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Are land use and short time climate change effective on soil carbon compositions and their relationships with soil properties in alpine grassland ecosystems on Qinghai-Tibetan Plateau?

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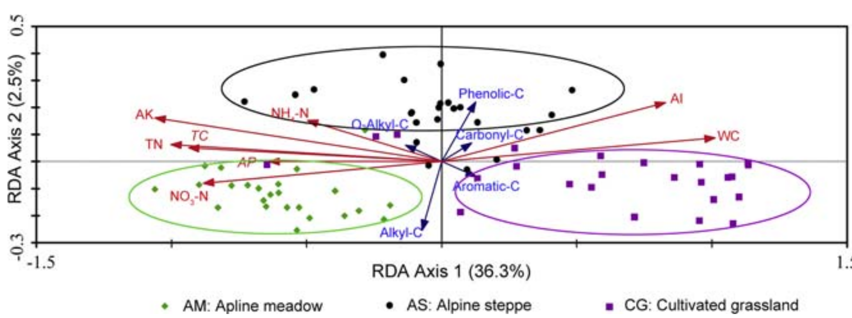
HIGHLIGHTS

- Grass plantation can promote the stability of soil organic carbon.
- Short-term climate change may not affect the molecular composition of the SOC.
- Land use can change the molecular composition of the SOC and soil nutrients.

GRAPHICAL ABSTRACT



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ABSTRACT

Fencing and grass plantation are two key interventions to preserve the degraded grassland on the Qinghai-Tibetan Plateau (QTP). Climate warming and N deposition have substantially affected the alpine grassland ecosystems. However, molecular composition of soil organic carbon (SOC), the indicator of degradation of SOC, and its responses to climate change are still largely unclear. In this study, we conducted the experiments in three types of land use on the QTP: alpine meadow (AM), alpine steppe (AS), and cultivated grassland (CG) under 2 °C climatic warming, 5 levels of nitrogen deposition rates at 8, 24, 40, 56, and 72 kg N ha^{-1} $year^{-1}$, as well as a combination of climatic warming and N deposition (8 kg N ha^{-1} $year^{-1}$). Our findings indicate that all three types of land use were dominated by O-alkyl carbon. The alkyl/O-alkyl ratio, aromaticity and hydrophobicity index of the CG were larger than those of the AM and AS, and this difference was generally stable under different treatments. Most of the SOC in the alpine grasslands was derived from fresh plants, and the carbon in the CG was more stable than that in the AM and AS. The compositions of all the alpine ecosystems were stable under short-term climatic changes, suggesting the short-term climate warming and nitrogen deposition likely did not affect the molecular composition of the SOC in the restored grasslands.

1. Introduction

In recent decades, global changes including climate change, land use change and social-economic transformation have been driving the degradation of alpine grasslands, the dominant ecosystems on the Qinghai-Tibetan Plateau, which is well-known as the “Third Pole of the World” and the “Water Tower of the Asia” (Harris, 2010; Dong et al., 2010;

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Wang et al., 2015b). Fencing and grass plantation were two key interventions to preserve the degraded grassland with the implementation of Chinese government policies “Grassland Ban” (also termed as “Returning to Grassland by Excluding Grazing” or “Retire Livestock, Restore Pastures”) (Dong et al., 2009, Dong et al., 2010). Up to now, many researchers have examined the plant biodiversity (Yang et al., 2014), soil physical and chemical properties (Dong et al., 2012; Liu et al., 2016a) or the carbon and nitrogen storage (Su et al., 2015; Zhang et al., 2016) to evaluate the effects of restoration practices in coping with land use changes and climate changes. However, few studies have been conducted to explore how the restoration practices under the changing environments impacted the components and stability of soil organic carbon (SOC) in the alpine grassland, which accounts for significant shares in China and global soil carbon, around 23.44% of China's total SOC and 2.5% of the global total soil carbon (Wang et al., 2002). It is widely reported that composition of SOC, the largest carbon pool on earth (Lal, 2004), varies greatly with the land uses across the world (Zhou et al., 2010; Pisani et al., 2015; Pisani et al., 2016; Wang and Zhong, 2016). Although the stabilization of SOC is mainly dominated by the elective preservation of recalcitrant organic components that accumulate in proportion to their chemical properties, it is still unpredictable as there are several mechanisms involved in SOC dynamics (Lützow et al., 2006). Some scholars believed chemical changes in organic materials would alter C stabilization in soil and reflect the stability of SOC (Angst et al., 2017).

Previous studies have revealed that vegetation, rather climate change, controls the SOM composition (Quideau et al., 2001; Feng et al., 2008). Organic detritus C, has a different chemical composition because of the different components of above-ground C, exhibits various decay speeds (Eviner and Chapin, 2003). Additionally, vegetation has significant effects on composition of soil microbe, which can decompose labile carbon to stable carbon. For example, Wang and Zhong (2016) found that soils dominated by coniferous species, which have more aliphatic compounds in their leaves, are higher proportion in alkyl C and a higher alkyl C/O-alkyl C ratio than the soils dominated by broadleaf species. Moreover, the aboveground plant community and soil properties have strong effects on soil microbial communities (Bardgett, 2005; Chu et al., 2016; Zhang et al., 2016), and thus may alter the SOM composition in the soil. In contrast, we assume that the climate change also impact the SOC composition and C stability. It was reported that global atmospheric temperature will rise by 1.5–4.8 °C by the end of this century (IPCC, 2013), nitrogen (N) deposition has continued to increase since last century (Liu et al., 2016b), both can influence the SOC content on a global scale (Feng et al., 2008; Pisani et al., 2015).

Climate change such as climate warming and N deposition might strongly affect the dynamics of carbon and nitrogen in soil, and the changes may lead to reduced CO_2 emission (Zhao et al., 2017). Long-term fertilization strategies have been shown to significantly influence the chemical composition of SOC (Li et al., 2015). Thus, future warming and N deposition could alter the composition of soil organic matter at the molecular level (Pisani et al., 2015). However, it is still largely unclear how warming and nitrogen deposition affect soil carbon stability (Feng et al., 2008; Feng et al., 2010; Pisani et al., 2014; Pisani et al., 2015), especially for the QTP's alpine grasslands in the era of rapid land use change. Thus, it is urgent to classify SOC molecular composition in the QTP's alpine grasslands and to study the molecular changes of SOC under warming and nitrogen deposition. Within this context, we conducted warming plus nutrient adding manipulative experiment to explore the pattern of SOC molecular composition in three types of grasslands, alpine meadow, alpine steppe, and cultivated grasslands on the QTP. We aimed to clarify the response of the QTP's alpine grasslands in the dimension of stability of soil carbon under land use change and climate change with two hypotheses: (1) the pattern of SOC molecular composition can be altered by land use; and (2) climate warming and nitrogen deposition can further change the SOC molecular composition.

2. Material and methods

2.1. Study sites

The study sites are located in Xihai Town, Haiyan County of Qinghai Province (36°56′N, 100°57′E, 3100 m ASL) and Tiebujia Town, Gonghe County of Qinghai Province (37°02′N, 99°35′E, 3270 m ASL) (Fig. 1). The alpine meadow (AM) is the major vegetation type dominated by *Kobresia capillifolia* in Haiyan County, and it is fenced since 2012. In Haiyan County, the mean annual precipitation is approximately 330–370 mm, and the mean annual temperature is approximately 1.4 °C. The alpine steppe (AS) dominated by *Stipa purpurea* and *Poa crymophila* is the major vegetation type of Gonghe County, and it is fenced since 2012. In Gonghe County, the mean annual precipitation is approximately 368.11 mm, and the mean annual temperature is approximately −0.7 °C. The cultivated grassland (CG) next to the alpine steppe in Tiebujia Town was planted with *Elymus nutans* in 2012.

2.2. Experimental design and sampling

2.2.1. Experimental design

Eight treatments were simulated: N1 deposition of ammonium nitrate (NH_4NO_3) at 8 kg N ha^{-1} $year^{-1}$ (corresponding to the annual N deposition on the QTP reported by Lu and Tian, 2007, N2 deposition of ammonium nitrate (NH_4NO_3) at 24 kg N ha^{-1} $year^{-1}$, N3 deposition of ammonium nitrate (NH_4NO_3) at 40 kg N ha^{-1} $year^{-1}$, N4 deposition of ammonium nitrate (NH_4NO_3) at 56 kg N ha^{-1} $year^{-1}$, N5 deposition of ammonium nitrate (NH_4NO_3) at 72 kg N ha^{-1} $year^{-1}$, warming treatment with open top chambers (OTC) at 2 °C warmer than the outside (W), and a combined treatment of warming with open top chambers (OTC) at 2 °C increment and N1 deposition (8 kg N ha^{-1} $year^{-1}$) (W&N1). In May of 2015, sets of 3 plots (replicates) in the size of 2 m × 5 m were randomly selected as replicates for each treatment in each type of grasslands, alpine meadow (AM) after 3 years fencing, alpine steppe (AS) after 3 years fencing and cultivated grassland (CG) after 3 years plantation. Meanwhile, three Open top chambers (OTCs) were randomly placed in the plots next to the nitrogen deposition plots for W treatment, another three OTCs (replicates) were randomly placed in the plots next to the nitrogen deposition plots for W&N1 treatment. Alpine meadow and alpine steppe are the main grassland types on the Qinghai-Tibetan Plateau (Fig. 1), and grassland fencing and grass plantation were two key interventions to preserve the degraded grassland (Dong et al., 2009). All the treatment areas were similar in their topographies and land use practices. The N was applied as ammonium nitrate (NH_4NO_3) in early May and early July of 2015.

2.2.2. Soil sampling and measurements

In the middle of August 2015, we collected 24 soil cores (8 treatments, 3 replicates for each treatment) at depths of 0–20 cm for each type of grassland. The samples were sealed in polyethylene bags and transported to the lab for extraction. Total nitrogen (TN) and total carbon (TC) were measured using an element analyzer (EA 3000, Italy). NH_4-N and NO_3-N were measured using a flow injection auto-analyzer (AACE, Germany). Five grams of soil was extracted with 50 ml of 0.01 M $CaCl_2$, and the solution was shaken for 1 h with a reciprocal shaker. It settled for 0.5 h after shaking, and the soil suspension was filtered using a filter paper. The concentrations of available potassium (AK) and available phosphorus (AP) were measured using inductively coupled plasma spectrometers (ICP; SPECTRO ARCOS EOP, Germany). Water content (WC) was measured using the wet soil and dry soil weights.

2.2.3. CPMAS-^{13}C NMR spectroscopy analysis

Soil samples were analyzed for SOC molecular composition by pretreating them with 10% (*v*/v) hydrofluoric acid (HF) and using NMR spectroscopy (Schmidt et al., 1997). Weigh 5 g soil sample in a