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Transition from intensive tillage to no-till enhances carbon sequestration in microaggregates of surface soil in the North China Plain

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ABSTRACT

Physical protection by soil aggregates is critical for building soil organic carbon (SOC) stock. The objective of this study was to identify SOC sequestrated in the microaggregate holding within macroaggregte (mM) fraction after shifting tillage systems in the North China Plain. Soil samples from 0–5 cm layer of a 6-yr field experiment (MP − R, moldboard plow without residue; MP + R, moldboard plow with residue; RT, rotary tillage with residue; NT, no-till with residue) were collected and separated into different water-stable aggregates. The macroaggregate (250–2000 μm) was further isolated into intra-aggregate particulate organic matter (iPOM) fractions by density flotation, dispersion and sieving. The results showed that the SOC concentration of fine iPOM (250f, 53–250 μm) was increased by 23% in RT and 39% in NT compared with MP + R, whereas the difference in the coarse iPOM (250c, >250 μm) was not observed. The ratio of 250f–250c (i.e., 250f/250c) followed the order of NT (2.12) ≈ RT (1.94) > MP + R (1.50) ≈ MP − R (1.47), indicating the alternative tillage systems decreased the turnover rates of macroaggregates. Adoption of NT and RT improved the mM formation by 36% and 23% and mM associated C concentration by 38% and 31% as relative to MP + R system. Additionally, the soil C concentration and storage of the iPOM and silt plus clay fractions located within the microaggregate were higher under NT and RT than that of MP + R and MP − R systems. Thus applying NT and RT improved mM formation and soil C sequestered inside this fraction. We concluded that adoption of NT and RT enhanced SOC sequestration in the microaggregates of surface soil of the intensive agroecosystem of North China.

1. Introduction

Application of no-till management in croplands has been considered as a way to sequester soil organic carbon (SOC) in the surface soil (West and Post, 2002; Angers and Eriksen-Hamel, 2008). This stratification of SOC in the top layer is consistent with the soil aggregate turnover model proposed by Six et al. (2000). Some studies have suggested that the decreased SOC stock coupled with the decreased macro-aggregates due to mechanical disruption under intensive tillage (Zotarelli et al., 2007; Six and Paustian, 2014). Regarding the role of soil physical structure in determining SOC stabilization, identifying the soil C pools involved in stabilization mechanisms is a key element to reliably assessing soil C dynamics (Christensen, 2001; von Lutzow et al., 2007).

Analyses of soil physical structure are usually conducted using physical fractionation techniques such as particle size and density to elucidate mechanisms involved in SOC stabilization (Cambardella and Elliott, 1993; Christensen, 2001). These approaches produce results that are good indicators for changes of soil management (Nascente et al., 2013). Aggregate formation in soils is regarded to be an important process in SOC stabilization (Tisdall and Oades, 1982; Blanco-Canqui and Lal, 2004), which is based on the separation of free light fractions and protected fractions that are occluded in secondary organo-mineral assemblages of different sizes (von Lutzow et al., 2007). The macroaggregates could be further fractionated into sub-structural elements, including intra-aggregate particulate organic matter (iPOM), macroaggregate-derived microaggregates (mM), and silt plus clay fraction (Tisdall and Oades, 1982; Golchin et al., 1994). The iPOM fraction contained within a macroaggregate could become a location of microaggregate formation within the macroaggregate (Oades, 1984). In the cultivated systems, Six et al. (1999, 2000) proposed a

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model of aggregate turnover in which increased physical disturbance led to a breakup of macroaggregates, which exposed iPOM fractions to the microbial decomposition. Additionally, the mM fraction is regarded as key microsite for physical protection of SOC in the long term (Six et al., 2000; Denef et al., 2004; Zotarelli et al., 2007). The accretion of SOC within mM fraction could be used as an early indication of C sequestration for changes in total SOC pool (Denef et al., 2007; Six and Paustian, 2014). To quantitatively evaluate the soil C sequestration in this fraction under tillage systems could help elucidate mechanisms of soil C stabilization in specific cropping system.

The North China Plain (NCP), with winter wheat–summer corn double cropping as the typical system, is characterized by high annual fertilizer inputs, intensive water use from irrigation of winter wheat, and high crop yields. Traditional agricultural practices included moldboard plow and straw removal, which have led to SOC loss and thus the degradation of soil quality (Qin et al., 2010). During the last two decades, conservation tillage system (i.e., no-till and rotary tillage) has been gradually adopted by the local farmers due to economic benefit and soil conservation (Hou et al., 2012). To date, challenges still remain for understanding the full influence of no-till adoption on SOC stabilization, such as changes in C preservation through soil aggregates. We hypothesized that the transition from intensive tillage to no-till system would promote microaggregate formation holding within macroaggregte (mM), resulting in greater soil C accumulation in the mM fraction. The objectives of this study were (i) to use physical fractionation methods to isolate the light fraction, coarse and fine iPOM, and mineral-associated fraction; and (ii) to analyze the changes in tillage systems on the sequestration of SOC in microaggregates formed within macroaggregates.

2. Materials and methods

2.1. Site description

The study was conducted at the Luancheng Agroecosystem Experimental Station (37°53′N, 114°41′E, elevation 50 m) of the Chinese Academy of Sciences, located in the Piedmont region of the Taihang Mountains of the NCP. The average annual air temperature is about 12 °C, and annual precipitation is about 536 mm with 70% falling from July to September. The soil texture is silt loam (13.8% sand, 66.3% silt, and 19.9% clay) (an Argic Rusty Ustic Cambisols, Gong, 1999). Winter wheat (early October–early June) and corn (mid-June–later September) double cropping is the prevalent agricultural system in the region. Depending on rainfall availability, three or four irrigations (40–50 mm each time) were applied for wheat and corn with a sprinkler system.

2.2. Experimental design and management

Prior to the experiment, moldboard plow had been practiced for many years in the study site: soil was tilled to a depth about 18 cm, followed by a sequence of harrowing, smoothing, and rolling. The experiment was established in the winter wheat season in 2001. Initially, there were three tillage systems: (i) moldboard plow with corn residue (MP + R) chopped into small pieces (5–10 cm long) and incorporated into soil using a moldboard plow, with a tillage depth about 18 cm, and winter wheat seeding and fertilizer application were accomplished simultaneously using a conventional seeder (15 cm row spacing and 3–5 cm seeding depth); (ii) rotary tillage (RT) with corn residues chopped and mixed with soil to a depth of 10 cm using a rotary tiller, and winter wheat seeding and fertilizer placement were completed using the same seeder as in MP + R; (iii) no-till (NT) where winter wheat was seeded into standing corn stubble using a paired-row no-till wheat seeder (20 cm between pairs, 10 cm between rows, and 3–5 cm seeding depth) and chemical fertilizers were applied simultaneously. There were three replications per treatment, and the plot size was 16 m by 70 m. In 2004, the MP + R treatment was split into two sub-treatments: half of the plot with corn residue incorporated (the original MP + R design) and the half with corn residue removed (MP − R). No treatment was imposed on summer corn crops, and corn was planted into wheat stubble (15–20 cm in height) after winter wheat harvest.

2.3. Soil sampling

Soil samples were collected from the 0–5 cm layer in June of 2007. Three soil cores per plot (the locations were determined randomly) were collected using a hand auger (4.1-cm diameter) and pooled together to make a composite sample. The samples were brought to laboratory and air-dried at room temperature. A portion of the sample was sieved through a 0.25-mm sieve for determination of bulk SOC concentration. Additional triplicate soil cores were taken using a stainless steel ring (5-cm high and 5-cm in diameter) for the determination of bulk density (Grossman and Reinsch, 2002). For determination of aggregate distribution, undisturbed cores were collected from the 0–5 cm depth. For each replication, two intact soil cores were collected and transferred to plastic bags. These samples were gently broken by hand and passed through an 8-mm sieve and then air dried in the laboratory,

2.4. Aggregate separation and isolation of soil carbon fractions

The procedures described by Elliott (1986) were used for aggregates separation through moist sieving to yield four classes (i.e., >2000, 250–2000, 53–250, and <53 μm). In this study, only the macroaggregate (250–2000 μm) was further fractionated into kinds of fractions. A sequential density fractionation, adapted from Six et al. (1998) was used to determine the free light fraction (LF) and light fraction occluded inside aggregates (Fig. 1). Briefly, a 5 g sample was placed in a 50 mL centrifuge tube and 35 mL of NaI

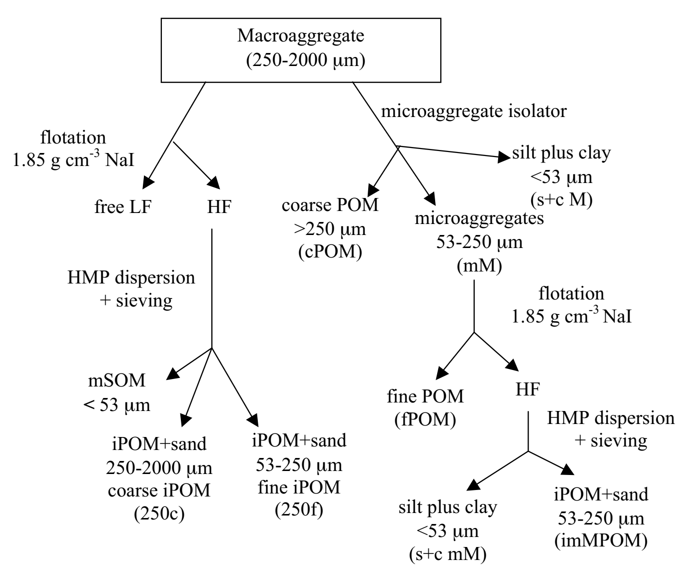

Fig. 1. Physical fractionation scheme to isolate different fractions (modified from Six et al., 2002). LF, light fraction (lighter than 1.85 g cm^{-3}); HF, heavy fraction; HMP, hexametaphosphate; mSOM, mineral associated soil organic matter; 250c, coarse intra-aggregate particulate organic matter (>250–2000 μm); 250f, fine intra-aggregate particulate organic matter (53–250 μm); cPOM, coarse particulate organic matter (>250 μm); s + c M, silt plus clay fraction within macroaggregates (<53 μm); mM, microaggregates within macroaggregates (53–250 μm); fPOM, fine inter-microaggregate POM (<250 μm); imMPOM, fine intra-microaggregate POM within macroaggregates (53–250 μm); s + c mM, silt plus clay fraction within microaggregates occluded within macroaggregates (<53 μm).