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Research article

Climate, soil texture, and soil types affect the contributions of fine-fraction-stabilized carbon to total soil organic carbon in different land uses across China

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ABSTRACT

Mineral-associated organic carbon (MOC), that is stabilized by fine soil particles (i.e., silt plus clay, <53 μm), is important for soil organic carbon (SOC) persistence and sequestration, due to its large contribution to total SOC (TSOC) and long turnover time. Our objectives were to investigate how climate, soil type, soil texture, and agricultural managements affect MOC contributions to TSOC in China. We created a dataset from 103 published papers, including 1106 data points pairing MOC and TSOC across three major land use types: cropland, grassland, and forest. Overall, the MOC/TSOC ratio ranged from 0.27 to 0.80 and varied significantly among soil groups in cropland, grassland, and forest. Croplands and forest exhibited significantly higher median MOC/TSOC ratios than in grassland. Moreover, forest and grassland soils in temperate regions had higher MOC/TSOC ratios than in subtropical regions. Furthermore, the MOC/TSOC ratio was much higher in ultisol, compared with the other soil types. Both the MOC content and MOC/TSOC ratio were positively correlated with the amount of fine fraction (silt plus clay) in soil, highlighting the importance of soil texture in stabilizing organic carbon across various climate zones. In cropland, different fertilization practices and land uses (e.g., upland, paddy, and upland-paddy rotation) significantly altered MOC/TSOC ratios, but not in cropping systems (e.g., mono- and double-cropping) characterized by climatic differences. This study demonstrates that the MOC/TSOC ratio is mainly driven by soil texture, soil types, and related climate and land uses, and thus the variations in MOC/TSOC ratios should be taken into account when quantitatively estimating soil C sequestration potential of silt plus clay particles on a large scale.

1. Introduction

Soil organic carbon (SOC) is fundamental in improving the physical, chemical, and biological functions of soil to sustain its fertility and productivity (Pan et al., 2009), as well as in predicting feedback of the terrestrial carbon cycle to climate change (Kirschbaum, 2000). Management practices have been widely used in increasing SOC stocks; such practices include afforestation, fertilization of forest and grassland soils, and the application of organic amendments in cropland (Chen et al., 2012; Paul et al., 2002; Purakayastha et al., 2008; Triberti et al., 2008).

The SOC pool consists of different fractions that vary in stabilization mechanisms and turnover times. Among these fractions, labile SOC (e.g., light fraction and particulate organic C) accounts for a relatively small proportion of total SOC (TSOC) because it is easily decomposed and extremely sensitive to environmental fluctuation (Schmidt et al., 2011). In contrast, mineral-associated organic carbon (MOC) is stabilized by fine soil particles (i.e., silt and clay) and is critical to SOC persistence. Previous research has demonstrated that MOC has long turnover time (Balesdent et al., 1998; Trumbore, 2000) and accounts for 50–80% of the TSOC (Gregorich et al., 2006; Kahle et al., 2002; Zhao et al., 2006). Therefore, quantifying MOC content and its contributions to TSOC were of great importance for predicting SOC stock and dynamics.

Although persistent, MOC is influenced by numerous variables, including climate, land uses, soil mineral type, soil texture, and ecosystem management practices (e.g., fertilization and crop

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Table 1
Data distribution of total soil organic carbon (TSOC) and organic carbon in the fine fraction (silt plus clay, MOC$_{<53\ \mu m}$) and clay particles (MOC$_{<2\ \mu m}$) under different land uses.

	TSOC (g C kg^{-1})			MOC$_{<53\ \mu m}$ (g C kg^{-1} soil)			MOC$_{<2\ \mu m}$ (g C kg^{-1} soil)		
	Cropland	Grassland	Forest	Cropland	Grassland	Forest	Cropland	Grassland	Forest
Sample No.	685	114	307	685	114	307	110	26	18
Mean	11.67β	23.52α	22.07α	8.19β	13.49α	14.57α	3.73β	4.57β	7.15α
Standard error	0.28	3.01	1.22	0.21	1.60	0.77	0.34	0.79	0.28
Median	9.77 b	9.96 b	14.79 a	6.58 b	6.39 b	10.76 a	2.61 b	3.12 b	6.52 a
Kurtosis	2.12	4.32	7.37	1.99	3.47	5.61	4.29	0.34	1.13
Skewness	1.31	2.26	2.42	1.35	2.02	2.11	1.90	1.36	0.63
Minimum	0.51	1.76	1.60	0.32	0.94	1.14	0.20	1.16	2.93
Maximum	50.50	144.2	141.71	34.54	71.43	81.15	18.8	13.26	23.61

Different letters in the same row indicate that MOC$_{<53\ \mu m}$, MOC$_{<2\ \mu m}$, and TSOC are significantly different across the three land uses at $P < 0.05$.

rotation). For example, climatic fluctuation can affect organic C quantity and quality, as well as microbial decomposition and stabilization processes (Li et al., 2014; Triberti et al., 2008). Additionally, different land uses and management practices can induce variation in organic C quantity and chemical composition, consequently affecting organo-mineral interactions, as well as MOC formation and turnover (Wiesmeier et al., 2014a; Yu et al., 2012).

Among the factors that influence MOC, soil texture and mineral type are considered main drivers of transforming organic material into soil organic C (Mikutta et al., 2006). Therefore, it is unsurprising that a strong and positive correlation exists between MOC and soil texture (Feng et al., 2013; Hassink, 1997; Six et al., 2002). Additionally, the nature of MOC suggests that its quantity and stability are strongly tied to soil mineralogy and organic matter chemistry (Feng et al., 2014). For example, differing specific surface areas and charge densities across 1:1 clay minerals (e.g., kaolinite), 2:1 clay minerals (e.g., montmorillonite, illite), and iron or aluminum (oxy)hydroxides translate to variation in bond strength between soils and organic C (Caravaca et al., 1999; Eusterhues et al., 2003). This interaction of organic C with soil minerals varies across ecosystems and influences organic C storage capacity in soils.

In conjunction with soil mineral type, the potential of soil texture (i.e., fine soil particles) to stabilize organic C inputs is attracting increased attention among researchers interested in MOC response to ecosystem management and climate change (Stewart et al., 2009; Wiesmeier et al., 2014a). The MOC/TSOC ratios can vary widely across studies, e.g., from 0.50 to 0.89 (Carter et al., 2003; Gregorich et al., 2006), suggesting that the ratio may be sensitive to environmental differences. In this study, we examined these relationships by performing a meta-analysis of published studies carried out in China with diverse land use and management patterns. By creating a dataset of publications spanning multiple climate zones and environments, we aimed to investigate variation in MOC content and MOC/TSOC ratios across forest, grassland, and cropland. In addition, we examined the impact of climate, soil texture, and land management on MOC/TSOC ratios.

2. Material and methods

2.1. Data sources

We performed a literature search in Web of Science and Web of China Knowledge Resource Integrated Database for papers published up to March 2014. Specific keywords included soil organic C, soil particle fractionation, and China. We selected publications that met the following criteria: (i) study sites were on mainland China; (ii) the soil particle size obtained from SOC fractionation analysis was >53 μm (or particular organic carbon (POC) and aggregates >53 μm) with/without <2 μm (clay); (iii) MOC concentrations (MOC$_{<53\ \mu m}$) in the fine fraction were reported, along with the proportion of the fine fraction in soil; (iv) studies in cropland included the application of mineral and organic fertilizers; (v) the MOC and/or POC content was obtained via dry-wet or wet sieving.

From these studies, we directly obtained SOC and MOC$_{<53\ \mu m}$ values, with or without MOC$_{<2\ \mu m}$ content, or else the values were calculated based on available soil aggregate data (>53 μm and/or 2–53 μm). Data reported as soil organic matter were converted to SOC content by multiplying with a conversion factor of 0.58 (Mann, 1986). We recorded all available information on study sites, such as climate conditions, land uses, soil types and textures, and managements (e.g., agricultural land uses and fertilization). We obtained the following variables for further analyses: TSOC, MOC$_{<53\ \mu m}$, and MOC$_{<2\ \mu m}$ (if available), all expressed as g C kg^{-1} soil, as well as the ratios of MOC$_{<53\ \mu m}$/TSOC and MOC$_{<2\ \mu m}$/TSOC.

We collected 103 published papers that met our criteria (Appendix), resulting in a dataset that included 1106 paired TSOC

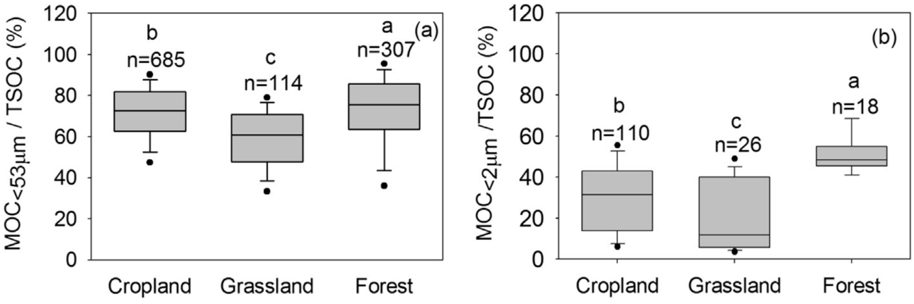

Fig. 1. Ratios of organic C in the fine fraction (silt plus clay; MOC$_{<53\ \mu m}$) (a) and the clay fraction (MOC$_{<2\ \mu m}$) (b) to total soil organic C (TSOC), across croplands, grasslands, and forests of China. Different lowercase letters indicate significantly different ratios among land uses at P < 0.05.