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Effects of water erosion on the redistribution of soil organic carbon in the hilly red soil region of southern China

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ABSTRACT

Water erosion processes can significantly affect the delivery and distribution patterns of soil organic carbon (SOC) within the landscape. While many studies focus on the erosion processes and runoff transport of SOC, little attention has been paid to the on-site redistribution and vertical transport of SOC. This study characterizes SOC erosion dynamics, including infiltration-associated movement, and discusses the effects of rainfall intensity and slope position on SOC transport within the hilly red soil region of southern China. The results show that SOC loss was likely due to sediment transport rather than runoff. The eroded SOC was not significantly enriched, which may be due to the soil properties and the type of rainfall event. The initial SOC concentration affected the enrichment ratio of eroded SOC in the sediment. On-site horizontal redistribution occurred regardless of rainfall intensity, whereas the SOC transport trends varied with rainfall intensity and slope positions. This demonstrates that soil preservation could reduce SOC loss, and thus influence the global carbon cycle.

1. Introduction

Despite the significant effect soil erosion has upon the global carbon cycle (Stallard, 1998), the most widespread form of soil erosion and degradation is a highly debated and uncertain topic (Lal et al., 1998; Lal, 2003; Lal and Pimentel, 2008). In the past decade, researchers have investigated the impact of erosion upon soil carbon, soil loss, as well as the associated carbon dynamics during rainfall. For example, Polyakov and Lal (2004) found that soil organic carbon (SOC) concentration in runoff decreases within creasing rainfall duration. Pan and Shangguan (2006) reported that soils in grasslands have higher percolation and provide less runoff and sediment than those in croplands. Seybold et al. (2002) found that soils not subjected to tillage are characterized by higher infiltration rates. While these studies reflect a range of complicated erosion processes that affect soil, they also focus on the impacts that land management practices can have on surface runoff, soil loss, and percolation (Seybold et al., 2002; Pan and Shangguan, 2006; Rimal and Lal, 2009). The behavior of SOC in different soil layers with varying infiltration processes has not been directly detected, and therefore the SOC vertical transport process is not completely understood.

SOC loss during erosion is affected by many factors such as soil properties, rainfall intensity/duration, topography, surface cover, and soil wetness (Foster and Wischmeier, 1974). Many rainfall simulation experiments have focused on the effects of rainfall intensity on soil erosion. For instance, Jin et al. (2009) reported that higher rainfall intensities produce more sediment and, consequently, higher nutrient losses and lower sediment SOC enrichment ratios (ER_{soc}). The research of Jacinthe et al. (2004) confirmed that soil erosion associated with intense rainstorms affects the loss of labile SOC. Topography can strongly influence both soil erosion and SOC distribution. Upperslope positions are generally eroded while lower positions are depositional (McCarty and Ritchie, 2002; Papiernik et al., 2005). Soil nutrients accumulate in depositional areas (Heckrath et al., 2005; Papiernik et al., 2007), and therefore, SOC concentrations are usually higher at the lower slope positions.

The main factors that affect water erosion and the resultant SOC loss processes have been intensively studied in the past (Engel et al., 2009; Jin et al., 2009; Rimal and Lal, 2009). In a previous study conducted in a tropical area (Rumpel et al., 2009), carbon exporting processes including horizontal redistribution, vertical transport, and sediment runoff were detected. However, the soil layer was too thin (10 mm) to confirm the vertical transport process, and the climate and soil conditions differed from those in a subtropical region. In this study, we attempt to (i) provide insight into the temporal patterns of sediment, runoff, and SOC discharge for rainfall events of varying intensities; (ii) determine the on-site redistribution of SOC

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along a slope; and (iii) verify the vertical transport of SOC within soil layers. From this, dynamic patterns of SOC concentrations and loading at the plot level can be determined.

2. Material and methods

2.1. Study site

Soil profiles for ten provinces in Southern China were examined in this study. These areas are characterized by red soil, which covers a total area of 2.18 × 10^6 km^2 (Zhao, 2002). Due to the subtropical conditions in the so-called "hilly red soil region," red soils are often heavily weathered and low in SOC (Shi et al., 2010). Water erosion occurs throughout this region, with raindrop splash and slope runoff erosion being the dominant mechanisms (Tang, 2004). Although the total amount of soil loss is lower than that of the Chinese Loess Plateau, the thin soil layer available for plant growth in the red soil hilly region can cause severe erosion conditions. The large geographic area of the hilly red soil region also makes it an important component of China's terrestrial carbon cycle.

This study was carried out at the soil and water conservation research station of Shaoyang (111°22′E, 27°03′N) in the southwest–central part of Hunan Province, China (Fig. 1). The research station is situated upstream of the Zi River, within the hinterland of the Hengshao Basin. The average yearly temperature and the mean annual precipitation of the station are 17.1 °C and 1327.5 mm, respectively. The region's soil is Quaternary red clay with a clay-to-loam texture (Yang et al., 1989), which is considered an Ultisol according to the U.S. Soil Taxonomy. The soils are generally low in organic matter concentrations, as is typical for the hilly red soil region.

2.2. Plot set-up and rainfall simulation

In 2009, a 5 m × 5 m land block was chosen as the experimental area (Fig. 2). The land block was previously planted with slope-cultivated *Polygonatum odoratum* (Mill.) Druce. After harvesting the crops, the land was disked several times to smooth the soil surface and then laid fallow. One year later, the slope of the land block was found to be slightly S-shaped, with a mean slope gradient of 15°. The mean SOC concentration of the 20 cm thick surface layer was 4.39 ± 0.42 g kg^{-1} (the mean value of 15 replicate plots ± standard error). The total nitrogen and phosphorus concentrations of the soil were 0.60 ± 0.05 and 0.79 ± 0.12 g kg^{-1}, respectively. The soil had a clay-loamy texture with 16.72 ± 0.83% clay particle size distribution, 27.50 ± 0.45% silt, and 55.77 ± 0.63% sand. During the summer of 2010, two 2 m × 5 m plots were delimited for the rainfall simulation experiment (Fig. 2). Each plot was bound with a thin metal frame driven into the ground in order to prevent runoff from adjacent areas. The lower end of each plot was equipped with a funnel-shaped collection trough that channeled runoff into a marked 2.5 L pail. The plots were designed to have (i) minimal soil disturbance during the boundary setting; and (ii) minimal local soil variations, which was achieved through the minimization of the distance between the plots. The upper part of each plot was the sediment and carbon source while the bottom parts typically accumulated any carbon that had not yet reached the outlet.

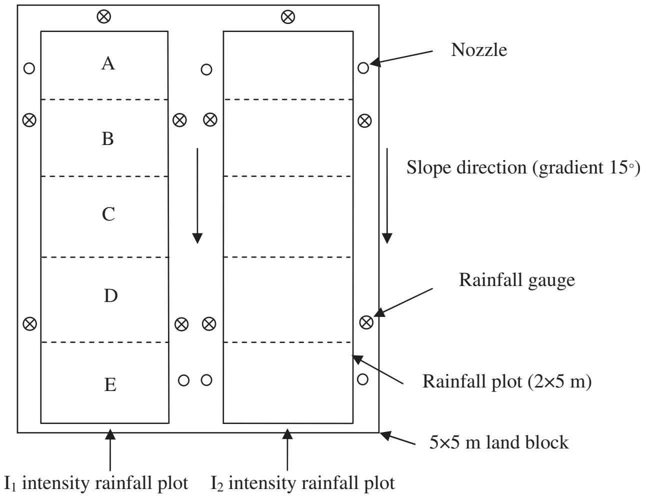

Fig. 2. Plot design for the rainfall simulation experiments.

For the erosion experiments, a rainfall simulator with a SPRACO cone jet nozzle mounted on the top of fixed 4.57 m long stand pipes was built. The nozzles were placed on the boundary of the plots

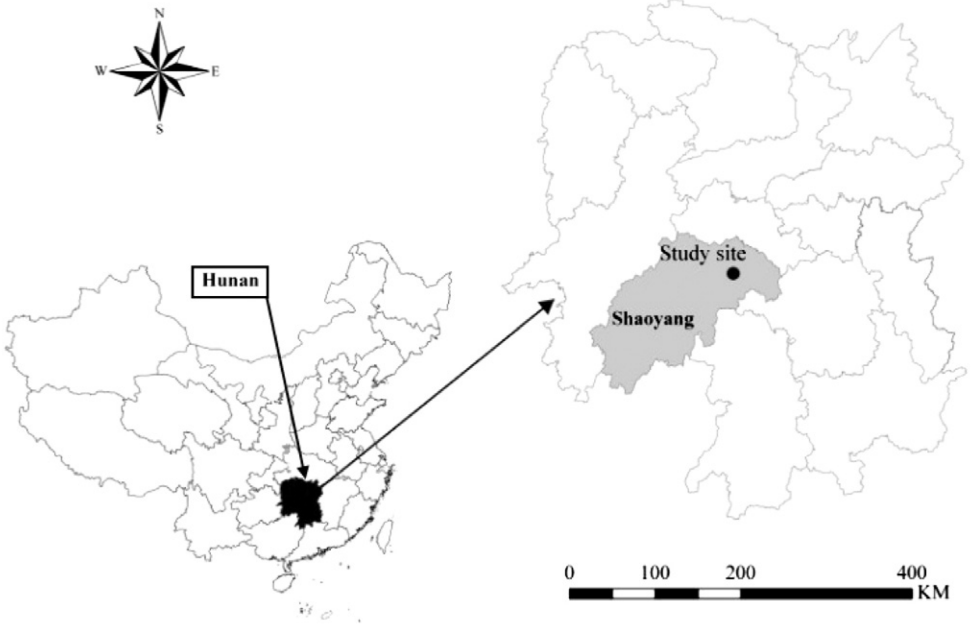

Fig. 1. Location of the study area.