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Visual examination of changes in soil structural quality due to land use

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ABSTRACT

This study aims to assess how responsive visual examination methods are to the effect of land use on soil structural quality (SSQ), and whether they are sensitive enough to detect significant changes on SSQ over a given sampling interval. The visual soil assessment (VSA), the visual evaluation of soil structure (VESS), the visual assessment of aggregate stability (VAAS) and the visual type of aggregates index (Tyagg) were used to evaluate the SSQ of a sandy loam and a silt loam soil. The land uses comprised cropland (CP) and grassland (PP). The survey was conducted twice in an agricultural cycle (in August and November). Results showed that VESS and Tyagg were in agreement with soil physical parameters when evaluating structural quality of a sandy loam, in contrast to VSA and VAAS. In the silt loam, all methods were responsive to land use effects on soil quality and sensitive in detecting changes in SSQ between evaluation times. We further showed that soils under PP resulted in the best SSQ compared to CP after harvesting, whereas SSQ of CP was better during cereal flowering than after harvesting. Despite the majority of the visual examination methods used in this survey were responsive in evaluating the effect of land use on SSQ and capable of representing structural dynamics (related to soil management) in an agricultural cycle, the lack of agreement between visual examinations and their interrelationships with the soil physical properties evaluated, however, highlight the need to conduct further work for exploring: a) method limitations, b) key factors such as soil moisture content and minimum number of samples for visual examination according to soil texture and spatial variability, and c) a judicious selection of a minimum data set of SSQ indicators omitting redundant material.

1. Introduction

Soil quality is defined as 'the capacity of a soil to function within the ecosystem boundaries and to interact positively with surrounding ecosystems' (Larson and Pierce, 1991). By this broad concept, it must be emphasized that soil quality can only be reflected by a group of indicators representing the interaction among several soil properties and processes involved, as well as external factors such as climatic conditions (Carter et al., 1997; Andrews et al., 2004). Therefore, selected indicators, for a certain survey, have to enable indirectly measure how well the specific relevant function is being performed.

One of the key indicators for assessing soil quality is the soil structure, being often recognized that a poor soil structure is the common cause of soil physical problems (Dexter, 2004; Pagliai et al., 2004). Because soil structure affects physical, chemical and biological processes that support soil's life functions (Eswaran et al., 2001; Osman, 2013), it is directly related to soil quality.

Soil structure has been defined as 'the arrangement of single mineral particles and organic substances into greater units known as aggregates and the corresponding inter-aggregate pore system' (Horn and Smucker, 2005). In a wider concept, soil structure controls the interaction between three phases in the soil, i.e., liquid, gaseous and solid. It thus becomes the common factor between the five soil functions mentioned by Karlen et al. (1997).

Apart from the natural pedogenesis that has an impact on structure-related processes, in agricultural soils; the soil structural complexity is also affected in nearly all range of scales by soil use

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and management (Carter, 2004). Consequently, favourable soil structure is important to improve soil fertility, increase agronomic productivity, enhance soil quality, as well as to decrease erodibility (Bronick and Lal, 2005), soil degradation and land degradation.

In soil structure quality (SSQ) assessment, an important consideration is the dynamic nature and the spatial variability of the soil structure (Lal and Shukla, 2004). The attributes used when observing soil structure at any given time reflect the net effect of numerous interacting factors which may change at any moment. Therefore, soil structure variation is a key point to consider for evaluating soil quality. In croplands, new conditions for soil structure dynamics are created by the diversification of tillage practices (Roger-Estrade et al., 2009), and consequently, soil workability is directly affected (Dexter and Horn, 1988).

Agriculture practices, involving heavy machinery, usually impact negatively on soil structure in the long run, i.e., increasing bulk density (BD), developing soil compaction, and decreasing aggregate size and stability, water content, as well as infiltration rate (Alvarez and Steinbach, 2009; Scholefield et al., 1985). In contrast, no-till management promotes favourable soil structure conditions such as aggregate formation and greater soil organic matter (SOM) concentration (Abid and Lal, 2008). When soils are exposed to changes in land use, the soil's physical and biological properties are affected by changes in SOM quality (amount and composition) and by intensive soil management (Pulido Moncada et al., 2010).

Ball et al. (2007) suggested including elements of soil properties such as form, stability and resilience when evaluating SSQ. In this sense, visual soil examinations, based on soil structure, involve the assessment of different soil structure-related indicators such as size and shape of aggregates, visible porosity, and root development (Ball et al., 2007). On the other hand, those visual examination methods based on soil quality, which is a broader concept than soil structure, include the mentioned soil structure-related indicators, but also other indicators such as soil fragment size distribution, aggregate stability, soil colour, texture, surface ponding and soil erosion (Shepherd, 2009; McKenzie, 1998).

Visual examination methods are very helpful as they are complementary to soil laboratory measurements, particularly with respect to evaluating soil structural, which is typically expresses by a variety of soil properties/characteristics. On the other hand, the interpretation of indirect evaluation of soil structure in conjunction with visual examinations could provide a more integrated assessment of soil structure dynamics as has been demonstrated (Pulido Moncada et al., 2014a, 2014b).

The objective of this study is to evaluate whether visual examination methods are sensitive enough to detect changes in SSQ related to soil management over a given sampling interval, and to select a minimum data set of indicators for soil structure change assessment by interpreting and integrating visual examination and laboratory measurements. This paper presents results of a characterization of the effect of land use, cropland (CP, under conventional tillage) and permanent pasture (PP), on SSQ in a sandy loam and a silt loam soil, with a focus on visual soil evaluations in an agricultural cycle, at two periods of the year.

2. Materials and methods

2.1. Soil and site description

The survey was conducted on two farmers' fields with a sandy loam and silt loam soil in the Flanders Region of Belgium. The sandy loam soil is located in the community of Kruishoutem (50° 59′ N, 3° 31′ E) on a southwest facing slope of 5.5% on a mid-slope position. It is classified as a Dystric Eutrudept (Soil Survey Staff, 2010). Clay, silt, sand, and soil organic carbon (SOC) contents are 119, 138, 743, and 23.2 g kg^{-1}, respectively. The silt loam soil is located in the community of Heestert (50° 47′ N, 3° 24′ E) on a slope of 4.5% on a mid-slope position facing southeast. The soil is classified as an Aquic Hapludalf (Soil Survey Staff, 2010). Clay, silt, sand, and SOC contents are 134, 652, 214, and 18.9 g kg^{-1}, respectively.

The SSQ was evaluated on two plots of 810 m^2 (18 m × 45 m) per soil, one under CP, and another under PP. On the sandy loam, the CP plot was under continuous maize (*Zea mays* L.), and on the silt loam it was under rotation of maize (*Zea mays* L.) and winter wheat (*Triticum aestivum L.*), both with conventional tillage. In the sandy loam conventional tillage consisted of primary tillage with mouldboard plough with four shares (30 cm depth), and a secondary tillage with harrow + seed drill (5–10 cm depth). In the silt loam soil, conventional tillage comprised primary tillage with cultivator (5–10 cm depth) + mouldboard plough with 15 shares (30 cm depth), followed by secondary tillage with harrow and seed drill (5–10 cm).

In the sandy loam, maize harvesting was conducted by using combine harvesters. Because of wet conditions three-wheel tracks were utilised. In the case of the silt loam, winter wheat harvesting was conducted only with combine harvester with wheels 48 cm wide and 3 m apart. The PP plot on the sandy loam soil was an ungrazed grassland which is used as a permanent 'cover crop' for conservation, whereas on the silt loam soil PP was grazing with presence of cattle (7.5 animals per ha).

In this study, the SSQ was evaluated at one sampling interval in an agricultural cycle. The first evaluation was conducted in August 2012, which corresponds to the period during flowering of the maize on the sandy loam and the winter wheat on the silt loam. The second evaluation was conducted in November, after harvesting of maize and winter wheat.

2.2. Soil sampling and measurements

For the first evaluation in August, soil samples were taken at six sampling points per plot randomly selected and spaced 25 m apart. For the second evaluation in November, in the plots under CP, the same number of samples was taken within the zone under the wheel track.

The examination of SSQ within the topsoil was conducted by evaluating undisturbed blocks of soil (20 cm deep, 10 cm thick and 20 cm long) and applying: i) the visual evaluation of soil structure (VESS) by Ball et al. (2007), ii) the visual soil assessment (VSA) by Shepherd (2009), iii) the visual type of the aggregates index (Tyagg) (Pulido Moncada et al., 2014b), and iv) the visual assessment of aggregate stability (VAAS) (modified from Field et al., 1997). Because of the rather low temperatures in November, the second evaluation was conducted on soil block samples (15 × 10 × 12 cm) in the laboratory and not in the field. The results were not affected by the size of the sample as observed and confirmed by previous tests in the field.

Additionally, at both evaluations and at each sampling point per plot, three soil core samples of ~100 cm^3 (5.1 cm in diameter and 5 cm in length), collected a half way of the top soil layer (0–10 cm), were used for measuring: i) saturated soil hydraulic conductivity (K_s) with the classical constant-head method (Klute and Dirksen, 1986); ii) dry BD according to Grossman and Reinsch (2002); iii) soil-porosity related parameters like macroporosity (MacP, $\theta_{h=0\,kPa} - \theta_{h=-1\,kPa}$), air capacity (AC, $\theta_{h=0kPa} - \theta_{h=-10kPa}$), and plant available water capacity (PAWC, $\theta_{h=-33\,kPa} - \theta_{h=-1500\,kPa}$) (Reynolds et al., 2007, 2009), which were calculated from soil water retention curve data using the sandbox and pressure plate method outlined in Cornelis et al. (2005). At the same time and locations, one disturbed soil sample was taken from the soil