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Variation in soil organic carbon by slope aspect in the middle of the Qilian Mountains in the upper Heihe River Basin, China

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ABSTRACT

Topography has an influence on both abiotic (e.g. soil) and biotic (e.g. vegetation) factors influencing soil organic carbon (SOC). In this study, three slope aspects, south-facing, semi-sunny (south-west), and semi-shady (north-west) of mountainous grassland in the middle of the Qilian Mountains were sampled to explore the variation in SOC caused by topography. Soil properties were analyzed at different depths (0–10, 10–20, 20–40, and 40–60 cm). The results showed that except soil total organic phosphate, SOC, soil water content, soil bulk density, daily soil temperature, biomass, vegetation cover, and species richness on the semi-shady slope aspect were significantly different to those on two other slope aspects. The SOC, vegetation cover, and biomass significantly increased, from the south-facing to semi-shady slope aspect, and their values on the semi-shady slope aspect were around two times greater than on the south-facing slope aspect. The plant community composition also varied by slope aspect, with *Agropyron cristatum* and *Stipa grandis* dominant on the south-facing slope aspect, and *Agropyron cristatum* and *Carex aridula* dominant on the semi-sunny slope aspect, and *Kobresia humilis* and *Carex crebra* dominant on the semi-shady slope aspect. Among all measured abiotic and biotic factors, daily soil temperature, soil bulk density and total soil organic nitrogen could be used to predict SOC, explaining 69.0% of the variation in the data ($p < 0.001$). On all slope aspects, SOC was greatest in the top 20 cm of soil, representing around 60.0% of the total SOC to 60 cm depth. The results indicated that the distribution of SOC was regulated by slope aspect through its influence on vegetation and soil properties in this region. Therefore, SOC protection measures should be aspect specific.

1. Introduction

Soil is the largest pool of carbon after the ocean, storing about 1580 Gt of organic carbon and 600 Gt of inorganic carbon in the top meter (Maraseni and Pandey, 2014). In the top 30 cm of soil there is two times more carbon than in the atmosphere and about three times that stored in aboveground vegetation (Batjes, 1996). Human disturbance of natural vegetation is estimated to have caused 1–2×10^{15} g C yr^{-1} to have transferred to the atmosphere, about 17% of which may be derived from soil organic matter (Houghton, 1991). Increasing soil organic carbon (SOC) may mitigate climate change and help to maintain or improve the soil fertility and quality (Wang et al., 2010; Fernández-Romero et al., 2016; Lozano-García and Parras-Alcántara, 2013). The sequestration of SOC is therefore of great concern, and understanding its spatial variability and its influencing factors are essential for understanding the process of carbon sequestration in soil (Li and Shao, 2014). Estimation of SOC at regional, national, and global levels is of importance for assessing changes in global carbon fluxes (Rodríguez-Murillo, 2001; Sharma et al., 2012; Yimer et al., 2006; Muñoz-Rojas et al., 2012) and for identifying soil vulnerability and implementing appropriate protection policy (Powlson et al., 2011).

Slope aspect, is defined as the direction a slope faces (Selvakumar et al., 2009), and it influences energy and water balances, temperature, and the composition, distribution, cover, abundance, species richness, and productivity of vegetation within a landscape (Peter et al., 2002; Badano et al., 2005; Begum et al., 2010; Halim and Normaniza, 2015). This means that slope aspect affects both abiotic and biotic factors, either directly or indirectly, and thus can contribute to spatial variability in SOC (De Deyn et al., 2008; Sigua and Coleman, 2010; Sharma et al., 2011; Wagner et al., 2015). Determination of aspect-induced variations in SOC can be important for prioritizing areas for ecosystem management practices, and particularly for improving the potential of soils to sequester organic carbon with a focus on mitigating climate change (Yimer et al., 2006). However, much of the work on the effects of topographic attributes on soil carbon storage and dynamics has been conducted in forest ecosystems, and soils in mountainous areas have received relatively little attention, especially in forage-based pasture

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systems (Sigua and Coleman, 2010; Podwojewski et al., 2011; Lenka et al., 2013).

The Heihe River Basin is one of the largest inland river basins in the arid regions of northwest China, with the length of 821 km, and it flows through the Hexi Corridor of Gansu Province to the western part of the Inner Mongolian Plateau, providing water for irrigated agriculture. It is an important carbon pool (Kang et al., 2007), but few soil carbon storage studies have been conducted in this region, especially for variation in carbon induced by slope aspect. To improve our understanding of terrestrial carbon feedbacks with the atmosphere, baseline soil carbon data for high altitudes must be obtained because of their high carbon concentration and sensitivity to climate warming (Johnson et al., 2011; Chen et al., 2016). The objective of this work was to test how much slope aspect exerts an influence on SOC as a result of the influence of aspect on abiotic factors and biotic factors in mountainous grassland areas used for forage grazing. The findings were interpreted in light of policy support needed to protect SOC in the Heihe River Basin.

2. Methods

2.1. Study area

The Heihe River Basin is located at the climatic intersection between the Westerlies and the East Asian summer monsoon. The highest air temperature in summer can reach about 40 °C in the plains and downstream areas, while the lowest air temperature in winter falls to about −40 °C in the high mountain upper basin area. The upper reaches are in the Qilian Mountains, in which the source of the Heihe River is located, and which are characterized by a humid, cold climate with an elevation between 2000 and 5500 m, and a mean annual precipitation from 250 to 500 mm. Below the snow line (about 4200 m). The vegetation can be divided into high mountain meadow, brush and meadow, mountain grass and forest (mainly *Picea crassifolia*), mountain grass and finally desert grass in the north. The upstream flow provides water supply for agricultural production and ecosystem stabilization in the middle and lower reaches of the basin (Qin et al., 2010; Wu, 2011; Zhao et al., 2005).

The study sites in the core eco-region of the water source were located in the middle of the Qilian Mountains, with an elevation between 2200 and 3000 m, a mean annual precipitation of about 435 mm, and an average annual temperature of 0.5 °C. The local residents believe that there has been little human or natural disturbance of vegetation in the last 60 years, and *Picea crassifolia* in the area is between 52 and 117 years old; therefore, the vegetation can be regarded as a climax community (Zhang, 2009). In this region, according to the Chinese soil classification system, chestnut soil (predominantly sandy textured) developed on south-facing and semi-sunny slopes, and subalpine meadow soil (predominantly silty-sand textured) developed on the semi-shady slopes, while grey cinnamon soil (predominantly silty-sand textured) developed on the north-facing slopes (Chen et al., 2015; Jiang et al., 2013).

2.2. Experimental design, soil sampling, and vegetation survey

In August and September 2013 and 2014, three slope aspects, including south-facing (0–90°, SF), semi-sunny (south-west-facing, 90–135°, SW) and semi-shady slope aspect (north-west-facing, 135–180°, NW) at around 2900 m altitude were selected for analysis. The north-facing slope (180–270°, NF) was not used because it is dominated by *Picea crassifolia,* which is a fundamentally different plant form dominating a different ecosystem with different SOC dynamics, as confirmed for this region by Chen et al. (2016) and Wagner et al. (2015). The three aspects studied have essentially the same functional plant forms and are of the same broad ecosystem type.

A sample was comprised of three plots 10 m apart (Fig. 1). In each plot, three 50 × 50 cm quadrats were established in a row 1 m apart. Within each of these quadrats, percent cover and the number of individuals of each species were recorded, and all plants were clipped at the soil-surface level as total aboveground fresh biomass, along with daily soil temperature (DST) monitored from 06:00 to 18:00 at one-hour intervals using an EM50 soil temperature datalogger (Decagon Devices Inc., USA). Soil samples were taken to a depth of 60 cm using soil control sections (S1: 0–10 cm; S2: 10–20 cm; S3: 20–40 cm and S4: 40–60 cm), which have been shown to permit better comparison by slope aspect (Lozano-García et al., 2016; Parras-Alcántara et al., 2015b) than soil entire profile (Parras-Alcántara et al., 2015a).

2.3. Soil analysis

Three replicates for each soil core were analyzed in the laboratory (three slope aspects × 3 soil cores in each plot × 3 replicates for each soil control section) with the minimum required processing for each of the analytical methods. Soil water content (SWC) was determined gravimetrically on a wet weight basis by oven drying 5–10 g of undisturbed soil at 105 °C for 48 h. Soil bulk density (SBD) was determined from the undisturbed core segments as dry soil mass per unit volume. The SOC content was determined with wet dichromate oxidation using an air-dried homogenized subsample of 0.2 g soil and titrating with $FeSO_4$ (Nelson and Sommers, 1982). Soil pH was determined using a 2.5:1 water to air-dried soil ratio and a standard pH meter (Chapman and Pratt, 1961). Total soil organic nitrogen (TON) content was determined on an air-dried homogenized 0.5 g soil samples digested with sulfuric acid and K_2SO_4:$CuSO_4$:Se catalyst, and analyzed using a SmartChem 200 discrete chemistry analyzer (WestCo Scientific Instruments, Brookfield, CT, USA). Total soil organic phosphate (TOP) content from a similar 0.5 g soil sample was determined by digesting with H_2SO_4-$HClO_4$ and analysis using the Olsen method (Olsen et al., 1954).

2.4. Vegetation analysis

Aboveground biomass was assessed as the weight of all plant species. The species richness was expressed as the species count in surveyed plots. Cover was estimated using the Braun Blanquet scale (Westhoff and Van Der Maarel, 1978). Fresh samples were oven dried at 80 °C to a constant weight (48 h) and biomass were expressed on a dry weight basis.

An Importance Value Index (I_v) of herbaceous plants was calculated as $I_v = (R_c + R_f + R_d)/3$, where R_c is relative cover, R_f is relative frequency and R_d is relative density.

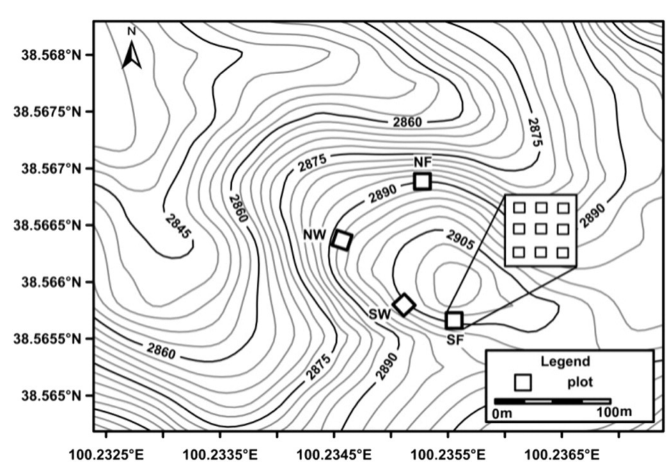

Fig. 1. Slope aspect selection and sample design of the herbaceous plant community. SF – south-facing slope, SW – semi-sunny slope, NW – semi-shady slope, NF – north-facing slope.