Subsoil amelioration with organic materials improves canola growth and water-use efficiency

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Abstract
Field trials examined the growth, water-use and grain production of a canola crop grown on a Sodosol that was 'subsoil manured' two years prior to the study. After three seasons of crop production, the organic-amended treatments continued to out-perform the non-amended treatments with 50-80% additional grain yield. The yield gain was attributed to the additional nutrient uptake, and water use mostly in the subsurface layers below 40 cm deep. Furthermore, the largest change in the subsurface structure was associated with the treatment effect on growth of crop plants.

Key Words
Organic amendments, sodic subsoil, grain yield, soil water.

Introduction
The amelioration of high clay, poorly structured, sodic subsoil is quite a challenge in terms of cost and the available technology. In Australia, the use of deep-ripping with application of gypsum has resulted in increased grain and pasture yields (Clark 2004; Ellington 1986; Greenwood *et al.* 2006; Hamza and Anderson 2003). Rarely have these methods achieved sustained increased grain yield. The use of organic matter as an ameliorant for high clay sodic soil will likely provide improved soil structure, thus providing a vastly improved environment for plant root growth. While Armstrong *et al.* (2007a; 2007b) achieved increased grain yield, and improved surface soil structure when organic amendments were applied to the surface of a Sodosol, there was nevertheless minimal change in the subsoil. The approach of our study was to incorporate a large amount of organic amendments into the subsurface at 40 cm in 2005. This showed impressive increased grain yield in the first year of crop production (Gill *et al.* 2008) in addition to improved macroporosity in the organic treatments (Gill *et al.* 2009). This study investigated the residual effects, after 3 seasons, on grain yield, soil water-use and soil structure from the deep incorporation of organic amendments. It was postulated that improved soil structure was likely linked to the presence of plant roots, as opposed to the presence of the organic amendment.

Materials and methods
The trial site was located at Yaloak estate near Ballan, Victoria (longitude 144.23 E, latitude 37.86 S, 508.7 m elevation). Two paddocks, both with permanent raised beds (1.7 m wide) for 8 years, were selected to apply the treatments. One paddock had 4 years of lucerne history (*Medicago sativa* cv. Cimaron) followed by canola and two years of wheat. The other paddock adjacent to the lucerne paddock was under continuous cropping. The soil of both paddocks was a Sodosol (Isbell 2002) or Solonetz (FAO) with dense sodic subsoil. Basic soil properties are listed for the non-lucerne site (lucerne site similar) in Table 6. Long-term average rainfall at the site is 576 mm with the most effective rainfall (rainfall exceeds evaporation) from June to August.

Experimental design and treatments
The field trials, established in April 2005, were a randomized block design with nine treatments (Table 2) in four blocked replicates. The size of each plot was a 5 m long and 1.7 m wide raised bed. The amendments were applied manually (Table 2) at 30–40 cm deep with the help of a pipe (15 cm diameter) attached to a deep ripper. Dynamic lifter® had 4% N, 2.2% P and 1.9% K, and lucerne pellet had 2.8% N, 0.9% P and 1.4% K. Amendments were applied in two rip lines on each 1.7-m bed (centre to centre) 1 week before sowing (Gill *et al.* 2008).

Crop
Canola crop (Brassica napus var. Thunder) was sown at a rate of 5 kg /ha on 1 June 2007. Mono-ammonium phosphate was applied at 70 kg/ha at the time of sowing and then urea was applied at the rate of 90 kg /ha 106 DAS. The crop was windrowed 186 days after sowing (DAS) and 10 days later was harvested for grain. Rainfall was below average for much of the year, with the 5 month period, prior to the sowing of the canola, 50 mm below average, and around half of the average for August to October, which resulted in around 50 mm below the annual average.

Soil water
Soil water was measured, in a limited number of treatments, T1, T3 T5 and T9, with a neutron moisture probe using access tubes located in the middle of the plot.
Water-stable aggregates
Soil samples were collected 128-129 DAS from the T2, T5 and T9 treatments. Soil was sampled at three locations across the bed; R1 was the outermost location, directly under the second outside row of canola plants, R2 was under the third outside row, while S was between R1 and R2. The R1 and R2 sampling locations were positioned directly over an actively growing canola plant. Water-stable aggregates were determined on field moist soils (mean θg 0.19 g /g soil) of 8-10 mm in diameter.

Table 6. Soil properties of experimental sites before treatments applied in 2005.

Site	Depth (cm)	pH[1]	EC[2] (dS/m)	Clay (g/kg)	ESP[3] (%)	BD[4] (g/cm^3)	θv (cm^3/cm^3) 0.3 MPa	θv (cm^3/cm^3) 1.5 MPa
Non-lucerne	0–10	5.2	0.10	550	12.9	1.07	0.40	0.19
	10–20	7.2	0.24	580	14.7	1.38	0.42	0.21
	20–40	5.7	0.08	610	17.1	1.46	0.48	0.29
	40–60	5.7	0.07	640	20.3	1.70	0.52	0.34

[1] 1:5 soil: 0.1M Ca Cl_2 , [2] Electrical conductivity 1:5 soil:water, [3] Exchangeable sodium percentage, [4] Bulk density

Results
Crop growth
The highest mass of shoots at 107 DAS (rosette stage), was found with the deep incorporated organic treatments (data not shown). T9 (lucerne site) showed and additional 1 t /ha DM while at the non-lucerne site T5 and T6 treatments produced 1 t /ha greater (p<0.05) shoot yield than T1-control and T2-deep ripping treatments. After a further 19 days of crop growth all treatments showed a similar yield of dry matter. The exception was T9, which produced approximately 1 t /ha more than the control (data not shown).
Shoot nitrogen
Nitrogen concentration (g N /kg DM) in the canola shoots 107 days after sowing, were generally higher in the treatments where organic amendments had been incorporated in the subsoil (Table 7). However, the N concentrations were only significantly greater (p<0.05) in T9 compared to the control.
Grain yield
All the organic treatments significantly (p<0.05) increased the grain yield in comparison to the control (Table 7). The organic-amendments contributed to a 50 to 80% increase, compared to the control, in grain yield at both sites while the inorganic treatments had a similar yield to the control and deep ripped treatment.

Table 7. Description of the treatments established in 2005, and nitrogen concentration in shoots and grain yield of canola in 2007.

Treatment	Description	Rate of addition (t /ha)	Nitrogen (g N /kg DM) L[3]	Nitrogen (g N /kg DM) NL[4]	Grain yield (t /ha) L	Grain yield (t /ha) NL
T1	Control	Direct sowing	44.4	44.5	1.61	1.56
T2	Deep ripping 30-40 cm	None	45.3	46.1	1.62	1.47
T3	Gypsum (DR40[1])	10	43.2	46.3	1.52	1.79
T4	MAP[2] (DR40)	0.1	44.7	46.7	1.53	1.49
T5	Lucerne pellets (DR40)	20	43.3	42.7	2.90	2.52
T6	Dynamic lifter (DR40)	20	47.4	42.8	2.45	2.34
T7	Sand (DR40)	20	48.5	49.4	1.79	1.39
T8	Gypsum+MAP (DR40)	10+0.1	49.9	50.5	1.66	1.31
T9	Lucerne pellets+gypsum+MAP (DR40)	20+10+0.1	53.8	51.5	2.94	2.76
		LSD (p=0.05)	5.0	6.4	0.47	0.76

[1] Deep ripping to 30-40 cm, [2] Mono-ammonium phosphate, [3] L-the site with Lucerne history, [4] NL-non-lucerne site

Water use from soil profiles and water use efficiency
The improvement in crop water use in 2007 was clearly demonstrated in the deep incorporated organic treatments at the non-lucerne site. Approximately 23 mm more soil water was depleted below the 40 cm layer, in the organic treatments, T5 and T9, compared to the control (**Error! Reference source not found.**). The most efficient conversion of soil water to grain was shown by the organic-amended treatments; showing an additional 2.5 to 3.2 kg/ha/mm, equating to a >50% increase in water use efficiency (Table 6).

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Table 8. Loss of soil water (mm) from soil profiles, and the apparent water use and water use efficiency (WUE) (June-November) for canola plants grown in selected treatments at the non-lucerne experimental site in 2007.

Treatment	Depth of soil layer (cm)				Total	WU[2]	WUE[3]
	0-20	20-40	40-60	60-80	0-80	(mm)	(kg/ha/mm)
T1-Control	2.7	5.3	0.1	7.3	15.4	317	4.9
T3-Gypsum	2.4	5.7	2.5	11.1	21.6	324	5.5
T5-Lucerne	3.3	4.9	12.1	18.7	39.0	341	7.4
T9-G+L+MAP	2.3	8.3	13.1	16.0	39.7	342	8.1
LSD[1]	n.s.	n.s.	6.6	10.2	13.4	13.4	2.2

[1] p=0.05, n.s. not significant at p=0.05, - not applicable, [2] Apparent water use = total profile loss + growing season rainfall, [3] Apparent water-use efficiency = grain yield (kg /ha) / water use (mm)

Soil aggregate stability

The formation of water–stable macroaggregates in soil sampled in October 2007 was increased significantly (p<0.01) by the deep incorporation of organic amendments in 2005. An additional 15% of the soil sample had formed macroaggregates >0.25 mm with the two organic amendment treatments (T5 and T9), compared to soil from the control (T1) treatment (Table 9). This represented an almost 1/3 increase in macroaggregation with the organic amendment treatments. The amendment treatment × sample position interaction for macro-aggregation was significant at p=0.06. The basis for this interaction was the increased percentage of macroaggregates in the soil sampled beneath a canola plant, compared to between the plant rows, when organic amendments had been incorporated in the subsurface 30-40 cm layers 2 years earlier (Table 4). In contrast, there was no difference in soil macroaggregation between positions of samples within the control treatment. The macroaggregation data were subject to the variation that occurs in the field, with a coefficient of variation that exceeded 28%. Thus, increases in macroaggregation, due to the presence of an actively growing canola plant (R location) were only significant (p<0.05) at the R1 location with treatment T5 and at the R2 location with the T9 treatment.

Table 9. for the effect of organic amendments on the formation of macroaggregates (%>0.25 mm) in soil samples from the amendment and location treatments.

	Aggregation (% >0.25 mm)			
		Position		
Amendment treatment	Mean (position)	S	R1	R2
Control (T1)	48.0	50.5	47.5	45.9
Lucerne (T5)	54.2	54.2	75.4	58.9
Lucerne+MAP+gypsum (T9)	62.7	51.5	64.8	71.7
LSD (p=0.05)	9.1		15.8	

Discussion

Crop growth and use of subsoil water

This field study has demonstrated the residual effects of subsoil-incorporated organic amendments on the growth and yield of canola after three seasons of crop production on this Sodosol with high clay, sodic subsoil. The increased grain yield of up to 80% has been achieved nearly three years after the initial deep incorporation of organic amendments (Table 7). The increased use of subsoil water by canola plants grown on the organic treatments, as shown at the non-lucerne site (Table 8), and the increased accumulation of nitrogen in the canola shoots (data not shown) appeared to be the factors that contributed to the increased grain yield. This was shown by the two organic-amendment treatments, lucerne (T5) and lucerne plus gypsum and MAP (T9), at the non-lucerne site. After 107 DAS the canola shoots from T5 and T9 had accumulated on average around 50 kg more nitrogen per hectare than the control and deep ripped treatments in addition to the 50 kg of fertilizer nitrogen applied during crop growth. In addition, these organic treatments used three times more water below the 40 cm layer than the control, resulting in a 50% improvement in apparent water-use efficiency (Table 8).

Soil structure

The improved crop yield and water-use efficiency in the organic-amended treatments could in part be attributed to the improved soil structure. In the 2007 season, two and half years after the incorporation of organic amendments, there was a one-third increase (p<0.01) in soil macroaggregation, in comparison to the non-amended control soil (Table 9). However, the treatment × soil sample location interaction at the 10% level (p=0.07) suggests that the presence of canola crop roots had a crucial role in stabilizing soil macroaggregates. Furthermore, the increased macroporosity of the subsurface in 2005 was attributed to the

presence of crop roots (Gill *et al.* 2009). Thus it is not surprising that after 2.5 years had lapsed since the incorporation of the organic amendments into the subsurface, that crop root growth played a prominent role in the maintenance of the improved soil structure. The importance of root growth was previously shown to be more important than total carbon input in rehabilitation of degraded prairie grasslands (Jastrow 1996). The use of gypsum with deep ripping is often used to minimize structural degradation that may occur when deep ripping sodic soils. In this field study, there was no evidence of any increased extraction of water from the profile (The improvement in crop water use in 2007 was clearly demonstrated in the deep incorporated organic treatments at the non-lucerne site. Approximately 23 mm more soil water was depleted below the 40 cm layer, in the organic treatments, T5 and T9, compared to the control (Error! Reference source not found.). The most efficient conversion of soil water to grain was shown by the organic-amended treatments; showing an additional 2.5 to 3.2 kg/ha/mm, equating to a >50% increase in water use efficiency (Table 6).
Table 8) and subsequently no difference to the control in dry matter yield or grain yield (Table 7) which has previously been reported (Hamza and Anderson 2002). In fact, gypsum can have a detrimental effect on root growth (Clark 2004) due to the high soil electrical conductivity (Clark *et al.* 2007) in the gypsum-amended soil. leading to reduced root density (Clark 2004) and lack of yield improvement (Hamza and Anderson 2002).

Conclusion

This study demonstrates that the use of subsoil 'manuring' improves production on soils with sodic subsoil on a long-term basis than with current methods of intervention, such as deep ripping. Importantly, the greatest improvement is probably due to the incorporation of subsoil nutrients, thus providing a stimulus to plant root growth. The presence of root growth in the subsoil is likely to be the most important vector for change of subsoil structure.

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