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Effects of various stocking rates on grassland soil respiration during the non-growing season

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ABSTRACT

Soil respiration is a key component of net CO_2 exchange in grassland ecosystems and directly influences the soil carbon pool dynamics. While numerous soil respiration studies in grazed grasslands exist, the accurate quantification of the net CO_2 exchange in grassland ecosystems throughout the entire year is required to determine whether grazed grasslands are carbon sinks or sources. In this study, we evaluated how stocking rate influenced soil respiration during the non-growing season in a typical grassland in the Hebei Province of North China. To examine the effects of stocking rate on soil respiration, soil respiration rates were measured using a soil greenhouse gas flux measurement system. Three stocking rates—ungrazed control (UG), moderate grazing (MG), and heavy grazing (HG)—were applied by grazing small tail sheep (ewes and lambs) at different densities from the end of June to early October in 2010 through 2013, and the relationships among soil respiration, stocking rate, and environmental factors were analyzed during the non-growing season (1 October 2013 to 30 April 2014). Variation in soil respiration followed a "V" pattern and was correlated with soil temperature and moisture for all stocking rates. Stocking rates did not significantly influence soil temperature or soil moisture; however, cumulative CO_2 emissions during the non-growing season decreased dramatically ($P < 0.05$) with increased stocking rates, following the order of UG (0.51 ± 0.015 kg C m^{-2}) > MG (0.38 ± 0.012 kg C m^{-2}) > HG (0.33 ± 0.009 kg C m^{-2}). The influences of air and soil temperature on soil respiration rate were best described by an exponential equation ($R^2 = 0.43$–0.55; $P < 0.01$). A significant quadratic relationship was found between soil moisture and soil respiration rate ($R^2 = 0.46$–0.67; $P < 0.01$). Soil respiration during the non-growing season was most strongly influenced by air temperature ($R^2 = 0.56$), with Q_{10}values either increasing or decreasing relative to the UG treatment for the MG and HG treatment, respectively. Given the strong influence of grazing intensity on soil respiration in this grassland ecosystem, we suggest that the accurate estimates of annual soil respiration should routinely account for soil respiration during the non-growing season.

1. Introduction

Net CO_2 exchange in grassland ecosystems consists of plant photosynthesis and respiration as well as soil respiration [1]. When growth activity of the plant community diminishes during the non-growing season, soil respiration becomes a main pathway of the net CO_2 exchange in grassland ecosystems, meanwhile it is also an important output way by which soil releases CO_2 into the atmosphere [2]. Numerous studies have quantified soil respiration in grassland ecosystems during the growing season [3–6], and typically assume soil respiration during the non-growing season is either zero or contributes little to estimates of annual cumulative CO_2 released by soil respiration [7]. However, because studies indicate that soil microbial metabolic activity still occurs at low temperature, and soil respiration is notable [8–9], quantifying soil respiration during the non-growing season can lead to more accurate assessments of carbon accumulated during the growing season and lost in soils [2]. For example, in recent years, studies on soil respiration during the non-growing season, have accurately estimated the ecosystem carbon balance in the arctic tundra and subalpine ecosystems [7–10]; yet, few have been reported in grassland ecosystems [2,11–12]. Therefore, studying soil respiration during the non-growing season is of great importance for the accurate quantification of the net CO_2 exchange in grassland ecosystems throughout the entire year.

As one of the most important forces in grassland ecosystems, livestock grazing interactively influences nearly all aspects of vegetation and soil due to their direct influence on biomass consumption, trampling and excretion [13], as well as directly or indirectly affects soil respiration. Grazing effects on soil respiration are inconsistent; with results supporting both higher rates in North American grasslands [14] and lower rates during the growing season in alpine scrubby meadow of the Qinghai-Tibet Plateau [15]. Furthermore, studies indicate that

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grazing also have no influence on soil respiration rates [5,16]. While studies recognize the influence of climatic factors, plant community composition, and soil properties on soil respiration in grassland ecosystems, stocking rate (i.e. grazing intensity) can also have both direct and indirect influences on plant community composition, litter, soil nutrient, soil temperature and moisture, and soil microflora, thereby affecting soil respiration [13,16–17]. For example, soil respiration in *Stipa breviflora* desert steppe under different grazing intensity showed that soil respiration decreased with the increase of grazing intensity [6]. However, A number of studies primarily focused on how stocking rate influences soil respiration during the growing season [6,16–17]. To improve our understanding of stocking rate influences on soil respiration during the non-growing season and associated changes in environmental factors, we studied soil respiration in a typical grassland of Hebei Province, northern China, in response to three distinct stocking rates.

2. Materials and methods

2.1. Site description

Our study was located at a national grassland ecosystem research station (41°46′N, 115°41′E, altitude 1380 m) in Guyuan County, Hebei Province, China. The station occurs in the Bashang Plateau, where the dominant plant species include *Stipa krylovii* and *Leymus chinensis* and less common species are *S. baicalensis*, *Artemisia frigida*, and *Potentilla acaulis*. The site had been continuously overgrazed throughout the entire year for >50 years. The local climate is characterized as semiarid continental monsoon climate, with the effects of warm moist air flow from the southeast in summer and cold dry climate controlled by high atmospheric pressure from Mongolia in other seasons. Mean annual temperature from 1982 to 2011 is 1 °C, with mean low and high temperatures occurring in January (−18.6 °C)and July (17.6 °C), respectively. Accumulated daily temperature greater than or equal to 10 °C is 1513 °C. Mean length of the frost-free period is 85–95 days. Mean annual precipitation is 400 mm with 80% precipitation occurring from June to September, while mean potential evaporation is 1735 mm. Mean annual wind speed is 4.3 $\text{m}\cdot\text{s}^{-1}$. Annual full sun time is 2930 h. The soil type is primarily chestnut soil group.

2.2. Experimental design

The study area was fenced in 2009 to prevent grazing and divided into the following three different stocking rate treatments in 2010: 1) Ungrazed control, UG = 0 sheep·ha·year, 2) Moderate grazing, MG = 1.67 sheep·ha·year, and 3) Heavy grazing, HG = 2.33 sheep/ha·year, respectively. The size of each plot was 1.5 ha. Grazing was from the end of June to early October every year. Local small-tail sheep, which included ewes and lambs freely ingested and rested in the sheepfolds located at the plots at night. Stocking rate treatments were not replicated because of larger area at the station, and the inconvenience of moving analytical instruments once installed.

2.3. Soil respiration measurements

The CO_2 concentrations were measured by using a soil greenhouse gas flux measurement system (LGR-9080010, Los Gatos Research, Mountain View, CA, USA) with off-axis integral cavity output spectrum (OA - ICOS) technology. The internal program, MCC-1-8 soil flux system Version 1.0 (LICA United Technology Limited, China), converts CO_2 concentration to CO_2 flux. The conversion formula of CO_2 flux is as follows.

$$F_{CO_2} = \frac{10VP_0\left(1-\frac{W_0}{1000}\right)}{RS(T_0+273.15)}\frac{dc}{dt}$$

Where $F_{CO_2}$is the soil respiration rate ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), V is the volume of chamber (cm^3), $P_0$is the initial atmospheric pressure value (kPa), $W_0$is the initial vapor mole fraction, R is value of the gas constant (8.314 $\text{J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$), S is the soil surface area (cm^2), $T_0$is the initial air temperature (°C), dc/dt represents CO_2 concentration change over time.

Within each treatment plot, five sampling points with consistent vegetation and topography were selected. The distance between the sampling points was about 5 m. PVC collars (20 cm inner diameter and 15 cm height) were installed to a soil depth of 12 cm for 15 days before the beginning of soil respiration measurements. The height was set to 3 cm and sampling time was set to 2 min in the MCC-1-8 program. Standing dead litter was removed from the area inside the PVC collars, while ground litter was left on the soil surface because its impact on the volume of the chamber was not accounted for. The fluxes of soil-atmosphere exchange of CO_2 were frequently observed from October 1 in 2013 to April 30 in 2014. CO_2 fluxes in the five sampling points were measured once at the same time (i.e. 9:00 to 11:00), because fluxes measured during this period can represent daily mean value [3]. Soil respiration rates were observed once every two days during the autumn freeze-thaw period, once each month during permanently frozen period, and once every two days during the spring thaw-freeze period. Soil respiration rates from November 23 to December 31 in 2013 and March 28 to April 12 in 2014 were not observed, resulting from the weather and the problem of instrument, respectively.

2.4. Auxiliary measurements

Air temperature and pressure were obtained from the weather instrument (Weather Hawk XP, Salt Lake City, UT, USA) by recording data at 30 min interval, when soil respiration rates were observed. Data of precipitation in winter were provided by the Bureau of meteorology in Guyuan County. Soil temperature and soil moisture were measured by using an ECH_2O dielectric aquameter (Decagon Devices, Pullman, WA, USA), which was installed near the each PVC collar in the each treatment to record data at 30 min interval. Because soil type and freeze-thaw events can affect the ECH_2O instrument, it was calibrated using the dry method before it was installed.

2.5. Data analysis

One-way analysis of variance was used to test the effects of stocking rate on soil temperature, soil moisture and soil respiration rate. The measured fluxes as daily mean values represented daily cumulative CO_2 emission through unit conversion. Cumulative CO_2 emission during the non-growing season was composed of that during the autumn freeze-thaw period, the permanently frozen period and the spring thaw-freeze period. Cumulative CO_2 emissions during the autumn freeze-thaw period and the spring thaw-freeze period were obtained using the linear interpolation method. However, cumulative CO_2 emission during the permanently frozen period was calculated as monthly mean fluxes multiplying by number of days. Fluxes measured only once in each month represented monthly mean fluxes, because of weak fluxes change during the permanently frozen period. The dependency of soil respiration rate on temperature was fitted by an exponential equation: $R_S = a \bullet e^{(b \bullet T)}$, where T represents temperature, and a and b are constants. Q_{10}values were estimated using an exponential equation: $Q_{10} = e^{10 \bullet b}$. Regression with stepwise multiple linear analyses was used to examine relationships of soil respiration rate with air temperature, soil temperature and soil moisture. The significant level was set at $P < 0.05$. Statistical analyses were conducted using SAS 8.2 (SAS Institute Inc., Cary, NC, USA) and results were displayed using Sigmaplot 10.0 software (Systat Software, Inc., San Jose, CA, USA).