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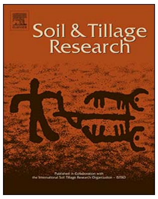

Short communication

# Soil organic carbon on the fragmented Chinese Loess Plateau: Combining effects of vegetation types and topographic positions

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## ABSTRACT

The influence of vegetation coverage and topography on soil organic carbon (SOC) stocks has been intensively studies. However, very few of the studies have recognized the potential combining effects of vegetation types and topographic positions onto SOC distribution, especially on the Chinese Loess Plateau where vegetation recovery has generated complex combination of fragmented topography and vegetation coverage. This study systematically sampled soil cores (259) from four vegetation types (woodland, grassland, cropland, and orchard) at three topographic positions (tableland, slope and valley bottom). Each soil core was divided into three layers: surface soil (0–20 cm), subsoil (20–60 cm) and deep soil (60–200 cm). Our results show that: (1) the SOC concentration declined over soil depths, regardless topographic positions or vegetation types. The absence of ancient cultivation layers at the valley bottoms further made the SOC stocks deep to 200 cm there much less than the tableland with thick loess soil layers (8.3 kg $km^{-2}$ vs. 13.4 kg $km^{-2}$). (2) The SOC concentration of cropland varied evidently with topographic positions, with the greatest on the tableland (8.0 g $kg^{-1}$), and the least along the slope (5.3 g $kg^{-1}$). However, grassland was rather stable across the three topographic positions. (3) In addition, the SOC concentrations of the three vegetation types were comparable on the tableland (6.1 g $kg^{-1}$), while differed noticeably at the valley bottoms (5.0 g $kg^{-1}$). Overall, our findings in this study call for the account for each combination of topographic position and vegetation type, so as to properly assess regional SOC stocks for sustainable land use.

## 1. Introduction

Substantial research has dedicated to investigate the potential effects of vegetation types to soil carbon pools (SOC) (Ayoubi et al., 2011; Ayoubi et al., 2012; Don et al., 2011; Shahriari et al., 2011; Wang et al., 2016), and has primarily recognized the contributions from different above- and under-ground biomass types, amount and return rates (Leeuwen et al., 2017; Post and Kwon, 2000). In general, it is agreed that conversion from natural vegetation types (e.g., woodland, grassland) to cropland will lead to a decline of surface soil organic carbon (Ayoubi et al., 2012; Malhi et al., 2003; Wang et al., 2009), mainly because tillage practices introduce soil disturbance, breakdown and nutrient output (Ayoubi et al., 2012). Meanwhile, changing from cropland land back to grassland is likely to help sequester SOC (Zhang et al., 2014; Deng et al., 2014a), yet the sequestration rate is likely to approach a plateau after 10–20 years (Deng et al., 2014a; Deng et al., 2014b).

Nevertheless, very few of these studies have taken topographic positions into consideration when addressing the potential effects of different vegetation types (Fernández-Romero et al., 2014). In fact, topographic positions are fundamentally relevant for hilly regions where the spatial distribution of SOC is primarily defined by erosion events (Karchegani et al., 2012; Khormali et al., 2007; Khormali et al., 2009; Zhu et al., 2014). Unlike flatland, selective erosion and transport of fine/light particles from eroding sites (mostly slope shoulder), and deposition SOC-rich fractions at valley bottom, all affect spatial redistribution of SOC across landscapes (Kuhn and Armstrong, 2012; Hu et al., 2013; Soinne et al., 2016). Such spatial redistribution relocates SOC into different micro-climate conditions, which potentially determines the accumulation and decomposition processes of SOC (Ayoubi et al., 2012 Fern & ndez-Romero et al., 2014; Zhu et al., 2014). Meanwhile, different vegetation types on varying topographic positions also have distinctive soil surface coverage, which fundamentally influences SOC input, hydrological processes and hence the spatial redistribution of SOC along hillslopes (Ellerbrock et al., 2011; Fern & ndez-Romero et al., 2014; Seibert et al., 2007).

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**Fig. 1.** Photo of the study area.

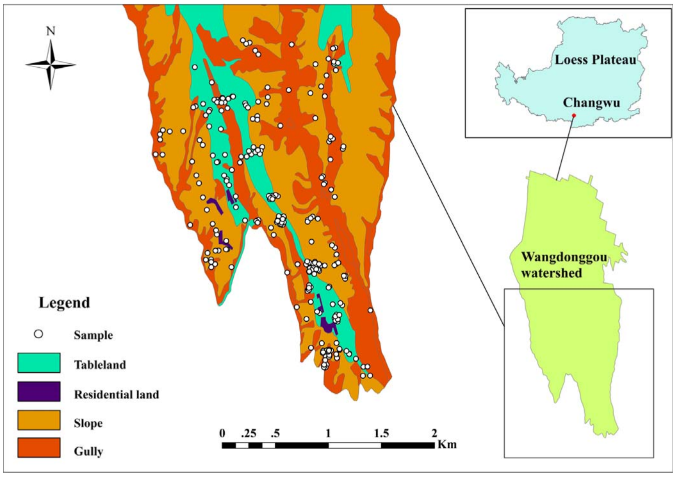

**Fig. 2.** Soil sampling sites and topographic positions of the study watershed.

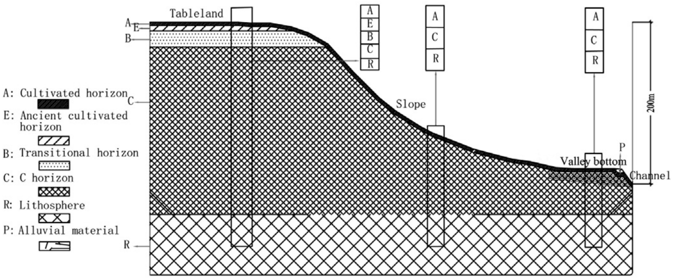

**Fig. 3.** Geological structure of tableland, slope and gully in the study watershed.

The Chinese Loess Plateau, a semiarid region covering a total area of $58 \times 10^4$ km$^2$, is characterized with thick (50 – 300 m) yet highly erodible soil (average soil loss rate 2860 t km$^{-2}$ a$^{-1}$) (Wang et al., 2011; Zhu et al., 2014). Hundreds of years intensive cultivation and severe erosion has incised into the plateau, fragmented the vast flat area into tableland (remnant flat parts of the plateau) and slopes (or gullies), with depositions in valley bottoms (Fig. 1). In addition, severe erosion has exposed parent materials and even bedrocks on slope back, meanwhile depositing the eroded materials in valley bottoms, forming a patchwork in the watershed (Fig. 1). In order to curb soil erosion on the Loess Plateau, a national-level "Grain-for-Green" rehabilitation project was launched in 1980 s, which forcefully converted cropland on slopes of gradient > 25° back to forest or grassland (Deng et al., 2014b). Variations in topographic positions and changes in vegetation types have fragmented the Chinese Loess Plateau into a complex combination of tableland, slopes and valleys with cropland, grassland, orchard and woodland. However, it lacks systematic investigations to particularly address the coupling effects vegetation types and topographic positions on the fragmented Loess Plateau.

The objectives of this study are to investigate the difference in SOC in the surface soil (0–20 cm), subsoil (20–60 cm) and deep soil (60–200 cm) layers among four vegetation types at three topographic positions, so that to identify the interactive effects of vegetation types, topographic positions and soil depth on SOC pools on the Chinese Loess Plateau.

## 2. Materials and methods

### 2.1. Description of the study area

The study area is located in State Key Agro-Ecological Experimental Station in Wangdonggou watershed (35°13′ N–35°16′ N, 107°40′ E–107°42′ E), on the Loess Plateau, Shaanxi province, China (Fig. 2). According to the long-term data set collected since 1984, the study area has a continental monsoon climate with mean annual precipitation of 560 mm, varying from 296 to 954 mm in recent 30 years. Out of that, 60% occurs between July and September. The soils are derived from wind-deposited loess with abundant SOC and $CaCO_3$ during the Holocene (Huang et al., 2003), and belong to Loessi-Orthic Primosols (USDA Soil Taxonomy) and Cambisols (WRB) (Wang et al., 2015).

In this study, we mainly focused on three topographic positions: on tableland, along slope and at valley bottom (Fig. 2). To be specific, tableland is relatively flat (gradient < 5°) at the altitude of 1220 m with soil erosion rate < 100 t km$^{-2}$ a$^{-1}$ (Li and Su, 1991). Dated back to the ancient Loess Plateau, the tableland has a full set of soil horizons (Fig. 3 and Table 1): cultivated layer (Horizon A), ancient cultivated layer (Horizon E), transitional layer (Horizon B), and C horizon (Horizon C). Slopes mainly distribute at altitude of 1000–1220 m with gradients of 5–50°. It basically consists of Horizon A and C being exposed on slope backs at erosion rates of 100–20,000 t km$^{-2}$ a$^{-1}$ (Li and Su, 1991). The valley bottom is mostly at altitude of 1000 m with gradient < 10°. As it accumulates eroded materials from tableland and slopes, soils at valley bottoms are mostly mixture of sediment sitting on loess parent materials in the deep layer.

Based on local vegetation distribution patterns, four vegetation types were investigated in this study: cropland, grassland (*Artemisia gmelinii, Bothriochloa ischaemum, Medicago sativa* L.), apple orchard (*Malus pumila* mill) and woodland (*Robinia pseudoacacia* L.). To be specific, cropland is rainfed, and mainly cultivated with mono-winter wheat and corn (*Triticum aestivum.* L and *Zea mays* L.) having annual crop yield of 5000 kg ha$^{-1}$ on average. Local management normally applies 600 kg N ha$^{-1}$ and 375 kg P ha$^{-1}$ chemical fertilizers every year, and removes crop residues for cooking or feeding cattle. Tillage practices are conducted twice a year to increase rainfall infiltration after the harvest (in July) and to prepare seed beds before the next sowing (in September). The apple orchard (*Malus pumila* Mill) was planted (by density of 2 m × 3 m) about 25–30 years ago, and tilled every year to control weeds. Fertilization management in apple orchard was similar to the cropland, and no irrigation was applied. Grassland and woodland have been redeveloped from cropland for 25–30 years, and received no fertilizer.

### 2.2. Soil sampling design

In mid-May 2012, soil samples were collected from the four vegetation types on the three topographic positions. Considering the demand for grains or fruits by local farmers who mostly live on the tableland meanwhile the impractical efforts to manage apple orchard at distant valley bottoms, no woodland was painted on tableland and no apple orchard was growing at valley bottoms. In total, 259 sampling