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Soil properties and species composition under different grazing intensity in an alpine meadow on the eastern Tibetan Plateau, China

Zhen'an Yang · Wan Xiong · Yingyi Xu · Lin Jiang · Erxiong Zhu · Wei Zhan · Yixin He · Dan Zhu · Qiuan Zhu · Changhui Peng · Huai Chen

Abstract As the main form of land use and human disturbance of grassland, livestock grazing has great influences on the soil resources and plant communities. This study observed the variation of soil properties and community characteristics of four treatments of different grazing intensity (no grazing, UG; light grazing, LG; moderate grazing, MG; and heavy grazing, HG) in an alpine meadow of Sichuan Province on the northeastern margin of the Tibetan Plateau. The results showed that grazing increased the pH, soil bulk density (BD), and contents of total carbon (TC) and total nitrogen (TN), and the BD increased while the others decreased with the grazing intensity. At the community level, with the increase of the grazing intensity, the vegetation coverage ($R^2 = 0.61$, $P < 0.001$), mean height of community ($R^2 = 0.37$, $P < 0.001$), aboveground biomass ($R^2 = 0.54$, $P < 0.001$), litter biomass ($R^2 = 0.84$, $P < 0.001$), and percentage of aboveground biomass of palatable grasses to total biomass ($R^2 = 0.74$, $P < 0.001$) significantly decreased, while the belowground biomass ($R^2 = 0.72$, $P < 0.001$) and the root/shoot (R/S) ratio ($R^2 = 0.65$, $P < 0.001$) increased. The species richness was the greatest at LG and the total biomass at UG. With grazing, the dominant species of the plant community shifted from palatable grasses (Gramineae and Cyperaceae) to unpalatable grasses (Compositae and Ranunculaceae). Based on the results, LG may be the optimal grassland management mode to be used in the long time in the alpine meadow of the Tibetan Plateau.

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Introduction

Nearly 25% of the world's land surface is occupied by grassland (Scurlock and Hall 1998), which was used in ways such as grazing (Luo et al. 2009; Zhou et al. 2006), enclosure (Ma et al. 2015), reclamation (Santoso et al. 1997), and other modern management (e.g., use of

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fertilizers, reseeding) (Clare et al. 2004). As its main form of land use (Luo et al. 2009) and human disturbance (Zhou et al. 2006), livestock grazing has a great influence on the soil resources and plant community of grassland (Deng et al. 2014b). Grazing has been found to influence the physical, chemical, and biological properties of soil (Altesor et al. 2006; Steffens et al. 2008; Zhu et al. 2016; Su et al. 2004). The direct result of livestock trampling includes destruction of soil structure (Su et al. 2005; Deng et al. 2014b) and reduction of infiltration rates and porosity of soil (Wu et al. 2010). The soil nutrient cycling and storage are affected through nutrient input and release (Cui et al. 2005), such as urine and feces directly inputted in the system (Bai et al. 2012; An and Li 2015). In addition, grazing also affects the microbial structure, enzyme activities (Su et al. 2004), and microbial activities (An and Li 2015) in the soil. The grassland community is found to be changed by grazing (Altesor et al. 2006) through selective defoliation, trampling, and excreta deposition (Wrage et al. 2012; Jerrentrup et al. 2015). Such change is mainly in terms of its structure and function (Altesor et al. 2005; Luo et al. 2012). Structurally, grazing modifies the species composition, richness, vertical profiles, plant traits, and a number of other attributes of grasslands. And functionally, grazing alters the flow of energy and the cycling of materials (Altesor et al. 2005; Pineiro et al. 2006). Abundant evidence demonstrates that the bite effect of grazing livestock reduces the vegetation coverage and the height of community (Medina-Roldán et al. 2012; Zhu et al. 2016). The influence of grazing on the plant community lies in two ways, i.e., the direct impact through diet preference and trampling of livestock on plant's survival, growth, and fecundity and the indirect one by altering the intraspecific and interspecific interactions or the water and nutrient availability (Wan et al. 2010). The response of the aboveground and belowground biomass allocation to grazing, however, is unclear, because the strategies of allocation in plant under grazing are very controversial (Yang et al. 2009; Gao et al. 2007; An and Li 2015), which led to observation results of decreased belowground biomass (Deng et al. 2014a) and also increased ones (Gao et al. 2007) related to grazing.

Compared with grazing exclusion, slight and moderate grazing is generally believed to be beneficial for biodiversity and aboveground biomass production of grassland ecosystems (Cui et al. 2005). However, overgrazing is one of main causes of grassland desertification (Deng et al. 2014a; Su et al. 2005; Wu et al. 2009), including desertification of soil properties (chemical and physical) and negative effects of vegetation, including reduction in biomass, vegetation coverage, and species diversity and increase in undesirable vegetation (Deng et al. 2014a; Zhu et al. 2016). Grazing prohibition (exclusion) or fencing is the common grassland management to reverse desertification grassland throughout the world in recent decades (Deng et al. 2014b; Deng et al. 2014a; Ma et al. 2015; Wu et al. 2009), and Feng et al. (2010) founded that *Elymus natans* establishment is an effective and applicable measure in restoring heavily degraded alpine meadow in the region of the Qinghai-Tibetan Plateau through 3-and 7-year-old *E. natans* re-vegetated grasslands.

As the third pole of the Earth (average elevation 4000 m a.s.l.), the Tibetan Plateau is the largest plateau in the world covering an area of about 2.5 million km^2 in China (Chen et al. 2014; Zhang et al. 2016). The dominant vegetation type in this region is the alpine meadow which occupies more than 40% of grassland on the plateau and provides fundamental sources of livelihood for local residents and ecosystem services (Zhang et al. 2016). However, the alpine meadow has been deteriorating recently, resulting in serious social and ecological problems (Zhang et al. 2016; Zhou et al. 2006). Previous studies of different grazing intensities showed that increased grazing intensity tends to increase biomass allocation of belowground and a potential to increase the ecosystem pool of plant N (Gao et al. 2007), that long-time grazing may cause the degradation of alpine meadow, and that moderate grazing may be desirable for plant communities in the Tibetan Plateau (Zhou et al. 2006). Currently, 4.67×10^6 hm^2 alpine meadow is degraded, accounting for 25% of the total area of this region and approximately half of the total alpine grassland (Dong et al. 2013). In terms of vegetation recovery and soil property improvement for the alpine meadow, livestock exclusion or fencing rather than grazing was found to be beneficial, which changes the biomass and soil properties to the better (Shi et al. 2010; Ma et al. 2015; Wu et al. 2009). The lightly and moderately degraded alpine meadow was found to recover by being kept away from disturbance, whereas the heavily and extremely heavily degraded alpine meadow requires artificial and semi-artificial grassland establishment for ecosystem restoration (Dong et al. 2013; Feng et al. 2010).

Recent research of alpine meadow in the Tibetan Plateau has focused on the effects of grazing vegetation (coverage, height, biomass, species richness, species diversity, species composition, etc.) or soil properties (physical, chemical, and biological) (Dong et al. 2013;

Gao et al. 2007; Ma et al. 2015; Shi et al. 2010; Zhou et al. 2006). Few studies explored the effects of grazing intensity both on soil and plant through the community shift. With the hypothesis that optimal grazing is beneficial for both soil properties and vegetation of alpine meadow in the Tibetan Plateau, this study aimed to (i) evaluate the effects of the grazing intensity on soil dynamics and (ii) analyze the community characteristics and community composition with different grazing intensities in the Tibetan Plateau. Based on the results, the variation of soil properties, community characteristics, and community composition of four different grazing intensity treatments would be assessed and the optimal management of alpine meadow in the Tibetan Plateau could be drawn for better maintenance and improvement of soil properties and the plant community.

Materials and methods

Study site

The study area is located in an alpine meadow in Hongyuan County, in the northwest region of Sichuan Province and on the northeastern margin of the Tibetan Plateau, China (34°54′ N, 102°06′ E, and 3480 m a.s.l.) (Fig. 1). For the past three decades, its mean annual temperature was 0.9 °C, with mean monthly temperature ranging from −10.3 °C (January) to 10.9 °C (July), and the precipitation fluctuates greatly among years, averaging about 690 mm each year, with 80% occurring during the growing season (May to August) (Shi et al. 2015). The area is characterized by alpine meadow soil (Chinese classification). The typical alpine meadow is dominated by Gramineae (*Elymus nutans* Griseb., *Deschampsia caespitosa* (L.) Beauv., *Festuca ovina* L., *Koeleria cristata* (L.) Pers.), Cyperaceae (*Carex enervis* C. A. Mey., *Scirpus distigmaticus* (Kukenth.) Tang et Wang), Compositae (*Anaphalis lactea* Maxim., *Saussurea nigrescens* Maxim., *Leontopodium leontopodioides* (Willd.) Beauv.) and Ranunculaceae (*Ranunculus tanguticus* (Maxim.) Ovcz., *Anemone trullifolia* Hook. f. et Thoms. var. *linearis* (Brühl) Hand.-Mazz, and *Anemone rivularis* Buch.-Ham. ex DC. var. *flore-minore* Maxim.) species. The vegetation has a mean coverage of 95% and a height of 10 cm.

Experimental design

We designed four different grazing intensity treatments (no grazing, UG; light grazing, LG; moderate grazing,

Fig. 1 Location of study area in the Tibetan Plateau
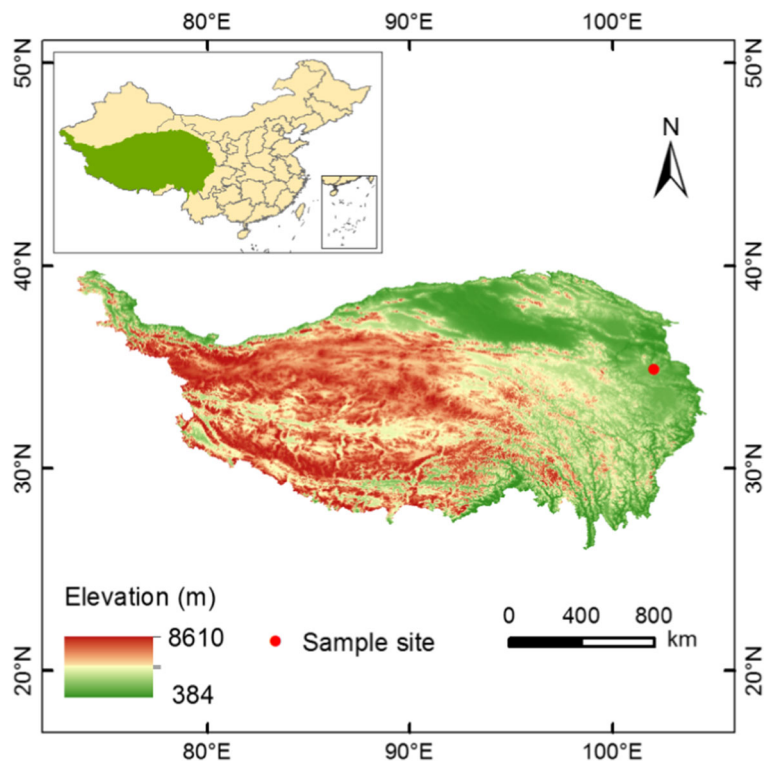
MG; and heavy grazing, HG), based on factors including acreage, aboveground biomass, theoretical intakes of yak, and grazing time. The area of UG was 1.6 hm^2, that of LG 4.2 hm^2, that of MG 2.5 hm^2, and that of HG 1.9 hm^2; the grazing intensity was 0, 0.7, 1.2, and 1.6 yaks hm^{-2}, respectively (Table 1). The yaks grazed in the corresponding experiment plots from May to October 2010–2015.

Each treatment area except for UG had three replicates; each replicate included three plots of 1 m × 1 m at least 20 m away from each other. For UG, nine plots (1 m × 1 m) at least 10 m from each other were randomly selected, every three plots being regarded as a replicate. Altogether, the experiment included 36 plots of 1 m × 1 m, which were all set in July 2015 when the aboveground biomass peaked. The plants in every plot were identified by morphology and later taxonomy. The vegetation coverage was measured by visually recording the grids and the height of 5–10 individuals of each species in each plot.

Biomass and importance value computation

For each plot, quadrates of 50 cm × 50 cm were randomly selected to investigate the aboveground biomass and the litter of the community, which were defined as the green part and all the other parts of the aboveground, respectively. For the same quadrates, belowground biomass was taken from 0- to 30-cm depths (with 90% of roots) by a soil core (4 cm in diameter). The aboveground and belowground parts as well as the litter were dried to constant weight at 60 °C. The belowground biomass (BB) was calculated as

$$BB\left(g\,m^{-2}\right) = DR(g)\Big/\left[\pi\left(d/2\right)^2\right] \times 10^{-4} cm^2 \quad (1)$$

where DR is the dry weight of roots in each soil core and d is 4.

The percentage of aboveground biomass of palatable grasses to total biomass (PPG) was calculated as

$$PPG(\%) = ABP\Big/TAB \quad (2)$$

where PPG is the aboveground biomass of Gramineae and Cyperaceae species and TAB is the total biomass of all species in the quadrate (Wu et al. 2009).

The root shoot ratio (R/S) was calculated as

$$R\Big/S = BB\Big/(AB + LB) \quad (3)$$

where BB is the belowground biomass, AB is the aboveground biomass, and LB is the litter biomass.

The importance value (IV) per family was calculated as

$$IV(\%) = (RH + RC + RB)\Big/3 \quad (4)$$

where RH is the relative height (RH = height of one family / total height of all vegetation), RC is the relative coverage (RC = coverage of one family / total coverage of all vegetation), and RB is the relative aboveground biomass (RB = aboveground biomass of one family / total aboveground biomass of all vegetation).

Soil sampling and determination

For each plot, two soil samples were taken from 0 to 10 cm depth by a soil core (4 cm in diameter). The fresh soil samples were sieved through a 2-mm mesh and air dried. Then, the air-dried samples were divided into two parts, one passed through a 0.25-mm mesh for pH and the other through a 0.15-mm mesh for determination of total carbon (TC), total nitrogen (TN), and total phosphorus (TP).

After the soil was dried at 105 °C, the bulk density (BD, g cm^{-3}) was measured by a soil bulk sampler (5 cm in diameter and 5 cm in height) as Mora and Lázaro (2014) described. Soil pH was measured by an acidity

Table 1 The study design

Grazing intensity		Number of yaks (yaks)	Treatment area (ha)	Stocking rate (yaks ha^{-1})
No grazing	(UG)	0	1.6	0
Light grazing	(LG)	3	4.2	0.7
Moderate grazing	(MG)	3	2.5	1.2
Heavy grazing	(HG)	3	1.9	1.6

meter (Sartorius PB-10, Gemany), with the ratio of air-dried soil and water as 1:5 (Lee et al. 2012). Soil TC content was determined by the Elementar Liqui II TOC (Elementar, Germany). Soil TN and TP contents were determined by the Kjeldahl method with an Kjeldahl analyzer (Kjeltec 8400, FOSS, Sweden) and colorimetrically after digestion with H_2SO_4 and $HClO_4$ by the molybdenum blue method (Li et al. 2013). The contents of TC, TN, and TP were converted into content in per unit soil dry weight.

Statistical analysis

All statistical (soil pH, bulk density, total carbon, total nitrogen, total phosphorus, coverage, mean height of community, species richness, aboveground, litter, belowground and total biomass, percentage of aboveground biomass of palatable grasses to total aboveground biomass, root/shoot ratio, importance value of each family, family number, and species number) tests were performed with StatGraphics 3.0 (STN, St. Louis, MO, USA) and analyzed by one-way (grazing intensity) ANOVA after the data were tested for normality. All P values of these multi-comparisons were corrected by the

Tukey HSD test. All data were expressed as mean ± standard error (SE). Differences between means were considered significant when the P value of the ANOVA F test was less than 0.05.

Results

Variation in soil physicochemical properties

The pH, content of TC and TN was lower in the UG than in the grazing meadow and decreased with the increase of grazing intensity (Fig. 2a, 2c and 2d). No significant difference of pH (Fig. 2a), BD (Fig. 2b), content of TC (Fig. 2c), TN (Fig. 2d) and TP (Fig. 2e) was found among treatments of different grazing intensity. The BD was significantly higher in treatments of greater grazing intensity ($P < 0.05$, Fig. 2b, Table S1). The soil TP content was nearly equal among all treatments (between 1.08 and 1.15 g kg^{-1}) (Fig. 2e). Correlation analysis indicated a significant negative correlation between TC and BD ($R^2 = 0.303$, $P = 0.037$) and a significant positive correlation between TC and TN ($R^2 = 0.356$, $P = 0.024$) (Table 2).

Fig. 2 Soil physical-chemical properties measured in the 0–10-cm soil layer. (a) pH; (b) soil bulk density; (c) total carbon; (d) total nitrogen; (e) total phosphorus. Data are means ± SE ($n = 3$). *Different letters on the bars* indicate variations significant at 0.05 level. P values of the ANOVAs of grazing intensity (P_G) are indicated as *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns* not significant
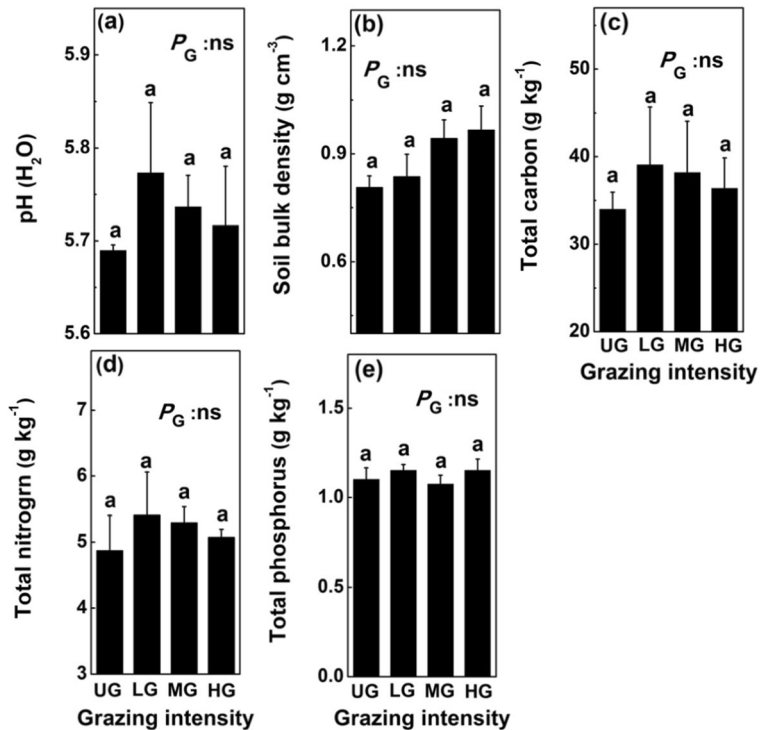
Table 2 Pearson correlation coefficients among soil physical-chemical properties at the 0–10-cm depth

	Soil properties (0–10 cm)			
	pH (H$_2$O)	Bulk density (g cm^{-3})	TC (g kg^{-1})	TN (g kg^{-1})
Bulk density (g cm^{-3})	$R^2 = -0.057$			
TC (g kg^{-1})	$R^2 = -0.076$	$R^2 = -0.303^*$		
TN (g kg^{-1})	$R^2 = -0.096$	$R^2 = -0.002$	$R^2 = 0.356^*$	
TP (g kg^{-1})	$R^2 = -0.097$	$R^2 = -0.100$	$R^2 = -0.083$	$R^2 = -0.051$

* means $P < 0.05$

Variation in community characteristics

At the plant community level, the vegetation coverage (Fig. 3a) and the mean height of community (Fig. 3b) decreased significantly with the grazing intensity ($P < 0.001$, Table 3). Species richness decreased with the order of LG > UG > MG > HG (Fig. 3c). No significant difference of species richness (Table 3) was found among the grazing intensities.

At the plant population level, species composition was found to be quite different among the four grazing intensities, with the most species in LG (57.67) and the least species (50) in MG and HG (Table 4). The number of family was the same in UG and MG (18.67), the highest in LG (19), and the lowest in HG (18.33) (Table 4). At the plant family level, Compositae had the highest importance value in all grazing intensities (22.77% in LG, 21.60% in MG, and 24.99% in HG) except for UG where Gramineae had the greatest importance value of 27.67% (Table 4). The summed importance value of Gramineae and Cyperaceae decreased with the grazing intensity (43.01% in UG, 31.74% in LG, 28.71% in MG, and 28.77% in HG), while the summed importance value of Compositae and Ranunculaceae increased with the grazing intensity (24.08% in UG, 33.83% in LG, 38.77% in MG, and 37.17% in HG) (Table 4). With the increase of grazing intensity, the dominant species of the plant community shifted from Gramineae and Cyperaceae to Compositae and Ranunculaceae (Table 4).

Variation in biomass and root shoot ratio

At the plant community level, with the increase of the grazing intensity, the aboveground biomass (Fig. 4a), litter biomass (Fig. 4b), and percentage of aboveground biomass of palatable grasses to total biomass (Fig. 4e) all decreased, while the belowground biomass (Fig. 4c), total biomass (Fig. 4d), and R/S ratios (Fig. 4f) increased significantly ($P < 0.05$).

Correlation analyses indicated that the grazing intensity was significantly and positively correlated to the aboveground biomass, litter biomass, and percentage of aboveground biomass of palatable grasses (Table 3). A significantly negative linear correlation was observed between grazing intensity and the belowground biomass, total biomass, and R/S ratio (Table 3).

Fig. 3 The vegetation coverage (**a**), mean height of community (**b**), and species richness (**c**) under different grazing intensity. Date are means ± SE ($n = 3$). *Different letters on the bars* indicate variations significant at 0.05 level. P values of the ANOVAs of grazing intensity (P_G) are indicated as *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns* not significant
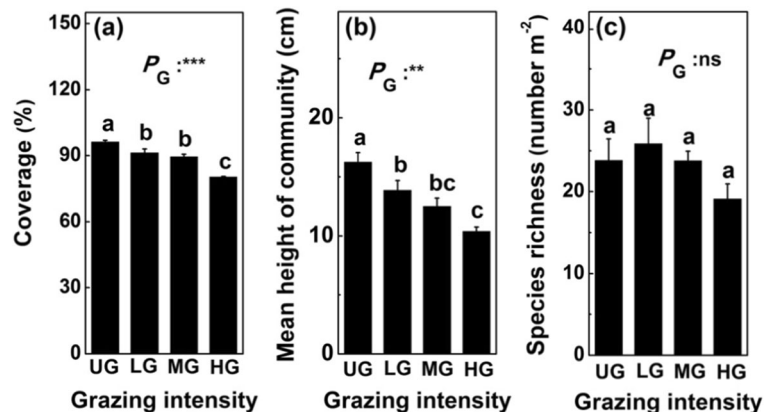
Table 3 Correlations between grazing intensity (x) and vegetation characteristics (y)

Vegetation	Coverage	Height	Species richness	AB	LB	BB	TB	PPG	R/S
	(%)	(cm)		(g cm^{-2})	(g cm^{-2})	(g cm^{-2})	(g cm^{-2})	(%)	
Yaks hm^{-1} correlations	$y = -9.3\times + 97.6$ $R^2 = 0.61$ $P < 0.001$	$y = -3.5\times + 16.3$ $R^2 = 0.37$ $P < 0.001$	$y = -1.9\times + 24.8$ $R^2 = 0.61$ $P = 0.198$	$y = -97.2\times + 311.7$ $R^2 = 0.54$ $P < 0.001$	$y = -67.7\times + 142.6$ $R^2 = 0.84$ $P < 0.001$	$y = 399.3\times + 947.7$ $R^2 = 0.72$ $P < 0.001$	$y = 234.5\times + 1402.0$ $R^2 = 0.41$ $P < 0.001$	$y = -17.8\times + 48.1$ $R^2 = 0.74$ $P < 0.001$	$y = 5.0\times + 2.5$ $R^2 = 0.65$ $P < 0.001$

The correlation analysis was performed between the grazing intensity (yaks hm^{-1}, x) and the vegetation characteristics (y)

AB aboveground biomass, LB litter biomass, BB belowground biomass, TB total biomass, PPG percentage of aboveground biomass of palatable grasses to total biomass, R/S root/shoot ratio

Discussion

The influence of grazing on the soil physicochemical properties

Generally, the direct influence of grazing on the grassland soil is litter trampling, vegetation coverage reduction, and feces and urine deposition (Ma et al. 2015). Previous studies revealed higher pH and BD in the grazing soil than in the no-grazing one in desert steppe (Deng et al. 2014a), hill landscape (Deng et al. 2014b), degraded sandy grassland (Su et al. 2005), and alpine meadow (Ma et al. 2015; Wu et al. 2010). Soil pH is one of the main factors determining grassland plant community composition and is mainly determined by parent material and organic and inorganic matter content (Basto et al. 2015). The variation in pH in this study is probably related to vegetation coverage, variations of root systems, and organic matter content (Su et al. 2005). The BD is an important factor affecting key soil functions including soil water, nutrients, and carbon stocks (Mora and Lázaro 2014) and therefore is an indicator of soil porosity versus compaction (Yang et al. 2015). Our experiment showed significantly increased BD in plots of higher grazing intensities (Fig. 2b, Table S1). Such variation tendency in BD could arise for two reasons. First, the increased grazing intensity could lead to soil compaction and could reduce soil infiltration rates and soil porosity, creating higher BD through animal hooves (Wu et al. 2010; Murphy et al. 2004). Second, the increase in grazing intensity could reduce the plant coverage (Fig. 3a) which in turn, by removed topsoil and exposed denser subsoil, would increase the potential of compaction and wind and rain erosion (Murphy et al. 2004).

Different from other study results that grazing could decrease TC and TN contents of soil (Deng et al. 2014b; Su et al. 2005; Ma et al. 2015), our experiment found lower TC and TN contents in UG than in treatments of grazing meadow, with a significant positive correlation between TC and TN contents ($P < 0.05$, Table 2). Since grazing can affect soil chemical properties by altering the soil nutrient cycle (Fernández-Lugo et al. 2013), the following mechanisms could attribute to the different trends observed between our study and others. First, organic matter is the main reservoir of C and N in terrestrial ecosystems (Golluscio et al. 2009), and in this study the total biomass of the grazing area was more than (nearly equal) that in the UG area (Fig. 3d), probably because grazing stimulated grass investing more

Table 4 The dominant vegetation families in plots of different grazing intensity

Importance values (%)

Family	UG	LG	MG	HG
Gramineae	27.67 ± 1.57 a	20.85 ± 1.32 b	17.29 ± 2.43 b	17.59 ± 0.95 b
Cyperaceae	15.34 ± 2.57 a	10.89 ± 0.33 a	11.42 ± 0.98 a	11.08 ± 2.33 a
Compositae	16.73 ± 2.22 b	22.77 ± 3.06 ab	21.60 ± 1.13 ab	24.99 ± 3.12 a
Ranunculaceae	7.35 ± 1.22 b	11.06 ± 1.69 ab	17.17 ± 3.44 a	12.18 ± 2.44 ab
Rosaceae	5.44 ± 0.86 a	7.40 ± 0.80 a	5.81 ± 0.10 a	8.53 ± 1.79 a
Rubiaceae	6.46 ± 2.63 a	4.15 ± 1.22 a	6.43 ± 0.32 a	5.36 ± 1.99 a
Family number	18.67 ± 0.33 a	19.00 ± 0.00 a	18.67 ± 0.33 a	18.33 ± 0.33 a
Species number	54.00 ± 0.00 b	57.67 ± 0.33 a	50.00 ± 0.00 c	50.00 ± 0.00 c

Lowercase letters indicate significant difference among the grazing intensities

resources in roots (Fig. 3b). Second, grazing increases plant biomass turnover through consumption (Medina-Roldán et al. 2012). Additionally, grazing often increases C-rich root exudates that stimulate microbial activity and turnover (Bai et al. 2012), consequently increasing TC and TN contents in the grazed sites and yielding a significant positive correlation between them. However, the reduction in TC and TN concentrations with the grazing intensity in our study could also be ascribed to the following reasons. First, the soil organic

matter (SOM) is determined by main inputs from decomposition of aboveground and belowground vegetation litter and animal excreta and main outputs though the mineralization and leaching of carbon and nitrogen (Golluscio et al. 2009; Cui et al. 2005). Second, grazing markedly reduced vegetation coverage (Fig. 3a), thereby accelerating decomposition and erosion (Ma et al. 2015). Additionally, the soil BD increased with the grazing intensity (Fig. 2b), which could reduce the microbial activity and decrease the quality and

Fig. 4 Aboveground biomass (**a**), litter biomass (**b**), belowground biomass (**c**), total biomass (**d**), percentage of aboveground biomass of palatable grasses to total biomass (PPG) (**e**), and root/shoot ratio (**f**) under different grazing intensity, respectively. The *bars* indicate the means ± SE (*n* = 3). *Different letters on the bars* indicate variations significant at 0.05 level. *P* values of the ANOVAs of grazing intensity (P_G) are indicated as *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; *ns* not significant
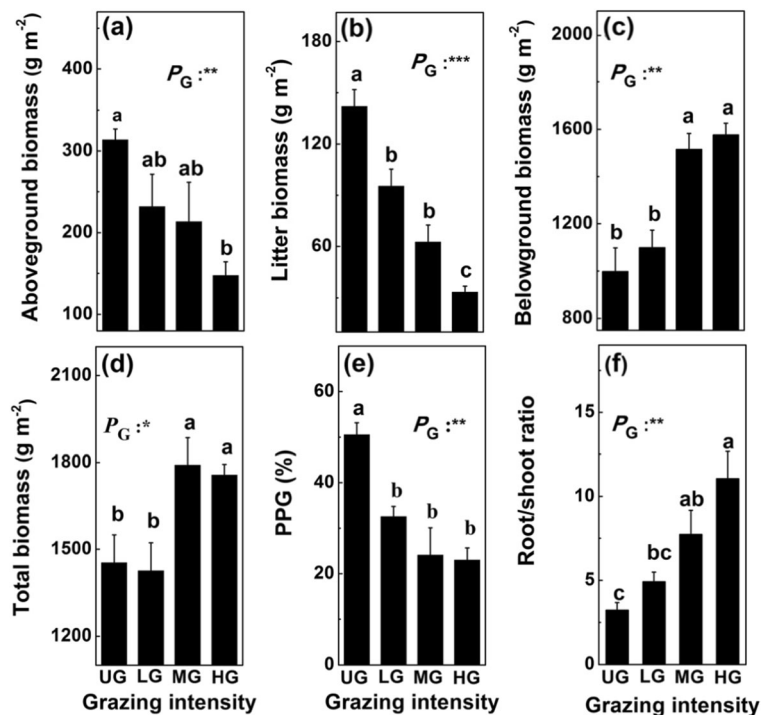
decomposition rate of the litter. On the other hand, feces and urine of yaks on the soil surface are an input of organic matter into soils, which may stimulate microbial biomass and activity leading to net C and N mineralization (Ma et al. 2015). Consequently, the TC and TN contents decreased as the grazing intensity increased.

Unlike variation of TC and TN contents, the concentration of TP was nearly the same in the treatments of all grazing intensities (Fig. 2e). This was probably because the main source of P is rock weathering, which is a long process (Shen et al. 2011) and not significantly influenced by grazing. A negative correlation between TC and BD ($P = 0.037$, Table 2) was found in this study, like some others (Steffens et al. 2008; Yang et al. 2015). This could be due to the fact that BD depends on the size and density of soil mineral and organic particles and how they are packed together (Mora and Lázaro 2014); therefore, low BD is a remarkable feature of soil organic matter immobilization (Yang et al. 2015).

The influence of grazing on community characteristics

Our study showed the highest number of species and families in the LG, which was in agreement with our hypothesis that optimal grazing is beneficial for both soil properties and vegetation of alpine meadow in the Tibetan Plateau. Similarly, Weithoff et al. (2001) also found high mean diversity with disturbances of intermediate intensity. To adapt to the variations of the environment, plant is often modified in different environments. As in the former research (Deng et al. 2014a), our results suggested significant decreases in the vegetation coverage (Fig. 3a) and the mean height of community (Fig. 3b) with the increase in grazing intensity (yaks hm^{-2}) ($P < 0.001$, Table 3), probably resulting from the bite effect of grazing livestock (Medina-Roldán et al. 2012; Zhu et al. 2016).

Species richness is sensitive to environmental heterogeneity (Pykälä 2003). Previous research suggested that grazing exclusion increases species richness (Deng et al. 2014a; Fensham et al. 2011). In agreement with former studies (Fensham et al. 2011; Deng et al. 2014a), our results showed a significant unimodal relation between the grazing intensity and the species richness (Fig. 3c) and number of species and families (Table 4), respectively, with the species richness and species number being the highest in the LG. However, the effects of grazing vary from area to area, mainly depending on the grazing intensity and history (Hu et al. 2015). Our results showed no significant difference in the

correlation of species richness with grazing intensity in all treatments (Fig. 3c, Table 3), which was similar to the previous study in the Tibetan Plateau (Zhou et al. 2006). It suggested that grazing intensity may not be an important factor influencing species richness (Deng et al. 2014a). Former research considered the duration of grazing exclusion an important factor affecting the species richness in the Tibetan Plateau (Wu et al. 2012).

At the community level, the plant community composition was observed to be altered with grazing or fencing (grazing exclusion) (Wu et al. 2009), which was characterized by the variations of the ratio between palatable grasses and unpalatable grasses. With grazing, the dominant species of the plant community shifted from palatable grasses (Gramineae and Cyperaceae) in UG to unpalatable grasses (Compositae and Ranunculaceae) in grazed meadow (Table 4). Herbivory is one of the important factors that strongly influence competitive relationships between plant species (Borgström et al. 2016). The change of dominant species between un-grazed and grazed meadow plots was probably due to the specific diet preference of the yaks in our experiment. Through their diet preference, the yaks reduced the proportion of palatable grasses in the species and the biomass in the whole community and therefore made dominant the unpalatable grasses. From the perspective of the grasses, palatable grasses have greater competitive ability than unpalatable grasses in the absence of grazing (Moretto and Distel 1997; Wu et al. 2009) and more regenerative potency under the disturbance of grazing (Belsky et al. 1992). In addition, the proportion of palatable grasses of the community is the largest in lightly or moderately grazed grassland, but the vigor of palatable grasses is reduced in overgrazed ones. However, the unpalatable grasses usually have "escape and defense strategies" to avoid the damage of grazing (Belsky et al. 1992).

The influence of grazing on biomass and root to shoot ratio

The biomass allocation of plant organs (e.g., root, stem, leaf) reflects the plant ecological adaptation to changes of environmental changes including grazing disturbance. In our study, the aboveground biomass (Fig. 4a), litter biomass (Fig. 4b) and percentage of aboveground biomass of palatable grasses to total biomass (Fig. 4e) were lower in the grazed treatments than in the ungrazed area and had a significant and positive linear correlation with the grazing intensity, respectively

(Table 3). Opposite results were found in belowground biomass (Fig. 4c, Table 3) and total biomass (Fig. 4d, Table 3). The results about aboveground and litter biomass were similar with previous findings (Deng et al. 2014a; Gao et al. 2007). This tendency should be a direct result of the consumption of biomass by the grazers (Gao et al. 2007; An and Li 2015). Grazing affects the root biomass by trampling and excretions, but the root biomass responses to livestock grazing are ambiguous (Gao et al. 2007; An and Li 2015). Our results indicated that the belowground biomass tended to increase with the grazing intensity (Fig. 4c) and had a negative linear correlation with the grazing intensity (Table 3). This was probably because plants growing in heavily grazed areas invested more resources in roots than those in less grazed or ungrazed ones (Gao et al. 2007). And the increasing biomass allocation to the roots is an important adaptive response of plants to grazing (An and Li 2015).

Aboveground and belowground biomass are different forms to fulfill the plant function as a whole (Mokany et al. 2006), which make aboveground and belowground biomass allocation a central issue in plant ecology (Yang et al. 2009). Former researchers used the R/S ratio to gain a greater understanding of the relationship between aboveground and belowground biomass. The R/S ratio is an index for the differential investment of plant photosynthates between the aboveground and belowground, a complicated process which is the cumulative response of vegetation to biotic, abiotic, and management influences (Mokany et al. 2006). In order to adapt to the changing environment conditions, the R/S ratio of plants is often modified to maximize the ability to capture resources (Deng et al. 2014a). We found that the R/S ratio significantly increased with grazing intensity (Fig. 4f, Table 3), indicating that grazing changed the aboveground and belowground biomass allocation (Fig. 4a and 4e). Such result was supported by the optimal partitioning hypothesis (Bai et al. 2012). When grazing intensity is increased, plants invest more resources to support root growth. Former studies indicated that a high proportion of root biomass in the total biomass can enhance the capacity to tolerate environmental stresses and external disturbances (An and Li 2015; Gao et al. 2007).

Conclusion

The present study suggests that compared to the UG, grazing increased the pH, soil bulk density, and content of TC and TN, where BD increased with grazing intensity at the grazed plots, and the opposite was true for the pH and contents of TC and TN. In addition, we found that with the increased grazing intensity, the coverage, mean height of community, aboveground biomass, litter biomass and percentage of aboveground biomass of palatable grasses to total biomass significantly decreased, while the belowground biomass and R/S ratio increased. Furthermore, the dominant species of the plant community shifted from palatable grasses (Gramineae and Cyperaceae) to unpalatable ones (Compositae and Ranunculaceae). Our results highlight that LG is the optimal grassland management mode in this region, because of the greatest species richness and relatively higher aboveground biomass under this management.

Compliance with ethical standards

Conflict of interest   The authors declare that they have no conflict of interest.

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