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Spatial variability and sampling requirements of the visual evaluation of soil structure in cropped fields

Saskia Leopizzi, Karine Gondret, Pascal Boivin*

Soils and Substrates, inTNE-hepia, University of Applied Sciences of Western Switzerland, 150 route de Presinge, CH-1254 Jussy-Geneva, Switzerland

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ABSTRACT

Scoring the structure quality of the soil with the Visual Evaluation of the Soil Structure (VESS) spade test receives growing interest due to its simplicity, reliability and the quality of the evaluation provided. Sampling requirements to achieve a predefined quality of estimation, however, were not defined. This paper aims at filling this knowledge gap. The spatial variability of VESS scoring is analysed in two field, one with homogeneous microtopography and vegetation growth and one showing spots of two distinct states with respect to these criteria. The semi-variograms showed purely random distribution of the scores from 6–10 to > 150 m of inter distances between observations, thus allowing to calculate the number of spade tests required to reach objectives of accuracy or minimum detectable difference. The two zones of the heterogeneous field, and the homogeneous field, showed the same coefficient of variation of 11%, which is small. Therefore, 5 spade tests only are enough to detect a 0.5 change of the scoring. This number is smaller than usually recommended or performed. The classical recommendation to sample in homogeneous vegetation growth is supported by our results. These results probably apply to most situations and can be used to design monitoring protocols.

1. Introduction

The soil structure integrates many soil properties and determines among others soil fertility, soil biodiversity, nutrient cycling, carbon sequestration and the quantitative and qualitative regulations of water cycle (Bronick and Lal, 2005; Young and Crawford, 2004). Assessing structure quality is, therefore, central for soil monitoring and soil quality assessment.

Taking into account soil structure quality in soil protection regulation or in agricultural management schemes is of great interest but is limited by the difficulties inherent to structure quantification. Soil structure refers to the arrangement of solids and the resulting porosity. The pore network is complex and the pores are swelling and shrinking with water. Consequently, among the many physical parameters associated with structure, none of them allows non-disputable classification of structure quality, and most of them are difficult and expensive to determine, though providing poor discrimination due to large and unexplained variability (e.g. Alaoui et al., 2011; Horn and Fleige, 2003; Keller et al., 2004; Lebert et al., 2007; Sisson and Wierenga, 1981).

In this context, visual evaluation of soil structure (VESS) receives growing interest (Askari et al., 2013; Askari and Holden, 2015; Mueller et al., 2013), since it allows fast and easy scoring of the structure, thus providing a semi quantitative assessment of the structure quality. Visual evaluation was used to make compaction diagnosis (Batey and McKenzie, 2006) or soil quality monitoring (Ball and Douglas, 2003). The method was recently developed and improved based on the classical spade test (Ball et al., 2007, 2015; Guimarães et al., 2011). It was adapted to clod size samples (Johannes et al., 2016) and showed good relationships with physical measurements, organic carbon content (Guimarães et al., 2013; Johannes et al., 2016; Moncada et al., 2015) or yield (Mueller et al., 2009).

To apply VESS in monitoring networks or soil regulation, sampling protocols for the calculation of an average structure quality score must be available. The corresponding requirements must be defined based on spatial variability analysis, which was to our best knowledge not investigated (Emmet-Booth et al., 2016). Only empirical recommendations based on expertise are provided for VESS. For instance, Ball et al. (2007) suggest to perform 10 to 20 tests on a regular grid located on a homogeneous area of the field. Homogeneity refers to plant growth and soil surface state but was not clearly defined. Based on similar criteria, Guimarães et al. (2011) performed 10 tests along a transect, and Giarola et al. (2013) 10 tests randomly distributed in the plot, while Munkholm et al. (2013) recommend to perform 2 tests at the centre of the plot and out of wheel tracks. The expected relative accuracy using these different protocols is not known. Soil physical properties are generally not randomly distributed and show spatial organization or

* Corresponding author.
E-mail address: pascal.boivin@hesge.ch (P. Boivin).

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autocorrelation (Gascuel-Odoux, 1987; Vauclin, 1982), which means that the experimental variance may decrease in the autocorrelation range (Journel and Huijbregts, 2004).

The aim of this study was to provide quantitative bases of the sampling requirements for the characterization of a field with VESS spade test. It was conducted in two cultivated fields of 3.2 and 5 ha area, respectively. The fields did not show evident heterogeneity in soil type and topographic units, that would have led to split them. The first one was tilled and apparently homogeneous with respect to surface micro-topography and crop growth. The second one, which was recently converted to no-till due to structure quality issues, showed marked heterogeneity according to the same criteria.

2. Methods

2.1. Sampled fields

A 3.2-ha homogeneous field, showing few and light wheel tracks and homogeneous crop growth, and a 5-ha heterogeneous field, according to crop growth and micro-topography, were selected. The homogeneous field was flat and cultivated under conventional tillage. A grazed meadow was seeded in summer 2016 after the harvest of an autumn wheat crop, and the sampling took place in October 2016. It showed light wheel tracks in the field and in the 10 meter large margins.

The heterogeneous field was gently sloping, with erosion hazard estimated from 40 to 0% along the slope on the regional erosion map (available at http://ge.ch/sitg/), but no erosion events were recorded. It was converted to no-till in 2011, after repeated structure degradation observation. Sampling took place in April 2017 and no wheel tracks were visible. A winter wheat seeded in fall 2016 showed two contrasting aspects. In general, the wheat growth was quite good in density and height, but also small patches of some m^2 of crop that were shorter and lighter green than the rest were distributed throughout the field. Moreover, poor crop growth could be observed at the same locations in the previous crop rotations on aerial pictures. Therefore, according to the recommendation to sample in homogeneous crop growth zones, this field was considered to contain two main units of growth vigour. In the following, the two fields are denoted Ho-field and He-field for the homogeneous and heterogeneous field, respectively.

2.2. Sampling network

To optimize the distribution of the inter-distances between sampling points for semi-variogram calculation, a stratified random sampling network was designed (Webster and Oliver, 1992). The sampling points were equally distributed into the grid cells of a primary large grid, and randomly attributed to the nodes of a thinner grid of 10 (Ho) and 6 (He) meter size, respectively. The grid sizes were optimized to reach about 30 pairs of points at each lag, the smallest lag corresponding to the thinner grid size. In the homogeneous field, 15 spade tests were located under wheel tracks and 15 on the trafficked field margins, while the 87 others were inside the field out of tracks. On the heterogeneous field, the 125 spade test locations were randomly selected regardless of wheat growth zones to characterize the spatial variability of the spade test. Moreover, 15 additional spade tests were performed in good and poor wheat growth spots, respectively, to determine their spade test mean and variance.

2.3. VESS spade test

The VESS is a semi-quantitative method developed for the characterization of soil structure quality (Ball et al., 2007). It consists in extracting a block with a spade and evaluating its structure quality based on a chart. The latter contains illustrations and evaluation criteria from which 5 structure quality classes are defined corresponding to scores from 1 (good) to 5 (poor structure). The main evaluation criteria were: difficulty of breaking, size and shape of aggregates and visible porosity. Each layer of the pit was evaluated separately. The final score for the whole pit was calculated by weighting the score of the horizons by their relative thickness.

2.4. Soil properties

The two fields were developed on moraines. The Ho-field was a cambi-luvisol according to WRB (Food and Agriculture Organization, 2014) with 2% organic carbon content on the first 30 cm, a pH of 6.8 and a clay content of 16%. The He-field was a cambisol with 1.29% organic carbon content on the first 30 cm, 24% clay content and a pH of 7.11.

2.5. Wheat growth in He-field

At the 30 additional spade test locations wheat growth was characterized for height and chlorophyll content using a N-Tester® (Yara LTD) (Arregui et al., 2006; Ortuzar-Iragorri et al., 2005). Wheat height was measured on 10 plants around the tested place, and N-tests were the average of 30 measurements as recommended from the supplier.

2.6. Statistical analyses

Directional and average semi-variograms were calculated using the Geostat Office software (Kanevski and Maignan, 2004). The number N of samples allowing to determine the average score with a 95% confidence that the relative error is smaller than some limit of ε was calculated using:

$$N = \left(CV*\frac{1.96}{\varepsilon}\right)^2 \tag{1}$$

where CV is the coefficient of variation of the scores. The number n of spade tests for a given minimum detectable change with time (MDD) was calculated according to Zar (2007) as:

$$MDD = \sqrt{\frac{S^2}{n}(t_{\alpha}, V + t_{\beta}, V)} \tag{2}$$

with s^2 = variance, n = sample size, t_{α},V = critical values of t-distribution at significance level α with V degrees of freedom, t_{β},V = critical value of t-distribution at statistical power of 1 − α with V degrees of freedom.

The differences between zones were tested with Kruskal-Wallis test and the correlations between vegetation development parameters and VESS scores were analysed using Spearman correlation with Minitab 17® software.

3. Results

3.1. VESS scores

The main statistical properties of the VESS scores found in the two fields are reported in Table 1, with distinction between wheel-tracks, field margins and inter-wheel for the Ho-field, and degraded and non-degraded zones for the He-field. The distribution of the scores was normal in the Ho-field and not in the He-field. A significant difference of the average score between the degraded and non-degraded zone was found in the He-field (Fig. 1).

In average, the Ho-field had a VESS score of 2.31, thus denoting a good structure. Unsurprisingly, no significant difference was found between the scores of the inter-wheel tracks and wheel tracks zones, in good agreement with the very light print of the wheels. The full data set is, therefore, used in the next steps. The coefficient of variation for the whole data set is 10.8%, which is small for a physical property (Vauclin,