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CO_2 emission pattern of eroded sloping croplands after simulated rainfall in subtropical China

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ABSTRACT

Soil water erosion can profoundly affect soil properties, especially their integration with serious cultivation. The mobilization and depletion of soil organic carbon (SOC) are likely to respond to this disturbance, which may profoundly change the patterns of ecosystem carbon cycles. The effects of water erosion on SOC mineralization within tillage (TT) and no-tillage (NT) sloping lands were examined in this study through the simulation of one-hour rainfall and field observation of CO_2 emission. During the rainfall, the estimated soil loss rates induced by erosion in NT and TT amounted to 0.72 and $0.05 \times 10^3\ g\ m^{-2}$ respectively, and the corresponding SOC loss rates amounted to 10.83 and $0.84\ g\ m^{-2}$. Most of the measured soil properties showed significant difference between NT and TT after erosion. The cumulative CO_2 productions of the three sub-plots in NT were lower than that of the control plot, while this observation was not detected in TT. NT also had larger variability in CO_2 evolution rate than TT. The potentially mineralizable C showed a pattern of increase from up slope to down slope in both NT and TT. Redundancy analysis results illustrate that soil bulk density, moisture and dissolved organic carbon were the major physical factors controlling erosion-induced carbon mineralization among the measured soil properties, and that a complex interplay between the above three factors and silt content could best explain the variability of the cumulative CO_2 productions. Together, these results suggest that patterns of CO_2 emission from sloping croplands are closely related to the changes of soil properties induced by erosion, and tillage practices may profoundly affect those patterns by inducing shifts in the erosion-resistance response of soil texture to rainfall. Moreover, tillage practices could slow SOC mineralization under the influence of a single rainfall event more than no-tillage practices in the hilly red soil region of subtropical China.

1. Introduction

Observed and projected increases in greenhouse gas emissions and their attendant effects on global warming and sea level rise have raised interest in identifying mitigation options (Lal, 2006). Soil organic carbon (SOC) pool is considered a potential major factor driving global climate change since it contains twice the amount of the atmospheric carbon pool (Alewell et al., 2009). Even a relatively slight dynamic variation in soil carbon content because of changes in land use, management practices, or natural disturbances may result in a significant net exchange of carbon between the soil carbon reservoir and the atmosphere (Van Hemelryck et al., 2011). As the most widespread form of soil degradation and the major inducer of SOC dynamics across terrestrial landscapes (Alewell et al., 2009), soil erosion has significant implications for atmospheric dioxide (CO_2) and climate warming (Jacinthe et al., 2002). Thus, intensive discussions on evaluating the direction and magnitude of an erosion-induced change in the global carbon balance have been conducted (Van Hemelryck et al., 2011). However, much debate still exists on concerning whether soil erosion is responsible for the increases or decreases of atmospheric carbon (Lal and Pimentel, 2008; Van Oost et al., 2008). One of the major uncertainties related to this debate is the fate of eroded and retained SOC.

Abbreviations: SOC, soil organic carbon; TT, tillage; NT, no-tillage; DOC, dissolved organic carbon; RDA, redundancy analysis; BD, soil bulk density.

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Determining to what extent these SOCs is degraded to CO_2 is critical to improving our knowledge on the role of soil erosion in global carbon cycling.

Soil erosion induces the redistribution of soil carbon within the landscape (Ritchie and McCarty, 2003) and affects the loss of C from the pedosphere to the atmosphere. As a natural geologic phenomenon, soil water erosion can cause a series of disturbances to soil respiration by changing the soil physicochemical properties (e.g., nutrient content, moisture, and pH) (Liu et al., 2003) and the substrate availability (i.e., SOC pools in different qualities and quantities) (Kuhn et al., 2009). Previous research has shown that abundant SOC is physically protected within soil aggregates, which are less resistant to external disruption (Shi et al., 2010). The physical protection of SOC through aggregation is eliminated by water erosion; when rain-impacted aggregates are broken down, the SOCs are released and exposed to microbial decomposition (Miller et al., 2005). Several experimental studies have shown that eroded SOC contains more labile fractions and is potentially unstable because of aggregate disruption (Bernoux et al., 2009). The selective removal of labile SOC fractions by water erosion strongly suggests that CO_2 emissions from soil into the atmosphere can be enhanced during and immediately after erosional events (Jacinthe et al., 2002). However, the net effects of water erosion on CO_2 emission remain uncertain, especially under different tillage practices. Subtropical China is covered with vast tracts of hilly red soil region characterized by extensive sloping croplands and is considered one of the most important food-producing areas. This region suffers from serious water erosion because of intensive agricultural cultivation (Jacinthe et al., 2002), which profoundly influences the regional carbon cycle patterns of China.

The majority of research on erosion-induced C mineralization has focused on the SOC budget by directly analyzing the variation of SOC pools. However, few studies provide direct evidence by field observation of CO_2 emission. The present study investigated the characteristics of C mineralization using in situ measurements of CO_2 efflux on tillage (TT) and no-tillage (NT) soils subjected to simulated water erosion in subtropical China. The objectives of this study are to (i) detect the changes in SOC stock and related soil physicochemical properties induced by water erosion, (ii) investigate CO_2 evolution in erosional croplands in relation to soil tillage practices, and (iii) evaluate the relationship between the CO_2 production and soil properties shaped by water erosion. The results of this research provide guidance to the management of soil carbon pool, which may be of considerable interest given the threats and predictions concerning global climate change.

2. Materials and methods

2.1. Experimental site

The experiments were performed at the Soil and Water Conservation Monitoring Station (111°22′ E, 27°03′ N) located in the Shuangqing district in Shaoyang city, Hunan Province, a hilly red soil region of south China (Fig. 1). This region is characterized by a subtropical monsoon climate with abundant precipitation in summer and annual mean minimum and maximum temperatures of 16.1 °C and 17.1 °C respectively. Mean annual precipitation is 1327.5 mm, 55% of which occurs during the rainy season from May to August. The soil in this area is classified as Quaternary red soil, which is heavily weathered and has inherently low SOC.

The experimental site, a typical sloping cropland, was planted with *Polygonatum odoratum (Mill.) Druce* for 10 years until 2009, and then left unused until the experiment field for rainfall simulation was established on it in 2011. Farming methods for this land adopt the chisel plow. The above-ground biomass of crops is typically stacked at the top of the sloping land to avoid being flooded after the root block is dug out. The sloping cropland consists of closely dissected short and steep slopes 1–3 m long and with gradients between 5% and 15%.

2.2. Experimental design and sampling schedule

The design of the experimental fields and sampling areas is shown in Fig. 2a. Two nearly identical, rectangular plots with dimensions of 2 m × 5 m (width × length) were bounded off with metal frames on the sloping cropland; one plot was used as the NT treatment block, and the other was used as the TT treatment block. The two plots were spaced 0.5 m apart and had a similar erosion-deposition pattern. Plant residues and sundries were removed from the soil surface prior to the rainfall simulation. Following traditional farming methods in the study area, the soil in TT plot was carefully loosened using a hoe. Plot loosening was conducted according to the following criteria: (i) minimal soil disturbance (0–10 cm) and (ii) avoiding soil lateral exchange along the direction of the slope. The 1 h rainfall simulation was conducted at 7:00–8:00 a.m. on July 16, 2012 for NT and at 7:00–8:00 a.m. on July 17, 2012 for TT. Four rainfall simulators were placed at the borders of the plot and were used to generate a rainstorm (Fig. 2a). The rainfall simulators were equipped with a SPRACO cone jet nozzle mounted on top of a fixed 4.57 m-high stand pipe. The median rain drop size was 2.4 mm with a uniformity of 89.7%. The same rainfall intensity of 1.5–1.7 mm min^{-1} was adopted in both NT and TT.

Soil sampling was conducted before and after the rainfall simulation at approximately 15 min intervals until six hours after the rainfall simulation. Each plot was divided into five equivalently arranged sub-plots (4 m width × 1 m length) along the slope. Three measurement sub-plots were sampled: the one on the upslope position of the plot (further termed UP-SLOPE), the one on the foot slope where considerable eroded sediments were deposited during the rainfall simulation (further termed DOW-SLOPE), and an additional measurement sub-plot (further termed MID-SLOPE) in the middle slope position where soil erosion and deposition occurred simultaneously (Fig. 2a). Soil layers (0–10 cm depth) at the measurement sub-plots in each plot were sampled along with their corresponding controls in a nearby flatland where did not suffer erosion. Sampling was conducted using a sterile push probe with a diameter of 70 mm. The soil properties for each sub-plot are summarized in Table 1. Three samples in each sub-plot were collected randomly as three replicates. All the soil samples were sealed and labeled in sterile air-tight Ziploc bags and immediately stored at −20 °C before use.

Non-steady-state gas-collecting hoods for CO_2 efflux measurements were installed in each measurement sub-plot and the control immediately after rainfall simulation (Fig. 2b and c). The hood, which is shaped like a cube and has a volume of 1 m^3, was made with five transparent PVC plastic sheets. It was equipped with a real-time CO_2 concentration detector (CO_2/C-500, Membrapor, SWISS) on its inner side wall and an electric fan on its ceiling to thoroughly mix the collected gas. The lower edge of the hood was carefully driven into the soil to a depth of 0–10 mm to avoid disrupting the soil structure. Once installed, the hoods were left in place throughout the course of the study; the measurement areas thus remained undisturbed during the entire study period. Soil samples from each sub-plot were collected around the hood after the installation.

CO_2-efflux from the soil surface was measured at regular time intervals (15 min) similar to soil sampling. All the CO_2 concentration detectors were linked to a data acquisition system (CO_2/C-500, Membrapor, China), which could receive real-time data from each detector to monitor the changes of CO_2 concentration in each hood.