Section Editor:
Kaye Ferguson &
Rhiannon Schilling
SARDI

Section 1

Soils

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

Brian Dzoma[1], Nigel Wilhelm[1,2], Amanda Cook[1,2], Ian Richter[1] and Craig Standley[1]
[1]SARDI; [2]University of Adelaide.

Location
Minnipa
Minnipa Agricultural Centre
Rainfall
Av. Annual: 325 mm
Av. GSR: 241 mm
2022 Total: 529 mm
2022 GSR: 332 mm
Paddock history
2020: Volunteer pasture
2021: Wheat
2022: Barley
Soil type
Calcareous red loam
Soil test
high pH and carbonate, poor P reserves, high N reserves
Plot size
30 m x 2 m x 4 reps
Trial design
RCBD with 4 replicates
Yield limiting factors
Nutrition, hostile subsoil, Boron toxicity, net form of net blotch and rust leaf

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Location
Poochera - Gosling Family
Rainfall
Av. Annual: 326 mm
Av. GSR: 247 mm
2022 Total: 550 mm
2022 GSR: 300 mm
Paddock history
2020: Volunteer pasture
2021: Barley
2022: Wheat

Key messages

- **A mildly calcareous soil was less responsive than highly calcareous soils to strategies which aimed to improve crop vigour and crop productivity.**
- **Short-term topsoil strategies resulted in better gains in crop biomass and yield when compared to the more longer-term subsoil strategies.**
- **Increasing seeding rates and nutrition at sowing is effective at achieving high plant densities, crop biomass and grain yield.**
- **A carbon-coated mineral (bespoke biochar) in the topsoil improved crop vigour, biomass and grain yield as well as providing good benefits into the second crop.**
- **High soil strength is an issue in calcareous soils but positive responses to deep ripping are not common and are usually limited by the hostile subsoil.**

Why do the trial?

Highly calcareous soils challenge crop production with a range of constraints and this limits the effectiveness of improved agronomic practices used elsewhere. When this project commenced in 2020, a literature review was undertaken to identify and develop integrated solutions to reduce the impact of multiple constraints to cropping in highly calcareous soils. The findings from the literature review helped formulate practical topsoil and subsoil strategies that had potential to lift crop production on the upper Eyre Peninsula and on similar soil types in other cropping regions in south-eastern Australia.

Initial trials were set up in 2021 at Poochera, Port Kenny and Minnipa, however, this article summarises results of topsoil and subsoil strategies from the second crop seeded on these trials in 2022. For details of trial set up and past results, see the article in the 2021 EPFS Summary: More profitable crops on highly calcareous soils by improving early vigour and overcoming soil constraints, p. 44.

How was it done?

The six replicated field trials established in 2021 at Poochera, Port Kenny and Minnipa were re-seeded in May 2022 with Maximus barley and DAP, both @ 50 kg/ha. At the Minnipa subsoil trial prior to seeding, a roller was used to break up clods which were a result of deep ripping in 2021.

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
RCBD with 4 replicates
Yield limiting factors
Nutrition, hostile subsoil, rhizoctonia

Location
Port Kenny
Simon Guerin
Rainfall
Av. Annual: 349 mm
Av. GSR: 270 mm
2022 Total: 487 mm
2022 GSR: 346 mm
Paddock history
2020: Volunteer pasture
2021: Barley
2022: Wheat
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
RCBD with 4 replicates
Yield limiting factors
Nutrition, hostile subsoil, take-all, crown rot

This was to improve seed soil contact at sowing and hence crop emergence and establishment. In the topsoil trials, all treatments were implemented at sowing, apart from sweep cultivation which was done in April 2022. Treatments are summarised in the table 1 below, and for comprehensive details of rates and formulations, see EPFS Summary 2021 article: More profitable crops on highly calcareous soils by improving early vigour and overcoming soil constraints, p. 44.

Plant measurements included crop establishment, crop vigour, early (GS31) and late (flowering) biomass, rhizoctonia, root health, plant nutrient analysis at flowering, grain yield & quality. Statistical analysis of data was performed using standard ANOVA models in R.

What happened?

Crop establishment

In the subsoil trials, deep ripping with or without inclusion plates, organic matter or fertiliser did not change plant populations and they averaged 80 plants/m^2 at Poochera and Minnipa, and 94 plants/m^2 at Port Kenny. In the topsoil trials, a higher seed rate (High seedrate fungicide banded N phosacid TEs) improved plant populations by 126% at Poochera, 96% at Minnipa and 65% at Port Kenny. Plant populations were just below 90 plants/m^2 at all sites with standard seeding rates.

Early crop vigour

Subsoil strategies at Minnipa and Port Kenny did not affect early crop biomass, however, at Poochera, deep ripping with inclusion plates plus Neutrog improved crop biomass by 30% when compared with typical practice.

Fresh carbon-coated minerals @ 500 kg/ha improved plant vigour in topsoil trials at all three sites (Table 2).

Table 1. Summary of topsoil and subsoil treatments in 2022.

Topsoil treatments	Details
Carbon-coated minerals 100kg/ha	Carbon-coated minerals @ 100 kg/ha
Carbon-coated minerals 500kg/ha	Carbon-coated minerals @ 500 kg/ha
Broadcasted urea	Broadcasted urea pre-seeding
Continuous P	Fluid P + trace elements at seeding + 2 in-crop foliar P sprays
Fungicide banded N phosacid TEs	Uniform fungicide + banded urea + phos acid + TEs (Zn, Cu, Mn)
Fungicide GranNP TEs	Uniform fungicide + Granular N&P + TEs (Zn, Cu, Mn)
Granfert N&P carbon coated minerals match	Granular N&P + nutrients to match Carbon-coated minerals
High seedrate fungicide banded N phosacid TEs	High seedrate (75kg/ha) + uniform fungicide + urea + phos acid + TEs (Zn, Cu, Mn)
Phosacid TEs	Phos acid + TEs (Zn, Cu, Mn)
Residual carbon-coated minerals	Residual Carbon-coated minerals
SE14 Wetter	SE14 wetter
Seed coating	Seed coating of microbes
Sweep cultivation	Sweep cultivation (pre-seeding)
Typical practice	***Typical practice (control)***

Table 1. Summary of topsoil and subsoil treatments in 2022 (continued).

Subsoil treatments	Details
Deep rip	Deep rip
DR carbon-coated minerals	Deep rip + carbon-coated minerals @ 5 t/ha
DR granfert carbon-coated minerals match	Deep rip + granular fert to match nutrients in carbon-coated minerals
DR granfert NEUTROG match	Deep rip + granular fert to match nutrients in Neutrog
DR Inclusion plates	Deep rip + inclusion plates
DR Inclusion plates NEUTROG	Deep rip + inclusion plates + Neutrog @ 5 t/ha
DR Neutrog	Deep rip + Neutrof @ 5 t/ha
DR Phos acid	Deep rip + Phos acid
DR Phos acid TEs	Deep rip + Phos acid + trace elements (Zn, Cu, Mn)
Typical practice	Typical practice (No deep ripping)
SE14 Wetter	SE14 wetter
Seed coating	Seed coating of microbes
Sweep cultivation	Sweep cultivation (pre-seeding)
Typical practice	***Typical practice (control)***

Table 2. Crop vigour (g DM/plant) in topsoil trials at Poochera, Minnipa and Port Kenny, 2022.

Topsoil treatment	Poochera	Minnipa	Port Kenny
Carbon-coated minerals 100kg/ha	1.50 abc	1.43 a	1.19 bcd
Carbon-coated minerals 500kg/ha	1.71 a	1.44 a	1.36 ab
Broadcasted urea	1.35 abcde	1.07 bcd	0.87 efg
Continuous P	1.44 abcd	1.40 ab	1.20 abcd
Fungicide banded N phosacid TEs	1.45 abcd	1.20 abcd	1.45 a
Fungicide GranNP TEs	0.78 f	1.14 abcd	0.88 efg
Granfert N&P carbon-coated minerals match	1.48 abc	1.19 abcd	0.97 defg
High seedrate fungicide banded N phosacid TEs	1.01 ef	0.90 d	1.08 cdef
Phosacid TEs	1.01 ef	0.98 cd	1.24 abc
Residual carbon-coated minerals	1.63 ab	1.24 abc	1.11 bcde
SE14 Wetter	1.16 cdef	1.16 abcd	0.86 efg
Seed coating	1.00 ef	1.01 cd	0.83 fg
Sweep cultivation	1.05 def	1.18 abcd	0.74 g
Typical practice	***1.23 bcde***	***0.98 cd***	***1.07 cdef***
LSD (0.05)	*0.42*	*0.34*	*0.3*
P value	*0.001*	*0.03*	*<0.001*
Mean (g DM/plant)	**1.25**	**1.15**	**1.05**

Crop biomass at GS31 was not affected by any of the subsoil strategies at Minnipa and Port Kenny. However, at Poochera Neutrog and carbon-coated minerals improved early crop biomass by more than 70% when compared to typical practice.

In the topsoil trials, 'high seedrate fungicide banded N phosacid TEs' improved early crop biomass by 97% at Minnipa, 68% at Poochera and 106% at Port Kenny, compared to typical practice. Carbon-coated minerals also improved crop biomass at Poochera and Port Kenny, but not at Minnipa.

Late flowering biomass was affected by many but isolated rhizoctonia patches across the Poochera trial; by take-all and crown rot patches at Port Kenny; and by boron toxicity, net form of net blotch and leaf rust at the Minnipa site. Late flowering biomass was not affected by any of the subsoil strategies at Minnipa or Poochera. However, at Port Kenny, deep ripping with Neutrog (with or without inclusion plates) resulted in 30% more biomass than typical practice. Physical disturbance alone, by deep ripping with or without inclusion plates did not affect flowering biomass at any site.

In the topsoil trials, 'high seedrate fungicide banded N phosacid TEs' consistently produced higher flowering biomass than the typical practice at all three sites (Table 3).

Fresh and residual carbon-coated minerals @ 500 kg/ha yielded more biomass at Minnipa, when compared to typical practice. There was a 20% reduction in late flowering biomass at Poochera from the use of ‘SE14 wetter’ and from the ‘seed coating’ when compared to typical practice.

Rhizoctonia

Root health measurements in August assessed the impact of both topsoil and subsoil strategies on plant tillering, seminal root health and crown root infection by rhizoctonia. Scores were quite variable and there were few clear trends with topsoil treatments.

‘Fungicide banded N phosacid TEs’ resulted in more tillers per plant in all three topsoil trials.

Carbon-coated minerals also improved tiller numbers at Minnipa, while continuous P improved tiller numbers at Poochera. Overall root health at Poochera and Port Kenny was not affected by the treatments implemented. However, at Minnipa, all three ‘carbon-coated minerals’ treatments had healthier roots and better root health scores.

In the **subsoil** trials, tiller numbers were not affected by treatments at Poochera and Minnipa. However, at Port Kenny, ‘carbon-coated minerals’ improved tillers numbers by nearly one per plant, compared to typical practice (3 per plant). Seminal root health was not affected by any of the strategies at any site. Crown root infection was not affected at Port Kenny and Poochera. However, at Minnipa, typical practice had the highest crown root infection (52%), while ‘DR carbon-coated minerals’ (17%), ‘DR Phos acid’ (22%) and ‘DR Phos acid TEs’ (23%) had much lower levels.

Nutritional status

Table 4 summarises ANOVA outputs for responses of key plant nutrient concentrations in flowering DM to topsoil and subsoil treatments at the three sites.

In the subsoil trials, nitrate N, boron and copper concentrations in whole shoots were not affected by treatments at any site. However, at Minnipa the highest shoot P concentrations occurred in ‘DR_ carbon-coated minerals’ (0.11 %), and highest K concentrations in ‘DR Inclusion plates’ (2.7 %). Zinc shoot concentrations were higher in “DR Neutrog’ at Poochera and Port Kenny only.

In the topsoil trials, nitrate N concentration (mg/kg) in shoot biomass was higher with ‘Fungicide banded N phosacid TEs’ at Minnipa (348 mg/kg) and at Poochera (197 mg/kg). Shoot P was higher with ‘Continous P’ at both Poochera (0.16%) and Port Kenny (0.08%). The highest shoot zinc concentrations (mg/kg) were in ‘Fungicide GranNP TEs’ at Poochera (20) and at Port Kenny (12). At Minnipa, ‘High seedrate fungicide banded N phosacid TEs’ had the highest zinc concentration (14 mg/kg).

Grain production

All sites had high grain yields in 2022 with the subsoil Minnipa trial having the highest site mean grain yield of 4.3 t/ha (Table 5). No subsoil treatments changed grain yields at Minnipa, when compared to typical practice.

Table 3. Topsoil - Late flowering biomass (t DM/ha) at Poochera, Minnipa and Port Kenny, 2022.

Treatment	**Port Kenny**	**Poochera**	**Minnipa**
Carbon-coated minerals 100kg/ha	9.60 abc	9.14 abcd	6.85 bc
Carbon-coated minerals 500kg/ha	10.30 a	9.29 abc	6.46 bc
Broadcasted urea	8.76 bcd	7.56 def	6.85 bc
Continuous P	8.96 abcd	8.06 cdef	6.94 bc
Fungicide banded N phosacid_TEs	10.40 a	9.76 ab	6.61 bc
Fungicide GranNP TEs	9.36 abcd	7.56 def	7.34 bc
Granfert N&P carbon-coated minerals match	9.36 abcd	8.57 bcde	6.82 bc
High seedrate fungicide banded N phosacid TEs	9.96 ab	10.23 a	9.10 a
Phosacid TEs	9.63 abc	7.27 ef	7.68 b
Residual Carbon-coated minerals	9.90 ab	9.23 abc	7.33 bc
SE14 Wetter	6.96 ef	6.78 f	6.14 c
Seed coating	7.12 ef	6.75 f	6.28 c
Sweep cultivation	6.19 f	7.50 ef	7.37 bc
Typical practice	***8.33 cde***	***8.42 bcde***	***6.83 bc***
P value	*<0.001*	*0.001*	*0.02*
CV	*11.85*	*13.69*	*13.49*
Site mean (t DM/ha)	**8.86**	**8.25**	**7.07**

Table 4. Average nutrient concentrations in flowering DM at Minnipa, Poochera and Port Kenny in 2022 and the impact of treatments.

Subsoil	Minnipa		Poochera		Port Kenny	
	P value	mean	P value	mean	P value	mean
Nitrate N (mg/kg)	ns	82	ns	45	ns	30
Phosphorus (%)	0.01	0.09	ns	0.14	ns	0.04
Potassium (%)	0.001	2.4	ns	1.5	ns	2.3
Boron (mg/kg)	ns	42	ns	22	ns	18
Copper (mg/kg)	ns	5.5	ns	4.3	ns	4.6
Zinc (mg/kg)	ns	13	0.001	17	0.009	8
Manganese (mg/kg)	0.03	39	ns	16	0.03	8
Topsoil	**Minnipa**		**Poochera**		**Port Kenny**	
	P value	**mean**	**P value**	**mean**	**P value**	**mean**
Nitrate N (mg/kg)	<0.001	104	<0.001	58	ns	35
Phosphorus (%)	ns	0.09	0.001	0.11	<0.001	0.05
Potassium (%)	0.001	2.5	ns	1.8	<0.001	2.7
Boron (mg/kg)	ns	49	ns	24	ns	18
Copper (mg/kg)	ns	5.8	0.001	3.8	0.05	5.0
Zinc (mg/kg)	<0.001	15	0.01	16	<0.001	9
Manganese (mg/kg)	<0.001	39	0.001	15	ns	7

ns = Not statistically significant

At Poochera, all amendments applied into the subsoil increased yields above typical practice, with 'carbon-coated minerals' (4.41 t/ha) and 'Neutrog' (4.28) being the highest yielding treatments (Table 5). At Port Kenny, only Neutrog incorporated by inclusion plates yielded higher than typical practice.

Port Kenny had the highest yielding topsoil trial with mean barley grain yield of 4.09 t/ha. 'High seedrate fungicide banded N phosacid TEs' produced the highest barley grain yields at Minnipa (4.37 t/ha) and Poochera (4.17 t/ha) (Table 6).

At Port Kenny, 'carbon-coated minerals 500 kg/ha' resulted in the highest barley grain yields (4.76 t/ha). Carbon-coated minerals 500 kg/ha consistently yielded better than typical practice across all three sites. A positive P response was evident at Minnipa and Port Kenny because 'Continous P' and 'Phosacid TEs' yielded better than typical practice at these two sites.

Microbial seed-coating was the only treatment in the topsoil trials that yielded lower than typical practice.

Table 5. Effects of subsoil amendments on barley grain yield (t/ha) at Poochera, Minnipa and Port Kenny in 2022.

Subsoil treatments	Minnipa	Poochera	Port Kenny
	t/ha	t/ha	t/ha
Deep rip	4.41	3.90 bc	3.81 cd
DR carbon-coated minerals	4.42	4.41 a	3.95 bcd
DR granfert carbon-coated minerals match	4.18	4.04 abc	3.82 cd
DR granfert NEUTROG match	4.18	4.13 ab	4.23 ab
DR Inclusion plates	4.13	3.71 cd	3.87 bcd
DR Inclusion plates NEUTROG	4.42	4.20 ab	4.42 a
DR Neutrog	4.47	4.28 ab	4.13 abc
DR Phos acid	4.29	4.02 bc	3.71 d
DR Phos acid TEs	4.33	3.99 bc	3.84 bcd
Typical practice	***4.14***	***3.40 d***	***3.93 bcd***
P value	*0.177*	*<0.001*	*0.02*
LSD (P=0.05)	*ns*	*0.38*	*0.38*
CV	*4.85*	*6.57*	*6.65*
Site mean	**4.29**	**4.01**	**3.98**

Soils

Grain protein in the **subsoil** trials was highest at Minnipa (site average of 12.1%) compared to Poochera (11.3%) and Port Kenny (10.4%). Grain protein with granular fertiliser to match nitrogen and phosphorus in Neutrog (DR granfert NEUTROG match), had the highest protein at Minnipa (12.4%) and Port Kenny (10.7%). Grain proteins were not changed by treatments at Poochera.

In the **topsoil** trials, grain protein was also highest at Minnipa (site average of 12.1 %) compared to Poochera (11.3%) and Port Kenny (10.3%). 'High seedrate fungicide banded N phosacid TEs' had higher protein at all three sites, and typical practice had the lowest protein.

In the **subsoil** trials, typical practice had the highest cumulative grain yield at Minnipa (Table 7). At Poochera, 'DR carbon-coated minerals' had the highest cumulative change in grain yield (1.58 t/ha) over and above typical practice. DR Inclusion plates NEUTROG produced cumulative changes in grain yield over 15% of typical practice at both Poochera and Port Kenny.

In the **topsoil** trials, 'High seedrate fungicide banded N phosacid TEs' had more accumulated yield benefit at all three sites. Cumulative change in grain yield relative to typical practice was 1.13 t/ha at Minnipa, 1.54 t/ha at Poochera and 1.34 t/ha at Port Kenny (Table 7). Carbon-coated minerals 500 kg/ha resulted in the highest change in grain yield (1.99 t/ha at Poochera) of all treatments.

Table 6. Effects of topsoil strategies on barley grain yield (t/ha) at Poochera, Minnipa and Port Kenny in 2022.

Topsoil treatments	**Minnipa**	**Port Kenny**	**Poochera**
	t/ha	**t/ha**	**t/ha**
Broadcasted urea	3.71 de	4.14 b	3.55 cde
Carbon-coated minerals 100kg/ha	3.73 cde	4.21 b	3.75 bcd
Carbon-coated minerals 500kg/ha	3.92 bc	4.76 a	3.98 ab
Continuous P	4.00 b	4.19 b	3.70 bcd
Fungicide banded N phosacid TEs	3.84 bcde	4.36 b	3.84 abc
Fungicide GranNP TEs	3.65 ef	4.10 b	3.24 ef
Granfert N&P carbon-coated minerals_match	3.74 cde	4.33 b	3.71 bcd
High seedrate fungicide banded N phosacid TEs	4.37 a	4.35 b	4.17 a
Phosacid TEs	4.03 b	4.30 b	3.55 cde
Residual carbon-coated minerals	3.88 bcd	4.37 b	3.99 ab
SE14 Wetter	3.64 ef	3.68 c	3.25 e
Seed coating	3.48 f	3.70 c	2.89 f
Sweep cultivation	3.73 cde	3.32 c	3.54 cde
Typical practice	**3.69 de**	**3.49 c**	**3.44 de**
P value	*<0.001*	*<0.001*	*<0.001*
LSD (P=0.05)	*0.21*	*0.38*	*0.36*
CV	*3.87*	*6.52*	*6.96*
Site mean	**3.82**	**4.09**	**3.61**

Table 7. Cumulative change in grain yields (t/ha) in the topsoil and subsoil trials, relative to typical practice at Poochera, Minnipa and Port Kenny from 2021 to 2022.

Subsoil	**Minnipa**	**Poochera**	**Port Kenny**
Deep rip	-0.31	0.31	-0.15
DR carbon-coated minerals	-0.18	1.58	0.39
DR granfert carbon-coated minerals match	-0.50	0.76	0.07
DR granfert NEUTROG match	-0.46	0.76	0.50
DR Inclusion plates	-0.95	0.06	0.08
DR Inclusion plates NEUTROG	-0.19	1.07	1.14
DR Neutrog	-0.05	1.35	0.60
DR Phos acid	-0.29	0.85	-0.01
DR Phos acid TEs	-0.45	0.82	0.08
Cumulative yield (t/ha) - Typical practice	**7.66**	**5.97**	**5.79**

Topsoil	Minnipa	Poochera	Port Kenny
Broadcasted urea	0.04	0.52	0.12
Carbon-coated minerals 500kg/ha	0.85	1.99	0.97
Continuous P	0.73	0.74	0.48
Fungicide banded N phosacid TEs	0.20	0.87	0.33
Fungicide GranNP TEs	-0.07	0.36	-0.43
Granfert N&P carbon-coated minerals match	0.26	1.02	0.42
High seedrate fungicide banded N phosacid TEs	1.13	1.54	1.34
Phosacid TEs	0.71	1.01	0.25
SE14 Wetter	0.09	-0.03	-0.34
Seed coating	-0.36	0.01	-0.81
Sweep cultivation	0.08	-0.24	0.06
Cumulative yield (t/ha) - Typical practice	**6.51**	**5.19**	**6.10**

What does this mean?

The focus of this project was to assess the impact of long-term (subsoil) and year on year short-term topsoil strategies on early crop vigour, their ability to overcome constraints and on grain production on challenging highly calcareous soils.

After two years of conducting these trials, crop responses to the more costly subsoil strategies are smaller and less likely in highly calcareous soils with underlying physical, biological and chemical constraints. Ameliorating high soil strength by deep ripping has proven to be less effective on these types of soils than on other sands. In highly calcareous soils, the incorporation of organic amendments (neutrog and carbon-coated minerals) into subsoils has shown potential to improve crop production but is still economically dubious. However, this response needs to be validated over more situations to determine their general impact on longer-term crop productivity and profitability.

Several short-term and cheaper topsoil strategies have good potential to increase crop vigour and productivity. Plant populations, crop biomass and grain yields can be improved through the use of higher sowing rates, providing that the denser plant populations are supported by improved nutrition (N and P and trace elements). Carbon-coated minerals have also boosted crop vigour and biomass production when placed just below the seed. We believe that at least part of the benefits from this carbon-coated mineral is to deliver P to the crop in a more effective way than current mineral fertilisers. The availability of P in these challenging soils is always low and several other treatments with higher P also improved crop production. Carbon-coated minerals at a lower rate (100 kg/ha) did not perform as well as the initial higher rate of 500 kg/ha but the residual benefits of carbon-coated minerals were very good. Further investigation is needed to determine how best to apply carbon-coated minerals and how low they can be applied to improve crop growth and productivity.

In the meantime, farmers can improve crop production on highly calcareous soils by increasing seed and fertiliser rates above those typically used.

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