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Effects of grazing exclusion in Xilin Gol grassland differ between regions

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ABSTRACT

Establishment of grazing exclusion has become an important rangeland rehabilitation strategy in semi-arid regions. However, the effect of grazing exclusion on soil has been controversial, and the regional differences in these effects have not been investigated sufficiently. Based on field investigation and lab experiments, the present study compared the vegetation cover, vegetation height, biomass, soil organic carbon (SOC), total nitrogen (TN) and available nitrogen (AN) contents inside and outside 18 grazing exclosures that had been established for approximately 10 years in the Xilin Gol grassland. Then, we examined the effect of grazing exclusion on vegetation and soil. We also analyzed the regional differences and the impact factors related to the restoration effects since the Beijing-Tianjin Sandstorm Source Control Project was implemented. Data processing and statistical analyses were carried out with SPSS 13.0. The results showed that the exclosures exhibited significantly ($p < 0.01$) higher values regarding biomass (153.407 g/m^2), vegetation height (27.417 cm) and vegetation cover (62.5%), compared to free grazing lands, where these values were 76.094 g/m^2, 12.587 cm and 45%, respectively. This suggested that exclosures are effective in restoring vegetation. The higher the annual precipitation, the better the effect of grazing exclusion on vegetation will be. The exclosures significantly improved soil physical properties: soil bulk density inside the exclosures (1.382 g/cm^3) was lower than outside (1.457 g/cm^3) in the 0–5 cm depth, and the proportion of soil clay was higher inside the exclosures (0.504%) than outside (0.411%) in the 0–10 cm layer. There were linear declines in the restoration effects for SOC and TN at the 0–10 cm depth with annual precipitation, and areas with more precipitation exhibited no significant or even a negative restoration effects. Therefore, the recovery of soil and vegetation showed regional differences. In follow-up management policies, different climate zones should adopt corresponding grassland management practices.

1. Introduction

Land degradation, which includes degradation of vegetation cover, soil degradation and nutrient depletion, is a major ecological and economic problem in arid and semiarid areas (Le Houérou, 2001; Mekuria et al., 2007). Continued overgrazing is one of the main causes of degradation in these areas (Le Houérou, 2001; Jeddi and Chaieb, 2010). The effects of overgrazing are considered destructive because of the reduction of ground cover, the loss of forage species, the increase of bush encroachment and the decrease of fodder production, while the regenerative capacity is often compromised, leading to a loss of biodiversity (Deléglise et al., 2011). Overgrazing or uncontrolled grazing always destroys the topsoil structure and increases soil compaction as a result of trampling (Manzano and Návar, 2000; Milchunas and Lauenroth, 1993). These processes, in turn, increase soil crusting, reduce infiltration, enhance soil erosion susceptibility and cause a decline in soil fertility (Manzano and Návar, 2000; Abril and Bucher, 2001; Bartley et al., 2010).

Grazing exclosure, which is considered an effective, simple and easy method to control desertifying grasslands, is a well-

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known management tool applied to restore degraded rangeland ecosystems (Verdoodt et al., 2009). It is widely believed that the composition and productivity of rangeland vegetation will shift to a more productive state following grazing exclusion or a reduction in grazing pressure. Previous studies have reported that exclosures enhance vegetation cover, biomass and litter accumulation (Sasaki et al., 2009; Deléglise et al., 2011), and also increase species richness (Verdoodt et al., 2009). The process of succession in rangeland vegetation involves a coupling of the ecological processes occurring between the soil environment and vegetation. It is generally assumed that exclosures can change the particle size composition and decrease soil bulk density (Pei et al., 2008), increase water availability and reduce soil erosion (Mekuria et al., 2007), and improve soil fertility (Pei et al., 2008) as well as biological soil properties (Shrestha and Stahl, 2008; Jeddi and Chaieb, 2010).

It is generally assumed that exclosure leads to the restoration of vegetation (Deléglise et al., 2011; Witt et al., 2011). However, whether exclosure improves soil chemical and physical properties is still questioned. Studies of ungrazed soils worldwide have shown both increases (Pei et al., 2008; Mekuria et al., 2007; Su et al., 2004; Verdoodt et al., 2009; Jeddi and Chaieb, 2010; Witt et al., 2011; Luan et al., 2014) and decreases or invariability (Arévalo et al., 2007; Enriquez et al., 2014; Shrestha and Stahl, 2008; Shi et al., 2013; Yayneshet et al., 2009; Medina-Roldán et al., 2012) in carbon storage and accumulation compared to adjacent grazed soils. Milchunas and Lauenroth (1993) conducted a review of 34 studies involving grazed and ungrazed sites around the world and found that 40% of them reported a decrease, while 60% reported an increase in soil carbon as a result of grazing exclusion. Based on an experimental study performed in a typical degraded area on a desert steppe in China, Pei et al. (2008) reported that exclosure enhanced SOC and TN accumulation: SOC and TN in the 0–20 cm soil layer both increased, with 22% higher SOC and 14% higher TN being observed after grazing exclusion for 2 years compared with grazed soil. Shrestha and Stahl (2008) examined the SOC contents inside and outside four long-term grazing exclosures on the semi-arid sagebrush steppe of Wyoming. The results showed that there was no significant difference in SOC due to grazing exclusion in three of the four sites. According to Verdoodt et al. (2009), significant improvements compared to open rangeland were recorded in the SOC and TN stocks in communal exclosures. In contrast to the results in communal exclosures, SOC and TN stocks showed a non-significant improving trend in private exclosures. Factors such as spatial variability, different soil and climate types, cultural practices and soil management may be responsible for these differences in results (Stoécio et al., 2009). However, recent studies in grasslands have suggested that not all plant communities exhibit the same classical patterns of vegetation change. The plant production and community composition in some arid ecosystems may depend more on climate than on grazing by livestock, and the high rainfall variability observed in arid and semi-arid grasslands may modify the effects of long-term exclosure (Sasaki et al., 2009; Slimani et al., 2010). Therefore, it is necessary to study the regional differences and influence factors of vegetation and soil properties inside and outside grazing exclosures more thoroughly.

The geographical location and landscape elements of the Xilin Gol grassland have a significant impact on the ecological environment of North China. Located on the north plateau of Beijing and Tianjin, the Xilin Gol grassland presents loose and crumbling soil, which is easily eroded and desertified. Strongly influenced by high atmospheric pressure from Mongolia during winter and spring, north winds are particularly prevalent in this area. Due to the impacts of the atmospheric circulation and its topography, the Xilin Gol grassland has become a sandstorm source, and Beijing and its peripheral areas are exposed to winds from Mongolia (SFAC et al., 2001). However, in 1988 the Xilin Gol grassland was presented as one of the most representative and best-preserved areas of the Inner Mongolian grasslands. In the past, nomadic herdsmen lived in equilibrium with the natural productivity of this fragile ecosystem. However, since the 1990s, the land degradation induced by overgrazing and improper land use in Inner Mongolia has become serious. The fragile grassland ecosystems have consequently been disturbed, and the region has shifted from a natural dust sink to a dust source (Hoffmann et al., 2008). In China's Agenda 21 and the Eco-environmental Improvement Plan of China, the Xilin Gol grassland was listed as a priority area for the implementation of ecological restoration programs. The Xilin Gol grassland belongs to a major control region of the Beijing-Tianjin Sandstorm Source Control Project (SFAC et al., 2001). This ecological restoration project has now been in place for more than 10 years, and the grasslands in this area are commonly fenced with exclosures. In view of the special geographical position and fragile ecological status of this area, it is of great significance for subsequent management measures, regional sustainable development and the ecological safety of the area to study the effects of grazing exclusion, understand the regional differences of the effects of exclosures on rangeland rehabilitation and evaluate the effectiveness of policies and measures. In the Xilin Gol grassland, in spite of the importance attributed to overgrazing management, the effects of exclosures on vegetation and soil have not been well studied. In the present study, our objectives are as follows: (1) to assess the effects of livestock grazing exclusion on vegetation and soil properties; (2) to understand the regional differences and influential factors related to exclosure strategies in rangeland rehabilitation; and (3) to analyze the existing problems in exclosure management strategies to provide a reference for follow-up treatment.

2. Materials and methods

2.1. Study area

The Xilin Gol grassland is located between 43°02′–44°52′ northern latitude and 115°13′–117°06′ eastern longitude in the middle of inner Mongolia, China, and covers approximately 20.3 million hectares (Fig. 1). This area belongs to the Inner Mongolian Plateau, and has an altitude ranging from 900 m to 1500 m. The continental climate produces warm, rainy summers and cold, dry winters. The precipitation regime is unimodal, with a dry season between October and April and a peak of rainfall from May to September. Based on meteorological data provided by the Chinese National Bureau of Meteorology, the mean annual precipitation ranges from almost 400 mm in the southeast to 150 mm in the northwest, with approximately 80% of the total received during the growing season from May through September. The summer rain is critical for the grass growth. The annual average temperature in this area is 1–2 °C, ranging from 0.6 °C to 12 °C, with a decreasing trend from the southeast to northwest. It is cool in the summer months (average July temperature, approximately 21 °C) and cold in winter (average temperature in January, less than −20 °C). However, the annual average number of windy days is 36.2, with higher numbers recorded in the northwest than in the southeast. The strong winds that are common in the Xilin Gol grassland throughout the year have become a major contributor to soil erosion and desertification. The dominant soils in the region are castanozems, chernozems and brown pedocals. The main vegetation types include typical grassland, meadow grassland, shrub and desert grassland. Most of the region is not suited for crops, and the bulk of the land is used for sheep and cattle grazing, ranging typically between 100 ha and 1000 ha in the central and eastern areas and over 2000 ha in the northwest per family. In 2000, the Beijing-Tianjin Sandstorm Source Control Project was initiated, and exclosures were gradu-