Do subsoil amendments provide benefits for crop productivity and the environment?

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Abstract

Subsoil properties that limit the infiltration of water into the B horizon are a common occurrence in the agricultural districts of South Australia, and can have impacts on both crop productivity and the environment. A field experiment on a sodosol at Stansbury, Yorke Peninsula, was used to assess the effect of subsoil amelioration on the soil properties that influence crop growth, water movement and soil water quality. Subsoil treatments applied at the field site in 2004 and 2007 at approximately 40 cm depth included: deep ripping with deep nutrients, gypsum, or organic matter. Crop growth, soil moisture and soil water quality were measured during the growing season. A post-harvest assessment of soil physical properties was also undertaken to identify the effects of the subsoil treatments on soil physical properties that are considered to influence the movement of water. In 2007, crops responded most significantly to deep ripping with liquid nutrients applied in 2007, and as a residual response to deep ripping with nutrients applied in 2004. Significant improvements in soil strength to the depth of the subsoil treatment were identified in all treatments that included deep ripping, but there was no change in bulk density or macroporosity. There was also no effect of subsoil amendment on soil water quality properties. The results suggest that crop growth responses are due largely to impacts of nutrient availability at depth and there was little evidence of impacts of treatment on water movement and soil water quality in 2007.

Key words

subsoil constraints, water, soil strength, macroporosity

Introduction

The ability of a crop to use subsoil moisture is highly dependent on characteristics of the subsoil, herein defined as that part of the soil profile below the cultivated layer for cereal crops. Many soils in southern Australia have physical and chemical constraints in the subsoil which restrict full utilisation of stored water (Belford *et al.* 1992). South Australian duplex soils have shown production gains from the application of subsoil amendments (Adcock *et al.* 2006; Graham *et al.* 1992), but it is not known whether these treatments influence soil water movement and quality.

Duplex soil types have a texture contrast between the A and B horizons, often with a sandy A horizon, and clay B horizon. The Stansbury field site for this study was a calcic mottled-hypernatric yellow sodosol (Isbell 2002) with an infertile deep siliceous sandy topsoil over a sodic clay subsoil of low hydraulic conductivity. The field site was established with subsoil treatments in 2004, and in 2007 treatments were reapplied within the existing trial in one sub-plot of four for each treatment (each treatment also had four replicates) in order to compare the immediate and residual effects of subsoil treatments. The objectives of the study were to measure crop growth and yield, infiltration rates and soil water quality in response to these subsoil amendments.

Methods

The texture contrast of the Stansbury sodosol presents a hydraulic limitation that has the potential to cause lateral water and nutrient flow in wet seasons. The infiltration rate of the subsoil (Table 1) is limited as <10mm/hr is considered a very low infiltration rate (Peverill *et al.* 1999). This soil also has higher bulk density, water retention, salinity (EC), pH and ESP (exchangeable sodium percentage) in the subsoil. The Colwell P and CEC status of this soil is relatively low (Peverill *et al.* 1999).

Table 1. Soil characteristics of the sodosol at the Stansbury field site.

Horizon	$pH_{1:5}$ H_2O	[1]$EC_{1:5}$ (dS/m)	[2]ESP (%)	Colwell P (mg/kg)	[3]CEC (meq/100g)	Field Capacity (%v/v)	Wilting Point (% v/v)	Bulk density (g/cm^3)	Infiltration (mm/hr)
A1	7.8	0.09	1.8	13.4	5.4	0.08	0.03	1.48	216
A2	7.2	0.03	4.4	14.0	1.0	0.3	0.22	1.60	17
B	8.5	0.19	24.4	7.3	18.8	0.3	0.25	1.95	0.12

[1]EC- electrical conductivity, [2]ESP-exchangeable sodium percentage, [3]CEC- cation exchange capacity.

Subsoil treatments were applied using a deep ripper to approximately 40 cm depth using deep working knife points (Primary Sales Aust.) with 47.5 cm spacing. Application of gypsum or nutrients occurred simultaneously with the deep ripping and were applied as liquid products in a jet behind the tyne. Deep lupins were applied as seed through the deep ripping tyne. The field site was established with subsoil treatments applied in 2004 and each randomised subsoil treatment plot contained 4 subplots, with 4 replicates arranged in blocks. In 2007, these subsoil treatments were reapplied in subplot 2, and compared to subplot 3 where subsoil treatments were applied in 2004. The subsoil treatments applied at the Stansbury site in 2004 and 2007 are described in Table 2. The effect of 1 and 4 year old subsoil treatments on crop production and soil properties were measured in 2007. The site was sown to Clearfield Stiletto wheat at 100 kg/ha on the 15th of June and harvested on the 11th of December, 2007.

Table 2. Subsoil amendment treatments applied at Stansbury in 2004 and 2007 and compared using 2007 crop growth and soil measurements.

Treatments	Rate of Product
District Practice (applied every season)	21 kg/ha P, 19 kg/ha N (as DAP) + 23 kg/ ha N + 26 kg/ha S (as sulphate of ammonia)
District Practice + Deep rip + deep nutrients	20 kg/ha P, 60kg/ha N, 2 kg/ha Zn, 4 kg/ha Mn, 2 kg/ha Cu (as liquid MAP, urea ammonium nitrate and Zn, Mn, Cu chelates).
District Practice + Deep rip + deep organic matter	lupins at 2000 kg/ha
District Practice + Deep rip + deep gypsum	liquid gypsum at 2000L/ha

Volumetric soil water content was measured every 2 weeks using a neutron moisture meter. Measurements were made at 20, 40, 60, 80 and 100 cm depth using a calibration determined according to the method of McKenzie et al. (1990). Soil cores were taken to one metre depth at sampling times during spring and harvest. A composite, sieved (<2mm) sample of each horizon was assessed for pH, electrical conductivity (EC), and phosphorus (P) using a 1:5 soil: water extraction (Rayment and

Higginson 1992). Total P concentration was determined by ICP-AES. Nitrate-N concentration was determined using the automated cadmium reduction colorimetric method 418F (APHA 1999) on a 1:10 soil: 2M KCl extract.

To evaluate soil strength post-harvest, a sampling area in the centre of each plot was pre-wet at 2L/hour for 10 hours, and allowed to drain for 14 hours to ensure consistent soil moisture contents across soil strength measurements. Following wetting, samples were taken for gravimetric water content and field penetration resistance was measured using a CP II penetrometer with 3 replicates in each sampling area.

After harvest replicated (4 per plot) bulk density samples were taken using a core sampler with slide hammer at 35 cm depth which is in the lower region of the deep rip treatments and within the zone of nutrient, gypsum and organic matter application. These samples were taken back to the laboratory, saturated with water, weighed, equilibrated at -10kPa (field capacity) then re-weighed. These 3 measurements were used to determine the macroporosity according to Baker et al. (2002).

Results and Discussion

Deep ripping with nutrients or organic matter in 2007 produced the best vegetative growth at mid-tillering (Table 3). The best grain yielding treatment was deep ripping with deep nutrients applied in 2007. The best grain yielding residual (2004 applied) treatment was also deep ripping with nutrients, despite recording significantly reduced dry matter production at mid-tillering (Table 3). These results suggest that the dominant subsoil factor controlling grain yield is lack of nutrient availability.

Table 3. Mid-tillering dry weight (t/ha) and wheat grain yield (t/ha) for different subsoil treatments at Stansbury [numbers in columns with the same letter are not significantly different P<0.05].

Treatment	Mid-till dry weight (t/ha)	l.s.d.	Wheat grain yield (t/ha)	l.s.d.
District Practice	0.63	bc	0.81	c
Subsoil treatments applied 2004				
Deep rip + deep nutrients	0.47	c	1.69	ab
Deep rip + deep organic matter	0.58	bc	1.22	bc
Deep rip + deep gypsum	0.61	bc	1.22	bc
Subsoil treatments applied 2007				
Deep rip + deep nutrients	0.90	a	1.89	a
Deep rip + deep organic matter	0.87	a	0.87	c
Deep rip + deep gypsum	0.65	bc	1.17	bc

The 2007 growing season received below average rainfall (decile 2) with 188 compared to an average growing season of 262 mm. There was no subsoil treatment effect on the volumetric soil water content at any stage during the growing season (data not presented). Water quality measurements were taken to evaluate readily extractable and therefore potentially mobile nutrients at different depths in the profile. There was not a significant difference between treatments (with a high standard deviation between replicated plot measurements) for the NO_3-N and P concentrations, or EC at a given sampling time. There was more readily extractable NO_3-N in the sandy A1 and A2 horizons, at harvest than in spring (Table 4) which can be prone to leaching if there was adequate rainfall, but can be a resource for the following crop if not leached . The readily extractable P concentration measured was relatively high compared to Dougherty et al. (2006) but this site is a much sandier soil with a lower sorption capacity for nutrients most likely explaining the higher water- extractable concentration. In light of this result, it is recommended that care is taken at this site to carefully match crop nutrient requirements (including assessing the nutrient resource in the soil) with nutrient application rates.

Table 4: Soil water quality measurements of readily extractable phosphorus (P) and nitrate (NO_3-N) sampled in spring and at harvest

	Spring Nitrate-N (mg/kg)			Harvest Nitrate-N (mg/kg)			Spring P (mg/kg)			Harvest P (mg/kg)		
Horizon	A1	A2	B	A1	A2	B	A1	A2	B	A1	A2	B
DP	0.5	0.5	0.6	3.2	1.6	1.0	12.7	7.8	1.1	7.6	4.0	2.7
07 DRG	0.6	0.6	0.8	3.5	1.0	1.0	13.3	10.9	6.09	7.8	4.7	9.1
07 DRG	0.6	0.5	0.6	6.2	3.2	0.2	12.1	9.5	4.8	10.6	5.5	7.1
04 DRN	0.6	1.1	1.0	5.4	1.9	1.7	18.5	11.4	4.7	7.6	5.2	5.8
04 DRG	0.5	0.5	0.6	2.8	0.3	0.4	22.4	7.8	5.2	10.6	5.4	10.3

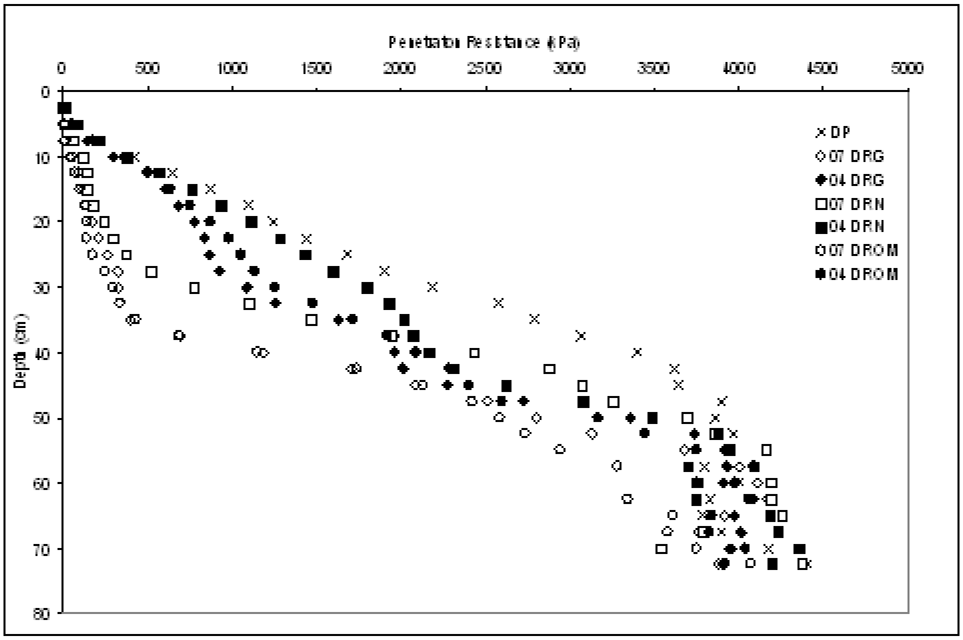

Figure 1. Penetration resistance (kPa) at depth (cm) for each treatment at the Stansbury field site where: DP= district practice DRN= deep ripping with nutrients, DRG= deep ripping with gypsum, DROM= deep ripping with organic matter (P<0.01, soil.depth LSD =177).

The post-harvest soil strength measurements indicated that the deep ripping with organic matter or gypsum applied in 2007 gave the lowest penetration resistance to the depth of the treatment (40cm) (Figure 1). The best residual treatments (applied 2004) with greatest impact on reducing penetration resistance were deep ripping with gypsum or organic matter (Figure 1). This reduction in soil strength did not eventuate as a yield response in 2007 and there was no significant difference between treatments in bulk density and macroporosity at the A-B horizon interface (Table 3). Soil strength measurements were the only evidence that the subsoil amendments may have improved water transmission through the profile. Soil strength provides an assessment of the potential ability of a plant root to penetrate a soil, with a measurement recorded every 2.5cm compared to macroporosity and bulk density measurements at a single depth of measurement at 35cm. The ability to measure soil strength at many points throughout the profile may help to overcome the heterogeneity across the site due to varying depth to clay across the site (27-66 cm). Some bulk density and macroporosity samples would have been taken in different horizons in the profile due to this variability in depth to clay.

Conclusions

Subsoil amendments, in particular deep ripping with deep nutrients, provided immediate and residual benefits for crop productivity. Amendments reduced soil strength, but had no significant effect on the bulk density, macroporosity and soil water quality properties of a sodosol in 2007. In the 2007 growing season of below average rainfall, the ability for the crop plant to access nutrients at depth far outweighed any structural changes due to ripping. Due to the low rainfall season, assessment of the potential effects of subsoil treatments on the movement of water and nutrients was restricted, and subject to high levels of heterogeneity in this sand over clay soil. The findings of this study suggest that careful monitoring of the environmental impact of subsoil amelioration is required to ensure there is not an offsite impact of the treatment. However, in this instance treatment effects were not detected.

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