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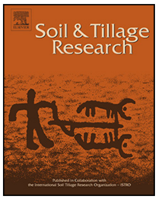

Chemical and physical amelioration of subsoils has limited production benefits for perennial pastures in two contrasting soils

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ABSTRACT

While broad acre grazing is the major agricultural land use in Southern Australia, there has been comparatively little research on the effect of alleviating subsoil limitations on pasture production under field conditions. The effect of modifying the physical and chemical properties of soil on perennial pasture production and root distribution was studied on 2 major soil types in two regions of Southern Victoria, Australia. Soil treatments included the deep placement of fertilisers, lime and organic matter, and soil disturbance to a range of depths. The Ellinbank field site on a Ferrasol was monitored for 2 years, while the Curdievale site on a Sodosol was monitored for 1 year. There were substantial changes in soil physical and chemical characteristics as a result of the soil treatment. Soils were softer, less acidic and had increased nutrient availability within the profile. However, these changes did not result in consistent gains in pasture productivity, over-and-above the normal practice of surface applied nutrients and lime. The deep placement of organic matter at the Ellinbank site resulted in an initial increase in pasture production, but this effect declined with time. The perennial ryegrass (*Lolium perenne* L.) based pasture was shallow-rooted and substantial modifications to the soil profile did not result in significant changes to root distribution. It appears that the productivity of perennial ryegrass pasture in high rainfall regions can be maintained at a productive level, with a localised nutrient and water supply.

1. Introduction

In their natural state, the soils of Southern Australia can provide a hostile environment for the growth of pastures and crops. Limitations to pasture and crop growth may be caused by inherently low levels of macro and micro nutrients, toxic levels of aluminium (Al) and manganese (Mn) in strongly acid soils, oxygen deprivation in waterlogged soils, and physical limitations in poorly structured soils (Williams and Raupach, 1983; Rovira, 1992; Rengasamy et al., 1992; MacEwan et al., 2010). Although soil limitations may in part be alleviated by the surface application of fertilisers, gypsum and limestone, adverse conditions below the surface may markedly restrict pasture and crop production (Graham et al., 1992a; Dracup et al., 1992; Gill et al., 2008).

It is often proposed that improving the root environment should increase above ground productivity through greater water and nutrient uptake (Fitter, 1991), production of plant hormones (Itai and Birnbaum, 1991) and enhanced soil biological activity (Bowen and Rovira, 1991). Deeper root growth is particularly important over drier months when a lack of available moisture may be the single greatest factor limiting crop and pasture production in non-irrigated soils (Dracup et al., 1992; Graham et al., 1992a; Gill et al., 2009, 2012; Espinosa et al., 2011). Moreover, with the accumulation of nutrients in shallow surface soils, most notably phosphorus (P), there may be limited availability when the surface soil is dry (Robson et al., 1992; Jarvis and Bolland, 1991; Pinkerton and Simpson, 1986). In contrast, soils with shallow topsoils and poor water permeability, such as duplex soils, may be prone to waterlogging during periods of high rainfall (McFarlane and Cox, 1992), leading to restricted gas exchange and elevated concentrations of toxic ions in solution (Drew, 1988).

There has been a considerable amount of research undertaken in Australia investigating subsoil limitations to crop production. Most of the studies have involved deep tillage or ripping with or without chemical ameliorants and crop production responses have varied considerably (Dracup et al., 1992; Hamblin, 1985; Jarvis, 1992; Jayawardane et al., 1992). More recently, Gill et al. (2008) reported how the incorporation of high rates of N-rich organic amendments into the top layer of the clay B horizon of a Sodosl soil in south west Victoria, resulted in large increases in wheat yields in

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2005. The yield increases, which were repeated in 2006 (Gill et al., 2012), and subsequently on Sodosol soils across the Victorian high rainfall zone (Sale et al., 2012), are attributed to the changes in the physical properties of the sodic clay subsoils with significant increases in macroporosity and hydraulic conductivity (Gill et al., 2009). These changes allowed root growth to increase in the clay subsoil, and for soil water to be extracted by the crop from the subsoil during the post-anthesis, grain-filling period.

The practice of ameliorating subsoil constraints by incorporating large amounts of organic amendments into clay subsoils has been termed ‘subsoil manuring’ (Gill et al., 2009), but has had limited adoption as it is generally considered to be too expensive to undertake on a commercial scale (Shaw et al., 1998). However Sale and Malcolm (2013) reported that the economic analysis of the costs and returns of subsoil manuring, based on two sites in south west Victoria and four crops between 2009 and 2012, found the practice to be highly profitable, given the large, consistent and continuing yield increases grown on subsoil-manured land.

While broad acre grazing is the major agricultural land use in Southern Australia, there has been comparatively little reported research on the effect of alleviating subsoil limitations on pasture production under field conditions. Studies on irrigated pasture soils in Northern Victoria identified subsoil constraints as a major restriction to pasture production (Blaikie and Martin, 1987; Blaikie et al., 1988; Mason et al., 1987). These studies suggest that major limitations to pasture productivity may be chemical and physical restrictions to root growth and function in subsoils. Martin (1982) increased perennial pasture production by 100%, achieving yields of 36 t DM in a single year in field plots when soils were mixed to 1 m and adequate water and nutrients were applied. Similarly, Gourley (1987) increased white clover (*Trifolium repens* L.) production by 60% when pasture was grown in 1 m deep soil profiles which were modified with fertilisers and organic matter. However, these studies confounded profile modification with increased nutrient and water availability and decreased physical constraints and therefore did not adequately define the factors which were responsible for increased pasture production.

The aim of this study is to evaluate physical and chemical amelioration treatments within gradational and duplex soils, and determine the effect on perennial pasture production and root distribution. A key issue to be addressed is whether fertiliser nutrients applying progressively throughout deeper soil layers will improve pasture production over and above the current practice of surface application? Additionally, can practices such as deep liming to overcome subsoil acidity, or the use of deep organic amendments to overcome physical constraints, increase rooting depth and improve overall pasture production?

2. Materials and methods

2.1. Field sites and treatments

2.1.1. Ellinbank

The first field site was located within a dairy pasture at Ellinbank in West Gippsland, Victoria (38° lat. 146° long.). The climate is temperate, with a mean summer maximum of 23 °C and mean winter maximum of 13 °C. The soil was classified as ‘Gn 4.11’ using the Factual Key (Northcote, 1979), and is a Krasnozem in the Great Soil Group (Stace et al., 1968), also described as a Ferrosol using the Australian Soil Classification (Isbell, 2002).

Field plots were 8 m × 4 m. The 10 treatments, including surface and subsurface applications of superphosphate, potash and trace elements, lime and organic matter, and soil disturbance to 5, 25 and 50 cm (Table 1), were applied in March, 1994. All plots were grazed with cows, with the exception of treatment 8 so that the effect of hoof traffic on disturbed soil could be determined (Table 1). Each treatment was replicated 4 times and laid out in a randomised block design. Soil was removed in 10 cm increments where soil disturbance was to 50 cm (i.e. 0–10, 10–20, 20–30, 30–40, 40–50 cm layers), and in 5 cm increments where soil disturbance was to 25 cm (i.e. 0–5, 5–10, 10–15, 15–20, 20–25 cm layers), using a commercial excavator (Hitachi EX120). Every layer was removed and kept separate, one plot at a time, then replaced, with treatments applied to each layer in situ and manually incorporated, before tamping evenly back to the appropriate depth, prior to the next layer being replaced. The organic matter was applied as chopped pasture silage (65% DM, 2.24% N, 0.38% P, 2.71% K, 0.28% S). The initial soil chemical properties of the site were determined by analyses of sub-samples of soil, collected from each plot as soil was removed in 10 cm layers (Table 3). All plots were sown to a perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pasture in April, 1994, and establishment was aided by spraying with broad leaf specific herbicide after seeding emergence.

The long-term mean annual rainfall at the Ellinbank site is 1100 mm, distributed evenly throughout the year (Fig. 1). Monthly rainfall figures for the period of January, 1994 to July, 1996, are also shown in Fig. 1. Rainfall was less than the long-term average throughout much of 1994, although total rainfall was 903 mm. In 1995, rainfall was greater from April to July than the long-term average, with a total rainfall for the year of 1269 mm.

2.1.2. Curdievale

The second field site was located on a dairy pasture at Curdievale, South-western Victoria (39° lat. 143° long.), on a hard setting duplex soil. The soil was classified as ‘Dy 5.41’ using the

Table 1
Depth of soil disturbance, nutrient rates, depth of fertiliser placement and hoof traffic applied to the various treatments in the Ellinbank field study.

Treatment	Depth of disturbance	Nutrient rate (t/ha/layer)				Fertiliser placement	Hoof traffic
		P	K + trace[a]	Lime	Organic matter[b]		
1	0–5 cm	0.220	0.5	10	nil	0–5 cm	yes
2	0–50 cm	0.220	0.5	10	nil	0–5 cm	yes
3	0–50 cm	0.044	nil	nil	nil	each 10 cm	yes
4	0–50 cm	0.044	0.1	nil	nil	each 10 cm	yes
5	0–50 cm	0.044	0.1	2	nil	each 10 cm	yes
6	0–50 cm	0.044	0.1	2	4	each 10 cm	yes
7	0–50 cm	0.220	0.5	10	8	each 10 cm	yes
8	0–50 cm	0.044	0.1	2	nil	each 10 cm	no
9	0–25 cm	0.044	0.1	2	nil	each 5 cm	yes
10	0–50 cm	nil	nil	nil	nil	each 10 cm	yes

[a] Zn (12.5 kg ha^{-1}), Cu (12.5 kg ha^{-1}), Mo (0.5 kg ha^{-1}), Co (0.5 kg ha^{-1}) also applied in total to soil profile.
[b] Organic matter applied as fresh silage, 65% DM, 2.24% N, 0.38% P, 2.71% K, 0.28% S.