Impact of land use change on profile distributions of organic carbon fractions in peat and mineral soils in Northeast China

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A B S T R A C T

The impact of land use on the content of labile soil organic carbon (SOC) has been studied well. However, limited information is known about its effect on the recalcitrant SOC pool, which is a key proxy for long-term carbon sequestration. We investigated the impact of land use change on the distribution of labile and recalcitrant SOC fractions in soil profiles (0–30 cm) in the Jinchuan peatland, Northeast China, where native peatland (with peat soil) and forest (with mineral soil) are converted to paddy and cropland, respectively. Peat and mineral soil profile samples were collected from 10 sites in native and cultivated land. Total organic carbon (TOC) and KMnO$_4$-oxidizable carbon (KOC) defined as the labile SOC fraction were measured in both peat and mineral soils. Fibre and lignin were also determined in peat samples. The mineral-associated organic carbon (MOC) and black carbon were examined as two recalcitrant SOC fractions. In peat soil profiles, the TOC and KOC contents increased with the increasing depth across all land uses. The conversion of peatland to paddy field can affect TOC content at each peat soil depth. The KOC content was lower in cultivated soils, indicating that cultivation decreased KOC. The KOC decrease was smaller than the TOC decrease, indicating that some recalcitrant SOC fractions were decomposed because of land use change. Unlike peat soil profiles, the TOC and KOC contents decreased with depth in mineral soil profiles across all land uses. The TOC and KOC contents in surface soil decreased remarkably after cultivation to cropland but were not affected in deep soil. Interestingly, recalcitrant SOC fractions, such as MOC, increased in mineral soil profile after cultivation but showed no change in peat soil profile. This study suggests that conversion of peatland to paddy can release the recalcitrant SOC fraction. In addition, conversion of cultivated forest to cropland decreased the TOC content but prolonged the long-term storage of some recalcitrant SOC fractions, such as MOC.

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1. Introduction

Soil organic carbon (SOC) is the largest carbon pool on Earth. The approximately 1500 Pg C in the top 1 m of soil is about twice the carbon content of the atmosphere (Lal, 2008; Debasish-Saha et al., 2014). Peat soil covers only 3% of land surface but contains about one third of the total SOC reserve (Chasar et al., 2000). The accumulation and circulation of SOC affects global carbon cycling and atmospheric carbon content (Zhang et al., 2014). The atmospheric carbon pool is increasing at a rate of 3.5 Pg C year^{-1} (Lal, 2008). The SOC pool contributes approximately 1.6 Pg C per year to the atmospheric carbon pool through deforestation, biomass burning, wetland drainage, and soil cultivation (Tan et al., 2014). Thus, a small change in the SOC stock can affect atmospheric carbon dynamics and influence global climate change (Lal, 1997; Ma et al., 2016).

Many factors affect SOC storage (Jobbágy and Jackson, 2000; Bronick and Lal, 2005; Bragazza et al., 2006; Xiong et al., 2014). For example, reactive nitrogen, produced from industrial and agricultural sources, can decrease the decomposition of native SOC (Ni et al., 2012). Moreover, the SOC content depends on inorganic particles because SOC can be preserved by association with minerals or aggregates (Mastrolonardo et al., 2015; Rumpel et al., 2015). The impact of climate change on SOC stock is not yet clear (Dorrepaal et al., 2009; Xiong et al., 2014; van Groenigen et al., 2014), but may be important. Temperature increases carbon fixation and SOC decomposition in humid climate zones, whereas precipitation constrains plant growth (carbon inputs) and SOC decomposition in arid regions. The impact of land use on SOC stocks has gained increased concern during recent decades. Converting land with natural landscape (i.e., peatland, forest, and grassland) to cropland reduces SOC in tropical and temperate humid regions (Dinesh et al., 2003; Ostle et al., 2009). In contrast, the SOC content can increase when natural land (i.e., desert

and shrub) is converted into cropland in arid and semi-arid areas (Cochran et al., 2007; Fallahzade and Hajabbasi, 2012). Therefore, SOC changes in response to land use change may depend on regional climate and types of human activity.

SOC stability also influences SOC storage (Krull et al., 2003). SOC can be generally divided into labile and recalcitrant pools based on their molecular structures. The labile pool, such as carbohydrate and protein, is rapidly metabolized and sensitive to physical and chemical disturbances, such as land use change and management activities (Sharma et al., 2014; Wang et al., 2014). Although the labile fraction accounts for only a small part of SOC (Conteh et al., 1999; Haubensak et al., 2002), its reduction is considered the major reason for total organic carbon (TOC) decreases after cultivation. By contrast, the dominant portion of SOC is the recalcitrant pool (Song et al., 2012), which is protected by chemically innate recalcitrance (Mikutta et al., 2006). For example, lignin is considered a recalcitrant SOC fraction in soils because of its non-hydrolyzable C—O—C and C—C bonds and the abundance of aromatic structures (Kiem and Kögel-Knabner, 2003). Therefore, recalcitrant organic carbon may indicate long-term carbon sequestration, since labile carbon is decomposed rapidly (Gulde et al., 2008). Many studies have considered recalcitrant SOC fractions under different land uses (Maia et al., 2010; Zhao et al., 2014). However, most studies separated the recalcitrant SOC fractions on the basis of their molecular structures. Many studies have challenged the dominant role of molecular structure in SOC (Han et al., 2016). For example, carbohydrates with labile molecular structure can persist in soils for a long term through association with minerals (Kiem and Kögel-Knabner, 2003). Some recalcitrant SOC fractions should be studied further because they can be decomposed to CO_2 under favorable conditions (Han et al., 2016). Recalcitrant SOC fractions protected by physical interactions with minerals and occlusion in aggregates should also be studied further.

The Jinchuan peatland in Northeast China, an important food-producing area in China, has undergone transition from native to cultivated land since the 1960s. Peatland and forests in this region have been converted gradually to paddy and croplands throughout this period. The main types of soils in this area are mineral and peat soil. The peat soils of this study are comprised mainly of undecomposed root litter and half-decomposed root litter due to the wet environments. The mineral soils, known also as fuscous soil, are mostly mineral material with <5% organic carbon. We evaluate the effect of land use change on the organic carbon fractions in different types of soil profiles in this area.

2. Materials and methods

2.1. Study area

The Jinchuan peatland is located in the foothills west of Changbai Mountain, Northeast China. Jinchuan peatland is based on a volcano landform and possesses a nearly circular outline. The forest occurs upland and around the peatland. The annual average temperature and precipitation are 4.1 °C and 704.2 mm, respectively. This area, an important food-producing area in China, has been transformed from native to cultivated land (typical crops are corn and rice) since the 1960s. Commonly, peatland is converted to paddy, and forest is converted to paddy or cropland, depending on the groundwater level. The peatland has been protected since 2004, thus no obvious drainage is observed in the peatland. People pump water from peatlands to water paddies nearby. An anthropogenic channel branches from the upstream of rivers that go through respective peatlands. These channels can also provide water to croplands away from the peatlands and reduce the water supply to peatlands by rivers. Generally, Jinchuan peatland suffers from seasonal waterlogging with the highest groundwater level of − 5 cm in July and August, but there is no obvious surface runoff in irrigation period because of pumping water from peatland to cropland. The study area (126°21′–126°22′E, 42°21′–42°22′N) includes the peatland, forest, and croplands (Fig. 1). Highly mechanized and conventional tillage are

prevalent in this area. Routine tillage practices involve moldboard plowing, ridging, seeding, and tamping in April, foliage fertilization in summer and reaping and removing residue by burning in October.

2.2. Sample collection

Soil samples were collected in June 2014 from peatland (three sites), rice paddy (three sites), cornfield (three sites), and forest (one site), with duplicate random samples for each site (Fig. 1).

All soil samples were obtained from the top 30 cm depth because the impact of cultivation on SOC occurred mainly in the 0–20 cm soil depth (Liu et al., 2014). The peat soil cores were collected from sites 1 to 5 by a Russian peat corer (diameter, 15 cm), underneath with 50 cm intervals; afterward, these cores were sectioned further into three layers: 0–10, 10–20, and 20–30 cm. Mineral soils were collected from a soil pit at three depths: 0–5, 5–20, and 20–30 cm. A shallow topsoil sample was obtained from mineral soil because organic matter in mineral soil at 0–5 cm depth was affected considerably by plant litter and roots. Duplicated samples were collected from the same depth at each site were mixed completely. All samples were air dried and ground homogeneously. Peat soils were passed through a 1 mm sieve, and mineral soils were passed through a 0.25 mm sieve. All treated samples were placed in a drying vessel until further analysis.

2.3. TOC and total nitrogen analysis

Sufficient 1 M HCl was added to 1–2 g of air-dried soils to cover the soils, and the samples were left until no bubbles were generated. This process was repeated three times to remove all of the carbonates. Subsequently, the soil samples were dried at 60 °C for 12 h to remove water. About 50 mg of the soil sample was weighed and analyzed in a CHN elemental analyzer to determine the TOC content and total nitrogen in the soils (Hedges and Stern, 1984).

2.4. Fibre and lignin content analysis

Fibers and lignins were measured by Cellulose analyzer (Fibertec M6, Sweden). Dried samples were weighed (ca. 1 g) into clean furnace pots, and 100 mL of preheated acidic detergent (solution of 20 g hexadecyl trimethyl ammonium bromide in 1 L of 1 mol/L sulfuric acid) and 2 mL naphthane were then added. The mixtures were boiled slightly for 1 h and vacuum filtered, then washed with distilled water for six times and acetone for three times. The insoluble residues (fibers and lignins). were dried and weighed.

2.5. SOC fraction analysis

SOC fractionations procedures are based on different extraction of SOC. We divided SOC fractions based on the resistance of SOC to oxidation and hydrolyzability of SOC hydrolysis with acids, respectively.

$KMnO_4$ oxidation can reflect the in situ enzymatic decomposition of labile soil organic matter (Loginow et al., 1987), thus, $KMnO_4$-oxidizable carbon (KOC) is considered as "labile organic carbon" in this study. Some aromatic structures and humic substances in soils may react with $KMnO_4$. KOC was estimated by the process proposed by Blair et al. (1985). Briefly, 2 g of soil samples were weighed into 30 mL centrifuge tubes with plastic screw top, and 25 mL of 300 mM $KMnO_4$ was added to each vial. The tubes were shaken completely and centrifuged for 5 min at 2000 rpm. Briefly, 1 mL of the supernatants was diluted at 1:250 with deionized water. The absorbance of the diluted samples and standards was measured using a split beam spectrophotometer 722 (Tianxiang, China) at 565 nm. The change in the $KMnO_4$ concentration was used to estimate the amount of oxidized carbon, assuming that 1 mM $KMnO_4$ was consumed (MnVII → MnII) in the oxidation of 9 mg of organic carbon. Labile OC was equal to the organic carbon oxidized by 300 mM $KMnO_4$.