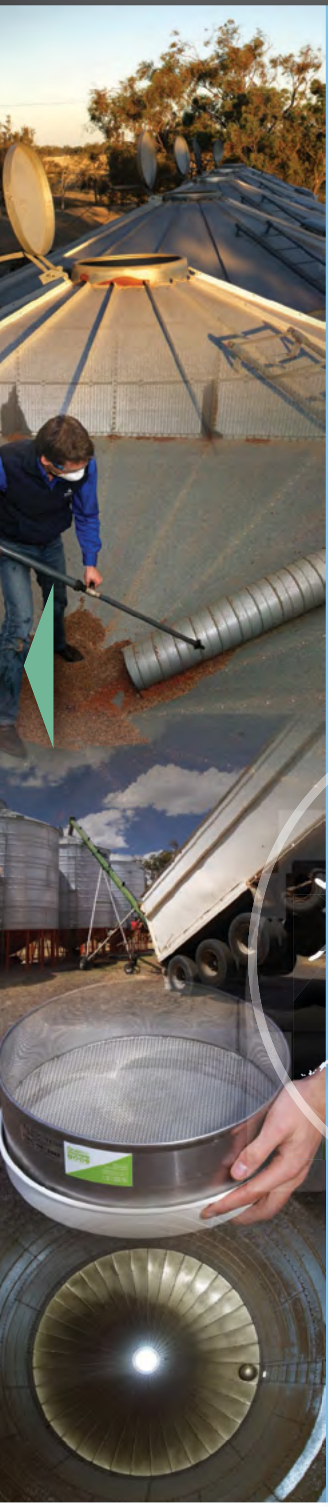

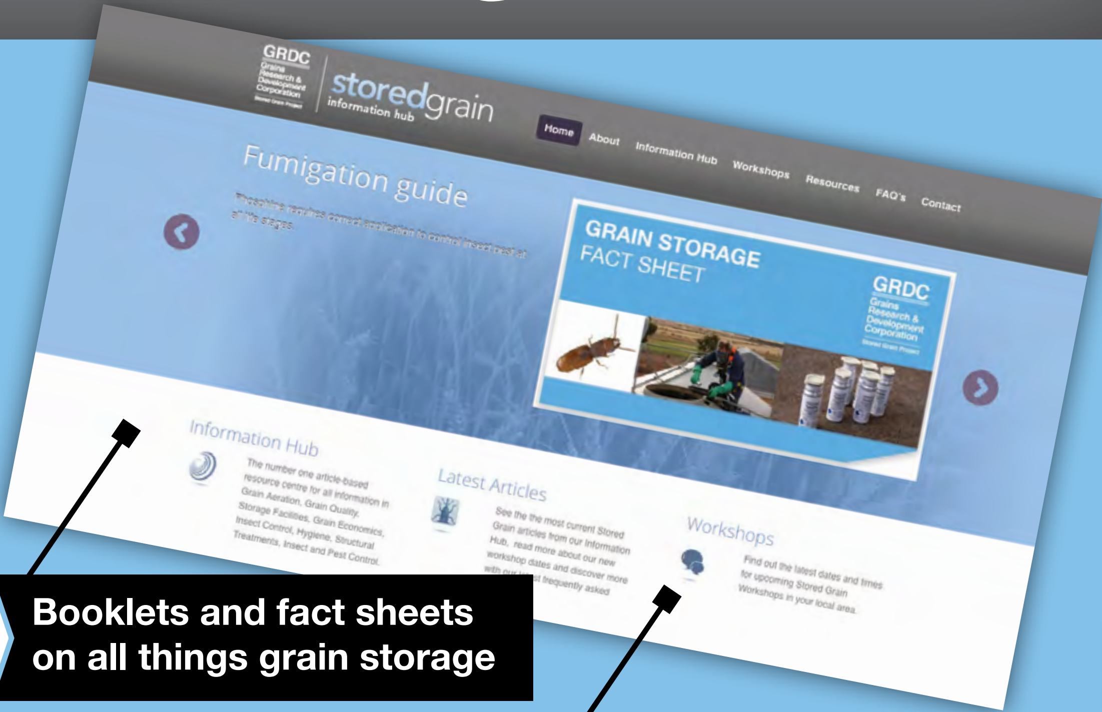

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