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Micromorphological and X-ray µCT study of Orthic Humic Gleysols under different management conditions

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ABSTRACT

The aim of this study was to evaluate the spatial distribution of different void types and Fe–Mn oxide segregations in the A and B horizons of three Orthic Humic Gleysols from an uncultivated area and two long-time experimental plots – an unfertilized continuous maize plot and a fertilized maize–oats–alfalfa–alfalfa rotation plot – from Woodslee, Ontario. In view of the fact that numerous X-ray CT studies have obtained diverse results, in principal because of a different resolution of the analyzed CT imagery, the utilization of standardized classes in the quantification of similar features (e.g. soil pores) seems necessary in order to obtain comparable results. This X-ray study, performed on polished blocks, is an example of how µCT quantitative results related to volume and area of pores and Fe–Mn oxide segregations can be interpreted in connection with micromorphological characterizations of thin sections of the same samples, using typical micromorphological classes separated based on size and shapes of the analyzed features. Maximum pore volume values, noticed in the Ah horizon of the uncultivated soil and in the Bg horizon of the soil from the rotation plot, were considered an indication of a more favourable aero-hydric regime in these soils compared to the soil from the continuous maize plot. The lowest volumes of Fe–Mn oxides were found in the same horizons. Porosity and pore morphology have a clear influence in the evolution of redox processes and, implicitly, in the formation of typical redoximorphic pedofeatures in Gleysols. The thin-section analysis revealed that Fe–Mn nodules and concretions, as well as Fe depletion areas, were more frequent and better developed in the soil from the continuous maize plot than in the other soils. It was concluded that the examination of the soil features from the perspective of defined size and shape groups may represent a basis for a standardized spatial characterization of soil and for the interpretation of certain pedogenetic processes.

1. Introduction

Compared to the classical soil micromorphological analysis, X-ray computed tomography (hereafter referred to simplify as CT) offers a detailed qualitative and quantitative characterization of the spatial configuration of soil components. Interpretations of the three-dimensional (3D) organization of soil from sequential analyses of two-dimensional (2D) thin sections are in general inaccurate (Stoops, 2003). Quantitative characterization of the spatial arrangement of soil components in X-ray computed tomography imagery, combined with micromorphological observations of soil thin sections, provides valuable information on soil structure, porosity and pore characteristics. While discrimination of the various soil solid phases in CT imagery is relatively difficult, the visualization and quantification of pores and the pore network is facilitated by the strong contrast between the linear attenuation coefficients of the soil groundmass and voids, or between solid and gas (Mees et al., 2003).

The efficiency of CT in the investigation of void space has been tested on soil and rock cores by Anderson et al. (1990), Daniel et al. (1997), Farber et al. (2003) and Van Geet et al. (2003). Various properties related to pores and pore networks have been determined in CT studies: porosity and pore diameter (Anderson et al., 1990; Peyton et al., 1992; Rachman et al., 2005), pore perimeter and area (Grevers et al., 1989; Adderley et al., 2001; Gantzer and Anderson, 2002), circularity (Gantzer and Anderson, 2002; Rachman et al., 2005), tortuosity, hydraulic radius in three-dimensions, connectivity and numerical density of networks (Perret et al., 1999). As a practical application of CT analysis, structural changes of soil, determined by anthropogenic processes such as soil ploughing and compaction, and revealed by a general diminution of soil macroporosity and faunal activity, have been studied in CT imagery by Olsen and Børresen (1997), Wiermann et al. (2000), Gantzer and Anderson (2002), as well as Rogasik et al. (2003).

Technical advancements have led to improvements of CT systems resolution, beyond the limit of 1–2 mm, specific to the first medical imaging scanners (Gantzer and Anderson, 2002). It was demonstrated that the scanning resolution has a considerable influence in the number and size of detected pores, high-resolution systems representing an

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Table 1
Summary of micromorphological characteristics (a complete micromorphological description of these soils can be found in Taina and Heck, in review).

Profiles	Rotation, fertilized (P2)	Continuous maize, unfertilized (P5)	Uncultivated (P9)
Horizons	Ap	Ap	Ah
Depth	8–16 cm	14–24 cm	5–13 cm
Structure	Complex: porous with isolated channels (diameter φ~1–1.5 mm) and packing voids (0.8–3 mm); rare vertical or horizontal fissures (<0.5–1 mm wide), some delineating partially accommodated subangular polyhedral elements (2/4 mm);locally spongy, in areas with earthworm casts (φ<2–3 mm)	Complex: massive in the most part, with isolated vertical and horizontal fissures (0.05–0.08 mm wide); in some areas, subangular polyhedral with <4/6 mm elements, or *porous*, with rare horizontal or oblique root channels and earthworm burrows (φ<2 mm)	Complex: dominantly granular (2–3 mm) and subangular blocky, with partially accommodated elements (3/5 mm); aggregates are separated by a system of planar voids (~0.5–2 mm wide); porous with packing voids and root channels
Grade of pedality	Moderate–weak	Moderate–weak	Good
Estim. porosity	7.5–10%	≤7.5–10%	20%
Groundmass	*C/f* 4 µm ratio is 65:35. *C/f* related distribution: double and single-spaced porphyric; locally, chito-gefuric. B-fabric: stipple-speckled, locally undifferentiated; in clayey zoogenic aggregates, mosaic-speckled and grano-porostriated	*C/f* 4 µm ratio is 70:30. *C/f* related distribution: porphyric and locally monic and chito-gefuric. B-fabric: stipple-speckled; in clayey zones, mosaic-speckled to parallel-granostriated	*C/f* 4 µm ratio is 65:35. *C/f* related distribution: chito-gefuric, locally porphyric. B-fabric: stipple-speckled; in zoogenic aggregates with clayey material, mosaic-speckled or granostriated
Coarse mineral fraction	Min. grains: quartz, plagioclase feldspars, orthoclase, microcline, green hornblende, augite, muscovite, epidote, diopside, zoisite, kyanite, garnet and opaques; rare sand-sized rock fragments: granitoids, quartzo-feldspathic aggregates, cherts, sandstones; oxidized lithoclasts	Min. grains: quartz, plagioclase, microcline, green hornblende, augite, epidote, muscovite, weathered biotite, garnet, zircon, secondary chlorite and opaques; sand-sized rock fragments: quartzo-feldspathic aggregates and rare cherts, sandstones, amphibolites; oxidized lithoclasts	Min. grains: quartz, oligoclase–andesine, microcline, green hornblende, muscovite, augite, epidote, chlorite, zircon, garnet, aegirine, kyanite, zoisite and opaques; coarse sand or very coarse sand-sized rock fragments: quartz and quartzo-feldspathic aggregates; oxidized lithoclasts
Coarse organic fraction	Herbaceous roots; stem fragments in channels; opaque or semi-opaque plant fragments and fungi in the groundmass	Herbaceous roots in channels and planar voids; opaque or semi-opaque plant fragments and fungi in the groundmass.	Herbaceous roots in channels; semi-opaque or opaque plant fragments in the soil groundmass.
Fine fraction	Brown-colored humo-ferric clay; gray clay areas (earthworm excrements) with brown organic punctuations (4–6 µm — "humons")	Brown humo-ferric clay, with opaque, black–brown organic punctuations (≤6 µm); zones with grayish ± brown clay	Brown clay, pigmented with numerous opaque organic punctuations (4–6 µm) and ferric oxyhydroxides
Cryptocrystalline and amorphous pedofeatures	Fe mottles (≤1 × 1 mm); rare Fe nodules (φ ≤ 0.4 mm); Fe pseudomorphosis on pl. fragm.; hypo- or quasi-coatings along horiz. fissures	Ferric mottles (0.05 × 0.9 mm); Fe nodules (φ ≤ 0.6 mm); isolated Fe–Mn nodules; ferric quasi-coatings in some channel walls.	Rare Fe nodules (φ ≤ 0.05 mm); ferric mottles
Other pedofeatures	Textural: sandy–silty infillings of former root channels. Zoogenic aggregates produced by earthworms and mesofauna	Zoogenic aggregates. Fabric: alternating silty–sandy and silty–clayey bands. Mineral grain concentrations in the groundmass	Zoogenic aggregates. Textural: coarse mineral grain concentrations in some packing or planar voids
Horizons	Bg	Bg	Bg
Depth	22–33 cm	22–30 cm	35–43 cm
Structure	Complex: planar voids (0.05–3 mm wide); former short horizontal planar voids marked by b-fabrics; isolated angular–subang. blocky elements (<3/3 mm); rare channels (φ ≤ 1.2 mm); rare zoogenic aggr. (<1.5 mm in diam.)	Complex: frequent horizontal and vertical channels (φ~0.02–0.3 mm); zones with large polyhedral angular peds (10/20 mm), partially accommodated, delineated by planar voids (width < 0.5–1 mm)	Complex: angular blocky with accommodated elements (<5/7 mm), associated with a root channel and earthworm burrow (<2 mm in diameter) structure
Grade of pedality	Moderate–weak	Moderate–weak	Moderate
Estim. porosity	7.5%	<7.5%	10%
Groundmass	*C/f*: 60:40. *C/f* related distribution: single and double-spaced porphyric. B-fabric: cross and random-grano-porostriated (clayey areas) and stipple-speckled (ferric areas); parallel striated b-fabric (areas with inclusions of illuvial clay coatings in the groundmass)	*C/f* is 60:40. *C/f* related distribution: porphyric, locally chito-gefuric. B-fabric: stipple-speckled (areas with humic or ferric material), mosaic-speckled to parallel-grano-porostriated (zones with argillic fine material)	*C/f* is 60:40. *C/f* related distribution: porphyric ± chito-gefuric. B-fabric: stipple-speckled; locally, poro-grano-parallel striated, according to the quantity of clay minerals
Coarse mineral fraction	Mineral grains are similar to previous horizon, with the difference that biotite and tourmaline are present; rock fragments: quartz aggregates, cherts, sandstones, amphibolites with epidote	Quartz, plagioclase, microcline, green hornblende, muscovite, biotite, epidote, zoisite, kyanite, hypersthene, staurolite, zircon; rock fragm.: quartzo-feldspathic. aggr., cherts and shales; oxidized fragm.	Biotite, tourmaline and chalcedony are the only difference compared to previous horizon; rock fragments: quartz and quartzo-feldspathic aggregates, shales and cherts
Coarse organic fraction	Root fragments (in different decaying degrees) in channels or fissures; opaque plant fragments and fungi in the groundmass.	Slightly decomposed herbaceous roots in some channels; opaque plant fragments embedded in the humic groundmass.	Partially decomposed herbaceous roots; semi-opaque or opaque plant fragm. embedded in the groundmass.
Fine fraction	Gray–brown clay with organic punctuations; brown or red–brown ferric ± humic impregnations in the groundmass; gray clay material along planar voids	Transition from brown, humo-ferric clay, with organic punctuations, to light gray ± brown clay; red–brown Fe mottles in the groundmass	Gray ± brown clay with organic pigmentations; reddish-brown mottles with ferric clay ± humic fine material
Redoximorphic pedofeatures	Fe and Fe–Mn mottles (≤6 × 5 mm), Fe nod. (φ ≤ 0.15 mm); Fe–Mn nod. (≤ 1 mm); Fe pseudomorphosis on pl. fragm; Fe hypo-coatings around root channels. Fe depletions (≤0.15–0.3 mm thick) along planar voids or channels	Ferric mottles (≤10 × 5 mm); Fe nodules (φ ≤ 1.65 mm); Fe and Fe–Mn concretions (φ ≤ 4 mm); ferric quasi-coatings associated with channels and planar voids. Depletion pedofeatures along channel walls	Ferric mottles with inclusions of Fe or Fe–Mn nodules (φ ≤ 0.4 mm); red–orange or red–brown ferric concretions (φ ≤ 0.15 mm). Depletion pedofeatures along some channel and fissure walls
Other pedofeatures	Textural: illuvial clayey and Fe-clayey-siltic coatings on channel walls; old illuvial clay coatings embedded in the groundmass; concentr. of fine sandy–silty felsic min. particles along voids or in the groundmass. Zoogenic aggregates	Textural: isolated illuvial impure clay coatings on channel walls and around some mesofauna excrements; horiz. argillaceous bands with depositional aspect inside the groundmass. Zoogenic aggregates	Fabric: coarse mineral concentrations in the groundmass (disintegrated rock fragments or partial infillings of former planar voids). Zoogenic aggregates.