Managing alkaline dispersive subsoil for improving farming productivity

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Key findings

- Crop residue deep placement in combination with chemical fertilisers and a low rate of gypsum demonstrated consistent yield improvement (27%; averaged for four successive years) in alkaline dispersive subsoil.
- Organic and inorganic amendment deep placement increased root growth, and soil water use from the deeper clay layers during the critical reproductive stages of crop development.
- Improvements in grain yield with organic and inorganic amendment deep placement were associated with a reduction in subsoil pH, exchangeable sodium percentage (ESP%) and increased microbial activity, which promoted soil aggregation.

Introduction

Among different soil constraints, alkaline dispersive subsoil is associated with the largest yield gap across the Australian grain belt, with an estimated yield loss of $A1,300 million per annum (Orton et al. 2018). The yield gap is caused by several physicochemical properties, which include:

- high exchangeable sodium (Na) concentrations
- dispersion
- poor structure
- waterlogging
- high soil strength
- in some circumstances pH higher than 8.2 (H_2O).

Applying large quantities of organic amendments, especially in the alkaline dispersive subsoil, has demonstrated increase in crop yields in high rainfall regions (Gill et al. 2008; 2009), but to date, practice change in the grain industry has been limited.

The major constraints for widespread subsoil amelioration adoption include:

- limited availability and high cost of suitable organic ameliorants delivered in-paddock
- lack of suitable commercial-scale machinery
- poor predictability of when and where the amelioration will consistently benefit crop productivity.

These factors can be significant as research to date in the high rainfall zones suggests that rates of up to 20 t/ha are required, and transport costs quickly become prohibitive if the amendments need to be sourced off-farm (Gill et al. 2008; Sale et al. 2019).

Therefore, solutions integrating complementary sources of organic amendments such as crop residue and cover crop biomass produced in-situ need to be investigated. This current experiment investigated the potential of using farm grown crop residues as ameliorants for alkaline dispersive subsoils in the medium rainfall region of southern NSW.

Site details

Location	Rand, southern NSW
Soil type	Sodosol
Previous crop	Canola
Design	Randomised complete block design (RCBD) with four replications
Sowing	Wheat (*Triticum aestivum* cv. Scepter(b)) was sown with an air seeder with rows spaced at 250 mm using a GPS auto-steer system (16 May 2020)
Seed rate	63 kg/ha
Fertiliser	• 78 kg/ha di-ammonium phosphate (DAP) (at sowing) • Urea 150 kg/ha (top dressed on 22 May 2020)
Rainfall	• Fallow (November 2019–March 2020): 170 mm • Fallow long-term average: 195 mm • In-crop (April 2020–October 2020): 401 mm • In-crop long-term average: 358 mm
Harvest date	7 December 2020

Treatments

Experiment treatments are shown in Table 1.

Table 1 Organic and inorganic amendments with their rate of application in February 2017.

Treatment	Organic/inorganic	Rate
Control	–	–
Deep gypsum	Inorganic	5 t/ha
Deep NPK (liquid nitrogen (N), phosphorus (P), potassium (K))	Inorganic	N to match poultry litter
Deep manure	Organic	Poultry litter 8 t/ha
Deep pea straw	Organic	15 t/ha
Deep pea straw + gypsum + NPK	Organic + inorganic	15 t/ha, 5 t/ha, N to match poultry litter
Deep pea straw + NPK	Organic + inorganic	15 t/ha, N to match poultry litter
Deep wheat straw	Organic	15 t/ha
Deep wheat straw + NPK	Organic + inorganic	15 t/ha, N to match poultry litter
Rip only	–	–
Surface gypsum	Inorganic	5 t/ha
Surface manure	Organic	Poultry litter 8 t/ha
Surface pea straw	Organic	15 t/ha

Deep amendments were incorporated at 20–40 cm depth in 50 cm bands.

Results

Growing conditions

In February 2017, a field experiment was established on-farm near the township of Rand in southern NSW. Treatments and physicochemical properties are detailed in Table 1 and Table 2, respectively. The paddock has a history of cereal-canola rotation as winter crop and summer fallow as per the local practices.

The soil is characterised as a sodosol (Isbell 2002), with increasing clay content at depth. The increasing levels of exchangeable sodium relative to calcium and/or magnesium in subsoil results in a decrease in soil structural stability and an increase in dispersion potential. The high clay content in this subsoil layer has a bulk density (BD) of 1.55 g/cm^3 that restricts water movement, and consequently the subsoil has very low saturated hydraulic conductivity.

Table 2 Soil chemical properties at different depths of the soil profile at the experiment site.

Soil depth (cm)	pH (1:5 water)	EC (µs/cm)	ESP (%)	CEC (cmol$_{(+)}$/kg)	Nitrate N (mg/kg)	BD (g/cm^3)
0–10	6.6	132.1	3.8	16.1	20.6	1.40
10–20	7.8	104.0	7.3	22.6	5.8	1.52
20–40	9.0	201.5	12.5	26.7	4.1	1.50
40–50	9.4	300.5	18.1	27.5	3.0	1.48
50–60	9.5	401.3	21.8	28.8	3.0	1.53
60–100	9.4	645.0	26.4	29.7	2.9	1.55

Values are means (n = 4).
EC = electrical conductivity; ESP = exchangeable sodium percentage; CEC = cation exchange capacity; BD = bulk density.

Grain yield

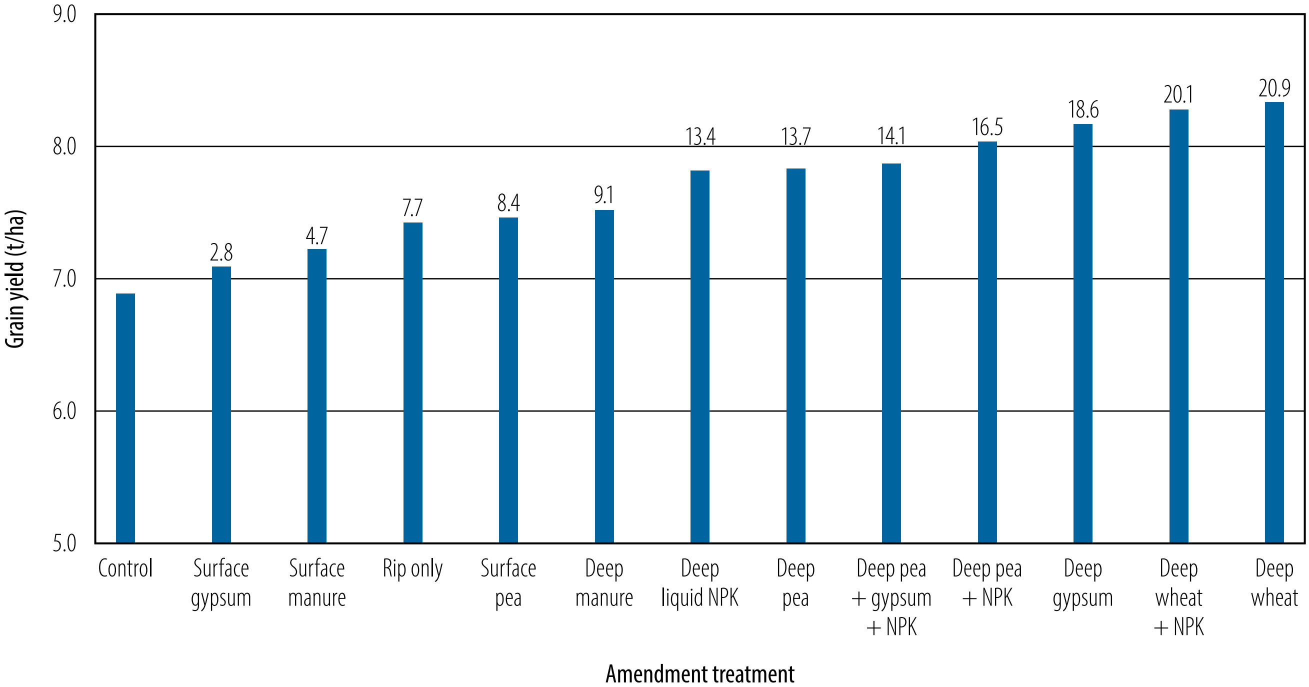
The single application of different amendments (Table 1) significantly affected the crop grain yield over four consecutive years. For example, in 2020, wheat grain yield (relative to control) increased following the deep placement of wheat straw, wheat straw + NPK and gypsum by 21%, 20% and 19% respectively (P<0.001) (Figure 1).

The yield variations in response to surface amendment application or rip only was not significantly different from the control.

A multi-year cumulative analysis of grain yield response (2017–20) from this experiment indicated that deep placement of plant-based straw, gypsum and their combinations with NPK resulted in significant and consistent improvements in crop yield. For example, the cumulative grain yield of deep pea + gypsum + NPK over the four successive years was 19.4 t/ha, which was 27% higher than the control (15.3 t/ha).

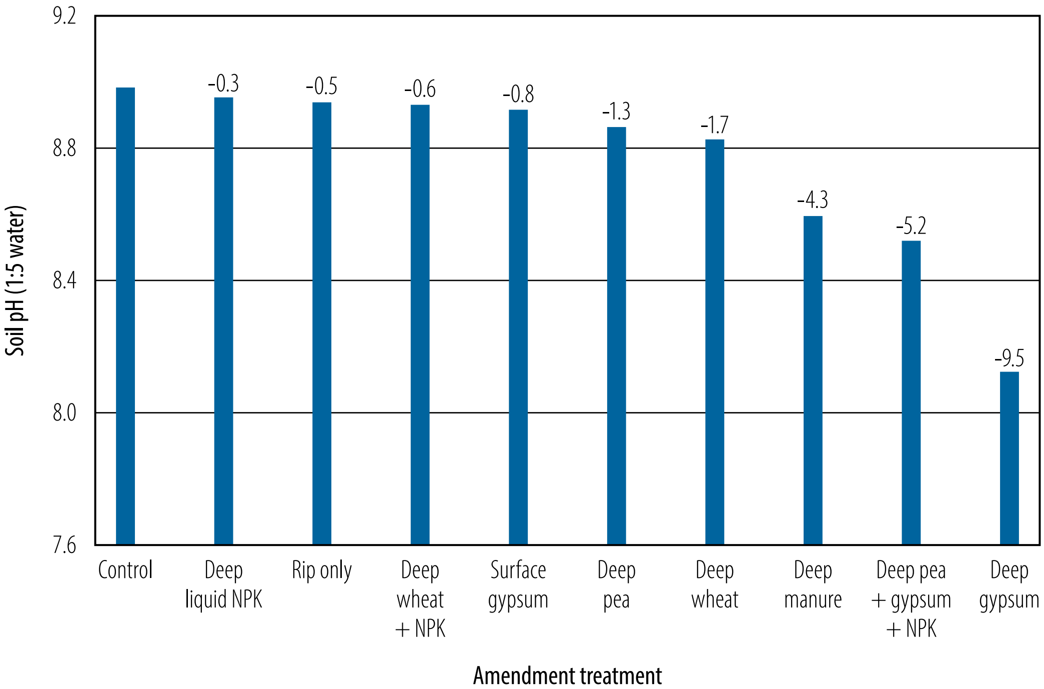
Soil pH

Variation in subsoil pH measured at the amended layer (20–40 cm) is shown in Figure 2. Compared with the control, gypsum deep placement reduced the soil pH by 0.86 units (8.99 to 8.13) at 20–40 cm depth, while deep placement of pea + gypsum + NPK reduced this value by 0.47 units (8.99 to 8.52). Along with greater infiltration rates, amendment deep placement significantly increased root growth and water extraction from the subsoil layers.



Values on the top of each bar represent the percent change in grain yield for individual amendments compared with the control.
Each data point is mean value of $n = 4$.
l.s.d. ($P = 0.05$) = 0.67 t/ha.

Figure 1 The mean effect of surface or deep-placed amendments on grain yield of wheat (cv. Scepter(b)) grown in alkaline sodic subsoil in Rand, southern NSW in 2020.



Values on the top of each bar represent the percent change in soil pH for individual amendments compared with the control.
Each data point is mean value of $n = 4$.
l.s.d. ($P = 0.05$) = 0.27.

Figure 2 The mean effect of surface or deep placed amendments on soil pH at the amended layer (20–40 cm soil depth).

Conclusion

Grain yield improvement was observed in the four seasons subsequent to the deep placement of a range of amendments in a medium rainfall region of NSW. This strong residual effect was supported by the observations reported in a high rainfall region of Victoria (Gill et al. 2008).

Despite receiving 401 mm of in-season rainfall in 2020, when compared with the control the best performing treatment (deep wheat) yielded an increase in grain of 21%. This was lower than the best performing treatments for 2017, 2018 and 2019, all of which comprised incorporating deep pea + gypsum, which produced yield improvements of 27, 53 and 36% respectively, despite ongoing and intensive drought.

The better yield improvement in the drier growing seasons could be attributed to the accessibility of stored subsoil water, which was linked with greater root proliferation in the amendment layer. Furthermore, deep placement of crop residues and/or gypsum significantly increased macro-aggregation, water infiltration and subsoil water extraction in this experiment (data not presented).

The results indicate that independent modes of action of various amendments (e.g. crop residue vs gypsum) are required in the amendment mix in order to effectively ameliorate sodic subsoils. For example, adding gypsum reduced pH in the amended subsoil to below 8.5, which can result in significant improvement (reduction) in soil dispersion (Tavakkoli et al. 2015). Adding crop residues and nutrients provided substrate for enhanced biological activity resulting in increased macro aggregation and improved subsoil structure. The co-application of organic and inorganic amendments can result in additive effects to improve soil physical and chemical properties (Fang et al. 2020), thus creating a favourable condition for root proliferation (Uddin et al. 2020).

A promising finding from the experiment, is that readily available farm-grown products such as wheat and pea straws, when mixed with nutrients, can improve soil aggregation, root growth, water extraction and grain yield, and produce yield responses comparable with, or better than nutrient-enriched animal manures and gypsum.

The results of this experiment showed that grain growers already have a potentially large supply of relatively inexpensive organic ameliorants available in their paddocks, a factor that could increase application options and the viability of correcting subsoil sodicity.

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