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Source identification and budget evaluation of eroded organic carbon in an intensive agricultural catchment

Yixia Wang[b,c], Nufang Fang[a,b,*], Lisha Tong[d], Zhihua Shi[b,d]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A & F University,26 Xinong Road, Yangling, Shaanxi Province 712100, PR China
[b] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources,26 Xinong Road, Yangling, Shaanxi Province 712100, PR China
[c] University of Chinese Academy of Sciences, Beijing 100049, PR China
[d] College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, PR China

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ABSTRACT

Soil erosion affects the redistribution of soil and associated soil organic carbon (SOC) from different landforms, and it has significant implications regarding the fate of eroded SOC and terrestrial carbon sequestration. Despite the importance of soil erosion, few studies have evaluated the sources and budget of eroded SOC in the Loess Plateau region, which suffers from severe soil erosion. Based on an 11.3 m check dam sediment profile, we used the ^{137}Cs activity and extreme rainfall events as dating methods to date sediment sequences. In addition, the natural abundance levels of the stable carbon isotope (δ^{13}C) of bulk organic matter and a two-end-member mixing model were used to discriminate the sources of eroded SOC from different siltation stages retained by the check dam in an intensive agricultural catchment of the Loess Plateau, China. The eroded SOC captured by the check dam was compared to potential source materials from different landscape units, which included sloping cropland and gully surface soils (0–5 cm). The results showed that the check dam intercepted 98.5 Gg of eroded soil and 172.6 Mg of SOC. The eroded SOC was primarily sourced from sloping cropland, which contributed to 81.3% of the total SOC retained by the check dam, whereas the gully soils contributed to 18.7% during the entire siltation stage. Additionally, the contribution of sloping cropland to eroded SOC increased from 1960 to 1990 as a result of rainfall and anthropogenic activities. A total of 89.7 Mg SOC was lost during soil erosion processes at a rate of 0.17 Mg ha^{-1} yr^{-1} and accounted for approximately 30% of the total eroded SOC exported from the eroding areas. Our results indicate that the soil erosion process has been an important net source of SOC in the study catchment. The check dam served as a carbon storage and sequestration structure for the hilly loess region due to its beneficial conditions for carbon sequestration over broad temporal and spatial distributions.

1. Introduction

Quantifying the carbon (C) fluxes of terrestrial ecosystems is vital for accurately evaluating the global C budget and predicting the effects of the C sink/source in the soil on the Earth's climate system (Falkowski et al., 2000; Mccorkle et al., 2016). The global soil C pool is 2.3 times larger than the atmospheric pool (760 Pg) and 3.5 times larger than the biotic pool (560 Pg) (Dungait et al., 2012; Lal, 2004a). Soil organic carbon (SOC), the primary component of the largest terrestrial C pool, plays a vital role in global C cycling (Lal, 2004a; Xin et al., 2016). Consequently, SOC redistribution by soil erosion processes and subsequent transport into depressional landforms plays an important role in C biogeochemical cycling (Battin et al., 2009; Berhe et al., 2007; Stallard, 1998).

Soil erosion, especially water erosion, facilitates the translocation of soil materials and SOC dynamics (Lal, 2003; Ran et al., 2014). Soil erosion redistributes approximately 75 Pg of soil and 1–5 Pg of SOC annually (Berhe et al., 2007; Stallard, 1998). The SOC redistribution caused by soil erosion removes C-rich topsoil from eroding uplands and buries the soil at low elevation sites. Approximately 70–90% of eroded SOC is redistributed downhill or downstream, whereas the reminder is decomposed during transport or exported through source watersheds (Doetterl et al., 2012; Lal, 2003). Soil erosion and subsequent deposition have led to a net terrestrial sink of 0.12-1.5 Pg C yr^{-1} globally, particularly when assessed at a watershed scale (Berhe et al., 2007, 2008; Stallard, 1998; Van Oost et al., 2007). Although previous studies have shown that soil erosion can result in a C sink, the studies conducted by Lal and colleagues (Jacinthe et al., 2004; Lal, 2003, 2004a,

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[*] Corresponding author at: Institute of Soil and Water Conservation, Northwest A & F University, 26 Xinong Road, Yangling, Shaanxi Province 712100, PR China.
E-mail addresses: wyixia@126.com (Y. Wang), fnf@ms.iswc.ac.cn (N. Fang), tongls@webmail.hzau.edu.cn (L. Tong), shizhihua70@gmail.com (Z. Shi).

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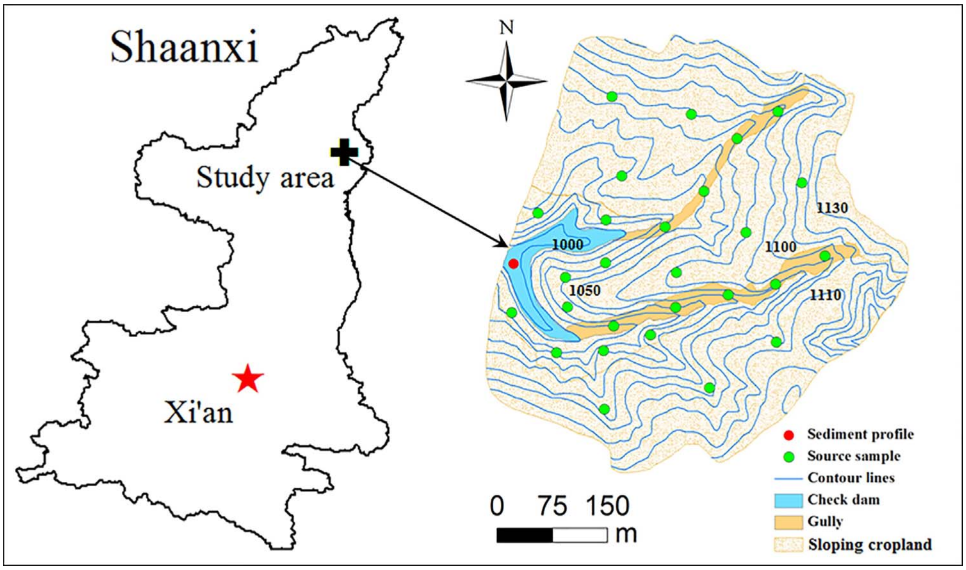

Fig. 1. Sampling sites and landscape units in the Nianyangou catchment.

2004b; Starr et al., 2000) suggest that soil erosion acts as a C source in the global budget. These works indicate that soil erosion transfers up to 1.14 Pg of C per year to the atmosphere because of aggregate breakdown via rain splash and runoff turbulence (Starr et al., 2000). The difference in sink/source terms primarily depends on the form of erosion, the various approaches used in different studies and an incomplete understanding of the interactions between soil erosion and the C cycle at the catchment scale, especially the uncertainty of SOC exported from eroding catchments (Berhe et al., 2007; Doetterl et al., 2016; Liu et al., 2003). Thus, additional studies are required to further our understanding of the SOC dynamics caused by soil erosion.

The amount and composition of SOC found at low-lying sites reflect the balance among SOC inputs, outputs, and transformations processes, including decomposition and leaching (Berhe et al., 2007). The identification of sediment sources (from different landscape units) is critical because the concentration and composition of SOC in the mobilized sediment (Collins et al., 2013; Mccorkle et al., 2016) and the persistence of the eroded SOC depend on the characteristics of the source material. Therefore, tracing the movement of SOC from eroding uplands is essential for quantifying the fate of laterally transported C in different landscapes (Berhe and Kleber, 2013; Mccorkle et al., 2016).

The stable carbon isotope (^{13}C) is of particular interest for catchment-scale assessments of SOC erosion, deposition and replacement. The stable isotope composition of C ($\delta^{13}C$) varies significantly among ecosystem pools due to isotopic fractionation during C cycling (O'Leary, 1988). Differences in the $\delta^{13}C$ values of SOC pools in upland soils and sediments have been used to investigate the transport of soil materials mobilized by precipitation events in catchments and deposited in accumulated sediments (Bellanger et al., 2004; Fox and Papanicolaou, 2007). Consequently, using $\delta^{13}C$ is a common and effective method of tracing erosion pathways (Meusburger et al., 2013).

The Chinese government has constructed a large number of check dams in small agricultural catchments to control soil and water losses in the Loess Plateau area, which has suffered from severe soil erosion (Fu et al., 2011). Check dams play an important role in carbon sequestration in the Loess Plateau ecosystems (Cao et al., 2009). By 2005, 122,028 check dams had been constructed on the Loess Plateau, and they stored more than 21 billion m^3 of sediment and 95.2 Tg of eroded SOC (Ministry of Water Resources of the People's Republic of China, 2010; Wang et al., 2011, 2014; Xu et al., 2004). The sediments intercepted by check dams exhibit a clear sedimentary sequence, with the thickness of a couplet varying from a few centimeters to tens of centimeters (Chen et al., 2016; Zhang et al., 2006). These characteristics are rare in natural environments (Fang et al., 2014; et al., 2006; McConnachie and Petticrew, 2006). Consequently, the sediments trapped by check dams can serve as natural archives for reconstructing the environmental history of soil erosion in these small agricultural catchments. The main objectives of this study were to (i) identify the sources and fate of SOC affected by soil erosion in a small agricultural catchment and (ii)clarify the impacts of check dams on the carbon flux in regional ecosystems.

2. Study area and methods

2.1. Study area

The study was conducted in the Nianyangou catchment (37°35′33″ N to 37°35′54″ N, 110°22′4″ E to 110°22′28″ E), which is located in Suide County of Shaanxi Province on the Loess Plateau. The elevation of the catchment ranges from 1027 m to 1118 m, and the mean slope gradient is 12.5°. The drainage basin exhibits terrain fragmentation and complex topography characteristics, which is vulnerable to erosion. The watershed is characterized by a temperate continental monsoon climate with a mean annual precipitation of 513 mm, and more than 70% of the precipitation is concentrated in the rainy season (June to September) in the form of high-intensity rainstorms (Yang et al., 2006).

The sediment sampling point, a check dam in the Nianyangou catchment, has a well-documented history. It was constructed in 1960 and filled in 1990. The check dam controls an area of approximately 18.1 ha, and the current silt area is approximately 6000 m^2 (Fig. 1). A high-precision Global Positioning System (GPS) combined with QuickBird imagery was used to obtain a catchment topographic map (scale 1:10,000). During the check dam siltation period, the land in the catchment was primarily characterized as sloping cropland, which covered 77.2% of the catchment area, and only a small fraction of the land was occupied by sparse shrubs, which were primarily located in gullies. The topographic map of the study area prior to the construction of the check dam was provided by the Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources (Fig. 1, contour lines).

2.2. Sample collection

The fieldwork involved the collection of potential source materials and the sediment depositional profile of the Nianyangou catchment. In this catchment, the primary landscape units are sloping cropland and gully, as shown in Fig. 1. Source material sampling involved the