Improving grain yields by ameliorating alkaline dispersive subsoils in southern New South Wales

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Abstract

Alkaline dispersive soils dominate crop production throughout south-eastern Australia. These soils are characterised by severe structural degradation that restricts root penetration, water and nutrient uptake, and crop performance. In February 2017, a field experiment was established on-farm near Rand in southern NSW to understand the amelioration processes arising from the application of different amendments to subsoil. A range of organic and inorganic amendments were applied, either at the surface or within the subsoil (20 – 40cm depth). Subsoil application of organic and inorganic amendments alone or in combinations reduced soil pH and exchangeable sodium percentage (ESP) and improved soil aggregation. These improvements in soil physicochemical properties was associated with increased root growth and water use from the deeper clay layers during grain filling, resulting in increased grain yields averaging 20 to 40% across four successive seasons. By using the unique properties of organic and inorganic amendments with a fundamental understanding of structural transformations in soils, we demonstrated step-change improvements in crop yields that were linked with improvements in soil physicochemical properties, root proliferation and increased subsoil water extraction.

Keywords

Amendments, soil aggregation, infiltration rate, root proliferation, subsoil water use

Introduction

The majority of the dryland cropping zones in Australia comprise of soils that contain a minimum of one, but more often, a multitude of surface and subsoil constraints that limit agricultural productivity (Adcock et al. 2007). Of the three major constraints, salinity, acidity and sodicity, the latter is thought to be the most detrimental to productivity in terms of the magnitude of the yield gap, which is estimated to cause financial loss of A$ 1.3 billion per annum (Orton et al. 2018). The physicochemical properties of alkaline dispersive subsoil restrict crop rooting depths, and subsequently the extraction of water and nutrients required for crop growth (Passioura and Angus 2010).

A range of approaches including deep ripping, subsoil manuring, gypsum incorporation, improved nutrition and use of 'primer-crops' have been tested to overcome these subsoil constraints. Overall, these approaches have been met with variable success (Adcock et al. 2007; Gill et al. 2008). For example, the benefits of deep ripping without the application of suitable soil ameliorants are likely to be short-lived, and may well be detrimental to crop productivity (Hamza and Anderson 2005). Similarly, the effect of surface application of gypsum in improving poor subsoil structure can be limited due to its poor solubility and mobility (Shainberg et al. 1989).

Application of large quantities of organic amendments, especially in the subsoil layer of alkaline dispersive soils can produce a step change in crop yields in high rainfall regions (Gill et al. 2009; 2008), but to date, practice change in the grain industry has been limited. The major constraints for widespread adoption of subsoil amelioration include, limited availability and high cost of suitable organic ameliorants delivered in-paddock, lack of suitable commercial-scale machinery and poor predictability of when and where the amelioration will benefit crop productivity. These constraints to adoption can be significant as research 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).

Hence, solutions integrating complementary sources of organic amendments such as crop residue and cover crop biomass produced *in-situ* and their residual effects on crop productivity need to be investigated. This study reports the potential of using farm grown crop residues as ameliorants for an alkaline dispersive subsoil and the residual affects observed during the fourth growing season after incorporating subsoil amendments in a medium rainfall region of southern New South Wales (NSW).

Methods

A field experiment was established on-farm near Rand in southern NSW in February 2017. Soil physicochemical properties of the experimental site are reported in Uddin et al. 2020. Briefly, the soil is a Sodosol (Isbell 2002), with increasing clay content at depth. Soil pH (water) was 6.6 at the topsoil (0 – 10 cm), which increased with depth and reached 9.0 at 20 – 40 cm and up to 9.5 at 60 – 100 cm depth. The exchangeable sodium percentage (ESP) showed a similar trend with a value of 3.3% at the topsoil, 12.5% at 20 – 40 cm and 26.5% at 60 – 100 cm depth. The high clay content in the subsoil layers had a bulk density of 1.55 g/cm^3 and low saturated hydraulic conductivity.

The trial consisted of 13 different amendments (Table 1) with four replicates arranged in a randomized complete block design. Individual plots within each block were 2.5 m wide (south-north) × 20 m long (east-west), separated at their long sides by 2 m buffers of uncultivated ground. Ripping and deep placement of amendments was carried out with a custom designed ripping machine (NSW DPI). The experimental plots were sown to barley (cv. La Trobe), wheat (cv. Lancer) and canola (cv. Pioneer® 45Y91CL) in 2017, 2018 and 2019, respectively (see Tavakkoli et al. 2019 and Uddin et al. 2020).

In 2020, wheat (cv. Scepter⁽ᵖ⁾) was sown 16May at a seeding rate of 63 kg/ha (target plant density of 120 plants/m^2). At sowing, diammonium phosphate (DAP) was applied at the rate of 78 kg/ha. Urea was top dressed at 150 kg/ha (69 kg N /ha) seven days after sowing (DAS) prior to rain. The crop was harvested 7 December. To investigate the effectiveness of amendments on amelioration, a range of soil and plant properties were measured, including pH, EC, water content and aggregate stability, crop shoot biomass, grain yield, and root growth.

Table 1. List of amendments and their application rates. Amendments were either applied at the soil surface (Surface) of incorporated to a depth of 20 – 40 cm (Deep) at trial commencement in 2017.

Amendments	Rates (t/ha)
Control	Nil
Deep gypsum	5
Deep liquid NPK	N to match chicken manure
Deep chicken manure	8
Deep pea straw	15
Deep pea straw+gypsum+NPK	12 (pea straw), 2.5 (gypsum) and N to match chicken manure
Deep pea straw+NPK	15
Deep wheat stubble	15
Deep wheat stubble+NPK	15
Ripping only	-
Surface gypsum	5
Surface chicken manure	8
Surface pea straw	15

Results

The one-off application of amendments (Table 1) in 2017, significantly ($P < 0.001$) increased the grain yield during the fourth growing season in 2020 (Figure 1). Deep placement of gypsum, wheat stubble + nutrient and wheat stubble alone increased wheat grain yields by 18, 20 and 21% respectively, relative to the control, while grain yields following surface application of amendments or ripping only did not differ significantly from the control. Similarly, deep placement of pea straw+gypsum+NPK produced a 15% increase in grain yield in 2020, and a cumulative increase of 27% over four years when compared to the control (data not shown).

Changes in subsoil pH measured at the amended layer (20 – 40 cm) is shown in Figure 2. Compared to the control, deep placement of gypsum reduced the soil pH by 0.86 units (8.99 to 8.13), while deep placement of pea straw+gypsum+NPK reduced pH by 0.47 units (8.99 to 8.52).

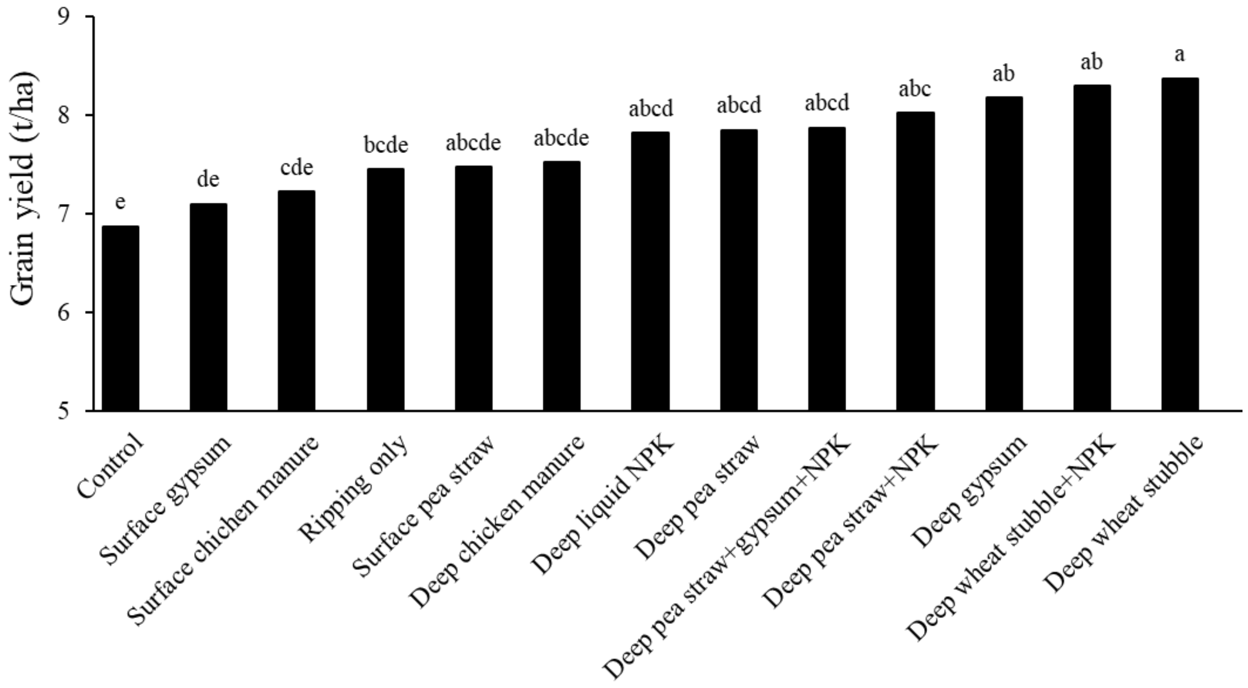

Figure 1. The mean effect of surface or deep-placed amendments on grain yield of wheat (cv. Scepter$^{\phi}$) grown in an alkaline dispersive subsoil in Rand, NSW in 2020. Bars represent the mean (n = 4). Amendments mean that share no common letters are significantly different from each other (*P* < 0.05).

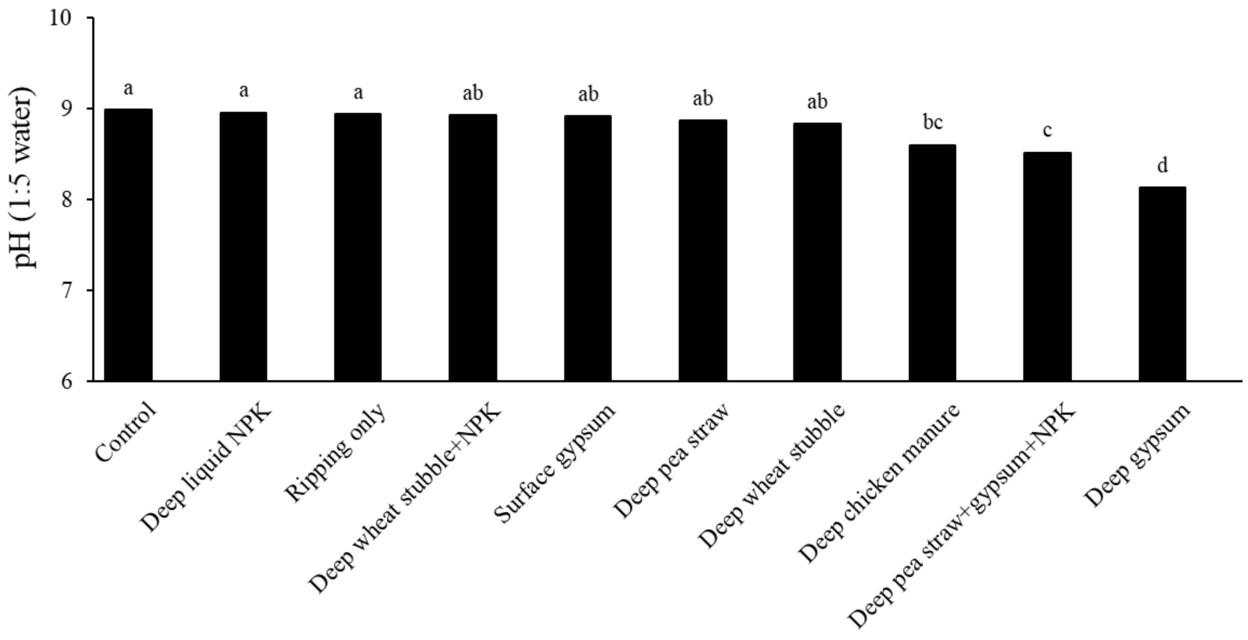

Figure 2. Changes in soil pH at 20 – 40 cm depth from selected treatment at Rand NSW. Samples were taken in May 2018 after 15 months of amendment application. Bars represent the mean (n = 4). Amendments mean that share no common letters are significantly different from each other (*P* < 0.05).

Discussion

The observed improvement in grain yield that latest at least four seasons after amelioration in a medium rainfall region of NSW (Tavakkoli et al. 2019; Uddin et al. 2020) demonstrated their strong residual effect, which were 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 to the control the best performing treatment (Deep wheat stubble) yielded an increase in grain of 21%. This was lower than the best performing treatments for 2017, 2018 and 2019, all of which comprised incorporation of deep pea straw+gypsum, which produced yield improvements of 27, 53 and 36% respectively, despite ongoing and intensive drought. The better increases in grain yield in the drier growing seasons may be attributed to the accessibility of stored subsoil water, which corresponded to greater root proliferation measured in the amendment layer (Uddin et al. 2020). Furthermore, deep placement of crop residues and/or gypsum significantly increased macro-aggregation, water infiltration and subsoil water extraction in this experiment (Tavakkoli et al. 2019; Uddin et al. 2020).

Our 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), while the addition of crop residues and nutrients provide 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.

A tentative, but promising finding from this field experiment is that readily available farm-grown products such as wheat and pea stubbles, when mixed with nutrients, can improve soil aggregation, root growth, water extraction and grain yield and produce yield responses comparable to, or better than nutrient enriched animal manures and gypsum. The results of this study showed that grain growers already have a potentially large supply of relatively inexpensive organic ameliorants available in their paddocks, a factor that may increase application options and the viability of correcting alkaline dispersive subsoils.

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