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Visual soil evaluation in relation to measured soil physical properties in a survey of grassland soil compaction in England and Wales

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ABSTRACT

Visual soil evaluation methods can provide a quick and easy, semi-quantitative approach to assessing the overall soil structural condition of a block of soil in three dimensions. To express this amount of information through other measures of soil physical condition (e.g. penetration resistance, bulk density or shear strength) requires a number of measurements at various depths and can be costly and time consuming. There is therefore a need to develop simple field methods to assess and monitor soil quality.

In a survey of grassland soil compaction in England and Wales, soil visual evaluation methods were used alongside more widely accepted physical measurements of soil compaction (e.g. bulk density – BD and penetration resistance). Soil structural condition was investigated in 300 fields located on 150 farms, with one 'mainly grazed' field and one 'mainly cut' field selected on each farm. The visual soil evaluation methods were the visual soil assessment (VSA) method from New Zealand and the Peerlkamp (soil structure – 'St') method.

Based on the Landcare VSA ranking score, 8% of the grassland fields were in poor condition (95% confidence interval = ±3), 54% (±6) in moderate condition and 38% (±6) were in good condition. Based on the Peerlkamp 'St' score, 12% (±4) of fields were in poor condition ('St' score < 4.0), 63% (±6) in moderate condition ('St' score 4.0–7.0) and 25% (±5) in good condition ('St' score > 7.0). Notably, the soil visual evaluations using the VSA ranking score and 'St' score were well related ($P < 0.001$; $r^2 = 66\%$).

At 30 field sites selected for more detailed investigation, there was an inverse relationship between 'St' scores and mid topsoil BD ($P < 0.01$; $r^2 = 25\%$), indicating that the measurement of BD in the middle of the topsoil provided an indication of soil structural condition, as determined by visual soil evaluation. Also, for the 300 grassland fields, there was a positive relationship ($P < 0.001$) between maximum penetration resistance (MPR) in the top 200 mm and both the 'St' score ($r^2 = 26\%$) and VSA score ($r^2 = 19\%$). The visual evaluation scores increased with increasing penetration resistance, indicating that better soil structure (as assessed visually) was associated with greater penetration resistance. This was contrary to the expectation that soils with better structure would be less dense than poorly structured soils and therefore would have lower penetration resistance values.

The use of multiple predictor models showed that the two most important factors ($P = 0.02$) influencing the VSA ranking score were (in order of importance): (i) soil organic matter content (positive relationship); (ii) soil sand content (positive relationship).

1. Introduction

Grassland soil compaction has potentially serious implications for the ability of soil to deliver important ecosystem services. Soil compaction is characterised by the compression of soil aggregates resulting in a higher mass per unit volume and a reduction in pore volume and continuity compared with a well structured soil (Batey, 2009). Soil compaction can also involve the rearrangement of soil aggregates and particles through compression or smearing (Scholefield et al., 1985), with the orientation, size and shape of soil aggregates evidence of soil compaction (Ball and Robertson, 1994; Roseberg and McCoy, 1992). Normally, soil compaction is evidenced by a coarsening or loss of soil structural units, decrease in soil volume, increase in bulk density, decrease in porosity (particularly macroporosity) and a reduction in hydraulic conductivity of the soil (i.e. reduced water infiltration). Soil structural

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units are sometimes compressed to the extent that they assume a 'platy' form, i.e. the structures are shallow, wide and angular (Environment Agency, 2006).

A reduction in the size and continuity of pores can reduce the ability of soils to perform important ecosystem services. It can reduce grassland productivity (ADAS, 1984; Frost, 1988) and increase flooding risk due to reductions in water infiltration rates (Heathwaite et al., 1990; Meyles et al., 2006). It is also implicated in increased nitrous oxide emissions, a potent greenhouse gas around 300 times more powerful than carbon dioxide (Ball et al., 2008; Ruser et al., 2006) and is often cited as a barrier to the restoration of grassland biodiversity (e.g. Palmer, 2004; Aritajat et al., 1977). There is also some evidence that reductions in air-filled porosity and pore continuity can reduce the exploration of fungal hyphae (Otten et al., 1999) and the abundance of soil microfauna (e.g. nematodes), mesofauna (e.g. collembola) and macro-invertebrates (e.g. earthworms) within soils (Pizl, 1992; Portillo-Aguilar et al., 1999) due to reductions in habitable pore space. Topsoil condition is therefore critical to many soil functions, including water infiltration and storage, biomass production, soil carbon storage, mitigation of nitrous oxide emissions, and biodiversity.

Soil compaction can result from both machinery use and livestock grazing and there is concern that changes in grassland management over the past few decades in England and Wales may have increased soil compaction, particularly through the increase in size of agricultural machinery and greater use of contractors for grass harvesting and manure spreading (Hakansson and Reeder, 1994; Batey, 2009). Trampling by livestock and trafficking by machinery when the soil is 'wet' is likely to give rise to soil compaction. Machinery use can give rise to compaction in the topsoil (typically 0–300 mm) and subsoil (typically >300 mm). Machinery can induce topsoil compaction through the sheer weight of machinery (high axle loads and/or high ground pressure tyres) and this has increased in recent decades. In the 1980s, wheel loads of 50 kN were considered to be high, but the use of 90–120 kN wheel loads is now common place (Van den Akker and Schjønning, 2004).

Soil physical damage caused by livestock is often restricted to shallow surface depths (0–150 mm) (MAFF, 1970; Drewry and Paton, 2000; Kurz et al., 2006; Scholefield et al., 1985; Singleton et al., 2000). However, under UK conditions, Scholefield and Hall (1986) found that cattle trampling can also result in most compaction at 100 mm depth and below. Compaction risk is generally greater at higher soil moisture contents (MAFF, 1970). There is some evidence that over the past decade increasing feed prices and the availability of new early/late season grass and clover varieties in the UK have resulted in an increase in the use of extended grazing and outwintering of livestock. Beef and dairy cattle grazed 3.5 million hectares of grazed grassland in England for an average of 7 months in 2006, whilst in 2010 livestock grazed for approximately 9 months (Defra, 2010). Around 55% of livestock farmers outwintered livestock in 2008 (Defra, 2008).

The characterisation of soil compaction presents numerous challenges due to the three dimensional nature of soil structure. Accepted physical indicators of soil quality such as bulk density (BD), penetration resistance and macroporosity are very useful (Merrington et al., 2006), but are relatively time consuming and expensive, and each sample only provides an indication of compaction or structural condition at one point in the soil profile. In addition, bulk density is strongly influenced by soil organic matter content and soil water content at the time of sampling (Merrington et al., 2006) and in terms of broad-scale monitoring, macroporosity is less indicative than bulk density (Merrington et al., 2006; Sparling and Schipper, 2004). For point measurements such as bulk density and macroporosity, no single depth can provide a definitive picture of physical soil quality or change. The soil layer most susceptible to physical change will vary between soils and management, so providing a comprehensive assessment of soil physical quality using bulk density or macroporosity sampling is time consuming and not straightforward. In contrast, penetration resistance measurements are relatively straightforward, rapid and inexpensive and have the potential to provide information at a range of depths with relative ease. The main advantages of a cone penetrometer are the potential relationship with soil physical conditions for root elongation and the capacity to measure spatial variation in soil compaction (Clark, 1999; Gerard et al., 1982; Hakansson and Voorhees, 1998; Taylor and Gardner, 1963). Disadvantages include the variation of penetration resistance values with soil water content, soil texture, soil organic matter content, clay mineralogy, insertion rate and friction forces on the drive shaft (Campbell and O'Sullivan, 1991; Gerard et al., 1982; O'Sullivan et al., 1987; Vaz and Hopmans, 2001).

There is therefore a need to develop simple field methods to assess and monitor soil quality, but it is important that such methods are robust and relate to other indicators of soil quality. National soil quality monitoring schemes need soil quality indicators that are relevant to a range of soil functions and are interpretable in quantitative terms of temporal changes in soil quality. It must also be clear what interpretation can or cannot be placed on the magnitude of change in an indicator (Merrington et al., 2006). In selecting indicators, it is important to consider the probability of detecting significant changes over given sampling intervals. Physical soil quality indicators selected in national soil quality monitoring schemes have included bulk density, macroporosity and aggregate stability (Cotching and Kidd, 2010; Sparling and Schipper, 2004). Notably, research investigating the relationship between visual evaluation methods and soil physical data is limited, particularly for grassland soils (Mueller et al., 2009).

This paper presents the results of a survey of soil condition in 300 grassland fields in England and Wales that used a combination of visual soil evaluation methods and soil physical measurements. The survey results provide an indication of the extent of soil compaction in grassland fields in England and Wales and enabled a comparison of simple and rapid visual evaluation methods with other physical measurements of soil condition.

2. Materials and methods

The 300 grassland fields were located on 150 farms; with one 'mainly grazed' field and one 'mainly cut' field selected on each farm (Fig. 1). The sample of 150 farms was stratified according to 1960–1991 average annual rainfall (<700 mm; 700–900 mm and >900 mm; Barrow et al., 1993), farm type (Dairy or Beef/Sheep/'Grazing Livestock'; as defined by the dominant source of revenue or "Robust Farm Type"; Defra, 2009) and soil type ('heavy', 'medium', 'sandy and light silty', 'chalk and limestone' and 'peaty'; Environment Agency, 2006) – such that each of the defining attributes was represented according to the relative grassland area that they occupied in England and Wales. The soil type definitions relate to topsoil clay content, soil depth, parent material and soil organic matter content. 'Heavy' soils have a topsoil clay content greater than 35%; 'medium' soils a topsoil clay content between 18 and 35%; 'sandy and light silty' soils a topsoil clay content less than 18%. 'Chalk and limestone' soils are less than 300 mm deep over chalk or limestone; 'peaty' soils have a topsoil organic matter content greater than 20% or organic carbon content greater than 12% (MAFF, 1986).

2.1. Field measurements

The study was conducted in late winter and spring 2010. In the first stage of the study, the focus was on characterising soil