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Review

Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review

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Abstract

This paper reviews natural recovery of deteriorated soil physical condition under animal treading in grazed pastoral systems, particularly in New Zealand and Australia. While much research has focused on soil compaction and physical deterioration from animal treading, there has been much less focus on natural recovery of soil physical properties after treading damage has occurred. Natural recovery of deteriorated soil physical condition improves soil properties including hydraulic conductivity, macropore volume and bulk density. Soil physical condition naturally recovers when animals are partially or completely excluded from pasture, although improvements are likely to be limited to no deeper than 10–15 cm soil depth, under common grazing practice or animal exclusion. However, the physical deterioration and natural recovery processes are linked in a cycle. Natural recovery of soil physical condition in this cycle is therefore important when evaluating management practices affecting soil deterioration on-farm, field trial interpretation, and ungrazed riparian zone soil structure. This review also discusses directions of future research to enhance soil management, including quantifying and evaluating soil physical deterioration and natural recovery. Several knowledge gaps relating to pastoral agriculture in New Zealand and Australia, particularly under rotational grazing management on intensive dairy farms are discussed. Further research is required into the consequences of farm management practices that enhance natural rejuvenation of degraded soils. Consequently, integration of both deterioration and natural recovery of soil physical condition in the soil compaction and recovery cycle is needed to improve farm system evaluation and management. Natural recovery of soil condition when animals are partially or fully excluded from grazing is therefore important in management and modelling of pastoral and ungrazed riparian soil, and subsequent environmental impacts.

Keywords: Compaction; Pugging; Recovery; Amelioration; Macroporosity

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1. Introduction

Animal treading can result in degradation of soil physical quality through hoof action of grazing animals (Betteridge et al., 1999, 2002; Pande et al., 2000; Ward and Greenwood, 2002). Deterioration in soil physical quality from trampling causes soil deformation through (i) soil compaction and (ii) soil homogenisation through shearing or pugging and poaching. Such terms, however, require careful use and defining. *Soil compaction* has been traditionally described as ‘‘the compression of an unsaturated soil body resulting in a reduction of the fractional air volume’’ (Hillel, 1980). The effect of soil compaction is to decrease soil porosity, particularly the volume of the large inter-aggregate pores (macropores). Once the air volume is reduced, or the soil is saturated, then the term consolidation can be used (Hillel, 1980). *Consolidation* is the compression of a saturated soil by squeezing out water. Consolidation is a more gradual process than compaction, as the viscosity of water is much greater than air. *Poaching* or *puddling* in contrast to compaction, are terms used for slurry-induced soil conditions on very wet soil when trampled by stock. *Pugging* in wet soft soil causes deep hoof imprints and is often associated with considerable pasture damage. In contrast to soil physical deterioration caused by machinery, soil physical deterioration by grazing animals is likely to be more widespread within paddocks particularly in wet conditions, than for example, under tracks of wheeled implements.

Such treading-induced damage described above includes reduced soil permeability through reduced pore space and continuity and disrupted soil pore networks, and increased bulk density (Drewry and Paton, 2000; Menneer et al., 2001). Indicators of soil physical health or condition are becoming an increasingly important area of research and for environmental reporting for government agencies (Sparling et al., 2004). Indicators of soil physical properties commonly include bulk density (dry soil mass per unit volume); a measure of large soil pore volume, for example macroporosity, (the volumetric percentage of soil drainage and aeration pores, commonly >30 μm diameter); and saturated hydraulic conductivity (ability of the soil to transmit water). Although macropore volume or macroporosity has been found to be a sensitive indicator, its definition varies. Macroporosity describes the volumetric percentage of pores greater than 30 μm diameter (McLaren and Cameron, 1996). It is primarily soil macropores that are responsible for adequate soil aeration and rapid drainage of water and solutes through soil (McLaren and Cameron, 1996). However, macropores have also been defined in other studies with a range of different equivalent pore diameters, which must be kept in mind when comparing studies. For example, macropore diameter has been defined as being >50 μm (Carter, 1988), and >195 μm (Koppi et al., 1992).

Soil compaction by treading and subsequent natural recovery of soil physical properties has been shown to be cyclical (Drewry et al., 2004), but few studies have integrated these components in pastoral systems. Processes contributing to natural recovery of physically degraded soil include wetting and drying cycles, subsequent soil cracking, earthworm burrowing and root penetration and decay, and freeze and thaw cycles during winter (Greenland, 1981; Hodgson and Chan, 1984; Dexter, 1991; Greenwood and McKenzie, 2001). Physical deterioration of soil from the surface to about 5 cm deep, for example, can be naturally ameliorated quite rapidly by the burrowing activities of macro-invertebrates associated with dung deposition. For example, air-filled porosity and infiltration rate increased, and soil bulk density declined in the top 3 cm of soil under cattle dung pats (Herrick and Lal, 1995). However, in contrast, physical deterioration of soil from depths below 15 cm are likely to be naturally rejuvenated much less slowly, if at all. Indeed, while soil physical deterioration is often visually evident on surface soil, or at 0–5 cm soil depth, deterioration of macropore structure commonly occurs at 5–10 or 10–15 cm depth under cattle treading (Drewry et al., 2004; Drewry and Paton, 2000). Macropore structure is often reduced particularly at 5–10 cm under dairy cow treading, but in contrast, may also be less damaged beneath 10 cm (Drewry, 2003; Singleton and Addison, 1999).

Cattle exert greater static pressure (160–192 kPa) on soil than sheep (83 kPa), although these pressures are known to at least double when animals are walking (Willatt and Pullar, 1983). However, even though dairy farms are often situated on well-structured soils, soils on New Zealand dairy farms have been shown to be more compact than similar soils on sheep farms (Drewry et al., 2000). Consequently, farm management strategies to reduce or prevent treading-induced soil deterioration have been devised. Treading management