Spading header rows for grassy weed control, improved crop yields and better soil protection. Final Trial Report, Feb 2020

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This project has been funded by SAGIT,
with contributions from the South Australian Murray-Darling Basin Natural Resources Management Board, through funding from the Australian Government's National Landcare Program, the Regional Landcare Facilitator Program and NRM Levies.

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Government of South Australia
South Australian Murray-Darling Basin Natural Resources Management Board

Natural Resources SA Murray-Darling Basin

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Chris McDonough would like to acknowledge and thank the co-operation and assistance provided for this project by project site farmers Wayne, Marilyn, Daridyn and Aaron Hayward, Fiona Gray and other staff from Natural Resources SAMDB, Brian Dzoma and other SARDI Farming Systems team members and Viterra Loxton for assistance with grain testing.

Chris would also thank Chris Preston (Adelaide University), Rick Llewellyn and Lynne MacDonald (CSIRO), Nigel Wilhelm (SARDI), Jack Desbiolles (Uni SA) and Allan Mayfield (SAGIT) for advice and results discussion of this trial.

Contents

1 Summary

The "Spading header rows for grassy weed control, improved crop yields and better soil protection" project brought both of positive and negative outcomes over the three below average rainfall seasons, providing a valuable contribution of practical knowledge from this farmer scale trial to the field of enquiry.

The spading of header rows undertaken within this trial did not lead to a sustained reduction in ryegrass numbers by burying a high percentage of weed seed. However, some ryegrass suppression was achieved through increased crop competition associated with soil improvements.

This trial did show that soil improvements achieved through the spading in of header rows was able to produce overall yield advantages across the 6 trial sites with varying soil types, which would justify the purchase of spading and deep ripping equipment by farmers and the costs of operations. Increases in production averaged across all trial sites, soil types and years equated to income gains of $125/ha/year for the spaded treatments above the control treatments. This was achieved despite the trial spanning across three well below average rainfall years. These benefits are expected to increase in more average or above average rainfall seasons and with long lasting soil benefits.

The clear soil advantages obtained from the Spaded Header Row treatments included the breaking of soil compaction leading to root access to deeper soil moisture and nutrients, increased moisture storage available for crop use in deep sandy soils, and increased subsoil nutrition in the form of organic carbon, nitrogen and phosphorus.

More work is required to improve our understanding of the most effective spading strategies, equipment and application across more farming environments and average rainfall years, to further develop the potential uptake of the findings within this trial.

2 Introduction

This project aimed to assess whether spading header rows can provide a non-chemical, highly effective, practical and affordable method of ryegrass and brome grass control, while ameliorating subsoils to improve soil health and yield potential, without the risk of wind erosion that is currently associated with common spading practices.

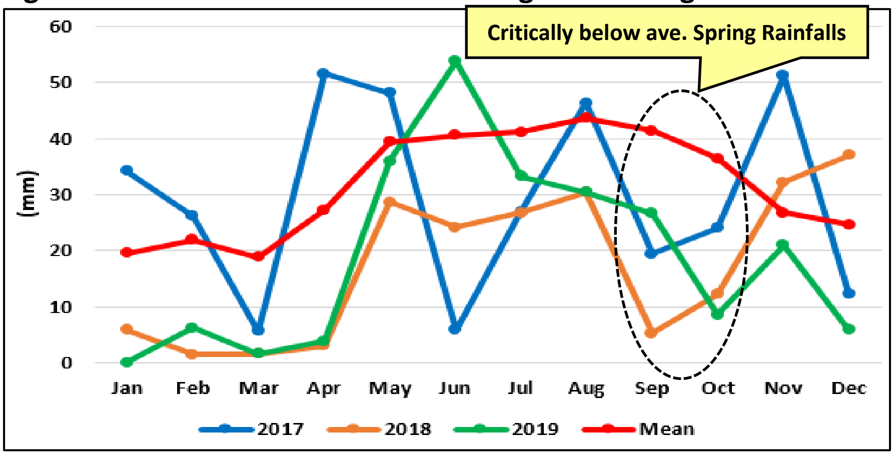
There is currently a great deal of research and development work going into practical and affordable ways that farmers can achieve effective subsoil amelioration on their properties. This trial has examined a unique method of achieving this, which does not involve the impediments of transporting and spreading of expensive animal manures or other forms of organic matter that are often unavailable to many farmers in some regions. It utilises the concentrated, readily available on-farm source of organic matter in the previous crops header row. Extra nutrition, if required, is supplied through spreading mineral fertiliser prior to spading, to help simulate the both the organic matter and nutrition applied in manures.

The three seasons of this was characterised by below average annual rainfalls and well below average growing season rainfalls (Figure 1). Both 2018 and 2019 had virtually no rainfall from January through April, and all three seasons had well below average September – October rainfall, which is absolutely critical for maintaining yield potential and setting grain fill. Added to this were severe frost events that strongly impacted on some of the trial sites in 2017.

From the trial's standpoint it is unfortunate that these seasonal factors meant that the higher yield potential shown by spading treatments across each year and particularly on the heavier textured Flat sites were often unable to be translated into increased yield. The superior early growth created was often detrimental to final yield, but such is the nature of farming in the Mallee on these soil types.

Despite these factors, the monitoring and evaluation of this unique, farmer scale trial using the farmers equipment to establish treatments and allowing each paddock's site management to be fully integrated with the farmers normal paddock practices, has uncovered some important findings about using these spading techniques as a potential tool to combat ryegrass, to build soil health and increase productivity and profitability.

Figure 1. Lameroo rainfall 2017- 2019 against average rainfall



Year	GSR (mm)	Annual (mm)
2017	222	352
2018	130	208
2019	192	227
Mean	270	382

3 Methods

Three paddocks representing different rotation phases were each set up with a Sand and a Flat trial site. There were 4 treatments, being Control, Burnt Header Row (each season where possible), Spaded Header Row (Spaded HR) and Spaded Header Row with High Nutrition (Spaded N). Both spading treatments were carried out once only in the autumn of 2017, prior to seeding. There are 3 replicated in each trial site, with each treatment area being 12m wide (the width of the farmers header to allow for the creation of appropriate header row widths), with each site 50m in length, within which all monitoring and harvest activities took place over 3 seasons of the trial. Each paddock was managed (sown, fertilised and sprayed) by the farmer according to his normal paddock practices.

The soil testing for this report was carried out on June 11, 2019 at 2 depths, being the surface (0-10cm), then to the spading depth, being 10-40cm on the Sand and 10-30cm on the Flat sites, to best match the depth of the soil amelioration through spading. 6 topsoil samples and 2 deep soil probe samples taken and mixed from within each plot for analysis across all replications on the Ewe and Dary paddock sites. Other soil test were conducted in each year of the project and analysed in previous project reports.

Early ryegrass plant counts were achieved using a 1/10th m^2 quadrat in 10 locations down the middle of each plot (within 5 seeding rows). In the first year the late ryegrass counts involved counting plants, but this was subsequently changed to counting all late ryegrass tillers that were capable of baring a viable seed head, as this gave a better indication as to each treatments ability to suppress ryegrass seed production.

Penetrometer readings were taken on July 29, 2018 at 6 sites per plot over 2 reps per site. The average readings of the Control and Burnt plots were then combined for the average Non-Spaded results, while the average Spaded HR and Spaded N were combined for the average Spaded results for comparison.

All plots each year were reapt by SARDI using their plot harvester, with grain being analysing at the Loxton VITERRA site. The one exception to this was the canola in 2018 on the Steers Paddock, where samples were cut, threshed and weighed by hand.

There were a total of 6 moisture probes with 5 sensors spaced at 20cm intervals within the top 1m and equipped with dataloggers along with tipping bucket rain gauges. They were strategically placed among key treatments to test the soil moisture dynamics between rainfall, treatments and crop growth and seasonal factors.

4 Results and Discussion

After presenting a table summarising the statistical analysis to the main crop monitoring results, this section has been set out to analyse and discuss the key trial findings that answer the research objectives, being:

- Can spading header rows be used successfully as a non-chemical strategy to control grass weeds?
- Can spading header rows be used as an efficient method of ameliorating subsoils to improve soil health and increase productively, while minimising the risks of soil degradation through wind erosion?
- Can the productivity gains made through this technique be substantial enough to justify farmers purchasing their own spading machinery or contracting in these services?

4.1 Statistical Ryegrass and Yield Results across all sites

Table 1 provides as summary of the statistical analysis of all sites across all years for early ryegrass, late ryegrass and yield, which are discussed in more detail within the sections below. While there are many results with significant differences, it was apparent that the large size of sites (being farmer machinery scale) along with the inconsistent spread of the pre-existing ryegrass seed burden within sites, meant that large average differences presented often did not translate into significant differences (LSD 5%) with the basic statistical analysis applied.

Table 1. Ewe Paddock Ryegrass and Harvest Results

Ewe Sand	2017 Wheat						2018 Barley						2019 Lupins					
Treatment	Early Ryegrass (pl/m^2)		Late Ryegrass (pl/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)	
Control	56	a	87	a	0.95	a	554	b	271	a	0.91	a	50	a	10	a	1.12	a
Burnt	34	a	49	ab	1.33	a	183	a	164	a	1.03	a	40	a	11	a	1.13	a
Spaded	23	a	32	b	1.34	a	307	ab	196	a	0.92	a	21	a	9	a	1.21	a
Spad Nutrit	28	a	18	b	1.00	a	177	a	128	a	1.15	a	21	a	1	a	1.21	a
LSD (5%)	54.7	ns	46.98	s	0.523	ns	179	s	134	ns	0.511	ns	24.74	ns	9.18	ns	0.632	ns
F Value (sig)	0.52		0.048		0.391		0.007		0.179		0.644		0.118		0.131		0.971	
Ewe Flat	**2017 Wheat**						**2018 Barley**						**2019 Lupins**					
Treatment	Early Ryegrass (pl/m^2)		Late Ryegrass (pl/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)	
Control	49	a	43	a	2.35	a	374	b	319	a	0.77	a	82	b	115	a	0.40	b
Burnt	26	a	44	a	2.2	a	322	ab	222	a	0.66	a	85	b	104	a	0.26	a
Spaded	19	a	30	a	2.27	a	124	ab	81	a	0.50	a	62	b	154	a	0.32	a
Spad Nutrit	9	a	17	a	2.28	a	53	a	15	a	0.42	a	23	a	72	a	0.31	a
LSD (5%)	49.9	ns	38.1	ns	0.413	ns	214.5	s	231.9	ns	0.553	ns	45.36	s	82.7	ns	0.087	s
F Value (sig)	0.201		0.342		0.905		0.019		0.064		0.475		0.051		0.213		0.049	

Table 2. Steers Paddock Ryegrass and Harvest Results

Steers Sand	2017 Lupins						2018 Canola						2019 Wheat					
Treatment	Early Ryegrass (pl/m^2)		Late Ryegrass (pl/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)	
Control	457	b	16	b	0.87	a	41	a	37	a	0.59	a	876	a	529	a	0.93	a
Burnt	179	b	2	b	0.84	a	20	a	8	a	0.46	a	324	a	364	a	1.45	a
Spaded	286	b	22	ab	0.74	a	34	a	18	a	1.41	b	257	a	384	a	2.35	b
Spad Nutrit	754	a	44	a	0.79	a	12	a	7	a	1.27	b	268	a	448	a	2.41	b
LSD (5%)	526.7	s	24.7	s	0.452	ns	38.76	ns	29.19	ns	0.37	s	742.8	ns	415.3	ns	0.526	s
F Value (sig)	0.09		0.03		0.941		0.327		0.145		0.002		0.226		0.771		0.001	

Steers Flat	2017 Lupins						2018 Canola						2019 Wheat					
Treatment	Early Ryegrass (pl/m^2)		Late Ryegrass (pl/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)	
Control	447	a	35	a	0.71	a	53	a	10	a	0.31	a	841	a	648	b	1.06	a
Burnt	563	a	12	a	0.51	a	13	a	20	a	0.39	a	124	a	221	a	1.71	b
Spaded	514	a	78	a	0.53	a	45	a	13	a	0.83	b	223	a	264	a	2.57	c
Spad Nutrit	508	a	16	a	0.82	a	40	a	35	a	0.70	b	281	a	429	ab	2.49	c
LSD (5%)	550	ns	66.7	ns	0.296	ns	45.29	ns	29.08	ns	0.07	s	708.4	ns	255.1	s	0.574	s
F Value (sig)	0.964		0.162		0.24		0.255		0.251		<.001		0.159		0.023		0.002	

Table 3. Dary Paddock Monitoring Results

Dary Sand	2017 Barley						2018 Wheat						2019 Wheat					
Treatment	Early Ryegrass (pl/m^2)		Late Ryegrass (pl/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)	
Control	130	a	149	a	0.41	a	565	a	154	a	0.44	a	721	a	472	a	0.35	a
Burnt	196	a	110	a	0.58	ab	392	a	123	a	0.40	a	511	a	762	a	0.32	a
Spaded	139	a	101	a	1.47	bc	162	a	133	a	1.20	b	504	a	671	a	0.47	a
Spad Nutrit	312	a	161	a	1.18	c	372	a	112	a	0.99	ab	510	a	578	a	0.44	a
LSD (5%)	291.2	ns	82.7	ns	0.401	s	302.9	ns	84.5	ns	0.457	s	417.8	ns	402.1	ns	0.21	ns
F Value (sig)	0.456		0.308		0.006		0.087		0.669		0.012		0.55		0.406		0.332	

Dary Flat	2017 Barley						2018 Wheat						2019 Wheat					
Treatment	Early Ryegrass (pl/m^2)		Late Ryegrass (pl/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)		Early Ryegrass (pl/m^2)		Late Ryegrass (tillers/m^2)		Yield (t/ha)	
Control	220	a	152	a	1.38	a	312	b	154	a	1.28	a	554	a	513	a	1.12	a
Burnt	185	a	102	a	1.71	a	226	ab	123	a	1.29	a	371	a	403	a	1.50	a
Spaded	108	a	109	a	1.6	a	80	a	133	a	1.38	a	480	a	548	a	2.03	a
Spad Nutrit	167	a	103	a	2.24	a	73	a	112	a	1.41	a	405	a	497	a	2.10	a
LSD (5%)	157.1	ns	150.8	ns	0.733	ns	149.9	s	84.5	ns	0.68	ns	299.5	ns	382.4	ns	0.891	ns
F Value (sig)	0.432		0.827		0.234		0.02		0.669		0.955		0.498		0.813		0.105	

4.2 Reduction in Grassy Weeds

This trial was primarily set up to test whether the spading of header rows could provide an effective and affordable non-chemical method of grass control, through the deep burial and break down of the weed seed. This was based on preliminary weed counts and observational data obtained from the previous season, which showed great potential (Photo 1). As this was a farming systems trial, using farmer's equipment and paddock scale operations, it was important to measure the effect on weed numbers within different phases of rotation, on varying soil types over a 3 year period.

Photo 1. Spaded Strip across brome grass filled header rows in Steers paddock, 2016

The three paddocks chosen consisted of:

- Ewe Paddock, which had lower grass numbers as it was following a 2016 lupin crop. It was sown to wheat in 2017, barley in 2018 and back to lupins in 2019;
- Steers Paddock, which had followed a cereal phase and was going in to Lupins in 2017 due to its very high grass weed populations. This was followed by canola in 2018 due to ongoing grass concerns, and then wheat in 2019;
- Dary Paddock to represent a long term cereal paddock (worst case scenario) continuing on with barley in 2017. This was a late change to this paddock as the original paddock did not have enough consistent deep sand to suit the width of the trial replications. The Dary paddock section sown to barley was cut out of a larger paddock sown to Lupins in 2017, for the purpose of the trial. It was sown to wheat in 2018 and 2019 in accordance with the rest of the paddock, and as a result suffered the from very high grass pressure throughout.

The results presented here focus on the final years weed numbers in the central header row sections of the trials, as this gives the best indication as to the success of the treatments over time.

4.2.1 Ewe Paddock

In 2017, the Ewe paddock (following lupins) initially had a considerably lower ryegrass level in both the Sand and the Flat sites than the Dary and Steers paddocks which followed cereals. There were significant differences between the Sand site Spaded and Control plots for late ryegrass in the first cereal year (Table 1, Figure 2) and early ryegrass counts in the 2018 barley, and the control plots consistently had the highest ryegrass numbers (Figure 2). It was felt that the advantage gained within the Spaded plots was more a result of the increased crop competition against the ryegrass, (Photo 2) which was far higher in the Spaded Nutrition plots, reducing late viable ryegrass tillers from the control by 79%, 53% and 90% across the 3 consecutive years. By comparison, spading alone (with slightly less crop vigour and competition) reduced late ryegrass tillers by 63%, 28% and 10% compared to control plots.

There was 95% reduction in late ryegrass tillers on the Flat with high nutrition, which carried through to a 37% reduction in the final lupin year. The overall lower numbers was not surprising given the grass weed control available in the 2019 lupin crop. However, it is likely that there could well be higher ryegrass seed carry over into the 2020 season from the Control and Burnt treatments on the Flat, given considerably higher late tiller counts producing viable seed in 2018 (Figure 3).

This paddock, starting with a lower ryegrass seedbank, did show signs of maintaining these low numbers with the Spaded Nutrition treatments. However, while the higher ryegrass levels on the flat in the second cereal year of rotation in the Control plots has led to populations that could significantly impact on yield, this would not justify the use of the Spader for the sole purpose of ryegrass control, given the impact of other rotational ryegrass management options at this site.

Figure 2. Ewe Paddock early season ryegrass results, 2017-2019, following 2016 Lupins

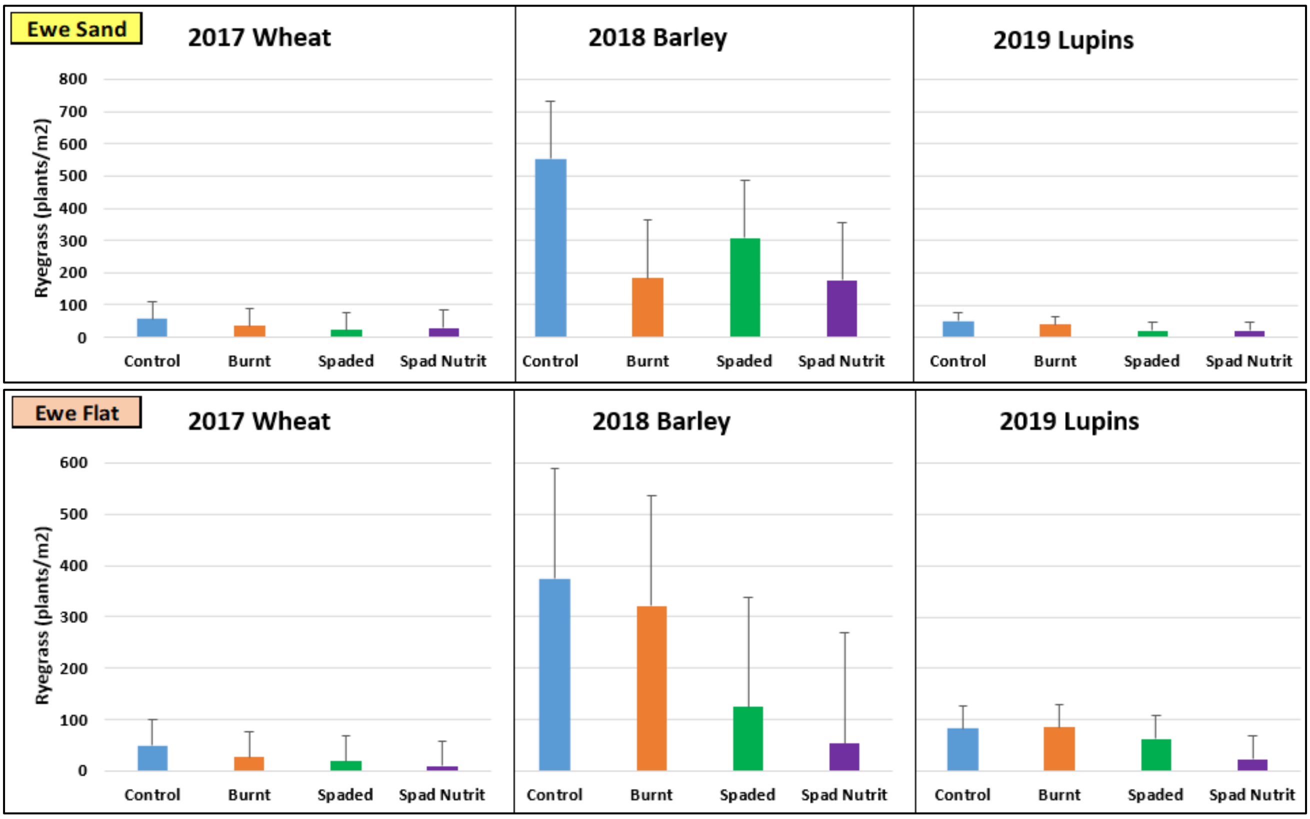


Figure 3. Ewe Paddock late season ryegrass results, 2017-2019, following 2016 Lupins

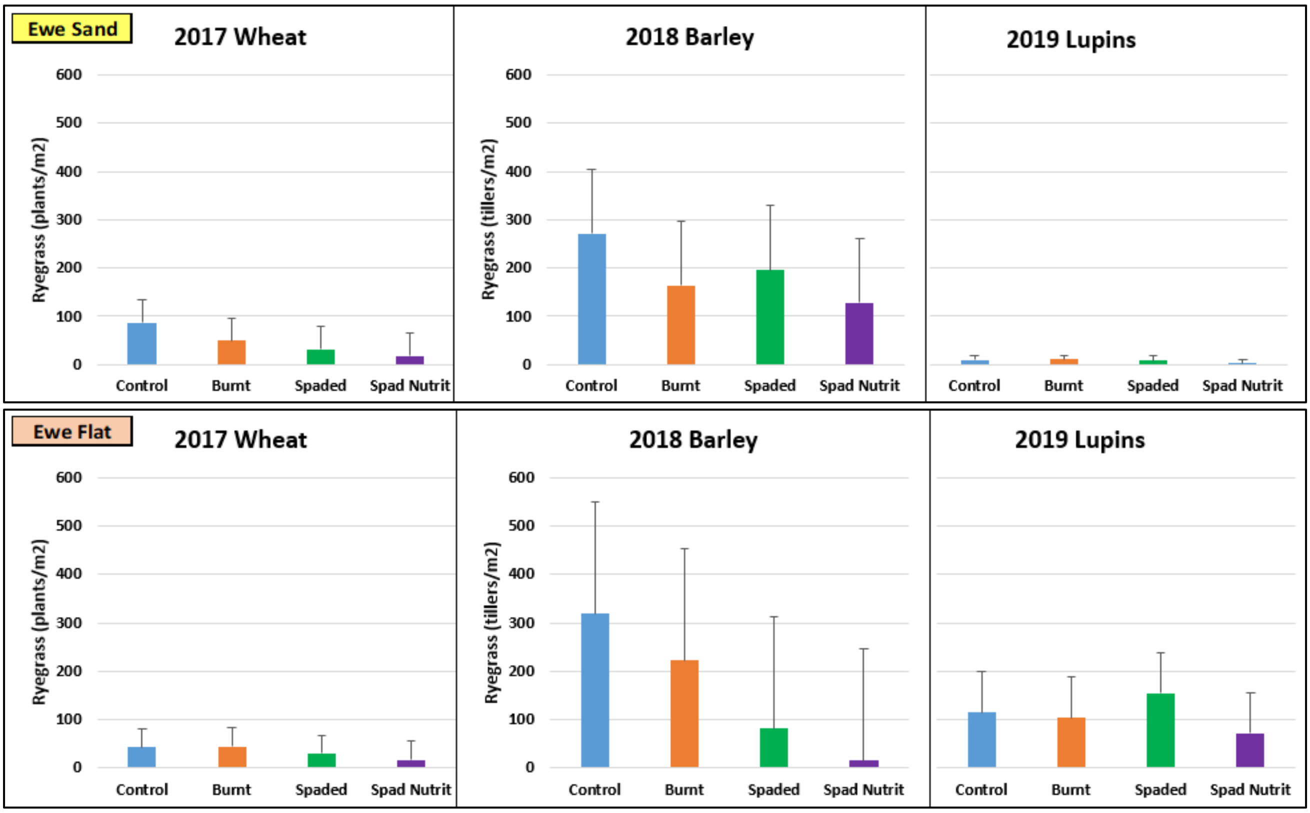


Photo 2. Strong Oct 2018 growth of Spaded N (left) next to thinner weed infested Control (right)

4.2.2 Steers Paddock

The Steers paddock was where the preliminary monitoring work was done as a project precursor in 2016, showing extraordinary levels of header row weeds, which were almost completely eliminated where the spading machine had passed prior to crop seeding, as evidenced in Photo 1. Surprisingly, there were very few brome grass plants evident on this paddock's trial sites over the next 3 years.

This paddock was suffering from very high ryegrass levels after a cereal phase, which is why the farmers decided to apply 2 years of break crops in 2017 (lupins) and 2018 (canola). This is evidenced in the high early ryegrass counts in 2017 (Figure 4), taken prior to selective herbicide grass removal. The significantly higher early ryegrass levels in the Spaded Nutrition on Sand plots in

2017 was thought to possibly be due to the higher nitrogen application stimulating a greater ryegrass germination. These high initial numbers in each of the spaded plots did indicate that the Spading operation had not been successful in burying and eliminating the threat of ryegrass germination at these levels, as had been hoped.

There was almost no significant difference in ryegrass levels in years 2 and 3 of the trial between treatments (Table 1), despite some very high average numbers for the control plots in both the sand and the flat in 2019, which were impacted by a few specific rows that had extremely high grass numbers.

The high ryegrass levels evident within late ryegrass counts in 2019 (Figure 5, Photo 3), suggest that there was an extremely high residual seedbank, even after two seasons of break crops. Again, the Spading operation appears to have had little effect on burying weed seed and reducing ryegrass populations to more manageable levels within this paddock.

Late counts on strips adjacent to each header row (shown in Photo 3) revealed only 25-50% of the viable ryegrass stems than in the historic header rows on the Flat site, and 40-55% on the Sand site, showing that the majority of the ryegrass burden remains within the narrow header row strips.

Figure 4. Steers Paddock early season ryegrass results, 2017-2019, following 2016 Barley

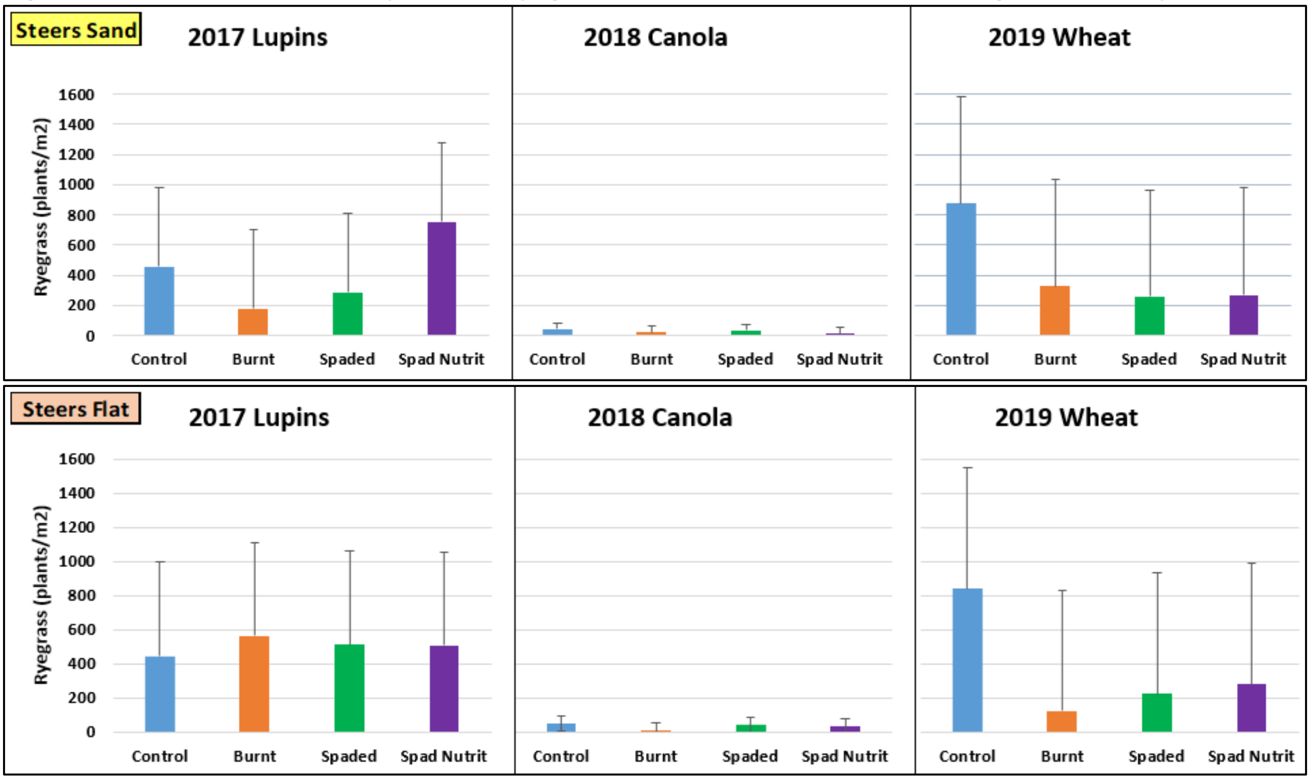


Figure 5. Steers Paddock late season ryegrass results, 2017-2019, following 2016 Barley

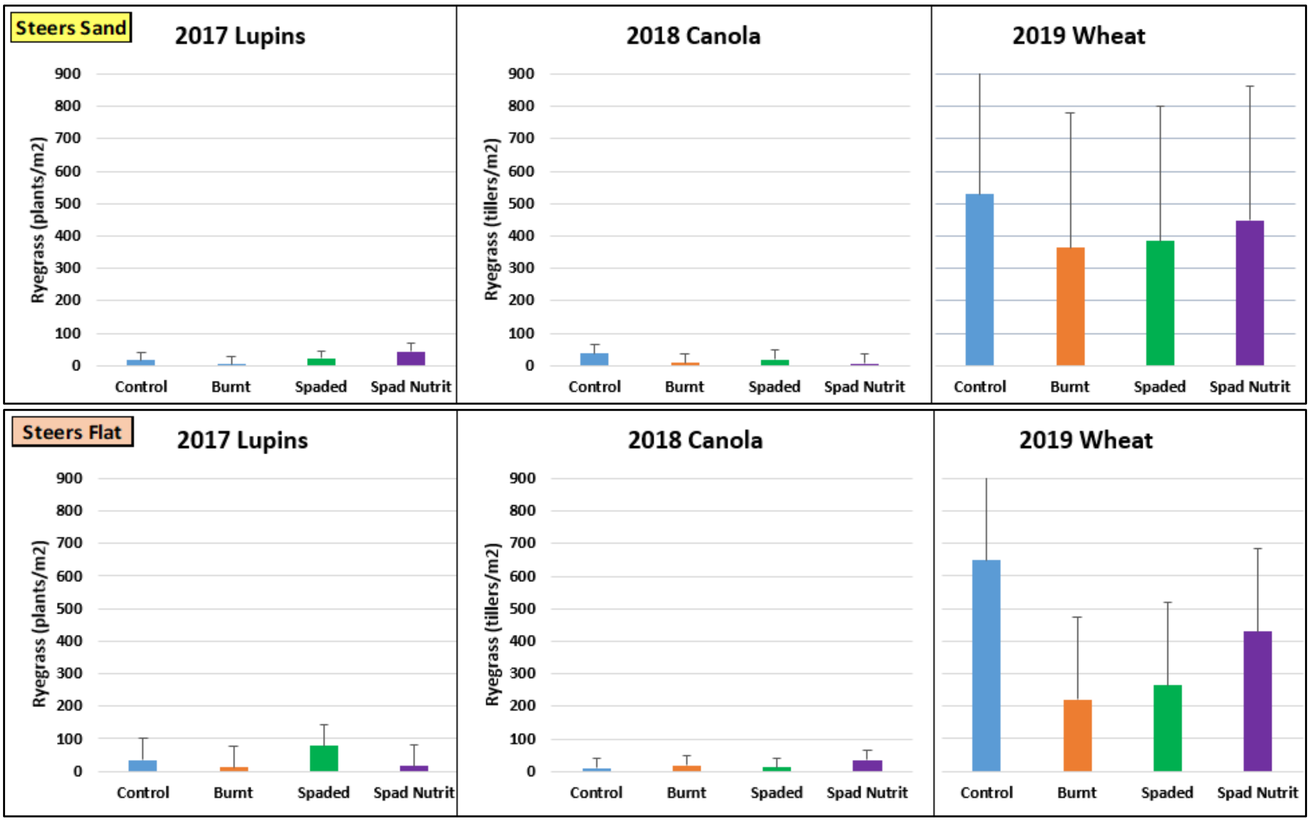
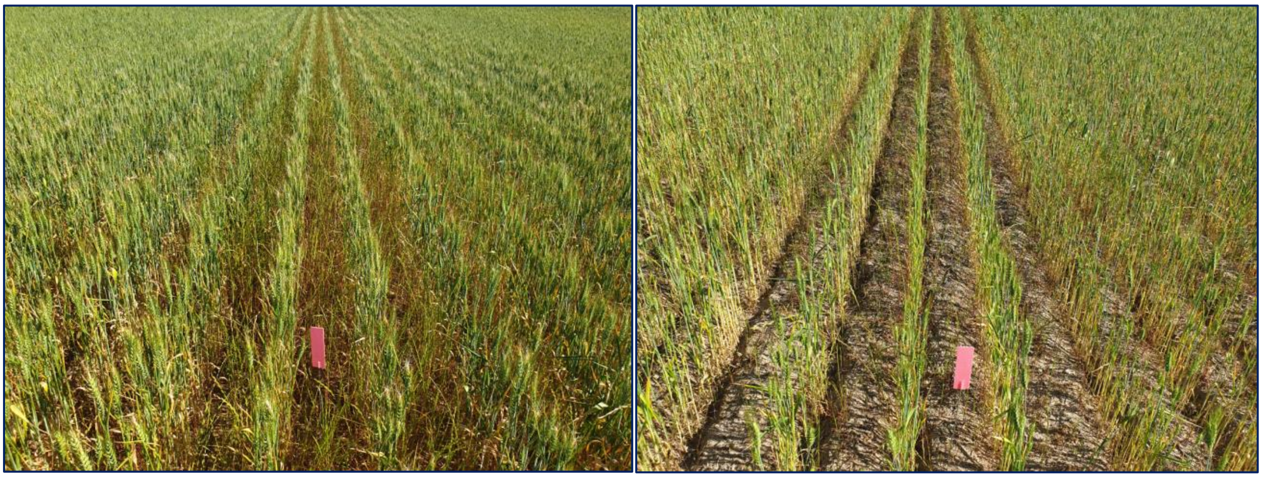


Photo 3. 2019 Control Central header row (left) vs adjacent Edge strip with few weeds (right)



4.2.3 Dary Paddock

The Dary Paddock was initially chosen to represent the 2nd year cereal phase of the rotation. While the rest of the paddock grew lupins in 2017, the trial portion of the paddock was sown to barley, with the expectation it would then be sown to lupins in 2018. However, for ease of operations, the farmer decided to keep these plots in line with the rest of the paddock in 2018 and 2019, meaning that these trial sites (Sand and Flat) have experienced 4 consecutive cereal years. This has meant that this site has been faced with the most challenging scenario for ryegrass competition.

The initial treatment set up was also achieved in a way that proved detrimental to the Spaded plots. This was due to the Spading happening in April, which would have resulted in the profiling of most of the ryegrass seedbank below the surface. However, after the opening rains a knockdown herbicide spray was used, which was more effective on the Control and Burnt plots where the majority of weeds were germinating in the surface, as opposed to the Spaded treatment in which a high percentage of these weeds were yet to emerge.

While it was initially hoped that the Spaded treatments might adequately counter these ryegrass control challenges, it is clear from the Figures 6&7 ryegrass counts, that after 3 seasons, all treatment are exhibiting unacceptable levels of ryegrass competition and there is no significant differences between them. Similar to the Ewe paddock, the second year in the Flat the spaded treatments appear to have increased crop growth and ryegrass competition enough to maintain some significantly lower ryegrass numbers than the Control treatments. However, this was not able to carry through to the 3rd season. This paddock trial section will require a number of ryegrass controlling rotational options to begin to bring numbers down to a manageable level.

Figure 6. Paddock early season ryegrass results, 2017-2019, following 2016 Barley

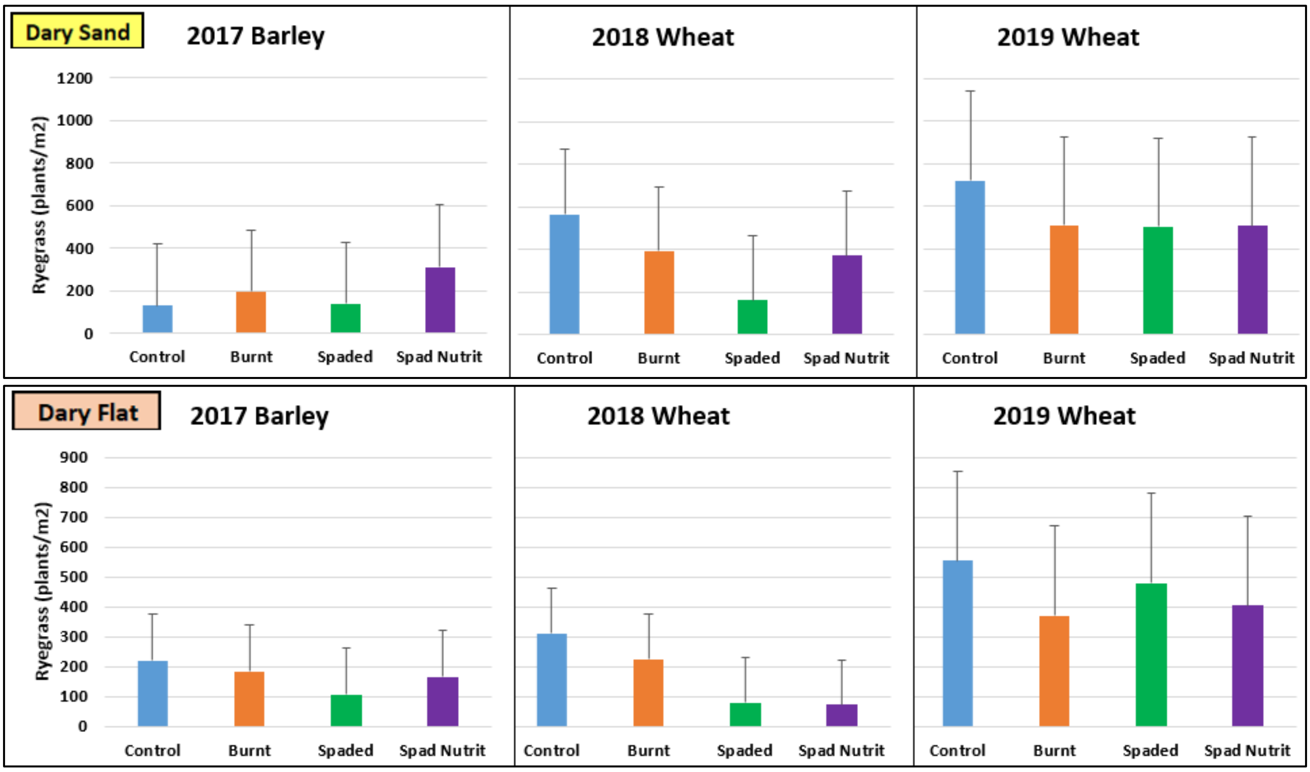
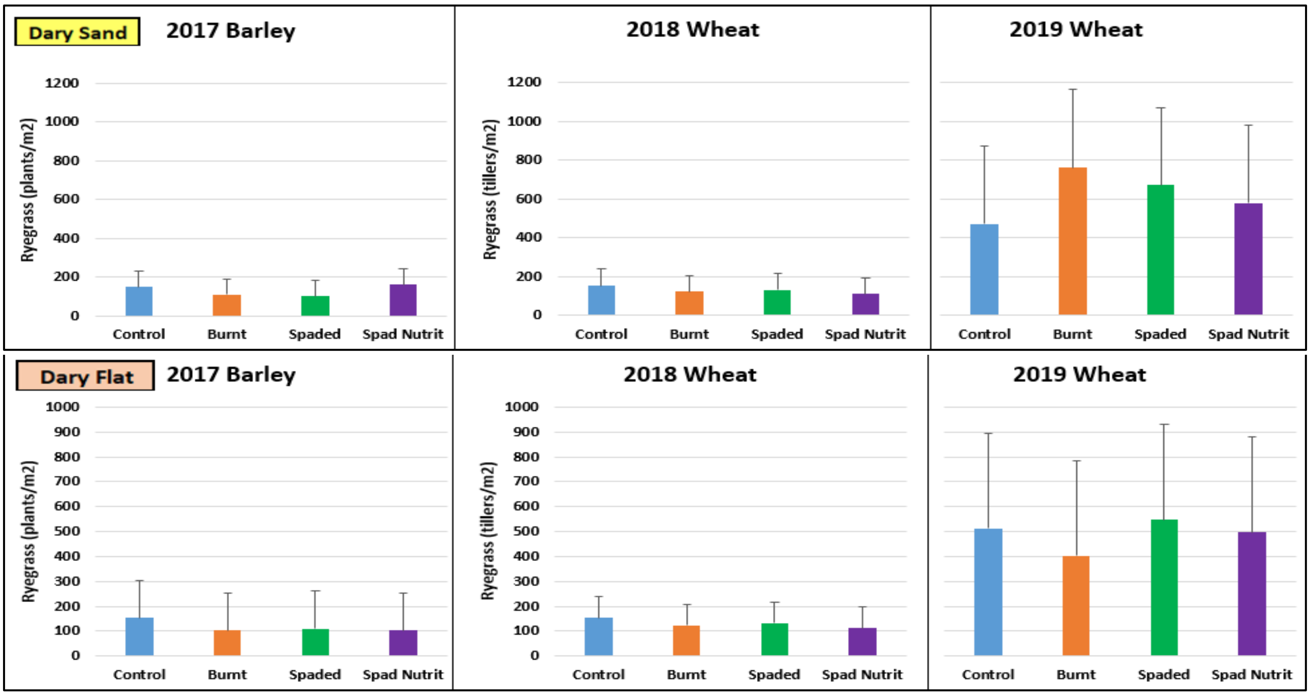


Figure 7. Paddock late season ryegrass results, 2017-2019, following 2016 Barley



4.2.4 Grass control summary

This trial has demonstrated that in its current form, spading of header rows in not an effective tool for dramatically reducing ryegrass populations through seed burial. However, excellent reductions in ryegrass numbers were achieved at sites with lower initial ryegrass pressure, mainly due to increased competition through improved crop growth of the Spaded Nutrition treatment. At other sites with very high ryegrass populations, the ryegrass levels carried through to unacceptable levels in the 3rd year, even after 2 years of break crops, attributable to the high seed bank still remaining.

The best methods for effectively burying grass weed seed needs further development, and having one only set treatment at the start of the trial did not allow for improvements to be made to the techniques and be monitored over time. For instance, it is possible that refinements to spading speed for specific soil types may have made some difference. In year 1 in the paddocks with higher grass weed burden (following 2 cereal years), the spaded plots had some seed profiled within the top 15cm which emerged well after the knockdown herbicide and so much better grass control was obtained on the non-spaded plots. This initial higher weed burden carried through the 3 years on these sites making it difficult for these plots to realise benefits from any partial weed seed burial. Deep soil testing in 2017 showed ryegrass germinating from 25cm depth after spading (Photo 4).

The team at the University of South Australia's Agricultural Machinery Research and Design Centre are also testing a narrow row spade and seed technique which has multiple spading blades in the rotation line (Desbiolles et al, 2019). This results in a consistent spading depth, rather than the undulating pattern resulting from the farmers spader used in this trial, as shown in in Photo 5 which varied in depth form 20-40cm. They are using computer simulation to test the dynamic interaction of various forms of spading technologies, and their abilities to bury surface materials. This may well lead to new machine designs and strategies that will greatly improve the benefits of spading techniques in achieving improved weed seed burial and crop competitiveness.

Photo 4. Spaded Steers Flat with straw mixed and ryegrass germination at 25cm depth

Photo 5. Indication of Spading pattern on Sand (approx. 40cm depth)

4.3 Soil Improvements

4.3.1 Changes to Subsoil Nutrition

In June 2019, surface and deep soil testing was completed on the Ewe and Dary paddocks, with separate analysis taken from each treatment replication to allow for more accurate comparisons (in previous years, samples between replications were combined for testing). This was over 2 years after the initial site treatments were established in April 2017. The graphs presented for each parameter show the mean results for each site and soil type.

It is important to consider that the Control and Burnt treatments were not spaded and were therefore unlikely to have experienced significant subsoil changes over the previous 2 years. The Spaded HR and Spaded N treatments have changed the subsoil to the spading depth (40cm in the Sand plots and 30cm in the loamy Flat plots) with stubble loads that on average varied from 14 to 31 t/ha, as shown in Table 4, and nitrogen contributions from the stubble of between 12-53kg/ha. The Spaded Nutrition plots had approximately 100kg/ha of MAP and 200kg/ha Urea applied to the stubble strips prior to spading, to assist with the straw breakdown and to increase nutrition to help match the future increased yield potential. This represents 22kg/ha of phosphorus and 102kg/ha of nitrogen. This means that in total, the Spaded Nutrition plots would have received and extra 114kg/ha N at the Dary Sand site, ranging through to an extra 155kg/ha at the Ewe Flat site to the subsoil (with spaded lupin residues), above that of the corresponding Control treatments.

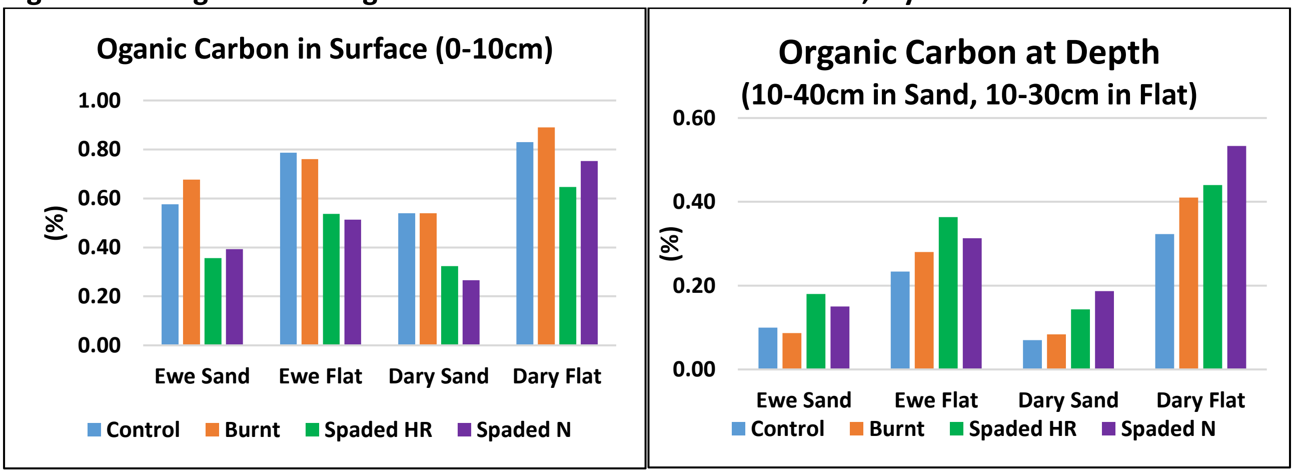
Table 4. Average Straw levels & Stubble Nitrogen originally spaded in central strips in April 2017

Site, Soil Type and Stubble Source from 2016	Average Straw of central strips (t/ha)	Nitrogen as NO_3 (mg/kg)	Nitrogen (%)	Stubble Nitrogen spaded into subsoil (kg/ha)
Ewe Sand Lupin Stubble	28.8	<30	1.13	33
Ewe Flat Lupin Stubble	22	87	2.35	53
Steers Sand Barley Stubble	30.2	<30	0.89	27
Steers Flat Barley Stubble	31.4	<30	0.89	28
Dary Sand Barley Stubble	14.5	<30	0.82	12
Dary Flat Barley Stubble	37.1	<30	0.72	27

NB Stubble Samples collected, weighed and tested at APAL Labs in autumn 2017 prior to trial treatments

Figure 8 reveals a clear trend of the dilution of the surface organic carbon levels due to spading, but an increase at depth, over the non-spaded plots. It is unsure how much of the subsoil increases are due to the mixing of the topsoil layer into this zone, or the deep placement and breakdown of between 14t/ha and 37t/ha of straw at the various sites. Any increase in subsoil carbon of 0.1-0.2%, particularly in the low fertility sands, is likely to make a difference to the soils ability to retain and exchange moisture and nutrients with plant roots, and slightly increase N mineralisation.

Figure 8. Changes in soil Organic Carbon levels measured in 2019, 2 years after trial treatments



The nitrogen dynamics over the previous 2 seasons can be complicated as they are impacted by soils, crops, seasons, application and grain exports. Figure 9 show that the extra N supplied on the loamier Flat sites Spaded Nutrition sites has been maintained, and would greatly contribute to the higher crop growth at these sites. This has been measured as approximately 38kg/ha N above the Control in the Ewe Flat, and 35kg/ha in the Dary Flat site. It is interesting that these high N levels were not sustained in the Sand sites, which was possibly due to N leaching to lower levels after the 40mm of rainfall in Nov 2017. While it was initially thought that the high levels of residual N may have been as a result of originally spading in the nitrogen rich lupin stubble of in the Ewe paddock, this appears less likely given a similar result was obtained on the Dary Flat site.

Figure 9. Changes in soil Nitrogen levels measured in 2019, 2 years after trial treatments

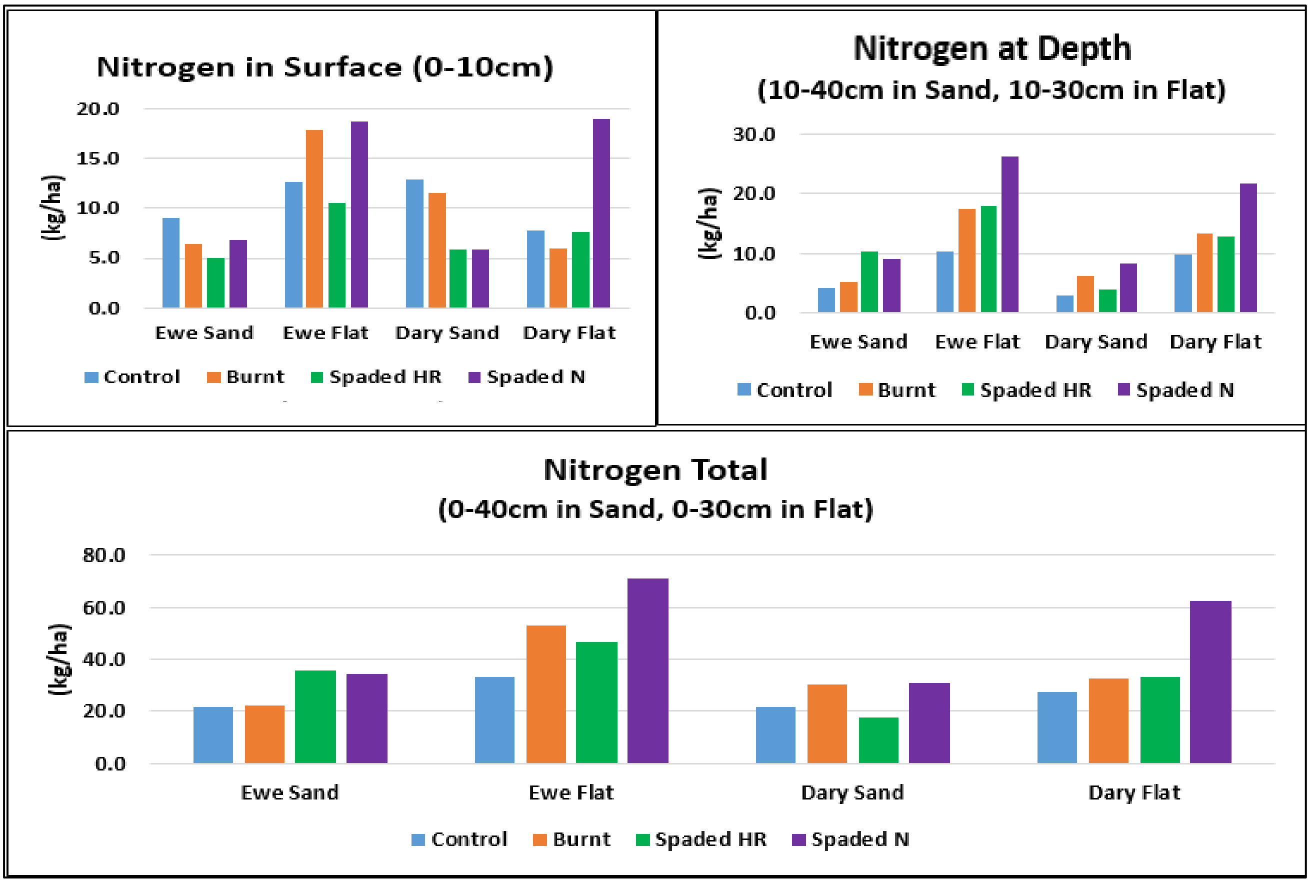
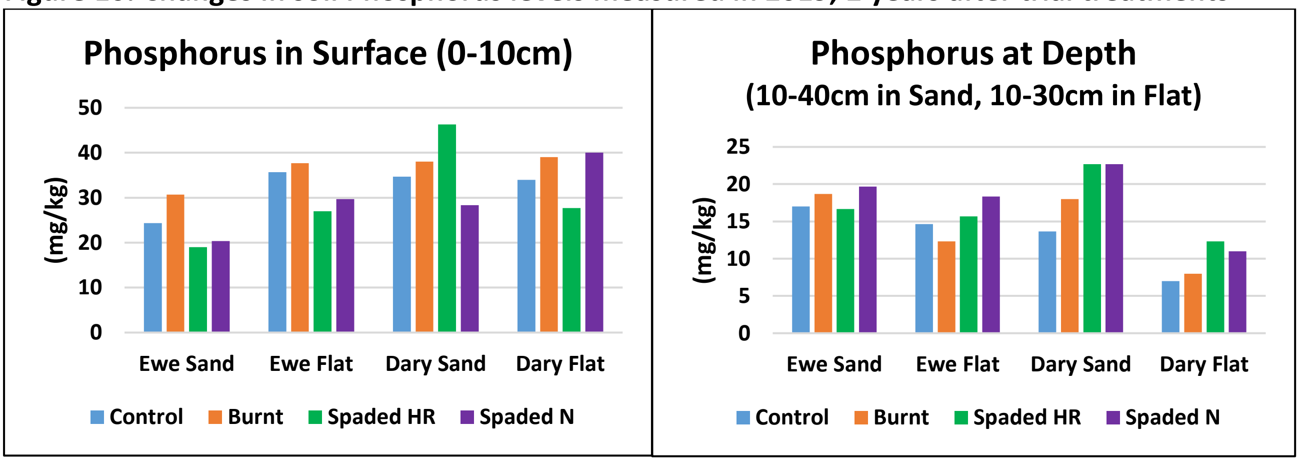


Figure 10. Changes in soil Phosphorus levels measured in 2019, 2 years after trial treatments



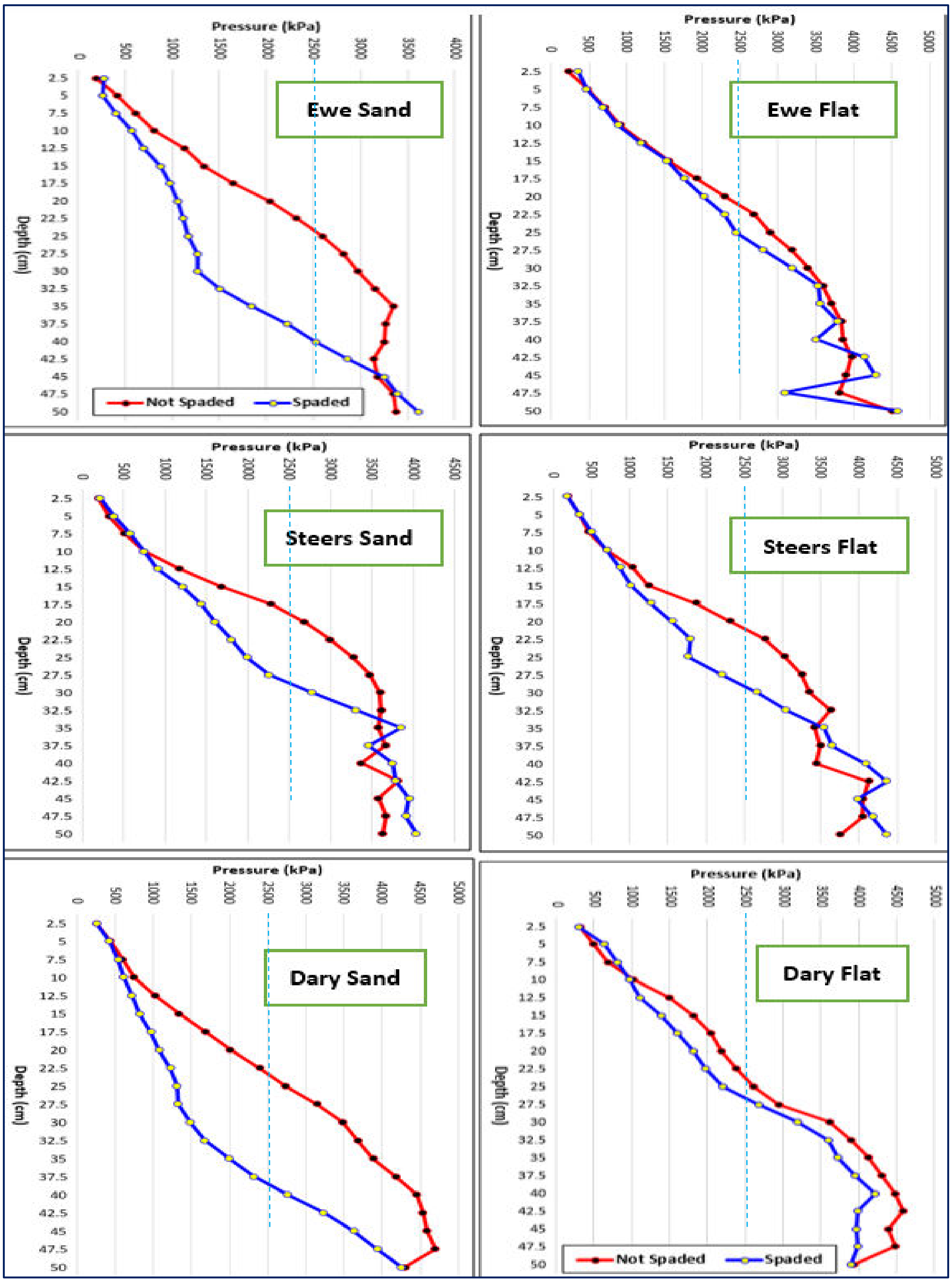
There was a significant difference surface soil P between the Burnt and Spaded treatments in the Ewe Sand, but none at Ewe Flat, despite the average differences (Figure 7). There were no significant differences in the phosphorus at depth readings.

There was no clear trends evident in surface or subsoil moisture, but after 2 years of drought this is not surprising. Where there is any compaction in the sand, the extra root growth from spaded treatments would have dried out any 0-40cm moisture, while for the unspaded compacted plots it is likely that the very dry summer period would have dried the soil profile to 40cm as well. There was also no clear trend of treatments causing changes to sulphur levels in the surface or at depth.

4.3.2 Changes to Subsoil Compaction

Root function can be severely restricted in sands once the pressure exceeds 2500 kPa, which is often reached at 17-25 cm in the non-spaded plots. Penetrometer readings in Figure 11 show that the spaded plots have greatly reduced soil compaction on the Sand within the top 30-50cm of soil, depending on the site. This effect was shallower at the Steers Sand site as the subsoil clay is often found at 30cm depth, resulting in a slightly shallower spading depth. While it is understandable that there has been less spading effects to the subsoil penetration pressures in the Flats, it is clear that mixing some topsoil into the heavy sodic clay at Steers Flat has been beneficial for root access. This is reflected in the higher yields obtained at this site with the spading treatments.

Figure 11. Average Penetrometer readings taken in Aug 2018 from each trial site



4.3.3 Changes to soil water retention and use by crops

The spading of organic matter into the top 40cm of sandy soils has shown to be extremely beneficial in retaining rainfall moisture within the crops improved rootzones, across numerous Mallee locations. Figures 12, 11 and 14 demonstrate this at the Dary Sand site after a 40mm rainfall event in Nov 2107. Where the spading header rows had occurred (Figure 9) it shows the 30cm soil moisture level was lifted and maintained until it was used by the crop in Spring. However, in the control plot 35m away this moisture penetrated to the 30cm, but was all lost within 6 weeks.

Figure 12. Dary Sand Spaded Nutrition Soil Moisture, July 201-Dec 2018

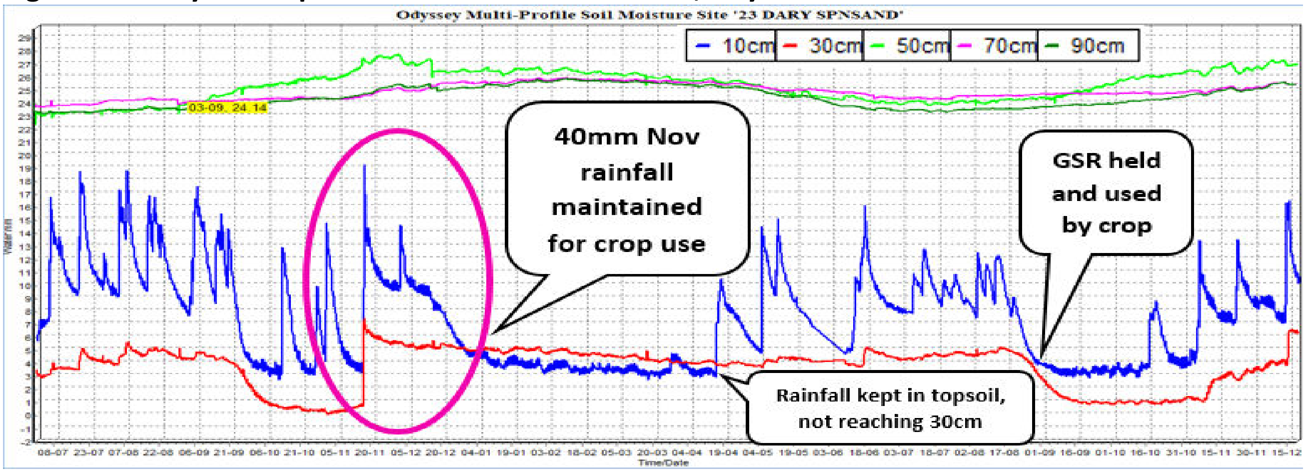


Figure 13. Dary Sand Control Soil Moisture, July 201-Dec 2018

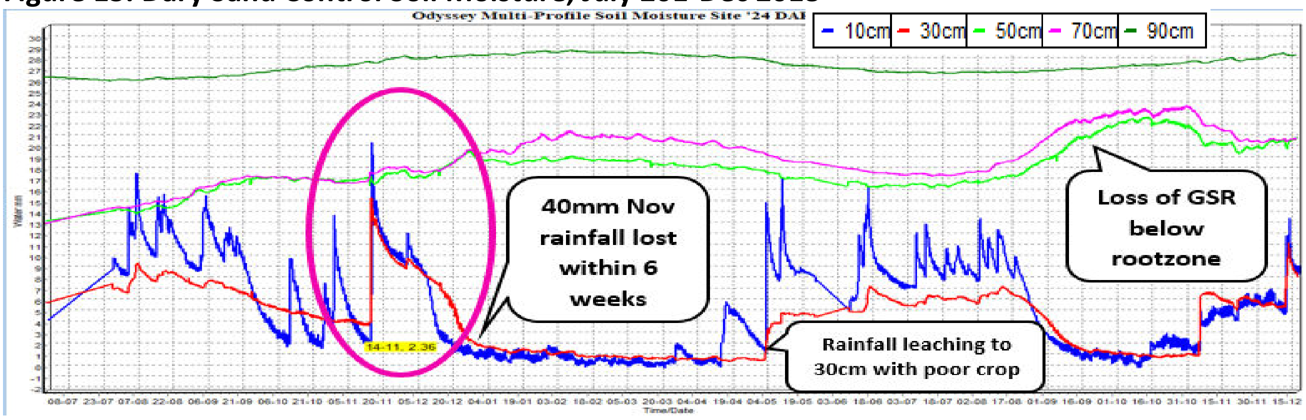
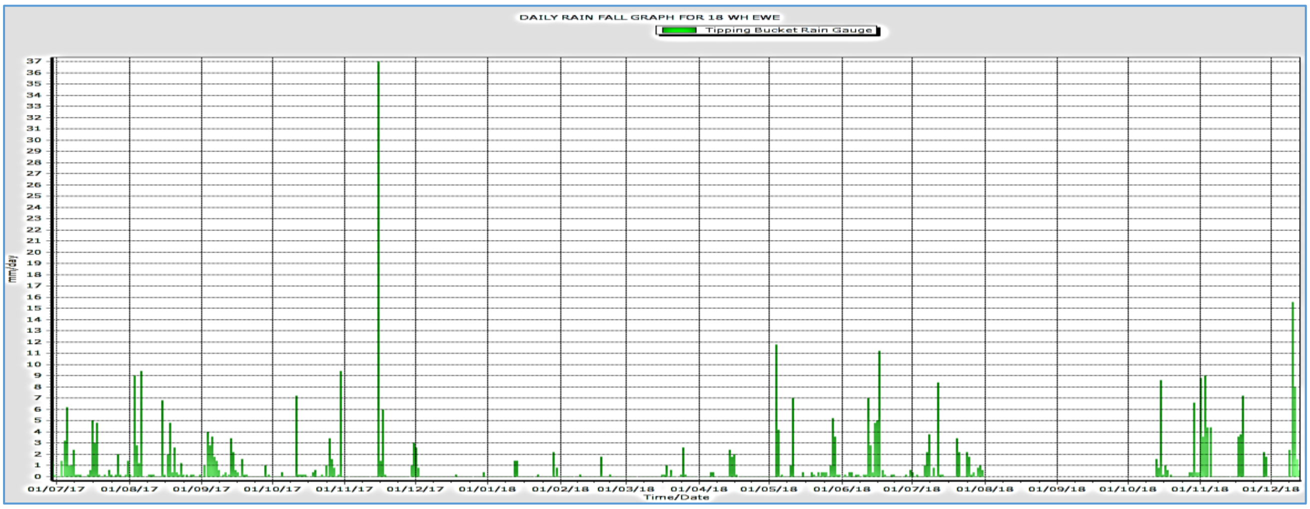


Figure 14. Rainfall, July 2017-Dec 2018



4.1 Soil Protection

One of the main features of using the strip spading method of header rows, is to reduce the risk to wind erosion when ameliorating sandy soils the complete spading in of organic materials, as shown in in Photos 6A&B.   There was no evidence of soil erosion occurring at any of the 3 sandy trial sites as a result of the initial spading operations. Wind erosion was also not evident in other areas outside of the trials, where the Spading Header Rows option was moved across one third of the header width to spade the whole paddock over a 3 year period.

Photo 6. A: Erosion of fully spaded sandhill; B: spaded header trials over same sandhill across adjacent paddocks at Lameroo (April 2016).

4.2 Yield Improvements

The yield improvements achieved by the spading of header rows over the 3 very challenging rainfall years of the trial was shown to be more frequent and higher than expected, as shown in Table 5.

Table 5. Average Yield Increases over Control plots for Spaded plots over all sites and years

Site	Extra Yield t/ha above Control		
Ewe Sand	**2017 Wheat**	**2018 Barley**	**2019 Lupins**
Spaded	0.39	0.01	0.09
Spaded Nutrition	0.05	0.24	0.10
Ewe Flat	**2017 Wheat**	**2018 Barley**	**2019 Lupins**
Spaded	-0.08	-0.27	-0.08
Spaded Nutrition	-0.07	-0.34	-0.08
Steers Sand	**2017 Lupins**	**2018 Canola**	**2019 Wheat**
Spaded	-0.13	0.82	1.41
Spaded Nutrition	-0.08	0.68	1.48
Steer Flat	**2017 Lupins**	**2018 Canola**	**2019 Wheat**
Spaded	-0.18	0.52	1.51
Spaded Nutrition	0.11	0.39	1.44
Dary Sand	**2017 Barley**	**2018 Wheat**	**2019 Wheat**
Spaded	1.06	0.76	0.12
Spaded Nutrition	0.77	0.55	0.09
Dary Flat	**2017 Barley**	**2018 Wheat**	**2019 Wheat**
Spaded	0.22	0.09	0.90
Spaded Nutrition	0.86	0.13	0.97

The Ewe paddock always showed exceptionally improved growth on the Spaded and Spaded Nutrition plots (Photos 7&8), but unfortunately frosts in 2017, pod shattering wind in 2019, and the nature of the white sands and the heavy sodic clay combined with a lack of spring rainfall each season meant that this improved yield potential was never realised at this site. (In 2019 there was superior lupin podding in the spaded plots, and while the rest of the paddock was windrowed, the standing trial sites suffered substantial grain loss from a hot windy day prior to harvest).

The most substantial yield increases were obtained from the Steers Paddock Sand and Flats in 2018 and 2019 (Figure 16). It would appear that the mixing of some straw and clay into the sandy profile on the rise on Steers Paddock, and some straw and surface sand into the sodic clay in the flat, provided key soil ameliorate to promote improved yields in canola and wheat (although initially detrimental to lupins).

Figure 15. Yield comparisons between treatments and years at Ewe paddock sites

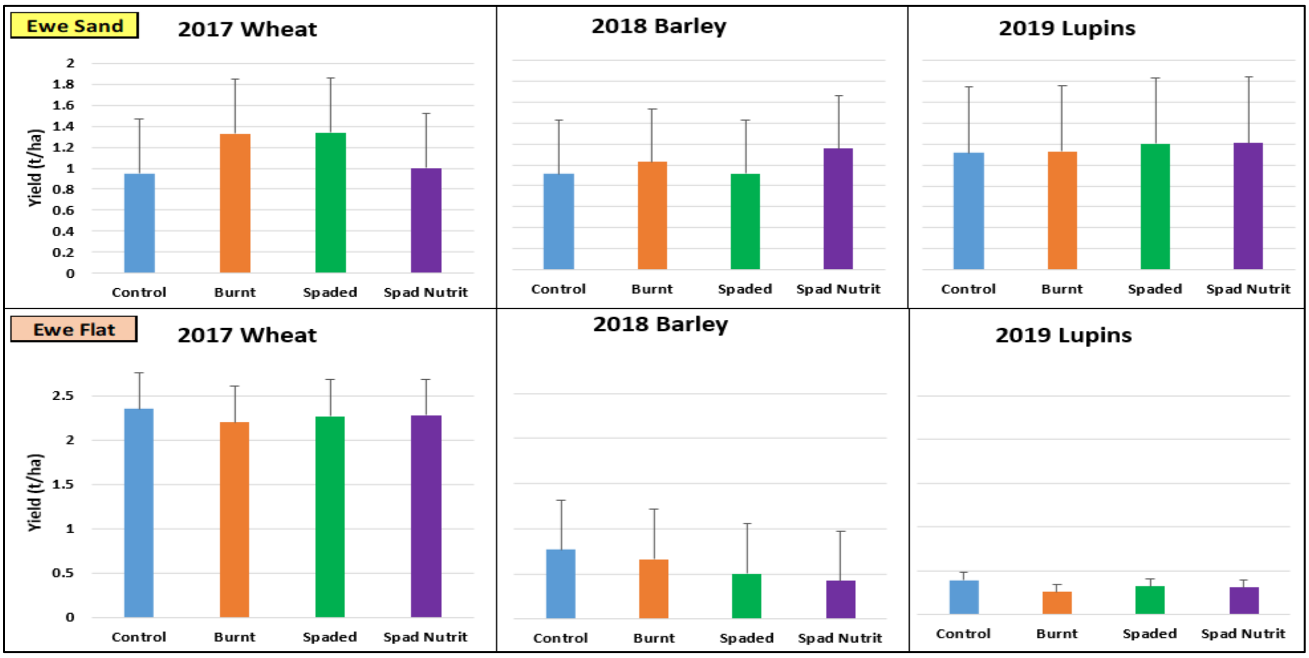
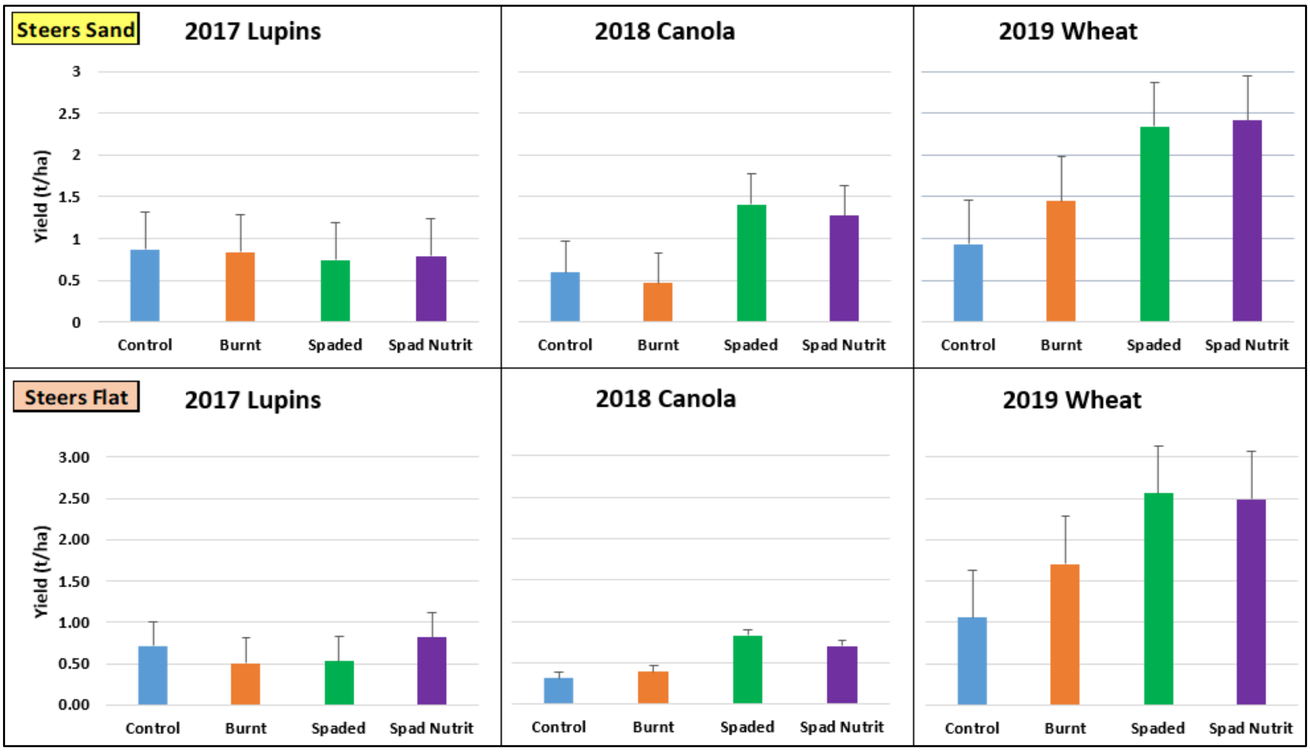


Photo 7. Clearly improved crop growth in spaded strips on Ewe Paddock Sand 2018

Photo 8. Superior 2019 early Lupin growth in Spaded Nutrition plot, Ewe Paddock 2019

Figure 16. Yield comparisons between treatments and years at Steers paddock site

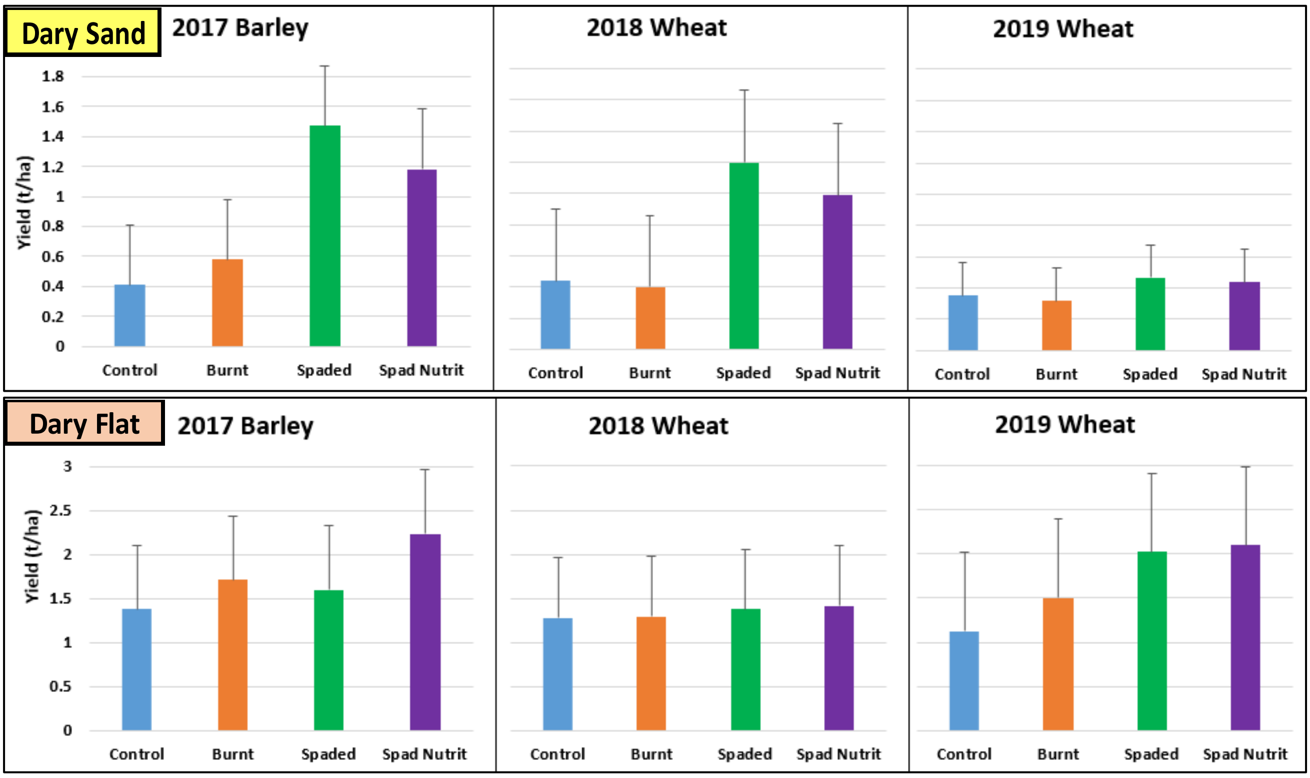


Yields in the Dary paddock proved significantly responsive to the spading treatments in 2019, but not so in 2018. The Sand site in 2019 had very poor yields mainly due to the very high ryegrass competition for moisture in a very poor season. This site shows the importance of getting whole farming system right to achieve the best results, as good rotational agronomy was not achieved in an attempt to test the weed seed burial technique under extreme circumstances and not quite getting it right.

This was clearly demonstrated in the area at the edge of the trial where 2 strips of spaded of header rows were applied with half rate and double the trials Spaded Nutrition rate, as a demonstration area for farmer interest. However, these strips were inadvertently sown to lupins with the rest of the Dary paddock in 2017 rather than wheat as in the trial site area. These strips therefore turned out to be on a far better crop sequence for both ryegrass control and nutrition. They were reaped by the trials plot harvester in 2019 achieving and averaged an amazing 2.1t/ha for the 2x Nutrition rate and 1.6t/ha for the half rate on (compared to 0.45t/ha for the Spaded Nutrition plots in the Dary Sand trial). On the Dary Flat the 2x Nutrition rate averaged 2.3t/ha and 2.7t/ha for the half rate (compared to 2.1t/ha for the Spaded Nutrition plots in the trial. This emphasises the importance of getting the whole farming systems right to get the maximum benefits from these soil amelioration treatments, and what could have been achieved at this site if a pulse crop had been able to be placed in this crop sequence.

All of these yield results suggest that this soil amelioration technique can be used to gain substantial yield increases in most soils, and that its' potential was not fully realised within the various circumstances occurring within this project.

Figure 17. Yield comparisons between treatments and years at Dary paddock sites



4.3 Economics

Despite the 3 years of well below average rainfall at the site, and the failure to demonstrate any clear advantage to ryegrass reduction through spading treatments, this trial has demonstrated economic reasons to justify the pursuit of these Spaded Header Row strategies based on the extra income achievable through higher yields on both sand and loamy flats.

Table 6 details the increased average yields obtained over the Control treatments by both the Spaded Header Row and the Spaded Header Row Nutrition treatments, for every site and every crop. It then converts these yield results into the extra income received based on the 5 year commodity price averages from PIRSA's 2019 Gross Margin and Enterprise Planning Guide (PIRSA

2019). This reveals that despite the Ewe Flat site consistently showing a negative income (due to the higher growth than yield potential crashing on this soil type with the lack of spring rainfall) and the first lupin crop after spading on Steers (suffering with sodic clay being brought to the surface upsetting germination), the extra income gained from all other sites and years far outweigh these negatives. Extra income on Steers paddock (despite 2017 losses) averaged between $207 and $256/ha /year.

Across all sites the Spading Header Rows alone produced the best financial outcomes on the sand, particularly when the extra $180/ha cost of the Spaded Nutrition treatment is taken into account (Table 3). However, it should be considered that these nutrition treatments on these highly infertile sands did result in superior crop potential that may well be realised and more profitable in more favourable rainfall years.

Table 6. Yield and Grain Income Increases of Spading Header Row Treatments over Control

Site	Extra Yield t/ha			Extra income $/ha			3 Yr Total	Ave
Ewe Sand	2017 Wheat	2018 Barley	2019 Lupins	2017 Wheat	2018 Barley	2019 Lupins	$/ha	$/ha/yr
Spaded	0.39	0.01	0.09	108	1	32	142	47
Spaded Nutrition	0.05	0.24	0.10	14	64	34	112	37
Ewe Flat	2017 Wheat	2018 Barley	2019 Lupins	2017 Wheat	2018 Barley	2019 Lupins		
Spaded	-0.08	-0.27	-0.08	-22	-70	-26	-119	-40
Spaded Nutrition	-0.07	-0.34	-0.08	-19	-91	-29	-140	-47
Steers Sand	2017 Lupins	2018 Canola	2019 Wheat	2017 Lupins	2018 Canola	2019 Wheat		
Spaded	-0.13	0.82	1.41	-46	420	393	767	256
Spaded Nutrition	-0.08	0.68	1.48	-28	348	412	732	244
Steer Flat	2017 Lupins	2018 Canola	2019 Wheat	2017 Lupins	2018 Canola	2019 Wheat		
Spaded	-0.18	0.52	1.51	-64	266	419	621	207
Spaded Nutrition	0.11	0.39	1.44	37	200	399	636	212
Dary Sand	2017 Barley	2018 Wheat	2019 Wheat	2017 Barley	2018 Wheat	2019 Wheat		
Spaded	1.06	0.76	0.12	281	211	33	525	175
Spaded Nutrition	0.77	0.55	0.09	204	153	25	382	127
Dary Flat	2017 Barley	2018 Wheat	2019 Wheat	2017 Barley	2018 Wheat	2019 Wheat		
Spaded	0.22	0.09	0.90	58	26	251	335	112
Spaded Nutrition	0.86	0.13	0.97	228	37	271	535	178
5 Year Ave Grain Prices ($/t)		Average increased income across all sites from Spading Header Rows					Sand	159
Wheat	278						Flat	93
Barley*	265						Combined	126
Lupins	353	Average increased income across all sites from Spading Header Rows with Nutrition					Sand	136
Canola	512						Flat	115
* ave of Malt and Feed Price							Combined	125

NB. 5 year average grain prices taken from PIRSA's 2019 Gross Margin and Enterprise Planning Guide

The current cost of a new 4.5m wide Farmax Spading machine is $160,000 and approximately $120,000 second hand. For a farmer to apply a spading operation for subsoil amelioration over their entire farm over 3 years by moving over header rows by 4m each year to profile increased organic matter and nutrition, it may make more sense for them to purchase their own spading machine. Using local spading contract rates of $300/hr, and an estimate of 3ha/hr, the spading costs come to approximately $100/ha. In the dry soils (particularly with heavier textured soils, there is a benefit to deep ripping the strips prior to spading. This is estimated at $50/ha. Where high nutrition was applied to assist with stubble breakdown and feed the increased yield potential, this has added an extra $180/ha (100kg/ha MAP + 200kg/ha Urea). This is summarised within Table 7, highlighting the costs of different combinations of operations, depending on the circumstances in which this strategy may be applied.

Table 7. Estimated cost/ha of Spading Header Row operations

Operations	All operations $/ha	Spading alone $/ha	Ripping & Spading $/ha	High Nutrition & Spading $/ha
Spading	100	100	100	100
Ripping	50		50	
High Nutrition	180			180
Total Costs	330	100	150	280
Cost/year/paddock (spading 4.5m strips, or 1/3 of paddock)	110	33	50	93

It is difficult to make a direct and clear final economic analysis of the exact $ benefits of applying this Spading Header Row treatments across a whole farming system basis, involving so many variables in soil types, rotations, machinery ownership, farm business management and seasonal factors. However, by presenting a clear estimation of the costs involved (Table 7) and the analysis of the benefits achieved at this Lameroo farm despite three very low rainfall years in a row, it is clear that pursuing this strategy for subsoil amelioration is justifiable, even with the highest cost options being applied. With total cost of the Spaded Nutrition treatment being $330/ha, the average increased income over the 3 drought years was $375/ha. It is also expected that many of the benefits obtained to produce these higher yields will last far longer than the 3 years of this trial.

The benefits of Spading header rows without added nutrition, even including the cost of the preceding ripping operation, would see a potential $378/ha increase for a cost of $150/ha, according to the figures presented in Tables 6 and 7. This provides strong justification for farmers to be able to purchase their own Spading and Ripping equipment, so they can utilise it across their farm at optimal times at their own convenience.

4.4 Contribution to Knowledge on Sub-soil Amelioration

While the trial has shown that this form of spading header rows is not a reliable tool for combatting ryegrass, it has also made a strong contribution to the farming and scientific community in areas of subsoil ameliorations though spading. This has been particularly evident in the way in which this trials findings were utilised within a joint paper and presentation at the Australian Agronomy Conference in Wagga Wagga 2019 (Desbiolles et al, 2019) providing a key source of longer term field data.

This trial has also contributed data that has been presented to farmers and agricultural industry representatives in at least 25 forums across the South Australian and Victorian Mallee and Eyre Peninsula, in relation to farmers attaining sandhill amelioration for management the growing issues of seeps and perched water tables. This is becoming a rapidly growing issue within modern farming systems. This author presented at the GRDC Advisors Update in Adelaide in February 2020 on this issue, including data from this SAGIT trial.

5 Conclusions

This large scale three year Spading Header Rows farming systems trial, utilizing the farmers equipment and fitting within the farmers actual practical operations over 6 sites across three paddock, has produced key outcomes that have answered the original aims of the project.

This work has shown that in its current form, the spading of header rows was not successful in burying enough weed seed to adequately reduce ryegrass populations over a three year period.

Project results have revealed that the amelioration of subsoils through this practical and convenient spading header rows technique has led to significant yield increases across a range of sites (various soil types and rotation phases), despite the 3 extremely challenging rainfall years across the southern Mallee. While the most profitable technique was shown to be spading header rows without the extra addition of fertiliser, it is possible that the spading of header rows with additional fertiliser could be more beneficial in years with average rainfall. The increased income gained spading header rows was found to average approximately $125/ha across all sites and years of the trial, which was shown to be more than enough to justify farmers pursuing the potential equipment purchases and inputs required to achieve these outcomes.

Further work is required to test these outcomes in more environments and in more favourable growing seasons.

6 References

Desbiolles J, Saunders C, McDonough C, Moodie M (2019) Improving the adoptability of spading practices in constrained sandy soil environments. *Proceedings of the 2019 Agronomy Australia Conference, 25 – 29 August 2019, Wagga Wagga, Australia.* http://www.agronomyaustraliaproceedings.org/images/sampledata/2019/2019ASA_Saunders_Chris_196.pdf.

PIRSA (2019) Farm Gross Margin and Enterprise Planning Guide 2019, Rural Solutions SA, Adelaide