Soils & Tillage

A survey of soil organic C and dissolved organic C on the upper Eyre Peninsula

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Key messages

• Soil organic carbon (C) concentrations from paddocks on the upper Eyre Peninsula are comparable to concentrations measured on alkaline soils from the Lower North of South Australia, but higher than those from paddocks in north-western Victoria.

• High soil pH was associated with lower concentrations of soil organic C and increased concentrations of dissolved organic C, both of which may restrict soil organic C accumulation.

• Increased cropping intensity was associated with lower soil C reserves and this trend appears to be little affected by the type of farming system practised.

Why do the trial?

This work was undertaken to survey soils on the upper Eyre Peninsula (EP) to measure the concentrations of soil organic C and dissolved organic C.

Despite widespread distribution of alkaline soils in southern Australia, relatively little work has been done to understand the chemistry of soil organic C at high pH and how this may influence the accumulation of soil organic C. Total soil organic C is made up of a number of fractions, one of which is dissolved organic C. Although it is only a small fraction of the total soil C pool, dissolved organic C is the most mobile and reactive of the soil C fractions and it helps to regulate a number of biological and chemical processes in soil. It can be an important substrate for soil microbial growth and is important in nutrient cycling. High pH increases the solubilisation of soil organic C and the amount of dissolved organic C in soils. The purpose of this work was to survey soil organic C and dissolved organic C concentrations in alkaline soils in three regions of southern Australia where alkaline soils occur to document their current levels and examine what factors may influence the levels.

How was it done?

Sixteen commercial paddocks on the upper EP were surveyed in autumn 2013 and 2014. Alkaline soils from the Lower North of SA (Pinery, Mallala, Roseworthy and Hart) and from north-western Victoria were also sampled as part of a wider survey of alkaline soils to allow values to be compared across regions.

Ten samples from a 25 x 25 m grid were taken. The samples were taken to 30 cm depth in 10 cm increments and the samples from each depth were bulked. The soil bulk density was measured from three cores taken from within the sample grid. The soils were dried, ground to pass a 2 mm sieve and the soil C was measured in a Leco CNS analyser. Each soil was measured twice, before (to measure total C) and after treatment with sulphurous acid to remove CaCO3 (to measure total organic C). Dissolved organic C was measured in a filtered solution after extraction in a 1:5 soil: water mixture.

The equivalent mass of soil C in the top 30 cm (total soil C estimated at the same bulk density) was estimated using the total organic C concentrations and the bulk density for each depth. Paddock histories for the last 10 years were obtained from the co-operating farmers.

What happened?

Compared to the other two regions in the survey, the soils on the EP were consistently more alkaline (Table 1). The average mass of soil C in the EP paddocks which averaged 46 t C/ha, was similar to that measured in paddocks from the Lower North, but was higher than that surveyed from north-western Victoria.
Table 1 Mean values for pH, total soil organic C and the equivalent mass of soil C in the top 30 cm from a survey of 16 paddocks on the upper Eyre Peninsula in 2013 and 2014 and means of comparable data from paddocks surveyed in the Lower North of SA and north western Victoria

<table>
<thead>
<tr>
<th>Eyre Peninsula</th>
<th>pH (H₂O)</th>
<th>Soil organic C (%)</th>
<th>Equivalent mass of C (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-10 cm</td>
<td>10-20 cm</td>
<td>20-30 cm</td>
</tr>
<tr>
<td>Mean</td>
<td>9.00</td>
<td>9.32</td>
<td>9.50</td>
</tr>
<tr>
<td>Minimum</td>
<td>8.49</td>
<td>8.89</td>
<td>9.04</td>
</tr>
<tr>
<td>Maximum</td>
<td>9.64</td>
<td>9.77</td>
<td>9.85</td>
</tr>
<tr>
<td>Lower North</td>
<td>8.35</td>
<td>8.69</td>
<td>8.97</td>
</tr>
<tr>
<td>NW Victoria</td>
<td>8.20</td>
<td>8.91</td>
<td>9.27</td>
</tr>
</tbody>
</table>

Dissolved organic C did not change markedly with depth and the values measured in soils from the upper EP were similar to those measured in paddocks in the Lower North (Table 2). Values in the top 20 cm were higher than the average values measured in paddocks from north-western Victoria. When expressed as a proportion of the total organic C, dissolved organic C increased with depth in all three regions, but the change with depth was least in the EP soils.

In the top 10 cm, variations in soil organic C and dissolved organic C were related to variations in pH among the surveyed paddocks. High pH was associated with lower total soil organic C (r = -0.49, P<0.10, n =12) and higher dissolved organic C expressed either in terms of total dissolved C (r = 0.48, P<0.10, n =12) or as a percentage of soil organic C (r = 0.67, P<0.05, n=12). There was no relationship with pH in the lower soil depths.

Among the surveyed paddocks the mass of organic C in the top 30 cm was inversely related to the intensity of cereal cropping over the last 10 years (Figure 1).

**What does this mean?**

High soil pH in the top 10 cm was associated with lower soil organic C and higher dissolved organic C, both of which may restrict the ability to maintain high soil C reserves. This suggests that the highly alkaline nature of many soils on the upper EP may impose a limitation on soil organic C accumulation irrespective of the farming system used.

Greater cropping intensity was associated with lower soil organic C and lower dissolved organic C. Most of the farms surveyed practice minimum tillage with retention of crop residues, but despite this there was no consistent improvement in soil organic C. The results imply that pasture is a more effective way of maintaining soil C reserves, a result that has been observed in other regions of Australia.

**Acknowledgements**

The work was funded by the Australian Department of Agriculture through the Filling the Research Gap under the National Soil Carbon Program. The cooperation of the many farmers who allowed their paddocks to be used as part of the survey is gratefully acknowledged.
Stubble and nutrient management trial to increase soil carbon

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Why do the trial?
The soil organic matter content of Australian soils is either decreasing or remaining stable. Trials have demonstrated that No-Till stubble retention systems are adding to the partially broken-down particulate organic carbon fraction but are not contributing to the stable humus fraction. Without an increase in soil humus the important functions of soil organic matter (i.e. improved soil water holding capacity, increased nutrient supply (N and cations), pH buffering capacity and better soil structure) are unlikely to be realised.

What is humus and how can it be increased?
Humus consists of the remains of bacteria and other microorganisms that consume and break down plant material returned to the soil from a crop or pasture. This plant material consists mainly of carbon (C). For soil microbes to consume this material they also need nitrogen (N), phosphorus (P) and sulphur (S) otherwise they cannot thrive and multiply. Australian soils are inherently low in nutrients and in most soils there is insufficient N, P and S for soil micro-organisms to rapidly break down the plant material returned to the soil. To increase the stable humus fraction in the soil, we need to supply soil microbes with additional N, P and S; this may have to be supplied as extra fertiliser.

How much N, P and S need to be supplied to stubble to form humus?
Dr Clive Kirkby, from CSIRO, has been working on this question and found that:
- In humus 1000 kg of C is balanced with 80 kg N, 20 kg P and 14 kg S.

- Dr Kirkby argues that for soil micro-organisms to breakdown stubble and form humus, we need to add sufficient nutrients (N, P and S) to feed these micro-organisms.
- For micro-organisms to efficiently break down wheat stubble to humus additional nutrients have to be added. Wheat stubble has a low nutrient:C ratio and one tonne of cereal stubble needs to be balanced with 5.8 kg N, 2.2 kg P and 0.9 kg S.

The DAFF and GRDC funded national trial will examine existing, new and alternative strategies for farmers in the cereal sheep zone to increase soil carbon. The trial will be used as baseline data for carbon accumulation in soils and to:
- discuss the various forms of soil organic carbon (plant residues, particulate, humus and resistant fractions),
- investigate how management affects each of these pools and how humus can be increased over the medium to long term,
- communicate how soil organic matter affects soil productivity (through nutrient and water supply, and improvements in soils structure).

Identical trials are being run by eight farm groups in SE Australia (Victoria: Mallee Sustainable Farming, Birchip Cropping Group, Southern Farming Systems; NSW: FarmLink, Central West Farming Systems; SA: Hart and Eyre Peninsula Agricultural Research Foundation, both through Ag Ex Alliance; and Tasmania: Southern Farming Systems) so information can be collected on different soils and climates in the Southern Region.
How was it done?
2014 was the third year of the trial. The 2013 trial stubble load was determined on 5 February 2014. Soil samples were collected on 10 February for Yield Prophet® (0-10, 10-40, 40-70, 70-100 cm) to determine soil available nitrogen and soil moisture.

In March the stubble management treatments: (i) stubble left standing, (ii) stubble worked in with single operation of the seeder before sowing (1 March) and (iii) stubble removed by raking and burning (2 March) were imposed.

Nutrient application treatments at seeding were: (i) normal practice for P at sowing and N in crop as per Yield Prophet® and (ii) normal practice PLUS extra nutrients (N, P, S) required to break down the measured wheat stubble. Based on the 2013 stubble load, the extra nutrients (17.5 units N, 2.7 units P and 5.2 units S) required to break down the stubble were applied on 13 February with a rainfall event. The extra nutrients (PLUS treatment) were applied as DAP (18:20:0:0) @ 14 kg/ha, ammonium sulphate (21:0:0:24) @ 22 kg/ha and urea (46:0:0:0) @ 37.5 kg/ha. Treatments were replicated 4 times.

The trial was sown on 30 April with CL Grenade wheat @ 60 kg/ha and a base fertiliser of DAP (18:20:0:0) @ 50 kg/ha. Pre sowing chemical applications were Roundup @ 1.2 L/ha, Trifluralin @ 1 L/ha and a wetter. On 2 June, Intervix was applied at 750 ml/ha with 500 ml/ha Supercharge. Prosaro @ 300 ml/ha was applied on 15 July for Yellow Leaf Spot, and tebuconazole was applied @ 290 L/ha on 21 August on the whole paddock using a plane.

Emergence counts, flowering date, grain yield and grain quality were measured.

What happened?
The mean stubble load calculated from 2013 was 5.7 t/ha and additional nutrient treatments were applied to aid in the breakdown of the stubble to humus.

Emergence counts were taken on 21 May with an average of 131 plants/m². Flowering occurred (GS 65 - when 50% of heads have anthers) on 30 August. The trial was harvested on 24 October. There were no significant differences between treatments in yield, test weight, grain weight and screenings (Table 1). There was a small increase in protein for those treatments that received additional nutrients (Table 1).

<table>
<thead>
<tr>
<th>Stubble treatment</th>
<th>Nutrition treatment</th>
<th>Yield (t/ha)</th>
<th>Protein (%)</th>
<th>Test weight (kg/L)</th>
<th>1000 Grain weight (g)</th>
<th>Screenings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble removed</td>
<td>normal practice</td>
<td>3.81</td>
<td>10.6</td>
<td>85.5</td>
<td>42.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Stubble removed</td>
<td>normal practice PLUS N,P&amp;S</td>
<td>3.90</td>
<td>10.9</td>
<td>85.3</td>
<td>41.2</td>
<td>3.4</td>
</tr>
<tr>
<td>Stubble standing</td>
<td>normal practice</td>
<td>3.55</td>
<td>10.4</td>
<td>85.4</td>
<td>42.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Stubble standing</td>
<td>normal practice PLUS N,P&amp;S</td>
<td>3.61</td>
<td>10.7</td>
<td>85.5</td>
<td>41.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Stubble worked</td>
<td>normal practice</td>
<td>3.81</td>
<td>10.7</td>
<td>85.0</td>
<td>41.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Stubble worked</td>
<td>normal practice PLUS N,P&amp;S</td>
<td>3.96</td>
<td>11.0</td>
<td>85.0</td>
<td>42.9</td>
<td>2.5</td>
</tr>
<tr>
<td>LSD (P=0.05)</td>
<td></td>
<td>ns</td>
<td>0.30</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Yield Prophet® was used early in the season (22 July) to predict if extra nitrogen fertiliser was required to achieve potential yield. UAN @ 50 L/ha was applied on 28 July using a broad-acre boom over all treatment plots.

What does this mean?
It is expected that the imposed treatments to increase soil organic matter will take a few years to become noticeable. The trial site was soil sampled for soil organic matter fractions at the start of the trial in 2012, and will be repeated prior to sowing the trial in 2015.

Acknowledgements
Funding for this trial is provided from DAFF and GRDC, and project management through Ag Ex Alliance and EPARF. Yield Prophet® is an on-line modelling service based on APSIM that provides simulated crop growth based on individual paddock information and rainfall, and is registered to BCG.
Effects of gypsum and legumes on soil pH and soil organic C

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1University of Adelaide, Waite, 2SARDI, Minnipa Agriculture Centre, 3NSW DPI, Wagga Wagga, 4NSW DPI, Hay, 5Dodgshun Medlin Agricultural Management, Swan Hill Victoria

Search for answers

Location: Minnipa Ag Centre, Paddock S7
Rainfall
Av. Annual: 325 mm
Av. GSR: 241 mm
2014 Total: 407 mm
2014 GSR: 290 mm
Yield
Potential: 4.0 t/ha (W)
Actual: 2.5 t/ha
Paddock History
2014: Scope CL barley
2013: Mace wheat
2012: Medic pasture
Soil Type
Red loam
Plot Size
34 m x 2 m x 3 reps

Location: Minnipa Ag Centre, Airport paddock
Rainfall
Av. Annual: 325 mm
Av. GSR: 241 mm
2014 Total: 407 mm
2014 GSR: 290 mm
Yield
Potential: 4.0 t/ha (W)
Actual: 2.5 t/ha
Paddock History
2013: Mace wheat
2012: Kord wheat
Soil Type
Calcareous red sandy loam
Plot Size
10 m x 3 m x 3 reps

Key messages

- The availability of aluminium (Al) in soil increases at pH above 9.
- There was no significant effect of gypsum on the biomass or yields of crops within 2 years.

Why do the trial?

Although alkaline soils are widespread throughout southern Australia and are the basis of crop production in South Australia, our understanding of the chemistry and cycling of C in these soils is poor. A survey of paddocks on the upper Eyre Peninsula (EP) showed that the concentrations of soil organic C and dissolved organic C were sensitive to pH, with soil organic C decreasing and dissolved organic C increasing as pH increased (see article this publication). Reducing soil pH may be a means of helping to retain soil organic C.

Many soils on the upper EP have pH values in the top 10 cm greater than 8.5 and this increases with depth. The subsoils can have a pH above 9 with high concentrations of sodium carbonate and are sodic; it is these properties that are especially damaging to plants. Past work on the reclamation of highly alkaline sodic soils has demonstrated that applying gypsum in conjunction with growing legumes can be effective in lowering soil pH. The greatest benefit is achieved by lowering soil pH from very high values (e.g. 9 or above) to about 8.5. Reducing pH further will be difficult because of the high buffering capacity of soils due to calcium carbonate at this pH.

To examine the effect of gypsum on the calcareous soils typical of the upper EP, two rotation experiments were conducted commencing in 2012 and 2013. The aim was to examine the effect of gypsum on soil pH and soil C and whether changes in soil pH could alter productivity of the following cereal crops.

How was it done?

Two short term rotation experiments were run, commencing in 2012 and 2013 on the Minnipa Agricultural Centre. The first experiment was conducted in paddock S7 (Experiment 1) and the second experiment was conducted in the Airport paddock (Experiment 2). Each experiment in the first year was a factorial combination of legume species, input levels and gypsum rates. In the first year three legumes (peas cv Morgan), vetch (cv Morava) and medic (a mix of Paraggio, Caliph and Parabinga) were grown at standard sowing rates (80 kg/ha for peas; 20 kg/ha for vetch and 5 kg/ha for medic) and fertiliser rates (10 kg P/ha for all crops) and at double these rates. All seeds were inoculated with commercially available rhizobia. Three rates of gypsum (0, 2.5 t/ha and 5 t/ha) were superimposed on these treatments. The gypsum was obtained from a local source and had a purity of 60%. The gypsum was spread prior to sowing and incorporated with the sowing operations.

The experiment in S7 commenced in 2012 and wheat (cv Mace) was sown in each plot in 2013 and 2014. The experiment in the Airport paddock commenced in 2013 and wheat (cv Mace) was grown in 2014. In 2012 only legume biomass was measured, while legume biomass and grain yield were measured in 2013. In 2013 and 2014 soil cores were taken in 10 cm increments to 30 cm in each plot to measure pH, soil organic C and dissolved organic C.

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Eyre Peninsula Farming Systems 2014 Summary
In the following cereal crops biomass was measured during the growing season and grain yield was measured by harvesting each plot. Grain quality was measured on the wheat crop after the legume phase. In this report only the cereal yields and protein contents are presented.

What happened?

Effects on legumes growth and yield

Gypsum had no significant effect on the biomass production or the grain yield of the legumes. Increasing P inputs significantly increased biomass production in both trials (by 30% in 2012 and 17% in 2013) but had no significant effect on yield. The grain yield of peas in 2013 was 1.44 t/ha, which was significantly greater than that of vetch (1.15 t/ha).

Soil measurements

The only factor to influence soil pH was the gypsum rate and the effect was consistent in both experiments. Applying gypsum significantly decreased pH in both experiments by between 0.2 and 0.4 pH units, with the largest reduction mainly occurring following the addition of 2.5 t/ha (Table 1). There was a corresponding decrease in the amount of dissolved organic C but soil organic C was not affected (data not shown). The effects of gypsum on pH and dissolved organic C were evident two years after application in the 2012 experiment. The concentration of dissolved organic C increased markedly once pH increased above 8.5 (Figure 1a). The concentration of Al was also sensitive to pH and increased at pH values greater than 9 (Figure 1b).

Table 1 The effects of gypsum applied during the legume phase on the pH and dissolved organic C concentration to 30 cm depth in two experiments. Experiment 1 was commenced in 2012 and measurements were made in the two successive years after applying gypsum, while Experiment 2 commenced in 2013

<table>
<thead>
<tr>
<th>Gypsum rate (t/ha)</th>
<th>pH (water)</th>
<th>Dissolved organic C (% soil organic C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-10</td>
<td>10-20</td>
</tr>
<tr>
<td></td>
<td>Depth (cm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-10</td>
<td>10-20</td>
</tr>
<tr>
<td></td>
<td>Experiment 1: 2013</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.76</td>
<td>9.17</td>
</tr>
<tr>
<td>2.5</td>
<td>8.76</td>
<td>9.07</td>
</tr>
<tr>
<td>5</td>
<td>8.61</td>
<td>8.98</td>
</tr>
<tr>
<td>F Prob</td>
<td>ns</td>
<td>P=0.025</td>
</tr>
<tr>
<td>LSD (P=0.05)</td>
<td>0.134</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>Experiment 1: 2014</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.48</td>
<td>8.86</td>
</tr>
<tr>
<td>2.5</td>
<td>8.30</td>
<td>8.40</td>
</tr>
<tr>
<td>5</td>
<td>8.26</td>
<td>8.45</td>
</tr>
<tr>
<td>F Prob</td>
<td>P=0.014</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>LSD (P=0.05)</td>
<td>0.155</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td>Experiment 2: 2014</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.98</td>
<td>9.02</td>
</tr>
<tr>
<td>2.5</td>
<td>8.79</td>
<td>8.89</td>
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<tr>
<td>5</td>
<td>8.59</td>
<td>8.80</td>
</tr>
<tr>
<td>F Prob</td>
<td>P&lt;0.001</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>LSD (P=0.05)</td>
<td>0.086</td>
<td>0.093</td>
</tr>
</tbody>
</table>
The gypsum treatments did not significantly affect the grain yield of the following cereal crops. The only effect of any of the first year treatments was in Experiment 2 where wheat yields were significantly highest after medic and lowest after vetch (Table 2).

**What does this mean?**

The pH of the top 30 cm of highly alkaline soils can be reduced within a year by applying gypsum at 2.5 t/ha. As the gypsum used had a purity of only 60%, lower rates of higher quality gypsum could be used to achieve the same result. A target pH in these soils is about 8.5 as below this changes in pH are highly buffered and there is no change in some soil properties (Figure 1). Highly alkaline soils (pH > 9) are the ones that would potentially benefit most from applications of gypsum.

Dissolved organic C is the most labile C fraction in soil. The reduction in dissolved organic C with the application of gypsum may help to stabilise soil organic C reserves.

There was no immediate benefit of the reduction in pH to the growth and yield of crops. It may take more than two seasons to allow any beneficial effects to become evident. Further long term studies are needed to assess whether gypsum can be effective in improving productivity and to measure the longevity of any effects.

There is growing evidence that Al toxicity can be an important limitation to yield on highly alkaline soils. The data suggest that soils with pH > 9 are at greatest risk. The reduction in pH following the application of gypsum reduced the concentration of Al in the soil.

**Acknowledgements**

The work was funded by the Australian Department of Agriculture through the Filling the Research Gap under National Soil Carbon Program.

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**Table 2 Grain yield of cereals and grain protein concentration of wheat grown after different legumes**

<table>
<thead>
<tr>
<th>Legume (year 1)</th>
<th>Wheat (year 2)</th>
<th>Barley (year 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain yield (t/ha)</td>
<td>Grain protein (%)</td>
</tr>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medic</td>
<td>1.81</td>
<td>11.2</td>
</tr>
<tr>
<td>Peas</td>
<td>1.87</td>
<td>11.2</td>
</tr>
<tr>
<td>Vetch</td>
<td>1.80</td>
<td>11.2</td>
</tr>
<tr>
<td>F Prob</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Experiment 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medic</td>
<td>3.40</td>
<td>9.6</td>
</tr>
<tr>
<td>Peas</td>
<td>3.13</td>
<td>9.5</td>
</tr>
<tr>
<td>Vetch</td>
<td>3.04</td>
<td>9.4</td>
</tr>
<tr>
<td>F Prob</td>
<td>P=0.024</td>
<td>ns</td>
</tr>
<tr>
<td>LSD (P=0.05)</td>
<td>0.262</td>
<td></td>
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</tbody>
</table>

**Figure 1** The effects of soil pH on the concentration of dissolved organic C in two experiments and the concentration of water-soluble Al in Experiment 2. The differences in pH were due to the effects of gypsum at three sampling depths.
Addressing subsoil constraints to increase organic carbon in Eyre Peninsula soils

Brett Masters and David Davenport
Rural Solutions SA, Port Lincoln

Why do the trial?
• There are around 40% of soils under agricultural production on EP that have subsoil constraints including bleached A2 horizons and sodic layers that limit crop and pasture production.
• To improve current soil modification practices.
• Deep ripping on poorly structured soils and the addition of clay to sandy soils with bleached A2 horizons can improve production but results have been inconsistent (refer EPFS Summaries 1999, p 72, 2000 p 105, 2005 p 129, 2010 p 154 and 2011 p 166).
• To increase soil organic carbon (SOC) levels of EP soils delivering improved productivity and offsetting carbon dioxide emissions to the atmosphere.

How was it done?
Soils targeted included:
• Duplex sandy soils with infertile A2 horizons
• Acidic ironstone soils with poorly structured subsoil clays
• Red brown earths with poorly structured subsoil soil layers.

Sites were selected by undertaking initial field characterisation sampling undertaken in September 2013. Four replicated trials and three demonstration sites were developed in May/June 2014 (Table 1).

Soil sampling using national protocols was undertaken in December 2013/January 2014 to determine baseline soil organic carbon, nutrition and bulk density (Table 2 and 3).

SOC levels are largely driven by clay content and rainfall. All sites, except for Holman, had SOC values considered to be in the low to moderate range for the rainfall/texture class. SOC and CEC at Young’s site are very low in the A horizons (0-30 cm) indicating poor inherent fertility. SOC levels at Holman’s are high, however this may indicate low microbial activity due to soil acidity (pH 4.5 CaCl₂).

Both Phillis and Beinke sites are alkaline with carbonate present in subsurface layers.

Bulk density (BD) is a measure of the weight of soil per cubic centimetres. Soils with BD greater than 1.6 g/cm³ are generally considered to restrict root growth. High BD can results from physical compaction, high exchangeable sodium and potassium levels, low organic carbon levels and/or highly weathered clay components. Surface BD levels are not considered high. The BD of the 10 to 20 cm soil layer was generally slightly higher than at the surface and in the 20 to 30 cm layer that may indicate physical compaction or increased soil texture and the presence of gravel.

High exchangeable sodium (ESP) values were found at the Phillis site.

What happened?

Beinke, Crossville
Gypsum treatments were broadcast early April with organic matter and ripping treatments being applied in the last week of May. A dry start to the season delayed seeding until the middle of June. Dry conditions continued with only 80 mm of rainfall to the end of November. Plant emergence counts taken in early July recorded lower plant density on the ripped treatments than the unripped (Table 4).
Soil modification and ameliorant treatments were applied in April and May 2014 prior to sowing (Table 3). Seeding and in-crop management was undertaken with farmer equipment except for the Young trial that was sown using the SARDI small plot seeder. Trial sites except for Phillis were harvested using the SARDI plot header. The mean weight of the harvest runs was extrapolated to grain yield (t/ha). Phillis site was harvested using the landholder’s header with grain yield extracted from the header yield monitor.

Dry matter levels were also lower on the ripped treatments except where OM had been added (Figure 1). Although the 5 t/ha of surface applied gypsum treatment had the highest plant density the only treatments that produced significantly higher dry matter were the 10 t/ha surface gypsum and the rip + gypsum + OM treatment. Grain yield largely reflected differences in dry matter production with these treatments (10 t/ha). (Rip +10 t/ha gypsum + OM) delivering significantly higher yields than all other treatments (Figure 2).

**Phillis, Ungarra**
Gypsum treatments and organic matter (10 t/ha vetch hay) were spread on the site in the first week of May. Ripping treatments were undertaken on 15 May using a DMR plough with the site sown to Fathom barley on 30 May 2014. Heavy rains prior to ripping resulted in the development of deep wheel ruts on the ripped treatments at ripping. This resulted in poor growth along these wheel tracks throughout the season. Wet conditions to the end of July resulted in some variable waterlogging on the site. Plant emergence counts taken in mid-June showed a variable response to both the ripping and the gypsum treatments (Table 5).
### Table 4 Beinke crop establishment, June 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean plants/m²</th>
<th>% control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Untreated control</td>
<td>113</td>
<td>100</td>
</tr>
<tr>
<td>2. Surface applied gypsum (5 t/ha)</td>
<td>126</td>
<td>111</td>
</tr>
<tr>
<td>3. Surface applied gypsum (10 t/ha)</td>
<td>117</td>
<td>103</td>
</tr>
<tr>
<td>4. Ripped + OM 10 t/ha</td>
<td>103</td>
<td>91</td>
</tr>
<tr>
<td>5. Ripped + gypsum 10 t/ha</td>
<td>108</td>
<td>95</td>
</tr>
<tr>
<td>6. Ripped + gypsum (10 t/ha) + OM (10 t/ha)</td>
<td>93</td>
<td>82</td>
</tr>
<tr>
<td>7. Ripped + 5 t/ha gypsum</td>
<td>115</td>
<td>101</td>
</tr>
<tr>
<td>8. Ripped only</td>
<td>101</td>
<td>90</td>
</tr>
</tbody>
</table>

**Figure 1** Dry matter cuts taken from Beinke site in August 2014

**Figure 2** Beinke wheat yields, December 2014

Eyre Peninsula Farming Systems 2014 Summary
Table 5 Phillis crop establishment, June 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>plants/m²</th>
<th>% control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Untreated control</td>
<td>139</td>
<td>100</td>
</tr>
<tr>
<td>2. Surface applied gypsum (5 t/ha)</td>
<td>145</td>
<td>105</td>
</tr>
<tr>
<td>3. Surface applied gypsum (10 t/ha)</td>
<td>153</td>
<td>110</td>
</tr>
<tr>
<td>4. Ripped + gypsum 10 t/ha</td>
<td>132</td>
<td>95</td>
</tr>
<tr>
<td>5. Ripped + gypsum 10 t/ha + OM 10 t/ha</td>
<td>161</td>
<td>116</td>
</tr>
</tbody>
</table>

No significant dry matter differences were recorded except for the ripping, gypsum and organic matter treatment that had almost double the biomass of the other treatments (Figure 3).

The higher dry matter levels did not translate to higher yields (Figure 4). This may be due to very low rainfall from the end of July to harvest. This requires further investigation and this site will be monitored in 2015.

**Young, Ungarra**

Heavy rainfall post seeding resulted in some water logging and surface water flow (particularly of the shallow clay treatment). Crop also appeared nitrogen deficient when establishment counts were taken. Very low plant densities were observed on the shallow clay and deep incorporated organic matter treatments (Table 6). This might have resulted from the difficulty achieving accurate seeding depths using the small plot seeder on these treatments.

Sustained cool and wet conditions to the end of July resulted in slow crop growth. Exceptionally dry conditions from the end of July to harvest resulted in the canola crop rapidly bolting and flowering. Dry matter cuts were taken in late August with only the deep incorporated clay treatments providing a significant response (Figure 5).

Yield data (Figure 6) showed that the deep clay + organic matter treatment was the highest yielding treatment but was not significantly higher yielding than the spaded clay treatment.

**Holman, Cockaleechie**

This site required lime to address the low pH in the surface and subsurface layers. Lime and organic matter treatments were applied to the site on 13 March 2014 with ripping treatments undertaken on 10 May using a DMR plough. The site was sown to Cobra wheat on 20 May.

Crop establishment counts undertaken 18 June 2014 showed little difference between treatments. Cool conditions and heavy rainfall to the end of July slowed crop growth and resulted in some variable waterlogging. Although visually the OM and ripping treatments looked better, dry matter cuts on 28 August did not record any significant difference between the treatments (refer Table 7). There was also no significant difference in dry matter and grain yield.
Table 6 Young crop establishment, June 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crop establishment 26/6/2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated control</td>
<td>24 plants/m²</td>
</tr>
<tr>
<td>Shallow incorporated clay (250 t/ha)</td>
<td>5 plants/m²</td>
</tr>
<tr>
<td>Deep incorporated OM (10 t/ha)</td>
<td>5 plants/m²</td>
</tr>
<tr>
<td>Deep incorporated clay (250 t/ha)</td>
<td>30 plants/m²</td>
</tr>
<tr>
<td>Deep incorporated clay (250 t/ha) + OM (10 t/ha)</td>
<td>27 plants/m²</td>
</tr>
<tr>
<td>Spading only</td>
<td>24 plants/m²</td>
</tr>
</tbody>
</table>

This trial will continue to be monitored in 2015.

What does this mean?
Results from these trials have been mixed. This may be due to a number of factors including:
- Seasonal conditions – waterlogging varied across some sites affecting rigour of data. Also high biomass treatments may have run out of water to deliver increased yield responses. For example, higher dry matter levels on the organic matter treatments on the Phillis site did not translate to higher yields whereas sites which were least affected by the extremes of the 2014 winter cropping season (Beinke and Young sites) did realise increased yields.
Time since the treatments were imposed and the method of modification – treatments may take more than one season to have an effect. The use of gypsum can have a benefit on soils with sodic subsoils, however the delivery of gypsum to the sodic layer provides some challenges. Where a subsoil layer is sodic ripping on its own will not provide a long term solution to what the best options are for incorporating gypsum to depth.

However, some treatments provide a clear benefit. Results from Young’s site supports earlier work which suggest that while clay incorporation into sandy top soils provides yield benefits, further increases can be realised by incorporation of clay and organic matter deeper into the bleached, sandy subsoil horizons. The incorporation of organic matter has provided a dry matter increase in many trials; however it is not well understood whether this benefit relates to soil nutrition, soil structure or microbial activity. The results from Phillis’ site has further highlighted that increased dry matter production does not necessarily translate to increased grain yield, particularly when there is a dry finish to the season. However it does provide the potential biomass to increase production if the season finishes well.

Further monitoring of these sites will occur to further investigate:

- Time before responses from applied soil ameliorants can be expected?
- What are the costs/benefits of these treatments options?

Acknowledgements

The authors would like to thank the landholders involved in this trial; Francis Beinke, Jamie Phillis, Terry Young, Geoff and Jim Holman. We would also like to thank Rebecca Tonkin, Rural Solutions SA for undertaking statistical analysis of the dry matter cuts and harvest results. This project is supported by Natural Resources Eyre Peninsula through funding from the Australian Government.
Improving soil structure on hardsetting soils of Eastern Eyre Peninsula

Brett Masters
Rural Solutions SA, Port Lincoln

Key messages

• Deep ripping soils with poorly structured clay subsoils can improve crop performance. However, on soils with sodic subsoil layers better results are achieved through the addition of gypsum.

• Knowledge of the characteristics of the soil profile at depth is vital for determining an appropriate and effective management strategy.

• High rates of surface applied gypsum can impact negatively on crop growth in at least the season of application.

• The development of appropriate and affordable machinery to effectively deliver soil ameliorants into constrained soil layers on a broadacre scale is required.

Why do the trial?

Poorly structured, hardsetting and sodic soils which can reduce plant emergence, restrict plant root growth and soil biological activity resulting in low water use efficiency are common in the Cleve Hills and district. Understanding of the most effective, practical and affordable means of addressing these constraints is limited. Trials have shown that the use of deep ripping and gypsum applications on soils with sodic subsoil layers can improve production but results have been inconsistent (refer EPFS Summaries 1999, p 72, 2000 p 105, 2005 p 129, 2010 p 154, 2011 p 166).

Constraints result from a number of different factors and appropriate treatments need to be developed.

How was it done?

This project demonstrated the use of disc and deep tillage technologies with and without the addition of soil conditioners such as organic matter and gypsum to effect improvements to soil structure and productivity.

The target soils were loam to clay loam surface soils with highly sodic clay subsoils with increasing carbonate at depth typical of soils of the Cleve Hills. Seven demonstration sites were established in August and September 2013 (Table 1). Tillage treatments included:

• deep ripping to 40 cm using an Ausplow DBS Easy-Till deep ripping plough (2.6 m wide demonstration model on 45 cm row spacings)
• discing (5 m wide offset with ribbed cutting coulters).

Soil ameliorant treatments consisted of organic matter and gypsum treatments as appropriate for the site. At Nield’s sites and Hannemann 2 the discs treatments also incorporated crop i.e. green manure. At Petersen 1 and Hannemann 1 sites oaten hay (10 t/ha) was applied to the surface prior to discing. Gypsum treatments were applied in spring at these sites and prior to seeding in 2014 at the other sites (Table 1).

Sites were sown by the farmer and treated the same as the rest of the paddock during the season.

What happened?

Heavy rainfall and cold temperatures in early winter slowed growth at all sites and resulted in some waterlogging at Nield and Hannemann sites. Emergence counts were taken on all sites in mid June 2014 (Figure 1). Discing alone did not result in increased crop establishment. On Nield 1 and Hannemann 2 emergence was greater where discs were used to incorporate gypsum and organic matter. The response to the other treatments at crop establishment was variable across the sites. There appeared to be crop establishment benefits from ripping with and without 5 t/ha of surface applied gypsum at Hannemann and Petersen sites. Surface applications of 10 t/ha gypsum prior to soil modification treatments had lower crop establishment figures than at the 5 t/ha rate. This is perhaps due to temporary salinisation around the seed from such a high rate and is not expected to cause an impact beyond the year of application.
Table 1 Summary of demonstration sites established in 2013

<table>
<thead>
<tr>
<th>Site ID/Location</th>
<th>Crop</th>
<th>Soil Type</th>
<th>Treatments</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nield 1, Yabmana</td>
<td>Wheat</td>
<td>Calcareous loam on dispersive red clay (Shallow Cleve soil).</td>
<td>Untreated, Disc (green manure), Surface applied gypsum (5 and 10 t/ha), Disc + gypsum (5 and 10 t/ha)</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment, spring dry matter, grain yield</td>
</tr>
<tr>
<td>Nield 2, Yabmana</td>
<td>Canola</td>
<td>Hard sandy clay loam on dispersive red clay</td>
<td>Untreated, Disc + organic matter (OM) (vetch green manure - low and high), Rip + OM (low and high) Disc + OM + gypsum (10 t/ha), Rip + OM + gypsum (10 t/ha)</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment</td>
</tr>
<tr>
<td>Hannemann 1, Mt Desperate</td>
<td>Wheat</td>
<td>Hard sandy clay loam on dispersive red clay</td>
<td>Untreated, Disc, Rip, Surface OM (10 t/ha oaten hay) Disc + OM, Rip + OM, surface gypsum (5 t/ha spring and autumn applied), Disc + gypsum, Rip + gypsum</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment, spring dry matter, grain yield</td>
</tr>
<tr>
<td>Hannemann 2, Mt Desperate</td>
<td>Wheat</td>
<td>Hard sandy clay loam on dispersive red clay</td>
<td>Untreated, Disc (green manure lupin crop), Rip, Disc + Rip, Surface gypsum (5 t/ha and 10 t/ha), Disc + gypsum, Rip + gypsum, Disc + Rip + gypsum</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment</td>
</tr>
<tr>
<td>Petersen 1, Mangalo</td>
<td>Wheat</td>
<td>Sandy loam on coarsely structured red clay</td>
<td>Untreated, Disc, Rip, Surface OM (10 t/ha oaten hay), Disc + OM, Rip + OM, Surface gypsum (5 t/ha spring), Disc + gypsum, Rip + gypsum</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment</td>
</tr>
<tr>
<td>Petersen 2, Mangalo</td>
<td>Canola</td>
<td>Sandy loam on coarsely structured red clay</td>
<td>Untreated, Disc, Rip, Surface gypsum (5 t/ha and 10 t/ha) Disc + gypsum, Rip + gypsum</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment</td>
</tr>
<tr>
<td>Turnbull, Mt Millar</td>
<td>Canola</td>
<td>Sandy loam on coarsely structured red clay</td>
<td>Untreated, Rip, Surface applied gypsum (5 and 10 t/ha), Rip + gypsum</td>
<td>Complete soil analysis, baseline soil carbon and bulk density, crop establishment</td>
</tr>
</tbody>
</table>

Figure 1 Plant density at crop establishment (% of control treatment), June 2014
Table 2 Dry matter cuts at Nield site 1, August 2014

<table>
<thead>
<tr>
<th>Nield 1</th>
<th>Dry matter (t/ha)</th>
<th>% of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.3</td>
<td>100</td>
</tr>
<tr>
<td>Disc only</td>
<td>7.1</td>
<td>97</td>
</tr>
<tr>
<td>Surface gypsum (5 t/ha)</td>
<td>8.2</td>
<td>112</td>
</tr>
<tr>
<td>Disc + gypsum (5 t/ha)</td>
<td>9.5</td>
<td>130</td>
</tr>
<tr>
<td>Surface gypsum (10 t/ha)</td>
<td>8.5</td>
<td>116</td>
</tr>
<tr>
<td>Disc + gypsum (10 t/ha)</td>
<td>9.0</td>
<td>123</td>
</tr>
</tbody>
</table>

Figure 2 Hannemann 1 dry matter, August 2014

Figure 3 Hannemann 2 dry matter, August 2014
Dry conditions from the end of July to harvest caused canola crops (Nield 2, Petersen 2 and Turnbull) to bolt rapidly from rosette stage to flower with little vegetative growth during this period so dry matter was not collected at these sites. Dry matter cuts were taken in the last week of August on the sites sown to cereals. Petersen’s wheat site at Mangalo was severely frosted throughout July and early August and dry matter cuts were taken from this site but it was difficult to separate the treatment response from the frost impact.

Dry matter data from Niiled 1 indicated some response from the application of gypsum with an increased response when incorporated with discs (Table 2). There was no additional response by increasing the rate of gypsum. There were no dry matter responses to surface application of gypsum at Hannemann’s sites however there was a response where gypsum was incorporated (Figure 2 and 3). Dry matter data and visual observations at the sites indicated slight responses to ripping.

Grain yield data from Hannemann’s wheat trial sites was obtained from 3 x 1 metre row cuts and threshing out the grain. Grain weights were extrapolated to give a plot yield in t/ha. Grain yield data reflected the dry matter trends (Figures 4 and 5).

The yield responses from tillage treatments alone were not statistically significant at Hannemann 1. However, ripping with addition of soil ameliorants did deliver significant yield increases (Figure 4).

At Hannemann’s second site grain yields from tillage treatments alone were also not significant except on the disc + rip treatments. The addition of gypsum did not generate a higher yield response than the combined ripping and discing (Figure 5).
What does this mean?
These demonstrations have shown that while production can be increased by a combination of appropriate soil modification practices and the results with the use of soil ameliorants vary between sites and with seasonal conditions. This is consistent with the results of earlier trials.

Gypsum can provide benefit on sites which have sodic layers, however treatment is most effective if gypsum is applied directly into the sodic layers. High rates of gypsum applied at the surface prior to sowing reduced crop establishment. This may be due to localised salinization around the seed at germination and should only be of short duration. The high rate may improve production on responsive soils in future years as soil structure improves.

Ripped treatments evidenced slightly better growth than unripped and disc only treatments. However, dry matter and grain yield increases were greater where the ripping treatment was accompanied with the addition of organic matter or 5 t/ha of gypsum.

These trials have further highlighted results from earlier work that although ripping can be used to break through a compacted layer; where a sodic layer is present it will not provide a long term benefit without the application of an appropriate soil ameliorant.

Further questions arising from these demonstrations are:
• What is the role of deep incorporated organic matter in improving soil structure on hardsetting soils and those with sodic layers?
• How long before responses from applied soil ameliorants can be expected?
• How long are the potential gains are going to last?
• What are the implications for soil carbon levels?
• What are the costs/benefits of these treatments options?

Acknowledgements
The author would like to thank the landholders involved in this project; Joel and Blake Nield, Grant Hannemann, Isaac Gill, Michael Petersen, John Turnbull. I would also like to thank Matt Crettenden (Ramsey Brothers Pty Ltd, Cleve) and Corey Yeates (Natural Resources EP) for their support in establishing the demonstrations sites and Rebecca Tonkin (Rural Solutions SA) for undertaking statistical analysis of the harvest results. This project is supported by Natural Resources Eyre Peninsula through funding from the Australian Government.
Bentleg tine openers for high speed sowing and low soil throw

James Barr, Jack Desbiolles and John Fielke
Agricultural Machinery Research Group, University of South Australia

Key messages

• Soil disturbance caused by tine openers affects the success of no-till seeding operations, influencing issues such as furrow moisture loss, weed seed germination, seeding depth variability across seed rows, crop safety and pre-emergent herbicide efficacy.

• Research shows that low rake angle openers increase soil layer mixing and deeper soil delving while slightly reducing furrow backfill. A bevel edge at the leading face increases furrow size and reduces lateral soil throw.

• Bentleg openers combined with bevel edge features can mostly cancel soil throw and maximise furrow backfill. They offer an unprecedented ability for high speed-low soil throw no-till tine seeders.

Background

Tine seeders are recognised for their greater soil disturbance at seeding, relative to disc seeders. Aspects of soil disturbance at seeding include furrow size and depth as well as the extent of soil movement or soil throw. The lateral soil throw (sideways movement of soil pushed out of the furrow) is a particularly important parameter to consider in a no-till seeding context. A limited amount of lateral soil throw at seeding is typically desired to mechanically incorporate soil-applied herbicides. However, excessive soil throw reduces the furrow backfill, affecting soil cover over the seed, and creates interactions (ridging) between adjacent seed rows, resulting in additional soil cover which increases seeding depth and potentially induces crop damage from herbicides (Figure 1).

Table 1 outlines plant density losses to trifluralin, showing 20% losses are expectable on seed rows subject to ridging, with up to 45% losses measured in the worst case scenario (high trifluralin rate combined with high speed and shallower seeding). The extent of seed row interactions (ridging) for a given tine seeder is influenced by the row spacing and the operating depth and speed. In practice, this limits the adoption of narrow enough row spacing to maximise crop competition with weeds, and also reduces the machinery work rate at the critical time of seeding. An aspect overlooked in the soil disturbance issues at seeding is the role of furrow opener design features, and how they influence the mechanics of soil movement.

Soil throw and narrow openers: what do we know?

Recent research conducted at the University of South Australia measured the 3-dimensional soil movement (using small clod-like PVC tracers) created by a number of furrow opener geometries. These tracers were pre-positioned within prepared soil bins in a known reference grid pattern and soil movement was calculated by recording the 3D positions of each displaced tracer. The experiments were carried out in remoulded sandy-loam soil bin environment at 8 km/h. The main findings were:

i) All straight openers have an ability to clear the top soil layer out of the furrow centre section, which is a desirable feature with pre-emergent herbicides. This finding explains the reduced weed control along the seed row often found in practice with herbicides incorporated by sowing, as well as the greater seedling vigour observed with tine seeding systems (relative to discs) in Rhizoctonia infested soils, where disease inoculum is concentrated in the top 2-3 cm soil depth layer.

ii) Low rake angles promote soil layer mixing, and the delving of deeper soil into the upper layers. This makes them useful for sowing into a drying profile where moist soil can be brought up into the seed zone for assisting seed germination.

iii) High rake angles create slightly narrower furrows at depth with minimal soil layer mixing.

iv) A chamfered face leading edge reduces both forward and lateral soil throw as well as the surface soil clearing ability, but increases the furrow size and the furrow width at depth. A single-sided chamfer creates an asymmetrical furrow shape.

Figure 1 Visual crop effect of trifluralin damage due to excessive soil throw

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The shank is connected where the upheaval of soil is from the centre of the furrow shank portion of the opener away. The bentleg design offsets the greatest. The shank is connected to the loosening foot via a side leg portion. Additionally, the use of a bevel edge is incorporated to maximise the benefits. This results in an opener that can loosen a large furrow size while achieving 100% furrow backfill and virtually cancelling lateral soil throw and soil layer mixing. Figure 3 shows a pictorial representation of furrow cross-sections contrasting the ‘bentleg effect’ on soil layer movement to that of a spear-point style opener. In practice, the availability of scaled-down bentleg openers offers an unprecedented opportunity for high speed, low soil throw tine seeding.

Why do the trial?
A field trial was conducted in a dry clay-loam soil at Roseworthy in September 2014 to validate the bentleg findings in a field situation and investigate the potential for higher speed seeding. A selection of straight and bentleg openers was tested at 8, 12, and 16 km/h and at 120 mm operating depth, measuring draft, vertical and side forces, as well as lateral soil throw and furrow backfill using a laser scanning device.

Two straight knife openers (53° and 90° rake angle) were included as controls, while the two bentleg openers evaluated had 45 and 95 mm shank offset values. Selected results are shown in Figure 4. The lateral soil throw quoted represents the equivalent row spacings to ensure limited or no interaction occurs between two adjacent furrows.

What happened?
Under the dry soil conditions, the vertical knife opener significantly reduced the extent of soil throw compared with the 53° rake angle opener. Both bentleg openers further reduced soil throw compared to these straight openers at 8 km/h. At the higher speeds, the 95 mm offset bentleg opener maintained low soil throw, while the 45 mm offset bentleg design displayed a sensitivity to speed, with soil throw at 16 km/h similar to that of the 53° rake angle opener. This showed the design of a bentleg opener must be optimised for its intended use.

The furrow backfill data show the ability of the 95 mm offset bentleg opener to maintain maximum furrow backfill regardless of speed, while the straight openers, from a comparative baseline at 8 km/h, significantly emptied the furrows at faster speed, with backfill in the range of 50-60%. This ‘furrow-emptying’ feature of straight openers was strongest for the 53° rake angle opener. The 45 mm offset bentleg achieved significantly lower backfill at 16 km/h in line with the increased soil throw.

Overall, the 95 mm offset bentleg design was able to maintain its baseline lateral soil throw at twice the sowing speed while maintaining 100% furrow backfill. The draft force measurements showed the following:

i) The vertical knife opener required approximately 50% more pull than the 53° rake angle opener, demonstrating the known beneficial effect of low rake angle on draft. This draft was also approximately twice that of the bentleg openers, which were able to minimise the pull requirement due to their 45° rake angle leading foot.

ii) Under the dry conditions, the draft force increased with speed for all openers, while the least effect was measured with the vertical knife opener.

Table 1 Experimental results on wheat seedling losses to trifluralin for 2 seed row types in a shallow alkaline clay-loam soil (Desbiolles, 2004)

<table>
<thead>
<tr>
<th>Herbicide rate (Trifluralin 480)</th>
<th>1.3 L/ha</th>
<th>2 L/ha</th>
<th>1.3 L/ha</th>
<th>2 L/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 km/h</td>
<td>-14 ns</td>
<td>-30 *</td>
<td>-13 ns</td>
<td>-39 *</td>
</tr>
<tr>
<td>10 km/h</td>
<td>-17 ns</td>
<td>-17 ns</td>
<td>-39 *</td>
<td>-63 **</td>
</tr>
<tr>
<td>10 km/h + shallow seeding</td>
<td>-11 ns</td>
<td>-18 ns</td>
<td>-54 **</td>
<td>-85 ***</td>
</tr>
</tbody>
</table>

NB: Untreated ref = 187 plants/m²; 2004 Minlaton - Alkaline clay-loam soil
What does this mean?
The field data acquired to date confirm the great potential benefits of bentleg opener geometries, both in controlling soil throw (and associated crop safety from pre-emergence herbicides) and in minimising draft forces, compared with existing knife and spear point style opener technologies.

Bentleg openers thus represent a new opportunity for optimising the performance of tine seeders and in particular enabling high speed sowing operations, perhaps on the par with disc seeders. Further, the soil handling features of the bentleg opener may achieve specific benefits of low weed seed germination, which would need to be validated in dedicated field studies.

The work also demonstrated the need for additional research to optimise the bentleg opener design, while opportunities exist for further scaling down the design (but not the properties) of this innovative opener, currently sized to operate at 120 mm depth, to suit shallow soils and further minimise power requirements. Current postgraduate studies are underway to further validate - and optimise via modelling - the bentleg opener concept and recommend solutions for the design of an integrated seeding system.

Acknowledgements
Funding from the GRDC, SAGIT and the University of South Australia for previous and ongoing seeding system research is gratefully acknowledged.