More profitable crops on highly calcareous soils by improving early vigour and overcoming soil constraints

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Location
Minnipa
Minnipa Agriculture Centre
Rainfall
Av. Annual: 325 mm
Av. GSR: 241 mm
2021 Total: 405 mm
2021 GSR: 248 mm
Paddock History
2020: Volunteer pasture
2021: Wheat
Soil type
Calcareous grey sand
Soil test
High pH and carbonate, poor P reserves, high N reserves
Plot size
30 m x 2 m x 4 reps
Trial design
Randomised complete block design (RCBD) x 4 reps
Yield limiting factors
Moisture, nutrition, hostile subsoil

Location
Poochera
Gosling Family
Rainfall
Av. Annual: 326 mm
Av. GSR: 247 mm
2021 Total: 362 mm
2021 GSR: 221 mm
Paddock History
2020: Volunteer pasture
2021: Barley
Soil type
Grey highly calcareous sandy loam
Soil test
Very high pH and carbonate, poor P reserves, high N reserves
Plot size
30 m x 2 m x 4 reps
Trial design
RCDB with 4 replicates
Yield limiting factors
Moisture, nutrition, hostile subsoil

Key messages

- **Bespoke biochar and Neutrog incorporated into the subsoil have shown great potential to improve both crop biomass and grain yield in this first year of conducting the trials.**
- **Bespoke biochar, a high seeding rate and adequate nutrition have also shown potential to improve crop yield when considered as a lower cost topsoil strategy.**
- **High plant densities can be simply achieved on highly calcareous soils by using high seeding rates.**
- **There was an indication of less crown roots at one site when fungicides and adequate nutrition were supplied at seeding. This response requires further investigation.**
- **A beneficial deep ripping response is less likely in these soils when multiple subsoil constraints are present.**
- **Biomass and grain yield penalties are highly likely when deep ripping with or without inclusion plates results in a rough seeding bed.**

Why do the trial?

Highly calcareous soils challenge crop production with a range of constraints and this limits the effectiveness of improved agronomic practices. Early crop vigour is poor and crop production continues to be limited to very low nitrogen (N) and water use efficiencies. Major constraints include poor phosphorus (P) status in crops, low water holding capacity, high burden of rhizoctonia, poor N cycling, severe fertiliser toxicity during germination. Constraints at depth can be extremely high pH, sodicity, salinity and low fertility. This new collaborative project involves teams of researchers from SARDI, Rural Solutions and NSW DPI, and is funded by the High-Performance Soils CRC and GRDC. This project aims to overcome these constraints in order to lift crop production on these difficult soils. There is also a complementary project funded by GRDC and undertaken by CSIRO which is investigating water and nutrient cycling in these soils as well as microbial activity and function.

The aim of this research initiative is to identify and overcome the impacts of topsoil and subsoil conditions of highly calcareous soils on crop productivity on the upper Eyre Peninsula. Outcomes will focus on modified agronomic practices and improved soil conditions which increase water use efficiency (WUE) of crops and farm profitability as well as improved knowledge of the impact of high carbonate on crop performance.

How was it done?

Three sites on the Upper Eyre Peninsula (UEP) at Minnipa, Poochera and Port Kenny were established in 2021 with two replicated field trials at each of the sites. They are investigating strategies to improve early crop vigour by overcoming soil constraints on poor performing highly calcareous soils.

Location
Port Kenny
Guerin family
Rainfall
Av. Annual: 349 mm
Av. GSR: 270 mm
2021 Total: 379 mm
2021 GSR: 261 mm
Paddock History
2020: Volunteer pasture
2021: Barley
Soil type
Grey highly calcareous sandy loam
Soil test
Very high pH and carbonate, poor P reserves, high N reserves
Plot size
30 m x 2 m x 4 reps
Trial design
RCDB with 4 replicates
Yield limiting factors
Moisture, nutrition, hostile subsoil

Three of the six trials were set up to investigate long-term subsoil strategies, and the other three, short-term topsoil strategies. A replicated field demonstration trial which was established in 2020 at Poochera, was re-seeded in 2021.

Soil analysis identified medium to very high carbonates, which increased with depth at all three sites (Table 1). Port Kenny is highly calcareous with water repellence in the top 10 cm. Port Kenny and Poochera have high levels of salinity in subsurface layers while boron is high in subsurface layers at Minnipa.

Subsoil treatments were implemented on 14 May at Minnipa, on 18 May at Poochera and on 19 May at Port Kenny. These subsoil treatments included a mixture of interventions using deep ripping with or without inclusion plates and organic matter (Table 2).

All but one of the topsoil treatments (Table 3) were intended as annual strategies implemented at sowing. Sweep cultivation was implemented on 15 April at all sites to simulate a practice common in these districts and as a strategy to reduce rhizoctonia. Treatments for the field demonstration trial at Poochera were the same as the previous year (EPFSS 2020, p. 73) and were not refreshed. Biochar used in the demo trial was different to the bespoke biochar used in the topsoil and subsoil trials. Bespoke biochar is phosphoric acid activated during its preparation and was sourced from our collaborative research partners - NSW DPI.

In 2021, all the trials were sown to Scepter wheat (60 kg/ha standard rate) with 50 kg/ha DAP as a basal on 4 June (Minnipa), 5 June (Poochera) and 6 June (Port Kenny).

Plant density, early and late crop biomass, root health, nutrient status, grain yield and quality were all assessed in 2021.

Table 1. Surface (0-10 cm) and subsurface (60-80 cm) soil characterisation at 3 sites in 2021.

Site	Depth cm	pH $CaCl_2$	Colwell P mg/kg	Nitrate N mg/kg	Exch Na mg/kg	Boron mg/kg	MED (0-5 cm) molar	Carbonates %
Minnipa	0 - 10	7.9	36	45	107	2.7	0	15
	60 - 80	8.5	<10	18	2455	24		40
Poochera	0 - 10	7.9	31	33	40	2.1	0	40
	60 - 80	8.4	<10	25	665	9.1		50
Port Kenny	0 - 10	7.9	45	52	127	2.2	1.2	75
	60 - 80	8.4	<10	19	524	9.6		82

Table 2. Summary of subsoil treatments.

Treatment	Treatment details
Typical practice (Control)	60 kg/ha seed, 50 kg/ha DAP
Deep rip only	Typical practice + deep ripping
Deep rip with inclusion plates	Typical practice + deep ripping with inclusion plates
Deep rip with inclusion plates + Neutrog	Typical practice + deep ripping with inclusion plates + Neutrog pellets
Deep rip + Neutrog	Typical practice + deep ripping with Neutrog pellets
Deep rip + granular fert (to match N & P in Neutrog)	Typical practice + deep ripping + 75 kg/ha urea + 250 kg/ha DAP
Deep rip + Bespoke biochar	Typical practice + deep ripping + Bespoke biochar
Deep rip + granular fert (to match N & P in Biochar)	Typical practice + deep ripping + 375 kg/ha DAP
Deep rip + Phos acid	Typical practice + deep ripping + 115 L/ha Phos acid
Deep rip + Phos acid + trace elements	Typical practice + deep ripping + 115 L/ha Phos acid + Zn:Cu:Mn (3:2:5)

Table 3. Summary of topsoil treatments

Treatments		kg/ha							L/ha			kg/ha		
		Seed rate	DAP at seeding	Urea*	MAP at seeding	Urea (fluid)	SOA banded	Biochar banded	Phos acid	Fungicide (Uniform)	Wetter (SE14)	Zn	Mn	Cu
1	Typical practice (Control)	60	50											
2	P + TEs delivered as a fluid	60				20			37			2	3	1
3	Urea broadcast pre-seeding	60	50	89										
4	Anti-Rhizoctonia^ + TEs chelates + fluid P and N	60				20			37	0.4		2	3	1
5	Anti-Rhizoctonia^ + TEs chelates + granular P and N	60	50				205			0.4		2	3	1
6	SE14 Wetter in the seed row	60	50								3			
7	Banded bespoke biochar + Urea*	60	50	89				500						
8	Granular N and P to match Biochar + Urea*	60	50	89	34									
9	Higher seeding rate	90	50											
10	Sweep cultivation 4 weeks pre-seeding	60	50											
11	Combination of treatments 4 and 9	90				20	205		37			2	3	1
12	Seed coating	60	50											
13	Continuous P supply (Treatment 2 + 2 x 2 kg P foliar)	60				20			37			2	3	1

^ Uniform fungicide on the seed + banded + furrow application
** Broadcast pre-seeding*

What happened?

Plant density

In the subsoil trials, deep ripping with inclusion plates caused a lot of soil disturbance which resulted in a rough and cloddy seedbed, and consequently the lowest plant densities at all sites. In comparison to typical practice (control), deep ripping with inclusion plates resulted in a 50% (Minnipa), 34% (Port Kenny) and 25% (Poochera) reduction in plant population. Furthermore, deep ripping without inclusion plates reduced plant density by 14% at Port Kenny, 20% at Poochera and 33% at Minnipa.

In the topsoil trials, mean plant density was 100 plants/m^2 at Minnipa, 103 plants/m^2 at Port Kenny, and 106 plants/m^2 at Poochera. A higher seeding rate (90 kg/ha) resulted in the highest plant densities at all sites, and none of the other strategies significantly improved plant density. Higher seeding rate resulted in 150 plants/m^2 (Minnipa), 161 plants/m^2 (Port Kenny) and 162 plants/m^2 (Poochera).

Soil compaction

Soil penetration resistance was measured on 10 August to a depth of 50 cm. Figure 1 shows that soil compaction is not a constraint likely to limit crop root growth at Poochera because penetration resistance was always below the level considered to inhibit root growth, 2500 kPa. There appeared to be a compacted layer at Minnipa at a depth of 25 cm and at Port Kenny at 15 cm. Deep ripping reduced resistance throughout the top 40 cm but may have increased it in the layer just below where the ripper tines reached at Port Kenny.

Plant nutrient status at flowering

P, sulphur (S) and zinc (Zn) were marginal to deficient for all three sites. However, potassium, manganese (Mn) and copper (Cu) levels were adequate and well above critical thresholds.

In the subsoil trials, bespoke biochar resulted in higher shoot P at Minnipa, and higher Mn at Poochera when compared to "Typical practice" (Appendix). Treatments with Neutrog also had higher Zn and Cu at Port Kenny and Poochera when compared to typical practice. Nitrogen status was highest in deep ripped plots with inclusion plates and Neutrog at Poochera.

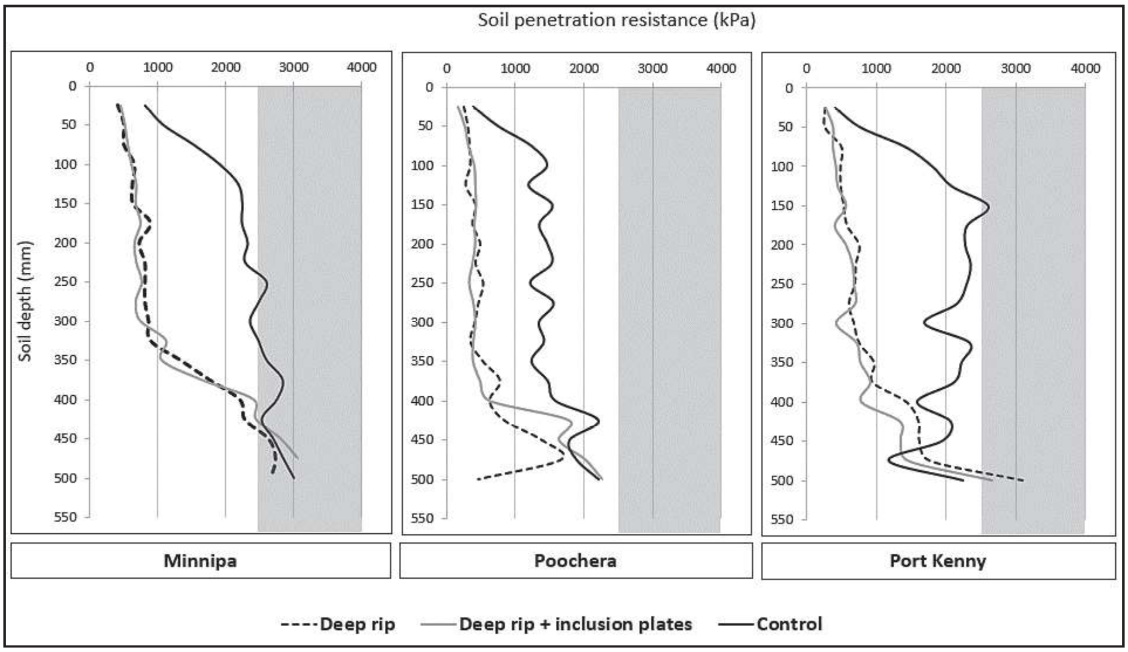

Figure 1. Soil penetration resistance (kPa) with no ripping (control) and after ripping with and without inclusion plates at Minnipa, Poochera and Port Kenny. The shaded grey zone represents "severe" penetration resistance greaten than 2500 kPa where root penetration and growth is significantly reduced.

In the topsoil trials, "continuous P" resulted in significantly higher levels of shoot P at Minnipa and Port Kenny but did not affect P levels at Poochera. The "combination" treatment resulted in significantly higher levels of leaf K, S and Mn at Minnipa, when compared to typical practice.

Root health

Root sampling was caried out on 3 August to assess root health (score 0-5 where 0 = no disease, and 5 = roots with absence of laterals and hairs, plant terminal), but only % crown roots infected and seminal scores are reported here.

In the subsoil trial, none of the treatments changed root health at Minnipa or Port Kenny. However, at Poochera, Neutrog (3.1) and deep rip (2.9) improved seminal root health when compared to the control (2.2).

In the demonstration trial at Poochera, the percentage of infected crown roots was lower with bespoke biochar (23%), Neutrog (28%) and deep ripping (33%), when compared to the control (52%).

In the topsoil trial, root health was not affected by any of the strategies implemented at Port Kenny. However, at Poochera, the percentage of crown roots infected was lower in the two treatments which had fungicides (20%), when compared to the control (48%). High seeding rate resulted in the highest % infected crown roots (70%) at Poochera (70%) and at Minnipa (77%). At Minnipa, the lowest crown root infection occurred with sweep cultivation (52%). The control had 64% infection.

Flowering biomass

In the topsoil trial, bespoke biochar and the combination strategy consistently yielded more biomass than the control. The biomass difference was 1.6 t/ha at Minnipa and Port Kenny and 0.7 t/ha at Poochera, when compared to the control (Table 4). At Port Kenny, high seeding rate increased biomass by 22% compared to the control.

Treatments imposed in 2020 did not affect flowering biomass in the Poochera demonstration trial.

In the subsoil trial, flowering biomass was not affected by any of the subsoil strategies implemented at Minnipa and Poochera. However, at Port Kenny, bespoke biochar (4.5 t/ha) and Neutrog (4.3 t/ha) had higher flowering biomass than the control (3.3 t/ha). Physical disturbance through deep ripping (with or without inclusion plates) did not improve flowering biomass at any site.

Grain yield and protein

Harvesting of trials commenced on 17 December. In the subsoil trial at Minnipa, none of the strategies improved grain yield (Figure 2) above the control which was the highest yielding treatment at 3.51 t/ha. Deep ripping with inclusion plates had the lowest yield (2.58 t/ha). At Poochera, deep ripping and incorporating 5 t/ha of bespoke biochar (3.13 t/ha) or Neutrog (3.04 t/ha) had higher yields than the control (2.57 t/ha). Deep ripping with inclusion plates and Neutrog, and deep ripping with phosphoric acid and trace elements (Zn, Cu, Mn) also yielded better than the control.

Table 4. Flowering biomass (t/ha) at Minnipa, Poochera and Port Kenny.

Treatments	Minnipa	Poochera	Port Kenny
Banded bespoke biochar + Urea	5.66 a	4.14 ab	4.68 a
Combination*	5.58 ab	4.28 a	4.65 a
Continuous P supply (Treatment 2 + 2 x 2 kg P foliar)	5.05 abc	3.28 c	2.98 cd
High seed rate (90 kg/ha)	4.89 abcd	3.33 c	3.74 b
Granular N and P to match Biochar + Urea	4.71 bcd	3.46 bc	3.24 bc
Fungicide + TEs chelates + granular P and N	4.43 cd	4.31 a	3.03 cd
Sweep cultivation 4 weeks pre-seeding	4.55 cd	3.47 bc	3.31 bc
P + TEs delivered as a fluid	4.56 cd	3.23 c	3.33 bc
Seed coating	4.40 cd	3.04 c	2.72 cd
Urea broadcast pre-seeding	4.61 cd	3.43 bc	2.88 cd
SE14 Wetter in the seed row	4.28 cd	2.97 c	2.52 d
Fungicide + TEs chelates + fluid P and N	4.09 d	3.20 c	2.69 cd
Typical practice (control)	**4.08 d**	**3.44 bc**	**3.07 cd**
P value	*0.002*	*0.004*	*<0.001*

** High seed rate + fungicide + TEs + fluid P + urea*

At Port Kenny, deep ripping with inclusion plates and incorporating Neutrog pellets resulted in the highest yield (2.51 t/ha), and deep ripping with bespoke biochar (2.24 t/ha) or with Neutrog (2.26 t/ha) also yielded better than the control (1.86 t/ha).

In the topsoil trial (Figure 3) at Minnipa, bespoke biochar had the highest yield (3.44 t/ha), while continuous P (3.24 t/ha), combination (3.27 t/ha) and phos acid + trace elements (3.19 t/ha) also yielded higher than typical practice (2.82 t/ha). At Poochera, only the combination treatment (3.27 t/ha) and bespoke biochar (3.09 t/ha) had higher yields than the control (2.66 t/ha). At Port Kenny, bespoke biochar (2.42 t/ha) and the combination treatment (2.38 t/ha) were the highest yielding treatments. The high seeding rate (2.07 t/ha) also yielded better than the control (1.7 t/ha).

In the demonstration trial at Poochera (Figure 4), biochar and Neutrog incorporated by ripping in 2020 resulted in yields better than the control in 2021. Physical intervention alone did not improve grain yield in the second crop after ripping.

In the subsoil trials, there was a trend at Port Kenny and Poochera of higher grain protein in treatments that had Neutrog, bespoke biochar, or phos acid and trace elements. Highest grain protein (12.3%, 10.2%) was in the deep ripped + granular fert (to match N and P in Neutrog) at Poochera and Port Kenny respectively.

In the topsoil trials, grain protein at Minnipa was not affected by any of the strategies and it ranged from 10.1 - 10.5%. However, at Poochera and Port Kenny, there was a consistent trend of higher protein in treatments that had fungicide + trace elements. AntiRhizo+ granNP +TEs treatment resulted in the highest grain protein at Poochera (11%) and Port Kenny (10.15%). The combination treatment (10.9%), broadcast urea (10.8%) and bespoke biochar (10.8%) also had higher grain protein than the control (10.4%) at Poochera. Higher seeding rate with standard nutrition had the lowest grain protein (10.1%).

In the demonstration trial at Poochera, both Neutrog (12.1%) and biochar (11.5%) had higher grain protein than the control (10.8%).

What does this mean?

The focus of this project is to assess long-term (subsoil) and short-term topsoil strategies that have the potential to improve early vigour, overcome constraints and improve crop production on challenging highly calcareous soils.

Our trials have shown that higher plant densities can be achieved in highly calcareous soils by an approach as simple as using higher seeding rates. However, our data also suggests that the high plant densities have to be complemented with more nutrition and fungicides for disease protection to fully realise the benefits of more plants per square metre.

On the other hand, there can be a penalty from physical disturbance using deep rippers and inclusion plates, as a result of a rough seed bed. Even where crop establishment following ripping has been reasonable, benefits from deep physical disturbance have been small or absent. This is supported by the penetration resistance measurements which are under 3000 kPa to a depth of 40 cm at all the sites. Values much higher than this are common in siliceous sands where deep ripping is producing large crop production increases.

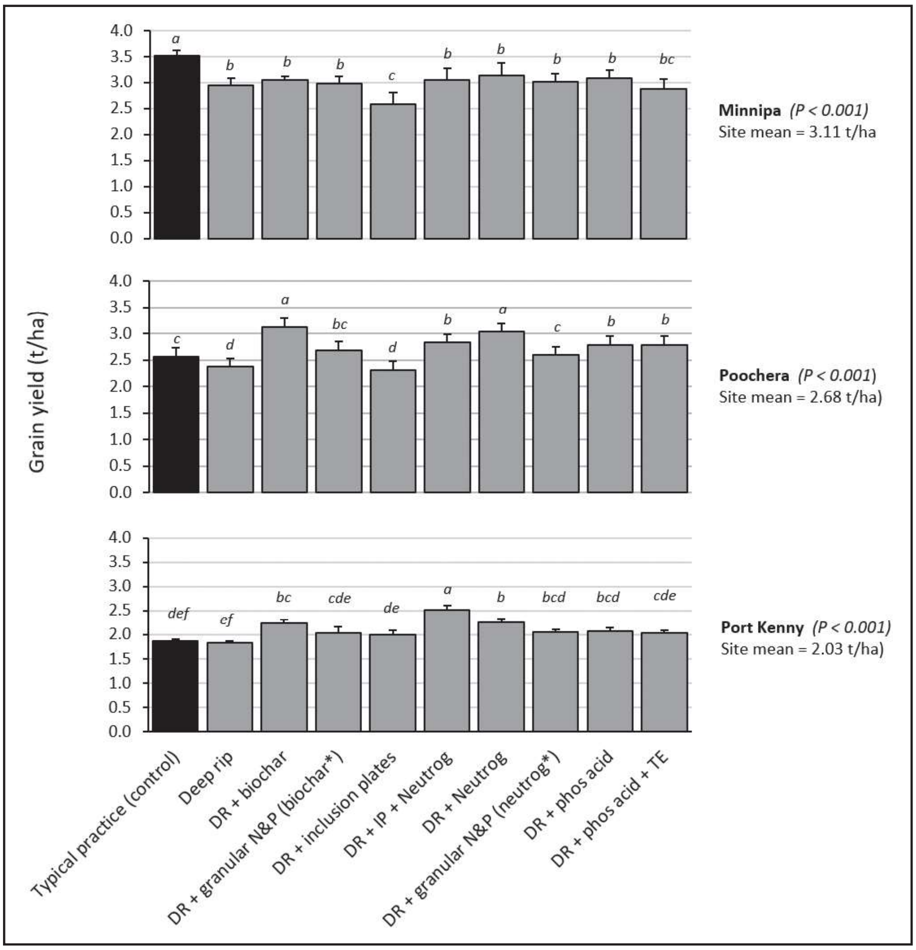

Figure 2. Grain yield (t/ha) for subsoil trials at Minnipa, Poochera and Port Kenny.
Error bars represent standard error. Acronyms DR = Deep rip, IP = inclusion plates, TE = trace elements.
** Represents treatments with nitrogen and phosphorus added as granular fertiliser to match N and P in biochar or Neutrog.*

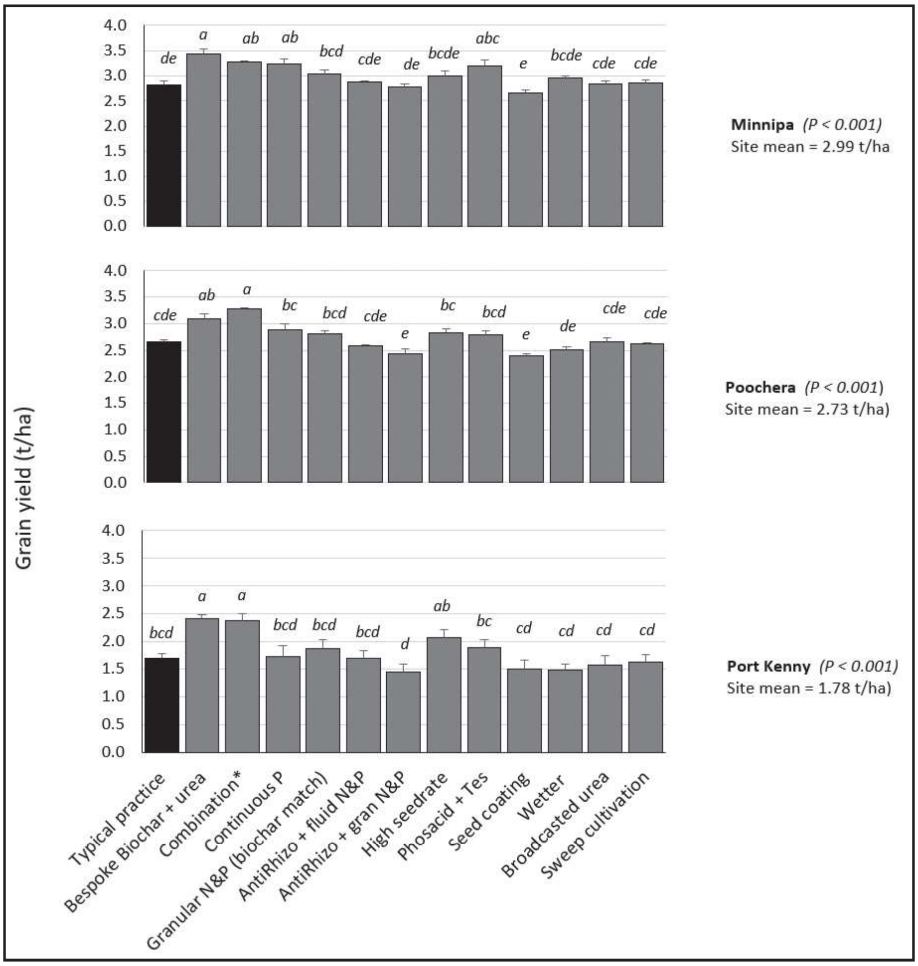

Figure 3. Grain yield (t/ha) for the topsoil trials at Minnipa, Poochera and Port Kenny.
Error bars represent standard error.
**Combination = High seeding rate + fungicide + TEs + fluid P + urea*

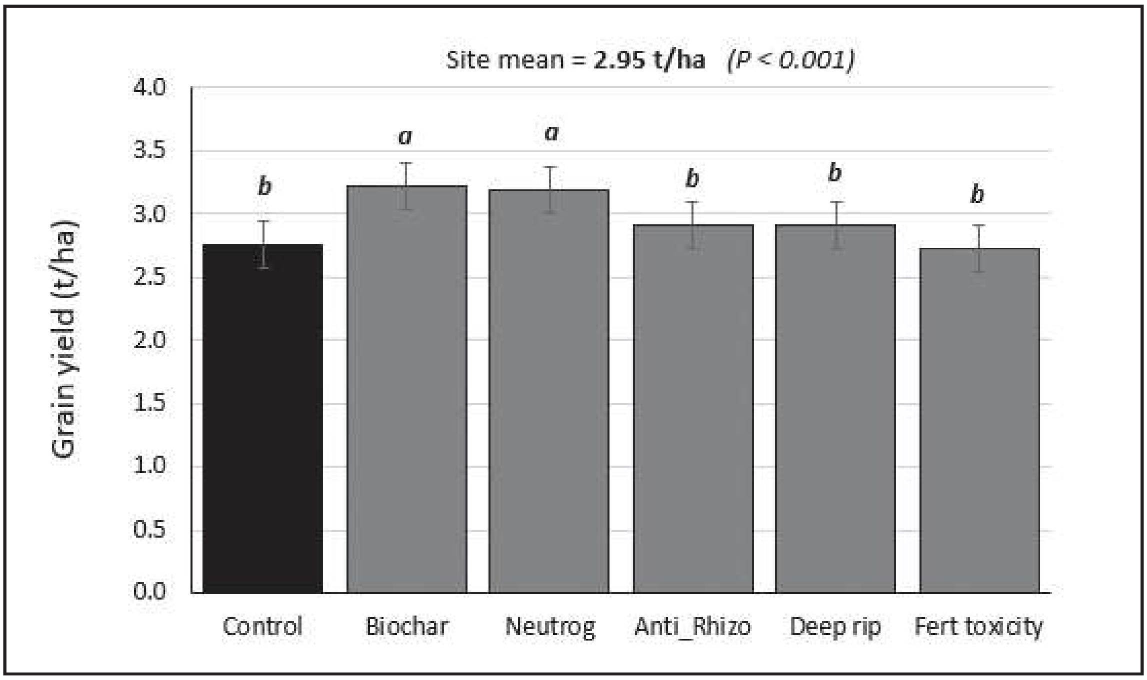

Figure 4. Grain yield (t/ha) at the demo trial at Poochera.
Error bars represent least significant differences (LSD).

Our results have been inconsistent in terms of strategies that can improve root health, however there is an indication from one of the sites (Poochera) of less crown root infection when fungicides are used at seeding with adequate nutrition.

In terms of final grain yield, deep ripping and incorporating bespoke biochar or Neutrog into the subsoil has shown promise as a way to increase grain yield at the two sites which were highly calcareous (Poochera and Port Kenny).

From the short-term topsoil strategies, the combination treatment and bespoke biochar consistently showed potential to increase grain yield at all sites. It is also important to note that the bespoke biochar used in these trials has a lot of phosphoric acid incorporated during its preparation, and out yielded the "fertiliser control". Tissue analysis also suggests that the effect of bespoke biochar is not a simple nutrition one – it did not consistently boost nutrient levels in the crop but boosted grain yield. In a similar vein, the fertiliser control did not match the Neutrog either, so there is something about nutrient delivery from organic matter sources in calcareous soils which warrants further investigation. There was also an indication of a phosphorous and trace element response at Minnipa, a result which needs further investigation as this was not the case at the other sites. All sites had soil P reserves which were considered adequate but phosphorus levels in the crop at flowering were low for the control at all sites.

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