Structure investigation of soil aggregates treated with different organic matter using x-ray micro tomography

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Abstract: *Soil aggregation, which is favorable for plant growth, can be modified by the presence of organic matter; farmers thus often apply different materials to promote soil aggregation and enhance its stability. However, the relationship between the type of organic matter used and the resulting properties of the aggregate structure is unclear. Using high resolution micro x-ray computed tomography we investigated the internal structures of aggregates from fields to which a variety of organic material had been applied. The sampling sites are five paddy fields with rice-wheat rotations – four treated with different organic matters and one untreated control – in southwest Japan. The organic materials used were rice straw, rice straw manure, wheat straw, and livestock manure. The soils were classified as Endogleyic Hydragric Anthrosol (Clayic). Imaging samples were hand-picked from bulk soil samples collected in October 2008. Tomography experiments were conducted using an x-ray micro-focus instrument at the Helmholtz Centre Berlin for Materials and Energy; the instrument had a spatial resolution of approximately 5 µm. Organic substances, such as manure, root and seed, in the aggregates were observed. By thresholding the gray-scale of the images, it was possible to distinguish between porous and solid phases. These imaging studies indicated that applying manure to soils effectively increased the porosity of their intra-aggregates. Pores reaching from the core of the aggregate to their surfaces were observed in organic-matter-applied fields and sponge-like pores were identified in manure-fed fields. This suggests that differences in the organic- fertilizers used might affect the pore network within intra-aggregates.*

1 Introduction

Soil aggregation is favorable for plant growth as it enhances the aeration, water retention and permeability of the soil. Aggregated soil has a dual-pore system; the first pore

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system is present within each aggregate (intra-aggregate), while the second is located between adjacent aggregates (interaggregate). The interaggregate spaces or cavities are wider and thus play an important role in infiltration and aeration, whereas intra-aggregate pores are relatively narrow and aid in soil moisture retention after drainage. In the field, aggregate structures should be stable against wetting-drying, mechanical loads or tillage for long periods of time. The primary constituents of the aggregates are sand or silt-sized quartz particles, clay and organic matter; the organic polymers act as cementing agents. Aggregate properties are modified by the presence of organic matter, and by texture and land use. Farmers, therefore, often apply various kinds of organic matter in order to promote soil aggregation and to enhance its stability. However, the relationship between the application of different organic matters and the resulting aggregate structure is as yet unclear.

The x-ray computed tomography (CT) technique permits the non-destructive investigation and visualization of soil structure. Due to the progress in this technique, investigators have been able to analyze the detailed structure of the intra-aggregates. SLEUTEL *et al.* (2008) have been able to image a pore size of 1.7 - 2.5 µm, and CHUN *et al.* (2008) have analyzed the differences in the organization and distribution of pores within aggregates of different sizes and found that they can be hierarchical. We used x-ray CT to investigate the intra-aggregates from fields treated with a range of organic matters. Agricultural management was similar in all the sampling fields except for the one treated with organic matter.

2 Materials and methods

Materials

The aggregates were obtained from the research fields of the National Agricultural Research Center for Kyushu Okinawa Region, located in southwest Japan. The sampling sites were four rice-wheat rotation paddy fields treated with different organic fertilizers and one control rotation paddy field. The fertilizers used were rice straw (RS: 10 t ha^{-1}, since 1963), rice-straw manure (RM: 20 t ha^{-1}, since 1963), wheat straw (WS: 6 t ha^{-1}, since 1985) and livestock manure (LM: 50-60 t ha^{-1}, since 2006). The control farm field (Cont.) had not been treated with organic matter since 1963. After harvesting, plant residues were removed from the fields. Conventional chemical fertilizers were applied in all the fields, except for LM-applied field. The grain yields of the organic fertilizer applied fields were significantly higher than that of the control field. The soil in these fields was classified as Endogleyic Hydragric Anthrosol (Clayic) according to the World Reference Base for Soil Resource; the texture and clay minerals of the sample farm fields were similar because of they were located adjacent to each other. Bulk soil samples were collected in October 2008 and sieved through 2-mm screens. Aggregates were subsequently hand-picked from the soil that remained on the screen. For imaging, the aggregate samples were divided into 2 groups: D_1 and D_2 with diameter of 2-4 mm and 6-10 mm, respectively.

Methods

The tomography experiments were conducted using an X-ray micro-focus instrument at the Helmholtz Centre Berlin for Materials and Energy which utilizes a micro focus beam tube (Hamamatsu photonics K.K.; Hamamatsu City, Japan). In the cone beam geometry different magnification ratios could be used by change of the distance between the sample and the beam source; the maximal spatial resolution achieved was approximately 5 µm for the D_1 sample. Radiographs were collected at 0.36°-step interval during the 360° sample rotation by using a flat panel detector (Hamamatsu photonics K.K.). The tomographic reconstruction was performed by back-projection algorithm for cone beam geometry using the software package Octopus 8.3 (Ghent University). Images were processed using ImageJ 1.42 (National Institutes of Health).

3 Results and discussion

Fibrous material could be distinguished in some CT cross-sections (**Figure 1a**). These types of substances were frequently observed in samples from manure-fed fields (RM and LM), but rarely in the samples from the control field. Hence, they could be some components of the manure. Some CT cross-sections showed plant residues, which could be identified from their features (**Figure 1b, c**). However, it was not possible to locate the organic matter complexed with minerals, a configuration that could have helped enhancing the long term stability of the aggregates.

After removing noise from the CT cross-section images by using a median filter (radius 2 pixels), the images were segmented between porous and solid-phase soil with a gray-level threshold of 8000, the lower limit of gray-level for visible organic substances. Nine representative cross-sections were selected each for 2 D_1 samples, and the porosity (the ratio of pore phase area to the total area of aggregate) was calculated. Pore segments having less than 20 µm diameter were neglected, since individual pores smaller than this were difficult to discern. The average porosities of Cont., RS, WS, RM, and LM soils were 1.4 ±1.4%, 3.1 ±2.6%, 1.7 ±0.9%, 2.6 ±2.0%, and 3.5 ±1.8%, respectively. This indicates that applying manure probably increases intra-aggregate porosity. The capillary suction of soils with a pore size of 20 µm, calculated from the capillarity formula, is 15 kPa (=pF2.2). Plants can easily take up water from soils if the suction is below pF2.7. Hence, if the pores in the D_1 aggregates were connected to inter-aggregate networks (i.e. if the water supply to them could be maintained), then the water trapped within them could be used to sustain plant growth.

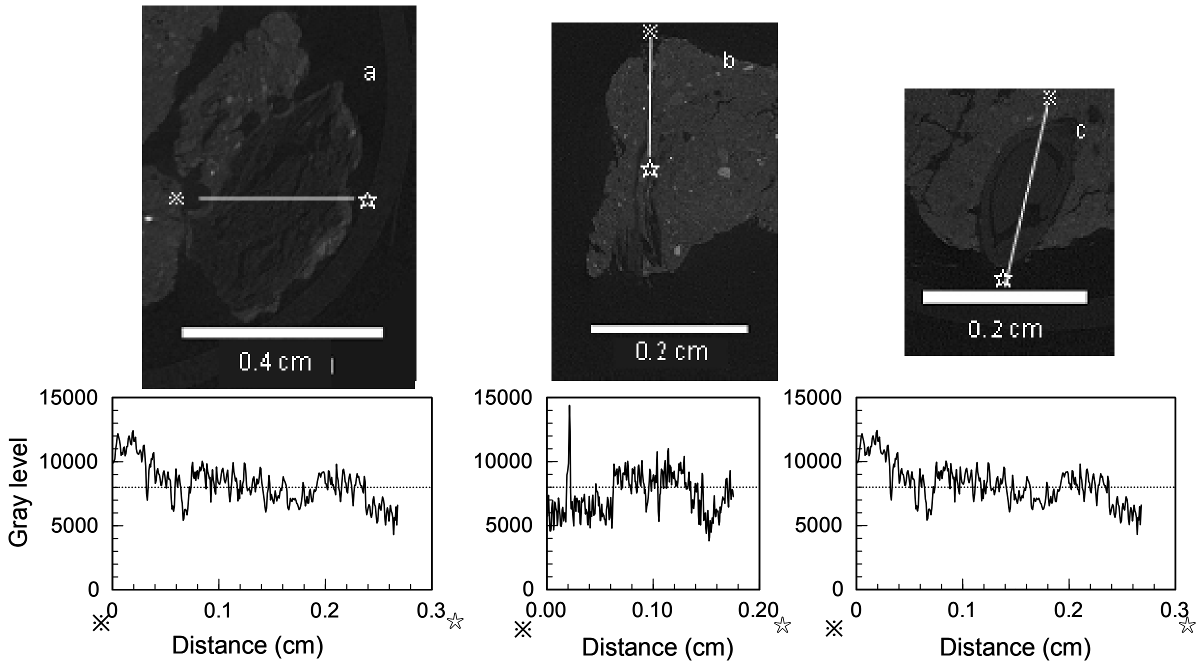

Figure 1: Representative images of organic materials found in the aggregates: (a) livestock manure, (b) root, (c) seed. The plots show the gray level profile along with the white lines.

The D_2 aggregates reflected the difference in sampling fields more clearly in another aspect (**Figure 2**). In soil aggregates from manure-fed fields, especially from the LM field, sponge-like pores could be detected, which generally are more effective in water retention. In organic fertilizer-fed fields, elongated pores that connect the cores of aggregates with the surface were observed. PAPADOPOULOS *et al.* (2009) concluded that such connecting pores help in maintaining the structural stability of the aggregate because they could act as escape routes for entrapped air thus avoiding the slacking of aggregates. In samples from the control field, the elongated and the sponge-like pores were rarely observed. Hence, it can be assumed that the peds from the control field which at best resembled aggregates were only fragments from soil blocks rather than true “aggregates”, although the difference among them could not be judged solely from their surfaces.

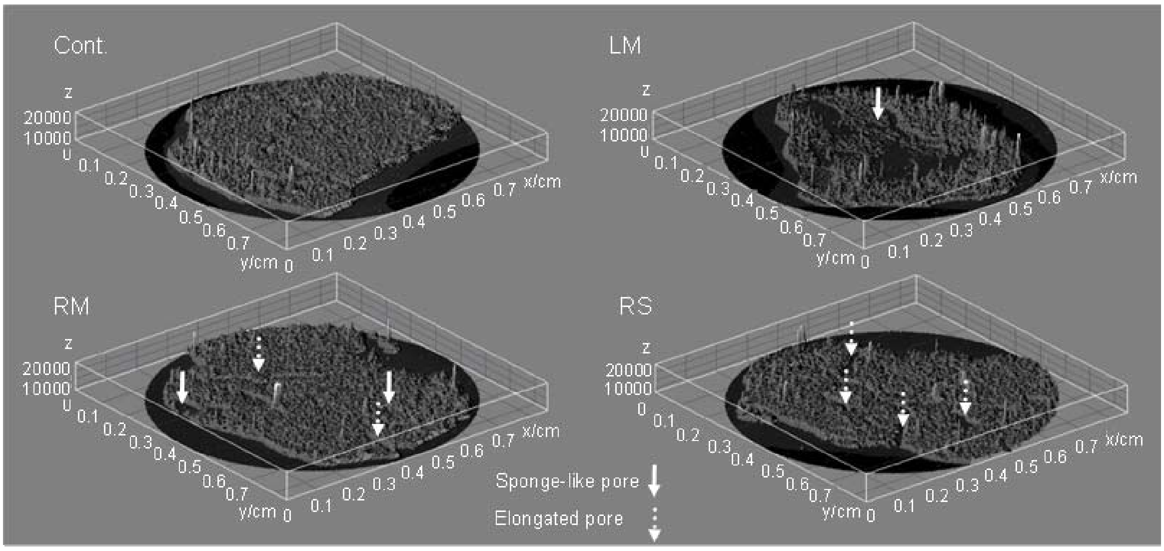

Figure 2: 3D surface-plots of selected porous CT cross-section images of D_2 aggregates constructed with ImageJ (Gridsize:256, Smoothing:0, Lighting:0.25).

4 Conclusions

Using micro x-ray CT tomography, intra-aggregate pore formation in soils from fields fed with different organic fertilizers was compared. Organic matter, especially manure-based matter, increased porosity of the intra-aggregate. Pores that connected the core of the aggregates with the surface were observed in organic matter-applied fields and sponge-like pores were observed in manure-fed fields. Future studies will focus on the shape of these pores, and analyze the effect of each organic fertilizer on the pore network or its structural hierarchy.

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