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Elevational gradient affect functional fractions of soil organic carbon and aggregates stability in a Tibetan alpine meadow

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ABSTRACT

The alpine meadow in the Tibetan plateau is predicted to be sensitive to climate change. Understanding soil organic carbon (SOC) characteristics and soil aggregate stability is essential for scientifically evaluating their effect as a carbon (C) sink or source under a climate change scenario. In this study, the spatial variations of the concentrations of SOC and its fractions, the chemical composition of SOC, and the water stability of aggregates and their relationships with climatic, vegetational and edaphic factors were investigated along an elevational gradient of an alpine meadow (4400–5200 m above sea level) on the Tibetan Plateau. The results showed that with increasing elevation, the concentrations of SOC, water-soluble organic carbon (WSOC), easily oxidizable organic carbon (EOC), humic acid carbon (HAC), fulvic acid carbon (FAC), humin carbon (HUC), and macroaggregate- and microaggregate-associated carbon increased gradually, reached a peak at 4800 or 4950 m, and subsequently decreased. Similarly, the proportion of alkyl C, the ratios of alkyl C/O-alkyl C, aliphatic C/aromatic C and hydrophobic C/hydrophilic C, and the mean weight diameter (MWD) of water-stable aggregates were higher at 4950 m than at other elevations. SOC, WSOC, EOC, HAC, FAC, HUC, macroaggregate- and microaggregate-associated carbon, alkyl C, and MWD were positively correlated with each other and with aboveground biomass (AGB) and free/amorphous Fe- or Al-oxides. The above results indicated that SOC and aggregate stability presented an unimodal pattern along the elevational gradient. The observed unimodal distribution of AGB associated with an optimal combination of temperature and precipitation was responsible for the distribution of SOC and aggregate stability. The physical protection in microaggregates, chemical interactions with Fe- or Al-oxide minerals, and biochemical protection by recalcitrant alkyl C may be the primary mechanisms for SOC preservation in alpine meadows. Our results suggest that climate change in the future can impact SOC and structural stability by regulating the distribution of AGB on this vertical transect. Given the low SOC and structural stability at lower elevations, we recommend that these sites be specifically protected from anthropogenic disturbance to sustain high grassland ecosystems and address future climate change in this region.

1. Introduction

Soil is the largest carbon (C) pool in terrestrial ecosystems, with approximately 2344 Gt organic C being stored in the top three meters of soil (Stockmann et al., 2013). Soil organic carbon (SOC) plays an important role in soil fertility and ecological process, such as C sequestration (Dinakaran et al., 2014), soil structure (Bronick and Lal, 2005), and microbial activity (Leinweber et al., 2008). In theory, the functions of SOC depend to a large extent on their quantity and quality. Therefore, understanding the amount and chemical composition of SOC will be of great importance for elucidating its response to actual conditions and underlying mechanisms of climate change in the future.

Soil organic matter (SOM) is a heterogeneous mixture of organic compounds and it consists of various fractions varying in stability,

Abbreviations: AGB, aboveground biomass; CPMAS TOSS NMR, cross-polarization magic-angle-spinning and total-sideband-suppression nuclear magnetic resonance; EOC, easily oxidizable organic carbon; FAC, fulvic acid carbon; HAC, humic acid carbon; HUC, humin carbon; MAP, mean annual precipitation; MAT, mean annual air temperature; MWD, mean weight diameter; SOC, soil organic carbon; SOM, Soil organic matter; WSOC, water-soluble organic carbon

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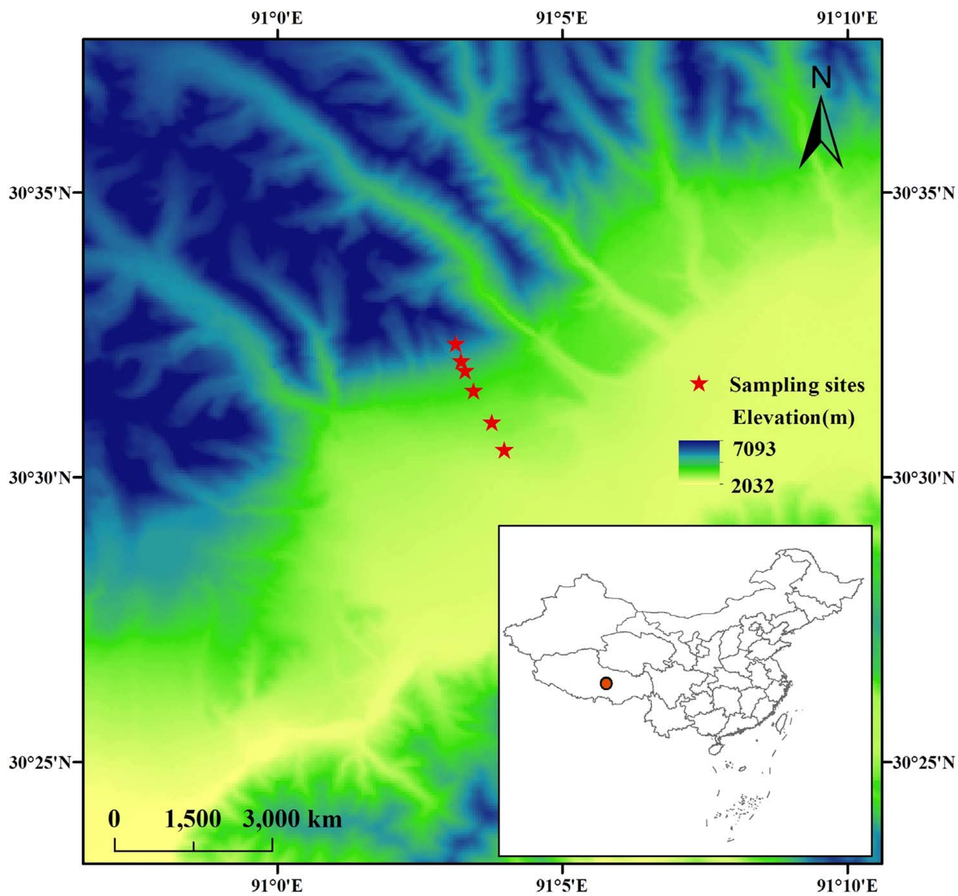

Fig. 1. Topographical map showing the sampling locations on the Tibetan Plateau.

decomposition degree and turnover rate (Huang et al., 2008). The different fractions of SOM exhibit different effects on soil fertility and environmental quality (Yang et al., 2009). Knowledge of SOM fractions is thus important for understanding the turnover and stabilization of SOC under climate change scenarios (Cao et al., 2016). Labile SOC fractions [e.g., water-soluble organic carbon (WSOC) and easily oxidizable organic carbon (EOC)] and chemically resistant SOC fractions [e.g., humic acid carbon (HAC), fulvic acid carbon (FAC) and humin carbon (HUC)] are two major fractions of SOM. They have both been reported to act as potential indicators of climate change (Steinberg, 2003; Cao et al., 2016; Wang et al. 2016a; Hu et al., 2017). Moreover, aggregate-associated C is also often considered as a key indicator in evaluating SOC sequestration and stability (Bronick and Lal, 2005). Microaggregate-associated C is generally more stable than macroaggregate- and silt + clay-associated C (Yu et al., 2012; Huang et al., 2016). Soil mineral phases (e.g., free/amorphous Fe- and Al-oxides) can not only act as binding agents for the formation and stability of soil aggregates (Bronick and Lal, 2005; Peng et al., 2015; Wang et al. 2016b) but can also protect SOC by chemical interaction (Six et al., 2002; Bruun et al., 2010; Adhikari and Yang, 2015). In addition to SOC contents, the knowledge of SOC chemical composition is essential for understanding the biochemical mechanism of accumulation and stabilization of SOM (Six et al., 2002; Plaza et al., 2013). Solid-state ^{13}C nuclear magnetic resonance (NMR) spectroscopy has proven to be a powerful tool to characterize the chemical composition of SOC (Simpson et al., 2011).

The Tibetan Plateau is the largest grassland unit on the Eurasian continent (Hu et al., 2016), with an area of 2.5×10^6 km^2 (Zheng, 1996), a mean elevation of 4000 m above sea level (Shang et al., 2016), and an elevation range from 500 to 8848 m above sea level (Dai et al., 2011). It is estimated that SOC storage at 0–0.75 m depth in the alpine grassland soils across the Plateau is approximately 33.5 Pg C, representing 2.5% of the global soil C pool (Wang et al., 2002) and > 20% of the SOC storage in China (Shang et al., 2016). The Plateau has been an ideal region for the study of C cycles and corresponding feedback interactions to climatic change in high-elevation ecosystems (Wang et al., 2002; Yang et al., 2008; Liu et al., 2012). On the mountainous Plateau, environmental conditions (e.g., climate, vegetation biomass, and soil mineralogy) change sharply along the elevational gradient of the mountains. Therefore, an investigation of the variation in quantitative and qualitative characteristics of SOC along the elevational gradient within this region is essential for scientifically evaluating their effect as a C sink or source under climate change scenarios. The alpine meadow, with elevations ranging from 3000 to 5400 m above sea level (Guo et al., 2012), is a major grassland type on the Tibetan Plateau (Fu et al., 2012). Meanwhile, the alpine meadow is considered extremely sensitive and vulnerable to climate change (Chen et al., 2014a). In previous studies, some researchers have reported on the variation of SOC concentrations (Xu et al., 2014; Yuan et al., 2014) and SOC pool (Ohtsuka et al., 2008) along the elevational gradient on the Tibetan Plateau. However, to our knowledge, no study has been conducted to explore the variations in SOC fractions concentrations, SOC chemical composition, and aggregate size and stability along the elevational gradient in alpine meadows on the Tibetan Plateau. Moreover, it is still unclear how the differences in environmental factors influence the variations in the qualitative and quantitative characteristics of SOC and aggregate stability at different elevations in this region.

In this study, along an elevational gradient (4400–5200 m above sea level) across the southern slope of the Nyainqentanglha Mountains on the Tibetan Plateau, we evaluated the variation in the concentrations of SOC and any chemical and physical fractions (i.e., WSOC, EOC, humic carbon, and water-stable aggregate-associated carbon), as well as the