



Extent to which pH and topographic factors control soil organic carbon level in dry farming cropland soils of the mountainous region of Southwest China

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ABSTRACT

Soil organic carbon (SOC) in agricultural land is influenced greatly by indeterminate human activity, making it difficult to understand the spatial pattern of SOC. Soil pH and topographic conditions are key indices in the Chinese Soil Genetic Classification System (CSGCS) and manage some critical factors that control the dynamics of SOC either directly or indirectly. To identify the extent to which pH and topographic factors control SOC levels in dry farming cropland soils of the mountainous region of Southwest China, we compared the differences along topographic gradients, and analysed the contribution of different factors in determining SOC status using analysis of variance (ANOVA) and linear regression. Our results indicated the SOC levels ranged from $10.46 \text{ g} \cdot \text{kg}^{-1}$ to $37.60 \text{ g} \cdot \text{kg}^{-1}$ and were significantly correlated with soil pH, landscape position, slope and elevation ($p < 0.05$). On a large scale, the combined effects of landscape position and elevation contributed to fluctuating SOC levels along the elevation gradient. SOC levels slightly, but significantly, decreased from base to summit. The difference of SOC levels along a 200 m elevation gradient exhibited statistical significance ($p < 0.05$). A slope range, from 0° to 42° , was categorized into three groups, namely, 5° to 15° , 15° to 30° and others. The slope range 15° to 30° had significantly greater SOC values than the other groups. These variables could all together explain approximately 40% of total variation in SOC, of which approximately 70% was attributable to soil pH, suggesting soil pH plays a key role in forming the spatial pattern of SOC levels in dry farming cropland soils of the mountainous region of Southwest China. The combined effect of landscape position and elevation could further explain 7.3% of SOC variation, which is more apparent than the effect of elevation alone.

1. Introduction

Soil organic carbon (SOC) is the largest pool of carbon in terrestrial ecosystems (Lal, 2008). Large emissions of carbon dioxide (CO_2) from soils can occur when land-use conversion occurs (Mooney et al., 1987; Smith, 2008), greatly influencing the atmospheric concentration of CO_2 (Smith, 2012). Change in SOC stocks has received considerable attention as global annual average temperature and CO_2 concentration have increased in recent decades. However, estimates of global SOC storage based on different methods differ due to shortage of observed data (Batjes, 1996; Bohn, 1976; Lal, 2004). To improve our estimates of CO_2 fluxes from soils, a better understanding of the factors determining SOC levels is required.

Soil pH, a measure of soil acidity or alkalinity, influences crop yields, soil nutrient release, and soil microbial activity, to a large

extent. Thus, it could be used as a predictor of soil biotic and abiotic properties that control the stability of soil organic matter (SOM), either directly or indirectly (Heggenlund et al., 2014; Lauber et al., 2009; Oades, 1984; Zhalnina et al., 2015). Soil pH value is also a key index that is used to identify soil type in the Chinese Soil Genetic Classification System (CSGCS), as well as to assess soil quality. However, soil pH value is adjustable because it can be impacted by many factors. For instance, soil-forming factors, including parent material, topography, climate and vegetation, affect soil pH to differing extents. Agricultural practices such as fertilization, liming and tillage also influence soil pH, but few reports have quantified the relationship between soil pH and SOC levels on a large scale (Weil and Brady, 2016).

In mountainous regions, topographic factors regulate the redistribution of heat, water, clay, ions and minerals, indirectly influencing SOC accumulation and decomposition (Appelgarth and Dahms, 2001;

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Lybrand and Rasmussen, 2015). For instance, Wiaux et al. (2014) observed 30% more soil respiration at the downslope and 50% more respiration at the backslope, relative to the summit position. Many papers reported that SOC stock had a good relationship with elevation (Dahlgren et al., 1997; Jobbágy and Jackson, 2000). Meanwhile, there was a higher potential risk of soil particle mobility in mountain areas than on flat land. Therefore, SOC levels in mountainous areas are highly variable, mainly due to local-scale heterogeneities in the soil environment, such as elevation, slope and landscape position (Griffiths et al., 2009).

Human activities such as tilling, grazing and land management can become the dominant factors controlling SOC levels after the conversion of natural land for agricultural production (Lal, 1999; Nayak et al., 2012). Currently, cropland soils are widely distributed across the world and occupy approximately 34% of the global land surface (Betts et al., 2007; Schlesinger and Bernhardt, 2013). Evidence increasingly shows that the conversion of most natural land to cropland has resulted in carbon losses by influencing the rate of SOC mineralization (Sun et al., 2013) and soil erosion (Quine and Van Oost, 2007). Fortunately, farmers have come to realize the importance of SOM as a critical soil property determining land productivity under long-term cultivation practices (Xiao, 2013). To sustain soil fertility, many farmers use measures such as crop rotation, organic amendments and tillage modifications to maintain SOM levels (Poeplau et al., 2011; Söderström et al., 2014). However, estimating SOC levels on a large scale is still a challenge (Zhang et al., 2008).

Southwest China is characterized by a mountainous and complex topography, contributing to the great spatial variability of SOC (Office of National Soil Survey, 1998). In Guizhou province, the mountainous areas account for 92.5% of total land. The elevation in the region increases from 147.8 m in the southeastern part to 2900 m in the west, with an average elevation of 1000 m. The annual mean temperature and rainfall show significant changes with elevation. In addition, the well-known Karst landscapes prevail throughout an area of 109,084 km², and there is an extensive outcrop of carbonate rock (Zhang et al., 2008). All of the above make it very difficult to estimate soil coverage or soil stock. Approximately 40 million people live in this province. Given the food requirements of this population, large areas of mountainous land have been converted to cropland. SOC distribution in this region has become more complex due to the combined effects of anthropogenic and natural factors. On the other hand, it is well-known that pH plays an important role in controlling the dynamics of SOC (Rousk et al., 2009). It is also a key index used to identify soil type in the CSGCS and to assess soil quality. Based on this situation, the aims of this paper are: 1) to establish the relationship between SOC, soil pH, and topographic factors; and 2) to estimate the extent to which pH and topographic factors control SOC levels in dry farming cropland soils of the mountainous region of Southwest China.

2. Materials and methods

2.1. Study site description

The study area is Xinyi County, located at the centre of Southwest China, lying between 140°32'–150°11'E longitude and 24°38'–25°23' N latitude, with an agricultural area of 30,400 km². Xinyi County has a population of 830,000 people and includes 180 administrative villages (Fig. 1). The climate is subtropical with an annual average temperature of 14–19 °C, and rainfall of 1300–1600 mm. Its topography is characterized by mountainous landscapes with various elevations from 625 m to 2200 m. Based on CSGCS, the soils in this region can be categorized into four types: red soil, yellow soil, limestone soil and yellow-brown soil. The distribution of natural soil types is significantly influenced by elevation and geological conditions (Table 1). However, due to a lack of investigation into the extent of the anthropogenic disturbances of soil properties, the soil under the dry farming cropland

has not been accurately and uniformly identified, or simply classified, at the lowest level (Guizhou Soil Survey Office, 1994). The prevalence of carbonate outcrops is very high and is considered the main parent material of the soil in this region (Guizhou Soil Survey Office, 1994). Dry farming land occupies > 80% of the total agricultural land. The main crops of most dry farming land are corn and rapeseed, which are rotated.

2.2. Data processing and statistical analysis

Data used in this study are derived from an agricultural census carried out by Guizhou University from 2008 to 2010. This agricultural census included almost all administrative villages of XinYi County. Soil samples to a depth of 25 cm were collected using a shovel. Each one was composed of at least 6 points. Slope, landscape position and elevation at each site were recorded in the field. Landscape positions of sites were grouped into four categories: Summit, Shoulder, Foothslope, Toeslope and Plain (Toeslope and Plain were classified as a single group). To provide input for the regression models, the landscape positions were transformed into continuous variables of 1, 2, 3 or 4.

Visible plant residues and > 2 mm rocks were removed before grinding. All soil samples were air-dried and ground in order to be able to pass through a 0.154 mm (100 mesh) stainless-steel sieve. SOM content was determined by dichromate digestion based on the Walkley–Black method, and divided by 1.72 to obtain the SOC value (g·kg⁻¹). Soil pH was measured with an electrode in a ratio of 1:2.5 (m/v) soil-to-water suspension (Bao, 2005). To control the quality of data and ensure representativeness, the Triple Standard Difference Method (Pauta Criterion) was used to exclude any anomalous values of SOC (Redeker and Kalin, 2012).

To identify the effect of pH and topographic factors on SOC and to ensure comparability within soils cultivated in a similar way, we selected the dry farming cropland soils for analysis. Analysis of variance (ANOVA) was used to assess the difference of SOC levels under different conditions. A correlation matrix (Pearson correlation) was used to identify the relationships between factors. Multiple regression analyses were carried out for SOC levels on a range of related factors. The regression analyses were performed using the stepwise procedure and interactions with an F ratio probability of 0.05 were included in the model. The normality of the model's residuals was tested using the non-parametric Kolmogorov–Smirnov test, and its independence was checked using the Durbin–Watson test. All analyses were performed using the SPSS 17.0 statistical package.

3. Results

The SOC levels in the dry farming cropland soils exhibited large variations, ranging from 10.46 to 37.60 g·kg⁻¹ (mean ± S.D.: 24.11 ± 4.58 g·kg⁻¹) (Table 2). SOC levels had significant relationships with pH, landscape position, slope and elevation ($p < 0.05$). Soil pH correlated closely with slope ($p < 0.05$), but the correlations between landscape, elevation and soil pH did not exhibit a statistical significance ($p > 0.05$) (Table 3).

For landscape position, over 56% of soil samples were scattered along the Foothslope, where SOC levels ranged from 10.46 to 37.51 g·kg⁻¹ with a mean value of 24.39 g·kg⁻¹. The order of mean SOC levels was Toeslope or Plain > Foothslope > Shoulder > Summit. There were significant differences among the four landscape positions ($p < 0.05$), but not between the Summit and Shoulder (Table 4).

The slope ranged from 0° to 42°, with a mean value of 14° (Table 2). Nearly 74% of soil samples were collected between 5 and 25°, which is representative of the distribution of dry farming croplands in the mountainous region of Southwest China. The sample sites were classified as 7 groups, based on 5° intervals (the sample sites above 30° were classified as one group) (Table 5). In terms of averages, the value of SOC in the 25–30° group was the highest (24.88 ± 4.38 g·kg⁻¹).

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