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EFFECTS OF LIVESTOCK EXCLUSION ON VEGETATION AND SOIL PROPERTIES UNDER TWO TOPOGRAPHIC HABITATS IN AN ALPINE MEADOW ON THE EASTERN QINGHAI-TIBETAN PLATEAU

ABSTRACT: Long-term overgrazing has resulted in grassland deterioration and even desertification on the eastern Qinghai-Tibetan Plateau. In this paper, we examined the characteristics of vegetation and soil properties in the livestock-excluded pastures and the adjacent grazed pastures under two topographic habitats (the flat valley and the south-facing slope). Seven-year exclusion of livestock has enhanced aboveground live biomass, root biomass and litter accumulation. Livestock exclusion has also increased soil bulk density and soil water content, soil organic C concentration, total N concentration and its transformation rate, and soil microbial activity. The results showed that livestock exclusion has facilitated vegetation recovery and improved physical, chemical and biological properties of soil. However, livestock exclusion has significantly decreased graminoid biomass accumulation, especially on the flat valley, the biodiversity also significantly decreased there. The results suggested that long-term livestock exclusion was disadvantageous for palatable forage production and biodiversity protection on the flat valley. Compared to the flat valley, the grassland on the south-facing slope was under more severe degradation, and the reversion was in a slower process. Thus, the optimal grassland management in the livestock-excluded pasture on the flat valley should include a low or moderate grazing intensity or adopt an alternate grazing system, but more effective and even longer livestock exclusion practice should be taken on the south-facing slope.

KEY WORDS: biodiversity, Qinghai-Tibetan Plateau, livestock-excluded pasture, soil properties, vegetation recovery

1. INTRODUCTION

Grasslands, occupying approximately one-third of the earth's terrestrial surface, are subject to varying degrees of grazing by livestock (Williams *et al.* 1968, Gitay *et al.* 2001). Overgrazing by livestock is one of the most significant human activities that degrade grasslands (Mainguet 1994). Numerous studies have shown that overgrazing by livestock causes dramatic changes in plant community, leads to reduction in canopy cover and productivity (Hill *et al.* 1992, Su *et al.* 2005), and causes heavy destruction in soil structure and compaction, also leads to decrease in soil organic C and N contents (Milchunas and Lauenroth 1993, Chaneton *et al.* 1996, Su *et al.* 2004), reduction in soil infiltration, increase in soil crusting and susceptibility to soil erosion (Hiernaux *et al.* 1999, Van der Maarel and Titlyanova 1989, Manzano and Návar 2000). Therefore, human being is facing a huge challenge of avoiding overgrazing and utilizing the grassland sustainability.

To control overgrazing by livestock and protect the regional environment, people have tried livestock exclusion in parts of grassland. In semiarid and arid grassland, the main aim of livestock exclusion practice was to prevent further degradation. Many studies mainly targeted on restoration of natural resources such as vegetation biomass and nutrient availability (Marc *et al.* 2003), and improvement of soil chemical and physical properties (Wolde *et al.* 2007). However, in subhumid and humid environments, taking Europe for example, the main aim of livestock exclusion practice was to conserve biodiversity. Many studies in the Mediterranean Basin mainly analyzed the effect of livestock exclusion practices on grassland communities, especially on species richness (Montalvo *et al.* 1993, Ortega *et al.* 1996, Peco *et al.* 1998, Lienert *et al.* 2002). Thus, for different environmental conditions, the grassland restoration criteria may not be the same, so we should take regional environmental conditions into consideration when assessing the effectiveness of management and conservation.

The alpine meadow (3000 m to 5200 m a.s.l.) located on the eastern Qinghai-Tibetan Plateau is a representative vegetation type and a primary grazing land of the region. On the one hand, as an important water resource area in the upper Yangtze River and Yellow River, it has abundant natural resources and high biodiversity. On the other hand, mountain nomadism is one of the ways for local people to utilize grass resources, and livestock grazing plays an important role in the local economy (Wu 2004). Long-term overgrazing in the area has resulted in grassland deterioration and even desertification (Wu and Liu 1998). The balance between utilization and protection of this area becomes an important issue. A restoration project was initiated in the area by local government since the end of 2001. Exclosures have been established and grazing by domestic herbivores has been gradually excluded. Up to now, a large area of alpine meadows is kept non-grazed by livestock exclusion. But its effect on vegetation recovery and soil properties is still unknown.

In this paper, we aimed to study effects of livestock exclusion on vegetation and soil properties in an alpine meadow on the eastern Qinghai-Tibetan Plateau of China. We hypothesized that livestock exclusion practice could increase the number of species, restore natural resources such as vegetation biomass, and improve soil properties.

2. MATERIAL AND METHODS

2.1. Study area

The study was conducted at the alpine rangeland of Kaka Gou (32°51′N, 103°33′E, 3 400 m a.s.l.), about 40 km north to Songpan County on the eastern Qinghai-Tibetan Plateau. The annual mean temperature is 2.8°C with a mean temperature of −7.6°C in January and 9.7°C in July. The annual precipitation is 718 mm, 72% of which falls in summer from June to August. The whole area consists of hills and flat valleys. Vegetation is typical of alpine meadow and dominated by *Kobresia* spp. and *Poa* spp. in the study area. Other common species include perennial grasses, *Clinelymus nutans* L., *Deschampsia caespitosa* L., *Festuca ovina* L.; the forbs, *Potentilla anserina* L. var. anserine, *Polygonum sphaerostachyum* L., *Gentiana squarrosa* Ledeb., *Gentianopsis paluosa* (Munro) ma., *Delphinium tongolense* Franch., *Scutellaris hypericifolia* L. and *G. macrophylla* Pall. var. fetissowii (Sichuan Vegetation Research Group 1980). The soil is a Mat Crygelic Cambisols (Chinese Soil Taxonomy Research Group 1995).

In the last several decades, the alpine meadow was used as winter rangeland grazed mainly by yaks (*Bos grunniens*) for a continuous period from early October to late June. For protection and restoration, a restoration project was initiated in the study area by local government since the end of 2001. Therefore, since 2001 exclosures have been established gradually and grazing by domestic herbivores excluded.

To assess the effects of livestock exclusion on vegetation and soil recovery, we selected within the area two study sites, with different topographic habitats. One was on the flat valley and the other on the south-facing slope. The livestock-excluded pastures in the two sites were approximately 50 ha respectively. Adjacent to each livestock-excluded pasture was the grazed pastures that we used as control.

2.2. Vegetation sampling

In August 2008, we chose five 10 m ×10 m plots in each habitat type both in livestock-excluded pasture and adjacent grazed pasture (the grazing intensity – 3–4 yaks ha^{-1}). In each plot three 1 m × 1 m quadrates were selected randomly for plant community investigation and biomass sampling. All species occurred in each quadrate was recorded, and percent of bare ground was estimated. The aboveground biomass was collected as living and litter. Living biomass was harvested and classified by life form (graminoids and forbs). Root biomass was measured by collecting three soil cores (10 cm in diameter) from the depth of 0–30 cm in each quadrate, the three soil cores were mixed as one composite soil sample and immediately washed over in a 1 mm mesh screen to remove soil. All plant samples were oven-dried for 48 h at 65°C and then weighed.

2.3. Soil sampling and analysis

We randomly took 6 soil samples (10 cm in diameter, 0–15 cm in depth) in each plot. Soil samples were kept at 4°C in cool boxes to the laboratory. 3 soil samples in each plot were used to measure soil bulk density by the core method, and another 3 soil samples in each plot were divided into two sub-samples respectively: one for soil water content, organic carbon, total nitrogen, ammonium and nitrate, the other for microbial biomass carbon and nitrogen analysis.

Rates of *in situ* net N mineralization and net nitrification in August were determined in the field using the buried-bag technique (Eno 1960). Three paired soil cores were taken from random locations in each plot. In each pair, one soil core was sealed in a gas permeable polyethylene bag and buried at a depth of 5 cm. The other core (initial) was taken right next to each buried bag and kept in cooler bags during the transportation to the laboratory, then frozen until analysis. The buried bags were retrieved after 30 days of incubation and were analyzed for NH_4^+-N and NO_3^--N. Net N mineralization was calculated by subtracting initial NH_4^+-N plus NO_3^--N concentrations from final concentrations. Net N nitrification was calculated as the difference in corresponding NO_3^--N concentrations.

We measured gross rates of nitrification, denitrification and microbial respiration using the Barometric Process Separation (BaPS) instrument (UMS GmbH Inc., Germany) through laboratory incubations. Three intact soil cores were randomly taken by soil containers in each plot with a diameter of 5.6 cm and a height of 4.1 cm. The soil cores were transported at coolers to the laboratory and processed immediately. Soil cores were put into the BaPS instrument to determine gross rates of nitrification, denitrification and microbial respiration. The BaPS instrument was closed gas-tight and incubated for at least 24 h at a temperature of 25.0°C (Ingwersen *et al.* 1999).

Fresh soil samples were sieved to separate plant material and fragments >2 mm in diameter. Soil moisture was measured gravimetrically. Soil organic C was measured with the potassium dichromate oxidation method (Lu 2000). Total N was measured with the alkaline persulfate oxidation method (Cabrera and Beare 1993, Lu 2000). Soil was extracted in 100 ml of 0.5 M potassium sulfate (K_2SO_4) solution for 24 h and subsequently filtered with Whatman No. 42. Soil extract was analyzed for NH_4^+-N with the potassium chloride-in dophenol blue colorimetric method (Lu 2000) and NO_3^--N with copperized cadmium reduction calcium sulphate–phenol disulfonic acid method (Keeney and Nelson 1982). Soil microbial biomass C and N were determined by the chloroform-fumigation extraction method (Brookes *et al.* 1982, 1985).

2.4. Data analysis

Values from all sampling quadrates within each plot were averaged. Then, One-way ANOVA procedures were used to detect the differences for livestock-excluded pasture and grazed pasture in the two topographic habitats. Two-way ANOVA procedures were used to test differences in relation to two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope), and their interaction. The SPSS 16.0 for Windows was used for all statistical analyses.

3. RESULTS

Livestock exclusion decreased average number of species from 36.2 to 31.2 on the flat valley, and significant difference was detected between two treatments (Table 1). However, livestock exclusion slightly increased average number of species from 29.6 to 30.4 on the south-facing slope, though no significant difference was detected between two treatments (Table 1). Ground cover was 25 and 15% higher in the livestock-excluded pasture on the flat valley and on the south-facing slope, respectively (Table 1). There was also a significant difference in both graminoid biomass and forb biomass between two treatments, with lower graminoid biomass and higher forb biomass in the livestock-excluded pasture (Table 1).

The aboveground live and belowground root biomasses were significantly different

Table 1. Number of species and community structure of livestock-excluded pastures and adjacent grazed pastures in the two topographic habitats. Average values and standard errors (in brackets) for five plots, August 2008.

Parameter	Flat valley		South-facing slope		Treatment		Habitat		T×H	
	Excluded	Grazed	Excluded	Grazed	*F*	*P*	*F*	*P*	*F*	*P*
Number of species	31.2^{b} (2.1)	36.2^{a} (2.5)	30.4^{b} (1.9)	29.6^{b} (2.6)	4.20	n.s.	13.04	**	8.31	n.s.
Bare ground (%)	9.3^{c} (1.4)	27.4^{b} (3.1)	29.4^{b} (4.3)	38.5^{a} (4.2)	98.39	***	353.43	***	61.79	**
Graminoids biomass ($g\ m^{-2}$)	98.86^{b} (11.58)	151.21^{a} (10.83)	98.82^{b} (7.97)	110.73^{b} (12.17)	53.29	***	19.53	**	12.81	*
Forbs biomass ($g\ m^{-2}$)	283.17^{a} (10.09)	114.07^{c} (16.46)	160.63^{b} (8.96)	110.94^{c} (11.80)	404.11	***	133.35	**	120.39	*

For livestock-excluded pastures and grazed pastures in the two topographic habitats, data that do not share the same letter are statistically different at $P < 0.05$ when analyzed by One-way ANOVA; for two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope) and their interaction, n.s. (not significant), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ were analyzed by Two-way ANOVA.

Table 2. Biomass of livestock-excluded pastures and adjacent grazed pastures in the two topographic habitats. Average values and standard errors (in brackets) for five plots, August 2008.

Parameter	Flat valley		South-facing slope		Treatment		Habitat		T×H	
	Excluded	Grazed	Excluded	Grazed	*F*	*P*	*F*	*P*	*F*	*P*
Aboveground live biomass ($g\ m^{-2}$)	380.49^{a} (14.14)	266.68^{b} (11.83)	263.62^{b} (14.25)	220.53^{c} (7.89)	203.76	***	219.97	***	41.40	***
Litter biomass ($g\ m^{-2}$)	92.75^{a} (12.21)	24.97^{b} (8.82)	80.14^{a} (9.50)	19.54^{b} (6.81)	263.17	***	0.89	n.s.	0.11	n.s.
Root biomass ($g\ m^{-2}$)	1410.64^{a} (142.98)	1125.42^{b} (170.52)	1183.67^{b} (73.22)	928.37^{c} (99.48)	22.55	***	13.87	**	0.69	n.s.

For livestock-excluded pastures and grazed pastures in the two topographic habitats, data that do not share the same letter are statistically different at $P < 0.05$ when analyzed by One-way ANOVA; for two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope) and their interaction, n.s. (not significant), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ were analyzed by Two-way ANOVA.

Table 3. Soil bulk density and water content of livestock-excluded pastures and adjacent grazed pastures in the two topographic habitats. Average values and standard errors (in brackets) for five plots, August 2008.

Parameter	Flat valley		South-facing slope		Treatment		Habitat		T×H	
	Excluded	Grazed	Excluded	Grazed	*F*	*P*	*F*	*P*	*F*	*P*
Soil bulk density ($g\ cm^{-3}$)	1.27^{b} (0.05)	1.34^{a} (0.05)	1.33^{a} (0.04)	1.36^{a} (0.02)	6.32	*	5.3	n.s.	2.15	n.s.
Soil water content ($kg\ kg^{-1}$)	0.48^{a} (0.04)	0.35^{b} (0.05)	0.37^{b} (0.03)	0.26^{c} (0.02)	50.62	***	36.57	***	0.51	n.s.

For livestock-excluded pastures and grazed pastures in the two topographic habitats, data that do not share the same letter are statistically different at $P < 0.05$ when analyzed by One-way ANOVA; for two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope) and their interaction, n.s. (not significant), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ were analyzed by Two-way ANOVA.

between two habitats with lower biomass accumulation on the south-facing slope (Table 2). Aboveground live biomass, litter accumulation and belowground root biomass in the livestock-excluded pasture were 43, 272 and 25% higher than in the adjacent grazing pasture on the flat valley. Significant increases of 19, 310 and 28%, respectively, were found in the livestock-excluded pasture on the south-facing slope as well (Table 2).

The soil water content was 31.8% higher on the flat valley than on the south-facing slope, and there was a significant difference between two habitats (Table 3). Livestock exclusion significantly increased soil water content, soil total N, NH$_4^+$-N and NO$_3^-$-N in both habitats (Tables 3 and 4). Livestock exclusion also significantly decreased soil bulk density, and significantly increased soil organic C on the flat valley, but no significant difference between the two treatments was detected on the south-facing slope (Tables 3 and 4).

The rates of net mineralization, net nitrification, gross nitrification and denitrification were 29, 33, 58, 96% higher and 24, 32, 41, 75% higher in the livestock-excluded pasture on the flat valley and on the south-facing slope, respectively (Table 5). Similarly, microbial biomass C and N, and CO$_2$ flux rates showed 28, 48, 82% higher and 14, 20, 35% higher, respectively (Tables 5 and 6).

Table 4. Soil chemical properties of livestock-excluded pastures and adjacent grazed pastures in the two topographic habitats. Average values and standard errors (in brackets) for five plots, August 2008.

Parameter	Flat valley		South-facing slope		Treatment		Habitat		T×H	
	Excluded	Grazed	Excluded	Grazed	*F*	*P*	*F*	*P*	*F*	*P*
Organic C (g kg^{-1})	63.41^{a} (2.01)	60.14^{b} (0.71)	61.17^{b} (1.46)	60.02^{b} (0.76)	13.10	*	3.75	n.s.	3.05	n.s.
Total N (g kg^{-1})	5.71^{a} (0.07)	4.53^{c} (0.12)	5.39^{b} (0.17)	4.64^{c} (0.15)	260.47	***	3.31	n.s.	12.64	n.s.
NH$_4^+$-N (mg kg^{-1})	11.43^{a} (1.62)	8.46^{c} (1.22)	9.81^{b} (1.25)	7.48^{c} (1.39)	16.16	**	5.43	*	0.61	n.s.
NO$_3^-$-N (mg kg^{-1})	8.04^{a} (1.59)	5.76^{b} (1.00)	7.34^{a} (0.80)	5.39^{b} (0.78)	16.80	**	0.86	n.s.	0.54	n.s.

For livestock-excluded pastures and grazed pastures in the two topographic habitats, data that do not share the same letter are statistically different at $P < 0.05$ when analyzed by One-way ANOVA; for two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope) and their interaction, n.s. (not significant), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ were analyzed by Two-way ANOVA.

Table 5. Soil N turnover rates and microbial respiration of livestock-excluded pastures and adjacent grazed pastures in the two topographic habitats. Average values and standard errors (in brackets) for five plots, August 2008.

Parameter	Flat valley		South-facing slope		Treatment		Habitat		T×H	
	Excluded	Grazed	Excluded	Grazed	*F*	*P*	*F*	*P*	*F*	*P*
Net mineralization (mg N kg^{-1} d^{-1})	0.81^{a} (0.07)	0.63^{bc} (0.06)	0.68^{b} (0.07)	0.55^{c} (0.05)	25.09	***	11.51	*	1.01	n.s.
Net nitrification (mg N kg^{-1} d^{-1})	0.68^{a} (0.05)	0.51^{bc} (0.06)	0.58^{b} (0.07)	0.44^{c} (0.04)	31.39	***	11.30	*	0.78	n.s.
Gross nitrification (mg N kg^{-1} d^{-1})	2.49^{a} (0.45)	1.58^{c} (0.15)	1.96^{b} (0.14)	1.39^{c} (0.11)	41.29	***	9.85	**	2.37	n.s.
Denitrification rate (mg N kg^{-1} d^{-1})	0.47^{a} (0.02)	0.24^{c} (0.03)	0.35^{b} (0.04)	0.2^{c} 1(0.03)	89.71	***	14.67	**	4.06	n.s.
CO$_2$ flux rate (mg CO$_2$ kg^{-1} d^{-1})	69.35^{a} (5.74)	38.11^{c} (6.51)	49.26^{b} (4.84)	36.42^{c} (8.11)	44.03	***	23.45	***	18.08	**

For livestock-excluded pastures and grazed pastures in the two topographic habitats, data that do not share the same letter are statistically different at $P < 0.05$ when analyzed by One-way ANOVA; for two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope) and their interaction, n.s. (not significant), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ were analyzed by Two-way ANOVA.

Table 6. Soil microbial biomass C and N of livestock-excluded pastures and adjacent grazed pastures in the two topographic habitats. Average values and standard errors (in brackets) for five plots, August 2008.

Parameter	Flat valley		South-facing slope		Treatment		Habitat		T×H	
	Excluded	Grazed	Excluded	Grazed	*F*	*P*	*F*	*P*	*F*	*P*
Microbial biomass C (mg kg^{-1})	749.75^{a} (53.46)	584.79^{c} (57.78)	638.71^{b} (31.47)	560.29^{c} (37.63)	36.46	***	15.92	**	7.89	*
Microbial biomass N (mg kg^{-1})	147.01^{a} (10.48)	99.12^{c} (9.79)	116.06^{b} (9.98)	96.60^{c} (6.49)	47.27	***	21.14	**	9.23	*

For livestock-excluded pastures and grazed pastures in the two topographic habitats, data that do not share the same letter are statistically different at $P < 0.05$ when analyzed by One-way ANOVA; for two treatments (livestock-excluded and grazed), two habitats (flat valley and south-facing slope) and their interaction, n.s. (not significant), * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ were analyzed by Two-way ANOVA.

4. DISCUSSION

4.1. Effects of livestock exclusion on species number

The livestock exclusion significantly decreased the number of species on the flat valley, which does not corroborate our original hypothesis. However, the result coincided with some short-term exclosure experiments in the humid Mediterranean Basin, especially in central Spain (Montalvo *et al.* 1993, Ortega *et al.* 1996, Peco *et al.* 1998). Cessation of livestock grazing not only avoids the damage by livestock trampling (Jensen 1985, Kiehl *et al.* 1996), but also modifies both the disturbance regime and interactions among plant species (Marc *et al.* 2003). The reason for the decrease of species number on the flat valley of the present study could be that some very competitive species, especially the forbs, dominated the plant community in the livestock-excluded pasture.

Generally, divergent selection pressure (competition for water and grazing tolerance) could maintain higher species diversity on the south-facing slope compared to the more humid flat valley. However, it was found that the species number on the south-facing slope was lower than that of the flat valley in this study (Table 1). We analyzed this might be related to the fact that yaks like to stay in the drier environment, especially on the south-facing slope. Thus, the continuous overgrazing and frequent trampling by yaks could be the main reason which resulted in the decrease of species diversity on the south-facing slope. Alleviating or even avoiding the heavy grazing was helpful for diversity preservation. As the result showed in the present study, livestock exclusion slightly increased the number of species on the south-facing slope (Table 1).

4.2. Effects of livestock exclusion on community structure and biomass accumulation

The modification in species processes would ultimately lead to change in plant community structure (Ackerly and Bazzaz 1995). In the present study, forbs biomass significantly increased in the livestock-excluded pastures. The result coincided with the research of Belsky (1992). He demonstrated that the removal of livestock grazing would give more chance for forbs in grassland to recover. In this region, some *Kobresia* and *Poa* species are the main food for yaks, and the increase of forbs biomass would inevitably increase some unpalatable forage in the livestock-excluded pasture. Therefore, the increase of forbs biomass and the decrease of graminoids biomass in the livestock-excluded pastures were disadvantages for the palatable forage production in this region, especially on the flat valley.

It is found that livestock exclusion significantly decreased bare ground cover in both habitats. The reason could be the significantly increased aboveground live biomass, belowground root biomass and litter accumulation in the livestock-excluded pastures. Livestock, as a disturbance generator, consume leaves, fruits and involve mechanical actions such as trampling (Crawley 1997). Thus, livestock exclusion would have a profound effect on vegetation recovery. The same effect had also been proved in other places, such as in the erosion-prone Horqin sandy grassland (Su *et al.* 2005).

We also found the bare ground cover on the south-facing slope higher than on the flat valley (Table 1). The result suggested that the grassland on the south-facing slope was under more severe degradation which might be caused by lower soil water content and heavier grazing stress. For this reason, the livestock exclusion practice appeared more important, especially on the south-facing slope.

4.3. Effects of livestock exclusion on soil physical and chemical properties

Livestock exclusion slightly or significantly increased soil organic C and total N concentrations in both habitats, especially on the flat valley. The result was in agreement with that of Sun *et al.* (2005), who reported that fenced pasture contained more soil organic matter and total N concentration than in the adjacent grazed pasture. We considered the increases in organic C and total N concentrations in the livestock-excluded pastures were partly due to vegetation recovery and litter accumulation after exclusion. The higher concentration of soil organic matter in livestock-excluded pastures could make soil aggregate more stably and become less susceptible to breakdown under the effect of raindrop splashing.

In addition to higher total nutrient pools within the livestock-excluded pastures, the cycling of nitrogen and the availability of nitrogen were also higher than the adjacent continuous grazing pasture in both habitats. Higher aboveground litter production is commonly associated with higher turnover rates of nutrients (Seastedt 1988, Tian *et al.* 1993, Shaw and Harte 2001, Koukoura *et al.* 2003). Researches also showed that higher soil water content would facilitate turnover rates of nutrients (Granli and Bockmann 1994, Burns *et al.* 1996, Maag and Vinther 1996, Elmi *et al.* 2003). Therefore, the faster cycling of nitrogen, and the higher availability of nitrogen in the livestock-excluded pastures could be a result of higher aboveground litter production and soil water content. In the livestock-excluded pastures of our study, we considered the elimination of soil trampling by livestock, as well as the increase of root biomass accumulation contributed to decrease in soil bulk density. Thus, the foresaid results were in agreement with Wolde *et al.* (2007) who reported that livestock exclusion can lead to improvement in soil chemical and physical properties.

Compared to the flat valley, we did not observe statistically significant change of soil organic C and soil bulk density between the livestock-excluded pasture and the grazed pasture on the south-facing slope. Xu *et al.* (1994) demonstrated that though the degradation caused by grazing in the initial stage is relatively easier to be reversed, the reversion of severe degradation is a slow process. Thus, our results indicated that the grassland on the south-facing slope was in the stage of more severe degradation than the grassland on the flat valley.

4.4. Effects of livestock exclusion on soil microbial biomass and respiration

In our study, significant increase of soil microbial biomass C and N was detected in the livestock-excluded pastures of both habitats. Higher microbial activity indicated that soil biological properties were improved by livestock exclusion practice. Higher microbial activity also facilitated CO_2 flux rate in the livestock-excluded pastures, especially on the flat valley.

5. CONCLUSIONS

In this study we found that livestock exclusion enhanced aboveground live biomass, root biomass and litter accumulation. After 7-year exclusion of livestock, there was an evident improvement in soil bulk density, soil water content, soil microbial activity, soil organic C concentration, total N concentration and its transformation rate. The results showed that livestock exclusion practice in the eastern Qinghai-Tibetan Plateau had facilitated vegetation recovery and improved soil physical, chemical and biological properties. As a result, it can improve the water retention ability of the soil, and also effectively protect soil from loss by water erosion in the upper Yangtze River and Yellow River. However, it was also found that livestock exclusion significantly decreased graminoid biomass accumulation, especially on the flat valley.

The biodiversity also significantly decreased there. The results indicated that long-term livestock exclusion was disadvantageous for palatable forage production and biodiversity protection on the flat valley. Thus, an optimal grassland management in the livestock-excluded pasture on the flat valley should include a low or moderate grazing intensity or adopt an alternate grazing system. We also found that the grassland on the south-facing slope was under more severe degradation, and the reversion was in a slow process. Therefore, stronger and even longer livestock exclusion practice should be taken to better rehabilitate the south-facing slope.

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