Understanding the amelioration processes of the subsoil application of amendments

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Abstract

A series of field and incubation experiments were conducted to address the amelioration process of physicochemical constraints of alkaline sodic dispersive subsoils. A range of organic and inorganic amendments were applied in the top and subsoils with the plots sown to barley and wheat in 2017 and 2018, respectively. The initial results indicated that deep application of combined organic and inorganic amendments resulted in significantly improved soil physicochemical properties and increased yield in the two consecutive years. The deep application of gypsum and organic amendments reduced the soil pH and exchangeable sodium percentage (ESP) and improved soil aggregate stability, addressing both chemical and physical constraints. The results indicated that amendments and strategies with different mode of actions are required for improving soils with multiple physicochemical constraints.

Key Words

Dispersive soil, sodic soils, sodicity, aggregate stability, reclamation

Introduction

Approximately 75% of Australian soils have subsoil constraints that limit agricultural productivity (Rengasamy 2002). The major constraints to crop growth are poorly structured subsoils that result from high clay content and bulk density as well as the presence of high subsoil exchangeable Na concentrations (Rengasamy 2002). These constraints adversely affect soil water and plant available water content (PAWC).

A range of practices including deep ripping, subsoil manuring and gypsum application have been tested to overcome subsoil constraints, usually with unreliable results and often potential financial losses to growers (Gill et al. 2008). For example, using gypsum for improving the poorly structured sodic subsoils is hardly possible due to the sparing solubility of gypsum. In regards to subsoil manuring, despite the demonstrated step change in crop yields that can be achieved by this management strategy, adoption in the grain industry to date has been limited, mainly due to limited local availability and high cost of suitable organic ameliorants delivered in-paddock. This factor can be significant as the required rate of the manures in the higher rainfall zones (up to 20 t ha^{-1}) significantly increases the cost of transportation (Gill et al. 2008). Therefore, solutions integrating complementary sources of organic matter, such as crop residue and cover crop biomass produced in-situ, need to be investigated.

This paper will provide findings from a GRDC co-funded project (DAV00149) aiming to ameliorate subsoil constraints and to understand the amelioration processes of the subsoil application of amendments.

Methods

Field trial

A 2-year field experiment was established on a farm in Rand, NSW in February 2017. Selected soil properties are presented in Figure 1. The profile is characterized by the soil pH ranges from 5.1 to 9.1 with increasing sodicity with depth (ESP up to 30%). A dispersion test (Emerson Aggregate Test) was performed on several aggregates and indicated a significant dispersion in subsoil increasing with depth.

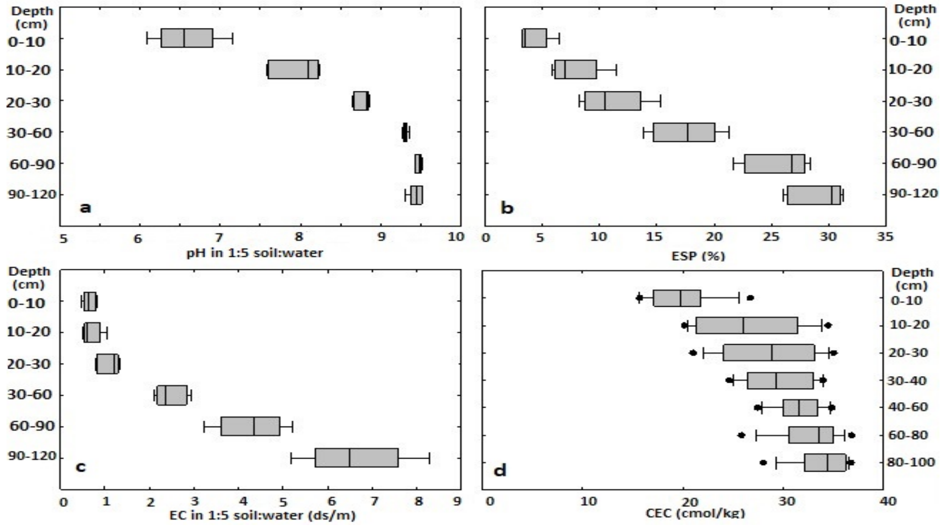

Figure 1. Soil characteristics of experimental site in Rand (NSW); pH (a), ESP is exchangeable sodium percentage (b), EC is electrical conductivity (c) and CEC is cation exchange capacity (d).

The experimental plots were 2.5 m wide and 20 m long. There were 14 treatments comprising 1) control, 2) surface application of gypsum, 3) surface application of chicken manure, 4) surface application of pea hay, 5) deep ripping, 6) deep placement of gypsum, 7) deep placement of manure, 8) deep placement of wheat stubble, 9) deep placement of wheat stubble + nutrients (liquid NPK), 10) deep placement of pea hay 11) deep placement of biochar, 12) deep placement of pea hay + nutrients, 13) deep placement of nutrients (liquid NPK), 14) deep placement of pea hay + gypsum + nutrients. The experiment was a randomised complete block design with four replicates. Ripping and subsoil incorporation treatments were carried out with a 3-D ripping machine (NSW DPI). The machine can deliver inorganic and/or organic amendments at two depths from 10 to 30 cm. The machine is also capable of delivering liquid nutrients/fertilisers at depth. The experiment at Rand was sown to barley (cv. LaTrobe) on 18 May 2017, and wheat (cv. Lancer) on 15 May 2018. The experiments were harvested in the first week of December. Various agronomic and nutritional traits including grain yield, protein content, seed quality and tissue nutrient concentrations were measured.

Incubation experiment

To provide further insight into the dynamics of C mineralisation and interactive effects of organic amendments and gypsum, we conducted a lab-based incubation experiment. The soil (450 g air-dried soils, equivalent to 430 g oven-dried soil) was uniformly mixed with organic amendments (*i.e.* crop stubble) at an application rate of 8 t C ha^{-1} soil with or without gypsum ($CaSO_4 \cdot 2H_2O$) of 9.4 t ha^{-1} soil or nutrients. The soils were incubated for 90 days and the changes in soil pH, exchangeable Na, microbial biomass carbon and aggregate stability were then measured.

Results

The growing season rainfall in 2017 and 2018 was 329 mm and 225 mm respectively. In 2017, growing season rainfall (April to November) was 62.5 mm less than the long-term average, whereas in 2018, it was 178 mm less than average rainfall.

This field experiment showed consistent significant ($P < 0.05$) effects of amendment on grain yield in two consecutive years (Figure 2). In 2017, each plot with deep placement of amendments was harvested in two locations including on the amended rip line and off the amended rip line. This approach was undertaken based on the field observations of differential responses between crop rows on and off the rip lines. While there was no significant difference ($P > 0.05$) between the control and yield response off the amended rip lines, a positive response was achieved for crop harvested on the amended rip lines. Compared with the control treatment, the highest increase ($P < 0.05$) in grain yield, on the rip lines, was observed for deep placement of pea hay + gypsum + nutrient (27%) followed by deep placement of manure (22%) and pea hay (20%). As a main effect, rip only, surface gypsum and surface pea hay treatments yielded 6, 10 and 13% less than control treatments (Figure 2a).

In the 2018 season, wheat grain yield was significantly ($P < 0.05$) increased 27-53% (compared with the control) following amendment application in 2017 (Figure 2b). The highest increase was observed for deep placement of pea hay + gypsum + nutrient treatment (53%) followed by deep placement of manures (34%), pea hay (34%) and deep wheat stubble + nutrients (27%).

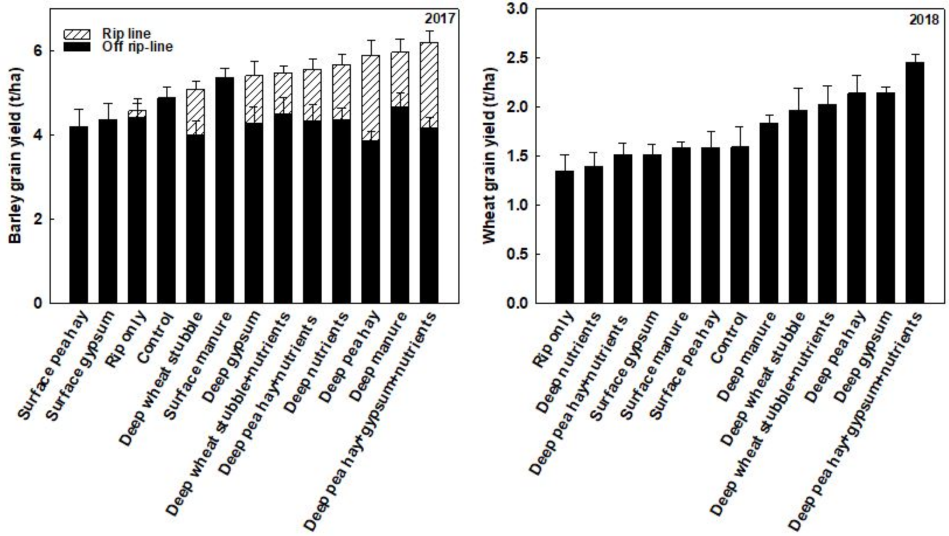

Figure 2. The effects of surface or deep placed amendments on grain yield of La Trobe barley in 2017 (a) and Lancer wheat in 2018 (b) at Rand, NSW. In 2017, plots with deep placement treatments were harvested on amended rip lines (dashed bars, on rip line) and off amended rip lines (black bars, off-rip line). Values are averages (n = 4).

Table 1 shows the effect of various amendments on soil ESP and pH at three depths. The deep placement of amendments at a depth of 10–30 cm had a marked impact on the physicochemical properties in the subsoil layers. The 20–30 cm deep subsoil layer in the control treatment had a pH of 8.99 and ESP of 13.4%. Deep placement of gypsum, pea hay + gypsum + nutrients and deep manure reduced the soil pH by 0.86, 0.61 and 0.39 unit respectively ($P < 0.05$). Compared with the control, the deep placement of pea hay + gypsum + nutrients treatments also reduced the ESP by 27%.

Table 1. The changes in soil ESP and soil pH in selected treatments at Rand site. Samples were collected in May 2018 pre-sowing. Values are means (n=4). The bold data are significantly ($P < 0.05$) different form the control.

Depth (cm)	Control	Deep gypsum	Deep nutrients	Deep manure	Deep pea hay	Deep pea+gyp+nutrients	Rip only
				ESP (%)			
0-10	5.89	7.00	6.43	7.89	6.09	5.13	7.23
10-20	8.47	8.18	9.11	11.41	8.33	**6.01**	9.69
20-30	13.35	11.70	12.59	16.24	12.91	**9.68**	14.09
				pH (1:5 water)			
0-10	6.61	6.96	7.04	6.37	6.87	6.89	6.86
10-20	7.98	7.77	7.99	7.66	7.76	7.69	7.91
20-30	8.99	**8.13**	8.96	**8.60**	8.87	**8.38**	8.94

To further explore the changes caused by organic amendments on subsoil physicochemical properties, an incubation experiment was conducted to investigate how the physicochemical conditions of the alkaline sodic subsoil may benefit from the addition of organic amendments. Figure 3 shows the effects of gypsum, organic matter (crop stubble), organic matter + gypsum and organic matter + nutrients on the formation of water-stable aggregates after 90 days of incubation. Similar to data from the field trial, gypsum had a significant effect ($P < 0.05$) on reducing soil pH (1.15 unit) and ESP (13-17%) compared with the control. The addition of organic matter with or without nutrients had no influence on soil pH or ESP. However, the input of organic matter and organic matter + nutrient increased total microbial biomass carbon by 3 and 4.7 fold, respectively ($P < 0.05$). Combined application of organic matter and gypsum had the greatest influence on the proportion of stable aggregates in the poorly structured sodic alkaline subsoil used in this study. While separate applications of gypsum and organic matter increased the aggregate stability, the much greater improvement in soil aggregation in organic matter + gypsum treatment suggests that their co-application have an additive and/or interactive effect.

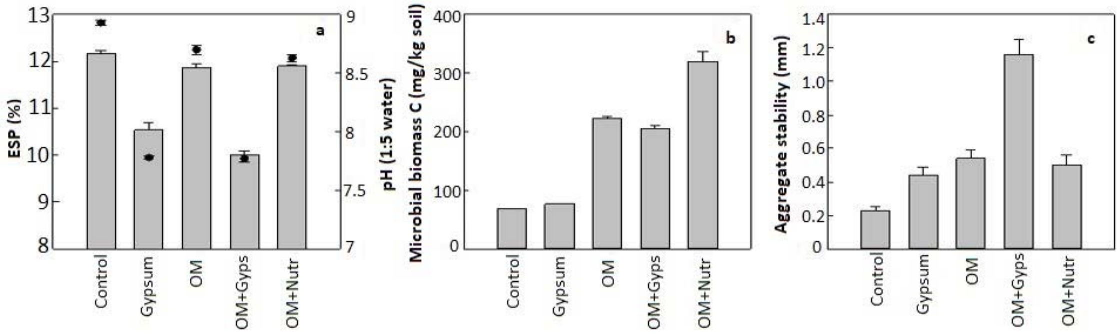

Figure 3. The effect of gypsum, organic matter (OM), OM + gypsum and OM + nutrients on (a) soil ESP (bars) and pH (●), (b) microbial biomass C and (c) aggregate stability over the 90-day incubation period. Error bars represent ± standard errors of the mean (n = 4).

Discussion

This study provides early but significant indications that soil amelioration of alkaline-sodic subsoils with organic and inorganic amendments can provide significant grain yield increases that are associated with soil physicochemical properties.

The changes in soil chemical and physical properties in the 10–30 cm layers occurred over the 14-month period between the incorporation of the amendments in late February 2017, and sampling in May 2018. The key change was a reduction in subsoil pH and ESP (Table 1) and an increase in soil porosity as well as improved crop water use in the amended subsoil (data not shown). While the soil analysis is still in progress, it could be suggested that this resulted from improved soil aggregation, as incubation studies using this clay subsoil and similar organic amendments, led to a rapid improved aggregation in the clay matrix over three months.

The results demonstrated that amelioration of multiple soil constraints (high pH, sodicity and poorly structured aggregates) requires amendments and strategies with various modes of action and independent mechanisms. The suggested improvement in subsoil aggregation with organic matter + gypsum and the resulting significant increases in grain yield in this study can be attributed to several causes. The first was that application of gypsum resulted in a reduction in pH of 0.86–1.15 unit. Tavakkoli et al. (2015) showed that carbonate salts of Na and K dominate above pH 8.5 of many sodic subsoils in south-east Australia and a reduction in pH below 8.5 can decrease the net dispersive charge and ESP by changing the speciation of carbonate salts (Rengasamy et al. 2016). The second reason for the suggested improvement in subsoil aggregation was that the organic amendments provide a substrate for greatly enhanced microbial activity in and around the rip lines. The incubation study discussed above, also found that the addition of organic matter to alkaline sodic, clay subsoil increased microbial biomass C over the 90 day of incubation period which in turn led to rapid improvement in aggregation (Gill et al. 2008).

Conclusion

The findings of this study demonstrate early results for amelioration of alkaline sodic subsoils in SNSW. Deep application of organic and inorganic amendments resulted in significant yield increase in 2017 and 2018. The increases resulted from the improvement in the chemical and physical properties of the subsoil around the rip line containing the organic and inorganic amendments. This improvement was mediated by a reduction in soil pH and ESP and an increased microbial activity that leads to improved soil aggregation.

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