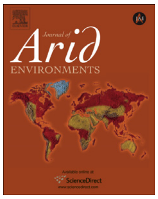
Journal of Arid Environments 114 (2015) 41–48

Contents lists available at ScienceDirect

Journal of Arid Environments

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



Grazing effects on carbon fluxes in a Northern China grassland

Lingling Zhu [a, b], Douglas A. Johnson [c], Weiguang Wang [a, d], Lei Ma [a], Yuping Rong [a, *]

[a] Animal Science and Technology College, China Agricultural University, Beijing 100193, China
[b] College of Medicine, Biology and Environment, Australia National University, Canberra 0200, Australia
[c] USDA-ARS Forage and Range Research Lab, Utah State University, Logan, UT 84322-6300, USA
[d] College of Engineering, Marshall University, Huntington, WV 25703, USA

ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form
5 November 2014
Accepted 13 November 2014
Available online

Keywords:
Ecosystem respiration
Daytime ecosystem CO_2 exchange
Gross ecosystem production

ABSTRACT

Grazing management is critical and can play a significant role in driving C sink and source activity in grassland ecosystems. In this study, CO_2 exchange patterns during the growing season were evaluated in the grasslands of northern China using a closed-chamber technique at three stocking rates sites. The results showed that heavy grazing markedly reduced green biomass, plant standing dead, and litter mass as well as reduced net ecosystem exchange (NEE) ($P < 0.05$). Principal component analysis (PCA) indicated that spatial and temporal patterns varied in ungrazed, moderate grazing, and heavy grazing sites. High NEE was associated with high biomass, high temperature, and high soil water content (SWC), ecosystem respiration (Re), and soil respiration (Rs). Rs was higher at the moderate and heavy grazing sites than the ungrazed site. In contrast, Re and canopy respiration (Rc) were higher at the ungrazed than the other grazing sites. These results indicated that grazing influenced vegetation and soil characteristics, which altered the spatial and temporal patterns of CO_2 fluxes in grasslands of northern China. Therefore, reducing stocking rates on heavily grazed grasslands of northern China to moderate grazing levels would enhance NEE, and benefit biomass and animal production.

1. Introduction

As with other grasslands, Chinese grasslands store C primarily belowground (Yang et al., 2010). Net ecosystem exchange (NEE) is the net effect of C fixation by plants, heterotrophic and autotrophic respiration, and soil C storage. These processes are sensitive to grazing intensity (Lecain et al., 2000; Welker et al., 2004; Ingram et al., 2008). Grasslands comprise almost 10% of the world's terrestrial surface area, and numerous studies have been conducted concerning soil properties and vegetation characteristics of various grasslands (Derner et al., 2006; Pineiro et al., 2006; Steffens et al., 2008). However, few research studies concerning the patterns of NEE have been conducted on the grasslands of northern China. Grasslands of northern China are severely degraded and desertified because of overgrazing (Han et al., 2008). In addition, plants there only have a few months to grow and assimilate C because of low precipitation and a cold climate. Measurements of CO_2 fluxes have been conducted in Chinese grasslands using Eddy Covariance methods (Hao et al., 2007; Fu et al., 2009; Lei and Yang, 2010; Dong et al., 2011; Yang et al., 2011; Bai et al., 2012; Gao et al., 2012; Kang et al., 2013), which are prone to underestimation of CO_2 fluxes. Chamber-based methods are simple and can be used to measure components of CO_2 fluxes on a small scale; however, few of these measurements have been obtained in grasslands of northern China.

Grasslands of northern China are sensitive to grazing disturbances and may intensify in the future with increasing demand for animal products in China. Although grazing is widespread on the grasslands of northern China, few studies have examined the effects of grazing on the components of CO_2 fluxes. In this study, we measured the spatial and temporal patterns of CO_2 fluxes on a grassland in northern China that was subjected to different grazing intensities. We hypothesized that grazing alters spatial and temporal patterns of CO_2 fluxes.

---

* Corresponding author. Department of Grassland Science, Animal Science and Technology College, China Agricultural University (CAU), 2 Yuan Ming Yuan West Road, Haidian District, Beijing 100193, China.
E-mail address: rongyuping@cau.edu.cn (Y. Rong).

http://dx.doi.org/10.1016/j.jaridenv.2014.11.004
0140-1963/© 2014 Elsevier Ltd. All rights reserved.

2. Methods

2.1. Study area

This study was conducted in a temperate grassland near Guyuan in northern Hebei Province in northern China (41°44′N, 115°46′ E; elevation 1380 m). This grassland has a semiarid continental monsoon climate, which in summer is dominated by warm moist air currents from the Pacific Ocean in a southeasterly direction. Autumn, winter, and spring seasons are dominated by cold, dry air currents from Mongolia. Mean annual precipitation is about 400mm, nearly 79% of which is received between July and September (Huang et al., 2007). In 2012, the rainy season began at the sites in late-June. Mean annual temperature at the sites is 1 °C, with a mean minimum temperature of −18.6 °C (January) and mean maximum of 17.6 °C (July). Annual evaporation at the sites is about 1735 mm, which is more than four times mean annual precipitation. The mean frost-free growing season is 85–95 days. Soil in this area is classified as a chestnut soil (Chinese classification) or a Calci orthic Aridisol (USA classification).

Three grazing treatment sites (1.5 ha each) located about 100- to 150-m apart within a 24-ha area were used in this study. The area encompassing the study sites had been free grazed by beef cattle and sheep for more than 50 years prior to 2009 and was seriously degraded. The study area was fenced in 2009 and rested for one year. In 2010, three grazing treatments were established: no grazing, moderate grazing (6.7 sheep/ha with 50–55% biomass removal), and heavy grazing (9.3 sheep/ha with 70–85% biomass removal). Each grazing treatment was replicated five times. The heavy grazing treatment was equivalent to the historical grazing intensity in this area. Vegetation in the study area was dominated by C_3 perennial grasses (*Leymus chinensis*, *Stipa krylovii*, and *Phragmites communis*), a C_4 perennial grass (*Cleistogenes chinensis*), a C_3 sedge (*Carex duriuscula*), and several broad-leaf species (*Taraxacum mongolicum*, *Artemisia frigida*, and *Polygonum sibiricum*).

2.2. CO_2 flux measurements

From early June to late September in 2012, net ecosystem CO_2 exchange (NEE), ecosystem respiration (Re), and soil respiration (Rs) were measured at about 10-day intervals. In May (about two weeks before measurements commenced), five 50-cm × 50-cm steel frames were inserted into the soil to a depth of 5 cm at each site (total of 15 frames). A PVC collar (20-cm diameter, 10-cm height, 1.5–2-mm thickness) was also inserted 5 cm into the soil beside each frame.

A 50-cm (length) × 50-cm (width) × 50-cm (height) transparent plexiglass chamber (3-mm thick) equipped with two small fans for mixing air inside the chamber was used to measure CO_2 fluxes (Niu et al., 2008). The canopy chamber was connected to an infrared gas analyzer (LI-6400, Li-Cor, Lincoln, NE, USA) to measure changes in CO_2 concentration inside the chamber. Prior to the measurement, a flexible rubber gasket was attached to the bottom of the chamber to seal the chamber and the frame. The plexiglass chamber was placed on the steel frame, and changes in CO_2 concentrations were monitored at 10-s intervals during a 90-s period. After the measurement period, the chamber was removed from the frame and opened to the atmosphere for about 1 min. The chamber was again placed on the frame and immediately covered with an opaque cloth to obtain estimates of Re. All measurements were conducted between 0900 and 1100 on sunny days with photosynthetic photon density (PPFD) greater than 1500 μmol m^{-2} s^{-1}. This period represented the time when net CO_2 exchange was near its peak and when changes in PPFD and temperature were minimal. In July and August, plants began to gradually wilt after about 1100. The calculations of NEE and Re are based on the method of Steduto et al. (2002). Negative values of NEE indicated a net C sink for the grassland ecosystem. Gross CO_2 assimilation (GCA) was calculated as NEE - Re.

During the measurements of NEE and Re, soil respiration (Rs) also was measured using a LI-8100 soil CO_2 flux system (LI-COR, Lincoln, Nebraska, USA). About 48 h before the Rs measurement, emerging seedlings were removed from the area inside the PVC collar. Soil temperature at a 10-cm depth was measured with a temperature probe in the LI-8100 system. Canopy respiration (Rc) was calculated as Re − Rs. A total of 6–8 min was required to complete a set of measurements for one plot.

Diurnal patterns of CO_2 flux were measured once every month at 0600, 0900, 1300, 1700, and 2100. However, because of water vapor condensation on the chamber wall during some early morning and night-time periods, we were not always able to collect a complete set of diurnal measurements on all measurement dates.

2.3. Plant biomass and soil sampling

In the middle of each month during May through September, aboveground biomass was clipped to ground level in five separate 50-cm × 50-cm quadrats. The clipped vegetation was separated into live and standing dead plant components, and litter was also collected. The live plant component was further subdivided into grasses, forbs, sedges, and other species. All plant samples were dried at 65 °C for 48 h, and dry weights were determined. Live, standing dead, and litter components were ground to pass through 1-mm sieve prior to C content analysis by a total organic C (TOC) analyzer (Elementer, Germany). Five soil samples were taken at three spoil-depth increments (0–10 cm, 10–20 cm, and 20–30 cm) near each chamber and placed into aluminum cans and tightly closed. Soil samples were oven-dried at 105 °C for 48 h, and soil water content (SWC) was determined gravimetrically.

2.4. Statistical analysis

Our study limitations did not allow a truly replicated experiment. The disadvantages of pseudo-replication are well known (Hurlbert, 1984); however, Oksanen (2001) argued that true replication in ecological studies may not be strictly necessary in large-scale experiments or when time and money preclude replication. Numerous scientists have published results of their pseudo-

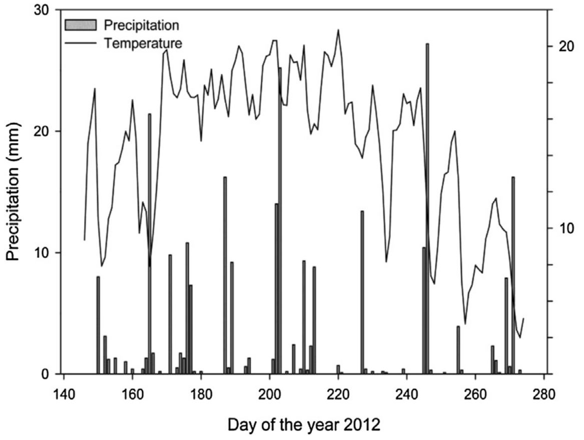


Fig. 1. Daily precipitation and mean daily soil temperature during the 2012 growing season (mid-May through September).