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# Effect of different tillage systems on aggregate structure and inner distribution of organic carbon

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ABSTRACT

Tillage is a common agricultural practice affecting soil structure and biogeochemistry. Pore network geometries are crucial to oxygen concentration, gas diffusivity, water location and water movement. Soil aggregates, 4–6 mm in diameter and collected from silty loam in Belgium and sandy loam in China, were scanned using a micro-computed tomography scanner. Images with a pixel size of 6.9 μm were then processed with ImageJ software for pore network analysis. The treatments were no tillage (C-NT) and conventional tillage (C-CT) in China, and shallow tillage (G-ST) and conventional tillage (G-CT) in Belgium. The results showed that aggregates in conservational tillage (G-ST and C-NT) had numerous connected pores compared with conventional tillage (G-CT and C-CT). The Euler number (Ev) was significantly lower and visible total porosity and surface area (SA) were significantly higher in conservational tillage (G-ST and C-NT) than in conventional tillage (G-CT and C-CT) in both studied locations.

The predominant size of pores was significantly higher in conservational tillage (G-ST and C-NT) than in conventional tillage (G-CT and C-CT) (>150 μm vs 90–120 μm). Pore location within the aggregates also showed differences, with porosity being evenly distributed in the aggregates under conventional tillage (G-CT and C-CT). Under conservational tillage (G-ST and C-NT), the aggregates were heterogeneous, showing higher porosity at the center of the aggregates. There was a higher soil organic carbon (SOC) content in the external layer than in the internal layer in conservational tillage in Belgium (G-ST). In no tillage in China (C-NT), the SOC in the external and internal layers, however, showed similar results.

Overall, conventional tillage (G-CT and C-CT) reduced the proportion of the largest pores within soil aggregates, whereas there was no significant relationship between pore morphologies and SOC content. Further investigation is required to measure the active and slow carbon pool distribution in the different layers and under different tillage practices.



## 1. Introduction

The management of agricultural systems is known to affect soil quality and structure through tillage, fertilization and other practices (Madari et al., 2005). Soil aggregates, especially macro-aggregates, have been widely used to evaluate soil quality and the response of soil to agronomic management and environmental change (Six et al., 1999;Yu et al., 2016). Recently, attention has been paid to soil organic carbon (SOC) levels within soil aggregates as a potential C sink. This sequestration may be a result of intra-aggregate structuration under different tillage practices (Smucker et al., 2007).

Structure plays a role in oxygen concentration, gas diffusivity, water location and water movement. All these variables control the pedoclimatic conditions in which the microorganisms develop (Lützow et al., 2006; Grandy and Robertson, 2007). The pore structure of macro-aggregates, however, is difficult to measure because of the lack of efficient measurements on an aggregate scale (Wang et al., 2011). In recent years, X-ray computed tomography has shown considerable promise in the non-destructive exploration of soil structure in 3D at different scales (Young et al., 2001;Peth et al., 2008). Some studies have scanned soil cores from 3 to 20 cm with a 15–500 μm resolution in order to visualize and quantify macro-pore characteristics and thus predict soil hydro-geochemical functions (Katuwal et al., 2015; Bottinelli et al., 2016). X-ray computed micro-tomography could produce high-resolution images and detect the microstructure changes in soil aggregates. Peth et al. (2008) applied synchrotron radiation micro-computed tomography (SR-μCT) and characterized the pore

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morphology and networks of two contrasting soil aggregates (5 mm) at a resolution of 5.4 μm by subtracting a sub-volume of aggregates at a micro-scale. Kravchenko et al. (2011) scanned 4–6 mm aggregates to study the effect of long-term tillage and land-use differences on intra-aggregate pore heterogeneity. Six et al. (2000a) found that tillage could induce a loss of C-rich macro-aggregates and a gain of C-depleted micro-aggregates; macro-aggregate turnover was greatly reduced under no tillage (NT), promoting the formation of C-enriched micro-aggregates within macro-aggregates. In X-ray research, there has been growing interest in studying the relationship between SOC and pore structure in order to evaluate soil quality within macro-aggregates (Six et al., 2000a; Lal, 2004; Blanco-Canqui and Lal, 2004). Research has found that some differences related to SOC affect not only aggregate size distribution and aggregate stability, but also intra-aggregate structure (Kravchenko et al., 2011). Therefore, understanding how an aggregate stores and protects SOC is essential in order to develop appropriate management practices for enhancing SOC sequestration (Blanco-Canqui and Lal, 2004).

Previous studies have examined soil properties within aggregates at a small scale and found differences between the internal and external layers (Table 1) (Jasinska et al., 2006; Urbanek et al., 2007; Ananyeva et al., 2013). Ananyeva et al. (2013) evaluated SOC in macro-aggregates from two sites with contrasting land management styles. They reported that aggregate interiors tended to have lower SOC than the aggregate exteriors. Other researchers (Urbanek et al., 2007), however, found that there was no SOC gradient within aggregates in arable soil under different tillage systems. Jasinska et al. (2006) found higher SOC concentration in the internal layer than in the external layer of forest soil aggregates, but no difference in that of arable soils. Currently, there is neither a generally accepted understanding of SOC distribution within soil aggregates, nor an understanding of the mechanisms that link it to differences in tillage practices.

The aim of this study was to investigate the relationship between pore morphology and SOC content from different tillage systems (conservational tillage and conventional tillage) in two locations, Belgium and China. We used X-ray computed micro-tomography and we hypothesized that: (1) SOC content differences between aggregate layers varied with different tillage practices; (2) different management practices could result in differences in aggregate pore distribution; and (3) these differences in pore-geometries within macro-aggregates are related to SOC distribution.

## 2. Materials and methods

### 2.1. Experimental site

The study was conducted at two long-term experiment locations with two soil types (Table 2) in the eastern part of the Chinese Loess Plateau (sandy loam soil) and the center of Belgium (silty loam soil).

The first experiment was set up in 1999 near the city of Luoyang, China (113°00′ E longitude, 34°54′ N latitude). The site (324 m altitude) has a warm temperate continental climate, with an average annual rainfall of 546 mm and a temperature average of 13.8 °C. Two treatments were used in this study: no tillage (C-NT) and conventional tillage (C-CT). In C-NT, 30 cm tall stubble remains on the field after harvest (25 May–1 June) and straw is returned to the field after threshing. Also, in C-NT there is no ploughing. In C-CT, 10–15 cm long stubble remains on the field after harvest (25 May–1 June). Straw and ears are removed from the plot at harvest. In C-CT, the soil is ploughed twice a year and turned at a depth of 20 cm, initially in the first week of July and then on about 1 October just before sowing. Winter wheat is sown on about 5 October, with chemical fertilizer (N: 105 kg/ha, $P_2O_5$: 105 kg/ha, $K_2O$: 45 kg/ha) being incorporated at the same time, followed by harrowing (seed bed preparation, 5–8 cm).

The second experiment was established in 2008 in the city of Gembloux, Belgium (4°42′ E longitude, 50°33′ N latitude). The site (161 m altitude) has a temperate marine climate, with an average annual temperature of 9.8 °C and an average annual precipitation of 856 mm. The two treatments were shallow tillage (G-ST) and conventional tillage (G-CT). In G-ST, 30 cm tall stubble remains on the field after harvest (25 May–1 June) and straw is returned to the field after threshing. In G-CT, 10–15 cm long stubble remains on the field after harvest. Straw and ears are removed from the plot at harvest. In G-ST, the soil is tilled once a year before sowing to a depth of 5 cm. In G-CT, the soil is ploughed once in a year before sowing to a depth of 25 cm. Organic fertilizer (N: 170 kg/ha) is incorporated in both these treatments.

**Table 1**
Soil organic carbon in different layers reported by other studies.

| | Soil texture | Land use | Soil organic carbon | |
|---|---|---|---|---|
| | | | Internal layer | External layer |
| Ananyeva et al., 2013 | Fine loam | Conventional tillage | ns | ns |
| | | Conservational tillage | ns | [a] |
| Jasinska et al., 2006 | Silty loam | Conventional tillage | ns | ns |
| | | Conservational tillage | ns | ns |
| | Sandy | Forest | [a] | ns |
| Urbanek et al., 2007 | Silty loam | Conventional tillage | ns | ns |

Note: ns = not significant at the 0.05 probability level.
[a] Significance higher at the 0.05 probability level.

**Table 2**
Soil characteristics at the experiment station.

| Location | Particle composition (%) | | | Soil texture | CEC (cmol/kg) | Fertilization |
|---|---|---|---|---|---|---|
| | Clay | Silt | Sand | | | |
| China (Luoyang) | 15.2 | 24.3 | 60.5 | Sandy loam | 4.02 | Chemical |
| Belgium (Gembloux) | 14.0 | 78.7 | 7.3 | Silty loam | 14.64 | Organic |

### 2.2. Sampling

At each site, six sampling locations were selected randomly. Soil samples were collected from 0 to 10 cm in China and 5–10 cm in Belgium with 40 mm PVC tubes (40 mm diameter × 55 mm long and 3 mm thick). The intact core samples, after transportation, were sealed and stored at 4 °C in order to minimize microbial transformation. The samples were crushed by hand along the natural planes of weakness. The crushed soil was air-dried and then sieved to retain the macro-aggregates that were 4–6 mm in diameter. This size of aggregate was a compromise taking into account both the stability of the aggregate and the potential resolution in X-ray computed tomography scanning (Ananyeva et al., 2013). The selected aggregates were oven-dried at 40 °C for 24 h (Zhou et al., 2013) and stored in air-tight containers at room temperature.

### 2.3. Data acquisition and image reconstruction

Aggregate samples were scanned using skyscan-1172 high-resolution desktop micro-computed tomography (Bruker, Belgium) at the Applied Chemistry Laboratory of the University of Liege. The scanner was set at 100 kV/100 μA. An aluminum/copper (0.5 mm/0.04 mm) filter was positioned between the aggregate and the detector to minimize beam hardening artefacts. 2D image slices were collected during a 180° rotation at 0.2° angular incremental steps and combined into a 3D image consisting of 980 slices with 1332 × 1620 pixels per slice, the pixel size being 6.95 μm. Nine 4–6.3 mm aggregates were selected from each soil for the micro-computed tomography study. Given the resolution limit, only pores larger than 6.95 μm were recognized. The size of the file made it necessary to reduce the resolution by resampling the images to a pixel size of 14 μm, the minimum size of pores that can be analyzed.