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Visual examinations and soil physical and hydraulic properties for assessing soil structural quality of soils with contrasting textures and land uses

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ABSTRACT

This study evaluates the use and the ability of visual examinations for assessing soil structural quality (SSQ) in soils with contrasting textures and under different land uses. The study searched for similarities in SSQ class between visual examinations and soil physical and hydraulic properties (soil organic carbon (SOC), aggregate stability, bulk density, porosity, plant available water capacity (PAWC) and unsaturated and saturated hydraulic conductivity), as well as the statistical relationships between them. The visual examinations used were the visual evaluation of soil structure (VESS), the visual soil assessment (VSA), the visual assessment of aggregate stability and the visual type of aggregates index. The latter is proposed as a new visual index for assessing SSQ. Samples were taken on a sandy loam and a silt loam soil, both under cereal monoculture (CM) and permanent pasture (PP), with conventional tillage and no tillage, respectively. Visual examination methods indicated significant differences between CM and PP in the silt loam soil ($0.01 < P < 0.05$), which were confirmed by significant differences in soil porosity and PAWC values. Wet sieving and the visual type of aggregates index were similar in identifying differences between land uses in both soils. Measurements of the visual type of aggregates index and of the hydraulic conductivity at different pressure heads were similar in indicating the soil structure condition of the soils. In the silt loam soil, the visual examinations were most related to properties such as SOC, PAWC, aggregate stability and porosity, whereas in the sandy loam soil they were most associated with water flow properties. The present study demonstrated that visual examinations are reliable semi-quantitative methods to assess SSQ and could be considered as promising visual predictors of soil physical properties ($0.33 < R^2 < 0.95$). Finally, from the dissimilarities in terms of soil quality found with the VSA, VESS and porosity compare to the amount of SOC, SOC should be used cautiously as a sole indicator for soil structural quality as has been proposed in the literature, because SOC *per se* is not always well related to soil structural quality.

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Abbreviations: AC, air capacity; BD, bulk density; CM, cereal monoculture under conventional tillage; K_s, saturated hydraulic conductivity; $K_{(h)}$, unsaturated hydraulic conductivity; LP, laboratory permeameter; MacP, macropores; MicP, Pmicropores; MWD, mean weight diameter; PAWC, plant available water capacity; PP, permanent pasture; SOC, soil organic carbon; SWRC, soil water retention curve; TI, tension infiltrometer; TPV, total pore volume; VESS, visual evaluation of soil structure; VSA, visual soil assessment.

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1. Introduction

In agricultural soils, tillage practices modify soil properties and quality and hence affect crop production and the environment (Batey and McKenzie, 2006). Machinery traffic, tillage and loss of soil organic matter have adverse effects on soil structural quality (Guimaraes et al., 2013) and are generally resulting in soil compaction (Batey, 2009). Loss of integrity of soil structural units, decrease in soil volume, increase in bulk density (BD), decrease in porosity and a reduction in saturated hydraulic conductivity (K_s) are the principal consequences of soil structure degradation and soil compaction (Newell-Price et al., 2013).

Soil structure is the property most frequently evaluated when determining soil quality under different land uses and tillage practices. Soil structure is usually evaluated in an indirect way from properties such as soil organic carbon (SOC) content, BD, porosity, soil water retention curve (SWRC), soil resistance to root growth, K_s, and infiltration rate (Lal and Shukla, 2004). These properties, which can be used as indicators of soil physical quality (Reynolds et al., 2009), are usually evaluated by classical tests, which refer in this paper to those laboratory and field measurements frequently used to characterize and monitor physical condition of soils. Despite the many instruments or techniques available to measure properties related to soil structure, there are many circumstances where such tests cannot be conducted or the number of samples has to increase to adequately capture the spatial and temporal variability (Batey, 2000).

Facing those limitations, the direct evaluation of morphological structural properties in the field is a possible alternative (Boizard et al., 2005). In recent years, several methods of visual field examination have been developed to provide a direct description of soil structure, helping farmers to take rapid decisions in order to improve the soil structural quality, and thus ensuring the soil's capacity of sustainable production. The importance of visual field examination of soil quality has been widely recognized as it plays a particularly important role in providing rapid semi-quantitative data on physical soil quality (Shepherd, 2000; Mueller et al., 2009; Garbout et al., 2013).

The morphological properties comprised in these methods are used in classical soil survey and classification. They are not competing with but rather complementary to soil physical properties measurements (Karlen et al., 2003). Morphological descriptions of soil structure also provide information that cannot easily be obtained by other methods, such as the shape and strength of aggregates, type of macropores, and macropores continuity and connectivity (Lin et al., 1999a). These are properties that reveal differences in quality between land use types and detect harvest compaction in cereal crops (Guimaraes et al., 2013).

Visual field examination methods are now being used in several countries and have shown value in explaining differences in crop performance and yield resulting from soil management and type (Ball et al., 2013). To provide similar information through other measures of soil physical condition such as BD, penetration resistance, porosity, water retention or hydraulic conductivity, requires several measurements and can be costly and time consuming (Newell-Price et al., 2013). Therefore, to encourage researchers and farmers to use simple but accurate indicators for evaluating and monitoring the soil structural quality and soil degradation, there is a need to extend the validation of simple visual examinations. In this survey, we seek for the applicability and validation of proposed visual examinations for soil structural quality assessment and the use of new visual indices such as the assessment of the type of aggregates.

Comparisons of visual examination of soils under different land uses and with contrasting textures, and their relationships with physical and hydraulic properties are not well documented in literature. The objective of this study is therefore to evaluate the use and the ability of visual field examinations for assessing soil structural quality in soils with contrasting textures and land uses by comparing them to soil physical and hydraulic properties related to function of the soil.

2. Materials and methods

2.1. Field site description

The survey was conducted in the Flanders Region of Belgium, on a sandy loam and a silt loam soil, textures commonly found in many agricultural soils in Belgium (Table 1). The sandy loam soil is a Cambisol located in the community of Kruishoutem (50°59′ N, 3°31′ E), where two plots of 810 m^2 (18 m × 45 m) were selected, one under cereal mono-cropping (*Zea mays* L.) with conventional tillage (CM) and another under permanent pasture (PP). Conventional tillage consisted of primary tillage with mouldboard plough, and secondary tillage with harrow + seed drill. PP is used in this area to protect the soil surface against erosion and is free of grazing. The silt loam soil is a Luvisol located in the community of Heestert (50°47′ N, 3°24′ E), where again two plots of 810 m^2 (18 m × 45 m) were selected: one under rotation of corn (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) with conventional tillage, and the other under PP with the constant presence of cattle (7.5 animals per ha). Here, conventional tillage comprised primary tillage with cultivator + mouldboard plough, followed by secondary tillage with harrow and seed drill.

2.2. Soil sampling

In each plot, six sampling points were randomly selected and soil cores were taken simultaneously with an on field morphological evaluation of soil structure. Three soil samples were taken with ~100 cm^3 Kopecky steel rings (inner diameter of 5.1 cm and a height of 5 cm) at the half way of the top soil layer (0–10 cm) in each sampling point to determine BD, SWRC and K_s, hence three replicates per point per property. Two undisturbed blocks of soil

Table 1
Description and characteristics of a sandy loam and a silt loam soil under cereal monoculture (CM) and permanent pasture (PP).

Soils	Land use	WRB class	Drainage status	Clay ($g\,kg^{-1}$)	Silt ($g\,kg^{-1}$)	VFS ($g\,kg^{-1}$)	FS ($g\,kg^{-1}$)	MS ($g\,kg^{-1}$)	CS ($g\,kg^{-1}$)	VCS ($g\,kg^{-1}$)	SOM ($g\,kg^{-1}$)	pH_{KCl}	EC ($dS\,m^{-1}$)
Sandy loam	CM	Cambisol	Well drained	136	120	426	272	38	6	2	23.2	5.96	0.10
	PP	Cambisol	Well drained	102	155	379	307	39	11	7	26.8	4.60	–
Silt loam	CM	Luvisol	Moderately well drained	125	657	128	74	13	2	1	18.9	6.22	0.18
	PP	Luvisol	Moderately well drained	142	646	113	82	12	3	2	55.6	5.58	–

WRB = World Reference Base for Soil Resources (soil classification system), VFS = very fine sand, FS = fine sand, MS = medium sand, CS = coarse sand, VCS = very coarse sand, SOM = soil organic matter.
pH and EC (soil electrical conductivity) were determined in 1:2.5 soil solution ratio.

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