REFINING THE PROCTOR COMPACTION TEST TO GUIDE OFF-GRAZING MANAGEMENT DECISIONS

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Abstract

Grazing intensification as a result of higher stocking rates and greater animal weight is associated with greater shear pressure on soil. Testing soil resistance and resilience to compactive forces is an important means of determining its bearing capacity. To date, much effort has been put into management strategies to remedy the effects of soil compaction in order to maintain or restore full productive capacity. In more recent time, the use of off-grazing management facilities such as animal shelters and wintering pads has become more prevalent within the dairy industry. Such infrastructures can provide multiple benefits to a farm system including improved nutrient management and effluent returns, particularly in winter, better feed supply and thermal stress control and decreased soil damage from animal treading. Guidance on appropriate climatic and soil conditions that would necessitate an 'off-grazing' regime, is not however available to farm mangers. Here, critical soil conditions i.e. 'trigger values' for decision support have been investigated that may better integrate such facilities into current farm practice and in doing so decrease the likelihood of compaction and pugging damage to soils.

The proctor test, using confined uniaxial compression, has been used to assess changes in bulk density of undisturbed soils of varying soil moisture content under increasing compactive force. This approach can be used to determine the critical moisture content (CMC) at which the greatest level soil compaction occurs. For the Timaru silt loam (Typic Fragic Pallic) this value has been identified as being 33% g/g. We hypothesise that the avoidance of cattle-grazed pasture when soil moisture content is greater than the CMC will maintain long-term soil macroporosity in soils prone to structural degradation.

Introduction

Land-use intensification requires more farm inputs to sustain or increase farm product outputs. However, a common concern for land-use intensification is the potential physical deterioration of a soil. Soil quality or health is commonly perceived as a soil resource which is 'fit for purpose' (Pierce & Larson 1993). An effectively functioning soil provides food and fibre for human consumption through key biological, chemical and physical activities, which provide a growing medium for plant production. Larson & Pierce (1991) defined soil quality as 'the capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem'.

The North Otago Rolling Downlands (NORD) has been undergoing considerable land use change and intensification as a result of a large community irrigation scheme (*c*. 10 000 ha) associated with increased pasture production, fertilizer input and animal carrying capacity (Houlbrooke *et al.* 2008). The NORD is dominated by Pallic soils (Hewitt 1998) that are characterized by poorly structured subsoil with a pronounced fragipan and have a high structural vulnerability (defined as susceptibility to degradation) under intensive management (Hewitt & Shepherd 1997). Soil physical damage, in particular the loss of macroporosity, has been shown to have a negative effect on pasture production due to decreased air and water transmission and root growth development (Drewry *et al.* 2008). Soil compaction and treading damage also increases surface runoff from either rainfall or irrigation-applied water (McDowell *et al.* 2003; McDowell & Houlbrooke 2009). Drewry *et al.* (2004) reported that macroporosity (at depths of 0–50 and 50–100 mm) strongly correlated with spring pasture yield when studying dairy pasture response to soil physical properties. These authors determined that an increase in macroporosity of 1 % at 0–50 and 50–100 mm depths would increase relative spring pasture yield by 1.8 and 2.5 %, respectively. The relationship was considered linear at macroporosities between 5 and 22 % v/v. However, a precautionary value of >10 % v/v is often advised for minimizing the impact of soil physical quality on plant health and pasture production (Drewry *et al.* 2008).

Under irrigation management, NORD pastoral land use has typically changed from traditional low intensity dryland sheep farming (8–10 stock units/ha; su/ha, defined below) to a mix of intensive lamb or beef cattle, dairy 'support-grazing' or dairy farming (> 20 su/ha). Recent research by Houlbrooke *et al.* (2011) compared soil physical measurements under the following land use treatments: sheep dryland, sheep irrigated, cattle dryland and cattle irrigated. Irrigation and cattle grazing, particularly the combined effect, increased soil compaction. Macroporosity on irrigated cattle-grazed plots ranged from 9.1–13.3 % v/v at a depth of 0–50 mm, compared with dryland sheep-grazed plots (18.9–23.0 % v/v, at a comparable soil depth). Houlbrooke *et al.* (2011) suggested that soil moisture content at the time of animal grazing played a large role in determining compaction and pugging risk under intensive land use.

Previously much effort has been put into management strategies such as mechanical soil aeration to remedy the effects of soil compaction in order to return soil to its full productive capacity (Drewry & Paton 2000). However, such an approach is akin to parking an ambulance at the bottom of the cliff. The use of recent off-grazing management facilities has become more prevalent within the dairy industry and can provide multiple benefits to a farm system such as: temporally optimised nutrient management and effluent returns, controlled feed supply, thermal stress control and decreased soil damage from animal treading. However, little guidance is available to farm mangers to make accurate decisions designed to decrease the likelihood of animal treading damage.

The objective of this research was to develop a methodology that will allow farmers to make improved grazing (and/or irrigation) management decisions so that grazing at high compaction risk periods is avoided. We hypothesise that avoiding the pastoral grazing of cattle when the soil moisture content is greater than the determined threshold will minimise the incidence of severe compaction and largely avoid the onset of pugging damage. On soil prone to structural degradation this should increase or maintain (depending upon original state) the long-term soil macroporosity under intensive land use.

Relationship between soil moisture and animal treading damage

Animal treading damage results from either the pugging or compaction of soil. Soil pugging involves the deformation and remoulding of soil when animal loads exceed a soil's bearing capacity, often causing an undulating soil surface. This typically takes place when soil water content is greater than the plastic limit. Soil compaction shows reduced or compressed soil pore space, occurring when soils are in either a friable or plastic state (Hillel 1980; Bilotta *et al.* 2007; Drewry *et al.* 2008). Whilst the potential for soil compaction decreases with greater water content, the risk of soil pugging increases (Drewry *et al.* 2008). Soil compaction results in deteriorated soil physical properties (particularly those measuring soil pore space or its continuity), and can happen concurrently with soil pugging, particularly under cattle hooves (Bilotta *et al.* 2007). The relationship between soil moisture and the maximum potential for compaction represented by soil bulk density is shown in Figure 1.

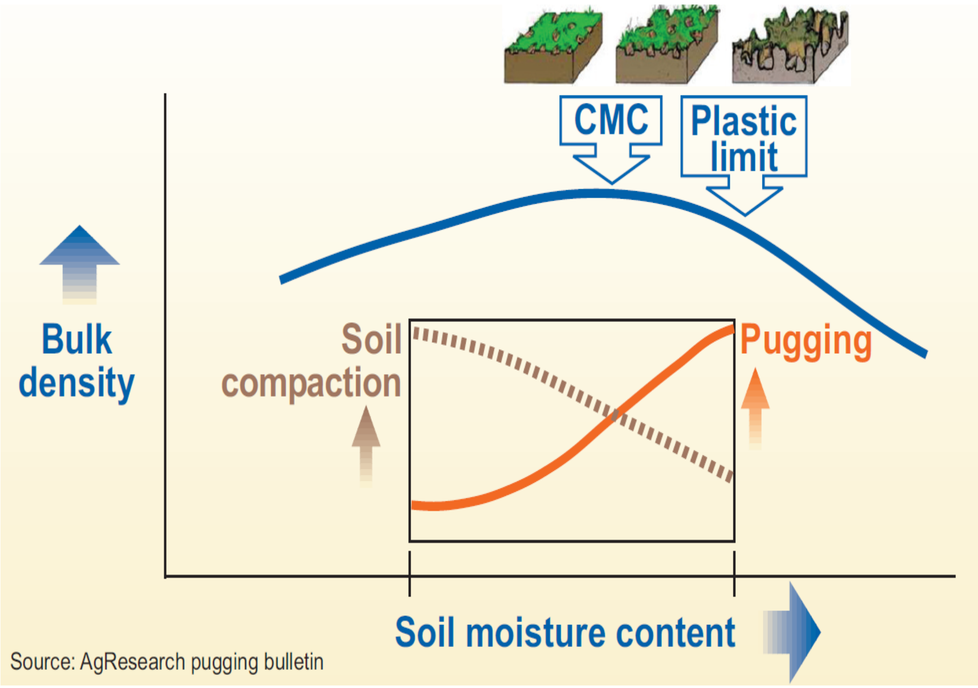

Figure 1. The relationship between achievable bulk density and soil moisture

Determination of critical moisture content using the Proctor test

The Proctor test (Dahwood *et al.* 1999) using intact 'in situ' samples from grass pasture, has been used to measure changes in bulk density caused by varying compactive forces on soil of differing soil moisture contents. This approach can be used to determine the critical moisture content (CMC) at which the greatest level of soil compaction can be achieved (Figure 1). The Proctor compaction test is described in detail by the New Zealand Standard 4402 part 2 (Standards Association New Zealand 1981). Soil cores of 100 mm diameter were taken at 0-50 mm depth from a trial site on Pallic soil in North Otago with three different historical land use treatments: irrigated cattle grazing, dryland sheep grazing and pasture fallow. The site is further described by Houlbrooke *et al.* (2011). Determination of the soil mesa and macropore content (on a volume by volume basis, v/v) was made using a hanging water column sand bed. Following this soil porosity assessment, treatments were then allocated. Five soil water tensions (-5, -10, -20, -30 and -40 kPa) were selected and samples equilibrated to their appropriate tension prior to being weighed then seven levels (50, 100, 150, 200, 250, 300 and 350 kPa) of uniaxial pressure applied. The confined uniaxial compression apparatus used to apply the compactive force is adapted from that of Krummelbein *et al.* (2008). Compactive force was applied for 30 minutes with height change (mm) of sample being recorded at 1, 2, 5, 10, 20 and 30 minutes.. The vertical displacement of the soil during compaction was measured by a potentiometric displacement transducer and displayed on an LCD display to ± 0.1 mm accuracy. Samples were weighed pre and post compression as a guide to soil water loss with oven dry weights being determined for dry soil bulk density. Samples were ovendried at 105°C for 48 hours in a force draught oven. Using Proctor test methodology we determined the CMC for the Timaru silt loam at three different compression forces (50, 150 and 300 kPa) on pooled land use treatments. A statistical analysis of pooled land use treatments has been determined at a CMC of 33% g/g (Figure 2).

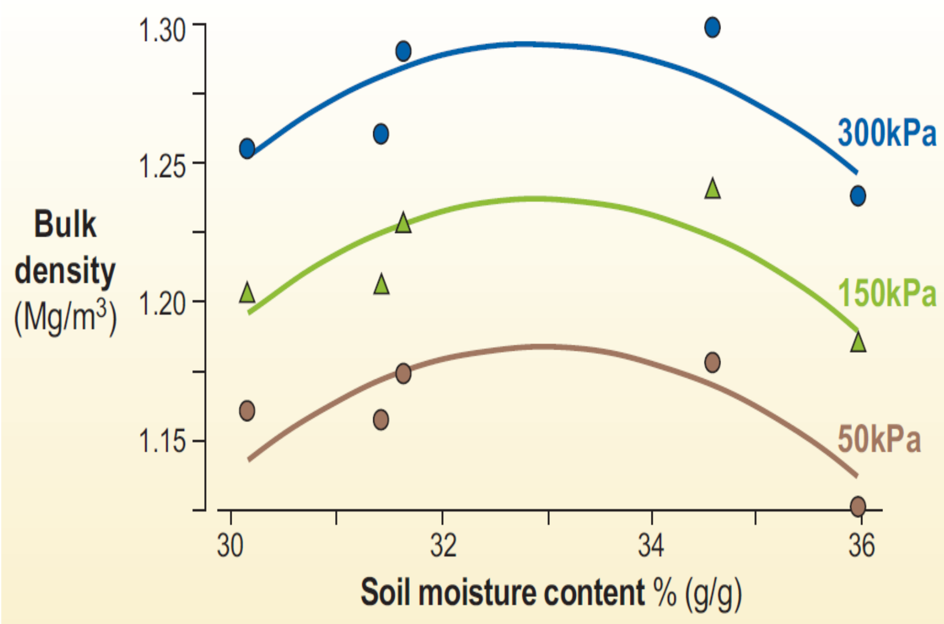

Figure 2. Proctor test compaction curves for the Timaru silt loam at three contrasting applied pressures.

Field trial implementation

A field trial has been established in the North Otago Rolling Downloads on an irrigated and cattle grazed Timaru silt loam to compare long term soil macroporosity and pasture response under standard practice grazing vs. strategic wet grazing avoidance using the determined CMC as a lower limit for stock exclusion. This comparison is being assessed on two historical land use treatments (dryland sheep and irrigated cattle) described in Houlbrooke *et al.* (2010) and will provide resistance and resilience testing to land use pressure.

Summary

Intensively grazing soils with a high structural vulnerability lead to compaction and pugging in relation to increased moisture content. The Proctor compaction test can be used to determine soil compaction curves of potential bulk density vs. soil moisture content. We have used this approach to determine the CMC at which soil compaction risk is greatest. We propose that implementing a grazing avoidance regime based on this threshold will maintain or improve long term soil physical condition under intensive land use scenarios. A field trial is currently being established which implements CMC as an off-grazing decision making criterion-.

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