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To what extent do physical measurements match with visual evaluation of soil structure?

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ABSTRACT

Soil structure quality can be scored by visual examinations or measured with soil physical properties. To investigate the relationships between these two approaches, we adapted the VESS (Visual Evaluation of Soil Structure, Guimarães et al., 2011) to the scoring of cores (CoreVESS) on which shrinkage analysis was also performed. Scoring was performed blindly after equilibrating the samples at −100 hPa matric potential and was compared to soil texture, soil organic carbon content (SOC), soil hydrostructural stability, structural porosity, plasma porosity, bulk soil porosity or density, and water content at standard matric potential. A large geographical area of Cambi-Luvisols was sampled at 55 locations with different soil management in western Switzerland. VESS was performed on the pits and layers prior to sampling undisturbed cores. Sandy soils presented medium CoreVESS scores compared to clayey soils. Only soils with more than 20% clay content obtained good scores in this study. The relationships between CoreVESS scores, SOC and most physical properties followed a broken-stick regression, with most breaking points close to score 3. Most regressions were significant and highly determined with R^2 above 0.45. Linear decrease with CoreVESS scores was observed for total porosity and bulk density of air-dried soil and for water content at −10hPa. The underlying model of structural quality decrease can be summarized as follows. From score 1 to 3 the decrease in structure quality corresponds to a decrease in SOC. From score 1 to 2 occurs most of the decrease in coarse porosity volume. From score 3 to 5 the decrease of structure quality corresponds to a loss of structural porosity, which converges to 0 $cm^{-3} g^{-1}$ for score 5, and to a collapse of the samples upon drying between scores 3 and 4, thus denoting a loss of hydrostructural stability. VESS scores of pits and layers were poorly correlated to CoreVESS scores and physical properties, probably due to local variability of the sampled layers. Our results suggest that the relation between visual scoring and physical properties is not site specific, and underline the need for standardizing the moisture conditions in soil structure quality assessment.

1. Introduction

Soil structure quality assessments by semi-quantitative visual examination methods using scores, such as VESS (Visual Evaluation of Soil Structure) (Ball et al., 2007; Guimarães et al., 2011) receive increasing attention. Among others, visual examinations can be used to monitor soil quality, to detect erosion and compaction in cropped fields or to support decision making for tillage practices. They integrate multiple degradation features and processes, are performed directly in the field, do not require extended training, specific equipment or laboratory analyses and the result is immediately available. However visual examinations are considered to be subjective compared to measured physical properties, adding to the fact that they do not address precise physical properties. They are, therefore, unsuitable to quantify structural degradation in physical processes and, for example, to account for structural degradation in the frame of legislation.

Visual examination methods are often compared to different soil physical properties, such as resistance to penetration

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(Guimarães et al., 2013; Mueller et al., 2009; Newell-Price et al., 2013), flow measurements (Guimarães et al., 2013; Moncada et al., 2015; Pulido Moncada et al., 2014b), aggregate stability (Moncada et al., 2015; Pulido Moncada et al., 2014b), water or air content (Moncada et al., 2015; Mueller et al., 2009), S-index (Moncada et al., 2015) and least limiting water range (Guimarães et al., 2013). Bulk density however, is the most represented property in these comparisons (Table 1). In a large scale study of 30 grassland fields with different soil types, a relation with $R^2 = 0.25$ ($p < 0.01$) was found between visual examinations and bulk density (Newell-Price et al., 2013). Pulido Moncada et al. (2014a) reported a non-linear relationship ($p < 0.01$, R^2:0.38) between visual scoring and bulk density in tropical soils from 7 different sites and soil types. Mueller et al. (2009) studied three different sites and soil types and concluded that the relation between bulk density and visual scores were site-specific. On a single field with sandy-loam Cambisol, Pulido Moncada et al. (2014b) found a linear relation with $R^2 = 0.53$ ($p < 0.01$). In another single field of sandy-loam Eutric-Cambisol, Guimarães et al. (2013) found a linear relationship with R^2 up to 0.62 ($p < 0.05$). Therefore, it seems that visual examinations and bulk density are more closely linked when a single soil type is considered. This makes sense because the porosity of the soil is among others determined by texture and type of clay mineral (Boivin et al., 2004; Goutal-Pousse et al., 2016).

Lack of precision is a problem often mentioned not only for visual examinations, but also for physical determinations. Indeed soil physical characterisation is well known to show large variability and unexplained variances (e.g. Horn and Fleige, 2009; Sisson and Wierenga, 1981). This may be due to changing field conditions, especially water content, which is a problem for both visual examinations (Guimarães et al., 2011) and physical measurements (Goutal et al., 2012; Mueller et al., 2009). Shrinkage curve analysis (ShA) provides a good opportunity to help overcome these difficulties, among others because the determined properties show small standard deviations (Boivin, 2007), good correlations with soil constituents (Boivin et al., 2009, 2004) and independence from field water content (Goutal et al., 2012). Therefore ShA receives increasing attention to assess soil compaction or structural changes (Boivin et al., 2006; Fontana et al., 2015; Goutal-Pousse et al., 2016; Peng et al., 2012; Schäffer et al., 2013, 2008). ShA provides a large set of soil physical properties in a single experiment, including bulk density at any water content. One of the specific features of ShA is that it quantifies separately the volume, the air and water content, and the swelling dynamics of the two soil pores systems, namely the plasma and structural pores. This distinction proved to be important because the two pore systems do not behave the same under compaction (Goutal-Pousse et al., 2016; Schäffer et al., 2013).

Our objective was to characterize and quantify the relationships between soil structure quality scores observed with VESS and physical changes quantified with ShA. To avoid spatial heterogeneity we measured and visually evaluated the same undisturbed sample. Using an adapted method, CoreVESS, we did the evaluations at a standardized soil matric potential. Our samples were collected on the same soil group, namely Cambi-Luvisol, but at large geographical scale, therefore including different textures and soil managements, to establish non-site-specific relations.

2. Material and methods

2.1. Study area – soil characteristics - soil sampling

The study took place across western Switzerland in the cantons of Bern and Vaud, spanning to a distance of 120 km. Samples were randomly collected in spring, summer and autumn from 2012 to 2014 on 55 locations under three different types of soil management, namely permanent grass (14 locations), no-till (24 locations) and plough-based tillage of 20–25 cm depth (17 locations). The sampling covered two textural classes, loam and sandy loam (Food and Agriculture Organization, 2014), and despite large geographical and textural coverage, all the collected samples belonged to the soil type “Braunerde”, according to the Swiss Soil Map (Bundesamt für Landestopographie, 1984), which is intermediate between Cambisols and Luvisols WRB soil groups (Food and Agriculture Organization, 2014). The sampled soils all developed on mixed morain – molasses bed rock. The soil characteristics are presented in Table 2. Undisturbed 5.6 cm diameter soil cores of approximately 150 cm^3 were collected at a depth of 5–10 cm at each location, next to the visually evaluated pit (see below). A custom-made sampler was used to allow easy extraction of the undisturbed core from the sampler without disturbing the structure of the sample.

Table 1
Some published relationships between bulk density and visual soil evaluation.

Reference	VSE method	relationship	equation	n	add. info.	rho	R^2	p value
Pulido Moncada et al. (2014b)	VSA	linear	$y = -0.0131x + 1.7266$	12			0.53	<0.01
Pulido Moncada et al. (2014a)	SQSP	logarithmic	$y = -0.199\ln(x) + 1.6094$	36			0.15	<0.05
	VESS		$y = 0.38\ln(x) + 0.9833$	36			0.38	<0.01
	VSA_{mod}		$y = -0.177\ln(x) + 1.9907$	36			0.25	0.01
Garbout et al. (2013)	VESS	linear (Pearson correlation matrix)	NA	8			0.42	<0.05
Newell-Price et al. (2013)	Peerlkamp	NA	NA	30			0.25	<0.01
Guimarães et al. (2013)	VESS	linear	$y = 0.1209x + 0.8865$	30	clayey		0.51	<0.05
			$y = 0.189x + 0.7914$	30	sandy loam		0.62	<0.05
Mueller et al. (2009)	Peerlkamp	monotonic (Spearman rank correlation matrix)	NA	59	Elora site (Canada)	0.56		n.s.
	Diez		NA	59		0.40		n.s.
	VSA – Structure		NA	59		0.58		n.s.
	VSA – Porosity		NA	59		0.63		<0.05
	Peerlkamp		NA	46	Luancheng site	0.02		n.s.
	VSA – Structure		NA	46	(China)	0.77		<0.05
	Werner		NA	46		0.42		n.s.

VSE: visual soil evaluation, VESS: visual evaluation of soil structure, SQSP: soil quality scoring procedure, VSA_{mod}: visual soil assessment (method modified), NA: not available, n: number of observations, add. info.: Additional information, n.s.: not significant, rho: Spearman correlation.

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