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Short communication

Different grazing removal exclosures effects on soil C stocks among alpine ecosystems in east Qinghai–Tibet Plateau

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ABSTRACT

Grazing removal exclosure is important to restore grass in rangeland. However, little is known about the effects of exclosure on soil organic carbon (SOC) in Qinghai–Tibet Plateau, and whether different ecosystems response equally to exclosure. In this study, we evaluated the effects of grazing removal exclosure on SOC and total nitrogen (TN) as well as SOC quality for the top soil layer (0–10 cm) through comparing three grazing-removal exclosure pairs of ecosystems (i.e., marsh, wet meadow, and meadow) in Zoige, east Qinghai–Tibet Plateau. Both SOC and labile OC (i.e. microbial biomass carbon, MBC; dissolved organic carbon, DOC; light fraction organic carbon, LFOC) were investigated. Our results indicated that the exclosures of five years old significantly increased SOC stock and marginal significantly increased soil N stock for meadow. No exclosure effects on SOC and N stocks were found for marsh and wet meadow. No significant changes of MBC and DOC were found for the three ecosystems as a consequence of five years grazing removal. However, grazing exclosures significantly increased LFOC, light fraction nitrogen (LFN), heavy fraction organic carbon (HFOC), and lability of carbon pool as determined by a density fractionation method (L_{LFOC}) for meadow, but no corresponding change occurred in wet meadow and marsh. The increase of SOC after grazing removal was attributed to increases in both labile (represented by LFOC) and non-labile (represented by HFOC) OC. Furthermore, the change of SOC is associated with TN both in light, heavy and dissolved fractions. Soil bulk density (BD) well explained the change of SOC after grazing exclusion, whereas the change of BD was mainly attributed to the change of heavy fraction. These results suggested that exclosure effects on SOC of rangeland were determined by ecosystem types.

1. Introduction

Rangelands occupy almost 50% of the terrestrial land cover and are estimated to contain more than one-third of the world's carbon (C) reserves (Allen-Diaz, 1996). In rangelands, more C is stored in soil than in vegetation (White et al., 2000). Over a quarter of the global soil C storage may be influenced by grazing (Scurlock and Hall, 1998), which is the most geographically expansive land use type. Facilitating soil C storage through improved grazing management was suggested as an important component for offsetting greenhouse-gas emissions to mitigate climate change (Lal, 2004). Therefore, recent studies have been focused on grazing effects on rangeland soil C. Some reports indicate that soil C and nitrogen (N) storage can be increased through increasing C and N allocation to the below-ground biomass (Hui and Jackson, 2006), or through increasing manure inputs after grazing (Conant et al., 2001). In contrast, introduced grazers can restrict potential soil C sequestration through impacts on plant community composition (Bagchi and Ritchie, 2010). As a consequence, both negative (Wu et al., 2009, 2010) and positive effects (Li et al., 2011) of livestock grazing on soil organic carbon (SOC) were reported in Tibetan alpine

Abbreviations: SOC, soil organic carbon; TN, total nitrogen; MBC, microbial biomass carbon; DOC, dissolved organic carbon; LFOC, light fraction organic carbon; LFN, light fraction nitrogen; HFOC, heavy fraction organic carbon; L_{LFOC}, carbon pool lability represented by density fractionation; BD, bulk density; FG, free grazing; GE, grazing removal exclosure.

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meadows. Lack of a clear relationship between grazing practices and SOC stocks may result from soil heterogeneity, inconsistent depth of soil sampling, and insufficient understanding of C and N distributions within the grazing system. Recently, Piñeiro et al. (2010) reported that SOC increased, decreased, or remained unchanged under contrasting grazing conditions across temperature and precipitation gradients. Derner et al. (2006) also showed that grazing increased SOC stocks in dry short-grass steppe ecosystems and decreased stocks in more humid mid- and tall grass prairie ecosystems. These results imply that different environmental conditions may contribute to inconsistent grazing effect on soil C.

Labile organic carbon (OC) has been suggested as the early indicator of C stock change after management practice or land use change (Six et al., 2002). The light fraction organic carbon (LFOC) obtained through density fractionation (Six et al., 2002), plays an important role in determining the structure and function of the soil ecosystem by acting as an energy source for heterotrophic organisms and as a reservoir of labile C and plant nutrients (Laik et al., 2009). Soil microbial biomass carbon (MBC), the most active component of SOC that regulates biogeochemical processes, has been considered as an important indicator of changes of soil quality and management practices (Holt, 1997). Additionally, dissolved organic carbon (DOC) fluxes are also sensitive to management practices (McTiernan et al., 2001). These indicators often respond more rapidly to management-induced changes in the SOC pool than bulk SOC, and can serve as early indicators for the overall stock change (Dubeux et al., 2006; Huo et al., 2013).

Qinghai–Tibetan Plateau (av. 4000 m a.s.l.), the largest grassland unit on the Eurasian continent, stores 2.5% of the global pool of soil C (Wang et al., 2002). The world's largest alpine wetland, Zoige wetland (Xiang et al., 2009), is located in this Plateau and contains 8% of the SOC of the plateau (Wang et al., 2002). Dramatic floristic changes in plant communities, such as decreasing plant productivity, increasing plant diversity (Wu et al., 2009) and altered species composition in the meadow, triggered by grazing of yaks and sheep, have been reported in this region (Niu et al., 2010). However, little is known about the response of SOC, especially the labile OC indicators to grazing removal exclosure practice (Shi et al., 2013; Rui et al., 2011), and there is no information on whether different ecosystems will response equally to this management practice. A thorough understanding of this response is beneficial for shaping future management practice and land-use policy in this region, particularly as Zoige has been experiencing conversions between ecosystems due to wetlands degradation or restoration (Zhang et al., 2012). To address these concerns, we constructed three pairs of grazing-exclosure treatments (i.e., meadow, wet meadow, and marsh). Our specific objectives are: (1) to investigate the influence of grazing removal exclosures for five years on top soil total and labile OC and N; and (2) to identify whether different ecosystems response equally to the treatment.

2. Methods and materials

2.1. Site description and soil sampling

The study sites were located at the Zoige National Wetland Reserve (33°56′ N, 102°52′ E, 3430 m a.s.l.), Sichuan Province, China, which is characterized by the mild, cold temperate continental monsoon type. The annual mean temperature is about 0.7–1.1 °C, with the highest monthly mean being 10.8 °C in July and the lowest being −10.6 °C in January. The annual mean precipitation is 656.8 mm, with 86% of this occurring between April and October (Xiang et al., 2009).

In this study, meadow, wet meadow, and marsh were chosen for the investigations. Three pairs of 10 m × 10 m free grazing (FG) and grazing removal exclosure (GE) treatment plots were constructed for each ecosystem type, the two treatment plots were over ca. 10 m apart from each other. A common set of stand attributes is summarized in Table 1. In September 2010, after five years of grazing removal exclosure treatment, three soil cores (7 cm in diameter) were taken at each plot from the top 10 cm of the soil. The samples were mixed and then divided into two parts. One was air dried for the measurements of pH, mass-based SOC, total nitrogen (TN), LFOC, and light fraction nitrogen (LFN). The other was kept at field moisture content at 4 °C for the measurements of MBC, microbial biomass nitrogen (MBN) and K_2SO_4 extractable C and N (extractable DOC, DON) in two weeks. 100 ml (50.46 mm diameter, 50 mm height) sampling cylinders were used for analyses of bulk density (BD).

2.2. Soil analysis

2.2.1. Physical fractionation

Light fraction soil organic matter (SOM) was obtained by a density fractionation method described by Luan et al. (2011). Bulk soil and light fraction OC contents were determined by a wet oxidation method with 133 mM $K_2Cr_2O_7$ at 170–180 °C (Lu, 2000). Heavy fraction organic carbon (HFOC) is the difference between SOC and LFOC. Heavy fraction nitrogen (HFN) is the difference between TN and LFN. Soil N concentration in bulk soil and light fractions were determined by the micro-Kjeldahl method. Soil pH was measured from soil–water suspensions (1:5, v/v).

2.2.2. Chemical fractionation

MBC and MBN of each sample were determined using a chloroform fumigation–extraction method (modified from Vance et al., 1987), and waterlogged soil was fumigated according to Inubushi et al. (1991). Both fumigated and nonfumigated soil was extracted with 50 ml 0.5 M K_2SO_4 after removal of the $CHCl_3$ from the soil by repeated evacuations, and then filtered. The extracts were kept frozen at −30 °C before being analyzed by a multi N/C 3100 (Analytik Jena AG). The total amount of MBC and MBN was determined by the difference between K_2SO_4-extractable C in fumigated and non-fumigated soil, with a correction factor of K_{EC} = 0.45 for MBC (Sparling et al., 1990) and K_{EN} = 0.54 for MBN (Brookes et al., 1985). Extractable DOC was determined as total organic C in extracts from nonfumigated soil.

We defined the term 'lability' of SOC as the ratio of the labile (LFOC) to non-labile (HFOC) C (Luan et al., 2010):

$$L_{LFOC} = \frac{LFOC}{SOC - LFOC} \quad (1)$$

2.3. Statistical analysis

One way analysis of variance (ANOVA) was performed to assess the effect of grazing removal exclosure treatment on soil C and N parameters. The general linear model (GLM) was employed to evaluate the effects of ecosystem, grazing removal exclosure treatment, and their interactions on the C and N parameters. Pearson correlations were derived to investigate the relationships between changes in belowground C (SOC, LFOC, HFOC, MBC, and DOC) and N (TN, LFN, HFN, MBN, and DON) after grazing removal (the difference between GE and FG treatment of variables), and the relationships between changes in SOC, LFOC, and HFOC with soil BD. Pearson correlations were also applied to evaluate the relationships between changed SOC and changed LFOC, HFOC, MBC, and DOC after grazing