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Effects of fencing on vegetation and soil restoration in a degraded alkaline grassland in northeast China

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Abstract: In order to restore a degraded alkaline grassland, the local government implemented a large restoration project using fences in Changling county, Jilin province, China, in 2000. Grazing was excluded from the protected area, whereas the grazed area was continuously grazed at 8.5 dry sheep equivalent (DSE)/hm^2. In the current research, soil and plant samples were taken from grazed and fenced areas to examine changes in vegetation and soil properties in 2005, 2006 and 2008. Results showed that vegetation characteristics and soil properties improved significantly in the fenced area compared with the grazed area. In the protected area the vegetation cover, height and above- and belowground biomass increased significantly. Soil pH, electrical conductivity and bulk density decreased significantly, but soil organic carbon and total nitrogen concentration increased greatly in the protected area. By comparing the vegetation and soil characteristics with pre-degraded grassland, we found that vegetation can recover 6 years after fencing, and soil pH can be restored 8 years after fencing. However, the restoration of soil organic carbon, total nitrogen and total phosphorus concentrations needed 16, 30 and 19 years, respectively. It is recommended that the stocking rate should be reduced to 1/3 of the current carrying capacity, or that a grazing regime of 1-year of grazing followed by a 2-year rest is adopted to sustain the current status of vegetation and soil resources. However, if N fertilizer is applied, the rest period could be shortened, depending on the rate of application.

Keywords: vegetation and soil restoration; fencing; grazing; alkaline soil; semi arid region; grassland degradation

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Currently, degraded grassland is widespread throughout the world, and grassland restoration has become a focus for ecologists (van der Merwe and Kellner, 1999; Snyman, 2003; Gonzales and Clements, 2010). Many factors can contribute to grassland degradation, including natural factors such as a long-term drought, wind erosion and sand storms (Schlesinger et al., 1990), and human interferences such as overgrazing (Manzano and Návar, 2000), land use change (Zhao et al., 2005) and mining (Wang et al., 2007).

It is deemed that overgrazing is the primary cause of grassland degradation (Fleischner, 1994; Mainguet 1994; Daily, 1995). Overgrazing has two major impacts on grasslands. First, the livestock grazing reduces vegetation height and changes species composition and cover of grassland communities (Su et al., 2005). Second, the trampling of livestock can cause serious damage to vegetation and soil during the process of grazing. Livestock trampling destroys the ground protection layer, including plant residues and litter on the soil surface (Taylor et al., 1993; Hofstede, 1995), and compacts soil and reduces soil water penetrability, hence increasing the risk of runoff and causing loss of soil nutrients (Dak and Gifford, 1980). Numerous studies indicate that overgrazing can result in dramatic changes in vegetation and modifications in

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nutrient cycling in grasslands (Bauer et al., 1987; Dormaar et al., 1994; Lavado et al., 1996).

In recent years, reducing grazing pressure by fencing has been encouraged as an effective way to restore degraded grassland, including the restoration of degraded vegetation and improvement of soil properties in different grassland ecosystems (Pei et al., 2008; Wu et al., 2009; Shang et al., 2013). Previous studies indicate that the restoration of degraded ecosystems depended on climatic conditions, disturbance history, soil texture and propagule resources (Holmgren and Scheffer 2001; Suding et al., 2004; Wang et al., 2013), and the restoration rates of vegetation and soil differ as vegetation generally restores more quickly than soil (Pywell et al., 2002). Therefore, the benefit of fencing may vary in different grasslands and among ecosystem components, such as plants and soil.

Songnen grassland is dominated by *Leymus chinensis* Tzvel. Most of the area of Songnen Plain is located in a basin surrounded by mountains, and it thus has very poor drainage. The accumulation of solutes induces primarily alkaline soil processes, with Na_2CO_3 and $NaHCO_3$ being the major sources for soil alkalinity. High pH and electrical conductivity are highlighted characteristics for alkaline soil, and these are the principal limiting factors for vegetation establishment in this area (Gao et al., 1996; Jiang et al., 2010). In the last few decades, most of the vegetated area in the Songnen grassland has been degraded severely due to overgrazing (Zhang, 1994). The vegetation degradation and soil erosion exacerbated the alkalinity levels in the surface soil, resulting in a severe secondary alkalinization process. The grassland degradation has restricted the local economy and development of society. Since 2000, with financial support from the government, a large grassland restoration project has been implemented. Large areas of degraded grasslands were protected from grazing by fencing in order to restore ground cover and forage production to the pre-degradation levels of 1983. However, there is limited information of restoration processes and duration. Therefore, the objective of this study is to understand the mechanisms of restoring vegetation and soil properties and to provide guidelines for farmers to manage severely degraded grasslands of the Songnen Plain in northern China.

1 Materials and methods

1.1 Study area

The study area is located in Changling county, Jilin province, China (44°15'N, 123°34'E). The climate in this region is semi-arid. Average annual precipitation from 2000–2008 was 364 mm, about 80% of which falling between July and September. The annual mean temperature was 4.9°C. The specific temperature and precipitation information during our experiment years (2005, 2006 and 2008) are shown in Fig. 1. The soil type is meadow solonchaks, according to the FAO/UNESCO taxonomy, with 23% sand, 37% silt, and 40% clay. Soil pH ranges from 8.5–9.5 and soil organic matter content ranges from 20–25 g/kg in the surface layer. *L. chinensis* has absolute dominance in the local mature vegetation.

1.2 Sampling and measurements

In mid-September 2005, two plots of 300-hm^2 meadow were selected from fenced and freely grazed areas for this paired paddock comparison study. The fenced area has been excluded from grazing since 2000, but it was subjected to 15 years of extensive livestock grazing from 1985–2000 and was seriously degraded. As a comparison, the outside area was continuously grazed by sheep and cattle at 8.5 dry sheep equivalent (DSE)/hm^2. The baselines for vegetation and soil in 1983 (pre-degradation) and 2000 (before fencing) are given in Table 1, based on historical survey data.

Two sampling stripes (100 m×50 m) were selected randomly inside and outside of the fenced areas. Ten quadrats (1 m×1 m) were selected as replicates at 10-m intervals along the 100-m sampling stripes. In each quadrat, the vegetation height was determined by measuring the vertical height of the tallest parts of the plants, the vegetation cover was estimated, and the number of individuals in each species was counted. All live, aboveground plant materials were clipped at the soil surface for aboveground biomass. Within each quadrat, three soil samples were collected using a soil auger with a 10-cm diameter at depths of 0–10 and 10–20 cm. These samples were combined into one for each depth. Roots were washed free from the soil. All above- and belowground biomass was dried at 70°C for 48 h to determine the dry weight. Within each quadrat, three soil samples were taken randomly using a 5-cm diameter soil auger at the depths of 0–10 and 10–20 cm, and then combined into one sample per depth for soil analysis. Soil bulk density at the depths of 0–10 and 10–20 cm was determined from five replicates by using the core method in each quadrat (Klute, 1986). The same sampling process was conducted in mid-September of 2005, 2006 and 2008.

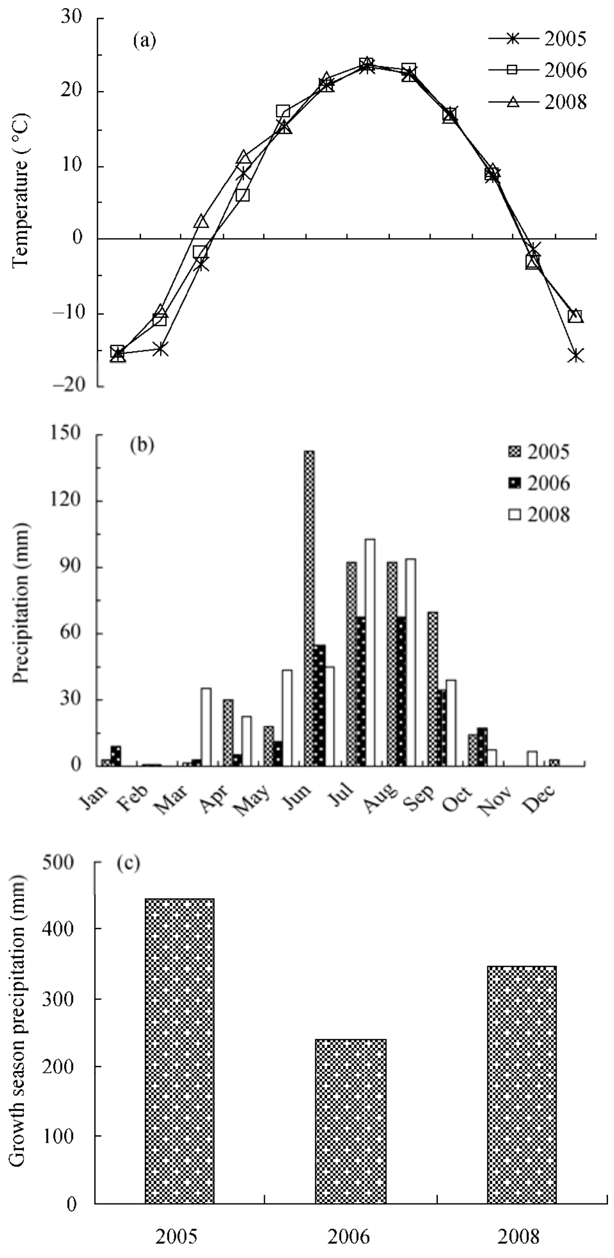

Fig. 1 The monthly temperature (a), monthly precipitation (b) and growth season precipitation (c) in 2005, 2006 and 2008; Growing season lasts from April to September.

Table 1 Vegetation and soil characteristics (0–10 cm) in the study meadow in 1983 (pre-degradation) and 2000 (before fencing)

	Item	1983	2000
Vegetation	Cover (%)	85	37
	Height (cm)	58	32
	Plant density (individuals/m^2)	678	684
	Above-ground biomass (g/m^2)	359.50	192.20
Soil	Bulk density (g/cm^3)	1.34	1.47
	pH	8.72	9.42
	Soil organic carbon (g/kg)	12.57	6.44
	Total nitrogen (g/kg)	1.24	0.79
	Total phosphorus (g/kg)	0.32	0.20

1.3 Soil analysis

The soil samples were air-dried and sieved to pass a 2-mm mesh. Then subsamples were ground to pass through a 0.25-mm sieve for analysis of soil organic carbon (C_{org}) using the $K_2Cr_2O_7$ method (Page, 1982), total soil nitrogen (N_{tot}) using the Kjeldahl method (Sparks et al., 1996), and total soil phosphorus (P_{tot}) using a spectrophotometer after NaOH digestion (ISSCAS, 1978). Soil pH and electrical conductivity (EC) were determined using a PHS-3C pH meter and a DDS-307 EC meter (Shanghai, China) in a 1:5 soil-water solution.

1.4 Data analysis

We used the Richness index (*R*), Shannon-Wiener diversity index (*H*) and Evenness index (*E*) to characterize the community structure characteristics (Wu et al., 2009).

Richness index (*R*): $R=S$, (1)

Shannon-Wiener diversity index (*H*):

$$H=-\sum_{i=1}^{s} P_i \ln P_i \,, \tag{2}$$

Evenness index (*E*): $E= H/\ln S$. (3)

Where *S* is the number of species in the community, and P_i is the density proportion of *i* species.

The statistical comparisons of means between fenced and grazed areas were conducted using independent sample *t*-tests. The least significance difference (LSD) was provided to compare the differences in vegetation and soil properties among years. A one-sample *t*-test was performed to determine the effectiveness of fencing on restoring vegetation and soil based on background data in 1983 and measurements in 2000. Pearson's correlation coefficients were used to evaluate relationships between the above- and belowground biomass and soil properties. Curve estimation regression was used to predict the time needed for the restoration of soil organic carbon and total soil N concentrations. Significant differences for all statistical tests were evaluated at P=0.05. All data analyses were conducted with SPSS16.0 software (Chicago, IL, USA).

2 Results

2.1 Community composition and structure

In total, there were 26 species found in fenced and grazed areas during our sampling process in 2005, 2006 and 2008, with 14 species common in fenced and grazed areas, 6 species present only in fenced area, and 6 species only found in the grazed area. The species numbers were lowest in 2006 in both fenced and grazed areas. It was noted that the number of annual grass species present in the fenced area decreased from 4 to 0 between 2005 and 2008. The aboveground biomass of annual species decreased in both fenced and grazed areas, but the aboveground biomass and proportion of *L. chinensis* increased continuously in the fenced area (Table 2).

There was no significant change in species richness between fenced and grazed areas (Fig. 2a). However, species diversity and evenness decreased significantly in the fenced meadow communities (P<0.05; Figs. 2b and c). The species diversity and evenness were lower in the fenced communities compared with the grazed communities in 2008 (P<0.05; Figs. 2a and c). In the

Table 2 The mean aboveground biomass (g/m^2) of species present in surveyed quadrats in 2005, 2006 and 2008

Species	Life type	2005		2006		2008	
		Fenced	Grazed	Fenced	Grazed	Fenced	Grazed
Leymus chinensis	PG	134.70	18.06	283.42	87.02	360.88	35.01
Phragmites australis	PG	59.88	0.30	-	-	6.68	0.50
Calamagrostis epigejos	PG	0.64	-	11.06	-	-	-
Saussurea runcinata	PF	6.74	-	-	-	-	-
Saussurea glomerata	PF	0.20	-	0.15	-	0.01	0.11
Cynanchum chinense	PF	0.40	0.08	2.40	-	0.22	0.01
Sonchus brachyotus	PF	2.10	0.06	-	-	0.21	0.12
Brachyactis ciliata	PF	-	0.26	-	-	-	-
Potentilla anserine	PF	-	0.02	-	-	-	-
Taraxacum asiaticum	PF	-	0.24	-	0.11	-	0.18
Ixeris chinensis	PF	-	-	-	-	-	0.03
Plantago asiatica	PF	-	-	-	0.07	-	-
Iris lactea	PF	-	-	13.63	-	0.61	-
Polygonum aviculare	PF	-	0.68	-	-	0.16	-
Digitaria sanguinalis	AG	0.46	-	-	-	-	-
Echinochloa crusgalli	AG	6.60	25.24	-	0.08	-	0.04
Chloris virgata	AG	35.10	28.60	0.05	3.01	-	0.50
Setaria viridis	AG	0.78	1.36	-	-	-	-
Atriplex patens	AF	-	0.14	-	-	-	-
Polygonum sibiricum	AF	-	-	0.31	-	-	-
Artemisia anethoides	AF	1.98	-	1.80	-	-	-
Artemisia scoparia	AF	-	-	0.10	0.18	0.38	-
Artemisia annua	AF	-	-	18.38	0.34	0.43	0.28
Artemisia anethifolia	AF	1.46	0.04	-	-	0.01	0.02
Suaeda glauca	AF	5.70	0.10	-	0.17	0.13	0.39
Suaeda hetroptera	AF	0.34	99.26	-	-	-	-

Note: PG, perennial grass; PF, perennial forb; AG, annual grass; AF, annual forb; –, not present.

grazed meadow communities, species diversity and evenness were the lowest in 2006 (*P*<0.05, Figs. 2b and c).

2.2 Vegetation cover, vegetation height and plant density

In the fenced meadow, the vegetation cover and height showed significant increases from 2000 to 2005 and from 2005 to 2006 (*P*<0.05), but slight increases from 2006 to 2008 (Table 1; Figs. 2a and b). They increased by 121.6% and 75% from 2000 to 2008, respectively. Plant density decreased significantly from 2000 to 2005 (*P*<0.01), and then increased significantly from 2005 to 2006 in the fenced meadow (*P*<0.01; Table 1; Fig. 2c). In contrast, in the grazed meadow, vegetation cover and plant density decreased by 75.7% and 81.1% from 2000 to 2008, respectively (*P*<0.01; Table 1; Figs. 2a and c). In comparison to the grassland with continuous grazing, the fenced meadow had significantly higher vegetation cover and vegetation height in each sampling year (*P*<0.05; Figs. 2a and b).

2.3 Above- and belowground biomass

In the fenced meadow communities, above- and belowground biomass increased significantly from 2000 to 2006 (*P*<0.05; Table 1; Fig. 4), but there was not significant difference between 2006 and 2008 (Fig. 4). In the grazed meadow communities, from 2000 to 2008, above- and belowground biomass decreased by 80.6% and 83.7%, respectively (*P*<0.001; Table 1; Fig. 4). In comparison to the grazed meadow communities, the fenced meadow communities had more above- and belowground biomass in each sampling year (*P*<0.05; Fig. 4).

2.4 Soil physical and chemical properties

In the fenced area, the soil pH, EC and bulk density decreased gradually over time, while the soil C_{org}, N_{tot}, P_{tot} concentrations and carbon/nitrogen (C/N) ratio increased gradually. However, the reverse trend was found in the grazed area (Table 3). Soil bulk density was significantly lower in the fenced area compared with that in the grazed area during the three sampling

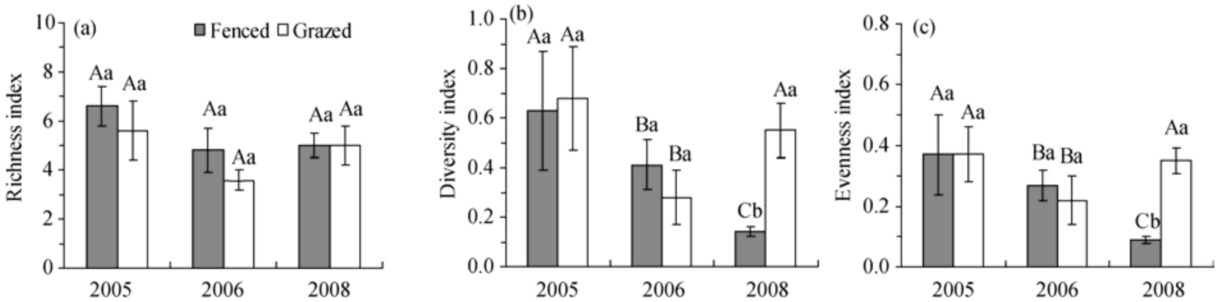

Fig. 2 Richness index (a), diversity index (b) and evenness index (c) in fenced meadow and grazed meadow in 2005, 2006 and 2008. Values (mean±SE) are means of ten quadrats for each year. Means with different lowercase letters for each pair of bars indicate significant differences between treatments at *P*<0.05. Means with different uppercase letters across bars indicate significant differences between years within each treatment at *P*<0.05.

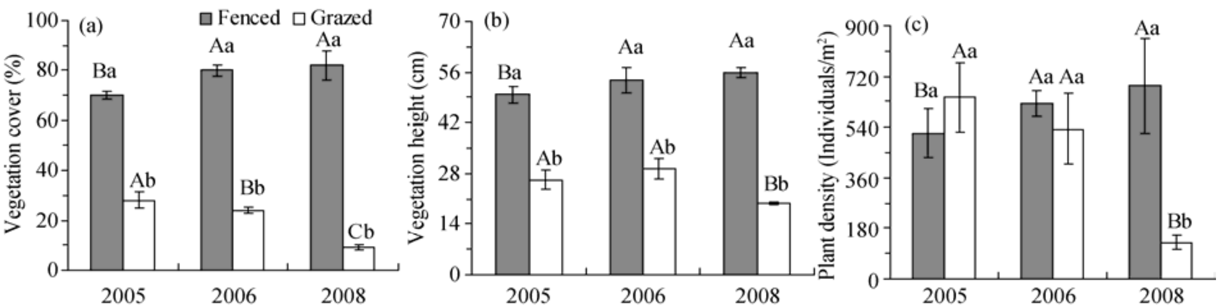

Fig. 3 Vegetation cover (a), vegetation height (b) and plant density (c) in fenced meadow and grazed meadow in 2005, 2006 and 2008. Values (mean±SE) are means of ten quadrats for each year. Means with different lowercase letters for each pair of bars indicate significant differences between treatments at *P*<0.05. Means with different uppercase letters across bars indicate significant differences between years within each treatment at *P*<0.05.

years (Table 3). Similarly, both soil pH and EC were also significantly lower in the fenced meadow than in the grazed area, particularly in 2006 and 2008 (Table 3). In each sampling year, the fenced meadow had significantly higher soil C_{org} and N_{tot} concentration than the grazed meadow at the depth of 0–10 cm (Table 3). There was no significant difference in the soil P_{tot} concentration between fenced and grazed areas (Table 3).

Correlation analysis indicated that there were significant positive correlations between above-, and belowground biomass and soil C_{org} and N_{tot} concentration at the depth of 0–10 cm (Table 4), but negative correlations between above- and belowground biomass and pH, EC and soil bulk density (Table 4). No significant correlations were found for above- and belowground biomass and soil P_{tot} (Table 4).

3 Discussion

3.1 Vegetation restoration under fencing

Grazing management has variable effects on community structure in different grazed ecosystems (Guo, 2007; Marriott et al., 2009). Yayneshet et al. (2009) suggested that fencing a semi-arid, grass-wood mixed rangeland for more than 5 years increased species diversity in comparison to a grazed area of the rang-

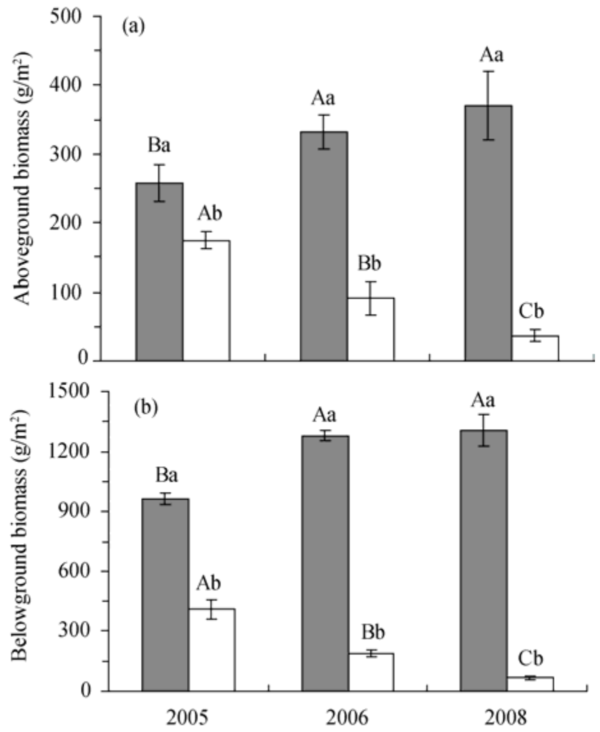

Fig. 4 Community aboveground (a) and belowground biomass (b) at 0–20 cm depth in fenced meadow and grazed meadow in 2005, 2006 and 2008. Values (mean±SE) are means of ten quadrats for each year. Means with different lowercase letters for each pair of bars indicate significant differences between treatments at $P<0.05$. Means with different uppercase letters across bars indicate significant differences between years within each treatment at $P<0.05$.

Table 3 Soil physical and chemical properties in fenced and grazed meadows

Soil property		Soil depth 0–10 cm			Soil depth 10–20 cm		
		2005	2006	2008	2005	2006	2008
pH	Fenced	9.23±0.12^{A}	9.14±0.06^{ABb}	8.91±0.11^{Bb}	10.24±0.07^{A}	9.99±0.07^{Ab}	9.49±0.10^{Bb}
	Grazed	9.48±0.07	9.51±0.07^{a}	9.48±0.18^{a}	10.34±0.04	10.32±0.08^{a}	10.38±0.14^{a}
EC (μs/cm)	Fenced	430±20^{Ab}	385±13^{Ab}	238±11^{Bb}	1,045±23^{A}	839±70^{Bb}	772±23^{Bb}
	Grazed	709±20^{Ba}	779±37^{ABa}	807±27^{Aa}	1,064±23	1,062±25^{a}	1,133±62^{a}
C_{org} (g/kg)	Fenced	6.92±0.22^{Ca}	7.96±0.13^{Ba}	9.45±0.36^{Aa}	6.00±0.27^{C}	6.88±0.10^{Ba}	7.56±0.33^{Aa}
	Grazed	6.20±0.12^{Ab}	5.94±0.26^{ABb}	5.51±0.33^{Bb}	5.64±0.20^{A}	5.01±0.15^{Bb}	4.34±0.11^{Cb}
N_{tot} (g/kg)	Fenced	0.82±0.01^{Ba}	0.86±0.02^{Aa}	0.90±0.02^{Aa}	0.75±0.01	0.78±0.03^{a}	0.78±0.02^{a}
	Grazed	0.77±0.01^{Ab}	0.76±0.02^{ABb}	0.72±0.01^{Bb}	0.70±0.01^{A}	0.64±0.02^{Ab}	0.56±0.02^{Bb}
C/N	Fenced	8.44±0.25^{B}	9.28±0.34^{Ba}	10.50±0.45^{Aa}	8.01±0.36^{B}	8.90±0.49^{ABa}	9.77±0.47^{Aa}
	Grazed	8.06±0.27	7.82±0.39^{b}	7.65±0.37^{b}	8.06±0.30	7.82±0.48^{b}	7.75±0.49^{b}
P_{tot} (g/kg)	Fenced	0.21±0.02	0.23±0.02	0.25±0.02	0.20±0.02	0.22±0.01	0.22±0.02
	Grazed	0.21±0.02	0.20±0.02	0.20±0.01	0.19±0.02	0.18±0.01	0.18±0.01
BD (g/cm^3)	Fenced	1.40±0.02^{b}	1.38±0.02^{b}	1.37±0.02^{b}	1.45±0.02^{b}	1.43±0.02^{b}	1.41±0.02^{b}
	Grazed	1.58±0.04^{a}	1.59±0.04^{a}	1.60±0.03^{a}	1.63±0.03^{a}	1.64±0.02^{a}	1.64±0.02^{a}

Note: Means with lowercase letters in a column indicate significant difference among treatments at $P<0.05$; means with capital letters in a line indicate significant differences among years at $P<0.05$.

Table 4 Pearson correlation coefficients between the above- and belowground biomass (0–10 cm) and soil properties (0–10 cm)

Soil property	Aboveground biomass	Belowground biomass
pH	–0.418*	–0.461*
Electric conductivity	–0.650**	–0.675**
Soil organic carbon	0.678**	0.625**
Total nitrogen	0.739**	0.721**
Total phosphorus	0.457	0.296
Bulk density	–0.748**	–0.847**

Note: * and ** indicate significance at $P<0.05$ and $P<0.01$ levels, respectively.

land. Wu et al. (2009) reported opposite findings from an alpine meadow, and their study showed that species richness and diversity were significantly lower in a fenced grassland than in a grazed grassland after 5 years of fencing. In our study, fencing did not induce any significant changes in meadow communities' species richness in comparison to grazed meadows. However, when protected from grazing by fencing, plant species composition, plant density and biomass were greatly changed in meadow communities. With fencing, plant density and biomass gradually increased for *L. chinensis* while declined for other species. Total plant density and aboveground biomass of *L. chinensis* increased by more than 72% in 2005, 5 years after fencing, and by more than 90% in 2006 and 2008 compared to the conditions prior to fencing in 2000 (Table 2). As a result, by 2008 the plant diversity and evenness in the fenced area had decreased in comparison to the grazed meadow.

Leymus chinensis is a perennial, rhizomatous grass that can establish individuals *via* rhizomes and that has better survival adaptations than other plants. When grazing pressure increases, rhizome propagation is favored over sexual reproduction as a way of avoiding frequent aboveground disturbance (Wang, 2000). Although individual growth and sexual propagation are suppressed, the dependence on rhizome propagation can help the *L. chinensis* population avoid local extinction. When grazing is excluded, the remaining *L. chinensis* propagules can quickly stimulate population restoration. The quick restoration of *L. chinensis* populations may inhibit the development of other species by out-competing them for resources. Therefore, it is well known that the restoration of vegetation in this degraded meadow is primarily driven by release of suppressed *L. chinensis* individuals and not by recruitment of new species (Zhou et al., 2011).

Frequent, heavy grazing or overgrazing reduces the vegetation cover, plant height and biomass in grasslands, while excluding herbivores can be an effective way to restore vegetation (Pei et al., 2008; Wu et al., 2009; Liu et al., 2011). In our study, excluding grazing by fencing gradually increased ground cover and belowground biomass at the depth of 0–20 cm over time. In 2006, 6 years after fencing, the vegetation cover, plant height, above- and belowground biomass had reached 80%, 53.7 cm, 331.3 g/m^2 and 1,307.5 g/m^2 respectively, which was no different from the pre-degraded status in 1983 (Table 1; Figs. 3 and 4). No further improvement was recorded, although the site received higher rainfall in the growing season (from April to September) in 2008 (240.3 mm, Fig. 1) than in 2006. We conclude that 6 years of grazing exclusion is an enough time to restore plant cover and productivity in degraded grassland that previously underwent 15 years of extensive grazing with a mean stocking rate of 8.5 DSE/hm^2.

3.2 Soil restoration under fencing

Increased soil bulk density is an important indicator of degradation in grazed ecosystems, as it can further alter soil properties, such as water infiltration and retention, and thereby restrain plant growth (Salihi and Norton, 1987; Rubio and Bochet, 1998). Removal of grazers can decrease soil bulk density by excluding livestock trampling and restoring vegetation (Dakhah and Gifford, 1980; Su et al., 2004). These findings were also supported by our study, in which soil bulk density decreased in the fenced area and subsequently promoted vegetation establishment, while continuous grazing increased soil bulk density and suppressed vegetation establishment. There were significant, negative correlations between soil bulk density and above- and belowground biomass (Table 4).

Soil alkalinity is the principal restriction on vegetation establishment in this area (Gao et al., 1996). Soil pH and EC are two synergetic, key measurements to assess soil alkalinity. High soil pH and EC can restrain plant establishment and growth by increasing osmotic stress, ion toxicity and pH stress (Shi and Wang, 2005). In the current study, we found negative correlations between soil pH, EC and plant biomass (Table 4). Shi and Wang (2005) confirmed that increasing the soil pH to above 8.8 can decrease the survival rate, tillering rate, number of rhizomes and relative growth rate of *L. chinensis*. Our results show that soil pH decreased from 9.42 in 2000 to 8.91 in 2008 in the fenced area. Reduced pH provided more opportunities for the establishment of *L. chinensis*, the dominant species in this grassland, thus facilitating vegetation restoration. Restoration of vegetation can promote nutrient cycling *via* decomposition and decreased nutrient loss *via* runoff and wind erosion, owing to its protection of soil surface, which has a positive effect on increasing the soil C and N concentrations (Li et al., 2009; Wu et al., 2010). Our results confirmed that the soil C_{org}, N_{tot} concentration and above- and below-ground biomass are strongly, positively correlated (Table 4).

In our research, although the soil C_{org} and N_{tot} synergistically increased with fencing and decreased under grazing, the soil C/N ratio varied in different years (Table 3). The change in the soil C/N ratio among years in this study indicates that grazing management affects soil C_{org} to a larger extent than N_{tot}, similar to findings reported from a sandy grassland and a desert grassland in northern China (Su et al., 2005; Pei et al., 2008). The slight change in soil P_{tot} concentration indicates that soil P_{tot} responds more slowly to changes in grazing management.

The improvement of soil properties during natural ecosystem restoration is a complicated and long-term process, particularly when they have deteriorated rapidly due to disturbances (Su et al., 2005). By our statistics, the soil pH at a depth of 0–10 cm in the fenced area did not change significantly from 1983 (pre-degradation) to 2008. The soil C_{org}, N_{tot} and P_{tot} concentrations in the fenced area at 0–10 cm depth in 2008 were 1.47, 1.14 and 1.25 times higher than the values in 2000 (before fencing), respectively. These values in the fenced area were 0.86, 0.91 and 1.00 higher relative to the values in the grazed area, but they were still significantly lower than those in 1983 ($P<0.05$; Tables 1 and 3). We established a best-fit equation by using a curve estimation regression to reflect the changes in soil C_{org}, N_{tot} and P_{tot} concentrations at 0–10 cm depth following restoration time (year), and the three equations are as follows: $C_{org}=6.174\times e^{0.044\times time}$, $N_{tot}=0.782\times e^{0.016\times time}$, $P_{tot}=0.196\times e^{0.026\times time}$. If soil C_{org}, N_{tot} and P_{tot} concentrations at 0–10 cm depth continue to be restored at the same rate as they were from 2000 to 2008, then the restoration of soil C_{org}, N_{tot} and P_{tot} concentration would need 16, 30 and 19 years, respectively, to attain their 1983 levels. Therefore, the complete restoration of soil chemical properties from degraded soil *via* fencing is a far longer process than 8 years and may take twice as long to accomplish as the degradation time. Certainly, a change in climate and disturbance may accelerate or retard it, and these factors need further research.

3.3 Implications for grassland management

Our results indicate that exclusion of grazers by fences can have a positive effect on restoring vegetation and soil properties in this degraded alkaline grassland. The vegetation in this degraded meadow was primarily restored by the release of suppressed *L. chinensis* individuals, which emphasizes the importance of remaining *L. chinensis* individuals as a precursor to vegetation restoration. Therefore, the *L. chinensis* population should be monitored closely as a criterion for managing and assessing the restoration potential of this degraded grassland.

The restoration processes for vegetation and soil were different in this degraded grassland. To restore the vegetation after overgrazing took less than half of the time than what was needed for the restoration of soil N. Therefore, it is recommended that stocking rate should be reduced to 1/3 of the current carry capacity, or a grazing regime of 1 year of grazing followed by a 2-year rest period should be adopted to sustain the current status of vegetation and soil resources. However, if N fertilizer is applied, the rest period of the degraded meadow could be shortened, with the duration of the rest depending on the rate of N application.

4 Conclusions

By examining changes in the vegetation characteristics and soil properties following fencing and grazing in this degraded alkaline grassland, we confirm that fencing can effectively increase the vegetation cover and forage production, reduce soil bulk density and pH, and improve soil nutrient properties in comparison to continuous grazing. However, the restoration of soil properties was a longer and more complicated process than vegetation recovery, and thus may need more time and investment. For example, 6 years of grazing exclusion was enough to restore vegetation, but the restoration of soil C_{org}, N_{tot} and P_{tot} concentrations may need 16, 30 and 19 years, respectively, in a degraded alkaline grassland that had undergone 15 years of extensive grazing with a mean stocking rate of 8.5 DSE/hm^2. The current study also emphasizes the importance of conserving the *L. chinensis* population, as the restoration of vegetation in this degraded meadow was primarily accomplished through the release at suppressed *L. chinensis* individuals, but not through recruitment of new species.

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