Cumulative effects of 20-year exclusion of livestock grazing on above- and belowground biomass of typical steppe communities in arid areas of the Loess Plateau, China

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ABSTRACT

Overgrazing affects typical steppe community in ways similar to grasslands in other areas. Exclusion of livestock grazing is one of the main management practices used to protect grasslands. However, it is not known if long-term exclusion of livestock grazing has positive effect on above- and belowground community properties in typical steppe of the Loess Plateau. We studied the long-term (20-year) cumulative effects of exclusion of livestock grazing on above- and belowground community properties compared with that before exclusion of livestock grazing in a typical steppe of the Loess Plateau, NW China. Our results show that twenty-year exclusion of livestock grazing significantly increased above- and belowground biomass, species richness, cover and height for five different communities. Most of belowground biomass was in the 0–20 cm horizon and grazing exclusion increased biomass especially at the depth of 0–10 cm. Our study suggests that long-term exclusion of livestock grazing can greatly improve community properties of typical steppe in the Loess Plateau.

Keywords: grazing exclusion; underground biomass; arid grasslands; the Loess Hilly-Gully Region

Grassland ecosystems contain a large part of the biosphere's carbon and are the largest source of uncertainty in the terrestrial carbon balance by their biomass accumulation (Piao et al. 2009). Grassland soil can influence global environmental change (Wright et al. 2004). Grazing disturbance can strongly affect grassland systems. Many studies were conducted to research the effects of grazing on individual species, population dynamics, community structure and biodiversity (e.g. Valone et al. 2002, Wu and Du 2007). Human alteration of natural ecosystems for agriculture is an important component of disturbance and has the potential to alter community cover and height, and function of grassland ecosystem. Improved grazing methods were considered as an important strategy to protect grassland ecosystem and renew degraded grasslands (Lal 2004, Wu et al. 2009). The exclusion of livestock became a common grassland management strategy throughout the world in recent decades (Smith et al. 2000, Shrestha and Stahla 2008, Wu et al. 2009,2010). Grazing exclusion was widely regarded as a simple restoration method for degraded grassland, and the fenced remnants were typically assumed to 'look after themselves' (Wu et al. 2010). Such management measures present a dilemma between grazing utilization and biodiversity protection for grassland (Smith et al. 2000). Recent research focused on the effects of exclusion of livestock grazing on vegetation succession and community structure (Gibson et al. 2001, Spooner et al. 2002, Wu et al. 2009, 2010). However, less information is available on the effects of long-term exclusion of livestock grazing on belowground biomass accumulation.

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In this paper, evaluation of changes in above- and belowground biomass accumulation, species richness, ground cover and height of a 20-year fenced typical steppe in the Loess Plateau was done to determine whether long-term exclusion of livestock grazing can be used as a grassland restoration tool. Our long-term hope is that the study will contribute to the protection and restoration of typical steppe ecosystem in the Loess Plateau.

MATERIALS AND METHODS

Study site. This experiment was conducted in a typical steppe grassland at 1800~2100 m a.s.l. in the Loess Plateau at the Natural Grassland Protection District of Yunwu Mountain (36°13'–36°19'N, 106°24'–106°28'E) in Ningxia Province, P.R. China. Mean annual air temperature is 5.0°C. Mean annual precipitation is 400~450 mm, and 65~75% of annual precipitation falls from July to September. Annual evaporation is 1330~1640 mm and accumulated temperature (≥ 0°C) is 2370~2882°C. The vegetation is typical steppe grassland dominated by *Stipa bungeana* Trin., *Thymus mongolicus* Ronn., *Artemisia sacrorum* Ledeb., *Stipa grandis* P. Smirn., *Artemisia frigida* Willd., *Aneurolepidium dasystachys* (Trin.) Nevski, and *Potentilla centigrana*. The Natural Grassland Protection District of Yunwu Mountain is about 6700 ha. The soil type of the study area was brown humus soil which was developed from the loess parent material.

Experimental details. Five community blocks (50 m × 50 m) were selected. They were dominated by *Stipa bungeana* + *Artemisia gmelinii* (S + A community), *Stipa bungeana* + *Potentilla centigrana* (S + P community), *Stipa bungeana* + *Thymus mongolicus* (S + T community), *Thymus mongolicus* (T community), and *Stipa bungeana* + other forbs (S + F community), respectively. They all were freely grazed by sheep before 1982, and were fenced completely excluding livestock grazing from 1982 until 2002 for measurements in this study. We established five randomly located sampling quadrats (1 m × 1 m) in each of the five community blocks. Samples were taken in mid-July of 1982 and 2002, when biomass reached its seasonal peak biomass in both years. The total cover of community was determined based on quadrats by cover of the vertical projection using point quadrats. Canopy height was determined in twenty random points of each quadrat and the mean height for the five quadrats was calculated. Species richness was the total number of species in each quadrat. Above ground biomass was determined by clipping to the ground level. After aboveground biomass was removed, litter was collected. The soil in each quadrat was removed by layers (0–10, 10–20, 20–30, 30–40, 40–50, 50–60, 60–80 and 80–100 cm) and taken to the laboratory where layers were washed inside filter gauze with 0.45 mm mesh, and dead and live roots were separated. We determined the above- and belowground biomass in every quadrat by weighing the plants after drying at 80°C for 48 h.

All data were expressed as community mean of quadrat values (± SD). Tests for significance ($P < 0.05$) of between-subjects effects were conducted with two-way ANOVA for aboveground, richness, cover and height of five-type communities and belowground biomass. All statistical analyses and figures were performed using the software SPSS, ver. 13.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Twenty-year exclusion of livestock grazing significantly increased above- ($F = 9.01$, $P < 0.001$) and belowground biomass ($F = 4.33$, $P < 0.01$) (Figure 1), species richness ($F = 7.01$, $P < 0.001$), cover ($F = 8.57$, $P < 0.001$) and height ($F = 3.13$, $P < 0.01$) of five community types (Figure 2). Additionally, there is a significant difference for above- ($F = 3.22$, $P < 0.01$) and belowground biomass ($F = 7.63$, $P < 0.001$), richness ($F = 2.03$, $P < 0.01$), cover ($F = 2.39$, $P < 0.01$) and height ($F = 7.12$, $P < 0.01$) among the five community types.

Our results showed that most of the belowground biomass was at the depth of 0–10 cm and twenty-year exclusion of livestock grazing significantly improved belowground biomass at different soil depth, especially at the depth of 0–10 cm (Figure 3).

DISCUSSION

Our results showed that the 20-year exclusion of grazing significantly increased above- and belowground biomass, community cover, height and species richness. Many similar studies in other areas also found that exclusion of livestock grazing is a simple and effective method for restoring vegetation productivity in degraded grasslands (Spooner et al. 2002, Wu et al. 2009,2010). Our experiment on five different typical steppe communities in the Loess Plateau demonstrated that

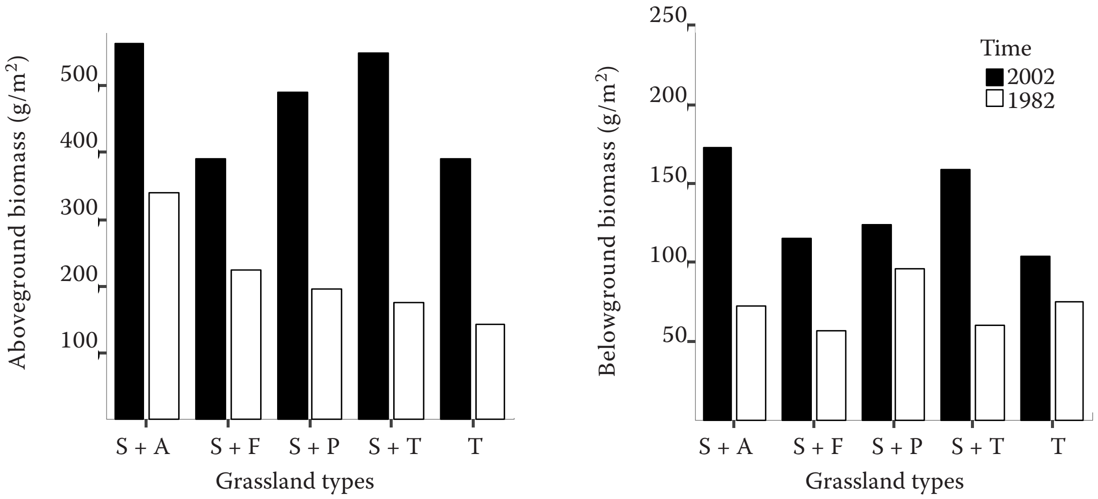

Figure 1. Comparison of (mean of) total aboveground and belowground biomass (0–100 cm) for five communities before (1982) and after (2002) 20 years of grazing exclusion. Communities were dominated by *Stipa bungeana* + *Artemisia gmelinii* (S + A), *Stipa bungeana* + *Potentilla centigrana* (S + P), *Stipa bungeana* + *Thymus mongolicus* (S + T), *Thymus mongolicus* (*T community*), and *Stipa bungeana* + other forbs community (S + F)

long-term exclusion of livestock grazing had significant effects not only on improvement of the above-ground biomass and vegetation cover, but also on the belowground biomass and species richness. These results on changes of aboveground biomass and cover were consistent with those occurring at other grassland communities (Wu et al. 2009, 2010).

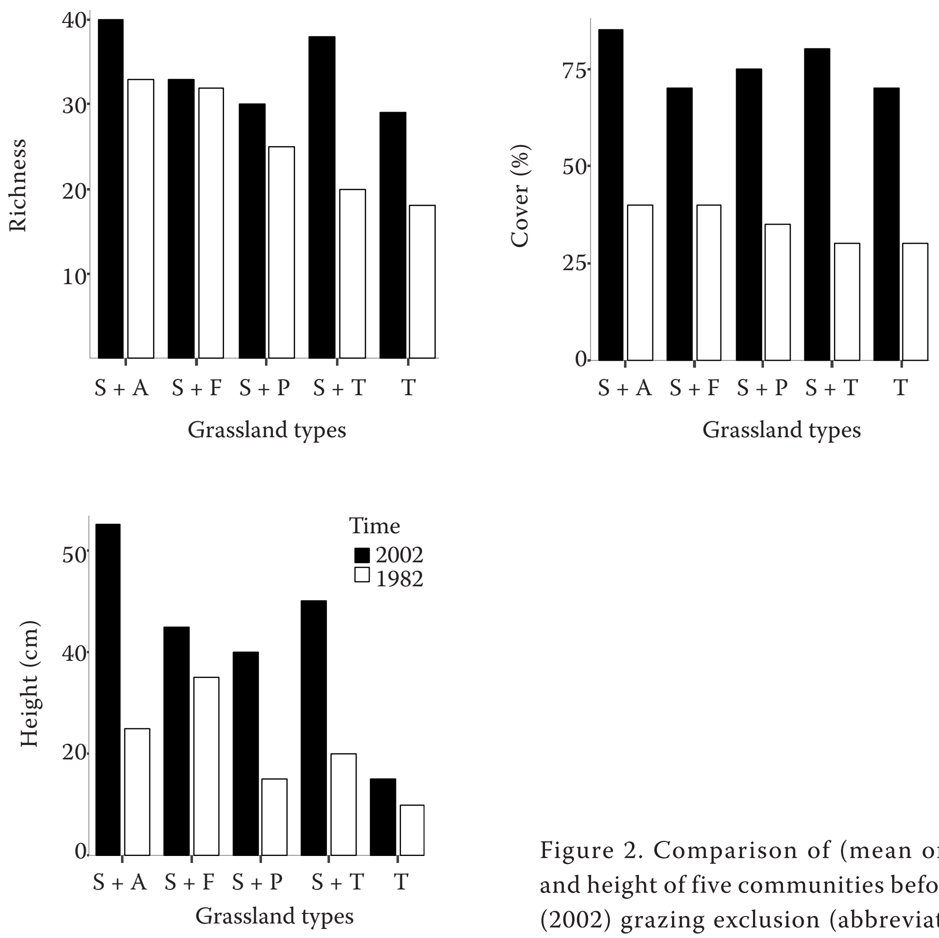

Figure 2. Comparison of (mean of) richness, cover and height of five communities before (1982) and after (2002) grazing exclusion (abbreviations are the same as in Figure 1)

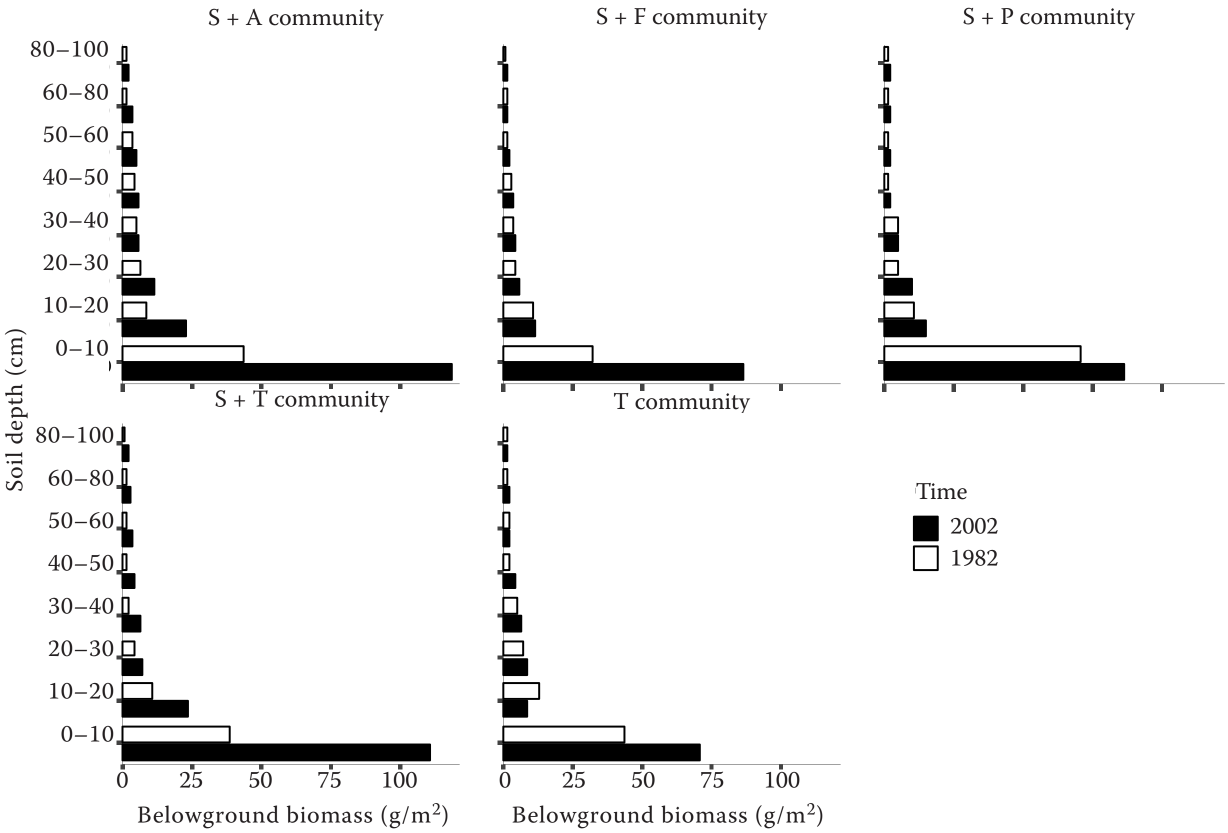

Figure 3. Comparison of (mean) belowground biomass at the depth 0–100 cm of five communities before (1982) and after (2002) grazing exclusion (abbreviations are the same as in Figure 1)

Belowground biomass (roots) is an important element of soil carbon sequestration (Langley and Hungate 2003). Our results showed that belowground biomass appears to be significantly increased after long-term exclusion of livestock grazing, which is consistent with the results of Li et al. (2006) that grazing significantly decreased belowground biomass. Zhao et al. (2008) found that long-term exclusion of livestock grazing can significantly improve soil nutrient properties and soil organic carbon in grassland community of the Loess Plateau. Conversely, improvement of soil nutrient conditions in grassland can promote the growth of plant species and biomass accumulation, especially for palatable grasses which have greater competitive ability than unpalatable grasses (Gallego et al. 2004).

Wu et al. (2009) found that nine-year exclusion of livestock grazing had negative consequences for biodiversity because it led to a reduction of plant density and species diversity in an alpine grassland community. However, our study showed that 20-year exclusion of livestock grazing increased species diversity in five typical steppe communities in the Loess Plateau. The difference between studies may be related to community density, because the steppe communities in our study never get anywhere near 100% cover, so there is always an opportunity for colonization of bareground. The alpine meadow community had higher plant density and it reached 1000–1400 individuals/m^2. Plant diversity loss in high-productivity grassland may result from greater competition for canopy resources (i.e. light) (Huston 1994) and some species with lower competitive ability reduce their density or disappear because of competition for light resources (Grime 1998) or nutrient availability (Van der Wal et al. 2004). Therefore, long-term exclusion of livestock grazing in alpine meadow resulted in lower species diversity and led to the community being dominated by a few species with strong competitive abilities (Wu et al. 2009). Conversely, the typical steppe communities had a relatively low plant density about 300–800 individuals/m^2 because of the arid climate in the Loess Plateau. Competition for light is low because leaf area is more limited by water availability. And, the increase of community covers, height and aboveground biomass can improve micro-habitats and increase condensed vapor as water resources for plant growth (Chen and Kang 1992, Cheng et al. 2010).

Therefore, it is apparent from this study that exclusion of livestock grazing is an effective restoration approach of above- and belowground biomass accumulation and potential function on soil carbon stocks in typical steppe of the Loess Plateau. Plant diversity was increased after long-term fencing in these communities in the Loess Plateau. But, there is too much litter accumulated in the excluded areas than grazed areas and this may negatively impact on seedling recruitment of community. These facts imply that the species diversity will be loss or limited when the aboveground biomass and plant density reached definite quantity. So, the future study should be conducted on the effects of accumulated litter on population recruitment and community properties and on the point when the biomass, plant density and diversity are balanced in grassland exclusion of livestock grazing management.

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