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Soil organic carbon stocks in relation to elevation gradients in volcanic ash soils of Taiwan

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ABSTRACT

Soil organic carbon (SOC) stocks are controlled by factors with varying degrees of importance at different spatial scales. In this study, soil data were collected from recently sampled pedons and previous studies on volcanic origin soils in Yangmingshan (YMS) National Park in northern Taiwan. This study evaluated the effect of soil order, vegetation type and elevation on the SOC stocks of humid subtropical volcanic ash soils. Analysis results indicate that SOC stock (mean ± standard deviation) was 15.6 ± 4.5 kg m^{-2} m^{-1} (n = 40) for Andisols and 17.3 ± 7.3 kg m^{-2} m^{-1} (n = 20) for Inceptisols with andic soil properties. Meanwhile, SOC stocks under silver grass (17.4 ± 5.5 kg m^{-2} m^{-1}, n = 20) and bamboo (17.9 ± 2.5 kg m^{-2} m^{-1}, n = 8) were significantly higher than those under secondary forests (14.9 ± 6.0 kg m^{-2} m^{-1}, n = 32). Additionally, statistically significant linear regressions were found between the mean SOC stock and the mean of elevation classes. Climate, vegetation types and soil mineralogy vary along elevation gradients in the complex terrain. Our results demonstrated that elevation is a simple and effective predictor of SOC stock.

1. Introduction

As the largest reservoir of carbon (C) in the terrestrial biosphere (Batjes, 1996), soil has received considerable attention as a potential source or sink of the greenhouse gas carbon dioxide (CO_2). The spatial distribution of soil C pool must be understood to manage soil C as well as predict its potential responses to global change (Powers and Schlesinger, 2002). Soil organic carbon (SOC) stocks represent a dynamic equilibrium of C input and release from the soil, which are controlled by factors such as climate (i.e. temperature and precipitation) (Burke et al., 1989), vegetation (i.e. quality and quantity of litterfall) (Garten and Hanson, 2006; Li et al., 2010; Quideau et al., 2001) and soil texture and mineralogy (Burke et al.1989; Torn et al., 1997) in natural ecosystems. Additionally, the relative importance of these factors varies at different spatial scales of an ecosystem (Powers and Schlesinger, 2002). Vegetation is the only source of carbon for the soils in terrestrial ecosystems; in addition, vegetation type change significantly affects SOC stocks (Jobbágy and Jackson, 2000). According to some studies, vegetation more significantly affects SOC stock than that of climate condition (Li et al., 2010; Quideau et al., 2001).

While some studies indicated that SOC stock increased with increasing elevation (Garten and Hanson, 2006), other investigations suggested that the variation of SOC stocks in mountain regions is likely attributed to soil forming factors other than the elevation. Tian et al. (2007) found that the soil C concentrations are positively correlated with the elevation only for bamboo, but not for a pasture system in Ecuador. Djukic et al. (2010) indicated that the SOC stock to bedrock increased with an increasing elevation from 900 m to 1500 m in the Austrian Limestone Alps. However, SOC stock decreased again at elevations higher than 1500 m because a harsh climate and short growing seasons limited the net primary production and C inputs to the soil system. Such a reduction in SOC content at higher elevations due to the decrease of litterfall was also observed in an alpine inner-tropical soil catena in Vietnam (Podwojewski et al., 2011). Li et al. (2010) found that SOC stocks were strongly correlated with the aboveground vegetation properties rather than climate or altitude. These contradictory results can be explained by the co-variation among vegetation, soils and climate conditions in response to elevation rather than as independent variables in natural soil landscape systems. For example, Kunkel et al. (2011) indicated that the elevation gradient strongly covered the differences of aspect that produces wetter and cooler conditions at higher elevations in a semi-arid landscape. The precipitation gradient translates into a vegetation gradient in which more biomass is supported at higher elevations. Meanwhile, less insulation (i.e. incoming solar radiation) on north-facing slopes may reduce soil temperatures and inhibit soil respiration, resulting in a higher SOC stock. Podwojewski et al. (2011) suggested that SOC content is controlled not only by temperature and organo-metallic complexes, but also by the pedogenic processes linked with vegetation type changes along the elevation gradient. To elucidate these factors and their interactions as well as their impact on SOC stock in natural ecosystems, a substantial

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database derived from long-term monitoring (e.g. Li et al., 2010) or from high cost instruments and techniques (e.g. normalized differential vegetation index (NDVI) data obtained from remote sensing) (Gamboa and Galicia, 2012; Kunkel et al., 2011) appears to be necessary.

As is well known, among the soils of the world, Andisols derived from volcanic material accumulate more SOC than other soils (Batjes, 1996; Eswaran et al., 1993). Although covering approximately 0.84% of the earth's surface, Andisols contain approximately 5% of global soil carbon (Eswaran et al., 1993). Andisols contain large amounts of non-crystalline and poorly crystalline minerals and oxides which cause their distinctive properties (Shoji et al., 1993). Previous studies have described various mechanisms for chemical and physical stabilization of SOC in Andisols, including Al toxicity, formation of Al–humus complexes (Matus et al., 2006; Shoji et al., 1993) and physical protection by SOC adsorbed or trapped in the fractal allophone structure (Chevallier et al., 2010), as major processes of sequestration SOC for volcanic ash soil ecosystems.

Yangmingshan (YMS) National Park, located in northern Taipei City, was established in 1985 to preserve the unique volcanic landscape and geological features of northern Taiwan. The volcano ejecta cover an area of approximately 200 km^2 in the northern tip of Taiwan. Tsai et al. (2010b) indicated that the SOC contents of surface soils decreased with a decreasing elevation along a climosequence transect. They also proposed that the additions of SOC from vegetation, temperature and soil properties contributed to the differences of SOC accumulation in different transects. However, that study failed to further calculate the SOC stocks distributed in the various regions of volcanic ash soils. Based on field observations and their study, we hypothesize that SOC stock in the YMS volcanic soils increased with an increasing elevation. Additionally, the SOC stocks were also affected by different vegetation types (i.e. secondary forest, silver grass and bamboo) along the elevation gradients and different major Soil Orders (i.e. Andisol and Inceptisol). In this study, data from 28 soil pedons recently sampled in the YMS National Park were collected, as well as available data from 35 soil pedons collected from previous studies. All selected soil pedons were derived from volcanic original. This study has the following objectives: (1) to estimate the SOC stocks in humid subtropical volcanic ash soils in the YMS National Park, and (2) to evaluate how Soil Orders, vegetation types and elevations affect the SOC stocks.

2. Materials and methods

2.1. Study site

Taiwan is located at the convergent boundary between the Eurasian plate and the Philippine Sea plate (Juang, 1993). The Tatun Volcano Group is located at 15 km north of Taipei (Fig. 1). It is formed by the Pleistocene island-arc volcanic activities related to the Ryukyu arc–trench system (Chen, 1983). The volcano group was a result of episodic volcanisms between 2.8 and 0.2 Ma (Song et al., 2000). Three soil parent material types are found in the YMS National Park, i.e. hypersthene hornblende andesite, two-pyroxene hornblende andesite and andesitic lower tuff breccia (Chen, 1975).

In general, the terrain of the YMS National Park is high in the central region and radially decreased toward the edges (Fig. 1). In the YMS National Park, climate data was recorded by Anbu (836 m asl) and Zhuzihu (607 m asl) meteorological stations in the central region and Tamsui meteorological station (19 m asl) in the southwestern side. Mean annual temperature ranged from 22.1 °C at low elevations to 16.7 °C at high elevations. The temperature decreased 0.6–0.7 °C/ 100 m upwards with altitude (Chen and Tsai, 1983). Chen and Tsai (1983) indicated that temperature decreasing rate in the northeastern region was larger than that of the southwestern region; on the other hand, the decreasing rate in winter was larger than that in summer. Temperature varied not only with elevation but also with landscape in the YMS National Park. Typhoons in summer and winter monsoons

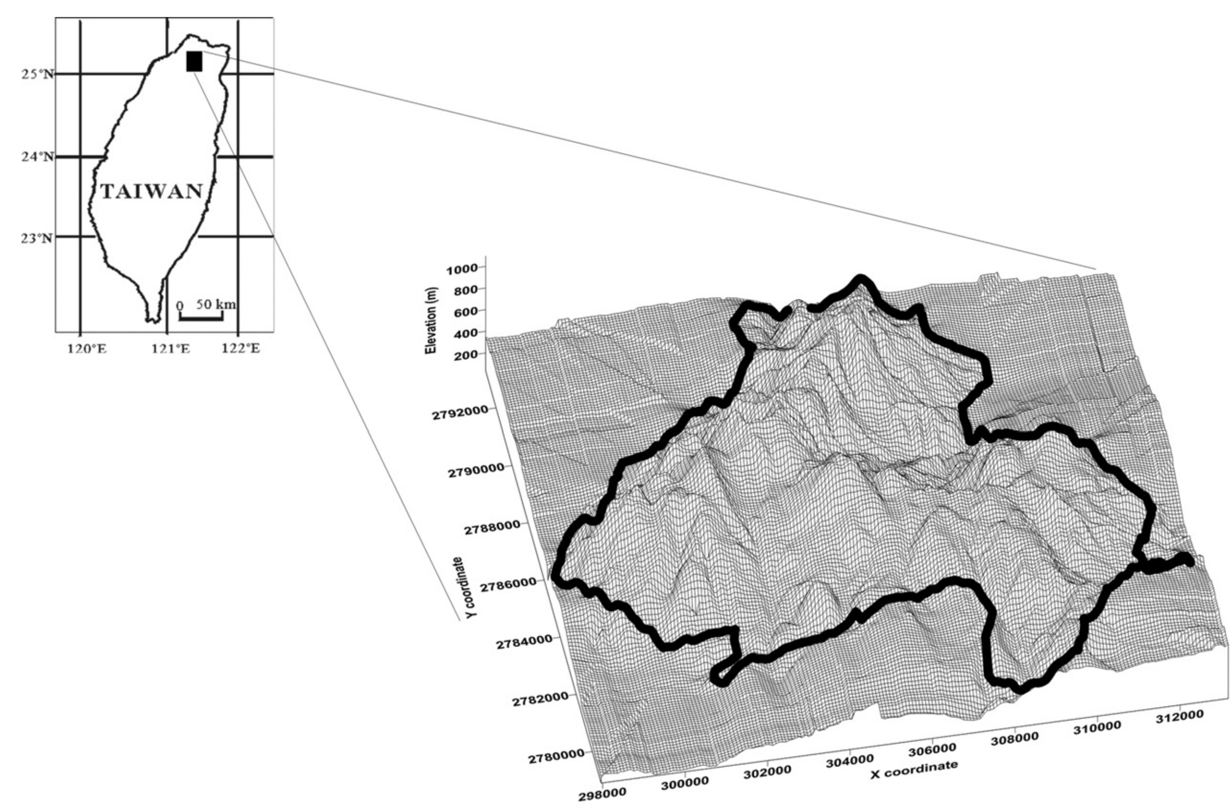

Fig. 1. Location and landscape of Yangmingshan National Park.