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Evaluation of soil structure in the framework of an overall soil quality rating

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A R T I C L E I N F O

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This paper is dedicated to the memory of our colleague Prof Dr Bev Kay.

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A B S T R A C T

Soil structure is an important aspect of agricultural soil quality, and its preservation and improvement are key to sustaining soil functions. Methods of overall soil quality assessment which include visual soil structure information can be useful tools for monitoring and managing the global soil resource. The aim of the paper is: (i) to demonstrate the role of visual quantification of soil structure within the procedure of the overall soil quality assessment by the Muencheberg Soil Quality Rating (M-SQR), (ii) to quantify the magnitude and variability of soil structure and overall M-SQR on a number of agricultural research sites and (iii) to analyse the correlations of soil quality rating results with crop yields. We analysed visual soil structure and overall soil quality on a range of 20 experimental sites in seven countries. To assess visual soil structure we utilised the Visual Soil Assessment (VSA) and Visual Evaluation of Soil Structure (VESS) methods. Results showed the feasibility and reliability of both VSA and VESS methods and the overall soil quality M-SQR rating approach to give scores and classes which characterised the soil potential for cropping. The structure status of soil can be reliably assessed by these procedures. In soils with clay contents > 30% unfavourable soil structure could not be reliably recognised by measurements of the dry bulk density, but significantly by evaluation of visual soil structure. Structure scores were clearly associated with the drainage status of soil. More than 70% of the variability of crop yields at a given intensity of input may be explained by the overall M-SQR-score which includes information on soil texture, relief and climate in addition to soil structure. We conclude that methods of visual soil assessment are useful diagnostic tools for monitoring and controlling agricultural soil quality over different scales, ranging from within-fields to global. Controlling the drainage status of land and action of machinery at appropriate drainage states are pre-conditions for preserving a suitable soil structure.

1. Introduction

Food insecurity due to limited and degraded soil resources is an increasing problem of the 21st century. Amongst soil functions, the capacity to produce plant biomass (productivity function) remains essential (Lal, 2009; Mueller et al., 2010). This capacity is globally limited and not yet well understood and quantified. A framework for overall soil quality rating approach could be a measure of soil productivity potentials and thus a useful diagnostic tool for monitoring and managing the global soil resource for agriculture. Such an approach based on field indicators of soil quality should be reliable but also straightforward to use.

Soil structure is an important aspect of agricultural soil quality and soil ecology (Kay et al., 2006; Roger-Estrade et al., 2010) and needs to be part of an overall soil quality evaluation framework. Soil structure can be reliably assessed by visual methods in the field (Batey, 1988; Mueller et al., 2009). Visual examination and evaluation procedures of soil structure obtain information on the features and function from macro-morphological characteristics of soil. Visual methods based on, or supplemented by illustrations, have clear advantages for the reliable assignment of a rating score based on visual diagnostic criteria. Illustrated methods such as VESS developed from the Peerlkamp method (Ball et al., 2007), and the Visual Soil Assessment method (VSA, Shepherd, 2000, 2009)

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produce ordinally scaled scores, easy to learn, use and interpret. Those methods are useful for extension purposes to eliminate discrepancies between what we can see and what we measure (Shepherd et al., 2001). Good soil structure is often associated with good soil quality, but soil quality includes more than soil structure (Karlen et al., 1997).

Soil structure and overall soil quality have an important influence on crop yields. On cropped fields sustainable land use for maintaining soil quality requires the balancing of plant nutrient fluxes. Crop yield is a crucial variable of nutrient fluxes in the soil and should easily be assessed from data of soil quality. From the growers' standpoint, it is also very important that the final result of soil quality scoring is reflected in crop yields (Andrews et al., 2004; Shepherd, 2009).

In previous studies (Mueller et al., 2009), we found visual soil structure scores may explain only part of crop yield variability, as the influence of soil and environmental properties such as texture, water and nutrient storage, relief and climate on crop yield are dominant, particularly over larger regions. The Muencheberg Soil Quality Rating (M-SQR, Müeller et al., 2007a) revealed a feasible approach of assessing overall soil quality (Richter et al., 2009). The aim of the paper is to analyse and quantify the role of soil structure within this overall SQ rating procedure. The main objectives were to find the magnitude and field-scale variability of soil structure and overall quality scores in some important agricultural regions, the soil and land factors associated with visual soil structure and correlations between soil productivity potentials in terms of soil quality rating scores and measured crop yields.

2. Materials and methods

2.1. Methods of soil structure evaluation

Two methods of examination of the soil structure and soil quality have been performed. These were Visual Soil Assessment (VSA, Shepherd, 2000, 2009) and Visual Evaluation of Soil Structure (VESS, Ball et al., 2007).

M 1: The VSA method (Shepherd, 2000, 2009)

In addition to other parameters, the VSA method evaluates the structure status of the topsoil and considers the existence of a possible plough pan. The first step, the evaluation of the soil structure and consistence, is based on a drop shatter test. Performing VSA, a 20 cm cube of topsoil is removed with a spade and dropped from 0.1 to 1 m height onto a firm base in a box. The drop height and number of times the soil is dropped are determined by the texture of the soil. The soil is then tipped onto a large plastic bag. The aggregates are sorted and scored by comparison with photographs in a field guide. Soil porosity, colour, mottles, earthworms, subsoil compaction, clodding and erosion risk are also assessed. Soil texture, soil smell, potential rooting depth, surface ponding, and surface cover and crusting were added in the 2nd Ed. (Shepherd, 2009). Each indicator is scored by reference to photographs or tables in the field guide and ranked from 0 = poor to 2 = good. The final weighted VSA scores in the 2nd edition often rank between about 10 and a maximum of 54; $<$20 means a poor soil quality and $>$37 a good soil quality. Within this study, we estimated the second and third indicators of the VSA procedure only. These were the structure and the porosity score.

M 2: The VESS method (Ball et al., 2007)

The VESS method is based on an illustrated rating table of the topsoil structure. First a hole is dug slightly wider and deeper than the spade. This will provide first information on different layers with depth and gives access to that part of soil being examined. Then a spadeful of soil is loosened, lifted out and laid on the ground. Recognisable or pre-determined layers of examination are then assessed by loosening and breaking up the soil. The key criterion is to assess the total soil block or its separate layers as a potential medium for rooting. Beginning with the top layer the soil is gently manipulated by hand, e.g., breaking apart into aggregates and splitting aggregates. The manipulated soil is put onto the soil surface or a sheet of plastic. A score number is assigned from comparison with reference photographs ranging from good structure (score 1) to poor structure (score 5).

2.2. Concept of overall soil quality rating

The Overall Soil Quality Rating procedure is based on productivity-relevant indicator scoring which provides a functional coding of soils. The method applied is the Muencheberg Soil Quality Rating (M-SQR, Müeller et al., 2007a). It has been developed as a potential international reference base for a functional assessment and classification of soils. The M-SQR approach includes both indicators of inherent (soil substrate) and management induced (soil structure) agricultural soil quality, and of climate in terms of the soil thermal and moisture regimes (Fig. 1).

The M-SQR is based on the concept of a deep and well-established rooting zone for cropping. Soil structure indicators characterise the rooting potential. Two types of indicator have been identified and defined by scoring tables. The first are basic indicators and relate mainly to soil textural and structural properties relevant to plant growth. These are soil substrate, depth and features of the A horizon, size and shape of topsoil aggregates, features of subsoil structure and compaction, depth of rooting, water supply, wetness and ponding, slope and relief. Of the field Basic Indicators of M-SQR, three are directly related to visual soil structure. These are: topsoil structure, subsoil structure and rooting depth (Basic indicators 3, 4 and 5 in Fig. 1). The second indicators of M-SQR are hazard, relating to the most severe restrictions of soil function at the site (Fig. 1). The sum of weighted basic indicator ratings and multipliers derived from ratings of the most severe (active) hazard indicator yield an overall soil quality rating index (M-SQR score). Indicator ratings are based on a field manual (Müeller et al., 2007b) and utilise soil survey classifications (AG Boden, 2005; FAO, 2006), soil structure diagnosis tools like VSA or VESS, and local or regional climate data. The field procedure consists of digging a small pit and augering a hole down to 1.5 m for detecting layering or a shallow watertable. For the results presented here, we dug larger pits to 1–1.3 m, then augered down to 1.5 m.

VSA and VESS ratings were converted into SQR-Ratings for the basic indicators 3 (topsoil structure) and 4 (subsoil structure) according to Table 1. VSA and VESS scores are well defined for topsoil conditions. VSA scores can also be used for scoring subsoil structure, but this is currently not supported by specific sample photographs. For scoring Basic indicator 4 (subsoil structure) we used the description in the M-SQR-Handbook (Müeller et al., 2007b, Table 3.2.4.1), which has focus on types and size of aggregates and macropores. The relative strength status of the subsoil as compared with the topsoil was another important criterion of rating. The structure was assessed by inspecting a small cube of soil cut from the profile with a spade or knife.

For SQR basic indicator 3 (topsoil structure), a common topsoil depth of 20–30 cm has been considered. In case of clear gradients within this depth, a weighted averaging of VSA and VESS scores was done. For example, in a reduced tillage system, the structure of the upper 0–5 cm was very favourable, but the lower part of the topsoil was more massive. In that case, the weighting considered both the depth and the importance of the particular layer. For small grain cereals, the upper 5 cm of soil are most important for crop establishment and were given highest weightings.