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Exploration of soil micromorphology to identify coarse-sized OM assemblages in X-ray CT images of undisturbed cultivated soil cores

N. Elyeznasni [a], F. Sellami [b], V. Pot [a,*], P. Benoit [a], L. Vieublé-Gonod [a], I. Young [c,1], S. Peth [d]

[a] INRA, AgroParisTech, UMR 1091 EGC, F-78850 Thiverval-Grignon, France
[b] INRAP, Grand Sud-Ouest, France
[c] SIMBIOS Centre, Univ. of Abertay, Dundee DD1 1HG, UK
[d] Institute of Plant Nutrition and Soil Science, Christian-Albrechts-University zu Kiel, Olshausenstr. 40, D-24118 Kiel, Germany

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ABSTRACT

We proposed to use micromorphology to help identify coarse-sized organic matter (OM) in X-ray computed tomography (CT) images of fresh undisturbed soil cores. We sampled three soil columns (5-cm diameter, 5-cm height) in the interfurrows that mainly contain macroporosity and straw residues of the ploughed horizon of a silt loamy Albeluvisol. Two of the samples were X-ray scanned at 68 and 88 μm voxel-resolution, and three thin-sections were performed in one of the scanned columns. Retention curve was measured on the third soil column. Micromorphology observations showed macropores from very fine to coarse size and numerous mesopores were heterogeneously distributed in the soil matrix and concentrations of OM of increasing stages of decomposition within and around the macroporosity. CT images easily detected coarse-sized OM concentrations and recovered part of the discontinuous pattern of the coarse-sized OM fragments in the macroporosity. We defined a table of correspondence between the structural features (porosity) and organo-mineral features of size down to about 40 μm and the grey level values of the scanned image. The values of the thresholds were adjusted from the micromorphological observations and the porosities of the 3D segmented images compared well with the measured porosity of the third soil column. The main limitation of the method was in choosing the threshold values separating pores and coarse-sized OM in order to recover the porosity of the zones containing the coarse-sized OM features. The proposed method is a preliminary work that showed to be well suited for undisturbed soil samples containing large pieces of straw residues incompletely mixed with soil matrix but cannot be applied to the identification of fine-sized OM.

1. Introduction

The nature and size of soil organic matter (SOM) can strongly affect the sorption of organic pollutants like pesticides and therefore modify their mobility and biodisponibility in soils (Benoit et al., 1999; Dao, 1991; Reddy et al., 1997). Coarse-sized OM can constitute highly reactive sites for pesticides (Benoit et al., 2008). Identification of the spatial location of the different natures of SOM in the soil pore space together with the spatial distribution of micro-organisms in soils will thus help in modelling the fate of pesticides, as suggested by recent studies (Monga et al., 2008; Or et al., 2007; Smucker et al., 2007; Vieublé-Gonod et al., 2009).

We propose, in a preliminary study, to use micromorphology to help identify coarse-sized OM at different stages of decomposition in X-ray computed tomography (CT) images of undisturbed soil cores at a medium voxel-resolution of about 80 μm. Identification of coarse OM in the soil pore space and the description of its stage of decomposition is successfully identified by micromorphology observations in 2D thin-sections (Bullock et al., 1985; Fitzpatrick, 1993; Grosbellet et al., 2011). However, the 3D reconstruction of the 2D observed features is not straightforward and needs interpolation using statistical models (Blair et al., 2007 for instance). To date, identification of coarse-sized OM in 3D X-ray CT images has been successfully performed only in mixtures of soil aggregates and added coarse-sized OM of easily recognisable morphology (De Gryze et al., 2006; Sleutel et al., 2008). To our knowledge, the identification in CT images of coarse-sized OM at different stages of decomposition and in undisturbed fresh soil samples has not been performed.

A key issue in identifying organic matter in X-ray CT images is that the grey level values of each voxel represent the averaged density of the particular volume through which X-rays are attenuated. The size of this volume depends on the resolution of the scan and thus, depending on the volumetric fractions of each phase (water/air filled pore, OM and mineral grains) same values of grey level can be attributed either to a mixture of 2 phases (OM and minerals or water/air filled pore and minerals) or to a mixture of the 3 phases. Furthermore, although the direct identification of coarse-sized OM in CT images

* Corresponding author. Tel.: +33 1 30 81 54 02; fax: +33 1 30 81 53 96.
E-mail address: vpot@grignon.inra.fr (V. Pot).
[1] Currently at School of Environmental and Rural Science, Univ. of New England, Amidale, NSW 2351, Australia.

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may be trivial, due to its distinct morphology (De Gryze et al., 2006) it may be different in undisturbed soil cores where coarse-sized OM has evolved with time and its morphology has changed. Thus it appears fundamental to assess the identification of grey levels attributed to coarse-sized OM in X-ray CT to visually observed OM as provided by thin-section micromorphological observations.

2. Material and methods

In this preliminary study, we sampled three soil columns (5-cm diameter, 5-cm height) in the horizontal layer of a silt loamy Albeluvisol (FAO, 2006) containing 19% clay, 75% silt and 6% sand. The site is a field experiment located in Feucherolles (Ile de France, 50 km west of Paris, France) designed to evaluate the impacts of urban waste composts on soil fertility and soil and water quality since 1998 (Houot et al., 2009). Sampling was performed 5 months after tillage and the cores were taken in the interfurrows that correspond to the ancient soil surface containing the straw residues that was inverted by the plough (Schneider et al., 2009). These interfurrows mainly contain large amount of coarse-sized OM and constitute local environments with a high level of microbial biomass and pesticide mineralisation (Vieublé-Gonod et al., 2009). After sampling, we closed both ends of the soil columns with parafilm and stored the columns in a cold chamber (4 °C) before analyses.

Two soil columns were scanned in a high resolution micro-CT machine (μSIMCT Equipment: SIMBIOS Centre University of Abertay Dundee, Scotland) operating at 90 keV and a current of 112 mA for column I and at 145 keV and a current of 55 mA for column II. The X-ray detector was a 12 bit CCD camera. We vertically placed the soil columns on a rotation platform. A voxel-resolution of 68 μm and 88 μm was obtained for columns I and II respectively. 3D reconstruction was performed with the CT-Pro reconstruction software. The difference in resolution was achieved because one column was scanned with its Plexiglas container.

Then, both soil columns were air-dried and impregnated with polyester resin mixed with a fluorescent dye (Uvitex). The dye permits to differentiate void from solid phase by observations under UV light (Bresson and Moran, 2004; Ringroase-Voase, 1996). We prepared three thin-sections out of column I by roughly selecting the vertical location of the sections after observation of the CT cross-sections and identification of well-shaped macropores. Due to imprecision of the saw, we could not reach perfect alignment to the horizontal plane. The largest deviation from horizontal alignment was about 1 mm in height. Thin section A was located at about 3 cm from the top of the soil column, thin sections B and C were located at about 3.5 cm and 4 cm from the top. A camera Canon PowerShot S 50 pictured two digitalised images of each of the three thin sections. One image was pictured under white light and the second image was pictured under UV light. The latter was segmented using a manual threshold with Image J free software (http://rsbweb.nih.gov/ij/) to quantify the porosity. The threshold was assessed by observations of the correctness of the pore connectivity of the corresponding thin-section under a binocular microscope. We observed the thin sections under polarised optical microscope at magnifications ranging from 40× to 200×. Micromorphological descriptions were based on Bullock et al. (1985), Fitzpatrick (1993) and Fedoroff and Courty (1994).

The third column, column III, was used as a replicate to obtain an estimation of the porosity of the core. To do so; the retention curve, relating the volumetric water content to the soil water pressure,

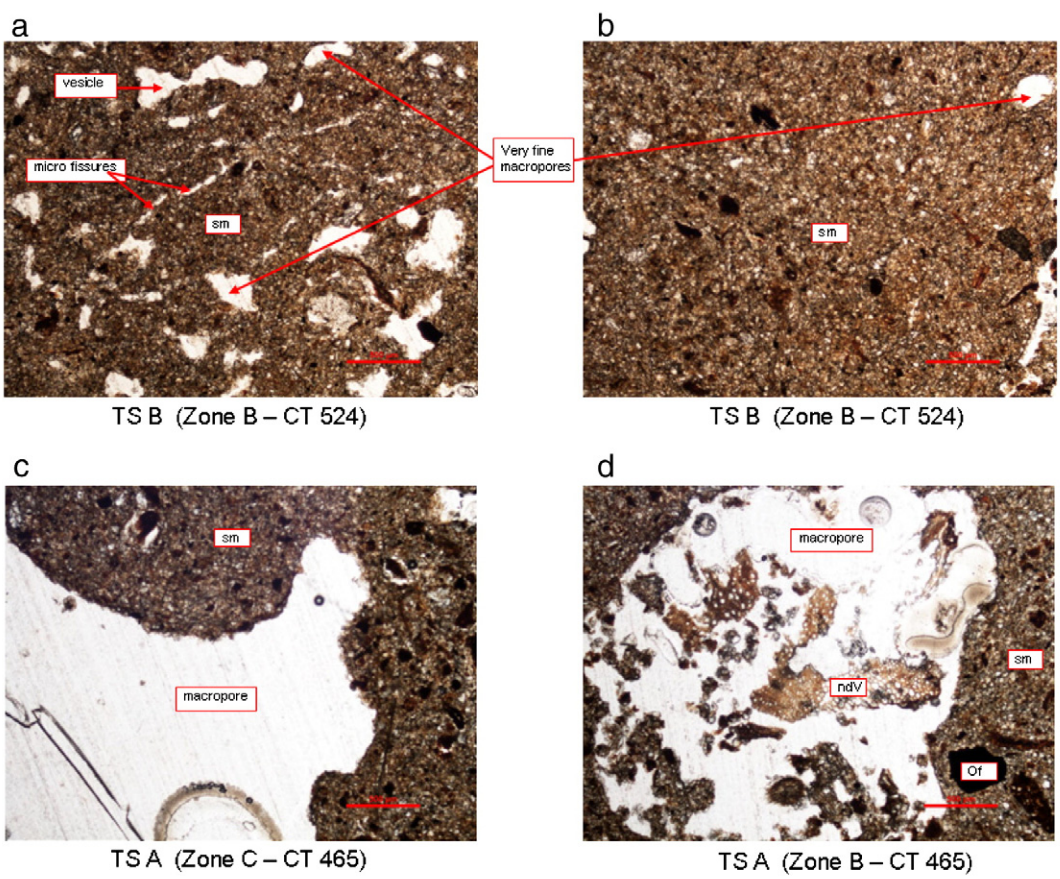

Fig. 1. Meso and macro-porosity pictured in thin-sections (TS) B and A, respectively. The size of the red bar is 500 μm. ndV stands for non-decomposed vegetal remains, Of stands for organic macro-fragments and sm stands for bulk soil matrix. References given in parenthesis indicate the corresponding X-ray CT cross-sections and the zone located herein (see Section 3.3 and Fig. 5). The images were pictured with a camera Nikon DS-Fi1.