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Effects of grazing exclusion on plant community and soil physicochemical properties in a desert steppe on the Loess Plateau, China

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ABSTRACT

Although fencing is an effective restoration strategy used to achieve the global sustainability of grassland ecosystem, it is unclear from the literature whether fencing results in positive effects on soil physicochemical properties, plant diversity and the relationship between soil particle and soil chemical properties in a desert steppe on the Loess Plateau. Therefore, we selected fenced communities and grazed communities to study the effects of grazing exclusion on desert grassland on the Loess Plateau in China. Our results indicate that plant coverage, plant height, richness index, above- and below-ground biomass, root/shoot ratio, the number of grasses and the number of perennials increased significantly, whereas litter biomass, the number of forbs and annuals significantly decreased after approximately 12 years of fencing. Fencing also resulted in marked increases in ammonium nitrogen (AN) in the 0–10 cm soil depth, soil organic carbon (SOC), total nitrogen (TN), nitrate nitrogen (NN), clay and silt in the 0–30 cm soil depth and soil total phosphorus (TP) in 0–100 cm soil depth. Our results also indicated that SOC, TN, NN, clay, silt, sand and belowground biomass were significantly affected by land use type, soil layer and their interaction between land use type and soil layer. However, AN was affected by only land use type, and TP was affected by land use type and soil layer but not their interaction. In addition, there was s significant correlation between soil chemical properties (SOC, TN, TP, NN, AN) and soil particles (silt, clay and sand) in the 0–5 cm soil depth. As part of our ongoing research, this paper can produce substantial ecological benefits by contributing to the development of a more scientific strategy for grassland management on the Loess Plateau.

1. Introduction

Grazing is widely recognized as a primary ecosystem driver in grassland (UNCCD, 2004). However, overgrazing has resulted in severe degradation and desertification of semi-arid grasslands in Northern China over the last decades (Wiesmeier et al., 2009). Although severe drought, water erosion, and environmental degradation are well known in the semi-arid Chinese Loess Plateau (Wei et al., 2015), overgrazing because of mismanagement is a major driver for biodiversity loss (Chillo et al., 2015), lower plant height, lower canopy cover, lower plant species abundance and lower aboveground biomass (Xu et al., 2014). Overgrazing also causes the degradation of soil chemical and physical properties by reducing plant cover and increasing soil compaction and erosion (Chartier et al., 2013) as well as soil heterogeneity (Su et al., 2006) and decreasing the total mycorrhizal colonization of *Scea. grandis* (Wang et al., 2014b). Therefore, appropriate grazing management is important for the rational utilization of grassland resources (Zheng and Sun, 2011).

To restore the degraded grassland in northern China, under the country's Tenth Five-Year Plan, a host of sustainable development initiatives were introduced (Deng and Shangguan, 2014). Foremost among them was the Returning Grazing Land to Grassland (GLG) policy (Deng and Shangguan, 2014). As a consequence of this policy, the grassland in this area has improved (Deng et al., 2014a, 2014b). Several studies have demonstrated that this project could significantly increase SOC stocks (Deng et al., 2014b; Wu et al., 2015) and net primary productivity (NPP) values (Song et al., 2012; Deng et al., 2014a; Wu et al., 2015), enhance the vegetation index

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(EVI) (Xiao, 2014; Fan et al., 2015; Li and Lu, 2015), leaf area index (Xiao, 2014; Fan et al., 2015), and the fraction of photosynthetically active radiation absorbed by canopies (Xiao, 2014) as well as control soil erosion (Dang et al., 2014) and combat land degradation (Wu et al., 2015). Overgrazing has a number of negative effects, often including undesirable vegetation increases (Louhaichi et al., 2009), reduced vegetation cover (Deng et al., 2014a), biomass reduction (Louhaichi et al., 2012), species diversity reduction (Louhaichi et al., 2012; Deng et al., 2014a), and reduced soil carbon (Deng et al., 2014a). However, grazing may increase biomass production in plant communities with a high re-growth potential (Olofsson and Oksanen, 2002; Deng et al., 2014b). such as perennial grassland (Loeser et al., 2004), or in plant communities with long evolutionary histories and low productivity (Milchunas and Lauenroth, 1993).

Recent research has focused on the effects of fencing on vegetation characteristics (Liu et al., 2015), vegetation succession (van Rooyen et al., 2015), community structure (Huallachain et al., 2014), quantitative phytosociological character (van Rooyen et al., 2015) and plant diversity (Vuorio et al., 2014). In addition, many studies have focused on the effects of fencing on soil physical and chemical properties (Su et al., 2004; Wu et al., 2010; Wang et al., 2014a), soil C and N cycling (Frank and Groffman, 1998; Herman et al., 2003; Miller et al., 2014) and soil C and N storage (Qiu et al., 2013; Deng et al., 2014b). However, few studies have investigated fencing's effects on soil–plant community composition, diversity and productivity, soil properties, soil particle size, and the relationship between soil particle size and soil chemical properties as a whole.

In this study, we examined the effect of a grazing exclusion (approximately 12 years) on grassland vegetation and soil properties in a desert steppe of the Loess Plateau. The objectives of this study were (1) to determine the quantitative phytosociological character, soil chemical properties and the soil particle size distribution, (2) to make clear the relationship between soil particle size distribution and soil chemical properties, and (3) to specify the effects of soil layer, land use type and their interaction on soil properties in the study area. Although grassland restoration is a long-term and complex ecological process (Hastings et al., 2007), we expect that short-term fencing can continue to significantly improve the vegetation and soil indicators.

2. Materials and methods

2.1. Study site

The experimental site is located in Huan County, Gansu Province, China (106°50.4′E, 36°8.4′N, 1650 masl) (Fig. 1) in the northern Loess Plateau. The study area receives a mean annual rainfall of 359 mm. The site's soil type is aeolian sandy soil, and the region receives more than 60% of its total rainfall during the July–September period. Wind erosion and the subsequent desertification are widespread in this area. The area's semi-arid temperate continental monsoon climate produces a mean daily temperature of 9.2 °C, a mean annual total of 2600 sunshine hours, a mean annual evaporation of 2000 mm, and 200 frost-free days per year on average.

The vegetation type is temperate desert grassland. The dominant perennial grasses are *Leymus secalinus*, *Pennisetum flaccidum* and *Stipa bungeana*. The main perennial forbs are *Artemisia capillaries*, *Heteropappus altaicus*, *Lactuca indica* and *Potentilla bifurca*. The main perennial legumes are *Astragalus adsurgens*, *Lespedeza daurica* and *Medicago sativa*, and the main annual plants are *Agriophyllum squarrosum*, *Corispermum puberulum* and *Setaria viridis*. The grass plants revive in mid-late April, remain reasonably productive from late June to late August, and wither in mid-late September.

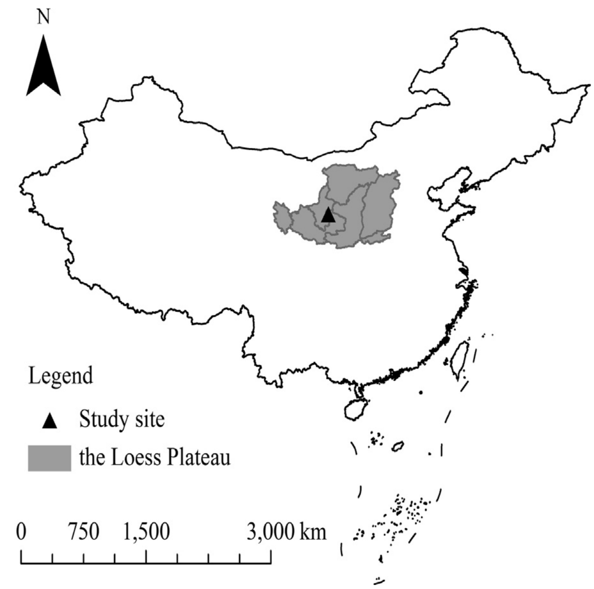

Fig. 1. Location of study site on the Loess Plateau, China.

In the study area, the implementation of the Returning Grazing Land to Grassland is the responsibility of the local government and typically assumes the form of specific projects, such as grazing prohibitions and the fencing of large parcels of grassland (Deng and Shangguan, 2014). However, sheep and cattle grazing continue near human settlement, and illegal sheep and cattle grazing frequently occurs at night on unfenced land that is distant from residential areas.

2.2. Experimental design and sampling

2.2.1. Experimental design

Within the experimental area, samples were collected in mid-August (2013), when the biomass had reached its peak. Using the line transect method, nine 10 m × 10 m blocks within open-grazing and fenced communities areas were randomly selected. The fenced communities were established in 2001, and approximately 12 years of grazing exclusion had passed since fencing. The grazed communities were unfenced, free-grazing communities. In total, there were 18 study blocks. Two adjacent 1 m × 1 m quadrats were established in the center of each block. One quadrat was used for overall investigation (i.e., the overall quadrat), and the other quadrat was used for individual species investigation (i.e., the sub-quadrat). The overall quadrats were investigated with respect to the entire quadrat community's aboveground-biomass, belowground-biomass, litter, canopy coverage, height and soils. The sub-quadrats were investigated with respect to the entire quadrat community's species composition, height, plant density (i.e., the number of individuals per square meter) and the aboveground-biomass of individual species. Humans could freely interfere in the grazed communities, whereas in the fenced communities, there was no external interference.

2.2.2. Biomass measurement, soil sampling and determination

In this study, the biomass measurement and the soil sampling procedures were the same as those used in previous studies (Deng et al., 2014a, 2014b). Soil organic carbon (SOC) content was determined by the $K_2Cr_2O_7$–H_2SO_4 oxidation method (Nelson and Sommers, 1996). Soil total nitrogen (TN) content was assayed using the Kjeldahl method (Bremner, 1996), and soil total phosphorus (TP) content was determined after soil digestion with $HClO_4$–H_2SO_4 (Parkinson and Allen, 1975). Inorganic or mineral N in soil was extracted by shaking samples in 1 mol L^{-1} KCL [1:5(w/w) soil: KCL solution] for 1 h and subsequent filtering through filter paper (Bremner and Keeney, 1966). The filtrate was analyzed for NH_4^+—N (Crooke and Simpson, 1971) and NO_3^-—N (Best, 1976) with a Continuous Flowing Analyzer (SAN++, SKALAR, Holland). A laser particle analyzer that operates over a range of 0.02–2000 μm (Mastersizer 2000 particle size analyzer, Malvern Instruments, Ltd., UK) and based on the laser diffraction technique was used to measure particle size. Each treatment was performed with ten replicates. In order to ensure each soil sample data accurate, each soil sample analysis was performed with two replicates.

2.2.3. Plant species identification, functional group and species diversity index

Most plant species were identified in the field. Unidentified specimens were identified later by plant taxonomists. The method of Allen et al. (2011) was used to divide all of the plants into three functional groups: grass (plant species of the *Poaceae* family), forb (any herbaceous, dicotyledonous broad-leaved plant) and leguminous (leguminous species group). The aim of forming functional groups is to represent the ecological structure of a flora, and perhaps to use that structure to make predictions at a level that is more practicable and more general than the level of individual species and that enables better prediction of species assemblages (do Vale et al., 2010). Species richness is the number of species in each quadrat (Stirling and Wilsey, 2001). Richness index (R), Shannon–Wiener diversity index (H) and Evenness index (E) of fenced and grazing grassland communities were calculated as follows:

$$\text{Richness index}(R): R = S \quad (1)$$

Shannon–Wiener diversity index (H):

$$H = -\sum_{i=1}^{S} P_i \ln P_i \quad (2)$$

Evenness index (E):

$$E = \frac{H}{\ln S} \quad (3)$$

S is the total species numbers of grassland community, H is the Shannon–Wiener diversity index and P_i is the density proportion of i species

2.3. Data analysis

One-way ANOVA was performed to test the differences in biomass, functional group composition, plant diversity and soil

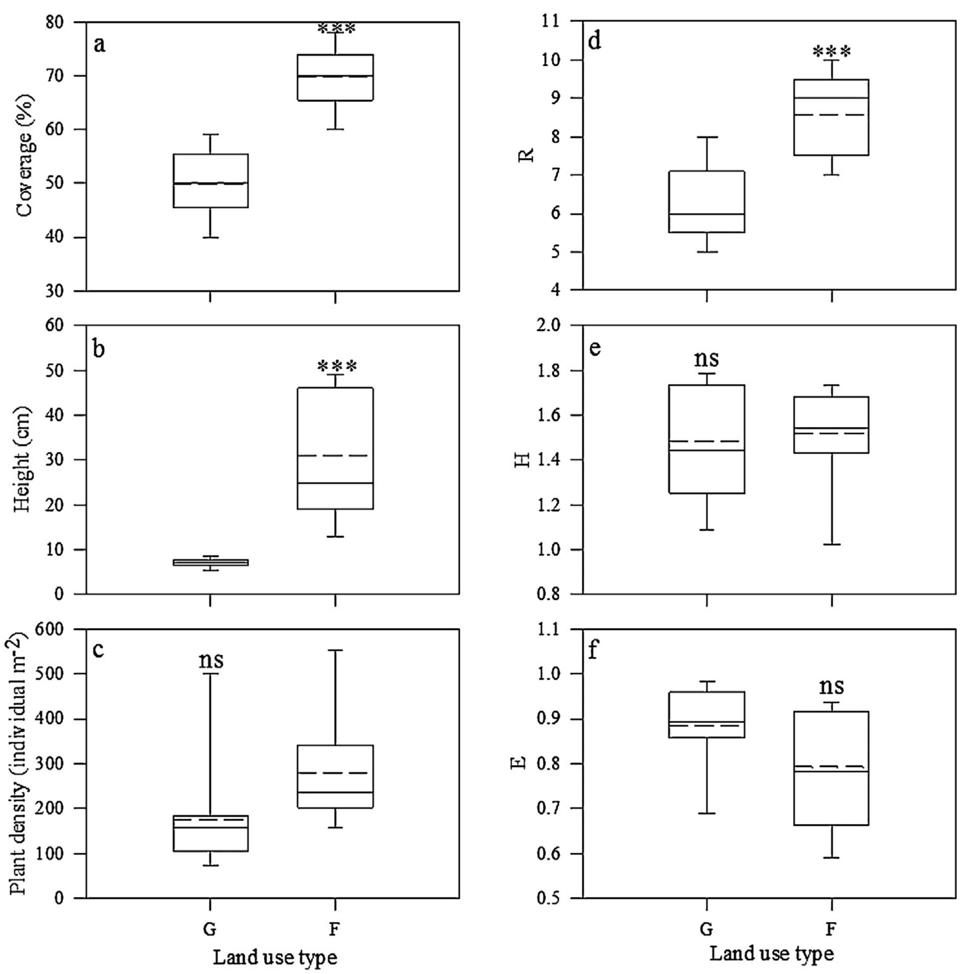

Fig. 2. Effects of fencing (F) and grazing (G) on coverage (a), height (b), plant density (c), richness index (d), Shannon–Wiener diversity index (e) and evenness index (f) of the arid or semiarid grassland community. Box plot key: the median 10th, 25th, 75th, 95th percentiles are plotted as vertical boxes with error bars, the dotted line represents mean values, and the solid line represents the median. Significant difference between fenced and grazed communities are indicated by symbols as follows: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$; ns (no significant difference).

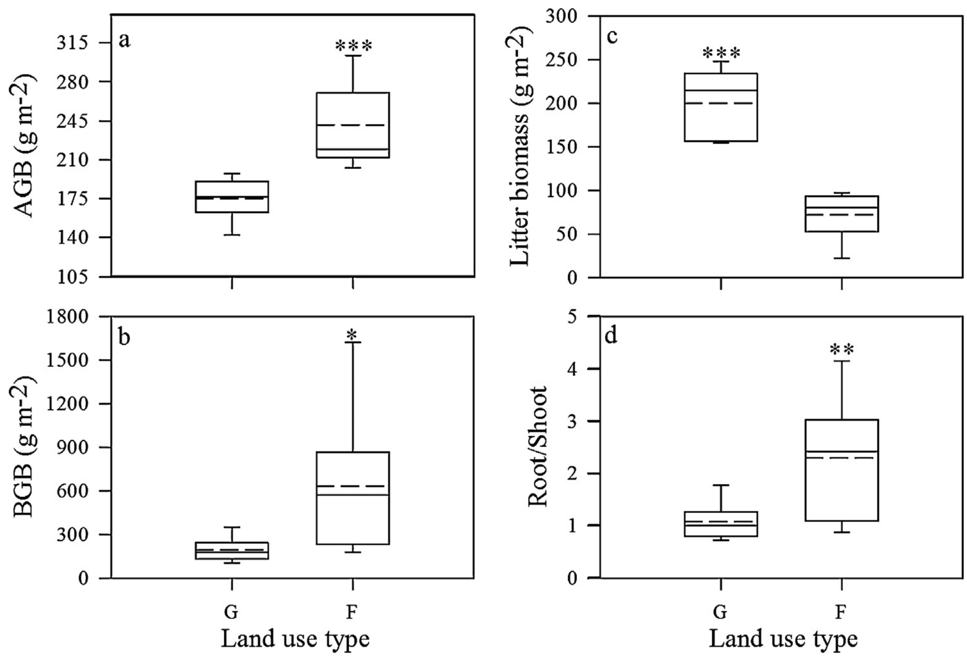

Fig. 3. Effects of fencing (F) and grazing (G) on above-ground biomass (a), below-ground biomass (b), litter biomass (c) and root/shoot ratio (d) of the arid or semi-arid grassland community. Box plot key: the median 10th, 25th, 75th, 95th percentiles are plotted as vertical boxes with error bars, the dotted line represents mean values, and the solid line represents the median. Significant differences between fenced and grazed communities are indicated by symbols as follows: *** $P<0.001$, ** $P<0.01$, * $P<0.05$; ns (no significant difference).

properties between fenced and grazed communities to assess the effects of grazing exclusion on above- and below-ground properties. Two-way ANOVA was performed to test the differences in land use type, soil layers and their interaction of soil layer and land use type. Significant differences were evaluated at the 0.05 level. When significance was observed at the $P<0.05$ level, the least significant difference (LSD) post hoc test was used to perform the multiple comparisons. Pearson's test was adopted to determine whether there were significant correlations between soil chemical properties and soil physical properties. All of the statistical analyses were performed using the SPSS software program, ver. 22.0 (SPSS Inc., Chicago, IL, USA). In addition, all processed data were converted into images using the SigmaPlot software program, ver. 12.5 (2011; Systat Software, Inc., leadtools, dundas software ltd., wpcubed GmbH, Germany, TE Sub Systems, Inc., and Sax Software).

3. Results

3.1. Coverage, height, plant density and diversity

Compared with grazed communities, fenced communities exhibited significantly greater coverage ($P<0.001$), height ($P<0.001$) and richness index (R) (Fig. 2a, b and d). Generally, fencing increased coverage and height (39.64% and 330.99%, respectively) compared with grazed communities. However, plant density ($P>0.05$), H ($P>0.05$) and E ($P>0.05$) were not significant (Fig. 2c, e and f).

3.2. Biomass, function group and life history

The above-ground biomass (AGB) ($P<0.001$), the below-ground biomass (BGB) ($P<0.05$) and root/shoot (R/S) ratio ($P<0.01$) in fenced communities were significantly greater. However, the litter biomass ($P<0.001$) was significantly decreased (Fig. 3). Specifically, above-ground biomass increased by 38.01%, below-ground biomass increased by 227.06%, R/S increased by 111.45% and the litter biomass decreased by 175.85% in fenced communities compared with grazed communities, and below-ground biomass increased mainly due to the BGB was significantly higher in the 0–20 cm soil depth (Fig. 7).

ANOVA analyses indicate tha fenced communities had higher grasses ($P<0.01$) and lower forbs ($P<0.01$) than grazed communities (Fig. 4a and b). However, leguminous plants displayed no significant differences between fenced communities and grazed communities ($P>0.05$) (Fig. 4c). The proportion of grass biomass in fenced communities and the proportion of forb biomass in grazed communities accounted for approximately half of the total biomass (Fig. 4a and b).

The annuals in fenced communities ($P<0.05$) (Fig. 4d) were significantly less than those in grazed communities. However, the results for perennials ($P<0.05$) were reverse (Fig. 4e).

3.3. Soil chemical properties

ANOVA analyses indicated that fenced communities had significantly increased soil organic carbon (SOC) ($P<0.01$), total nitrogen (TN) ($P<0.05$) and nitrate nitrogen (NN) ($P<0.05$) in the 0–30 cm soil depth (Fig. 5a, b and e). However, SOC ($P<0.001$) and TN ($P<0.05$) significantly decreased in the 30–50 cm soil depth compared with grazed communities (Fig. 5a and b). Total phosphorus (TP) ($P<0.05$) in fenced communities was significantly greater than in grazed communities in all soil depths (Fig. 5c). Ammonium nitrogen (AN) ($P<0.05$) was significantly greater in fenced communities in the 0–10 cm soil depth (Fig. 5d). Soil C/N ($P<0.05$) in fenced communities was significantly greater in the 0–5 cm soil depth (Fig. 5f).

3.4. Soil particles

ANOVA analyses revealed that fenced communities had significantly increased silt ($P<0.05$) in the 0–30 cm soil depth, but decreased silt ($P<0.05$) in the 50–100 cm soil depth (Fig. 6b). Although it was not significant in the 20–30 cm soil depth, clay also

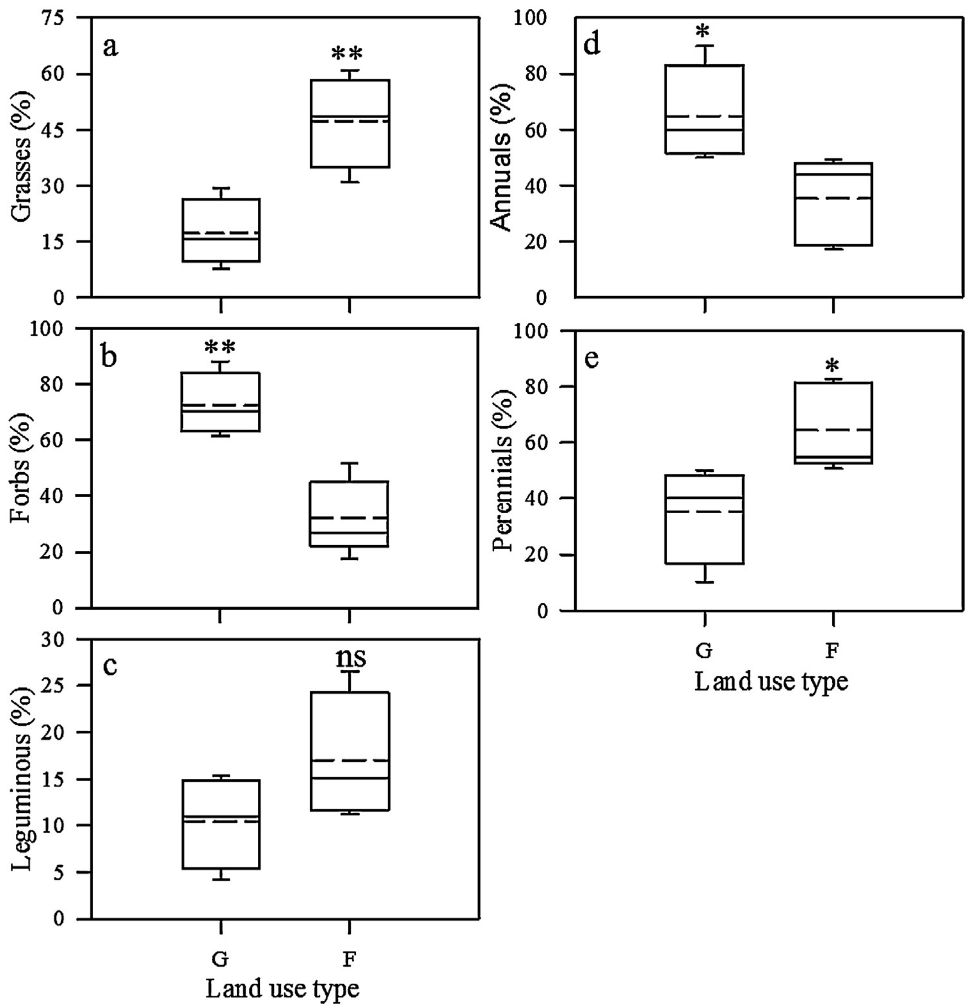

Fig. 4. Effects of fencing (F) and grazing (*G*) on grass species group (a), forb species group (b), legume species group (c), annuals (d) and perennials (e) of the arid or semiarid grassland community. The values are the ratios of above-ground biomass in each functional group and life history. Box plot key: the median 10th, 25th, 75th, 95th percentiles are plotted as vertical boxes with error bars, the dotted line represents mean values, and the solid line represents the median. Significant differences between fenced and grazed communities are indicated by symbols as follows: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$; ns (no significant difference).

followed this trend (Fig. 6a). However, the result for sand was the reverse. Fenced communities had significantly less sand ($P < 0.05$) in the 0–30 cm soil depth and more sand ($P < 0.05$) in the 50–100 cm soil depth (Fig. 6c).

4. Discussion

4.1. Effects of land use type, soil layer and their interaction on soil properties and BGB

In Our study, SOC, TN, NN, clay, silt, sand and BGB were significantly affected by land use type, soil layer and their interaction of land use type and soil layer (Table 1). However, AN was affected by only land use type, and only TP was not affected by their interaction of land use type and soil layer. Wei et al. (2009) demonstrated no significant difference in TP in the soil layer, and their results for AN were similar to ours The decline of soil TP is caused primarily by the plants consuming too much.(Wei et al., 2009). According to other reasearch, AN primarily aggregates and is more prevalent in the surface soil than in deep layers (Xue et al., 2013), and our results also indicated this phenomenon (Fig. 5d). AN strongly adsorbs onto soil particle surfaces or is fixed by soil mineral substances (Xue et al., 2013). Perhaps for this reason, AN was not affected by the soil layer. The determination of the vertical distribution mechanism of TP and AN in the soil is an important goal of our future research.

4.2. Effects of fencing on plant diversity and productivity, and soil particles

As in many other studies (Zhao et al., 2007; Zuo et al., 2009; Miao et al., 2015), our results suggest a positive effect of grazing exclusions on coverage, richness, height, aboveground biomass (AGB) and belowground biomass (BGB). Medina-Roldán et al. (2012) documented that this outcome may result from the bite effect of grazing livestock. In addition, compared with the results from Deng et al. (2014b), our study indicates lower plant density in fenced communities. Perhaps these short-term fenced communities do not represent a climax community, and its interspecific competition has not intensified. Wu et al. (2009) reported that long-term fencing decreased species diversity. And Deng et al. (2014a) have reported that peak species richness appeared under moderate and light grazing but not long-term fenced grassland. In long-term fenced communities, the plant community may be mature, and competition for light and nutrients may be more intense than in fenced communities that we studied (Grime, 1998; Van der Wal et al., 2004). In other studies, grazing results in increases in unpalatable

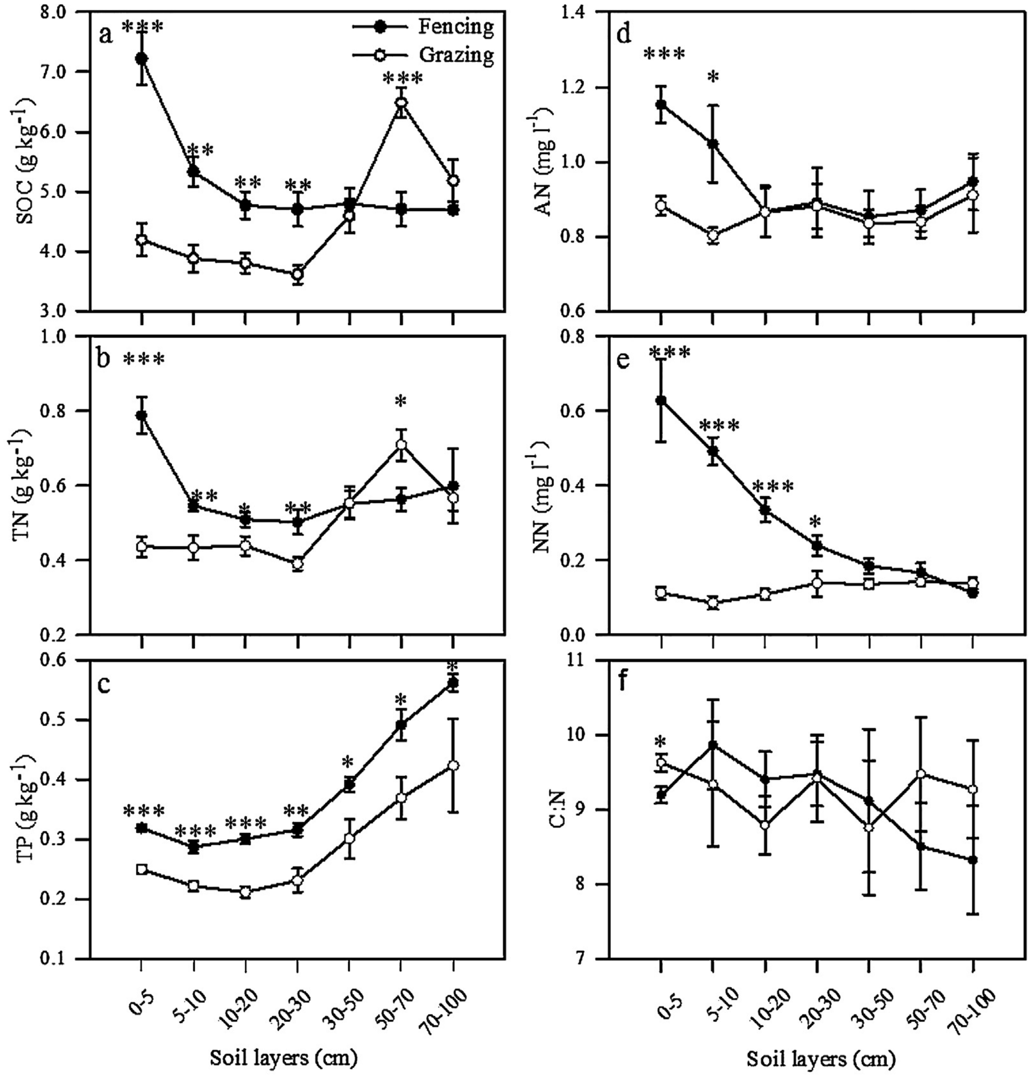

Fig. 5. Effect of fencing (F) and grazing (*G*) on soil organic carbon (SOC) (a), soil total nitrogen (TN) (b), soil total phosphorus (TP) (c), ammonium nitrogen (AN) (d) and nitrate nitrogen (NN) (e) of the arid or semiarid grassland community. The values are mean ± SE. Significant differences between fenced and grazed communities are indicated by symbols as follows: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

plants (Díaz et al., 2007; Deng et al., 2014a, 2014b). As is known, most unpalatable plants are forb species. Thus, the results of those studies agree with our results. However, few studies have analyzed palatability (Landsberg et al., 2002; Vesk et al., 2004), primarily because of bias in meta-analyses. In addition, the results of our study are different from Deng et al. (2014b), as we discovered that *R*/*S* in fenced communities was significantly greater than in grazed communities. This result suggests that plants allocate more to BGB than AGB to capture water resources and soil nutrients for optimal growth during severe droughts and to counter water erosion and environmental degradation in fenced communities (Ma et al., 2010; Wei et al., 2015). Annuals were increased by grazing pressure (Díaz et al., 2007). In addition, the seasonal and annual dynamics of climatic conditions result in animals causing greater damage to underground plant parts than to above-ground plant parts. Consequently, to state that grazing increases the below-ground biomass allocation ratio is inaccurate (Sun et al., 2014). Grazing requires suitable environmental conditions and appropriate grazing pressure.

Fencing has positive effects on soil particle size distribution. Su et al. (2004) found that in grazed communities, the proportion of annuals reached 70%, which was coupled with lower productivity. Thus, ground surfaces were left bare and directly exposed to strong soil and wind erosion (Su et al., 2004), which increased sand and decreased silt and clay. Additionally, previous studies demonstrated that clay and silt had a significant positive correlation with SOC, TP and TN in grassland, whereby sand was exhibited the opposite trend (Cao et al., 2013), particularly in highly productive land (Bronick and Lal, 2005). However, our results reveal that SOC and TN were related to only soil particles in grazed communities (Table 2). Fenced communities involve too many biological and chemical factors, which may be the reason SOC and TN were not related. Soil texture, cations and microbial activity also influence soil particle size distribution (Bronick and Lal, 2005; Ehrlich et al., 2015), However, in the Loess Plateau, the determinants of soil particle size distribution require additional study.

4.3. Effects of fencing on soil chemical properties

Fencing also significantly affects soil chemical properties, and increases soil nutrient content (e.g., SOC, TN, the C:N ratio, available P) (Wang et al., 2006). Our results also indicated that fencing management significantly increased SOC, TN TP, AN and NN in the surface soil. The same trend was apparent with respect to the soil particle size distribution. Wang et al. (2014a) observed no changes in TN in any of the investigated soil layers. Their result does

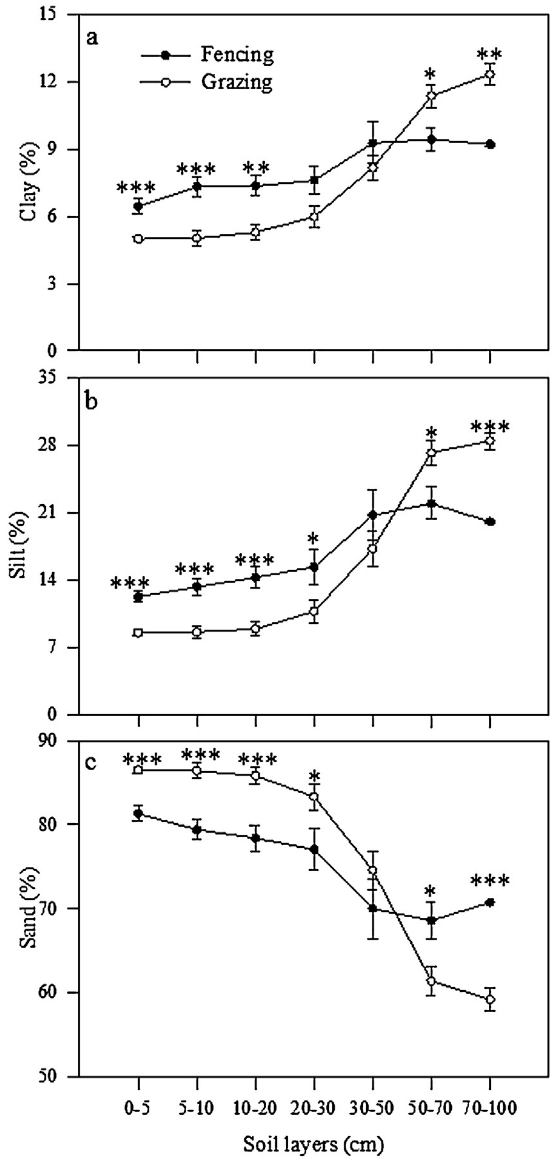

Fig. 6. Effect of fencing (F) and grazing (*G*) on clay (a), silt (b) and sand (c) of the arid or semiarid grassland community. The values are mean ± SE. Significant differences between fenced and grazed communities are indicated by symbols as follows: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

not agree with ours. The primary reason the lack of TN changes observed by Wang et al. (2014a) is that plants allocate more to AGB than BGB, and the N input is less than the N output in grazed communities (Medina-Roldán et al., 2012; Shang et al., 2012). In addition, our results indicated a significantly greater presence of SOC and TN at the 50–70 cm soil depth in grazed communities, according to Fig. 7 we speculated that below-ground biomass is the main reason. Fig. 7 shows that the SOC and TN distribution trend in the 0–100 cm soil depth was broadly consistent to some extent. However, Wang et al. (2014a) did not observe a similar trend. The relationship between SOC and TN needs further research. Several studies demonstrated that fenced communities had less TP than grazied communities in deeper soils (50–100 cm) ($P < 0.05$) (Deng et al., 2014b). However, our results indicated that fenced communities have significantly more TP than grazied communities in all soil depths. This phenomenon may have occurred because the heavy soil P eluviation and root biomass exhibited no significant differences in deep soils when fenced communities and grazed communities were compared.

Table 1
Two-way ANOVA results for the effects of land use type, soil layer and their interaction of grassland type and the soil layer on soil chemical properties, soil particle size and below-ground biomass on the Loess Plateau.

Soil properties	Variance Source	Land use type	Soil layer	Land use type × Soil layer
SOC	Degree of freedom	1.000	6.000	6.000
	F value	25.486	10.571	15.406
	P-value	0.000^{***}	0.000^{***}	0.000^{***}
TN	Degree of freedom	1.000	6.000	6.000
	F value	16.902	9.624	10.958
	P-value	0.000^{***}	0.000^{***}	0.000^{***}
TP	Degree of freedom	1.000	6.000	6.000
	F value	63.337	29.778	0.648
	P-value	0.000^{***}	0.000^{***}	0.692
AN	Degree of freedom	1.000	6.000	6.000
	F value	5.835	1.818	2.003
	P-value	0.018^{*}	0.103	0.072
NN	Degree of freedom	1.000	6.000	6.000
	F value	94.756	8.547	12.550
	P-value	0.000^{***}	0.000^{***}	0.000^{***}
Clay	Degree of freedom	1.000	6.000	6.000
	F value	10.667	32.709	5.699
	P-value	0.001^{**}	0.000^{***}	0.000^{***}
Silt	Degree of freedom	1.000	6.000	6.000
	F value	8.588	40.098	5.423
	P-value	0.004^{**}	0.000^{***}	0.000^{***}
Sand	Degree of freedom	1.000	6.000	6.000
	F value	9.382	39.209	5.643
	P-value	0.003^{**}	0.000^{***}	0.000^{***}
BGB	Degree of freedom	1.000	6.000	6.000
	F value	17.087	3.352	3.890
	P-value	0.000^{***}	0.005^{**}	0.002^{**}

Significant differences are indicated by symbols as follows: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

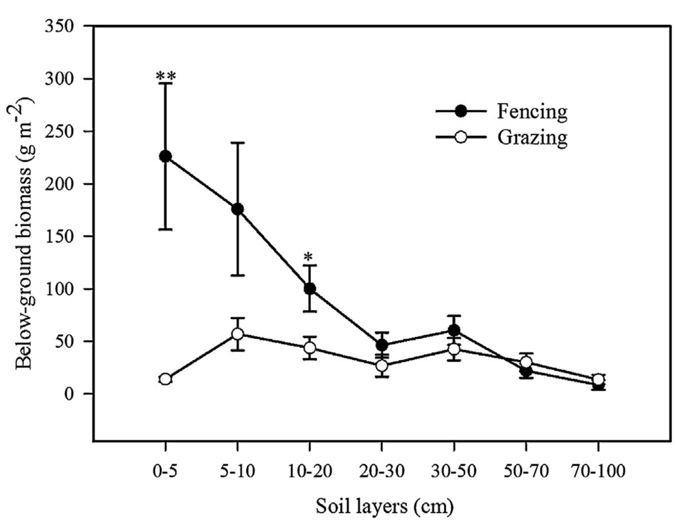

Fig. 7. Effect of fencing (F) and grazing (*G*) on below-ground biomass of the arid or semi-arid grassland community. The values are mean ± SE. Significant differences between fenced and grazed communities are indicated by symbols as follows: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

NN moves with the flow of water (Liu et al., 2013). Thus, during August, soil physical properties such as soil and water conservation of fenced communities were in better condition than grazed communities on the Loess Plateau. AN easily volatilizes in alkaline

Table 2
Correlations between soil particle size and soil chemical properties and correlations between soil total nitrogen, and ammonia nitrogen and nitrate nitrogen.

Soil properties	Soil layers (cm)	Clay		Silt		Sand		TN	
		F	*G*	*F*	*G*	*F*	*G*	*F*	*G*
SOC	0–5	0.926**	0.923**	0.866**	0.605	−0.898**	−0.718*		
	5–10	0.364	0.631	0.268	0.590	−0.302	−0.612		
	10–20	0.374	0.401	0.396	0.433	−0.392	−0.440		
	20–30	0.464	0.181	0.430	0.295	−0.441	−0.266		
	30–50	0.392	0.148	0.306	0.162	−0.330	−0.160		
	50–70	0.434	−0.069	0.381	0.113	−0.398	−0.063		
	70–100	–	−0.337	–	−0.074	–	0.180		
	All	−0.036	0.637**	−0.099	.684**	0.085	−0.674**		
TN	0–5	0.905**	0.962**	0.888**	0.677*	−0.904**	−0.783*		
	5–10	−0.137	−0.019	−0.001	−0.093	0.048	0.069		
	10–20	0.011	0.265	0.046	0.091	−0.036	−0.154		
	20–30	0.092	0.110	0.174	0.183	−0.154	−0.165		
	30–50	−0.591	−0.241	−0.494	−0.301	0.523	0.290		
	50–70	−0.014	−0.610	0.142	−0.399	−0.107	0.474		
	70–100	−0.577	−0.636	0.833**	−0.240	−0.289	0.408		
	All	−0.194	0.542**	−0.148	0.582**	0.161	−0.574**		
TP	0–5	0.835**	0.970**	0.827**	0.693*	−0.839**	−0.798**		
	5–10	0.443	−0.120	0.563	−0.234	−0.525	0.199		
	10–20	0.638	−0.177	0.551	−0.247	−0.580	0.234		
	20–30	0.187	−0.230	0.030	−0.302	−0.071	0.286		
	30–50	−0.512	−0.812**	−0.688*	−0.908**	0.649	0.894**		
	50–70	−0.209	−0.319	−0.150	−0.909**	0.165	0.477		
	70–100	0.214	0.566	−0.125	−0.910**	−0.485	−0.534		
	All	0.412**	0.624**	0.462**	0.581**	−0.453**	−0.594**		
NN	0–5	0.985**	0.879**	0.926**	0.860**	−0.961**	−0.897**	0.910**	0.825**
	5–10	0.084	0.772*	0.083	0.642	−0.083	−0.694*	0.488	0.167
	10–20	0.060	0.417	−0.018	0.131	−0.005	−0.234	−0.340	0.356
	20–30	0.283	.850**	0.155	0.862**	−0.189	−0.870**	0.183	0.125
	30–50	0.301	0.204	0.320	0.194	−0.318	−0.198	−0.543	−0.611
	50–70	−0.307	0.500	−0.451	0.385	0.422	−0.431	0.017	−0.790*
	70–100	–	0.482	–	0.383	–	−0.447	–	−0.266
	All	−0.254	0.392**	−0.358**	0.349**	0.335*	−0.362**	0.494**	0.136
AN	0–5	0.873**	0.933**	0.840**	0.693*	−0.862**	−0.787*	0.983**	0.908**
	5–10	0.090	0.323	0.211	0.253	−0.172	−0.280	0.108	0.229
	10–20	0.125	−0.259	0.013	−0.028	−0.045	0.108	0.072	0.079
	20–30	0.207	−0.399	0.156	−0.168	−0.170	0.235	−0.202	0.084
	30–50	−0.009	−0.288	0.118	−0.268	−0.087	0.275	0.202	−0.007
	50–70	0.156	0.455	0.307	0.481	−0.274	−0.489	−0.355	−0.140
	70–100	−0.746*	−0.059	0.309	0.147	−0.747*	−0.079	0.309	−0.146
	All	−0.089	0.002	−0.094	0.031	0.094	−0.023	0.345**	0.006

* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

soils, and fencing results in marked decreases in soil pH (Deng et al., 2014b; Li et al., 2014). Grazing results in greater soil aeration but also nitrogen leaching loss. In addition, AN was affected by only grassland type (Table 1). All of these factors resulted in high AN in fenced communities..

4.4. *Relationships between among soil chemical properties and soil particles*

Regardless of land use type, our results showed a significant positive correlation between soil chemical properties (SOC, TN, TP, NN, AN) and soil particles (silt and clay) in the 0–5 cm soil depth (Table 2). TP also exhibited this trend in all 0–100 cm soil depths. However, the result for sand was the opposite. In addition, SOC and TN had a significant positive correlation with soil particles (silt and clay) in all 0–100 cm soil depths in grazed communities, whereas the result for sand was the opposite. Compared with fenced communities, soil aeration and nitrogen leaching loss were greater in grazed communities. Perhaps for this reason, NN exhibited a significant positive correlation with soil particles (silt and clay) and a significant negative correlation with sand at all soil depths in grazed communities, whereas NN exhibited the opposite trend in fenced communities. AN is available nitrogen and easily absorbed by plants. Additionally, AN can convert into NN under good soil aeration conditions. Therefore, in both fenced communities and grazed communities, AN was unrelated to soil particles. In addition, AN and NN were related to TN, and there was a significant positive correlation at the 0–5 cm soil depth for both land use types (Table 2). Moreover, becaues of low nitrogen leaching in fenced communities, AN and NN exhibited a significant positive correlation with TN at all soil depths in fenced communities.

5. Conclusion

Fencing significantly increased plant coverage, height, richness index, above- and below-ground biomass, root/shoot ratio, grasses and perennials, whereas litter biomass, forbs and annuals significantly decreased after short-term fencing. Short-term fencing also resulted in marked increases in ammonium nitrogen (AN) in the 0–10 cm soil depth, SOC, TN, nitrate nitrogen (NN), clay and silt in the 0–30 cm soil depth and soil total phosphorus (TP) in the 0–100 cm soil depth and. In addition, fencing displayed a significant correlation between soil chemical properties (SOC, TN, TP, NN, AN) and soil particles (silt, clay and sand) in 0–5 cm soil depth.

Consequently, fencing is an effective measure that can result in ecological benefits. The question of how to manage the grassland when the ecosystem has been restored to a certain extent will be the focus of our future research.

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