Subsoil manuring on problem clay soils: increasing crop yields to the next level

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Abstract
Subsoil manuring is a new practice that involves the incorporation of high rates of organic amendments into the top of the B horizon of problematic duplex soils, where dense clay subsoils limit crop yields, particularly in seasons with dry springs. The practice resulted in increased grain yields across sites and seasons in the high rainfall zone of Victoria. At nine site by season combinations from 2005 to 2011, grain yields were increased on average by 60 %, from 5.7 in the control to 9.1 t/ha with subsoil manuring. The yield increases are attributed to the improvement in the physical properties of the clay subsoil. Measurements taken after one crop had been grown on the subsoil-manured plots showed that macroporosity in the clay subsoil between the rip-lines increased 2.7 times, from 8 to 19% v/v, while the saturated hydraulic conductivity increased almost 50-fold. These improvements enabled the crop roots to extract more subsoil water during the crop cycle. The net effect was to increase the plant available water capacity of these soils, enabling the crop to use more rain that fell during the year.

Key Words
Dense, clay, subsoils, constraints, crop yields.

Introduction
Large areas of cropping land in south west and south east Australia have dense clay subsoils. These are the so-called duplex soils, where lighter textured sandy-loam to clay-loam topsoils, overlie dense clay subsoils. The problem with many of these subsoils is that there is limited pore space for air to move to the respiring roots, or for water to infiltrate into the subsoil. They are often sodic and so the porosity of the subsoil is further limited by dispersive clay particles. The subsoils are considered to be 'hostile' to plant roots; the roots are generally unable to grow readily into the clay layers because the dense clay is too hard when dry, or too anaerobic when wet. In some drier areas, the clay subsoils are saline and can contain toxic levels of boron. However these constraints are not generally present in the high rainfall zone (HRZ).

Plant roots are generally restricted in these soils to the topsoil layers. The so-called "bucket size" of the soil (the soil volume providing water and nutrients to plant roots) is small and limited. High yielding crops just do not 'finish' in dry springs, because they run out of water, as their roots cannot grow into and through the clay subsoil. Grain growers in the HRZ had been asking whether anything could be done to address this problem. However, the prevailing attitude was that it was just too costly to ameliorate these hostile subsoils, and so you just had to live with them.

This paper reports on results from six years of field trials from 2005 to 2011 in the HRZ of Victoria where we have been evaluating subsoil amelioration treatments to improve the physical properties of these dense clay subsoils. One treatment, involving deep ripping and the incorporation of high rates (20t/ha) of organic materials at a depth of 30-40 cm at the top of the clay B horizon, has proved to be particularly effective. We report on the effects of this treatment, now termed 'subsoil manuring' (Gill et al. 2009), on cereal yields over a range of site by season combinations. Measurements of selected soil physical properties in the subsoil between the rip-lines, ten months after the incorporation of organic amendments, are presented to test whether subsoil manuring improves the physical properties of the subsoil. Finally we present measurements of the loss in soil water between sowing and harvest, for the 20-80 cm subsurface layers, during the 2005 and 2006 crops, and the accumulation of summer rainfall in these layers, during the 2005-2006 fallow period. These tested the hypothesis that subsoil manuring increased crop water extraction from subsoil layers, which were then able to be replenished with water from summer rain falling over the fallow period.

Methods

Cereal yields at experimental sites across the Victorian HRZ

A series of replicated experiments were established in paddocks on farms across the high rainfall zone of Victoria from 2005 to 2011. They involved small plots, ranging in size from 2m by 5 m to 4m by 10m, where subsoil manuring and other subsoil treatments were established prior to sowing the paddock to a commercial crop. We present grain yield data for the control (commercial crop) and the subsoil manured crop where 20 t/ha of organic amendment (lucerne pellets or poultry litter) were incorporated at a depth of 30-40 cm behind a ripper in two rip-lines, 80 cm apart, on 1.7- or 2.0-m wide raised beds. The crop at Stewarton was grown on the flat and not on raised beds. Mature plants were sampled from two 50 cm^2 quadrats by hand at crop maturity. The data were accepted if there was satisfactory crop establishment and if experimental variation was kept to a minimum. All told there were 9 different site by season crop combinations involving wheat or barley crops.

Soil physical properties in the subsoil

Duplicate intact soil cores were collected in brass rings (63 mm long, 72 mm internal diameter) at a depth of 35-45 cm, midway between the rip-lines in February 2006, following the harvest of the first wheat crop at Ballan in 2005. Cores were taken for the control, the deep-ripped control, a gypsum + MAP fertiliser treatment, and a subsoil-manured treatment. The sampling occurred 30 cm from the edge of each rip-line, to ensure that the soil from the amended rip-line was not sampled. Macroporosity in the soil was measured by saturating the soil in a sand tray containing 3 cm of water, before placing them on a hanging column tension plate. The volumetric water content of the soil was determined at a water potential of -10 kPa. Macroporosity was determined as the difference between the volumetric water content at saturation, and at –10kPa. The saturated hydraulic conductivity (Ks) was measured by the constant head method of Klute and Dirksen (1986), while the bulk density was calculated from the soil dry weight, divided by its volume.

Soil water measurements in 2005 and 2006

This study involved 2 consecutive wheat crops grown in 2005 and 2006 at a field site at Ballan in south west Victoria. The site had been continuously cropped with a canola-wheat-barley-wheat-canola rotation for the previous 8 years. Normal spring rainfall occurred in 2005 (170 mm) whereas 2006 was a drought year with only 74 mm of spring rainfall. However 200 mm of summer rain fell during the 2005-2006 summer fallow period. The experimental design was a randomized block with 9 treatments in 4 replicated blocks. We report on the control, a deep-ripping control, a gypsum and a subsoil manured treatment, which received 20 t/ha of lucerne pellets (2.8 %N, 0.9 %P, 1.4%K), at a depth of 30-40 cm. The gypsum was added at 10 t/ha. The volumetric water content (θv), in 20-cm soil layers from the depth of 20 to 80 cm, was determined when the wheat crop was sown in 2005 and 2006, and at crop maturity in December 2005 and 2006, using a calibrated Neutron Probe. The soil water in layers was expressed in mm using the calculation [θv (%) x depth (mm)]/100.

Results

The striking feature in the yield data from the HRZ experimental sites was the consistent yield increase of cereals of 2 t/ha or higher, for the subsoil-manured crops compared to the commercial crops (Table 1).

Table 1. Summary of cereal yields for commercial and subsoil-manured crops, at sites across the HRZ in Victoria, from 2005-2011

Year	Site	Crop number following treatment	Grain Yield (t/ha)			Percent Increase (%)
			Commercial crop	Subsoil manured [1]	Increase in yield	
2005	Ballan	Wheat (1st crop)	7.6	12.5	5.3	70
2009	Derrinallum	Wheat (1st crop)	5.0	9.8	4.8	96
2009	Penshurst	Wheat (1st crop)	4.8	7.6	2.8	58
2010	Wickliffe	Wheat (1st crop)	9.1	11.6	2.5	27
2011	Stewarton	Wheat (1st crop)	5.7	8.1	2.4	42
2006	Ballan	Wheat (2nd crop)	3.6	5.6	2.0	55
2011	Derrinallum	Wheat (3rd crop)	5.0	7.4	2.4	48
2011	Penshurst	Wheat (3rd crop)	6.8	11.3	4.5	66
2009	Winchelsea	Barley (1st crop)	4.4	7.7	3.4	77

[1] Subsoil manured plots received 20 t/ha (fresh weight) of organic amendment (lucerne pellets or poultry litter) (< 20% moisture content) incorporated into the subsoil.

The consistency of these yield increases gives us confidence to think that subsoil manuring will result in crop yield increases on these soils, at least for the first three years following the subsoil intervention. When cereal yields are averaged over the site x season combinations, the commercial control crop yielded 5.7 t/ha, while the subsoil manured plots yielded 9.1 t/ha, which represents an average 60% yield increase above the commercial crop. This is indeed a marked increase in grain productivity.

A transformation of the soil physical properties in the 35-45 cm deep subsoil layer between the rip-lines occurred with subsoil manuring (Table 2). The macrporosity of the clay layer more than doubled, indicating that 19% of the soil volume consisted of macropores that were >30 µm in diameter, whereas only around 9% of the clay volume in the control and other treatments was occupied by these macropores. Given that the root-limiting macroporosity in moist soil is 10% (Silva et al., 1994) due to the lack of aeration for root growth, then it follows that subsoil manuring was able to overcome this subsoil constraint. Similarly there was more than a 45-fold increase in the saturated hydraulic conductivity in the 35-45 cm clay subsoil layer with subsoil manuring. These findings indicate that the abilities for both air and water to pass through this clay subsoil layer, which was located 30 cm from the incorporated organic amendment, were substantially increased.

Table 2. The bulk density, macroporosity, and the saturated hydraulic conductivity (*Ks*) in the clay subsoil of selected treatments at a depth of 35-45 cm between the rip-lines, at Ballan in February 2006.

Subsoil treatment	Bulk density (g/cm^3)	Macroporosity (% v/v)	*Ks* (cm/h)
Control	1.54	9.3	0.03
Deep ripping (DR)	1.47	9.4	0.07
DR +Gypsum+MAP	1.52	9.0	0.22
Subsoil manuring [1]	1.22	19.1	1.36
LSD(*P*=0.05)	0.15	6.0	0.28

[1]The subsoil manuring treatment involved deep ripping plus lucerne pellets at 20t/ha.

Subsoil manuring resulted in more than a doubling of the soil water that was lost from the 20-80 cm soil layers between sowing and the harvest of the crop in 2005 and 2006, compared to the control treatment (Table 3). This loss in water would have resulted mainly from the extraction by the crop roots and resulted in a very dry subsoil at harvest, for the subsoil-manured plots. Our concern at the time was that the excessively dry subsoil would penalise the following crop. However some 200 mm of rain fell during the 2005-2006 summer at Ballan, of which almost two thirds (125 mm) was captured and stored in the 20-80 cm subsurface layers by the time the next crop was sown in May 2006,. This was 2.7 times more soil water than that captured and stored in these subsurface layers in the control plots.

Table 3. Changes in soil water (mm) in subsoil layers (20-80 cm depth) for selected treatments during the wheat crop in 2005, the summer fallow period in 2005-2006, and the wheat crop in 2006, at Ballan.

Treatment	Water loss during 2005 crop [from sowing to harvest]	Water gain in 05-06 fallow [from harvest to sowing]	Water loss during 2006 crop [from sowing to harvest]
Control	57.4	45.0	64.0
Deep-ripped (DR)	93.0	67.4	67.8
DR+gypsum	50.9	74.7	95.1
Subsoil manuring[1]	123.2	125.0	135.6
LSD (*P*=0.05)	26.3	27.8	28.7

[1]The subsoil manuring treatment involved deep ripping plus lucerne pellets at 20t/ha.

The yield increases with subsoil manuring are attributed to increased water extraction from subsoil layers by crop roots, and to the increase in the supply of nutrients from the organic amendment. The increased availability of subsoil water is less of an advantage in wet springs, as we found that the addition of fertiliser nutrients in the subsoil resulted in similar yield increases above the control yields, to the subsoil manuring treatment (data not presented). This was the situation at the Wickliffe site in 2010 (Table 1).

The incorporation of these high rates of organic amendments into the subsoil of these duplex soils resulted in an increase in the capacity of the soil to store plant-available water. This increase in plant-available water capacity or 'bucket size' of the soil is a unique achievement. The mantra that we attach to this practice is that (i) it increases the capture of fallow and in-crop rainfall, (ii) it stores this extra captured rainfall deep in the root zone, resulting in (iii) the increased use of this rainfall by the crop and this occurs generally after anthesis. All of these effects result in (iv) an increased crop yield. It is interesting to note that the basis for the differences between low and high yielding parts of paddocks, identified by yield maps, can be generally attributed to increases in plant-available water in the high yielding areas (Sadras et al., 2002). Thus subsoil manuring can transform low yielding cropping land to higher yielding land under rain-fed conditions, where dense clay subsoils limit deep root growth and water extraction from the subsoil.

The high costs of the subsoil manuring intervention, at around $700-1000/ha, will nevertheless limit the widespread adoption of the practice. In addition the availability of the poultry litter might restrict the practice if it were widely adopted because of the high rates of manure addition. We are currently assessing the profitability of the practice in Victoria and are evaluating alternative organic amendments including the use of nutrient-enriched crop stubbles, as alternative amendments to poultry litter.

Conclusion

Subsoil manuring, involves the deep incorporation of high rates of organic amendment into the top of the B horizon in duplex soils. It results in the marked improvement of the physical properties of the clay subsoil. This in turn increases the movement of air and water into the clay subsoil enabling crop roots to use more of the subsoil water during crop growth. The net effect is to increase the plant-available water capacity of the soil profile or its 'bucket size'. The practice is expensive, but it delivers large increases in grain yield over at least three successive crops, and increases the efficiency with which the annual rainfall can be used by the crop. Further research is underway to find cheaper, cost-effective stubble-based amendments to replace the poultry litter that is currently the amendment of choice.

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