Soil & Tillage Research 127 (2013) 92–99

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Relating visual evaluation of soil structure to other physical properties in soils of contrasting texture and management

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ARTICLE INFO

Article history:
Received 31 August 2011
Received in revised form 21 January 2012
Accepted 24 January 2012

Keywords:
Soil quality
Soil structure
Visual analysis

ABSTRACT

The sustainability of agricultural systems depends on the evaluation and monitoring of soil use and tillage in order to mitigate soil degradation. The visual evaluation of soil structure (VESS) was developed to provide a quick, simple and easily understood test to enable researchers, farmers and consultants to score soil quality. In this paper we test the hypothesis that soil structural quality, as specified by VESS (S_q), is sensitive enough to identify differences in structure, resulting from soil management, in and between layers of topsoil. The S_q score ranges from 1 (good) to 5 (poor soil structure). Improvements have already been made to this method, but we wished to test the validity of S_q results compared with other indicators of soil physical quality. Our aims were (1) to evaluate the usefulness of VESS to compare layering of topsoil structure under different soil management and (2) to identify which soil physical properties S_q most closely relates to. We chose to work on soils of contrasting texture in response to criticism that the test works well only on medium-textured soils. In our first experiment, we assessed Scottish soil from native forest that had never been cropped and from arable soils just after harvest so where there was a visible difference between soil tracked or not tracked during harvesting operations. Soil qualities measured were soil resistance to penetration (SR), bulk density (B_d) and air permeability (K_a). In our second experiment we compared the least limiting water range (LLWR) with VESS in a Brazilian Oxisol under no-tillage. VESS showed the differences between the treatments and layers of topsoil. S_q increased with SR and B_d but decreased with air permeability. Results for LLWR showed that for $S_q \geq 3.5$, the LLWR was zero, indicating soil physical condition highly restrictive to plants. Harvest is a time of significant soil compaction and the VESS test detected compaction even where it was not visible at the surface and as such may prove useful in diagnosing and remediating compaction and assessing suitability for minimum tillage.

1. Introduction

The need to increase agricultural production with less impact on the environment has renewed interest in assessing how land use systems and management influence soil properties and whether changes create any adverse effect on crop production and on the environment (Batey and McKenzie, 2006). Adverse effects on soil quality can result from machinery traffic, tillage and loss of organic matter. Visual techniques for assessing soil quality in the field are useful to diagnose and control erosion, soil compaction and decisions about systems of tillage (Shepherd, 2000; Ball and Douglas, 2003; McKenzie, 2001; Mueller et al., 2009, 2010).

The visual assessment of soil is a low cost method for semi-quantitative assessment of soil quality (Shepherd, 2000). Visual assessment methods should be simple, inexpensive, reliable, highly accurate, produce results fast and be understood by researchers, technical advisors and farmers (Shepherd, 2003).

Visual assessment of soil profiles has been a standard method used by many scientists mainly in pedology and soil classification (Boizard et al., 2005). The methods used for evaluation of the soil profile are 'whole profile assessment' (Batey, 2000), SOILpak method (McKenzie, 2001) and the cultural profile method (Roger-Estrade et al., 2004). However, these methods require considerable knowledge of pedology and time to do in the field. In order to make the assessment of soil physical quality simpler, methods based on the assessment of topsoil (30 cm) have been widely used, such as visual soil assessment (VSA), developed by Shepherd (2009) and "Visual Evaluation of Soil Structure" (VESS),

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0167-1987/$ – see front matter
doi:10.1016/j.still.2012.01.020

described by Ball et al. (2007) and improved by Guimarães et al. (2011).

VESS has proven to be one of the simplest methods which includes a variety of aspects of soil structure and rooting. This method was developed from the Peerlkamp method (Peerlkamp, 1959) and involves taking a sample of undisturbed soil, breaking it up and visually assessing the size and porosity of aggregates, the strength of aggregates, the presence of roots and soil color (Ball et al., 2007; Guimarães et al., 2011). A distinctive feature of VESS is the ability to distinguish layers in the topsoil of differing structure. Giarola et al. (2010) stressed the importance of evaluating the soil layers individually rather than giving only the weighted average of the total soil sample. This can improve the choice of management methods which preserve or improve soil quality.

Many authors have stressed the importance of relating visual methods with other indicators of soil physical quality (Shepherd, 2003; Mueller et al., 2009), as doubts persist about the validity of the results of visual evaluations of soil structure and whether is it equally valid in soils of different textures. Shepherd (2003) indicated the importance of evaluating the soil mainly by visual methods to empower farmers to monitor and maintain soil physical quality. We have already shown that VESS relates well to the tensile strength of individual aggregates (Guimarães et al., 2011) and wished to discover if this also extended to bulk soil properties.

This study tested the hypothesis that the quality of soil structure as measured by the VESS score (S_q) is related to quantitative indicators derived from physical measurements in soil of differing textures and managements. Our objectives were (1) to evaluate the usefulness of VESS in identifying the quality of the structure of the surface layers of soil of contrasting texture under different management and (2) to identify soil physical properties which are most related to S_q, *viz.* soil bulk density, soil resistance to penetration, air permeability and the least limiting water range, as they are commonly used to identify soil physical quality. Most of the measurements were made in the UK, but those measurements involving least limiting water range were made in Brazil.

2. Materials and methods

For this study two experiments were made. The first was in the UK where VESS, soil bulk density, soil resistance to penetration and air permeability were evaluated in two soil types of differing textures but similar soil use and management. The second one was held in Brazil to evaluate VESS against LLWR in a very clayey soil under long-term no-tillage.

2.1. Experiment 1—contrasting textures

2.1.1. Experimental areas

The experiment was conducted in south-east Scotland on two soils, clayey and sandy loam. Soil characteristics are presented in Table 1. The climate is temperate mesothermal with annual rainfall of 660 mm. This region, called East Lothian, has very productive soils, with good relief and weather making them suitable for a wide range of crops. The most common crop rotation in the region has grass, potato, wheat, barley, brassicas and barley. Soil preparation usually consists of plowing at 25 cm followed by disking. On the clay soil the crop was spring barley (*Hordeum vulgare*) on the sandy-loam soil the crop was spring barley followed by Brussels sprouts (*Brassica oleracea*).

2.1.2. Treatments

Initially, the fields were covered with barley straw and were sampled in early fall (September), one to three weeks after harvest. In each soil, three different systems of use and management were selected and which we call treatments: (1) native forest – soil adjacent to the field that has undergone no changes due to agriculture. This area was close to the agricultural area, about 100 m distant, (2) non-tracked area – field soil showing no visible signs of tracking by machinery during harvest of barley crop, and (3) tracked area – soil under wheels of the machinery used in the recent harvest. In the cropped areas samples were obtained in a transect across the rows, a distance of approximately 10 m between each point. At the native forest samples were taken randomly. In each treatment we sampled five points.

2.1.3. Visual assessment of soil structure

Two slices of soil were collected at each sampling point: one of them was evaluated in the field and the second slice was wrapped in PVC film for more detailed evaluation in the laboratory using VESS as described by Ball et al. (2007). This methodology consisted of extracting a slice of soil 25 cm deep and 10 cm thick, the manual breakdown of its structure, identification of any layers of contrasting structure and assignment of a score by comparing the structure of the sample with a chart containing the description and photos of each soil structure quality. The parameters used to describe soil structure are size, porosity and strength of aggregates, number and distribution of roots and color and shape of aggregates (Ball et al., 2007). The shape of aggregates was a diagnostic under development for improving the VESS (Guimarães et al., 2011). The S_q score ranges from 1 (good) to 5 (poor soil structure).

2.1.4. Soil air permeability (K_a) and soil bulk density (B_d)

We selected two soil layers for collection of undisturbed soil samples. The depths, 0–5 cm and 12.5–17.5 cm, were chosen based on the average thickness and position of the two layers detected by VESS. We used one ring of 7 cm in diameter and 5 cm of height in each layer, a total of 10 rings per treatment. In these samples, air permeability and bulk density were measured. For the determination of air permeability, we used the method of constant flow of Ball and Schjonning (2002). In this technique, a steady stream of air is applied and the resulting pressure difference is measured. The samples were equilibrated at soil water potential equivalent to −60 h Pa to ensure a condition of moisture content near field capacity (O'Sullivan and Ball, 1993). The K_a was determined according to Eq. (1):

$$K_a = \left(\frac{q_v}{\Delta \mathrm{Pa}}\right) \times 0.3739 \quad (1)$$

where K_a is the air permeability (μm^2); q_v is the applied constant air flow (4 and 8 ml min^{-1}), ΔPa is the resulting pressure difference. The constant is specific for the dimensions of the core samples and air viscosity (Ball and Schjonning, 2002). After determining K_a, bulk density was determined for each sample,

Table 1
Characteristics of the soils used in this experiment.

Soil textural class[a]	Soil series	Latitude	Longitude	Location	FAO class	Sand (%)	Silt (%)	Clay (%)	Organic matter content (%)	Drainage status
Clay	Cauldside	55°59′N	2°40′W	East Linton, UK	Mollic Fluvisol	21.1	28.2	50.7	3.07	Imperfect-poor
Sandy loam	Dreghorn	56°05′N	2°46′W	North Berwick, UK	Eutric Cambisol	75.5	10.6	13.9	2.66	Free

[a] Skiba and Ball (2002).