Review: The effects of soil compaction on root penetration, pasture growth and persistence

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Abstract

A review of the literature shows that soil compaction by stock treading has been an issue for New Zealand farmers for over half a century. Soil compaction restricts root penetration resulting in poor anchorage and susceptibility of plants to uprooting during grazing. In addition, access to moisture and soil nutrients is reduced which decreases the fitness of the sward under stress conditions. Mechanical treatment of compacted soil improves soil physical properties but beneficial effects on pasture growth have been less readily demonstrated. Options to reduce the impact of soil compaction on pasture persistency include better soil management to reduce the incidence and severity of compaction and, in the longer term, new grasses with root and shoot traits that mitigate the effects of compaction.

Keywords: roots, ryegrass, soil compaction, soil moisture, soil nutrients, trampling

Introduction

Treading of wet soils by dairy cattle causes soil compaction resulting in decreases in hydraulic conductivity, air permeability and macroporosity (Drewry *et al.* 2000a), and an increased proportion of large soil aggregates (Singleton & Addison 1999). Soil compaction by treading has been known for decades (e.g. Sears 1956), and the effects of cattle treading on pasture and soil responses have been reviewed by Drewry *et al.* (2008). Loss of soil's natural capital due to intensification of pastoral agriculture was discussed by Mackay (2008). Soil compaction under grazing is a common problem, widely reported in New Zealand and overseas (e.g. Federer *et al.* 1961; Mullen *et al*. 1974; Willat & Pullar 1984), with local variations in intensity controlled by soil type, soil moisture conditions, and stock class and stocking rate. Effects are most apparent between 50 and 100 mm soil depth (Singleton & Addison 1999).

Smearing of the soil surface ("pugging") by treading under very wet conditions can substantially reduce pasture regrowth rates, with particularly damaging effects on clover. On a Te Kowhai soil at the DairyNZ No. 2 dairy farm near Hamilton, a single severe pugging event by dairy cows reduced ryegrass DM yield by 37% and clover DM yield by 52% over the following 12 months (Menneer *et al.* 2005). Once pugged, the pasture remains susceptible to further pugging damage for months after the original event (Zegwaard 2006).

The increased penetration resistance of the compacted soil reduces the downward growth of grass roots (Chapman & Allbrook 1987). For ryegrass this effect is mainly mechanical rather than being caused by the anoxic conditions typical of pugged and compacted soils, because, although ryegrass root growth is slowed, it is not stopped at soil oxygen levels that are prohibitively low for most other species (Gradwell 1967). Restrictions to root growth can be overcome if the compacted soil layer is treated by subsoiling or mechanical aeration (Houlbrooke 1996; Burgess 1998). Subsoiling increases soil macroporosity and air permeability, and reduces bulk density (Drewry & Paton 2000; Drewry *et al.* 2000b; Burgess *et al.* 2000). However, these improvements have not always been associated with recorded increases in pasture growth in the short term. In some cases the lack of pasture growth response may have been caused by root damage making the sward susceptible to dry spells (Drewry & Paton 2000), so timing of the soil treatment is important.

Deleterious effects of impeded root growth

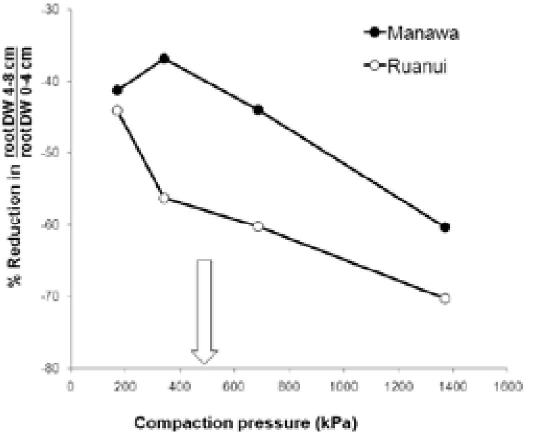
Enforced shallow-rooting makes pasture plants susceptible to uprooting during grazing (Charles 1979); this is a major contributor to poor pasture persistence. The effect of limited root penetration is exacerbated by any root-damage caused by insect pests. Shallow rooting reduces access to subsoil moisture by forage grasses (Torbert *et al.* 1990), and hence the ability of swards to cope with dry conditions. The environmental footprint of the pasture increases, as the risk of nitrate leaching increases (Dunbabin *et al.* 2003) and the potential for carbon sequestration in the subsoil is reduced (Lorenz & Lal 2005) when root penetration is limited.

Managing soils and pastures to optimise pasture persistence

Managing soils that are susceptible to damage

Soils differ in their resistance to treading and

Figure 1 Percentage reduction in root dry weight (DW) at 4-8 cm soil depth compared with root DW at 0-4 cm for both Ruanui and Manawa ryegrasses under increasing soil compaction. Data from Edmond (1958). The arrow shows front hoof ground pressure for a 500-kg cow (Kubo & Isobe 1975).



consequent effects on pasture (Edmond 1970; Climo & Richardson 1984; Ledgard *et al.* 1996; Singleton *et al.* 2000; Menneer *et al.* 2004). Because of the lubricating effect of water on soil under compression, drainage characteristics of soils are critical in determining the severity of treading damage. Where soils are known to be susceptible to treading damage under wet conditions, moving stock from pasture before damage is severe has become established good practice (Thom *et al.* 1985; Bilotta *et al.* 2007). Ryegrass pulling, usually a summer phenomenon, also varies with soil type – Te Rapa peaty silt loam being worse than Te Kowhai silt loam (Thom *et al.* 2003). A compacted layer between 7 and 10.5 cm below the surface with 80% of root mass located in the top 5 cm was reported for both these soils by Houlbrooke (1996); presumably the lower strength of the peaty soil provided poorer anchorage than in the mineral soil. No broad systematic study of differences among soil types in susceptibility to pasture pulling has been found. Such information would enable development of technologies to mitigate pulling.

Research on the recovery of pasture soils from treading damage was reviewed by Drewry (2006). Soils do recover naturally over a period of months to years depending on the soil type, the severity of the damage, and post-damage management of the site. Rotationally grazed North Island dairy farms, where the stock are on the farm all year round, may be at risk of cumulative treading damage with inadequate spelling for recovery to occur. Beneficial responses on soil physical properties from mechanical loosening have been widely reported (Houlbrooke 1996; Burgess 1998; Drewry & Paton 2000; Drewry *et al.* 2000b; Burgess *et al.* 2000), but only a few studies have included studies of root responses. Harrison *et al.* (1994) showed that subsoiling resulted in a greater (36%) root length below 30 cm depth and increases in spring pasture growth on a dryland Templeton soil. Decision support tools and best practice guidelines for mechanical treatment of compacted pasture soils are required.

Managing forage plant traits

There is a strong relationship between larger root diameters and the ability of different plant species to penetrate compacted soil layers (Materechera *et al.* 1992). Ryegrass is poorly adapted to growing roots through compacted soil because of its relatively fine roots. Some genetic differences among ryegrasses have been noted for root response to impeded soil (Edmond 1958, Fig. 1; Houlbrooke *et al.* 1997), and for growth of ryegrass roots through a high-strength root medium (Crush *et al.* 2002). However, research on genetic variation in root morphology with the aim of developing grasses with superior root traits is a recent development (Crush & Nichols 2010), and is yet to impact on cultivar development. Tall fescue has a reputation for deep-rooting, and fescue cultivars capable of growing roots into the subsoil have thicker roots than surface rooting types (Torbert *et al*. 1990), confirming the importance of root diameter for root penetration. However, the roots of New Zealand ryegrass and tall fescue cultivars are quite similar (Crush *et al*. 2005), so a change of species may not provide a quick fix to the compaction/pulling problem.

Relationships between soil compaction, root impedance, and pasture pulling seem obvious but are unproven. Interacting factors such as differences in soil strength (anchorage related to soil types), the shear strength of leaves and root weakening by insect larvae (Thom *et al*. 1996; 1998; 2003) will all contribute to observed differences in pulling rates.

Nutrient management

Increasing phosphate fertiliser inputs can offset the negative effects of soil compaction on pasture growth (Mackay *et al.* 2010) indicating that impeded root growth reduces access to soil nutrients. Any nutrient limitations will reduce the fitness of pasture plants and their ability to cope with other stresses. Compensating for the effects of soil compaction by increasing phosphate inputs has negative economic and environmental footprint implications. A better option than the common practice of applying basic fertiliser annually may be to use repeated applications at lower rates - fertilising each crop of grass as it is grown. This would reduce the amplitude of the change over time from nutrient luxury to progressive impoverishment and mal-adjusted herbage nutrient ratios, inherent with annual fertiliser inputs. It would also provide opportunities to tailor inputs to sward requirements e.g. higher P: N input ratios during the clover growing season, and animal requirements such as increased magnesium in early lactation. From trials on nine pasture soils in Victoria, Burkitt *et al*. (2002) concluded that smaller, more frequent applications of phosphate may result in more effective increases in extractable P than the equivalent rate applied annually. Many farmers currently apply N fertiliser post-grazing suggesting that extending this practice to use of compound fertilisers should be investigated in a study that includes economic and environmental cost/benefit analyses.

Reducing hoof impacts

Pressures of 490 kPa can be exerted by a front foot of a 500-kg cow (Kubo & Isobe 1975), and this is more than enough to compact wet soil to a point where ryegrass root growth is reduced (Fig. 1). No consideration seems to have been given to breeding stock with larger hoof surface areas to reduce ground pressures. There is evidence for sire effects on hoof area in Angus beef animals (Morris & Baker 1988), and an investigation of the potential to breed dairy cows with big, flat feet is warranted. The mechanical hoof used by Di *et al*. (2001) to simulate animal treading could be modified to investigate hoof-size impacts on soils. Fitting stock with shoes that increase the soil contact area and reduce ground pressures was suggested as a strategy to reduce soil damage by Wind & Schothorst (1964). The idea was not taken any further but development of veterinary cattle shoes suggests that fitting cows with low ground-pressure shoes may be worth investigating.

Future Directions

There is unlikely to be a single simple solution to the problems associated with soil compaction. A key point is that better management of the pastoral soil resource is required. Grazing strategies and tools to protect soil physical properties as described for a Southland dairy farm by Houlbrooke *et al*. (2009), need to be researched and adopted nationally. Detailed within-farm soil mapping combined with farmer experience could identify the most susceptible paddocks that should be grazed early in the winter rotation. Under wet conditions, getting stock off at-risk soils and onto pads or herd homes will reduce rates of compaction. Best practice guidelines and decision support tools for mechanical treatment of soil compaction should be developed for major regional soil types.

Research underpinning cultivar development needs to investigate genetic variation in root traits such as diameter (for penetration of compacted soils) and tensile strength (resistance to pulling forces during grazing). Protection of plants from insect damage by appropriate use of *Neotyphodium* shoot endophytes and the effect on roots is discussed in Popay & Hume (2011, this volume). In the longer term, better soil husbandry and better adapted pasture grasses should contribute to improved pasture persistency.

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