Soil & Tillage Research 181 (2018) 37–45

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

# Geometric characterization of soil structure through unconventional analytical tools

Chien Ling Tseng[a,*], Marlene Cristina Alves[b], Débora Marcondes Bastos Pereira Milori[c], Silvio Crestana[c]

[a] University of São Paulo, "São Carlos School of Engineering", 400 Avenida Trabalhador São-carlense, CEP: 13566-590 São Carlos, São Paulo, Brazil
[b] Universidade Estadual Paulista, "Rural Engineering and Soil", 56 Avenida Brasil, Centro, CEP: 15385-000 Ilha Solteira, São Paulo, Brazil
[c] Embrapa Instrumentation, 1452, Rua XV de Novembro, CEP: 13560-970, São Carlos, São Paulo, Brazil

ARTICLE INFO

*Keywords:*
Microtomography
Porosity
Shape factor
Fractal dimension
Lacunarity
Tropical soil

ABSTRACT

Soil structure is essential for soil function and environmental quality. Therefore, adequate evaluation of management systems is essential to ensure the preservation and regeneration of soil structure. Techniques such as X-ray microtomography and automated soil particle size analysis based on gamma-ray attenuation provide rapid quantification of soil physical properties and allow for the evaluation of soil structure. The aim of this study is to determine soil physical parameters using unconventional analytical tools to characterize and evaluate the geometric characteristics of soils with different structures at high accuracy. Soil samples extracted from the UNESP experimental farm (Brazil) were separated into two different management groups according to their textural similarity. The following results were obtained from the analysis: 1) Microtomography can be used to extract soil porosity, including soil microporosity. 2) The shape factor indicates the geometric organization of the soil structure, which is relevant and valid for evaluating the degree of soil degradation. 3) The fractal dimension is related to the soil particle and aggregate size distribution but was not sufficient for describing the soil geometric properties when used alone. 4) Coupling the fractal dimension with the lacunarity provides an important tool for estimating the soil structure. Finally, the application of the physical parameters from the unconventional method provided new insights for understanding soil geometric structure, which can support future investigations of flow phenomena in the soil.

## 1. Introduction

Adequate soil management is essential for guaranteeing agricultural production and for promoting environmentally and socio-economically sustainable development around the world. Soon, the preservation and regeneration of soil structure will become essential for maintaining important soil functions and for securing environmental quality. However, one of the current challenges in the study of soil structure is the lack of knowledge on how to non-destructively and reliably evaluate soil physical parameters, including soil structure, which is influenced by management practices and intensity.

Soil physical parameters are usually measured to obtain a better understanding of soil processes, such as the effects of tillage on soil structure (Reynolds et al., 2009). Using visual analysis, Carducci et al. (2016) assessed how the structure of an Oxisol changed as a consequence of management and validated their findings by X-ray Computerized Tomography (CT) scanning of undisturbed soil samples. Pires et al. (2017) explored diverse tools to quantify pore system differences between conventional and no-till management systems. Likewise, Naveed et al. (2016) quantified vertical stress transmission in an arable topsoil and determined compaction-induced soil structure by applying X-ray CT.

For the first time, a set of unconventional analytical tools was used concomitantly to investigate the geometric structure of tropical soils under different types of management. We selected several unconventional techniques and methods to determine the most pertinent analysis options. These techniques and methods include an automated soil particle size analyzer (Naime et al., 2001), X-ray CT and digital image processing (Crestana et al., 1985, Passoni et al., 2014). We mainly chose these methods and techniques based on the concept that the soil texture directly affects the soil structure. In addition, CHNS/O Elemental Analysis and Laser Induced Fluorescence Spectroscopy (LIFS) (Milori et al., 2006 and Senesi et al., 2016) were introduced to supplement the discussion.

* Corresponding author.
*E-mail addresses:* chienlt86@sc.usp.br (C.L. Tseng), mcalves@agr.feis.unesp.br (M.C. Alves), debora.milori@embrapa.br (D.M.B.P. Milori), silvio.crestana@embrapa.br (S. Crestana).

https://doi.org/10.1016/j.still.2018.03.018
Received 22 December 2017; Received in revised form 17 March 2018; Accepted 27 March 2018
0167-1987/ 

Tseng et al. (2018) focused on a methodological evaluation of soil structural quality using one representative image. Tomographic images were used to qualitatively evaluate the regeneration process of a Brazilian Oxisol under different types of management by Marchini et al. (2015). Vaz et al. (2011) quantified the porosity and the pore size distribution of two Brazilian Oxisols, resulting in important information for establishing appropriate scanning parameters for these soils. Beraldo et al. (2014) also applied a tomographic method to evaluate the porosity of three soil management systems and verified that their method could be used to obtain information at the macropore scale.

For this study, we used an elemental analyzer and a LIFS system to calculate the soil carbon (C) content and humification index of soil organic matter (Milori et al., 2006 and Senesi et al., 2016) as indicators of the resistance of the soil to microbial decomposition. The humification index can be low if the soil organic matter is protected inside aggregates; the C content of macroaggregates is greater than that of microaggregates (Six et al., 2000).

With respect to shape factors or pore form, Passoni et al. (2014) applied ImageJ software to characterize Oxisols from the southeastern region of Brazil and successfully demonstrated the possibility of using this software to identify the characteristics of pores in tropical soils. Munkholm et al. (2016) confirmed that long-term management of the soil alters both its aggregate form and pore characteristics by using CT scanning and tensile strength measurements.

The fractal dimension is an indicator of the complex geometrical structure of an object, e.g., the soil structure; thus, the fractal dimension can be used to quantify small-scale soil structure data obtained with X-ray CT (Zeng et al., 1996). Then, the fractal dimension can be used to describe the soil physical properties, model soil physical processes and quantify soil spatial variability (Perfect and Kay, 1995). In this study, the fractal dimension was correlated with the soil texture (granulometry), which were obtained using X-ray CT and an automated soil particle size analyzer, respectively.

Although the lacunarity concept was initially conceived to describe fractal properties, it can be extended to other natural spatial patterns without any restrictions (Plotnick et al., 1996; Allain and Cloitre, 1991). In other words, the lacunarity curve corresponds to the degree of spatial heterogeneity and the self-similar characteristics of the soil texture in practical terms. This concept applies regardless of whether the soil texture is fractal or random, i.e., the presence or absence of a geometric pattern. The work of Monreal et al. (2013) is particularly interesting because these authors applied the concept of lacunarity to investigate the spatial distribution of pedotaxa in Europe. In Roy and Perfect (2014), analytical and digital tools were used to investigate lacunarity and its influences on flow and transport processes within grayscale representations of soil aggregates. In another study, Martínez et al. (2017) analyzed lacunarity in 3D images of soil columns to characterize their macropore space geometry. Additionally, when the lacunarity (L) decreases toward ln [L (r)] = 0 and remains constant, the box or cube size (r) is approached as the representative elementary volume (REV) (Luo and Lin, 2009).

The aim of this study is to determine soil physical parameters using unconventional analytical tools to characterize and evaluate the geometric characteristics of soils with different structures at high accuracy.

## 2. Material and methods

### 2.1. Experimental sites

The soil samples were obtained at the Fazenda de Ensino e Pesquisa da Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Teaching and Research Farm of the Paulista State University "Júlio de Mesquita Filho", on the Ilha Solteira campus in the city of Selvíria (Mato Grosso do Sul State - Brazil). This farm is located on the banks of the Paraná River (22° 22′ S and 51° 22′ W). In the 1960s, at the beginning of the construction of the hydroelectric power dam in Ilha Solteira (São Paulo State), an 8.6-m-thick soil layer was sampled from the original soil surface to prepare and construct the dam's foundation. Since 1969, subsoil containing B horizon material has remained exposed at the surface and has shown serious stages of superficial compaction and a low presence of vegetation. The soil in the experimental area is a Brazilian Oxisol characterized by advanced stages of weathering and an acidic pH that is typical for equatorial and tropical regions (Embrapa Solos, 2013).

### 2.2. Soil sampling description

In this study, soil samples were collected at a depth of 0–10 cm in the form of undisturbed blocks (30 cm x 30 cm x 10 cm) from areas under six different types of management, (i.e., with different soil geometric structural statuses). The samples were preserved at ambient temperatures and then one subsample (8 mm diameter x 12 mm height) was obtained from each block by using an acrylic tube. Next, the subsamples were dried at 105 °C for 48 h. Upon their collection, the samples were divided into two groups based on their textural similarity as follows. **Group I**: 1) NF - soil from native forest (control); 2) RS - regenerated soil, formed by applying green manure to the soil over seven years, from 1992 to 1999, followed by cultivation with *Brachiaria decumbens*; 3) G - regenerating soil with *Astronium fraxinifolium* (Gonçalo-alves) + *Brachiaria decumbens* + domestic sewage sludge and without heavy metal contamination from the Araçatuba Sewage Treatment Plant; and 4) D - degraded soil (remaining soil from the construction of the hydroelectric power plant). **Group II**: 5) RP - regenerating pasture soil and 6) DP - degraded pasture soil. The soil from the NF was considered to be a reference for comparison in both groups.

### 2.3. Equipment

Four analytical apparatuses were used in this study: i) an Embrapa Instrumentation homemade automated soil particle size analyzer; ii) a commercial X-ray microtomograph, model 1172 – Skyscan/Bruker (Kontich, Antwerp, Belgium); iii) a commercial CHNS/O elemental analyzer, model 2400 – PerkinElmer (Waltham, MA, USA) and iv) an Embrapa Instrumentation homemade LIFS (Laser Induced Fluorescence Spectroscopy). With these devices, sets of physical parameters were derived for each management system.

#### 2.3.1. Automated soil particle size analyzer

The automated soil particle size analyzer is an instrument developed by Embrapa Instrumentation - São Carlos. It uses gamma-ray attenuation based on the modified Beer-Lambert Law and Stoke's Law to quickly determine particle size distribution, soil texture (granulometry), particle density, the water retention curve and the S index for soil (Vaz et al., 1992; Naime et al., 2001).

For pretreatment, the soil samples were dried in an oven at 105 °C for 24 h and passed through a 1.5 mm mesh sieve to remove gravel and any remaining plant roots. The soil organic matter not was oxidized with $H_2O_2$. Next, the mass attenuation coefficients ($\mu_m$) (Eq. 1) were determined for all the samples. Subsequently, 40 g of soil was mixed with 10 ml of sodium hydroxide solution (NaOH) and distilled water in a Wagner type shaker for 16 h to ensure that the solutes were uniformly dissolved in the water. Finally, the solution was transferred to a cuvette and placed in the automated soil particle size analyzer to acquire the particle size distribution. For each soil management system, three measurements were gathered with the aid of QUALISOLO software (Vaz et al., 2007), and soil texture was obtained for each system (Table 1).

$$\mu_m = \frac{\mu}{\rho} \quad (1)$$

where μ is the linear attenuation coefficient, and ρ ($kg\,m^{-3}$) is the physical density of the material.