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Effect of soil erosion on dissolved organic carbon redistribution in subtropical red soil under rainfall simulation

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ABSTRACT

Water erosion governs soil carbon reserves and distribution across the watershed or ecosystem. The dynamics of dissolved organic carbon (DOC) under water erosion in red agricultural soil is not clear. To determine the effect of tillage management and water erosion on vertical and lateral transportation of soil organic carbon (SOC) and DOC production under distinct rainfall intensities in the hilly red soil region of southern China, a chisel tillage plot with low rainfall intensity (CT-L) and two no-tillage plots with high (NT-H) and low rainfall intensity (NT-L) studies were conducted. Soil samples were collected from 0–5, 5–10, 10–20, and 20–40 cm soil layers from triplicate soil blocks pre- and post-rainfall for determining concentration of SOC and DOC. Runoff samples were collected at every 6 min for determining concentration of DOC and sediments during rainfall simulations on runoff plots (2 m × 5 m) with various intensities. No fertilizer was applied in any plots. Results clearly show that runoff volumes, sediments and SOC entrained with sediment, and laterally mobilized DOC were significantly larger on NT-H compared to other plots, coinciding with changes in rainfall intensity; and the extent of roughness of the plot surface (CT vs. NT) was the variation in runoff DOC concentration. During the simulated rainfall events, DOC exports average 0.76, 0.64, and 0.27 g C m^{-2} h^{-1}; SOC exports average 3.52, 1.08, and 0.07 g m^{-2} h^{-1} in the NT-H, NT-L, and CT-L soils, respectively. The maximum export of DOC was obtained under a high intensity rainfall plot, which lagged behind maximum runoff volumes, sediments, and SOC losses with sediment. Export of DOC was proportional to SOC content of soil loss. The least DOC losses in surface runoff and SOC losses with sediment were observed in CT-L plots. Vertical DOC mobilization achieved its maximum with low intensity rainfall under CT treatment. The DOC did not accumulate at the soil surface and was distributed mainly in the second and third soil horizons. The distribution of DOC content down the soil profile increased compared to pre-rainfall, except for subplots E at NT-H and NT-L. Results indicate that rainfall significantly increased DOC content in experimental plots. The SOC content of sediment leaving the erosion zone was significantly correlated with overland flow volume and soil loss. These observations lead to the conclusion that soil erosion is an important factor controlling the export of dissolved organic carbon.

1. Introduction

Soil organic carbon (SOC) storage and transportation across terrestrial ecosystems are strongly affected by water erosion (Lal, 1995). The earth's surface soil contains large quantities of organic carbon, storing 1462–1548 Pg C (Batjes, 1996), (1 Pg = 10^{15} g) in the top 1 m and roughly 2344 Pg C in the uppermost 3 m (Jobbagy and Jackson, 2000). Any changes in it will therefore cause a series of environmental problems, i.e., eutrophication, nonpoint source pollution (Lal, 1998; Ning et al., 2006), and eventually, land degradation (Singer and Shainberg, 2004). Water erosion has the greatest impact on C storage in the world (Lal, 2003) because of the loss of soil carbon during erosion by transport of surface runoff and sediments, which carries part of the soil carbon and, moreover, different sized soil particles may carry different amounts of soil carbon (Shi et al., 2013; Wang et al., 2014). Principal factors affecting erosion include soil properties, intensity and duration

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Abbreviations: NT-H, no-till plot with high intensity; NT-L, no-till plot with low intensity; CT-L, chisel till plot with low intensity.

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of rainfall, topography, surface cover, and soil moisture (Nearing et al., 2005). The complex process of soil erosion comprises detachment and transport of soil particles combined with the influence of raindrop impact and surface runoff (Quansah, 1981). The kinetic energy of raindrops breaks soil aggregates into individual components. The amount of soil available for removal by runoff depends on the strength of aggregates to resist the disruptive force of raindrop impact (Wuddivira et al., 2009).

Effect of soil erosion on the C dynamics (Rimal and Lal, 2009; Shi et al., 2013) and attendant emission of greenhouse gas are widely recognized (Gregorich et al., 1998; Lal, 2003). A large proportion of terrestrially derived C has been found that may have been mineralized (Durrieu et al., 2000; Goñi et al., 1998) and estimated that 1.14 Pg C yr^{-1} is emitted into the atmosphere (Lal, 1995). Jacinthe and Polyakov used microrunoff plots and laboratory incubation to quantify erosion-induced CO_2 evolution from the soil surface and runoff during rainfall events (Jacinthe et al., 2002; Polyakov and Lal, 2004). Results showed that CO_2 emission from the deposition areas (17.0 g C m^{-2}) during a 60-day period was higher than that from the eroded site (13.80 g C m^{-2}) under the condition of tillage practice, and that 29–35% of the C exported in runoff was mineralized in 100 days. More specifically, the mineralizable carbon in runoff, eroded site, and deposition sediment should be a majority of labile carbon, in particular DOC (Lal, 2003). Previous researcher's studies also indicated that the solubility characteristics of SOC might be another reason for high C loss associated with high surface runoff and soil loss during simulated rainfall (Jin et al., 2008). Lal estimated that depletion of the SOC pool upon cultivation was attributed to leaching and translocation as dissolved organic carbon (DOC < 0.45 μm) or particulate organic carbon (POC > 0.45 μm) (Lal, 2003). Jacinthe also reported that 29–46% of C is transported in surface runoff (Jacinthe et al., 2004). Leaching of DOC to subsoil horizons or groundwater results from water erosion also leads to soil carbon loss in another way. Leaching of DOC increases terrestrial land carbon storage and plays a major role in carbon sequestration (Dlugoß et al., 2012; Rumpel and Kögel-Knabner, 2011).

To date, previous reports on the relationship between SOC and soil erosion have largely been confined to the lack of data of dissolved organic carbon (DOC) distribution and to a failure of understanding vertical transport of SOC down the soil profile (Bremenfeld and Poesen, 2012; Zhang et al., 2006). The literature related to soil erosion and the carbon cycle is abundant (Lal, 2003; Van Oost et al., 2007). However, data related to the transport rate of DOC with various tillage management by water erosion are unavailable, particularly the downward movement pattern. The purpose of this study were, in the context of diverse conditions of rainfall intensity and soil surface treatments, (i) to determine the on-site vertical distribution of DOC and SOC along a slope, (ii) to identify the export of DOC and SOC at field plots, and (iii) to investigate the relationship between soil organic carbon content and DOC transportation. From this we can further understand the dynamics of soil carbon under water erosion typical of a subtropical red hilly region.

2. Material and methods

2.1. Site description

Red soil, which covers a total area of 2.18×10^6 km^2 in southern China, is characterized by low SOC and extensive weathering (Shi et al., 2010). Water erosion occurs throughout this region, with raindrop splash and slope runoff erosion being the dominant mechanisms (Zhang et al., 2013). Although the total amount of soil loss is lower than that of the Chinese Loess Plateau, the large geographic area of the hilly red soil region also makes it an important component of China's terrestrial carbon cycle. The current study site (111°22′ E., 27°03′ N.) is located at the Soil and Water Conservation Research Station of Shaoyang in the southwest of Hunan Province, China (Fig. 1). The average annual temperature is 17.1 °C and the mean annual precipitation is 1327.5 mm.

Soil in the region is Quaternary red clay with a clay-to-loam texture, which according to the U.S. Soil Taxonomy is classified as an Ultisol (Zhang et al., 2013). As is typical for the hilly red soil region, it has low organic matter content. Soil general properties from experimental plots were tabulated in Table 1.

2.2. Plot setup and rainfall simulation

The study was carried out in 2012 on three plots (5 m long and 2 m wide) with a 10% slope (Fig. 2). Each plot was surrounded with thin metal frames driven into the ground to shield them from runoff from adjacent plot areas. A V-shaped runoff funnel was positioned at the end of each plot to collect runoff samples. A plastic sheet was used to cover the runoff funnel at the lower end to prevent direct rainfall from falling into the collection system. The plot design was determined according to the following criteria: (i) minimal soil disturbance when setting the plot; and (ii) minimal distance between plots to minimize local variations in soil between plots.

The simulated rainfall experiments were conducted at the three plots described above using Spraco cone jet nozzles placed on 4.75-m-long stand pipes, which provided homogeneous rainfall on an area 2.4 m in diameter. To test for homogeneity of rainfall, a pre-experiment was carried out. The homogeneous coefficient reached 89.75, 90.23, and 91.36%, respectively, which was characterized by Christiansen's uniformity coefficient (CU) (Christiansen, 1942).

Types of rainfall intensity with 1.38 ± 0.06, 0.53 ± 0.08, and 0.52 ± 0.10 mm min^{-1} representing the high and low intensity storms (lasting for 60 min) of this region were applied in the three plots. The time at which runoff first occurred was measured using a clock. Runoff samples were collected every 6 min in covered storage tanks (1 L) and plastic buckets (30 L) until runoff generation ended. Runoff samples quantified the losses of soil and solution volume and determined the rate of soil and water loss. Portion of runoff samples were taken to the laboratory to test DOC within 24 h. From the amount of rainfall on the tray surface and the total runoff volume, runoff coefficients were calculated. The runoff from the storage tanks was later air-dried to determine sediment delivery and carbon content.

2.3. Sampling

Three plots were divided into five subplots (A to E) at 1-m intervals (Fig. 2). In order to assess the vertical transport of SOC and DOC during a simulated rainstorm, the sampling strategy involved pre- and post-rainfall samples. Sampling depths of 0–5, 5–10, 10–20, and 20–40 cm were set. In a pre-rainfall experiment, three arranged grids were chosen as the three replicates in each subplot. Each grid had dimensions of 20 cm × 20 cm. Three replicated samples (0.5 kg) were obtained. In this way 360 samples (4 layers × 3 replicates × 5 subplots × 2 pre- and post-rainfall × 3 plots) were obtained. Samples were taken to the laboratory, air-dried, and sieved through 0.25 mm mesh to determine organic carbon. During sieving, residual plant matter was removed by hand. All soil samples for determination of DOC were stored in a refrigerator at 4 °C until tested.

2.4. Sample treatment and analysis

The SOC concentrations were determined with the dichromate oxidation method of Walkley and Black (1934). Soil bulk density was obtained from three plots with the cutting ring method (Black and Hartge, 1986).

Dissolved organic carbon is the fraction of organic substances that passes through a filter (0.1–0.7 μm) (Liu et al., 2007). In our study, it is the fraction of organic substances that passes through a 0.45-μm filter. For determination of DOC content, 15 g of freeze-dried soil was shaken