Soil organic carbon dynamics in physical fractions in Black soils of Northeast China

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Abstract
It is important to identify the impacts of soil management systems on soil organic carbon (SOC) and especially SOC fractions that are active in soil aggregate stabilization. A total 32 pairs of non-cultivated and cultivated soil samples were taken to study SOC in physical fractions and their relationships in Black soils. Soil particulate OC (POM-C, >53 µm), mineral-incorporated C (MOM-C, <53µm) and aggregate-associated C were measured. The POM-C content accounted for 9.1% of total SOC in 0-30 cm layer of non-cultivated soil and the majority of this C was coarse POM-C (>250µm). Comparatively, cultivation led to greater decline in coarse POM-C than fine POM-C (53-250 µm). The MOM-C greatly declined with depth in non-cultivated soils (P<0.05), but this decline did notoccur in cultivated soils. There were significant positive correlations between the coarse POM-C (also fine POM-C) and total SOC, macroaggregate-associated C, respectively, in non-cultivated soil. For the cultivated soils the same correlations became weak; however, the relationships between POM-C and microaggregate-associated C became strong and the POM-C loss was at the same rate as macroaggregate-associated C loss. The correlations between MOM-C and microaggregate-associated C, and total SOC were greater for cultivated than for non-cultivated soils. Also, MOM-C loss was significantly related to aggregate-associated C loss and total SOC loss. We speculate that POM-C was released and mineralized during cultivation resulting in breakdown of macroaggregates into microaggregates, and thus protecting soil aggregation could play an important role in C sequestration.

Key Words
Black soils; soil organic carbon, particulate organic carbon; mineral-incorporated C, aggregate-associated C

Introduction
Aggregate dynamics has been suggested as a key factor controlling SOC dynamics (Denef *et al.* 2001). Hence, it is important to identify soil management systems that improve the build up of soil organic matter and especially the active organic matter in soil aggregate stabilization (Oyedele 1999). Soil particulate organic matter (POM>53 µm) is closely related to soil water-stable aggregates, especially macroaggregates (Angers and Mehuys 1988), and rapidly responds to agricultural managements. Soil mineral-incorporated organic carbon (MOM-C <53 µm) is closely related to soil organic matter accumulation and sequestration (Fang *et al.* 2007). The Northeast Plain, dominated by Black soils (Udolls, US Soil Taxonomy), is an important region of crop production in China. Intensive cultivation with improper management practices has resulted in serious soil loss and soil degradation. Our objectives were to study the changes in total SOC, POM-C, MOM-C and aggregate-associated C in cultivated and non-cultivated Black soils, as well as the relationships among them. Results will be valuable for evaluating the mechanism of SOC loss induced by cultivation of Black soil.

Methods
Study site
Soil samples were collected from the Black soil zone in Heilongjiang and Jilin provinces (Figure 1). Black soil is located in the temperate zone with a continental monsoon climate. The mean annual temperature varies between 0.5 ºC and 6.0 ºC, and the mean annual precipitation varies between 500 mm and 600 mm with more than 80% occurring in June to September.

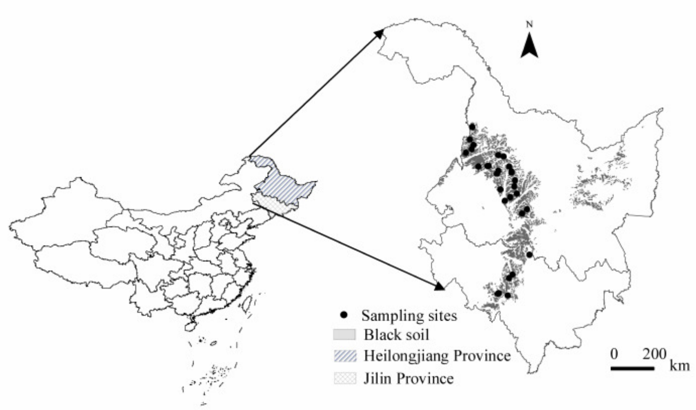

Figure 1. Sampling sites in Jilin and Heilongjiang provinces.

Soil sampling and analysis

In 2004 and 2005, 32 pairs of Black soil samples were collected from cultivated/non-cultivated sites. In each paired site, soils were developed under similar soil-forming conditions and the non-cultivated counterpart was never used for crop production. Soil samples were taken to a depth of 30 cm including 0-5, 5-10, 10-20, and 20-30 cm. Soil water-stable aggregates were measured using the wet sieving technique. For the remainder of this paper, the term “aggregate” means water-stable aggregate. Soil POM-C was dispersed by sodium hexametaphosphate solution, and transferred to a set of nested sieves having mesh sizes of 250 and 53 µm. Organic carbon remaining on the 250 µm sieve was termed coarse POM-C and that remaining on the 53 µm sieve was called fine POM-C. MOM-C was equal to total SOC minus POM-C. The SOC in bulk soil and fractions was measured using dry combustion.

Results

POM-C contents in cultivated and non-cultivated soils

POM-C in 0-30 cm layer of non-cultivated soils accounted for 9.1% of total SOC (Table 1). Coarse POM-C was greater than fine POM-C (Figure 2). POM-C was less in cultivated than in non-cultivated soils and C content was similar in coarse and fine POM. Reference to non-cultivated soil, cultivation decreased POM-C by 76.4%, 40.6%, 14.3% and 0.86% at 0-5, 5-10, 10-20 and 20-30 cm depths, respectively. The POM-C losses at 0-5 and 5-10 cm depths were much greater than total SOC loss (46.6% and 26.8%) (Liang 2008), suggesting sensitivity of POM-C to cultivation practices relative to total SOC.

Table 1. Comparisons of POM-C between non-cultivated and cultivated Black soils.

Soil depth （cm）	POM-C (g/kg)		POM-C/Total SOC (%)		（Non-cultivated-Cultivated）/Non-cultivated（％）	
	Non-cultivated	Cultivated	Non-cultivated	Cultivated	POM-C	Total SOC
0~5	9.17a(a)	2.16a(b)	20.5	9.0	76.4	46.6
5~10	3.42b(a)	2.03c(b)	10.6	8.6	40.6	26.8
10~20	1.94bc(a)	1.66ab(a)	6.8	7.3	14.4	20.6
20~30	1.16c(a)	1.15b(a)	5.0	5.6	0.86	11.2
Weighed mean	3.13	1.64	9.1	7.2	24.6	22.9

Means inside and outside the parentheses and in the same column and followed by the same letter are not significantly different at $p = 0.05$, respectively. The same applies to Figure 2.

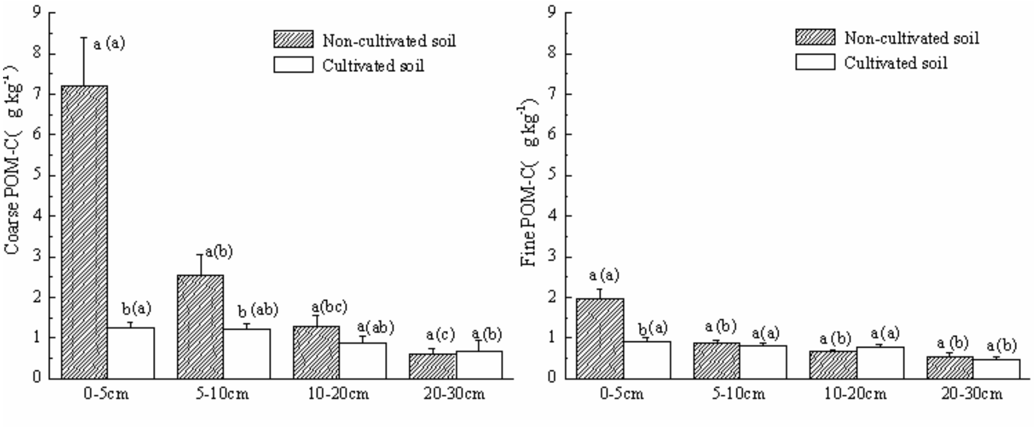

Figure 2. Coarse and fine POM-C in non-cultivated and cultivated Black soils (0-30 cm).

Changes in MOM-C

The MOM-C in 0-30 cm layer accounted for 90.5% and 92.5% of total SOC of non-cultivated and cultivated soils, respectively (Figure 3). Greater relative loss of MOM-C occurred in the surface (0-10 cm) than in sub-surface soil (10-30 cm). Although MOM-C was relatively stable and played an important role in maintaining C levels, the share of 86.6% total SOC loss from this fraction in cultivated Black soils indicates that attention needs to be paid to the fate of C in both fine and coarse particles when studying effects of agriculture on C dynamics.

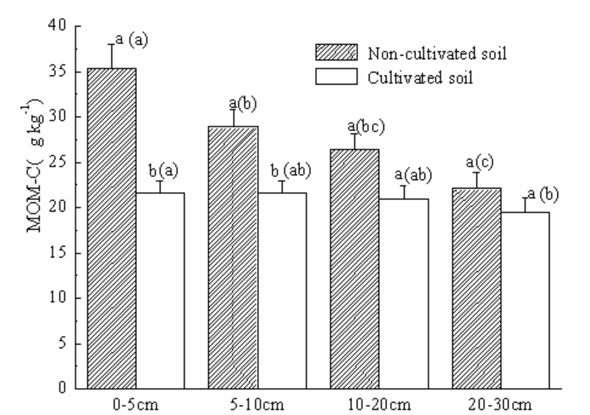

Figure 3. Soil MOM-C in non-cultivated and cultivated Black soils (0-30 cm).

Correlations among POM-C, MOM-C, aggregate-associated C and total SOC

There were significant positive correlations between coarse (also fine) POM-C and total SOC, macroaggregate-associated C, respectively, in non-cultivated soils ($P<0.01$) (Table 2). The similar relationships were weak for cultivated soils; however, the relationships between POM-C and microaggregate-associated C were stronger and POM-C (coarse and fine POM-C) was at the same rate as for macroaggregate-associated C loss. Also, MOM-C loss was significantly related to aggregate-associated C loss and total SOC loss. Therefore, POM-C and MOM-C both made large contributions to C accumulation retention in non-cultivated soil.

Table 2. Correlations between POM-C and aggregate-associated C, total SOC.

Non-cultivated soil	Coarse POM-C	Fine POM-C	MOM-C
SOC in >1000 μm aggregate	0.701**	0.525**	0.702**
SOC in 250-1000 μm aggregate	0.609**	0.533**	0.828**
SOC in 53-250 μm aggregate	0.170	0.314**	0.310**
Total SOC	0.771**	0.615**	0.969**
Cultivated soil			
SOC in >1000 μm aggregate	0.222*	-0.007	0.271**
SOC in 250-1000 μm aggregate	0.377**	-0.011	0.684**
SOC in 53-250 μm aggregate	0.228**	0.476**	0.677**
Total SOC	0.512**	0.292**	0.991**

* Correlation is significant at 5% level; ** Correlation is significant at 1% level

Table 3. Correlations among values of SOC loss for size fractions in cultivated soils.

	Macroaggregate-associated C loss	Microaggregate-associated C loss	Total SOC loss
Coarse POM-C loss	0.683**	0.043	0.695**
Fine POM-C loss	0.605**	0.169	0.690**
MOM-C loss	0.751**	0.378**	0.952**
Total SOC loss	0.834**	0.318**	1

* Correlation is significant at 5% level; ** Correlation is significant at 1% level

Conclusion

Carbon associated with soil macroaggregates (>250 μm) is more sensitive to agricultural management than POM-C. Cultivation weakens the relationship between the coarse or fine POM-C and total SOC, but strengthens the relationships between POM-C and microaggregate-associated C. Stronger correlations between MOM-C and microaggregate-associated C, total SOC in cultivated than in non-cultivated soils suggest that MOM-C could play an important role in C accumulation and retention.

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