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Effects of grazing exclusion on the grassland ecosystems of mountain meadows and temperate typical steppe in a mountain-basin system in Central Asia's arid regions, China

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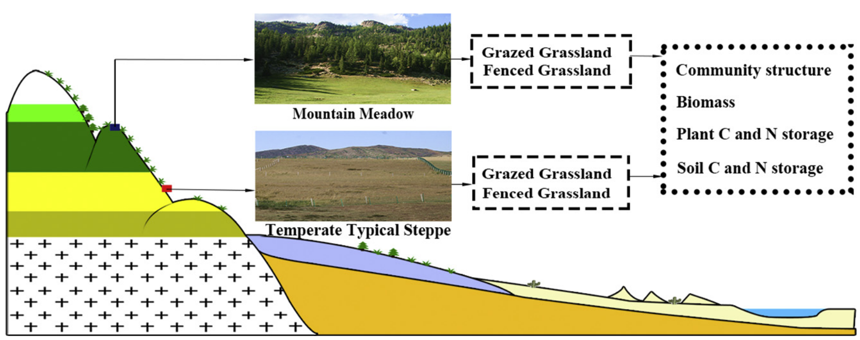
HIGHLIGHTS

- Productivity, diversity, and C and N storage of aboveground plants increased with grazing exclusion in mountain meadow.
- Grazing exclusion was not an effective option for soil C and N sequestration in mountain meadow.
- A trade-off between biomass productivity and diversity after grazing exclusion was detected in temperate typical steppe.
- Provide a basis for developing grazing exclusion strategies for the management of degraded grasslands in arid regions.

GRAPHICAL ABSTRACT



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ABSTRACT

Grazing exclusion has been proposed as a method of restoring degraded grassland ecosystems. However, its effectiveness remains poorly understood in mountain-basin grasslands in arid regions. Thus, we investigated the plant community characteristics, C and N storage levels, and soil organic carbon and total nitrogen concentrations and storage within the upper 0–40 cm soil layer in a grazed grassland (GG) and a fenced grassland (FG) with grazing exclusion in mountain meadow (MM) and temperate typical steppe (TTS) habitats in a mountain-basin ecosystem in an arid region of Central China, which are both vital grassland resources for livestock grazing and ecological conservation. In MM, our investigation revealed that grazing exclusion was beneficial to the productivity, coverage, height, diversity, and C and N storage of aboveground plants. However, grazing exclusion was not an effective option for soil C and N sequestration. In TTS, grazing exclusion effectively improved the plant productivity, coverage, height, plant and soil C and N sequestration, although it was not beneficial for maintaining plant diversity. Our findings suggest that reduced or rotational grazing may be a better choice than grazing exclusion in MM. In addition, considering the trade-off between biomass productivity and species diversity in TTS, short-term grazing exclusion should be considered. Additionally, grazing exclusion should be combined with other appropriate measures rather than operating on a standalone basis.

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1. Introduction

Grassland ecosystems cover approximately 30% of the land surface of the world (Houghton, 1994) and provide many crucial ecosystem services, such as C and N sequestration, primary production, ecosystem diversity maintenance, soil retention, water conservation and cultural services (Lal, 2004a; Jing et al., 2014; Ebrahimi et al., 2016). Arid regions cover approximately 12.0% of the earth's land area (Lal, 2004b). An alternating distribution of mountains and basins is the basic feature of the natural geography of ecosystems in arid regions of Central Asia (Fu et al., 2017). Zhang (2001) defined this landform as a mountain-basin system (MBS) (Supplementary Fig. 1). The grassland ecosystems in the MBSs of arid regions around the world are the basis for forage production and the focus of ecological conservations.

Livestock grazing is the dominant utilization of grasslands worldwide (Dong et al., 2011). However, most grasslands have experienced an increasing threat from continuous overgrazing, which has caused severe grassland degradation (McSherry and Ritchie, 2013; Chen et al., 2014). In order to eliminate the negative effects of continuous grazing, grazing exclusion has been extensively employed around the world (Golodets et al., 2010; Hu et al., 2016). However, the effects of grazing exclusion have not been conclusive. With respect to plant diversity, the results are controversial. Several studies reported that grazing exclusion could enhance plant diversity (Mekuria and Betemariam, 2011; Zhang and Zhao, 2015), but others reported a decrease or no change (Meissner and Facelli, 1999; Altesor et al., 2005; Wang et al., 2014). Some studies indicated that grazing exclusion increased the aboveground biomass (AGB) (Wang et al., 2014; Liu et al., 2016), some studies indicated that grazing exclusion increased belowground biomass (BGB) (Zhao et al., 2016; Wang et al., 2017), whereas others observed BGB decreases (López-Mársico et al., 2015; Wang et al., 2016) or no changes (Mcnaughton et al., 1998). Additionally, there was growing evidence suggesting that grazing exclusion could increase the C and N pools (Mekuria and Veldkamp, 2012; Qiu et al., 2012), but others reported no change (Shrestha and Stahl, 2008; Medinaroldán et al., 2012) or even lower soil C and N storage levels after exclusion (Reeder et al., 2004; Liu et al., 2012). Also, a number of studies were conducted in Chinese grasslands at different scales and sites (Li et al., 2014; Deng et al., 2017), especially on the grasslands of Inner Mongolia (Steffens et al., 2008; Chen et al., 2012) and the Qinghai-Tibetan Plateau (Miao et al., 2015; Li et al., 2017). However, the effects of grazing exclusion on the grassland ecosystems of the MBS in the arid region north of the Junggar Basin remain poorly studied. Therefore, it is critical to understand the effects of grazing exclusion on the key properties of these grassland ecosystems.

In this study, we compared the plant community structure, plant productivity and C and N storage levels in plants and soils in grazing exclusion grasslands and traditional grazing grasslands in Fuyun County, a representative of the MBS in the arid region of Central Asia. The main objectives of the study were to (1) investigate the responses of the plant community structure, productivity, and C and N storage to grazing exclusion and (2) understand how soil C and N concentrations and storage respond to grazing exclusion. The results can provide bases for the restoration and management of degraded grasslands of the MBS in arid regions.

2. Materials and methods

2.1. Study site

This study was conducted in Fuyun County, China (45°00′N to 48°03′N, 88°10′E to 90°31′E) (Fig. 1), which is located in a border region of the northern part of the Xinjiang Uygur Autonomous Region. This region extends from the southern base of the Altai Mountains to the area north of the Junggar Basin. The study area, which lies through the Irtysh River and the Ulungur River originated from the Altai Mountains and covers semi-arid and arid climatic belts of the temperate climate zone, is 32,186 km^2 with the elevation ranging from 317 to 3863 m and encompasses complex landforms that alternate between mountains and basins. The area has a mean annual temperature of 4.60 °C (2007–2016) and mean annual precipitation of 208.41 mm (2007–2016). Grassland is the main ecosystem type in this area and accounts for 87.46% of the total area. There are ten types of grasslands in Fuyun County according to China's grassland resource classification system (Ren et al., 2008). Different types of grasslands, which are characterized by obvious vertical zonality along elevation gradients, are distributed over in this typical MBS under different climatic conditions. Overgrazing is serious in these grassland ecosystems, especially in the grasslands used during the spring and autumn seasons (Table 1). By July 2016, the area of degraded grassland had reached 16,891 km^2, accounting for 35.06% of the entire grassland area (Fuyun Grassland Ecology Station, 2017). In our study, we selected MM as a representative summer pasture and TTS as a representative spring/autumn pasture (Table 1); both are vital grassland resources for livestock grazing and ecological conservation in the studied MBS. The details of the plots were shown in Table 1.

2.2. Field sampling and laboratory analysis

2.2.1. Experimental design

The experiment was conducted in the MM and TTS grassland areas, each with a fenced grassland (FG) site and a neighboring grazing grassland (GG) site (Fig. 1). The grazing exclusion areas of MM and TTS were fenced in 2006 and 2011 by the local government, respectively. The fenced grasslands were completely excluded from livestock grazing since the fencing was established, while seasonal grazing occurred in the grazed grasslands (Table 1). The grazed plot in MM was typically utilized in June to August and the grazed plot in TTS was typically utilized in spring and autumn. Plant and soil sampling was conducted in August 2017, which is the typical period of peak AGB. Four sampling plots (10 × 10 m^2, with an interval of 500 m–1000 m) were investigated in the grazing exclusion and grazed grasslands in each area.

In each plot, three quadrats of 1 × 1 m^2 were chosen to investigate the composition of vegetation species. The species types, coverage, height and number of each species were recorded. Then, the AGB in each quadrat was harvested. All aboveground parts (green parts and litter) of individual species were cut, collected, and placed in envelopes. To measure the BGB, soil samples were collected at three depths (0–10, 10–20, and 20–40 cm) using a 9-cm-diameter root auger. The root biomass below 40 cm was too low to be measured and considered negligible. Roots in the composite soil samples were collected after washing the soil in a 2-mm sieve. We measured the AGB and BGB by weighing the aboveground parts and belowground parts of the plants after drying at 65 °C to a constant weight.

Three soil profiles with an S-shaped pattern were selected in each plot. Core samples were collected from all depth intervals using stainless steel tubes with a volume of 100 cm^3 (5.1 cm in height and 5 cm in diameter) to quantify the bulk density. Soil samples were collected at a depth of 40 cm and separated into three segments starting from the top to obtain layers of 0–10, 10–20 and 20–40 cm. After manually removing fresh roots and plant residue from the samples, we air dried the samples at room temperature and then passed them through a 0.14-mm sieve after grinding. The initial weight of the soil core from each layer was measured immediately after collection.

2.2.2. Plant and soil indexes

C and N concentrations were determined using a total organic carbon (TOC) Analyzer (Multi N/C 3100, Analytik Jena AG, Germany) and the modified Kjeldahl method (Liu et al., 1996), respectively.

In this study, we used the Shannon-Wiener diversity index, Richness index and Pielou evenness index to describe community diversity characteristics. The relative coverage, relative height and importance value