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Long-term grazing effects on vegetation characteristics and soil properties in a semiarid grassland, northern China

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Abstract Understanding the responses of vegetation characteristics and soil properties to grazing disturbance is useful for grassland ecosystem restoration and management in semiarid areas. Here, we examined the effects of long-term grazing on vegetation characteristics, soil properties, and their relationships across four grassland types (meadow, *Stipa* steppe, scattered tree grassland, and sandy grassland) in the Horqin grassland, northern China. Our results showed that grazing greatly decreased vegetation cover, aboveground plant biomass, and root biomass in all four grassland types. Plant cover and aboveground biomass of perennials were decreased by grazing in all four grasslands, whereas grazing increased the cover and biomass of shrubs in *Stipa* steppe and of annuals in scattered tree grassland. Grazing decreased soil carbon and nitrogen content in *Stipa* steppe and scattered tree grassland, whereas soil bulk density showed the opposite trend. Long-term grazing significantly decreased soil pH and electrical conductivity (EC) in annual-dominated sandy grassland. Soil moisture in fenced and grazed grasslands decreased in the following order of meadow, *Stipa* steppe, scattered tree grassland, and sandy grassland. Correlation analyses showed that aboveground plant biomass was significantly positively associated with the soil carbon and nitrogen content in grazed and fenced grasslands. Species richness was significantly positively correlated with soil bulk density, moisture, EC, and pH in fenced grasslands, but no relationship was detected in grazed grasslands. These results suggest that the soil carbon and nitrogen content significantly maintains ecosystem function in both fenced and grazed grasslands. However, grazing may eliminate the association of species richness with soil properties in semiarid grasslands.

Keywords Horqin grassland · Vegetation characteristics · Soil properties · Grazing

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Introduction

Grassland is one of the most widespread biomes in China, accounting for 41% of the total national land area. Disturbance or unreasonable human activities lead to the degradation of the temperate grassland ecosystem (Li et al. 2007; Jiao et al. 2011; Limb et al. 2011) and subsequent desertification (Li et al. 2000; Reynolds et al. 2007). Grassland desertification characterized by vegetation and soil degradation is commonly caused by the continuous over-grazing (Golluscio et al. 2009; Zhou et al. 2010). Grazing affects semiarid and arid grassland ecosystems in various ways, ranging from effects on individual plant growth and population dynamics to vegetation characteristics and soil properties (Cui et al. 2005; Wan et al. 2010; He et al. 2011a; Cheng et al. 2012). The soil and vegetation degradation caused by long-term grazing disturbance has been a serious global environmental problem for the recovery, management, and utilization of local grassland ecosystems (UNCED 1992). So, it is very important to gain a better understanding of how long-term grazing affects vegetation characteristics and soil properties, which could facilitate the provision of guidelines for improving grassland management practices in northern China.

Abundant studies indicate that grazing affects the allocation of biomass in the above- and belowground parts of plants (Pandey and Singh 1992; Pucheta et al. 2004; Frank 2007; López-Mársico et al. 2015). Grazing also results in compensatory growth (Wise and Abrahamson 2005; Li et al. 2011), which enables plants to adapt to more severe disturbance. Some studies have reported that grazing results in changes in the interspecific competition between plants (Graff et al. 2007), and the replacement of palatable species by unpalatable species (Wu et al. 2008). The regeneration of grass is affected by the trampling, ingestion, and excrement of domestic animals (Myers et al. 2004; Cosyns et al. 2005). Trample treatments have been shown to enhance the dominance of legumes and short forbs (Ludvíková et al. 2014). Moderate grazing has been shown to sustain the highest biodiversity (Zhao et al. 2014a), whereas over-grazing or grazing exclusion can result in the decline of species diversity and richness (Deng et al. 2014). Species richness tends to increase with higher productivity but decrease at low productivity due to the effects of herbivores (Bakker et al. 2006). Furthermore, the responses of species richness to grazing are not only contingent on grazing intensity but also on grazing history. Grazing may increase the sustainability of the community structure of grassland (Adler et al. 2004; Price et al. 2009), and this may also be restricted under grazing seasons, which has a major influence on spring annual plants but no effect on perennial plants (Pérez-Camacho et al. 2012). Thus, to examine vegetation composition and plant life, group responses to grazing disturbance could make a significant contribution to aid the restoration and management of degraded grassland.

Soil properties also show a variety of response to grazing disturbance (Reszkowska et al. 2010; Steffens et al. 2010). Some studies have shown inconsistent responses (positive or negative) of soil organic carbon to grazing under different grassland ecosystems (Derner et al. 2006; Li et al. 2010; Wright et al. 2004). Observations of soil nitrogen responses to increasing grazing intensity have reported a decrease (Su et al. 2005), increase (Wright et al. 2004), and no change in soil N (Schuman et al. 1999; Binkley et al. 2003; Evans et al. 2012). Grazing often increases soil bulk density due to trampling, especially in semiarid sandy grassland ecosystems (Li et al. 2008; Hiernaux et al. 1999). Inconsistencies in the effects of grazing on soil properties may be the results of many factors that differ among studies, including differences in landform and vegetation types (Binkley et al. 2003; Sasaki et al. 2007), and differences in grazing history, animals, intensity, and frequency (Han et al. 2008; Zhao et al. 2007; Bardgett et al. 2001). Many studies have also demonstrated that grazing alters the vegetation community structure and function through soil properties (Rietkerk et al. 1997).

Some improved grassland management strategies, such as fencing, is commonly practiced to protect degraded arid and semiarid grasslands throughout the world. The effects of fencing on the structure and function of grassland, such as productivity, community composition, and soil properties, have potentially positive or negative repercussions, depending on grassland type, grazing history, and environmental factors (Osem et al. 2004; Schultz et al. 2011; Fernández-Lugo et al. 2013). Accordingly, when studying the responses of vegetation characteristics and soil properties of grassland to grazing, it is essential to perform a comparative investigation that includes the adjacent grazed and ungrazed grassland plots.

The Horqin grassland is located in the east of the semiarid agro-pastoral transition zone in northern China. This region has been historically subjected to continuous grazing by cattle and sheep at increasingly high levels (Zhang et al. 2004; Han et al. 2009). Previous studies in this area have focused on the vegetation characteristics, vegetation succession, soil properties, soil–microbe, and vegetation–soil relationships in the degradation or restoration processes of sandy grassland (Su et al. 2005; Zuo et al. 2008a, b, 2015; Li et al. 2012; Zhao et al. 2014b; Zhou et al. 2008; Wang et al. 2016; Yao et al. 2013). However, there is much unknown about how long-term grazing affects plant community structure, function, and their relationships with soil properties in Horqin grasslands.

In this study, we examined the effects of long-term grazing on vegetation characteristics and soil properties across the following four grassland types: meadow, *Stipa* steppe, scattered tree grassland, and sandy grassland. The objectives of the present study were to (1) analyze the effects of long-term grazing on vegetation structure, life-form group, and soil properties, and (2) identify the relationships between vegetation characteristics and soil properties. Understanding long-term grazing effects on vegetation structure, ecosystem functioning and soil properties will be beneficial for the ecological restoration and sustainable management of semiarid grassland.

Materials and methods

Site description

The study area is part of the Horqin Sandy Land (42°55′ N, 120°42′ E; 360 m elevation) region located in the province of Inner Mongolia, northern China. The temperate continental semiarid climate of the area is characterized by an average annual precipitation of 360 mm and temperature of 6.4 °C. The winter in this area is long and cold, whereas the spring is dry and windy. The summer is cool but short, and the fall is cold and snowy. The accumulative temperature (≥10 °C) is 2200–3200 °C, and the frost-free season averages 150 days. The soil types mainly include chestnut, meadow, and boggy soils.

This study selected eight paired fenced and grazed sites in four typical grassland types, including meadow grassland, *Stipa* steppe, scattered tree grassland, and sandy grassland. The dominant species of meadow are perennial grasses, including *Leymus secalinus*, *Phragmites communis*, *Calamagrostis pseudophragmites*, and *Carex dispalata*, whereas *Stipagrandis* and *Festucaovina* are the dominant species in the *Stipa* steppe. Grassland with only a few scattered elms mainly consists of *Cleistogenes squarrosa*, *Setaria viridis*, and *Chloris virgata*. The main species of sandy grassland are *Cleistogenes squarrosa*, *Setaria viridis*, *Phragmites communis*, *Lespedeza davurica*, and *Digitaria sanguinalis*. The fenced sites of the four grasslands have excluded grazing disturbance for approximately 25 years. In contrast, the public free grazing sites, located outside the fencing sites, have been grazed by cattle and sheep (over 1 cattle and 6 sheep ha^{-1}) since the 1970s.

Experimental design

We established six plots (50 × 50 m) in each of the eight paired fenced and grazed sites. Six plots within each grassland type were located at a 0.5–10 km distance from each other. In late July 2014, when plant biomass was at a maximum, three 1 m × 1 m quadrats were randomly selected to carry out vegetation surveys and soil sampling. We measured the height of each species within each quadrat. Total vegetation cover and the cover of individual species were estimated in each quadrat using the projection method. We then harvested the aboveground biomass of each species and collected litter. In each quadrat, two samples of root biomass were collected from the soil depths of 0–10 cm, 10–20 cm, to 20–40 cm using a 10-cm-diameter soil auger. We separated the two samples of root biomass from the soil at each depth and combined them. Aboveground plant biomass, litter mass, and root biomass were dried at 65 °C for 24 h and weighed. All plant samples were ground using a mill (CT 193 Cyclotec™, Denmark) and analyzed for total C and N with an elemental analyzer (Costech ECS4010, Italy).

In addition, two soil samples were collected in each quadrat using a 3-cm-diameter soil auger at three different depths (0–10 cm, 10–20 cm, and 20–40 cm) and mixed as a composite soil sample. Concurrently, one soil core was taken to measure soil moisture within the quadrat using the same auger. For soil bulk density, we obtained soil samples in 5-cm increments using a soil auger equipped with a stainless steel cylinder (5 cm in both diameter and height) and the bulk density was calculated as the average of two or four samples for each of the abovementioned three soil layers (Zuo et al. 2016). The physical and chemical properties of soil samples were analyzed in the laboratory. Soil pH and electrical conductivity (EC) were determined using soil/water ratios of 1:2.5 and 1:5, respectively. Soil total C and N were determined using an elemental analyzer (Costech ECS4010, Italy).

Data analysis

All data are presented as the mean ± SE and an analysis of variance (ANOVA) was performed across the plot level. A two-way ANOVA was used to test the effects of grassland type and treatment (grazing and fencing) on cover, aboveground biomass, litter mass, species richness, and life-form group. The effects of long-term grazing on belowground biomass and soil properties were tested with a three-way ANOVA, using grassland type, treatment (grazing and fencing), and soil depth. These ANOVAs were followed by least significant difference (LSD) tests ($P < 0.01$ and $P < 0.05$). Correlations among plant characteristics and soil properties in the four types of grassland under fencing and grazing (soil depth 0–40 cm) were estimated using a linear mixed model. All statistical tests were performed using SPSS 16.0.

Results

Long-term grazing or grassland types had a significant effect on vegetation cover, aboveground plant biomass, and litter mass (Table S1 in Supporting Information, $P < 0.001$). The interaction of grazing and grassland type had a significant effect on aboveground plant biomass, litter mass, and species richness ($P < 0.001$). In the different grassland types, grazing significantly decreased the vegetation cover, aboveground plant biomass, and litter mass (Fig. 1, $P < 0.01$). The aboveground plant biomass and litter mass of fenced and grazed *Stipa* steppe plots were higher than those of the other grasslands ($P < 0.05$), whereas there were no significant differences regarding vegetation cover and species richness among the four grazed grasslands. However, long-term grazing resulted in a increase of species richness in scattered tree grassland. Moreover, long-term grazing eliminated the differences in vegetation cover and species richness among four grassland types.

The ANOVA results showed that there were significant effects from grazing ($P < 0.001$) and soil depths ($P < 0.001$), and there were also significant interaction

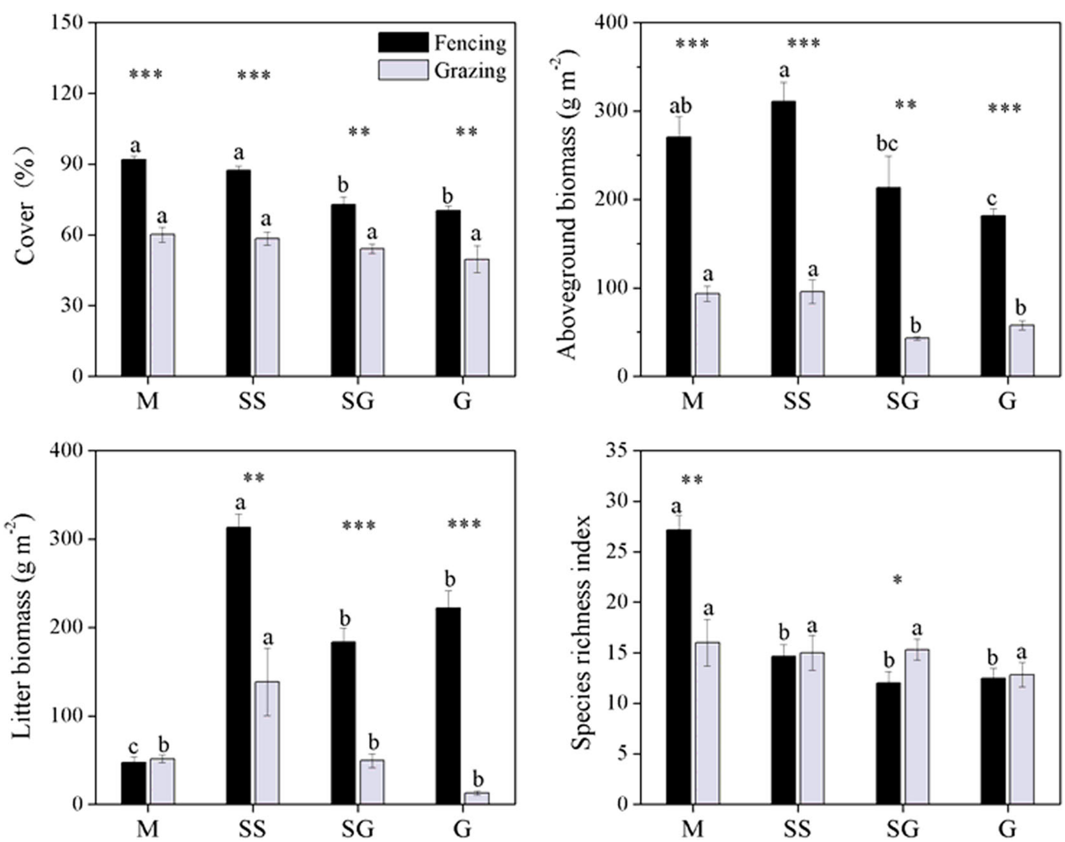

Fig. 1 Effect of grazing on the cover, aboveground biomass, litter mass, and species richness of four types of grassland. Values represent the means ± SE ($n = 6$). Different *letters* indicate statistically significant differences of the same treatment at $P < 0.05$ (LSD). Significant differences between fenced and grazed grasslands are indicated by *asterisks*, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. *M* meadow, *SS Stipa* steppe, *SG* scattered tree grassland, *G* sandy grassland

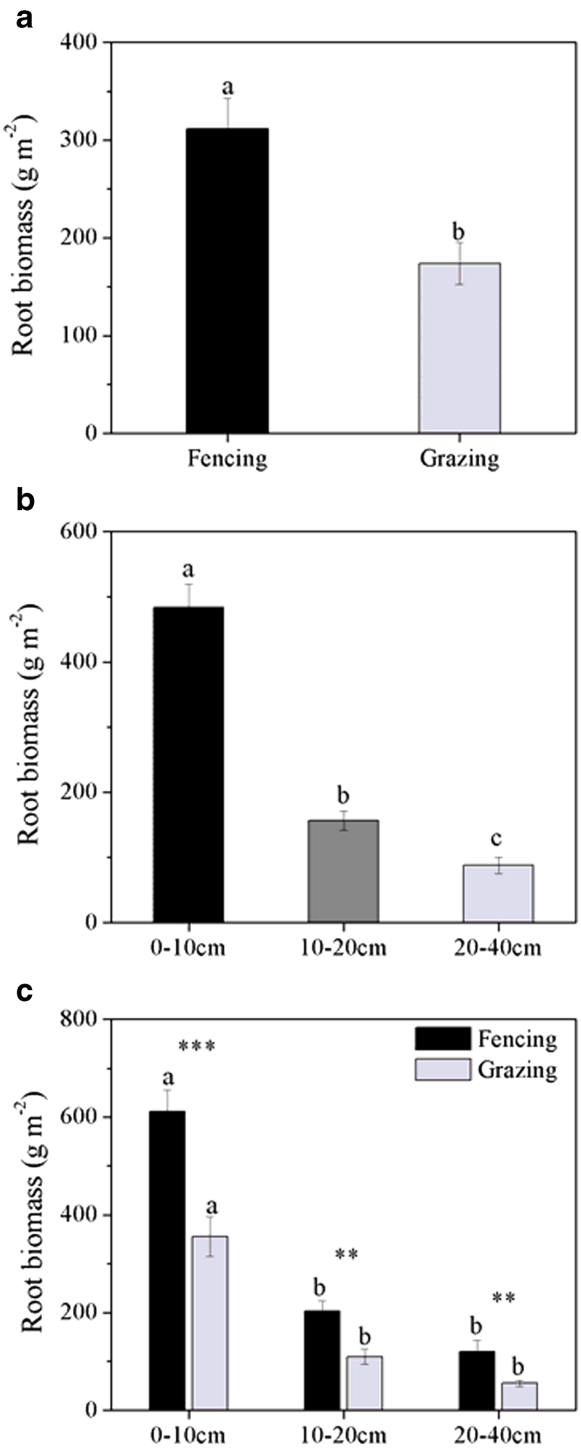

Fig. 2 The response of root biomass to grazing in four grasslands. **a** Changes in root biomass after long-term grazing. Data in the figure represent the mean ± SE ($n = 72$). **b** Change in root biomass along a depth gradient. The values are presented as the mean ± SE ($n = 48$). The different *letters* indicate statistically significant differences at $P < 0.05$. Different *letters* indicate statistically significant differences of the same treatment at $P < 0.05$ (LSD). Significant difference between fenced and grazed grasslands are indicated by *asterisks*, $^{**}P < 0.01$, $^{***}P < 0.001$. Values are presented as the mean ± SE ($n = 24$)

effects between grazing and depth on root biomass (Table S2, $P < 0.005$). The root biomass of grazed grassland was lower than that of fenced grassland (Fig. 2a) and decreased with the soil depth (Fig. 2b, $P < 0.05$). The root biomass at a soil depth of 0–10 cm was higher than that at the other depths in both fenced and grazed grasslands (Fig. 2c, $P < 0.05$).

There were significant differences in cover, plant biomass, and species richness of the three life forms (annual plants, perennial plants, and shrubs) among the different grassland types ($P < 0.01$). In these grasslands, long-term grazing had a significant effect on perennial plant cover, aboveground biomass, and species richness ($P < 0.001$). There were significant interaction effects between grassland types and grazing on perennial plant biomass and species richness, and on the cover and biomass of shrubs (Table S3, $P < 0.001$). Long-term grazing increased the cover and species richness of annual plants, and the effect was notably significant in scattered tree grassland ($P < 0.01$). The perennial plant cover and biomass clearly decreased in grazed grasslands (Table 1, $P < 0.05$), and the species richness decreased only in meadow grassland. With regard to shrubs, long-term grazing increased the cover and biomass of shrubs in *Stipa* steppe ($P < 0.05$).

The interaction of grassland types and grazing had significant effects on soil C, soil N, soil bulk density, soil moisture, and pH (Table S4, $P < 0.05$). Long-term grazing markedly decreased soil C at a depth of 0–10 cm in *Stipa* steppe, and soil C and N at depths of 0–10 cm and 10–20 cm in scattered tree grassland ($P < 0.05$). The topsoil C and N in grazed scattered tree grassland were approximately 48 and 28% lower than the corresponding values in fenced scattered tree grassland, respectively. For all three soil depths, the soil bulk density of grazed scattered tree grassland was higher than that of fenced scattered tree grassland. Long-term grazing significantly decreased the soil pH and EC of annual-dominated sandy grassland. Soil moisture in both fenced and grazed grasslands decreased in the order of meadow, *Stipa* steppe, scattered tree grassland, and sandy grassland (Figs. 3 and 4, $P < 0.05$).

Table 1 The cover, aboveground biomass, and species richness of annual plants, perennial plants, and shrubs in four types of grasslands under fencing and grazing

	Fencing				Grazing			
	M	SS	SG	G	M	SS	SG	G
Annual plants								
Cover (%)	16.47 ± 2.72^{bc}	4.22 ± 1.44^{c}	19.92 ± 4.40^{Bb}	34.36 ± 7.14^{a}	26.65 ± 8.43^{b}	3.72 ± 0.81^{c}	46.25 ± 4.12^{Aa}	43.78 ± 7.35^{ab}
Biomass (g m^{-2})	34.54 ± 11.83^{b}	10.89 ± 3.39^{b}	45.40 ± 9.00^{b}	92.49 ± 23.51^{a}	34.68 ± 12.51^{a}	6.62 ± 2.97^{b}	31.75 ± 3.86^{a}	51.01 ± 7.04^{a}
Species richness	7.17 ± 1.19^{a}	3.50 ± 0.96^{b}	$5.83 \pm 0.70B^{Bab}$	7.17 ± 0.65^{a}	6.50 ± 1.23^{b}	5.83 ± 1.22^{b}	10.00 ± 0.89^{Aa}	8.83 ± 0.54^{ab}
Perennial plants								
Cover (%)	91.92 ± 6.21^{Aa}	78.67 ± 4.07^{Aa}	44.61 ± 4.56^{Ab}	33.03 ± 7.26^{Ab}	38.97 ± 7.20^{Ba}	33.92 ± 5.14^{Ba}	11.00 ± 3.21^{Bb}	6.20 ± 1.80^{Bb}
Biomass (g m^{-2})	234.99 ± 15.72^{Aa}	291.16 ± 22.16^{Aa}	136.90 ± 28.98^{Ab}	76.57 ± 27.52^{Ab}	57.64 ± 12.06^{Ba}	55.58 ± 5.86^{Ba}	9.12 ± 3.15^{Bb}	5.56 ± 1.65^{Bb}
Species richness	18.50 ± 0.99^{Aa}	9.67 ± 0.92^{b}	4.17 ± 1.01^{c}	4.33 ± 0.61^{c}	8.33 ± 1.56^{Ba}	8.17 ± 0.60^{a}	4.33 ± 0.84^{b}	3.33 ± 0.71^{b}
Shrubs								
Cover (%)	1.33 ± 0.51^{b}	4.42 ± 0.75^{Bb}	12.61 ± 1.80^{Aa}	4.67 ± 2.49^{b}	0.56 ± 0.56^{b}	24.22 ± 2.88^{Aa}	2.39 ± 0.51^{Bb}	1.25 ± 0.60^{b}
Biomass (g m^{-2})	0.93 ± 0.33^{b}	9.06 ± 1.30^{Bb}	30.44 ± 10.86^{Aa}	18.05 ± 8.41^{ab}	1.15 ± 0.69^{b}	33.48 ± 6.48^{Aa}	2.01 ± 0.50^{Bb}	1.99 ± 1.05^{b}
Species richness	1.50 ± 0.43	1.50 ± 0.22^{A}	1.17 ± 0.17	1.00 ± 0.00	1.00 ± 0.52	1.00 ± 0.00^{B}	1.00 ± 0.00	0.67 ± 0.21

Lowercase letters indicate multiple comparison of cover, aboveground biomass, and species richness of the same treatment among different types of grassland (LSD); uppercase indicate multiple comparison of cover, aboveground biomass, and species richness from the same grassland among different treatments; the same letters indicate no statistically significant difference at the $P < 0.05$ level

M meadow, *SS Stipa* steppe, *SG* scattered tree grassland, *G* sandy grassland

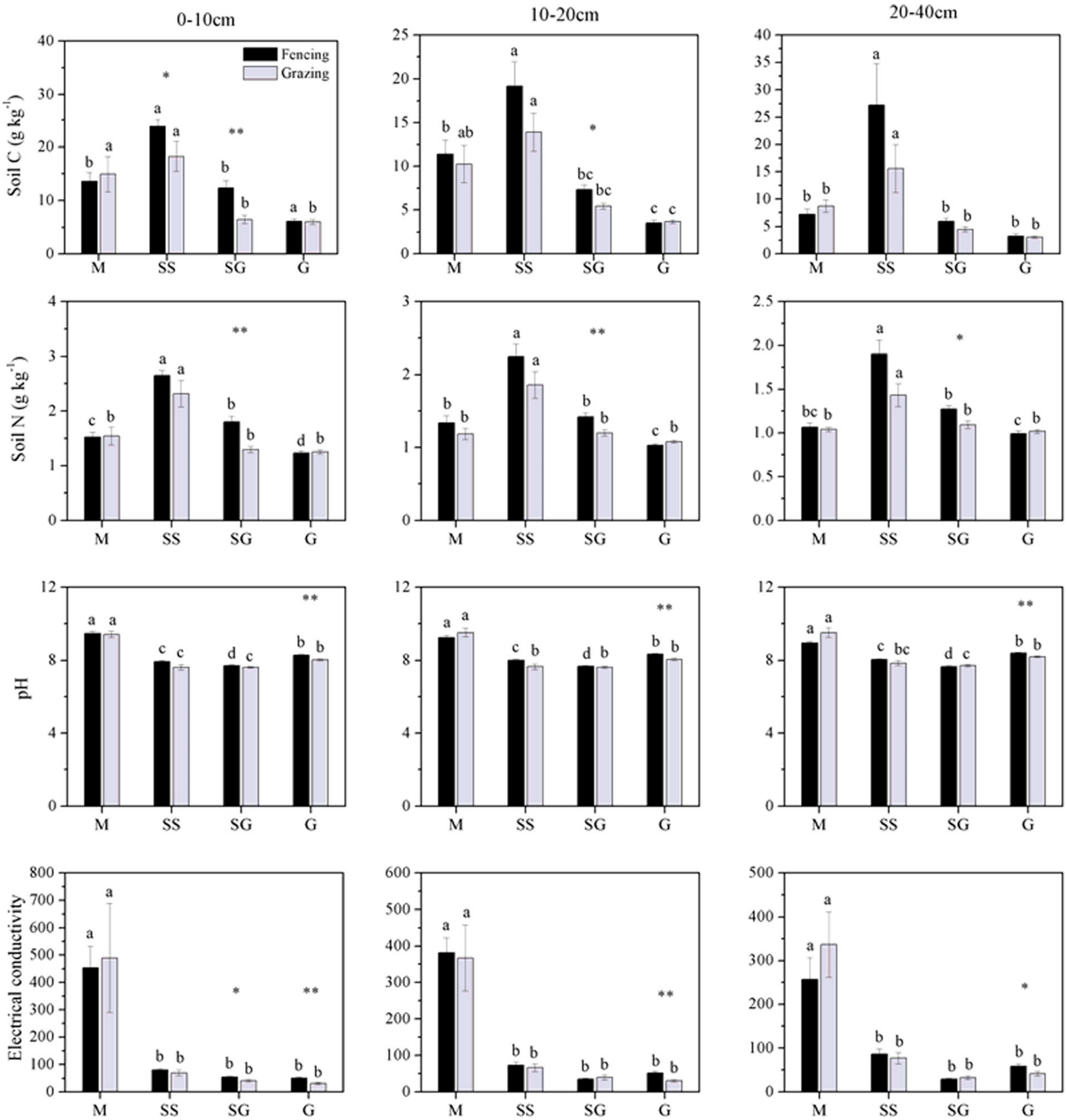

Fig. 3 Effect of grazing on soil carbon, nitrogen, pH, and electrical conductivity of four types of grassland. Different *letters* indicate statistically significant differences for the same grassland at $P < 0.05$ (LSD). Significant differences between fenced and grazed grasslands are indicated by *asterisks*, $^{**}P < 0.01$, $^{***}P < 0.001$. Values are presented as the mean ± SE ($n = 24$)

Correlation analyses showed that there were significant relationships among plant characteristics and soil properties (Table 2). In fenced grasslands, vegetation cover was significantly positively associated with species richness, aboveground biomass, soil C, soil moisture, EC, and pH ($P < 0.05$). There were significantly positive correlations among species richness, soil bulk density, soil moisture, EC, and pH ($P < 0.01$). Litter biomass was significantly negatively associated with soil bulk density, soil moisture, EC, and pH ($P < 0.01$). In both fenced and grazed grasslands, soil C and N had significantly positive associations with aboveground biomass ($P < 0.01$). However, there were different relationships between vegetation

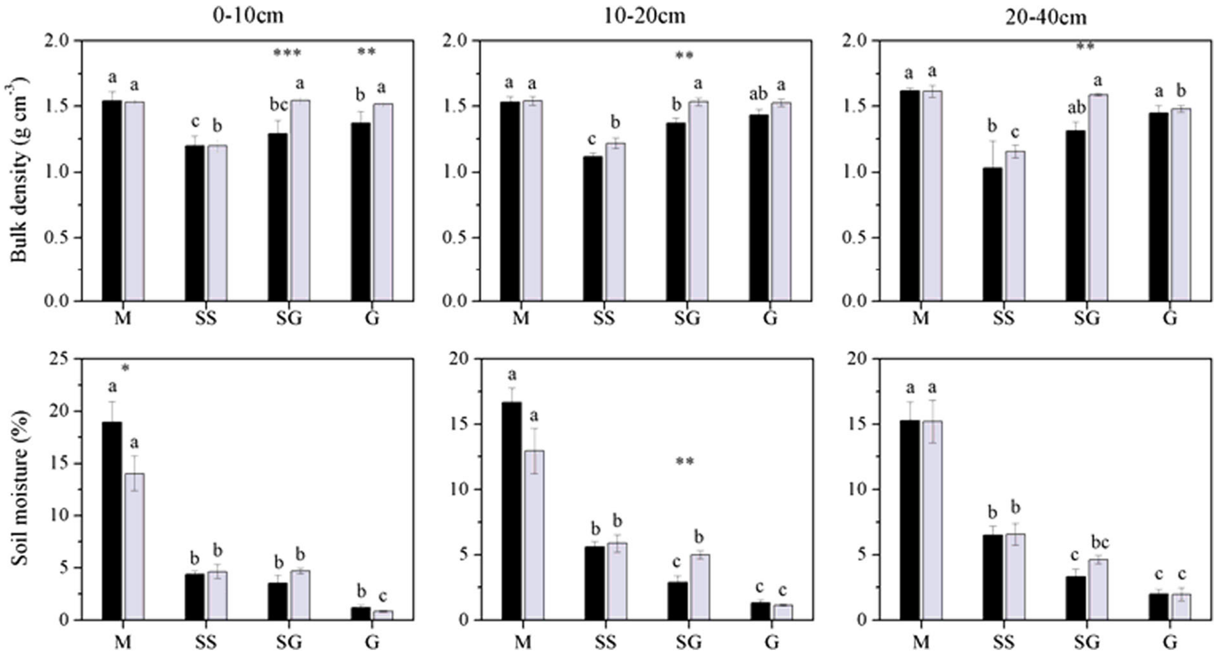

Fig. 4 Effect of grazing on soil bulk density and soil moisture of four types of grassland. Different *letters* indicate statistically significant differences for the same grassland at $P < 0.05$ (LSD). Significant differences between fenced and grazed grasslands are indicated by *asterisks*, $^{**}P < 0.01$, $^{***}P < 0.001$. Values are presented as the mean ± SE ($n = 24$)

characteristics and soil properties in the grazed grasslands. There was no association of species richness with soil properties ($P > 0.05$). Aboveground biomass was negatively correlated to soil bulk density ($P < 0.05$).

Discussion

Grazing is regarded as one of the main factors resulting in grassland degradation and the reduction in plant productivity and soil nutrients (Gill 2014). Our results obtained from four grassland types of grassland in the Horqin region indicated that grazing markedly reduced vegetation cover and above- and belowground biomass, which is consistent with the results from a number of previous studies (Zhang et al. 2004; Li et al. 2008). However, the effects of grazing on species richness remarkably differed among grassland types. There was a significant decrease in species richness of grazed meadow and a marked increase in that of grazed scattered tree grassland, whereas species richness had no differences between grazing and fenced sites in other two grassland types. The different effects of grazing on species richness among the four grassland types may be explained by the original plant community composition, soil environment, and grazing disturbance. The uneven use of grazing animals and the dispersal and deposition of plant seeds through excrement can result in small-scale heterogeneity in grassland (Jaramillo and Detling 1992; Bakker et al. 2003; Ruifrok et al. 2014). Different grasslands in the Horqin region have historically sustained high numbers of livestock and endured high grazing pressure, thus selecting the plant species that have adapted to grazing (Adler et al. 2004).

We found that long-term grazing has also produced many diverse effects on vegetation characteristics related to plant life forms. Lower aboveground plant biomass can be explained in terms of a change in the plant life group caused by animal grazing (Suzuki and Suzuki 2011). Compared to the perennials, grazing increased the cover of the annuals, and this effect was particularly notable in the scattered tree grassland. Grazing decreased the biomass and cover of perennials in the four grassland types. In the meadow, *Stipa* steppe, and scattered tree grassland, the percentages of perennial biomass accounting for aboveground biomass were 87, 94, and 64% in fenced grasslands and 62, 58, and 21% in grazed grasslands, respectively. These are in agreement with the previous study that cattle grazing can increase the cover of annuals and the species richness

Table 2 Pearson's correlation coefficients among plant characteristic and soil properties in four types of grassland under fencing and grazing (soil depth 0–40 cm)

	Cover	Species richness	Aboveground biomass	Litter biomass	Root biomass	Soil C	Soil N	Soil bulk density	Soil moisture	EC
Fencing										
Species richness	0.692**									
Aboveground biomass	0.637**	0.262								
Litter biomass	−0.293	−0.663**	0.142							
Root biomass	0.110	0.040	0.047	−0.172						
Soil C	0.494*	0.130	0.622**	0.397	0.135					
Soil N	0.391	−0.082	0.599**	0.577**	0.221	0.932**				
Soil bulk density	0.038	0.532**	−0.301	−0.732**	−0.237	−0.460*	−0.647**			
Soil moisture	0.731**	0.854**	0.327	−0.705**	0.187	0.155	−0.035	0.450*		
EC	0.656**	0.859**	0.261	−0.748**	0.072	0.063	−0.166	0.553**	0.947**	
pH	0.493*	0.805**	0.121	−0.685**	−0.280	−0.151	−0.406*	0.677**	0.769**	0.853**
Grazing										
Species richness	0.329									
Aboveground biomass	0.287	0.025								
Litter biomass	−0.002	−0.207	0.579**							
Root biomass	0.564**	0.170	0.282	0.159						
Soil C	0.129	−0.206	0.601**	0.585**	0.27					
Soil N	0.035	−0.168	0.580**	0.724**	0.096	0.889**				
Soil bulk density	−0.006	0.220	−0.475*	−0.739**	0.050	−0.697**	−0.865**			
Soil moisture	0.303	0.042	0.420*	0.150	0.502*	0.471*	0.123	0.123		
EC	0.289	−0.096	0.432*	−0.025	0.495*	0.444*	0.073	0.145	0.824**	
pH	0.221	−0.001	0.425*	−0.172	0.317	0.229	−0.128	0.346	0.697**	0.832**

**Correlation is significant at the 0.01 level (2-tailed); *correlation is significant at the 0.05 level (2-tailed)

of mesic grassland in the coastal areas of California (Haves and Holl 2003), whereas there are the opposite responses for perennials (Bartolome et al. 2004). Our findings demonstrate that grazing could increase the competitive advantage of shrubs in *Stipa* steppe, which had higher cover and biomass but lower species richness in grazed plots. Shrub abundance may respond positively to grazing by large ungulate animals in tallgrass prairie (Briggs et al. 2005). Similarly, it has been suggested that shrub expansion in semiarid grassland has mainly been influenced by heavy grazing (Auken 2000).

Our results indicated that some physical and chemical properties of grassland topsoil were altered with long-term grazing disturbance. Grazing increased soil bulk density, particularly in annual-dominated grassland. Furthermore, grazing markedly reduced soil C and soil N in *Stipa* steppe and scattered tree grassland, but had no effect on the C and N contents of soil in meadow and annual-dominated grassland. These findings are consistent with previous reports where soil bulk density increased in sandy grassland (Greenwood 1998; Evans et al. 2012) and soil C and soil N decreased with a gradient of grazing intensity in comparison to ungrazed plots in the steppe ecosystem (Steffens et al. 2008). Numerous studies have indicated that soil properties passively respond to grazing in two ways. First, intensive trampling by ungulate animals can result in changes in soil invertebrate density and biomass (Cluzeau et al. 1992), moisture, bulk density, infiltration rates, and mechanical resistance (Chaichi et al. 2005; Dunne et al. 2011). Second, the amount of soil nutrients derived from litter and root, and particularly the biomass and decomposition rate of litter and root are affected by grazing (He et al. 2011b; Cornwell et al. 2008).

Nutrient-limited soils may directly and indirectly affect plant growth, species richness and productivity, as well as ecosystem structure and function (Pauli et al. 2002; Niinemets and Kull 2005; Crous et al. 2015). Our results showed the positive correlations between aboveground plant biomass and soil C and N in both fenced and grazed grasslands, which is consistent with the findings that soil C and N level are one of the critical factors influencing the primary production of grassland ecosystems (Gao et al. 2011). Our results also showed that aboveground plant biomass in grazed grassland had a markedly positive correlation with soil moisture, EC, and pH, but a negative correlation with soil bulk density. These results suggest that soil physical and chemical properties determined by grazing are closely linked with aboveground plant biomass in grazed grassland ecosystem (Hata et al. 2014). Moreover, a clear relationship between species richness and soil properties appeared in fenced grasslands, while this relationship disappeared in grazing grasslands, indicating that grazing results in the disappearance of association of species richness with soil properties in grassland ecosystem. These results are in support for the previous finding that grazing is responsible for shifts in relationship of vegetation characteristics and soil properties (Tahmasebi Kohyani et al. 2008).

Conclusions

Our study demonstrates that the response of vegetation to long-term grazing is more sensitive than soil in Horqin grasslands. Long-term grazing had a strong influence on the plant community structure and ecosystem function. Long-term grazing resulted in a decrease in vegetation cover, aboveground biomass and root biomass, as well as a decrease in the cover and aboveground biomass of perennials in Horqin grasslands. The soil carbon and nitrogen contents greatly affected aboveground plant biomass in grazed and fenced grasslands. However, the relationship between species richness and soil properties was removed by long-term grazing in semiarid grasslands. Therefore, grazing exclusion is necessary to lessen the negative effects of long-term grazing on vegetation structure and function. The fencing should be considered a promising strategy that could promote the conservation and sustainable use of the semiarid grassland.

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