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Effect of grazing exclusion on ecosystem respiration among three different alpine grasslands on the central Tibetan Plateau

Jingxue Zhao[a,b,*], Xiang Li[a], Ruicheng Li[b], Lihua Tian[c], Tao Zhang[d]

[a] Key Laboratory of Alpine Ecology and Biodiversity, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Institute of Qinghai-Tibetan Plateau, Southwest University for Nationalities, Chengdu 610041, China
[d] College of Pastoral Agricultural Science and Technology, Lanzhou University, Lanzhou 730000, China

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ABSTRACT

Alpine grasslands are currently experiencing an increasing threat from overgrazing, and grazing exclusion has been widely used as a simple and effective method for restoring degraded grasslands on the Tibetan Plateau (TP). This paper studied effects of grazing exclusion on ecosystem respiration (Re), plant and soil characteristics for two growing season (2012 and 2013) in three alpine grasslands (alpine steppe, alpine meadow and swamp meadow) on the central TP. Grazing exclusion enhanced plant height, total cover, aboveground biomass and belowground biomass in all the three alpine grasslands. Grazing exclusion increased Re in alpine steppe and alpine meadow, but decreased Re in swamp meadow. Soil temperature and soil moisture well explained the seasonal variations of Re in alpine steppe and alpine meadow. However, soil temperature, rather than soil moisture, was the major environment factor controlling the seasonal variation of Re in swamp meadows. The temperature sensitivity of Re (Q_{10}) was higher in swamp meadow and alpine meadow compared with alpine steppe. Grazing exclusion had a slight tendency to decrease Q_{10} in alpine steppe and alpine meadow, but increase Q_{10} in swamp meadows. Results suggest that grazing exclusion effects on Re and Q_{10} of alpine grassland were determined by vegetation types.

1. Introduction

Alpine grasslands are currently experiencing rapid climate and land use changes (Chen et al., 2013; Saito et al., 2009). The large carbon storage in the vast area of alpine ecosystems is likely to release under warming condition, and small changes in soil carbon pool potentially have strong feedbacks to atmospheric CO_2 concentration and ongoing climate change (Chen et al., 2013; Ernakovich et al., 2014; Saito et al., 2009). Livestock grazing is the dominant form of land use in alpine grasslands, which in conjunction with climate warming, is the main driver of ecosystem processes and carbon cycles (Cao et al., 2004; Lin et al., 2011). With increasing livestock populations during recent decades, alpine grasslands have experienced an increasing threat from overgrazing, which has caused severe grasslands degradation or even desertification (Chen et al., 2014; Song et al., 2009). Grazing exclusion has been widely considered as a practical restoration and management regime in alpine grasslands (Wu et al., 2008; Hu et al., 2016). Many studies have indicated that the practice of grazing exclusion has significantly improved vegetation biomass and soil C content in alpine grasslands on the Tibetan Plateau (TP) (Wu et al., 2010; Wang et al., 2014), which might also modify the rate and temperature sensitivity of ecosystem respiration (Re). However, only few studies are available about grazing exclusion effects on Re in alpine grasslands. Therefore, knowledge on how Re of alpine grasslands response to grazing exclusion is still rudimentary.

Ecosystem respiration is a major carbon flux from terrestrial ecosystems to the atmosphere (Davidson et al., 2006; Chen et al., 2014), which is mainly controlled by temperature and moisture (Lloyd and Taylor, 1994; Saito et al., 2009) as well as plant growth and substrate availability (Wan and Luo, 2003). In grasslands, the controls on Re can be confounded by livestock grazing, which may make it difficult to clarify the grazing effects from other biotic and

Abbreviations: Re, ecosystem respiration; Q_{10}, temperature sensitivity of Re; AGB, aboveground biomass; BGB, belowground biomass; SOC, soil organic carbon; T_{air}, air temperature; T_s, soil temperature; PPT, precipitation; M_s, soil moisture; NDVI, normalized difference vegetation index; TP, Tibetan Plateau.

* Corresponding author at: Key Laboratory of Alpine Ecology and Biodiversity, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Building 3, 16 Lin Cui Rd., Chaoyang District, Beijing, 100101, China.
E-mail address: zhaojx@itpcas.ac.cn (J. Zhao).

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abiotic factors (Cao et al., 2004; Peichl et al., 2012; Wang and Fang, 2009). Observations have been conducted on the response of grazing to Re but their results are conflicted in grasslands, with some reporting that grazing increased Re (Cao et al., 2004; Jia et al., 2007), and others obtaining inconsistent results (Gong et al., 2014b; Lin et al., 2011; Wei et al., 2012). The temperature sensitivity of Re (Q_{10}), which is an integration of several confounding ecosystem processes (Davidson et al., 2006; Janssens and Pilegaard, 2003; Yuste et al., 2004), is considered as one crucial determinant of the climate-carbon cycle feedback in terrestrial ecosystems (Fang and Moncrieff, 2001; Mahecha et al., 2010). There is increasing evidence to suggest that Q_{10} is negatively correlated with temperature and positively correlated with soil moisture (Peng et al., 2009; Rayment and Jarvis, 2000; Xu and Qi, 2001). Studies have revealed that Q_{10} is also dependent on the substrate quality and availability (Davidson et al., 2006). In grassland ecosystem, grazing exclusion treatment modifies vegetation conditions and soil microclimate which could also feed back to Q_{10}. However, the response of Q_{10} to grazing is still under debate, with contradictory results that Q_{10} may decrease (Cao et al., 2004; Lin et al., 2011) or increase (Paz-Ferreiro et al., 2012; Wei et al., 2012) under the disturbance of grazing activity. Such discrepancies between these results suggest that the effect of grazing on Re is complex and might be ecosystem-dependent in grasslands.

The Tibetan Plateau is the highest grassland plateau in the world. It covers an area of greater than 2.5 million km^2 in western China, and has an average elevation of over 4000 m. The most widely distributed grassland ecosystems across the TP are the alpine meadow, alpine steppe and swamp meadows (Harris, 2010; Zhu et al., 2015). During recent decades, in conjunction with a rapid warming, overgrazing has caused severe alpine grasslands degradation on the TP (Song et al., 2009; Chen et al., 2014). To protect grassland degradation on the TP, the Chinese governments have carried out the project of restoring pasturage to natural grassland, in which grazing exclusion through mesh fencing to create a large-scale enclosure has been widely applied as a simple and effective method. However, few data were available on the response of Re to grazing exclusion, and there is no information on whether Re of different alpine grasslands will response equally to this management practice. To address these concerns, the present reported study was conducted in three alpine grasslands, situated on the central TP. Ecosystem respiration and related environmental factors were obtained across the fenced and grazed plots in alpine steppe, alpine meadow and swamp meadow. The main objectives of the study were to: (1) clarify the effects of grazing exclusion on plant and soil characteristics; (2) to determine how grazing exclusion influence the variation of Re and Q_{10} among different alpine grasslands; and (3) to clarify the major driving factors of Re in alpine grasslands on the Tibetan Plateau.

2. Materials and methods

2.1. Study sites and experiment design

This study was conducted in an alpine steppe site (30°30′N, 91°3′E, 4500 m), an alpine meadow site (30°3′N, 91°3′E, 4800 m) and a swamp meadow site (30°28′N, 91°3′E, 4330 m) near the grassland station of Damxung County, in Xizang Autonomous Region (Tibet), China. The alpine steppe was dominant by *Stipa capillacea* and the alpine meadow site was dominant by *Kobresia pygmaea* and the swamp meadow site was dominant by *Kobresia tibetica*. Other coexisting species mainly included *Stipa purpurea*, *Androsace tapete*, *Carex tenebrosa*, *Kobresia robusta*, *Stipa capillacea*, *Potentilla nivea* etc. At community level, the canopy height of these alpine grasslands was generally no more than 20 cm. Most plant species in this region green up in late May and turn yellow at the end of September. Pasture for yak and sheep is the main land use in these alpine grasslands. The stock rate would be higher at swamp meadow site and alpine steppe site because the most severely degraded grasslands were found at these sites.

To identify the effect of grazing exclusion on alpine grasslands, we fenced a 20 × 20 m plot for the three sites in May 2006. The fence completely excluded livestock grazing during the growing season. HOBO weather stations (Onset Inc., Bourne, MA, USA) were used to record the environmental conditions for each site. Air temperature (T_{air}) and precipitation were recorded at 30-min intervals using the HOBO weather stations. Moderate Resolution Imaging Spectroradiometer (MODIS) data of the MOD13Q1 product (MODIS/Terra Vegetation Indices 16-Day L3 Global 250 m SIN Grid) were downloaded for the TP during the growing season. The normalized difference vegetation index (NDVI) was quantified using satellite-derived reflectance data to indicate the seasonal variation of plant biomass.

2.2. Vegetation and soil sampling

We set up five quadrats (1 × 1 m) at intervals of 3 m in the fenced plots and grazed plots. In each quadrat, the relative coverage and plant height of the dominant species and other co-dominants were measured. We harvested AGB in each quadrat when biomass had reached its maximum and estimated BGB by collecting five soil cores in each quadrat (diameter: 5.0 cm; depth: 30 cm) in 2013. BGB samples were weighed after washing off the soil by a 2-mm sieve and drying at 65 °C for 48 h. After removing the aboveground biomass, we collected top soil samples (0–10 cm depth) in fenced sites and grazed sites with a soil auger (diameter: 3.0 cm) from each quadrat in mid-August of 2012. After removal of any visible roots, soil samples were air-dried at room temperature and sieved for measuring SOC according to the Walkley and Black dichromate oxidation method (Nelson and Sommers, 1982).

2.3. Field measurements of ecosystem respiration (Re)

Within each of the 3 fenced plots, five polyvinyl chloride collars (diameter: 20 cm; height: 5 cm) were set at 3-m intervals along the contour line. At a distance of 5 m from the upper edge of the fenced plot (grazed treatment), additional five collars were set at the same space intervals. All the PVC collar was inserted about 3 cm into the soil in early May, with 2 cm remaining above the surface of the grass floor. According to our experience, there were no noticeable changes in plant cover and soil temperature and moisture between inside and outside the PVC collars. On a sunny day, diurnal variation (08:00–18:00, local time) of Re at 2–3 h intervals were measured once a month during the growing seasons (June to September) of 2012 and 2013 using the opaque chamber of Li-8100 103 automatic soil CO_2 flux system (LI-COR Biosciences, Lincoln, NE, USA). The chamber (29.2 cm in height) fitted well the plant canopy (<25 cm). The sampling frequency of Re measurements for each month during the growing season was low because of difficulty in the field campaign at high altitude regions. Given that the Re measurements at the same site were taken on the same day and the measurements were only made under sunny days, the sampling procedure would be fine for a comparison between fenced and grazed treatments among study sites at a certain point in time.

To determine the differences in soil temperature (T_s) and moisture (M_s, volumetric) between fenced and grazed plots, T_s and M_s at −5 cm for each collar were measured simultaneously with Re using a digital temperature sensor (Type E, OMEGA Engineering, Inc., Stamford, CT, USA) and a Time Domain Reflectometer with a handheld push probe (Type ML2x, Delta-T Devices Ltd, Burwell, Cambridge, United Kingdom) attached to the Li-8100 system. The