Vegetation Traits and Soil Properties in Response to Utilization Patterns of Grassland in Hulun Buir City, Inner Mongolia, China

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Abstract: Numerous studies have focused on vegetation traits and soil properties in grassland, few of which concerned about effects of human utilization patterns on grassland yet. Thus, this study hypothesized that human disturbance (e.g., grazing, mowing and fencing) triggered significant variation of biomass partitioning and carbon reallocation. Besides, there existed some differences of species diversity and soil fertility. To address these hypotheses of grassland with diverse utilization patterns in Hulun Buir City, Inner Mongolia, China, we sampled in situ about aboveground biomass (AGB) and belowground biomass (BGB) to evaluate their biomass allocation. Species diversity and soil properties were also investigated. Subsequently, we discussed the relationship of species diversity with environmental conditions, using data collected from 23 sites during the ecological project period of Returning Grazing Lands to Grasslands (RGLG) program. The results were as follows: 1) both AGB and BGB were lower on grazing regime than those on fencing and mowing, but the ratio of root-to-shoot (R/S) was higher on grazing regime than the other two utilization patterns; 2) neither of evenness and Simpson Index was different significantly among all grassland utilization patterns in desert, typical, and meadow grassland at 0.05. In meadow grassland, species richness of fencing pattern was significantly higher than that of grazing pattern ($p < 0.05$); 3) both of soil organic carbon content and soil available phosphorous content were increased significantly on fencing pattern than grazing pattern ($p < 0.05$) in desert grassland, and mowing patterns increased the soil nutrients (soil organic carbon, soil total phosphorous, soil available phosphorous, and soil total nitrogen) significantly compared with grazing patterns ($p < 0.05$) in typical grassland. However, there were no significant differences among utilization patterns in meadow grassland. In conclusion, both of AGB and BGB were increased significantly by fencing. Moreover, species diversity and soil nutrients can be promoted via mowing and fencing. This study suggested that implementation of Ecological Project played a positive role in sustainable grassland utilization of Hulun Buir City and a strong positive influence on the entire temperate grassland.

Keywords: grassland utilization patterns; biomass allocation; species diversity; soil properties; temperate grassland; Hulun Buir City

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1 Introduction

Grazing, mowing, and fencing are the most prevalent types of land-use applied to grassland worldwide. These land-use types substantially affect community structure, primary productivity, and soil properties (Zheng *et al.*,

2012). It is essential to understand influences of different utilization patterns on grassland production to improve grassland conservation and management (Yang *et al.*, 2012). Grazing is more suitable management to maintain high biodiversity than mowing (Weiss *et al.*, 2013), and seasonal grazing could enrich soil nutrient

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content (Whitford and Steinberger, 2012). Numerous studies have focused on vegetation traits and soil properties under different utilization patterns of grassland with contrasting results. For example, grazing was found to increase temperature sensitivity of soil organic matter decomposition in temperate grassland (Paz-Ferreiro *et al.*, 2012). By contrast, Shi *et al.* (2013) found that grazing exclusion decreases soil organic carbon storage at an alpine grassland in the Qinghai-Tibet Plateau. It also was proposed that grazing affected aboveground production diversely in different communities, and had no effect on roots in any semi-arid grassland (Milchunas and Vandever, 2013). Grazing optimization hypothesis stated that productivity should be maximized at a light-to-moderate level of grazing to increase photosynthetic rates and to promote the primary production of grassland (Luo *et al.*, 2012). Therefore, questions regarding the effects of these utilization patterns on vegetation traits and soil properties remain unanswered.

China is one of the largest grassland-distributed countries in the world. Due to increased grave degradation problems of grassland, the government initially implemented Returning Grazing Lands to Grasslands (RGLG) program. This project aimed to protect the steppes and to accomplish the urgent and strategic task of sustainable development between ecology and economy in the pastoral districts. There is about 100 000 km² of grassland in Hulun Buir City, Inner Mongolia, China, 80% of which is covered by natural temperate grassland. The anthropogenic disturbances of fencing, mowing and grazing have all contributed to vegetation traits and soil properties in the Hulun Buir Grassland. In this study, we explored grassland production, species diversity, and soil properties in temperate grassland under various grassland utilization patterns with data from 23 sites during the project implementation period in Hulun Buir City. The main objective was to select a suitable grassland management protocol for the sustainable development of the Hulun Buir Grassland.

2 Materials and Methods

2.1 Study area

The study area is located at the western Hulun Buir City, Inner Mongolia Autonomous Region, China (Fig.

1). Study area is an open and flat site, whose maximal elevation difference is no more than 50 m. The mean annual precipitation is 339 mm, and the mean annual temperature is 2.2°C. The main soil types include chernozem and chestnut soil. Plant communities are floristically distinct including arid steppe, semiarid steppe, and meadow steppe. Table 1 shows the dominant vegetation types in this area.

2.2 Experiment design

In 2007, aboveground biomass (AGB) and belowground biomass (BGB) were surveyed at 23 sampling sites (Table 1), including desert, typical, and meadow grassland in the temperate grassland at key growth periods of vegetation during the first stage of the Ecological Project. There were 7 fencing sites, 6 mowing sites, and 10 grazing sites as sampling sites in total (Fig. 1). Land-use

Table 1 Description of sampling sites in Hulun Buir Grassland

Utilization pattern	Sampling Code	Dominant	Grassland type
Grazing	1	<i>Allium polyrrhizum</i>	Desert grassland
	3	<i>Allium polyrrhizum</i>	Desert grassland
	4	<i>Allium polyrrhizum</i>	Desert grassland
	6	<i>Artemisia frigida</i> & <i>Caragana microphylla</i>	Desert grassland
	8	<i>Stipa grandis</i>	Desert grassland
	9	<i>Cleistogenes squarrosa</i>	Desert grassland
	15	<i>Leymus chinensis</i> & <i>Carex pediformis</i>	Meadow grassland
	18	<i>Leymus chinensis</i>	Meadow grassland
	21	<i>Leymus chinensis</i>	Meadow grassland
	23	<i>Leymus chinensis</i>	Meadow grassland
Fencing	2	<i>Allium polyrrhizum</i>	Desert grassland
	5	<i>Serratula centauroides</i> & <i>Artemisia frigida</i>	Desert grassland
	7	<i>Stipa grandis</i>	Desert grassland
	10	<i>Stipa baicalensis</i>	Typical grassland
	11	<i>Stipa baicalensis</i>	Typical grassland
	12	<i>Leymus chinensis</i> & <i>Forbs</i>	Meadow grassland
	22	<i>Leymus chinensis</i>	Meadow grassland
Mowing	13	<i>Aneurolepidium sibiricum</i> & <i>Leymus chinensis</i>	Typical grassland
	14	<i>Leymus chinensis</i> & <i>Carex pediformis</i>	Typical grassland
	16	<i>Leymus chinensis</i>	Meadow grassland
	17	<i>Leymus chinensis</i>	Meadow grassland
	19	<i>Leymus chinensis</i>	Meadow grassland
	20	<i>Leymus chinensis</i>	Meadow grassland

Fig. 1 Location of study area and distribution of sampling sites in Hulun Buir City, Inner Mongolia, China

types were defined according to administration documents and an interview with local farmers. The three land-use types were identified as follows: 1) Fencing sites. Pastures have been prohibited from grazing since 2003. 2) Mowing sites. Mowing pastures have been prohibited from grazing since 2003. 3) Grazing sites. Pastures have always been used for grazing.

At each site, we harvested AGB and BGB in five plots ($1\text{ m} \times 1\text{ m}$) of similar topography and solar status every 10 m intervals along a transect. Species abundance and richness were surveyed. AGB was determined by clipping the plants at the ground level, and were weighed after oven-dried at 60°C for 48 h. BGB was determined by collecting 10 diameter soil cores from 0 to 30 cm soil depth, where majority of BGB is located; soil cores were then sifted through a 2-mm sieve, washed by water, dried at 60°C for 48 h, and weighed. Ratio of root-to-shoot (R/S) denotes the division of AGB and BGB. Furthermore, soil samples were collected from five replicate soil profiles to determine soil properties in 30 cm soil depth. Soil samples were carefully handpicked, air-dried and sieved (2-mm mesh) to extract the surface organic materials and fine roots for soil chemical property analysis.

Each mixed soil sample was divided into two parts. One sub-sample was oven-dried at 105°C to constant weight to measure gravimetric soil water content. The other remaining soil sub-sample was ground in a ball mill for soil organic carbon, soil total phosphorous, soil available phosphorous, and soil total nitrogen analysis. Soil properties were determined following all standard protocols (Bao, 2000). A vegetation survey was performed in July 2007. In addition, aboveground vegetation was investigated in the $1\text{ m} \times 1\text{ m}$ quadrat, with five replicates. All living vascular plants in each quadrat were sorted according to species. Subsequently, the plant height, coverage, numbers, and density were determined.

2.3 Data analysis

One-way ANOVA was used to test the differences of soil properties, grassland production, and species diversities among the different utilization patterns in desert, typical, and meadow grassland. An LSD test was used to distinguish differences at 0.05. All analyses were performed by using the SPSS 16.0 statistical software package (SPSS Inc., USA).

The Simpson index (D) was calculated as follows (Bakelaar and Odum, 1978):

$$D = 1 - \sum P_i^2 \quad (1)$$

where P_i is the relative importance of species i (calculated with frequency). The relative importance of species is calculated as follows:

$$P_i = W_i / W \quad (2)$$

where W_i is the individual number of species i , and W is the sum of individual numbers of all species in quadrat.

The Shannon index (H') was calculated as follows:

$$H' = -\sum P_i \ln P_i \quad (3)$$

where P_i is the relative importance of species i (calculated with the individual number of species). Evenness (J) was calculated as follows:

$$J = (\sum P_i \ln P_i) / \ln S \quad (4)$$

where H' is the Shannon index, and S is the number of

species in the community.

3 Results

3.1 Grassland production in different utilization patterns

AGB in fencing and mowing utilization patterns is significantly higher than that in the grazing pattern at 0.05 (Fig. 2). There was no significant difference between fencing and mowing utilization patterns of grassland. By contrast, BGB and the maximum total biomass of mowing pattern were greater than the other two utilization patterns. R/S in the grazing pattern was significantly higher than that of mowing and fencing patterns ($p < 0.05$). Moreover, variations of AGB, BGB, and R/S exhibited were quietly obvious among different sites, ranging from 50.77 g/m² to 163.65 g/m² for AGB, 615.70 g/m² to 1150.91 g/m² for BGB, and 4.54 to 12.13 for R/S under the fencing patterns; ranging from 108.41 g/m² to 176.62 g/m² for AGB, 858.43 g/m² to

Fig. 2 Aboveground biomass, belowground biomass, total biomass and ratio of root to shoot (R/S) of different utilization patterns (fencing, mowing and grazing)

1627.83 g/m² for BGB, and 6.45 and 12.04 for R/S under the mowing patterns; and ranging from 21.27 g/m² to 123.25 g/m² for AGB, 380.54 g/m² to 1188.96 g/m² for BGB, and 3.26 to 42.81 for R/S under the grazing patterns.

3.2 Species diversity in different utilization patterns

It was indicated that neither of evenness and Simpson index were significantly different among all utilization patterns of grassland in desert, typical, and meadow grassland ($p < 0.05$) (Fig. 3). Shannon index and species richness, were dropped evidently by the fencing pattern, whereas they were significantly enhanced by mowing pattern in typical grassland. In meadow grassland, species richness of fencing and mowing pattern were significantly higher than that of grazing pattern ($p < 0.05$).

3.3 Soil properties in different utilization patterns

Grazing and fencing in desert grassland did not signify-

cantly affect soil total phosphorous, and soil total nitrogen (Fig. 4). However, both soil organic carbon and soil available phosphorous under fencing in desert grassland or mowing in typical grassland were significantly greater than those of grazing or fencing ($p < 0.05$). The soil total phosphorous content and soil total nitrogen content under the mowing pattern were significantly greater than those of the fencing pattern in meadow grassland.

3.4 Relationships of vegetation traits with soil properties

Effects of soil properties on the vegetation traits were explored in Table 2. Results indicated that Shannon index was significantly correlated with soil properties except soil total phosphorous and available phosphorous content ($p < 0.05$). By contrast, the index was negatively correlated with soil bulk density, which is similar with the relationships among soil properties, richness, and Simpson index. Meanwhile, there was no significant

Fig. 3 Comparison of Shannon index, evenness index, Simpson index and species richness for different utilization patterns (grazing, fencing and mowing) in three kinds of grassland. D, T and M represent desert, typical and meadow grassland, respectively

Fig. 4 Comparison of soil properties (soil organic carbon, soil total phosphorous, soil available phosphorous, soil total nitrogen) for different utilization patterns (grazing, fencing and mowing) in three kinds of grassland. D, T and M represent desert, typical and meadow grassland, respectively.

Table 2 Statistics of correlations between soil properties and vegetation traits

	Shannon- Wiener	Even- ness	Simpson's Diversity	Rich- ness	SOC (g/kg)	TP (g/kg)	AP (mg/kg)	TN (g/kg)	AN (mg/kg)	C/N	C/P	N/P	SWC (%)	BD (g/cm ³)
Shannon-Wiener	1	0.510**	0.886**	0.941**	0.491**	-0.056	-0.145	0.462**	0.604**	0.343**	0.570**	0.579**	0.626**	-0.475**
Evenness		1	0.799**	0.216	-0.085	-0.062	0.172	-0.079	0.091	0.074	0.077	0.084	-0.049	0.152
Simpson's Diversity			1	0.693**	0.341**	-0.007	-0.045	0.309**	0.449**	0.344**	0.440**	0.419**	0.380**	-0.258*
Richness				1	0.597**	-0.031	-0.216	0.569**	0.668**	0.358**	0.627**	0.636**	0.752**	-0.605**
SOC (g/kg)					1	0.409**	-0.053	0.923**	0.588**	0.702**	0.754**	0.596**	0.759**	-0.759**
TP (g/kg)						1	0.320**	0.514**	0.135	0.111	-0.228	-0.376**	0.179	-0.394**
AP (mg/kg)							1	-0.074	-0.233	0.011	-0.243*	-0.376**	-0.072	0.147
TN (g/kg)								1	0.589**	0.430**	0.577**	0.553**	0.739**	-0.791**
AN (mg/kg)									1	0.309**	0.505**	0.495**	0.642**	-0.558**
C/N										1	0.766**	0.430**	0.457**	-0.345**
C/P											1	0.897**	0.667**	-0.479**
N/P												1	0.636**	-0.448**
SWC (%)													1	-0.805**
BD (g/cm ³)														1

Notes: SOC (Soil organic carbon), TP (soil total phosphorous), AP (soil available phosphorous), TN (soil total nitrogen), AN (soil available nitrogen), C/N (carbon/nitrogen), C/P (carbon/phosphorous), N/P (nitrogen/phosphorous), SWC (soil water content), and BD (soil bulk density). The sample size is 69.

relationship observed between evenness index and soil properties.

4 Discussion

AGB in grazing management sites was significantly lower than that in fencing and mowing sites, which was accordance with results from Medina-Roldan *et al.* (2012), who found that grassland production could be relatively decreased in grazing areas because of livestock's consumption. A higher BGB amount was observed in top soil layer of fencing pattern than that in grazing pattern. This result suggested that the fencing pattern leads to shallower rooting distribution compared with grazing grassland, which was attributed by the physical barriers inhibiting root growth in ungrazed regions. For instance, consumption by livestock may result in fast root turnover. Jackson *et al.*, (1996) verified that 83% of BGB was distributed in upper 30 cm soil depth of temperate grassland. The ratio of R/S was remarkably greater in Hulun Buir Grassland than that observed in global temperate grassland (Mokany *et al.*, 2006). Higher R/S in Hulun Buir Grassland could be associated with the comparatively slow depletion of carbohydrates in roots, resulting from low respiration rates during extremely cold winter. This finding may also be caused by the slow root turnover in colder environments in contrast to average level of turnover in global temperate grassland (Gill and Jackson, 2000). This phenomenon was explained by the fact that plant biomass were likely to allocate more to BGB than to AGB, which was beneficial for maximum resources use and optimal growth in environment changed by grazing.

Conservation management had uncertain effect on both targeted and non-targeted species groups (Baldi *et al.*, 2013). In this study, Shannon index and species richness were greatly enhanced by mowing than fencing in typical grassland. However, in meadow grassland, species richness of fencing pattern was significantly higher than that of mowing and grazing patterns ($p < 0.05$). Wu *et al.* (2011) denoted that moderate grazing had positive effects on seedling recruitment and offspring diversity, but heavy grazing may alter community succession by affecting recruitment patterns. Therefore, we proposed a requisite ban on grazing patterns in meadow grassland. However, potential reasons for these variations should be examined, given that it was incon-

sistent comparison within management regimes. It is necessary to encourage a functionally diverse plant community over the entire managed area, rather than promote high localized species diversity within grassland (White *et al.*, 2004).

Grazing intensity is one of the most relevant factors that influence soil property variations in rangeland ecosystems. Trampling of grazing animals was reported to affect soil by increasing bulk density and mechanical resistance, and reducing porosity, water infiltration, and aggregate stability (Evans *et al.*, 2012). Zhou *et al.* (2010) denoted that grazing and trampling by livestock cause deterioration of soil physical properties and increased soil erodibility. In our study, we found that both soil organic carbon and soil available phosphorous were significantly greater with fencing of desert grassland or with mowing of typical grassland than those with grazing or fencing. Soil total phosphorous content and soil total nitrogen content under mowing patterns were significantly greater than those of fencing patterns in meadow grassland. We concluded that effective utilization patterns for protecting soil fertility is as follows: mowing, fencing, and grazing. These results confirmed that appropriate grazer densities will promote soil carbon sequestration in the grassland of the northern China.

The relationship between species diversity and soil properties has been widely considered. The correlation analyses indicated that significant relationships exist among plant species diversity, soil organic matter, and soil total nitrogen (Yang *et al.*, 2009). Our study also discovered that soil nutrient was related to species diversity. Consequently, promoting soil fertility is a highly valuable solution to maintain or increase herbaceous plant species richness (Pausas and Austin, 2001; Dybzinski *et al.*, 2008). Nevertheless, the amendment of nitrogen fertilizer may increase species diversity (Ostertag and Verville, 2002) because the most significant relationship of species diversity exists with soil available nitrogen (Table 2).

5 Conclusions

Our study demonstrated that exclusive livestock grazing had significant effects on AGB and BGB, which can also improve environmental conditions. Soil nutrient status was bettered after the fencing establishment. Nevertheless, long term over grazing showed negative

effects on species diversity compared with mowing, while the latter is quite effective to protect grassland ecosystem. Therefore, implementation of the Ecological Project in China played a positive role for the sustainable development of the Hulun Buir Grassland, especially for the entire temperate grassland.

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