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Grazing management affects plant diversity and soil properties in a temperate steppe in northern China

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ABSTRACT

In recent decades, temperate steppe have become seriously degraded, and rest grazing or moderate grazing approaches have been widely adopted since 1998 to restore degraded grasslands in northern China. The importance of choosing an appropriate grazing management regime for optimizing carbon sequestration in light of climate change or promoting other multiple ecological benefits of grassland ecosystems to humankind have long been recognized. In particular, the various uncertainties in plant and soil properties affected by grazing management require clarification. In this study, we selected fifteen blocks within three kinds of grazing management practices, including free grazing, warm-season grazing, and rest grazing, to test the responses of plant and soil properties to grazing management. The results showed that the species richness, the Shannon-Wiener index, and the proportion of forb functional group were higher for the warm-season grazing sites than for the free grazing sites. Soil bulk density, pH, the Pielou evenness index and the proportion of legume functional groups showed no difference among the three kinds of grazing managements. However, aboveground biomass, root biomass, canopy cover, and height of the vegetation community were larger in the rest grazing sites than in the free grazing sites. Soil organic carbon and total nitrogen contents decreased as management intensity increased, with the lowest and highest values occurring in the free grazing and rest grazing sites, respectively. Furthermore, soil organic carbon and total nitrogen contents were correlated positively with root biomass. Rest grazing was a suitable management strategy for carbon and nitrogen sequestrations, while moderate grazing was a suitable management strategy for diversity conservation in the temperate steppe, in northern China.

1. Introduction

Global land cover estimates for grasslands range between 20% and 40% of the Earth's land surface (Ward et al. 2016). Grasslands store > 10% of the terrestrial biomass carbon and 10–30% of the global soil organic carbon, which is known to be vulnerable to changes in land use type and intensification on a global scale, especially under dry climate conditions (Dlamini et al. 2016; McSherry and Ritchie 2013; Wang et al. 2016). The multiple benefits of grassland ecosystems for humankind have long been recognized, ranging from the direct benefits of agricultural production to indirect ecosystem services such as the regulation of climate and water quality, pollination services, and diversity conservation (Xiong et al. 2016).

However, increasing pressures to meet the food requirements of a more affluent and larger global population have resulted in widespread grassland degradation. Free grazing (areas that are used for grazing throughout the year) has been shown to reduce plant species diversity, productivity, canopy cover, and change soil structure and soil nutrients (Conant et al. 2001; Dlamini et al. 2016; Gass and Binkley 2011; Jiang et al. 2011). It has been recognized that the conversion from extensively to intensively managed grassland can decrease belowground carbon and nitrogen stocks due to reduced litter and root biomass inputs, and can increase the risk of soil erosion and desertification (McSherry and Ritchie 2013; Nagler et al. 2015; Wang et al. 2016). Seeking a sound grazing regime is an urgent issue for herders and the government in order to achieve sustainable animal production, while maintaining the health of the grassland ecosystem (Conant et al. 2001; Wang et al. 2015).

Globally, rest grazing (area that are excluded from grazing throughout the year by fencing), as one grazing management type, has been used effectively to increase the sustainability of grassland ecosystems (McSherry and Ritchie 2013; Davies et al. 2014; Wang et al. 2015). Previous studies have indicated that rest grazing stimulated soil nutrient content through aboveground biomass and root biomass, which act as primary input sources to the soil (Liu et al. 2016; Sun and Wang 2016; Wang et al. 2014). However, rest grazing can result in a

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loss of plant density and species richness (Dullinger et al., 2003), changes in plant community composition and functional groups (Diaz et al. 2007; Davies et al. 2014), and can decrease soil bulk density (Wang et al. 2014) and pH (Wang et al. 2014), all of which may suppress soil organic carbon and soil total nitrogen sequestration (Giese et al. 2013; Manning et al. 2015). Therefore, a reduction in grazing intensity, such as warm-season grazing (areas that are only used during summer and autumn), can be considered a suitable regime for restoring degraded grasslands (Buttolph and Coppock 2004; Cui et al. 2014; Medina-Roldán et al. 2012; Shrestha and Stahl 2008). Warm-season grazing is an appropriate management strategy for maintaining species composition and soil texture, and also yielding benefits for livestock productivity (Buttolph and Coppock 2004; Cingolani et al. 2005). A better understanding of the relationships between grazing management and the status of soil organic carbon content, soil total nitrogen content, plant diversity, and biomass is crucial for the sustainable use of grassland resources and critical for applying the proper management regime.

Grasslands constitute the largest category of land use in China at 42% (Liu et al. 2016), accounting for approximately 9–16% of the world's grassland carbon stocks (Fan et al. 2008) and playing an important role in regional climate change and global carbon cycling (Ni 2002). Grazing is one of the main grassland disturbances in the temperate steppe in northern China, which is an arid and semi-arid region. To obtain the maximum economic benefits from products such as milk, meat, wool and hides, sheep numbers have increased in recent decades leading to a reduction in steppe productivity. Because the stocking rates usually exceeding the safe carrying capacity in China, over 90% of rangelands are considered degraded and the grass production per hectare has decreased about 40% since the 1950s (Liu and Diamond 2005; Wu et al. 2014).

In order to promote ecosystem recovery associated with decreasing grazing intensity, rest grazing regimes to control grassland degradation have been designed and implemented by China's central government since 1998 (Chen and Tang 2016; Cui et al. 2014; He et al. 2012). In China, the grazing systems have changed from nomadic systems to semi-sedentary systems or sedentary systems, and the stocking methods have changed from continuous stocking to rotation stocking due to fencing since 1998 (Allen et al. 2011). It is necessary to make an assessment of the effects of contrasting grazing management regimes to determine management options to improve natural grassland-based land use systems (Xiong et al. 2016). In this study, we tested the effects of various grazing management regimes on overall plant and soil properties in a temperate steppe in northern China. We hypothesize that an increase in the grazing intensity will suppress the plant biomass and the soil nutrient content in the temperate steppe, and that a decrease in the grazing intensity will stimulate these properties. Moreover, we hypothesize that moderate grazing (warm-season grazing) will result in the largest plant diversity.

2. Materials and methods

2.1. Study site and experimental design

The study region (100°48′ ~ 101°12′ E, 38°54′ ~ 39°11′ N; 1790–1920 m elevation) is located in northern China, and has a typical desert climate, characterized by cold winters and hot dry summers. According to data from the National Meteorological Information Center of China, for the period from 1952 to 2007, the mean annual air temperature was 7.0 °C, ranging from −7.9 °C in January to 22.1 °C in July. The mean annual precipitation was 202.7 mm, 84% of which falls from May to September. The terrain is gentle hilly with slopes of generally < 5°. The main soil types in the study region have been classified as Aridisols in terms of the USDA soil taxonomy classification. No fertilizer or herbicides had been applied to the grasslands prior to the experiment.

The growing season ranges from May to September in the study region. The experiment was conducted in middle of July 2016, two weeks after the last grazing period had occurred. Five sampling sites were selected with the distance larger than 1 km between any two sites. In order to minimize the spatial heterogeneity, three 20 × 20 m sampling blocks in each site with the same slope and elevation were assigned to free grazing (FG), rest grazing (RG) and warm-season grazing (WG), and the distance between any two pairs of sampling blocks was < 40 m (Fraterrigo et al. 2005). In the center and at the four corners of each sampling block, five 1 × 1 m quadrats were chosen to survey the vegetation community's cover and height, the plant composition, and the soil. The grazing intensity of the FG sites was 2–3.5 sheep ha^{-1} from May to September and 1–2 sheep ha^{-1} from October to April of the following year. The grazing intensity of the WG sites was 2–3.5 sheep ha^{-1} from May to September, and no grazing activity from October to April of the following year. Rest grazing and warm-season grazing began in 1998 in the study region (He et al. 2012). The grazing intensities were highest in the FG sites, followed by the WG sites and the smallest in RG sites. Prior to the rest grazing and warm-season grazing regimes, the grasslands were managed under a free grazing regime from the 1960s, according to information obtained from farmers. The predominant plant species in the study region were *Stipa bungeana* Trin., *Artemisia frigida* Willd. and *Leymus secalinus* Tzvel..

2.2. Plant sampling

Canopy cover was measured in June 2016 and using a metal frame of 1 × 1 m with 100 equally distributed grids in the quadrat. The canopy height of each quadrat was the average of at least five random measurements of the height of an individual plants'. In each quadrat, all aboveground plant parts for each species were cut, collected, and placed into envelopes and tagged. In order to measure the root biomass (RB), soil sampling was performed five times in three soil layers (0–10–20-30 cm) in each quadrat using a 7-cm diameter root auger. After the larger roots had been removed from the soil samples, the remaining roots were separated by washing-sieving using a 0.5-mm sieve. The root tissue and aboveground plant materials were dried at 65° for 48 h and weighed to determine the RB and aboveground biomass (AGB). The root to shoot ratio of the biomass (R:S) was calculated by using RB and AGB in per square meter.

The Shannon-Wiener diversity index (*H*) and Evenness index (*E*) of the grassland communities were calculated as (Wang et al. 2014):

Richness index (*R*): $R = S$.

Shannon-Wiener diversity index (*H*):

$$H = -\sum_{i=1}^{s} (Pi \ln Pi),$$

Evenness index (*E*):

$$E = \frac{H}{\ln S},$$

where *S* is the total species numbers in the grassland community, *H* is the Shannon-Wiener diversity index and *Pi* is the weight proportion of *i* species to the total biomass.

2.3. Soil sampling

One soil sample was obtained at five points from each quadrat (four corners and the center of the quadrat) by using a 4-cm diameter soil-drilling sampler at depths of 0–10–20-30 cm. Samples from the same layer were then mixed together to create one sample, which was air-dried and passed through a 0.25-mm sieve. A total of 225 soil samples (75 quadrats with 3 soil layers) were obtained and evaluated for bulk density (BD), pH, soil organic carbon content (SOC), and soil total nitrogen content (TN). Soil pH was determined at a soil-water ratio of 1:5. Soil BD of the different soil layers was measured using the soil cores (volume, 100 cm^3) and the volumetric ring method. The SOC was assayed by dichromate oxidation (Nelson and Sommers 1982). The TN was assayed by using the modified Kjeldahl method (Bremner 1996). Each analysis was performed in duplicate.