



## Research paper

# Thermal stability of organic carbon in soil aggregates as affected by soil erosion and deposition



Xiaodong Nie<sup>a,c,d</sup>, Zhongwu Li<sup>a,b,c,\*</sup>, Jinqian Huang<sup>e</sup>, Lin Liu<sup>b</sup>, Haibin Xiao<sup>b</sup>, Chun Liu<sup>a,c</sup>, Guangming Zeng<sup>a,c</sup>

<sup>a</sup> College of Environmental Science and Engineering, Hunan University, Changsha, 410082, PR China

<sup>b</sup> State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, CAS and MWR, Yangling, Shaanxi Province, 712100, PR China

<sup>c</sup> Key Laboratory of Environmental Biology and Pollution Control (Hunan University), Ministry of Education, Changsha, 410082, PR China

<sup>d</sup> Guangdong Key Laboratory of Integrated Agro-environmental Pollution Control and Management, Guangdong Institute of Eco-environment Science & Technology, Guangzhou, 510650, PR China

<sup>e</sup> Department of Soil and Water Conservation, Yangtze River Scientific Research Institute, Wuhan, 430010, PR China

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## ABSTRACT

Knowledge about the stability of soil organic carbon (SOC) after erosion is essential for understanding the water erosion-induced organic carbon (OC) exchanges between soil and atmosphere. However, this issue has suffered from a shortage of focused studies and consensus results due to the complex processes and the use of various methods. The objective of the study was to estimate the stability of SOC in soil aggregates post-deposition by using thermogravimetric and differential scanning calorimetry (TG-DSC) techniques. Soils in eroded and depositional transects in subtropical China were collected and studied. To obtain the maximum difference in SOC along the transects based on the distributions of SOC concentrations along soil profiles, soils at depths of 0–5, 5–10, 20–30 and 120–150 cm were selected to represent the transects. Water-stable aggregate distributions and the thermal stability of the aggregate SOC in the selected soils were determined. The study results showed that significant differences in edaphic properties and aggregate-associated OC thermal indices were only found at depth of 0–5 and 5–10 cm ( $P < 0.05$ ). The distributions of soil aggregates indicate that soils at the depositional site had a better aggregate structure than those at the eroded site. The TG-T<sub>50</sub> (the temperature resulting in 50% of SOM loss) and DSC-T<sub>50</sub> (the temperature at which half of energy release occurred) values indicated that the eroded SOC was more stable than deposited SOC, and the thermal labile fractions (Exo<sub>1</sub>/Exo<sub>tot</sub>) suggested that the eroded SOC had a higher decomposition rate. In spite of this, the deposited soils retained higher amounts of SOC. We attributed these results to the protection provided by macroaggregates. For the soils deeper than 20 cm, there was no significant difference in soil aggregation, SOC content and SOC thermal stability between the soils at the two sites ( $P > 0.05$ ). Burial does not promote the formation of macroaggregates. The study results suggested that the quantity and quality of SOC are the primary factors controlling soil aggregation. Therefore, it is concluded that the protection provided by macroaggregates is an important mechanism for SOC stability.

## 1. Introduction

Soil organic carbon (SOC) loss induced by water erosion degrades soil quality, reduces crop yields and even may increase carbon emission from soil to the atmosphere (Doetterl et al., 2016; Kirkels et al., 2014; Kuhn et al., 2012; Lal, 2003). Researchers have devoted themselves to revealing the SOC fate induced by water erosion (Chaplot and Cooper, 2015; Li et al., 2016; Liu et al., 2017; Van Oost et al., 2007; Wang et al., 2014). However, most of the studies were performed to investigate short-term dynamics of organic carbon (OC) during erosion processes

(Huang et al., 2014; Van Hemelryck et al., 2011), and the long-term effects of erosion on OC post deposition remain uncertain.

Soil and the related OC are disturbed during the erosion processes, via detachment, transport, redistribution and deposition (Lal, 2005). The breakdown of soil aggregates caused by raindrop splash and runoff shear stress can enhance the liberation of protected OM, and the released OM can be transported and deposited preferentially due to its low density compared to other soil constituents (Maïga-Yaleu et al., 2013; Müller-Nedebeck and Chaplot, 2015; Nie et al., 2015). On the one hand, these processes increase the decomposition of OC because the

\* Corresponding author at: College of Environmental Science and Engineering, Hunan University, Changsha, 410082, PR China.  
E-mail address: [lizw@hnu.edu.cn](mailto:lizw@hnu.edu.cn) (Z. Li).

disturbed OM is exposed to oxidizing conditions and has lost the protection from macroaggregates (von Lützwow et al., 2006); on the other hand, the preferentially transported and deposited OM has been considered to belong to light and labile fractions (Nie et al., 2015; Schiettecatte et al., 2008a, 2008b), and the accumulation and burial of such materials can improve soil aggregation, thereby protecting OC from decomposition (Wang et al., 2013). Meanwhile, in eroded sites, sub-surface carbon-poor soil is exposed to the air due to the removal of surface soil, and replacement of eroded OC has taken place (Nadeu et al., 2012). However, it is difficult to monitor the dynamics of SOC after soil deposition at both eroded and depositional sites directly. Therefore, the stability of OC is often used to indicate the SOC changes (Ma et al., 2016).

In soil science, the stability of OC has been well studied. Three stabilization mechanisms of SOC were concluded by Six et al. (2002): (1) physically stabilized through microaggregation, (2) intimate association with silt and clay particles, and (3) the formation of recalcitrant SOM compounds that are biochemically stabilized. Meanwhile, von Lützwow et al. (2007) reviewed references and noted three main stabilization mechanisms: (1) physical separation of SOM, (2) chemical fractions resistant to oxidation or destruction of the mineral phase, and (3) combinations of the above ways. However, we tend to support the classification proposed by von Lützwow et al. (2006): (1) selective preservation of recalcitrance of OM, (2) spatial inaccessibility of OM against decomposer organisms, and (3) stabilization by interaction with mineral surfaces and metal ions. However, no matter what the classification is, researchers agree upon the physical protection of SOC by soil aggregates. Meanwhile, the dynamics of aggregates and aggregate-associated OC can appropriately reflect the influence of erosion because the dispersion, transport and deposition of sediment are often accompanied with the breakdown and reaggregation of soil aggregates (Lal, 2005; Six et al., 2000). To assess the effect of aggregation on SOC stabilization, Wang et al. (2014) found that aggregate crushing increased SOC mineralization by 10–80% at the eroded site. Furthermore, the analysis revealed that aggregate-associated OC can be better protected at eroded sites than at depositional sites. That study also clarified that transport results in disaggregation and consequently SOC mineralization, while depositional and burial processes promote the formation of macroaggregates that protect OC. However, the microaggregates within macroaggregates and aggregation should be further studied.

To determine SOC stabilization, many different parameters have been used to indicate the stability of OC. The most common indicators are labile and refractory compartments, such as dissolved organic carbon, water-soluble organic carbon, easily oxidizable organic carbon, particulate organic carbon, humic acid, fulvic acid, humin, and others (Li et al., 2015, 2017; Sequeira et al., 2011; Wang et al., 2016). Mineralizable carbon is also often used. Field monitoring and laboratory incubation experiments were performed to assess the emission of CO<sub>2</sub> and CH<sub>4</sub> to evaluate the stability of OC over a period of 30–90 days (Chaplot and Poesen, 2012; Van Hemelryck et al., 2011). However, these experiments are time and labor consuming. In recent years, the molecular structure of SOM was used to estimate SOC stability. A common hypothesis is that molecular structures can be used to predict the stability of SOM (Han et al., 2015). Sjögersten et al. (2016) observed a strong relationship between OC molecular structures and decomposed CO<sub>2</sub>. However, recently emerging evidence indicates that the molecular structure does not necessarily predetermine the persistence of OC in soils (Han et al., 2015). Schmidt et al. (2011) argued that environmental and biological controls have to be considered to explain the protection of OM, especially potentially labile compounds against microbial decomposition for centuries to millennia. Therefore, the various parameters may produce different and even contradictory results. The main reasons may be related to the various environmental factors, e.g., soil structure, availability of resources and diversity of microorganisms (Han et al., 2015).

Researchers have introduced thermal analysis techniques, which

have long been used to study clay mineralogy, to estimate the stability of OM. The thermal stability of SOM is based on the relationship between energy and the form of materials and is a complex reflection of the effects of various factors on SOM. Thermal analysis techniques are based on the detection of several peaks in material loss (differential thermogravimetry: DTG), and the release of energy in the form of heat (differential scanning calorimetry: DSC) (Rovira et al., 2008). Thermal stability of OM was found to be strongly correlated with chemical composition and biological decomposition (Gregorich et al., 2015; Plante et al., 2011). Similar results were also obtained by Peltre et al. (2013), but they noted that the C concentration affects the dominant SOM stabilization mechanisms and thermal analysis results. Overall, in comparison to other measurement methods, thermal analysis has the advantage of being rapid, and the emerging application of thermal analysis has been attracted more and more attention world-wide.

Therefore, to improve the understanding of SOC dynamics after deposition using a convenient and low-cost method is essential for exploring the SOC fate. The main objective of the current study was to reveal the stability of OC in response to erosion and deposition using thermal analysis method. Distributions of water-stable aggregates and the associated OC at both eroded and depositional sites were measured. The stability of aggregate-associated OC at different depths in response to erosion and deposition were determined via the TG-DSC methods. We hypothesized that the OC at the eroded site has a higher stability than at the depositional site, and that the burial can improve the formation of macroaggregates and increase the stability of OC.

## 2. Materials and methods

### 2.1. Study site and sampling

The study site was located in the Institute of Soil and Water Conservation of Shaoyang City, Hunan Province (111°22'E, 27°03'N), and there are national monitoring stations of soil and water conservation in this site. This region has suffered serious water erosion and low soil quality, with low OC and nutrients contents due to the frequently heavy rain events (Li et al., 2015, 2016; Nie et al., 2017; Zhang et al., 2013). This region has a typical subtropical monsoonal climate with an average annual temperature of 16.1–17.1 °C and an annual frost-free period of 272–304 days. The mean annual precipitation of this region is 1218.5–1473.5 mm, which mainly occurs in spring (April and May) and summer (June). The altitude varies from 231.18 m to 276.63 m. The soil is developed from Quaternary parent material.

A typical small watershed in this site was selected and studied. Soil samples were collected from an upslope site and a downslope site, referred as the eroded and depositional sites in the following text. Three soil cores were taken at each site. Soil samples at the depths of 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100, 100–120, and 120–150 cm were collected. A portion of each sample was air dried, and the other part was stored at 4 °C. Soil bulk density samples were also collected from each layer. Following the removal of plant residues and gravel, the air-dried samples were prepared for SOC and <sup>137</sup>Cs analyses. According to the OC distribution with soil depth (S1), soil samples at 0–5, 5–10, 20–30 and 120–150 cm, which had the maximum difference, were selected to represent the whole range of differences in C between the eroded and depositional sites.

### 2.2. Isolation of soil aggregates

The aggregate-size distributions for soil samples were determined via the wet sieving method (Plante et al., 2006; Six et al., 2002). Briefly, 50 g of air dried soil were submerged in deionized water for 30 min to promote slaking of macroaggregates and poured onto a 250 μm mesh screen inside a cylinder and reciprocally shaken with 50 glass beads. A continuous flow of water that immediately flushed the 250 μm material out of the shaker and onto a 53 μm sieve. The material on the 250 μm

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