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Changes in plant community composition and soil properties under 3-decade grazing exclusion in semiarid grassland

Zhaobin Jing[a], Jimin Cheng[a,b,*], Jishuai Su[a], Yu Bai[a], Jingwei Jin[b]

[a] College of Animal Science and Technology, Northwest A&F University, Yangling, Shaanxi Province, China
[b] Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi Province, China

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ABSTRACT

Grazing exclusion is an effective way to restore the degraded grassland, and significantly influences the vegetation compositions and soil properties. Plant–soil interaction plays an important role in the maintenance of both plant community composition and soil properties. However, there is littler information on the changes and feedback plant community and soil properties in the semiarid grassland on the time series of the long-term scale that has been continuous grazing exclusion grassland for thirty years. Using the monitoring data of five reference years from 1982 to 2011, we studied the effects of long-term grazing exclusion on plant community and soil properties, the grazing management treatment was as the control. Our results showed that the coverage, plant density, species richness above- and belowground biomass, and Shannon–Wiener index are higher in the mid- and transitional stage of succession in arid and semiarid grassland and then decreased with increasing restoration time. The plant density, coverage and aboveground biomass of plant functional groups showed similar results. Soil organic matter (SOM), total nitrogen (TN), available potassium (AK), available phosphorus (AP), and available nitrogen (AN) significantly increased with the increase of restoration time. There was an interaction between coverage, species richness, total productivity and some soil properties. For plant functional groups, only perennial bunchgrasses was significant positively related to SOM, TN, AN, and AK. This implies that perennial bunchgrasses may be an indicator of soil properties and improve soil nutrient. Our studies provide new sights into the plant–soil interactions and grassland management in semiarid region.

1. Introduction

Globally, about 30% of terrestrial areas are arid and semi-arid ecosystems, which provide substantial and effective ecosystem services (Zhan et al., 2007). Nowadays, due to global climate change, human disturbance and desertification, parts of grassland ecosystems have undergone degradation, such as a reduction in biodiversity and productivity, and ecosystem services (Sala et al., 2000; Sivakumar, 2007; Slimani et al., 2010). Grassland degradation is influencing the ecological function, productivity, social-economic of the world because of vegetation degradation and soil erosion (Zhang et al., 2011). In addition, grassland degradation impacts species diversity, above- and below-ground productivity, soil organic carbon, soil total N and soil total P (Wang et al., 2009; Wu et al., 2010). About 90% (3.99 billion ha) grasslands are degraded in China (Wu et al., 2009). Therefore, how to restore degraded grassland is an important ecological engineering to improve the restoration of degraded environment in grassland ecosystem.

Nowadays, many methods have been used to restore the degraded grassland successfully. Of them, grazing exclusion is regard as one of most approach to restore and improve the degraded grassland ecosystem (Su et al., 2005; Wu et al., 2009, 2010; Zhang et al., 2005). Previous studies on grassland restoration engineering, the main focus has been on the plant species and communities (Galvanek and Leps, 2008; Zhang and Dong, 2010). Soil also plays an important role in supply organic matter, nitrogen and carbon cycles, and weathering rocks and minerals in grasslands (Piao et al., 2009; Yuan et al., 2012). In addition, soil could directly affect community composition and plant species richness during restoration succession process (Tilman et al., 1996; Cione et al., 2002; De Deyn et al., 2003; Potthoff et al., 2005). In recent years, numerous studies have focused on the restoration evaluation of vegetation and soil based on different grassland types (Wright et al., 2004; Wu et al., 2009, 2010; Zhang et al., 2005, 2011). For example, Wu et al. (2009) showed that grazing exclusion significantly improved aboveground productivity but reduced plant density and

* Corresponding author at: College of Animal Science and Technology, Northwest A&F University, Yangling 712100, Shaanxi Province, China. Tel.: +86 2987012272.
E-mail addresses: gyzcjm@ms.iswc.ac.cn, zxxjzb520@gmail.com (J. Cheng).

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species diversity. He et al. (2011) reported that long-term grazing exclusion significantly affected the heterogeneity, dominant species and community composition. However, these studies were based on the methods in short-term scale and a spatial series representing temporal series. Little is known about the changes and relationships between vegetation compositions and soil properties on the time series at the long-term scale that is the data from continuous grazing exclusion grassland for thirty years.

In this paper, we hypothesize that: (1) the undisturbed community did support relatively higher richness, diversity and community productivity than the degraded community; (2) the species richness, diversity and productivity are higher in the mid- and transitional stage of succession in arid and semiarid grassland; (3) the changes of plant community composition and soil properties are not in balance and plant community may be influenced by soil properties; (4) there should be positive relationships between the some plant functional groups and the soil properties. Therefore, our objectives were to examine the changes of species richness and diversity, productivity and soil properties on time series during grassland restoration process. In addition, we explored the interactions between vegetation characteristics and soil properties. The goal is to provide the basis for biodiversity restoration and management of degraded grassland in semiarid areas.

2. Materials and methods

2.1. Study area

The study area was located the typical steppe grassland of the Loess Plateau at Yunwu Mountain (106°21′–106°27′ E, 36°10′–36°17′ N) in Ningxia Hui Autonomous Region, China. Yunwu Mountain was protected as a long-term monitoring site in 1982. The area is located at an elevation of 1800–2100 m, and has a total area of 6660 hectares. The grassland protection area includes core conservation area (1000 hectares), buffer conservation area (1300 hectares) and experimental area (4360 hectares). Starting in 1982, different grazing exclusion treatments were established at different times in the grassland protection areas, and no agricultural activities (such as fertilization and the cultivation of crops) have been carried out in this region since 1982. The climate of the study area is semi-arid within the middle temperate zone. The temperature is 22–25 °C in July, and the mean annual temperature is 7.01 °C. Mean annual rainfall is 425.42 mm, with about 60–75% of the annual rainfall falling in July–September. Accumulative temperature (≥0 °C) is 2847–3592 °C (Fig. 1), and annual daylight hours are 2300–2500. Annual evaporation is 1017–1739 mm, and the frost-free season averages 137 days. The vegetation types mainly include *Stipa grandis*, *S. przewalskyi*, *S. bungeana*, *Artemisia sacrorum*, and *Thymus mongolicus*. The vegetation consists of 297 plant species. *Gentianaceae*, *Stipa* and *Potentilla* are important plant components, and the main dominant species include *S. bungeana*, *S. grandis*, *T. mongolicus*, *A. sacrorum*, *Potentilla acaulis*, *Androsace erecta*.

2.2. Experimental design and sampling

This experiment was divided into two parts: grazing exclusion grassland and grazing management treatment. The long-term experimental plots of grazing exclusion in *S. bungeana* grassland, *T. mongolicus* grassland, *A. sacrorum* grassland were established in core conservation area in 1982. These grasslands were in similar landscape position and all areas adjoined each other. The study area had previously been grazed by sheep prior to protection, and the stocking rates are heavy density (>50 sheep/ha). These plots

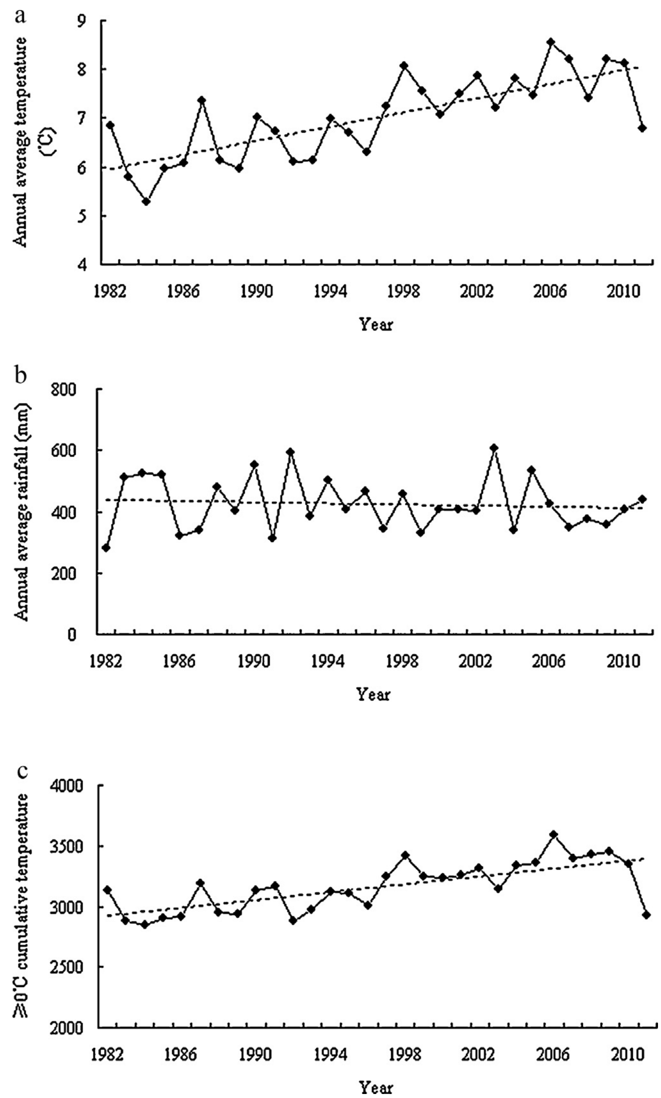

Fig. 1. Changes in rainfall and temperature from 1982 to 2011 in the region of this study.

have been excluded from life stock grazing since 1982. A grazing area selected as a control in an adjacent area outside of the grassland protection zone. This grazing management treatment is a medium density of sheep during the whole year (4 sheep/ha), and the dominant species is perennial bunchgrasses by *Stipa bungeana*.

Within each plot, three equal-sized replicate blocks (300 m × 100 m) was established at grazing exclusion grassland, and then fifteen permanently fixed sampling quadrats (1 m × 1 m) were established in each block. Ten random quadrats (1 m × 1 m) were established in a 200 m × 100 m block at grazing management treatment. Investigations of the vegetation were carried out on mid-August each year, when the biomass reached its highest. Plant coverage was measured by projection method, height was measured using ruler, abundance, and individual quantities were recorded by coenology and statistic methods. Aboveground biomass of each species (only the green plant parts) was measured in each sampling quadrat (Adler et al., 2011). In each quadrat, ten samples of belowground root biomass were collected from each 20 cm layer between 0 and 120 cm depth using a stainless steel auger, 9 cm in internal diameter. Roots were separated from the soil samples and then weight. We classified species into the five plant functional groups (PFGs): annuals and