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Effect of soil redistribution on various organic carbons in a water- and tillage-eroded soil

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ABSTRACT

The information gap concerning the effect of soil redistribution on various carbon (C) pools will limit our understanding regarding the fate of eroded C. In this study, we selected a water- and tillage-eroded hillslope with a horizontal length of 45 m from the Sichuan Basin, China, to determine the impact of soil redistribution on particulate organic C from 0.0053 to 2 mm soil particles (POC), light fraction organic C (LFOC), dissolved organic C (DOC) and microbial biomass C (MBC). Soil erosion was evaluated at 5-m intervals from the summit to lower parts and soil deposition at the bottom of the hillslope. Within the erosional sites, tillage erosion- and water erosion-dominated subsites were identified. The POC content firstly decrease and then increased downslope, while the DOC exhibited an opposite pattern to the POC. The MBC content decreased downslope, while the LFOC increased. Overall, the erosional sites had lower POC and LFOC contents than depositional sites, demonstrating the depletion of POC and LFOC induced by soil erosion and the enrichment of POC and LFOC by soil deposition. Conversely, the contents of DOC and MBC were greater in the erosional sites than depositional sites. It was also observed that the LFOC distribution was strongly linked to fine (<0.05 mm) soil particles, indicating a preferentially transport of the light fraction C downslope in the process of water erosion. In addition, tillage erosion-dominated subsites had higher values of POC/SOC and DOC/SOC than water erosion-dominated subsites, suggesting lower depletion of POC and DOC by tillage erosion than water erosion. Likewise, the higher MBC/SOC values were found in tillage erosion-dominated subsites, thus implying that more SOC may be assimilated into microbial C under tillage erosion than water erosion. Our study confirms the need to consider microbial response to the dynamic replacement of erosion depleted SOC.

1. Introduction

Soil erosion may deplete soil organic carbon (SOC) pool in agricultural landscapes. Globally, vast quantities of SOC (0.47–0.61 $\mathrm{Pg\,C\,a^{-1}}$) pool are moved across the earth surface as a result of soil erosion (Van Oost et al., 2007). The pathways of erosion-induced SOC loss generally include the redistribution over the landscape, the delivery to distal depositional environments or fluvial systems, and the mineralization during delivery (Lal, 2003). However, recent studies have highlighted that the vast majority of eroded soil is redistributed within the landscape, rather than exported off the field (Smith et al., 2005; Quine and Van Oost, 2007). Therefore, SOC dynamics in relation to soil redistribution (erosion and deposition), such as SOC erosion and burial (Doetterl et al., 2012; Vandenbygaart et al., 2012; Nie et al., 2013a), SOC mineralization (Van Hemelryck et al., 2010, 2011), and SOC replacement (Harden et al., 1999; Berhe et al., 2008; Nadeu et al., 2012; Dungait et al., 2013) have attracted more attention. In these studies, the consistent results that soil erosion depletes total SOC pool are observed, while soil deposition accumulates total SOC pool. Nonetheless, there is a debate regarding soil redistribution as a C source or a C sink among these studies due to poor understanding of the fate of eroded organic C fractions, such as dissolved, particulate, and light fraction C (Rasmussen et al., 2011; Kuhn, 2012).

Among various C fractions, dissolved organic C (DOC) is a most labile fraction responsive to soil disturbances due to its high content of hydrophilic compounds (Cook and Allan, 1992). It is well documented that DOC is prone to transport-related depletion in

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the case of water erosion (Gregorich et al., 2003; Martínez-Mena et al., 2012; Maïga-Yaleu et al., 2013). The organic C from coarse soil particles (0.053–2 mm), often termed as POC, is mainly derived from plant residue and is a labile organic fraction (Christensen, 2001). Several studies suggested that POC has a close integration with soil aggregates (Grandy and Robertson, 2006; Fultz et al., 2013). It is believed that the erosion-induced destruction of soil aggregates may accelerate the mineralization of POC (Polyakov and Lal, 2008; Doetterl et al., 2012), while deposition-induced soil re-aggregation may reduce the mineralization (Gregorich et al., 1998; Berhe et al., 2012). Unlike DOC and POC, light fraction organic C (LFOC) is a recalcitrant fraction of SOM. It is often assumed that LFOC is preferentially transported from eroding soils and then is buried in deeper depositional soils during the process of water erosion because of its low density ($<1.8\,\mathrm{g\,cm^{-3}}$) (Gregorich et al., 1998; Lal, 2003), thus impacting the spatial pattern of SOC pool within a landscape. However, there is a lack of direct evidence about how soil redistribution affects these specific C pools in current studies.

In soil, microbial biomass is generally considered as an important biotic driver of soil C efflux (Paterson et al., 2008). Though microbial biomass C (MBC) from living microbial bodies (e.g., bacteria, fungi and algae) is not SOM, it responds more sensitively to soil disturbance than SOC (Powlson and Jenkinson, 1981). Moreover, the microbial C pool is related to microbial community structure (Alvear et al., 2005). Different responses of fungal and bacterial communities to soil erosion have been reported in recent studies (Bossuyt et al., 2001; Gordon et al., 2008; Huang et al., 2013). Therefore, it would be expected that the impacts of soil redistribution on microbial biomass C are different if there are different microbial community structures between erosional and depositional sites within a landscape. Clearly, more accurate quantification of the biological process associated with soil erosion is required for estimating the dynamics of microbial biomass C.

Considering the relative large portion of the earth's surface covered by cultivated land subjected to intensive erosion (Van Oost et al., 2007), the combined effect of water and tillage erosion on soil C dynamics should also be considered in the landscape with a humid subtropical climate. A few studies have indicated that arable soils are affected by water and tillage erosion at around the same order of magnitude (Govers et al., 1996; Quine et al., 1999; Li and Lindstrom, 2001; Van Oost et al., 2006). Tillage erosion exerts less effect on mineralization-induced total SOC loss than water erosion (Zhang et al., 2006). It is also concluded that tillage erosion plays a dual role: enhancing SOC stock at depositional positions, and accelerating the depletion of SOC stock when combined with water erosion within the same landscape (Zhang et al., 2012). Despite growing recognition of the influences of water and tillage erosion on total SOC dynamics, little is known about the combined effect of both erosion processes on various organic C pools.

Caesium-137 (^{137}Cs) can be used as a tracer of post-1950 soil redistribution by water erosion and tillage practices (Walling and Quine, 1991; Li et al., 2011). There remain some drawbacks to the use of ^{137}Cs for assessing soil erosion due to the fundamental assumptions (Parsons and Foster, 2011). However, the ^{137}Cs technique for estimating soil redistribution overcomes many difficulties with long-term monitoring programs by providing retrospective information on medium-term erosion or deposition. Therefore, the ^{137}Cs technique is still regarded as a relatively effective and rapid method to assess soil erosion by fifteen international scientific teams and the International Atomic Energy Agency (IAEA) (Mabit et al., 2013). The relationships between ^{137}Cs and total SOC patterns have been well established (Ritchie and McCarty, 2003; Zhang et al., 2006; Martinez et al., 2010; Chappell et al., 2012; Teramage et al., 2013; Nie et al., 2013b). In order to further determine the impacts of water erosion and tillage erosion on C dynamics, quantitative calculation for individual erosion rate is essential. Within a landscape where both water and tillage erosion occur, the quantitative estimation to water and tillage erosion may be realized by a combined application between total erosion models derived from ^{137}Cs technique (Zhang et al., 1999) and region-scale tillage erosion models (Lindstrom et al., 2000; Zhang et al., 2004a), wherein water erosion rate can be estimated by the difference between total erosion and tillage erosion (Li and Lindstrom, 2001; Zhang et al., 2006; Nie et al., 2013b). In the present study, we used the same methodology to evaluate the relationship between erosion and specific organic C pools in a water- and tillage-eroded hillslope of the Sichuan Basin, China.

This study aims to (1) investigate soil redistribution and determine the contribution of water and tillage erosion to soil redistribution along the hillslope; (2) examine the spatial patterns of four different C parameters including DOC, POC, LFOC, and MBC; (3) assess the relationships between four C parameters and soil redistribution, and (4) explore effects of water and tillage erosion on these C pools.

2. Materials and methods

2.1. Site description

The study area was located in Jianyang County of the Sichuan Basin, southwestern China (30°04′28″–30°39′00″N, 104°11′34″–104°53′36″E). The study area is one of the most important grain-growing areas of the Sichuan Basin where more than four-fifths of people still depend on farming. This region, with elevation ranging from 400 to 587 m a.s.l., is typical of hilly areas of Sichuan, and is a humid subtropical monsoon climate with distinct seasons. Its average annual temperature is 17 °C with a maximum temperature of 38.7 °C and a minimum temperature of −5.4 °C. Mean annual precipitation is $872\,\mathrm{mm\,yr^{-1}}$, 90% of which occurs between May and October. The soils in the study area, derived from purple mudstone and sandstone of Jurassic Age, are classified as Orthic Regosols in the FAO soil taxonomy. In the soils, dominant clay minerals are illite and montmorillonite. Tillage by hoeing always starts at the bottom of cultivated slopes and moves upslope step by step, but at every step the tillage direction is always downslope (i.e. always pulling down). Crop rotation involves wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.)/sweet potato (*Ipomoea batatas*). For wheat and maize, the residues are always cut by hand as low as possible and removed, and retained residues with about 10-cm height above the ground are mixed into the tillage layer by manual hoeing. For sweet potatoes, all residues are removed from the fields.

The hillslope under study has a horizontal length of 45 m and an average slope gradient of $0.13\,\mathrm{m\,m^{-1}}$ (or *c.* 7.5°), with altitudes ranging from 413 to 419 m above sea level. There is a drainage ditch at the lower end of the hillslope (Fig. 1). In the ditch, sediment deposit can be clearly observed. The thickness of soil profile above bedrocks varied between 34 cm and 49 cm over the hillslope. The average depth of tillage layer was 17 cm with the range of 16–19 cm, with a slight depth increase from upper to lower slopes. The soil of tillage layer has a silt loam texture (18% clay, 59% silt, and 23% sand) and pH of 8.3, containing less than 1.5% SOM (Table 1).

2.2. Soil sampling

Soil sampling was carried out during October 2012. Two sampling points with a contour distance of 7 m were set up at 5-m intervals along two parallel downslope transects (Fig. 1). The coordinates of each sampling point as well as elevation were measured using a survey-grade Differential Global Positioning