Agriculture, Ecosystems and Environment 248 (2017) 136–143

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Warm- and cold- season grazing affect soil respiration differently in alpine grasslands

Hao Wang[a,b,1], Huiying Liu[a,1], Yonghui Wang[a], Wei Xu[a], Anrong Liu[a], Zhiyuan Ma[a], Zhaorong Mi[b], Zhenhua Zhang[b], Shiping Wang[c,d], Jin-Sheng He[a,b,*]

[a] *Department of Ecology, College of Urban and Environmental Sciences, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, 100871 Beijing, China*
[b] *Key Laboratory of Adaptation and Evolution of Plateau Biota, Northwest Institute of Plateau Biology, Chinese Academy of Sciences, 810008 Xining, China*
[c] *Key Laboratory of Alpine Ecology and Biodiversity, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, 100085 Beijing, China*
[d] *CAS Center for Excellence in Tibetan Plateau Earth Science of the Chinese Academy of Sciences, 100101 Beijing, China*

ARTICLE INFO

Keywords:
Autotrophic respiration
Heterotrophic respiration
Carbon dioxide
Carbon cycling
Grazing pattern
The Tibetan Plateau

ABSTRACT

As a traditional practice in grasslands, grazing significantly affects soil respiration (R_s). To improve our understanding of grassland carbon cycling, it is critical to partition the responses of soil respiration to grazing into autotrophic (R_a) and heterotrophic (R_h) respiration. In addition, it remains unclear how grazing patterns, such as warm- and cold- season grazing, influence R_s and its components in alpine grasslands that are subject to increasing grazing pressure. Here, we conducted a six-year manipulative experiment combining with a meta-analysis, to investigate the responses of R_s and its components to moderate grazing in a Tibetan alpine grassland. Grazing patterns included warm-season grazing by sheep during the growing seasons of 2008 to 2010 and simulating cold-season grazing by clipping during the non-growing seasons of 2011 to 2013. Our results showed that warm-season grazing minimally affected R_s while cold-season grazing significantly increased R_s by 13.1%. This result was supported by a meta-analysis at seven grassland sites across the Tibetan Plateau. Further, we found that warm-season grazing did not affect R_a or R_h, whereas cold-season grazing enhanced R_a (23.2%) more than R_h (4.9%). Cold-season grazing affected R_s and R_a differently depending on interannual variation in climate conditions. A significant increase of 17.1% and 26.3%, respectively, was recorded in dry and cold years, but no change was recorded in wet and warm years. This study highlights the differential responses of R_s components to grazing, and suggests that different grazing patterns should be considered when evaluating future carbon cycles in grazing ecosystems on the Tibetan Plateau.

1. Introduction

Grazing is a common, traditional practice in natural grasslands, and it has a substantial influence on terrestrial carbon cycling process (McSherry and Ritchie, 2013; Schuman et al., 1999). Soil respiration (R_s) is the second largest carbon flux between soil and atmosphere, and encompasses autotrophic (R_a) and heterotrophic (R_h) respiration (Davidson and Janssens, 2006; Hanson et al., 2000; Kuzyakov, 2006). Previous studies have extensively explored the effect of grazing/clipping on R_s, with reported positive, neutral, and negative effects (Cui et al., 2014; Wan and Luo, 2003; Xu et al., 2015). However, few studies have partitioned the responses of R_s components, including R_a and R_h, to grazing, which constrains our understanding of the underlying mechanism for the controversial results obtained.

A number of studies have shown that the effects of grazing/clipping on R_s components are dependent on changes to plant properties and soil physical conditions (Bahn et al., 2006; Li and Sun, 2011; Wan and Luo, 2003). When considering plant properties, on one hand, grazing reduces photosynthate supply and above-ground litter by removing the above-ground part of plants, which might reduce R_a and R_h (Wan and Luo, 2003). On the other hand, grazing stimulates root growth (Cui et al., 2014; Hafner et al., 2012), thus increasing R_a and R_h. When considering soil physical conditions, grazing increases soil temperature (Li and Sun, 2011; Luo et al., 2010), which accelerates the decomposition of soil organic matter (Li et al., 2013) and improves the metabolic activity of plants (Melillo et al., 2011). However, grazing usually

* Corresponding author at: Department of Ecology, College of Urban and Environmental Sciences, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing, 100871, China.
E-mail address: jshe@pku.edu.cn (J.-S. He).
[1] Hao Wang and Huiying Liu contributed equally to this work.

http://dx.doi.org/10.1016/j.agee.2017.07.041
Received 9 March 2017; Received in revised form 27 July 2017; Accepted 31 July 2017
Available online 12 August 2017
0167-8809/

decreases soil moisture, which might inhibit R_h (Li et al., 2013). Hence, R_h and R_a might respond differently to the grazing-induced changes of plant properties and soil conditions. Assessing the direction and magnitude of their responses, along with identifying their drivers, will improve our understanding of carbon cycling processes.

The Tibetan Plateau covers approximately 370 million km^2 (Tang et al., 2009), with alpine grasslands covering approximately 62% of the total area (Zhang et al., 2007). Two types of grazing patterns are conducted in the Tibetan Plateau grasslands; namely, warm-season and cold-season grazing (Cui et al., 2014). Warm-season grazing is usually conducted from June to October during the growing season, whereas cold-season grazing is often conducted in the other months during the non-growing season. Warm-season grazing reduces the volume of living plants and cuts off the photosynthetic supply (Wan and Luo, 2003). Cold-season grazing removes standing litter and alleviates light limitation for plant growth (Zhu et al., 2015). The two grazing patterns might affect R_s in different directions and degrees. Until now, most studies have explored the response of R_s to either warm- or cold-season grazing in Tibetan alpine grasslands; however, it remains controversial how R_s components respond to the two grazing patterns (Chen et al., 2016; Cui et al., 2014; Lin et al., 2011). Moreover, few studies have explored interannual variation in how grazing affects R_s and its controls, because short-term studies have not captured the interannual dynamics (Chen et al., 2016; Fu et al., 2014). Here we used a long-term (6 years) manipulative experiment with two grazing patterns, combined with a meta-analysis, to (1) investigate the responses of R_s to the two grazing patterns, and further (2) partition the responses of R_s components.

2. Materials and methods

2.1. Study site

Our research site is located at the Haibei Alpine Grassland Ecosystem Research Station, which is located in the northeast of the Tibetan Plateau (37°36′E, 101°18′N) at an altitude of 3198 m (Fig. 1). Climatological data at this site from 1980 to 2014 shows that the mean annual air temperature was −1.1 °C, and that annual precipitation was 486 mm with 80% occurring during May to September. The alpine meadow is dominated by *Stipa aliena*, *Elymus nutans*, and *Kobresia humilis*. The averaged forage production was 344 $g\,m^{-2}$ from 1980 to 2014. The soil is Mat Cry-gelic Cambisols according to the Chinese national soil survey classification system. The organic carbon density in the 0–10 cm layer is 63 $g\,kg^{-1}$ (Lin et al., 2016).

2.2. Experimental design

In May 2006, a 27 m × 27 m area was fenced and divided into 16 plots separated by 3-m-wide buffer strips. Four treatments were applied to the 16 plots; namely, the control, warming, grazing, and a combination of warming and grazing. Four plots were used for each treatment. Considering that this research aimed to explore the effects of grazing on R_s, we only selected the treatments of control and grazing for analysis (warm-season grazing from 2008 to 2010 and cold-season grazing from 2011 to 2013). The control was set without grazing, warm-season grazing was carried out in July and August of every summer, and cold-season grazing was simulated by clipping vegetation from October of one year to March of the next year (Luo et al., 2009; Zhu et al., 2015). More specifically, for warm-season grazing, we fenced the sheep into three 5 m × 5 m plots one day before the grazing experiment started, to help the Tibetan sheep adapt to the small size of the plots. Two adult Tibetan sheep were fenced in the grazing plots for approximately 1 h on July 8 and August 20 in 2008, on July 9 and August 24 in 2009, and on July 7 and August 23 in 2010 (Lin et al., 2011). The exact length of grazing time depended on forage utilization. If forage utilization was below 50%, we grazed two sheep in the following day until the plant height was approximately half the initial height after grazing. For cold-season clipping, we clipped 50% of the litter biomass (Zhu et al., 2015). Forage utilization was set at 50%, because moderate grazing often uses nearly half of the forage production in the Tibetan Plateau grasslands (Cui et al., 2014; Dong et al., 2015; Gao et al., 2009).

2.3. Measurement of R_s and its components

We inserted polyvinyl chloride collars with a diameter of 20 cm (10 cm height) into a soil depth of 3 cm for measuring R_s, and inserted collars (65 cm height) into a soil depth of 60 cm for measuring R_h. The above-ground plants were removed in all collars. Compared to the collars for R_s, the deeper collars blocked the transportation of photosynthate from the plants outside the collars. Until R_h rate was no longer affected by dead roots and steady after six months (Wang et al., 2014), R_h was used for the analysis in this study. R_a was calculated by subtracting R_h from R_s.

From June 2008 to December 2013, R_s and R_h were both measured four or five times per month from May to September, and one time per month in the other months by using an automated chamber system (LI-8100; Li-Cor Inc., Lincoln, NE, USA). One day before conducting the measurement, we clipped the above-ground part of the plants inside the collars for R_s. All the measurements were done between 09:00 and 12:00 local time. To estimate annual emissions of R_s and its components, we first derived the daily R_s by calibrating the observed daytime value (09:00–12:00) based on the daily average value obtained from LI-8150 which automatically measured R_s and R_h once an hour in the control (Li-Cor Inc., Lincoln, NE, USA). Annual cumulative emissions were calculated by multiplying the time intervals by average daily fluxes between the two consecutive sampling dates (Wang et al., 2017).

2.4. Measurement of soil temperature and moisture

Soil temperature and moisture at the depth of 5 cm were obtained by using the temperature (LI-8100-203; Li-Cor Inc., Lincoln, NE, USA) and moisture sensors (Decagon Devices Inc., Pullman, WA, USA). Soil moisture was expressed as volumetric percentage (%).

2.5. Data collection

We conducted a meta-analysis to assess the grazing effect on R_s in the Tibetan Plateau grasslands. We used the Web of Science and China National Knowledge Infrastructure to search for all relevant literatures and dissertations. The results were filtered by the following conditions: 1. the studies were based on field experiments; and 2. the studies were located in an alpine meadow or alpine steppe on the Tibetan Plateau. For each study, we compiled the R_s data from the control and grazing treatments. To ensure the independence of the experiments, only the results in recent year were employed. Moreover, we separated grazing intensity into different levels (Gao et al., 2009). Moderate grazing intensity was defined as a forage utilization higher than 35%, but lower than 60%, or a grazing intensity between 4.2 sheep per hectare and 7.0 sheep per hectare. Heavy grazing intensity was defined as a forage utilization higher than 60% or a grazing intensity higher than 7.0 sheep per hectare (Dong et al., 2015; Gao et al., 2009). Based on the timing of grazing, we also separated grazing patterns into warm- and cold-season grazing.

2.6. Statistical analysis

A paired-*t* test was used to determine the differences in soil temperature and moisture at 5 cm depth, annual cumulative R_s and its components, and the ratio of R_h to R_s between the control and grazing treatments. We used linear regressions to examine how cold-season grazing effects varied with annual mean air temperature and annual