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Soil CO_2 emissions from different slope gradients and positions in the semiarid Loess Plateau of China

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ABSTRACT

Knowledge of CO_2 emissions under different slope gradients and positions and its controlling factors is critical in accurately estimating CO_2 emissions and carbon cycling on the slopes of eroded regions. In this study, three east-facing plots of 100 m^2 (20 m × 5 m) with a slope gradient of 0.5° ($S_{0.5}$), 1° (S_1), and 3° (S_3) were established in an eroded gully of the semi-arid Loess Plateau, China. The CO_2 emission, temperature, moisture, runoff, sediment, fine root biomass and grain yield of these three plots were measured from October 2013 to September 2015 to investigate the relationship between slope gradients and soil CO_2 emissions. The results showed that the mean annual cumulative CO_2 emissions at S_1 and S_3 (731.0 ± 65.1 and 628.3 ± 74.8 g C m^{-2} year^{-1}) were about 13.4% and 25.5% lower than that at $S_{0.5}$ (843.7 ± 84.9 g C m^{-2} year^{-1}). The CO_2 emissions were higher at bottom slope than at upper slope, with an increase of 26.2% at S_3, 22.9% at S_1 and 14.5% at $S_{0.5}$, respectively. The mean soil moisture ranged from 40.8% to 44.8% water-filled pore space (WFPS) among the slope gradients, and from 35.8% to 45.6% WFPS among the slope positions. There was a significant difference in mean fine root biomass among different slope gradients ($S_{0.5} > S_1 > S_3$, $P < 0.05$), but no significant difference among different slope positions. The mean soil organic carbon (SOC) ranged from 8.8 g kg^{-1} at S_3 to 9.9 g kg^{-1} at $S_{0.5}$, and that at the bottom and middle slope were higher than that at the upper slope at S_1 and S_3. Slope differentiated soil moisture content and redistribution, and the thus derived spatial differences in fine root biomass and crop yields, was the major factor influencing the soil CO_2 emissions among slope gradients and positions. Slope gradients and positions should be considered when estimating soil CO_2 emissions and carbon cycling in the complex and fragmented topography regions.

1. Introduction

Soil CO_2 emission is an important component of global carbon cycle, and even a small variation in soil respiration can have a significant effect on the atmospheric CO_2 concentration and soil organic carbon (SOC) stock (Bond-Lamberty and Thomson, 2010; Hursh et al., 2017). However, the potential effect of slope gradients and positions on soil CO_2 emissions has not yet been fully elucidated (Chen et al., 2015; Van Hemelryck et al., 2011). In fact, more than 60% of global land areas are slopes of > 8° (Berhe and Kleber, 2013). Slope gradients can not only affect soil water and heat at the slopes, but also change soil properties and vegetation (Fehmi and Kong, 2012; Wei et al., 2014; Xiao et al., 2015). Therefore, knowledge of the effect of slope land on soil CO_2 emissions is essential for a better understanding of the global atmospheric CO_2 budget and climate change.

Soil CO_2 emissions in sloping land can be particularly affected by the spatial distribution of soil moisture (Liu et al., 2016; Singh et al., 2017), SOC (Fereidoonia et al., 2013; Hursh et al., 2017) and fine root biomass (Makita et al., 2016; Pandey et al., 2016) at different positions of the slope. To be specific, soil moisture in sloping land was reported to be significantly lower than that on plains, mostly because of the increased loss of runoff and, consequently, a reduction in infiltration (Zhang et al., 2015a; Zhao et al., 2015). Soil moisture varied spatially along the slope and it was

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significantly higher at the toe of the slope than at the summit (Wei et al., 2014). In consequence, the spatial difference in soil moisture at different slope positions may have considerable impacts on CO_2 emissions. In addition, SOC, as the main substrate for microbial organisms, can also differ spatially along the slope due to the selective or non-selective erosion effects (Pei et al., 2012; Van et al., 2010). For instance, SOC at the upper slope where soil was severely eroded was 9.1% lower than that at the middle slope where soil was mildly eroded, and 13.8% lower than that at the bottom slope where soil was deposited in a severely eroded slope land (Li et al., 2015b). Fine root biomass can reflect the varying biotic conditions at different slope positions, and decreases in an order of upper < middle < bottom in a *Pinus tabuliformis* forest at the south slope of *Qinling* Mountains of China (Liu et al., 2004). However, there have been no systematic studies investigating the effects of soil moisture, temperature, root biomass, grain yield and SOC under different slope gradients and positions on soil CO_2 emissions.

The main purpose of this study was to investigate whether soil CO_2 emissions at different slope gradients and positions were related to erosion-induced variations of water, crop growth and SOC. To address this problem, we compared CO_2 emissions at different positions (bottom, middle and upper slope) on the slopes of different gradients, and evaluated the potential effects of slope differentiated water, crop growth and SOC on CO_2 emissions at an eroded slope.

2. Materials and methods

2.1. Study area

In the semi-arid Loess Plateau, China, the area of arable land is 14.5×10^4 km^2. Tableland, steep slope and gully are the major topographical features of the Loess Plateau, each accounting for about one third of the watershed area. The tableland with a gentle slope (<5°) has a high nutrient content and thus has been the primary site for residence and agricultural production (Zhang et al., 2015b). However, these slopes are subject to serious water and soil loss due to the poor resistance to water erosion and the intensive cultivation (Jiang et al., 2015), thus resulting in gradually steeper slopes cutting into the edges of the tableland and a significant reduction in the tableland area (Chen et al., 2009).

The study area is located in the State Key Agro-Ecological Experimental Station, Wangdonggou (35°13′ N–35°16′ N, 107°40′ E–107° 42′ E), Changwu county, Shaanxi province, China, which is a typical eroded gully (altitude: 1220 m) of the south Loess Plateau (Fig. 1). This area has a continental monsoon climate with an annual mean precipitation of 560 mm for the period 1984–2014 (523 mm in 2013 and 597 mm in 2014 during the measurement period), 60% of which occurs between July and September (Zhang et al., 2015b). Over 70% of the crops (wheat and corn) are planted in rain-fed areas, which are highly susceptible to climate change impacts (Jiang et al., 2015). In general, the soil erosion is serious in the study area with a soil erosion modulus of 2860 t km^{-2} a^{-1}, which has a detrimental effect on the crop yield, surface water quality and regional hydrological regimes (Zhu et al., 2014). This makes it suitable to investigate the potential effect of soil erosion along different slope gradients on CO_2 emissions.

2.2. Experimental design

2.2.1. Arrangement of plots

Three east-facing rectangular plots, each with an area of 100 m^2 (20 m × 5 m), and three slope gradients of 0.5° ($S_{0.5}$), 1° (S_1) and 3° (S_3) were established in the study area in 1998. Since then, all the plots have been planted with winter wheat every year. In order to make the experimental conditions as identical as possible, the plots were prepared following the same procedure. To be specific, all plots were filled with surface soil (0–20 cm) collected from the

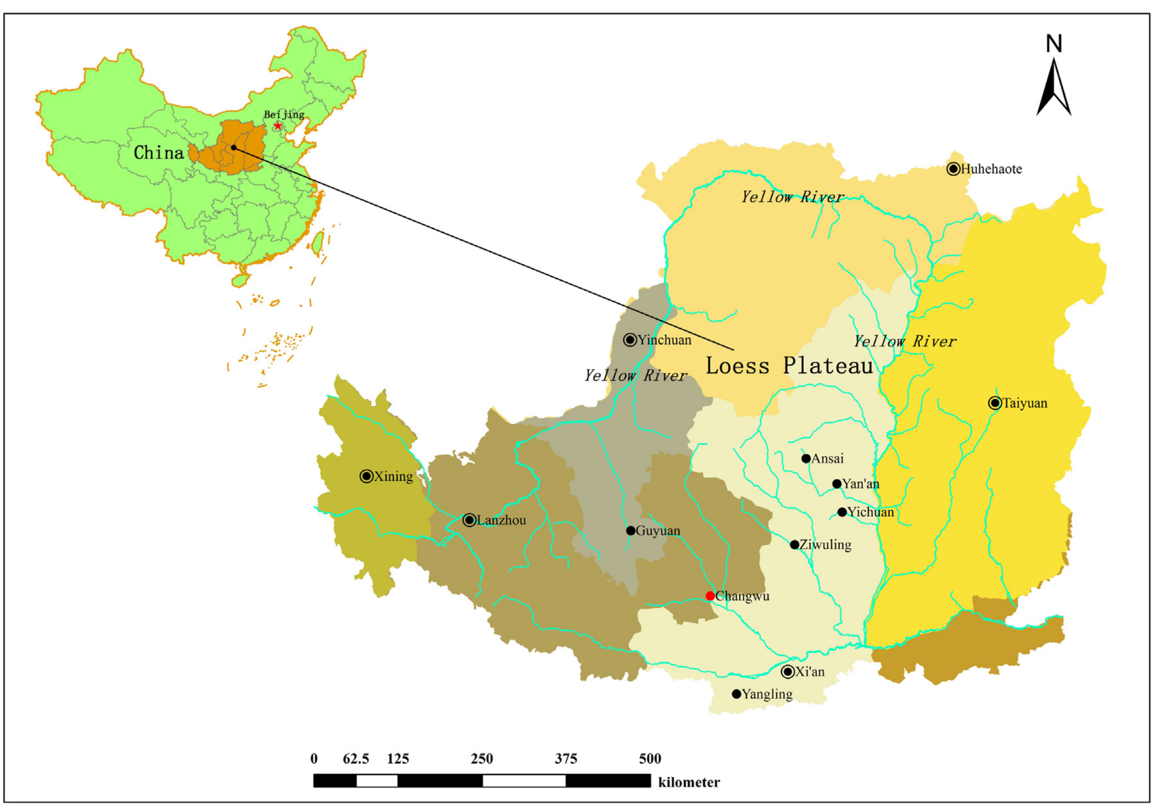

Fig. 1. A sketch map of the Loess Plateau.