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Environmental variables controlling soil organic carbon in top- and sub-soils in karst region of southwestern China

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ABSTRACT

Detailed information about the variability of soil organic carbon (SOC) content in different horizons is vital for the effective management of soil fertility and can improve understanding of SOC accumulation and decomposition. However, few studies have explored the variations of SOC content of cultivated lands in different horizons at the regional scale, particularly in a karst region in southwestern China. In this work, 235 soil samples were collected from the A to C horizons at 80 sites over the study area. Classical statistics and classification and regression trees (CARTs) were applied to investigate the critical environmental variables (topography, climate and parent material) that control SOC content variability in various horizons. Results indicated that SOC content decreased and its variability increased with an increase in horizon depth. The SOC content in the three horizons was predicted well by the CART models. The mean absolute prediction error, root mean square error and coefficient of determination ranged from 2.38 to 3.85 $g\,kg^{-1}$, 3.23 to 5.2 $g\,kg^{-1}$ and 0.5837 to 0.856, respectively. The importance of the environmental variables in SOC content varied with the horizons. In the A horizon, topographical variables, such as terrain wetness index (TWI), terrain ruggedness index and slope, were the key factors affecting SOC content variability. In the B horizon, the topography still showed the primary influence by elevation and TWI, meanwhile the importance of the parent material strengthened. Climate variables had the greatest impact on SOC content in the C horizon. TWI and precipitation that directly influenced soil moisture were the primary factors controlling SOC content in the three horizons.

1. Introduction

Soil organic carbon (SOC) is closely related to the levels of soil fertility and plays a crucial role in determining soil quality (Gami et al., 2009). SOC determines the soil's physical, chemical and biological properties. This maintains soil quality by supplying nutrients, enhancing cation exchange capacity, supporting biodiversity and improving aggregation and water-holding capacity (Bationo et al., 2007). These physical, chemical and biological processes occurring in soils can also affect SOC in terms of quantity and quality. In many environments, SOC shows high spatial variability and its distinct differences are often found within short distances of meters or even decimetres (Schöning et al., 2006; Wiesmeier et al., 2009). Understanding the spatial variability of SOC content and the relationship between SOC and environmental factors is essential for evaluating nutrient cycling, sedimentation and other functions in soils (Yang et al., 2015); consequently, detailed information about sustainable soil utilisation and management should be provided (Baets et al., 2013).

Numerous studies have explored the relationship between SOC content and environmental variables (Jordi et al., 2007; Hattar et al., 2010; Cinzia et al., 2010; Umali et al., 2012; Xu et al., 2012; Wiesmeier et al., 2014; Falahatkar et al., 2016). Topographic variables generated from digital elevation models (DEMs) are numerical representations of relief attributes (Webster et al., 2011; De Oliveira Jr et al., 2014), and they provide quantitative and reliable landscape descriptions (De Oliveira Jr et al., 2014). They influence soil properties through geomorphological, hydrological and biogeochemical processes (Creed et al., 2002). The spatial variability of SOC content is generally controlled by primary topographic variables, such as elevation, slope and aspect, and secondary geomorphologic parameters, such as terrain wetness index (TWI) and terrain ruggedness index (TRI) (Jordi et al., 2007; Hattar et al., 2010; Umali et al., 2012; Wiesmeier et al., 2014). Previous studies have reported that elevation is significantly correlated with SOC content (Leifeld et al., 2005; Neufeldt, 2005; Wiesmeier et al., 2013b). In certain environments, elevation is responsible for reduced SOC degradation. For example, Leifeld et al. (2005) and Zhao et al. (2017) reported that SOC content increases with elevation in Switzerland and in the Loess Plateau of China. By contrast, Jordi et al. (2007)

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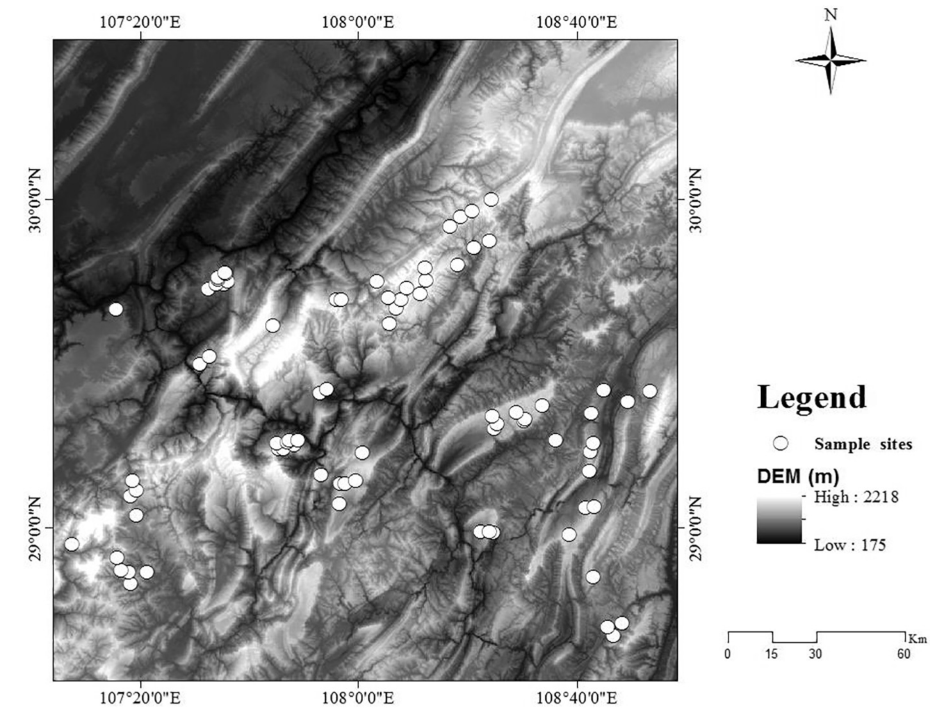

Fig. 1. Maps of digital elevation model (DEM) and distribution of sampling sites.

found that in Spain, SOC content is low at high altitudes possibly due to the overall temperature limitation of the net primary productivity. Recently, Różycka et al. (2016) explained that TWI and TRI provide information about landslide morphology and influence the distribution of SOC (Hattar et al., 2010). Parent materials considerably affect ecosystems (vegetation and soil) and serve as an important driver of SOC at the regional scale (Jenny, 1994; Wiesmeier et al., 2013b). Precipitation and temperature determine the size of plant productivity and the speed of SOC decomposition. Global warming has resulted in the quick turnover of topsoil organic carbon (Chen et al., 2013). SOC decomposition is sensitive to temperature, and substrate supply can influence the temperature responsiveness of SOC decomposition rates (Cinzia et al., 2010; Xu et al., 2012). SOC content is generally negatively associated with temperature (Hobley et al., 2015) and positively associated with annual mean precipitation for increases in soil moisture (Yang et al., 2010; Hobley et al., 2015). However, these studies were largely restricted to the SOC content of the ground surface, and most of them focused on forest or grassland soils instead of cultivated soils (Jordi et al., 2007; Seibert et al., 2007; Fernández-Romero et al., 2014). In recent years, SOC in deep horizons has received increasing interest (Rumpel and Kögel-Knabner, 2011; Wiesmeier et al., 2013b). For instance, Hobley et al. (2015) found that environmental variables show different levels of importance affecting SOC content in several depth intervals. Wiesmeier et al. (2013a) proved that explained variances are higher for SOC content in the topsoil (A horizon) than for entire soil profiles.

A broad range of statistical methods, such as classic statistical methods (Zhang et al., 2012), geostatistical methods (Umali et al., 2012; Różycka et al., 2016) and machine learning methods (Grimm et al., 2008; Guo et al., 2013; Wiesmeier et al., 2014; Falahatkar et al., 2016), have been applied to study the relationship between SOC content and environmental variables. The classification and regression tree (CART) method, which is a non-parametric technique, was used in the present study (Breiman et al., 1984). One of the outcomes of the CART method is the relative importance of independent variables, which could then be applied to investigate the influence of environmental variables on SOC content.

The karst region of southwestern China belongs to the Wuling Mountain area, which has complex environmental conditions. Karst landforms in this area developed well, and limestone is widely distributed. In this mountainous ecosystem, SOC content is inevitably controlled by the combined effects of topography, climate and human activities. The current study aimed to (1) explore the spatial distributions of SOC content in different horizons of the mountainous karst region in southwestern China and (2) evaluate the effects of environmental variables (topography, climate and parent material) on SOC content variability in different horizons using CART models.

2. Materials and methods

2.1. Study area

The study area (28°30′–30°30′ N, 107°–109° E) is located in the Wuling Mountain region of southwest China. The topography is mountainous and has elevations ranging from 175 to 2218 m. The climate is temperate and humid with a mean annual temperature of 13 °C and mean annual precipitation of 1359 mm. Precipitation in the rainy season (May–September) accounts for approximately 70% of the total annual precipitation. The landform type in this area is karst. Limestone is widely distributed over the study site, and groundwater resource is abundant, thereby serving as an important living water source for the locals. Soil developed from different parent materials namely, Silurian marlite and Triassic, Permian, Ordovician and Cambrian limestone (Gong, 1999). The main soil types are alluvial, cambisols and luvisols. The soil textures in the profiles are clay, loam and clay loam. The slope ranges from 0.45° to 37.12°. As the slope increases, the planting density of tobacco decreases artificially over the study area. Tobacco plants are mainly planted in the sunny (aspect between 135° and 275°) or semi-sunny (aspect between 45° and 135°) aspect in this area. Tobacco is one of the main economic crops in Wuling Mountain; it is usually planted in April and harvested in August.

2.2. Soil data

Eighty points were generated randomly by the geographic information system with respect to topography and parent material