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WARM-SEASON GRAZING BENEFITS SPECIES DIVERSITY CONSERVATION AND TOPSOIL NUTRIENT SEQUESTRATION IN ALPINE MEADOW

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ABSTRACT

Seasonal grazing is one way of the moderate grazing regimes, but little information is available on compared study of seasonal grazing in alpine meadow. We studied the aboveground and belowground properties among warm-seasonal grazing meadows and cold-seasonal grazing meadows on the Qinghai–Tibetan Plateau. Results showed that the warm-seasonal grazing increased forb functional group proportion, plant density and evenness index but decreased root biomass, plant height and graminoid functional group proportions. Grazing seasons affected variation in soil bulk density, soil water content, pH and soil nutrient content, and the variations caused the various of soil carbon and nitrogen density. The highest values of soil carbon and nitrogen contents and densities in the warm-season grazing meadow occurred at the top 10-cm soil, while the highest values in the cold-season grazing meadow occurred at the depth of 30- to 50-cm soil. Our results indicated that the warm-season grazing is suitable for the species diversity conservation and the nutrient sequestration at the topsoil. However, the cold-season grazing is suitable for the nutrient sequestration at the deep soil. This study implied that the warm-season and cold-season grazing might be exchanged regularly to practice continuous carbon and nitrogen sequestration. Periodic cold-season and warm-season grazing would be the suitable grazing regime to keep alpine meadow sustainability. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: productivity; plant diversity; root biomass; soil carbon and nitrogen; seasonal grazing

INTRODUCTION

Grazing is a common land use practice in grasslands that influences soil properties (Augustine & Frank, 2001; Klumpp *et al*., 2009; Xie *et al*., 2014; Costa et al., 2015) and plant community characteristics (Zhu *et al*., 2012; Tarhouni *et al*., 2015; Álvarez-Martínez *et al*., 2016). With increasing human population, the demands on grasslands are increasing. It is necessary to raise the profile of the issues involved and to improve our understanding of the applied ecology requirement for successful management (Watkinson & Ormerod, 2001; Wang *et al*., 2002). However, because of raising of intensive livestock, grassland appeared widespread vegetation and soil degradation, such as reducing plant species diversity (Álvarez-Martínez *et al*., 2016; Angassa, 2014), net primary productivity and vegetation cover (Buttolph and Coppock, 2004; Cingolani *et al*., 2005; Pulido *et al*., 2016) and changing soil structure and soil nutrients (Gass & Binkley, 2011; Jiang *et al*., 2011; Mcsherry & Ritchie, 2013; Fivez *et al*., 2014; Lu *et al*., 2015; Palacio *et al*., 2014). So seeking a rational grassland management regime is an urgent issue for professionals, herders and the government to achieve sustainable animal production and to maintain the health of the grassland ecosystem (Conant *et al*., 2001; Watkinson & Ormerod, 2001), because overgrazing was widely occurred and resulted in degradation of plant community structure, soil physical and chemical properties, water infiltration features and even soil erosion in grassland ecosystem (Cerdà & Lavee, 1999; Sarah & Zonana, 2015).

Grazing exclusion by fencing was conducted as an effective grassland restoration and management regime to restore soil structure (Prosdocimi *et al*., 2016; Wu *et al*., 2010), nutrients and return grazing potential (Xie *et al*., 2007; Seymour *et al*., 2010; Wang *et al*., 2014; Keesstra *et al*., 2016). However, grazing exclusion could also result in loss of plant density and species richness in high-productivity grassland (Oba *et al*., 2001), which may result from greater competition for canopy resources, for example, light (Borer *et al*., 2014) or/and nutrient availability (Van der Wal *et al*., 2004). Species diversity plays an important role in maintaining ecosystem resilience. And it is necessary to graze at a moderate stocking rate for restoring and maintaining a high level of biodiversity and ecosystem function (Bai *et al*., 2004, 2007; Tilman *et al*., 2006; Shang *et al*., 2008; Wu *et al*., 2009; Cong *et al*., 2014; Qian *et al*., 2014). Furthermore, grazing exclusion might result in slowing down the rates of carbon (C) and nitrogen (N) cycling and reduction of soil C stocks (Hafner *et al*., 2012). Therefore, reduction

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of grazing intensity without excluding grazing would be considered a regime for restoring degraded grassland (Buttolph & Coppock, 2004; Medina-Roldán *et al*., 2012; Papanastasis *et al*., 2015).

The Qinghai–Tibetan Plateau is susceptible to climate change and anthropogenic perturbation, because of its fragile ecosystem, which plays a vital role in mediating future global carbon cycling. Grassland soil on the Qinghai–Tibetan Plateau stores a huge amount of organic carbon, which is about 2·5% of the global soil C pool (Wang *et al*., 2002; Xie *et al*., 2014). Animal husbandry represents the traditional land use on Qinghai–Tibetan Plateau (Hafner *et al*., 2012). A proverb that 'Habitat is constructed following water and grass' showed mobility is a feature of animal husbandry on Qinghai–Tibetan Plateau. Animals are usually moved by herders onto the meadow that grows very well. The grazing mode is 'pure nomad', and animals are moved constantly year-round (Long *et al*., 2008). Because of the increasing disturbance from the increase of livestock numbers over the last 50 years and one-third of grassland was degraded, grazing regime adjustments (including grazing intensity and grazing season) were potential effective strategies to increase soil nutrients on the Tibetan grasslands (Chang *et al*., 2014). However, previous studies focused on potential for C and N sequestration only at the topsoil profile, and few studies addressed the vertical distribution of soil C, N and water contents, bulk density at the depth of 0- to 100-cm soil (Liu *et al*., 2012; Chang *et al*., 2014). Moreover, it is essential to identify the main factors (such as root biomass, soil water content, soil texture and bulk density) that influenced the soil C and N vertical distribution (Gass & Binkley, 2011).

Compared with the grazing exclusion and heavy grazing, moderate grazing and periodic resting could increase the annual net primary productivity, improve community composition and increase belowground C input; therefore, moderate grazing had a positive effect on soil C stock in alpine meadows (Cingolani *et al*., 2005; García *et al*., 2008; Hafner *et al*., 2012; Cui *et al*., 2014). Seasonal grazing with periodic resting was the main way of using grassland. Traditonally, it was often divided into two seasons for grazing, with the warm-season grazing and the cold-season grazing (Cui *et al*., 2014). On one hand, seasonal grazing may be a good management strategy to maintain species composition and soil texture in alpine meadow. And on the other hand, it could yield benefits to livestock productivity (Buttolph & Coppock, 2004; Cingolani *et al*., 2005). However, few studies have focused on the relative influence of seasonal grazing on the plant–soil interface, plant community composition, diversity and productivity and other soil properties in alpine meadow.

Based on the previous studies, we address the following questions: Is the warm-season or the cold-season grazing favourable to the aboveground and belowground ecological properties in alpine meadow ecosystem? The main objectives of this study were (i) to explore the relative influence of seasonal grazing on the aboveground and belowground ecological properties and (ii) to provide valuable insight into the plant–soil interface process with important implications for grazing management of the alpine meadow. This study will contributed to keep alpine meadow sustainability by the suitable grazing regime in the Qinghai–Tibetan Plateau.

MATERIAL AND METHODS

Study Site and Experimental Design

The study habitat was situated in the eastern part of the Qinghai–Tibetan Plateau, within the Maqu county, Gansu Province, PR China (Figure 1). The mean altitude was about 3,500 m, and the physionomy of the Qinghai–Tibetan Plateau was typical altiplano. According to data available for the period 2003–2012 at the study site from the National Meteorological Information Center of China, the mean annual air temperature was 2·6 °C, ranging from −7·7 °C in January to 12·0 °C in July. The annual precipitation was 628·3 mm, approximately 80% falling during the short, cool summer. Cloud-free solar periods represent about 2,511 h. The soil type of the study area was mainly Mat Cryi-gelic Cambisols (alpine meadow soil, Cambisols in Food and Agriculture Organization/United Nations Educational, Scientific and Cultural Organization taxonomy), and grazer was mainly Tibetan sheep and yaks (Xie *et al*., 2014). The vegetation was typically an alpine meadow (Wu *et al*., 2009), and it consisted mainly of arctic–alpine and Chinese Himalayan plants and was dominated by aboriginal

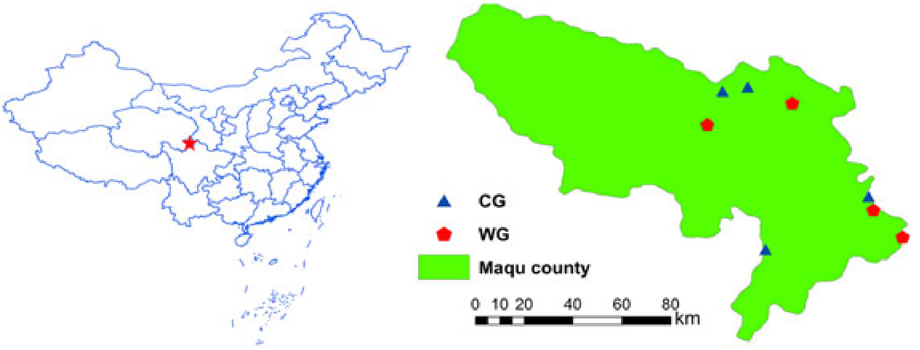

Figure 1. Sampling sites of the four warm-season grazing meadows (WG) and the four cold-season grazing meadows (CG) in Maqu county. [Colour figure can be viewed at wileyonlinelibrary.com]

constructive species, sedges (*Kobresia*) and grasses (e.g. *Agrostis*, *Elymus*, *Festuca*, *Poa* and *Stipa*).

The alpine meadow was divided into two seasons for grazing, with the warm-season grazing from June to October and the cold-season grazing in the other months from 2003 (Cui *et al*., 2014). A one-way factorial design (season grazing) was used by two treatments with four replicates: the warm-season grazing meadow (WG) and the cold-season grazing meadow (CG). We selected a 100 × 100 m block for each replicate and one plot (60 × 80 m) randomly established in each plot. The grazing intensity was 2–2·5 Tibetan sheep per hectare of WG and 1–1·5 Tibetan sheep per hectare of CG. The rate of herbage utilization is about 30% for warm-season and cold-season grazing intensities (Dong *et al*., 2015). In mid-September 2013, when community biomass and root biomass peaked, selected five sampling quadrats (0·5 × 0·5 m) at 20-m intervals along a 100-m line transect in each plot (Wu *et al*., 2011). In total, we surveyed plant cover and height, aboveground and belowground biomass and soil samples in 0- to 100-cm soil cores at 40 quadrats in this experiment.

Community Sampling

In each quadrat, all green aboveground plant parts for each individual species were cut, collected and put into envelopes and tagged. Aboveground biomass was divided into three functional groups: graminoid species, forb species and legume species. Belowground biomass was carried out three times at six soil layers, 0–10, 10–20, 20–30, 30–50, 50–70 and 70–100 cm depth using a 9-cm diameter root auger in each quadrat. The majority of roots were found in soil samples, thus obtained and then isolated using a 0·5-mm sieve. The root tissue and aboveground plant were dried at 65 °C for at least 48 h and weighed to determine dry matter mass.

Plant density (N, m^{-2}) was the total number of the individual plants per square metre. Richness index (R, m^{-2}) was the total number of the species per square metre. Shannon–Winener's diversity index (H) and Pielou's evenness index (E) of each quadrat were calculated (Wu *et al*., 2009).

Soil Sampling and Determination

Composite soils consisting three soil cores were taking using a soil auger (4 cm inner diameter) from the same quadrats after the aboveground plant harvested in six soil layers as the root samplings. All soil samples were air-dried and then passed through a 0·14-mm sieve. Soil pH was determined using a soil–water ratio of 1:5, and soil water content before air drying was obtained by the oven-drying method. Soil bulk density ($g\,cm^{-3}$) of different soil layers was measured using the soil cores (volume, 100 cm^3) by the volumetric ring method. Soil organic carbon was assayed by dichromate oxidation (Nelson & Sommers, 1982), soil total nitrogen using the modified Kjeldahl method (Bremner, 1996). Soil C, N density ($kg\,m^{-3}$) and volumetric water content ($mm\,m^{-1}$) were calculated by multiplying soil C, N and water content by soil bulk density. Soil C, N stocks ($kg\,m^{-2}$) and water stocks (mm) per depth were calculated by soil C, N density and volumetric water content by soil depth. Summing up the soil C and N stocks of the different soil layers resulted in the cumulative soil C, N and water stocks (Cong *et al*., 2014).

Statistical Analyses

All data were expressed as mean ± standard error of mean in 20 quadrats. One-way analysis of variance was performed to test for differences in biomass, functional group proportions, plant diversities, soil properties, soil C, N and water densities and stocks between the WG and the CG to assess the effects of seasonal grazing on vegetation components and soil characteristics. Pearson's correlation coefficients were achieved to explore the potential correlations between plant and soil characteristics. Non-normal data were log-transformed before analysis, and all effects and comparisons were considered significant at the 0·05 level. All statistical analyses were performed using the software programme SPSS, version 12·0 (SPSS Inc., Chicago, IL, USA), and figures were calculated using SIGMAPLOT version 8·0 (Systat Software Inc., San Jose, CA, USA).

RESULTS

Effects of Seasonal Grazing on Community Structure and Diversity

Compared with the CG, 10-year WG resulted in some changes in biomass (Table I), functional group proportions (Table II) and plant diversities (Table III). Warm-season grazing had the significantly lower aboveground net primary production ($F_{1,\,38} = 5{\cdot}02$, $p = 0{\cdot}03$), root biomass (0–100 cm, $F_{1,\,38} = 9{\cdot}27$, $p < 0{\cdot}01$) and plant height ($F_{1,\,38} = 15{\cdot}08$, $p < 0{\cdot}01$), but no change in cover ($F_{1,\,38} = 0{\cdot}33$, $p > 0{\cdot}05$), and the ratio of root to shoot ($F_{1,\,38} = 0{\cdot}40$, $p > 0{\cdot}05$) were found. Biomasses at the all six soil layers in WG were significantly lower than in CG (Figure 2a). Belowground

Table I. The mean values (SE) of community properties in grazing meadows ($n = 20$)

Treatment	ANPP ($g\,m^{-2}$)	BGB ($g\,m^{-2}$)	Height (cm)	Cover (%)	R/S
CG	246·61 (16·72)	2,899·76 (247·99)	34·90 (1·94)	96·10 (1·55)	13·83 (1·92)
WG	192·44 (17·47)	2,009·60 (154·82)	22·12 (2·66)	94·65 (1·97)	12·32 (1·40)
$F_{1,\,38}$	5·02	9·3	15·08	0·34	0·40
p	0·03	<0·01	<0·01	0·57	0·53

ANPP, aboveground net primary production; BGB, root biomass; R/S, the ratio of root to shoot; WG, warm-season grazing meadows; CG, cold-season grazing meadows; SE, standard error.

Table II. The mean values (SE) for biomass proportions of three functional groups in grazing meadows ($n=20$)

Treatment	Forb	Legume	Graminoid
CG	35·87 (2·50)	8·13 (2·10)	56·00 (2·54)
WG	48·71 (4·46)	5·78 (1·53)	45·52 (4·29)
$F_{1,\ 38}$	6·30	0·82	4·43
p	0·02	0·37	0·04

WG, warm-season grazing meadows; CG, cold-season grazing meadows; SE, standard error.

biomass of the 0- to 20-cm soil profile was more than 90% of the belowground biomass in 100-cm soil (Figure 2b). The dominant species proportions under CG were graminoid functional group (graminoid species, 56·00%), whereas in WG, forb functional group (forb species, 48·71%) was dominant. Legume functional group proportions (legume species) of CG and WG were similar. Plant density (N) and evenness index (E) increased from 1,393·80 to 2,063·30 ($F_{1,\ 38}=10{\cdot}33$, $p<0{\cdot}01$) and 0·65 to 0·69 ($F_{1,\ 38}=4{\cdot}76$, $p=0{\cdot}04$) under WG compared with CG, respectively. Species richness (R) and Shannon–Winener’s diversity index (H) were similar between WG and CG.

Overall, the warm-season grazing increased forb functional group proportion, plant density and evenness index by 36%, 48% and 7%, respectively, but decreased aboveground net primary production, root biomass, plant height and graminoid functional group proportions by 22%, 31%, 16% and 37%, respectively.

Effects of Seasonal Grazing on Topsoil Properties

Soil properties showed the different advantages between the cold-season grazing and the WGs (Figure 3). Soil bulk density of WG at the surface 10-cm soil was significantly higher than CG. But CG had a significantly higher bulk density at the depth of 30–50 cm. Soil pH value in WG was higher at the depth of 0- to 50-cm soil and lower at the depth of 50–100 cm than the CG. Soil water contents in WG were higher than CG at all the six soil depths. Soil organic carbon content at the surface 10-cm soil was significantly greater in the WG than in CG. Total nitrogen content was also slightly higher at the depth of 0–10 cm in WG. But soil organic C and N were significantly lower in WG than CG at the 30- to 50-cm soil depth.

Soil C density and soil N density of CG were lower only at the depth of 0–10 cm, but higher at the 10–100 cm than WG at the same soil layers (Figure 4). Volumetric water content of CG was lower at the depth of 0–30 and 50–100 cm and higher only at the depth of 30–50 cm compared with the other soil layers (Figure 4). The lower density of soil C, N and water at the surface 10-cm soil in CG was both due to the lower surface soil (0–10 cm) bulk density in CG compared with WG (0·95 vs 1·03 g cm^{-3} in CG and WG treatments, respectively) and the lower contents of C, N and water in the surface 10 cm of the soil profile in CG than in WG (Figure 3). Correspondingly, the higher density of C, N and water at the depth of 30- to 50-cm soil was due to both the higher soil bulk density in CG and higher contents

Table III. Comparisons of diversity in grazing properties ($n=20$)

Treatment	S	N	H	E
CG	17·45 (1·19)	1,393·80 (104·74)	1·81 (0·05)	0·65 (0·01)
WG	16·45 (0·84)	2,063·60 (180·20)	1·92 (0·06)	0·69 (0·02)
$F_{1,\ 38}$	0·47	10·33	1·85	4·76
p	0·50	<0·01	0·18	0·04

S, species richness; N, the total number of the individual plants; H, Shannon–Winener’s diversity index; E, Pielou’s evenness index; WG, warm-season grazing meadows; CG, cold-season grazing meadows.

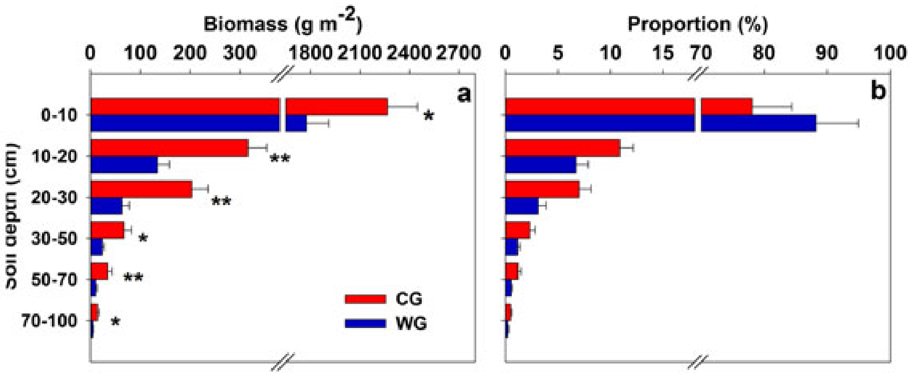

Figure 2. Averaged profiles for root biomass (a) and root biomass proportional (b) distributions in the top 100 cm of soil at the WG and CG meadows. Error bars express standard error of the mean ($n=20$). Note: WG, the warm-season grazing meadows; CG, the cold-season grazing meadows. $^{**}p<0{\cdot}01$; $^{*}p<0{\cdot}05$; no symbol, no significant difference. [Colour figure can be viewed at wileyonlinelibrary.com]

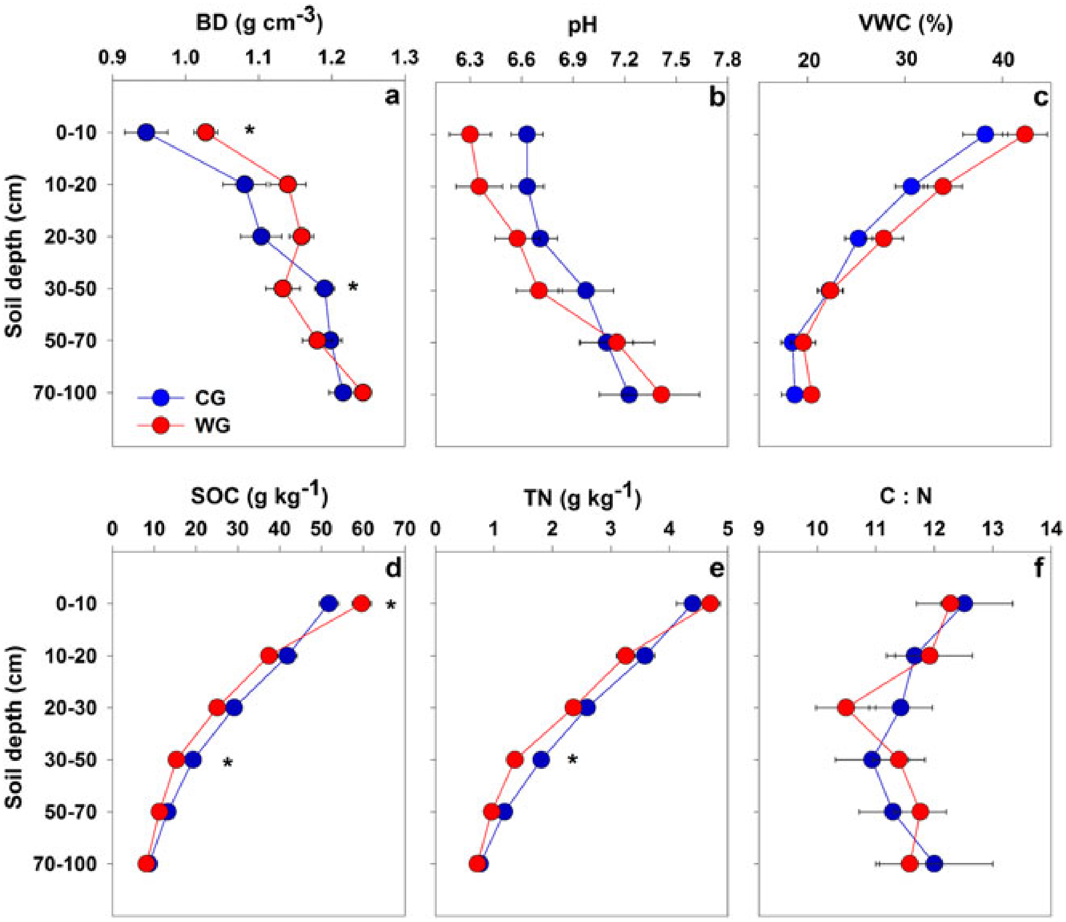

Figure 3. Averaged profiles for soil properties and distributions in the top 100 cm of soil at the WG and CG meadows. Bulk density (BD, a), soil water content (SWC, c), soil carbon content (SOC, d) and soil total nitrogen (TN, e). Error bars express standard error of the mean ($n = 20$). Note: WG, the warm-season grazing meadows; CG, the cold-season grazing meadows. $^{*}p < 0{\cdot}05$; no symbol, no significant difference. [Colour figure can be viewed at wileyonlinelibrary.com]

of C, N and water at the depth of 30- to 50-cm soil in CG than WG.

Soil C, N, water content and soil C, N and water density sharply decreased with the soil depth, while the soil bulk density and pH increased with soil depth both at the warm-season grazing and the CGs (Figure 3,4). The correlation matrix showed significant positive correlations among soil C content, soil N content, soil water content and the belowground biomass ($p < 0{\cdot}01$, Table IV). The soil bulk density and soil pH showed the negative correlations with the soil C, N and water contents ($p < 0{\cdot}01$, Table IV).

Effects of Seasonal Grazing on Topsoil C, N and Water Stocks

Soil C stock at the surface 30-cm soil included about 61% and 68% of the 0- to 100-cm soil C stock in the CG and WG, respectively (Figure 4). Cumulative soil C stocks at the depth of 0–10 and 10–20 cm soils in WG were significantly larger than CG (0·92 vs 0·65 kg m^{-2}). However, the cumulative soil C stocks at 0–50 cm (0·52 kg m^{-2}), 0–70 cm (1·05 kg m^{-2}) and 0–100 cm (1·07 kg m^{-2}) soil depth in CG were larger than the WG. Compared with those in WG, cumulative soil N stocks in CG were −0·06, −0·04, −0·03, 0·09, 0·15 and 0·15 kg m^{-2} at depths of 0–10, 0–20, 0–30, 0–50, 0–70 and 0–100 cm, respectively. Soil water stocks at the WG were higher at the six cumulative soil depths and around 24 mm higher than CG at the depth of 0–100 cm.

DISCUSSION

Plant Community Response to Seasonal Grazing

Our results indicated the multiple advantages of the alternative utilization of cold-season grazing and the warm-season grazing. Generally, continuous warm-season grazing reduced source size of carbon assimilating organs and intensified re-translocation of root carbohydrates to shoot meristems than that at the cold-season grazing (Gao *et al.*, 2008). And thus, the CGs showed a greater root biomass compared with the WGs. Plant function group composition may influence soil decomposer diversity through the differences of substrates and habitats (Porazinska *et al.*, 2003), and these effects exerted by controlling the timing and duration of favourable periods for plant growth (Perez-Camacho *et al.*, 2012). Pulido *et al.* (2016) also showed that the heavy

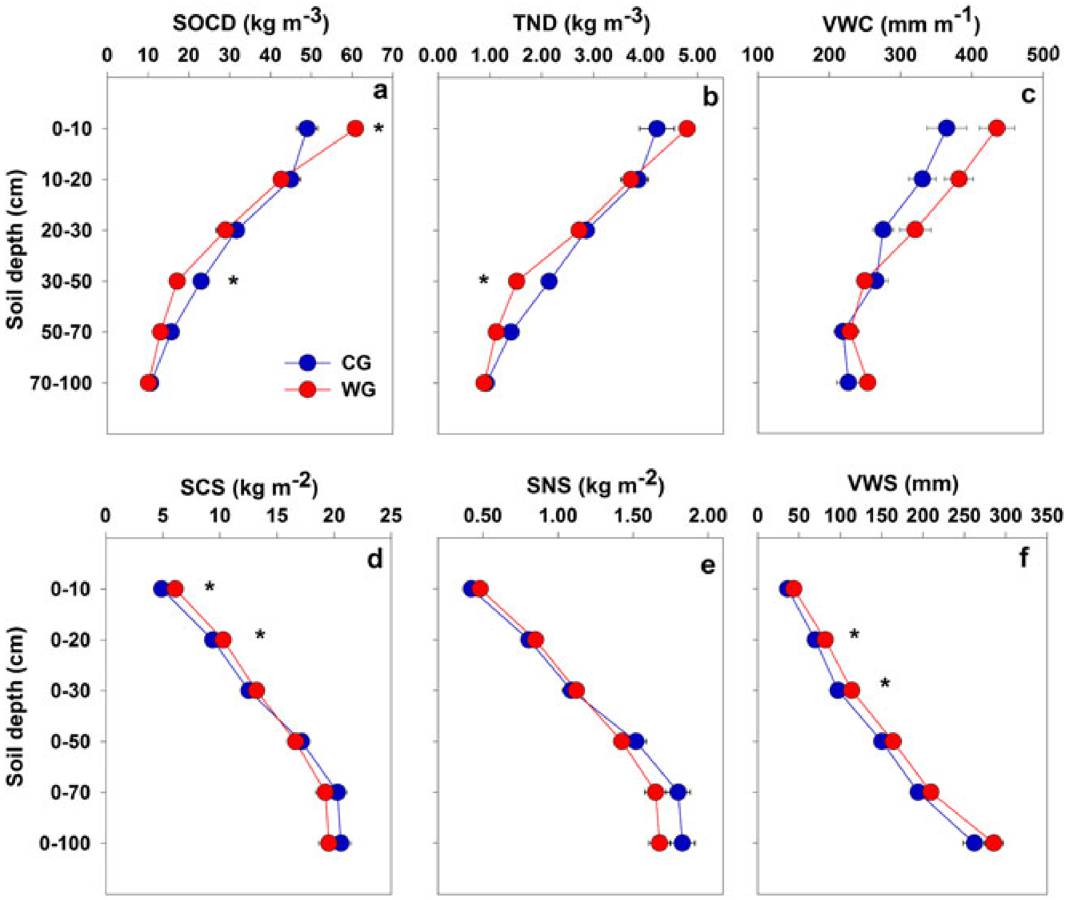

Figure 4. Averaged profiles for soil carbon, nitrogen, water density and stocks distributions in the top 100 cm of soil at WG and CG meadows. Error bars express standard error of the mean ($n = 20$). Note: WG, the warm-season grazing meadows; CG, the cold-season grazing meadows; SOCD, TND and VWC represent the soil carbon, total nitrogen density and volumetric water content; SCS, SNS and VWS represent the soil carbon, total nitrogen and water stock. $^{*}p < 0{\cdot}05$; no symbol, no significant difference. [Colour figure can be viewed at wileyonlinelibrary.com]

grazing results in the reduction of legumes proportion in rangelands of SW Spain. Graminoid had predominantly positive responses, whereas forb species mostly showed negative responses to cold-season grazing (Diaz *et al.*, 2007). The current results recommended that graminoid function group proportions, biomasses benefit from the cold-season grazing.

Plant density and evenness index significantly increased, while biomass decreased at the WGs. The relationship between biomass and species richness had been described as a hump-back response model (Oba *et al.*, 2001), and the optimum richness might be corresponded to a biomass level belowground the aboveground biomass at this study sites. Angassa (2014) also reported that herbaceous species richness was highest at an intermediate level of biomass and seems to decline as biomass increases. The quality of C entering soil is a key controlling factor for belowground transformation processes that primarily depend on the composition of plant communities (Klumpp *et al.*, 2009; Breulmann *et al.*, 2012; Cong *et al.*, 2014). The nutrient that was input to soil may be greater in more diverse communities, because high plant diversity may enhance soil fertility or improve

Table IV. Pearson's correlation coefficients matrix of soil properties both at the warm-season grazing and the cold-season grazing meadows

	SOC	TN	SWC	pH	BD
TN	0·950**	—	—	—	—
SWC	0·784**	0·769**	—	—	—
pH	−0·397**	−0·343**	−0·405**	—	—
BD	−0·504**	−0·457**	−0·366**	0·141*	—
RB	0·674**	0·660**	0·513**	−0·161*	−0·405**

SOC, carbon content; TN, total nitrogen content; SWC, soil water content; BD, bulk density; RB, root biomass.
*significant effects at $p < 0{\cdot}05$.
**significant effects at $p < 0{\cdot}01$.
***significant effects at $p < 0{\cdot}001$.

ecosystem stability and productivity (Dybzinski *et al*., 2008; Steinbeiss *et al*., 2008; Isbell *et al*., 2015). The results indicated that the warm-season grazing might be an optimal grassland regime for the conservation of species diversity.

Soil Paramenters Response to Seasonal Grazing

Overall, the warm-season grazing could increase soil C, N contents and soil C, N density only at the top 0- to 10-cm soil, increase soil bulk density at the top 0- to 30-cm soil, decrease pH at the top 0- to 50-cm soil and increase soil water content at the 0- to 100-cm soil compared with cold-season grazing. The cold-season grazing significantly increased soil C, N content and C, N density at the depth of 30–50 cm soil. The reasons for the higher soil nutrient at the upper 10-cm soil by warm-season grazing might be the following: First, trampling by animals at the WGs had a larger physical breakdown, and acceleration of the decomposition process by fragmenting plant material and mingling of the litter in the soil than the CGs (Naeth *et al*., 1991; Zacheis *et al*., 2002). Second, livestock dung deposition and urine input as well as nitrification rates increased at the WGs, while the CGs slowed down the decomposition process of nutrient cycling and microbial activity because of the lower temperature (Augustine *et al*., 2003; Bardgett & Wardle, 2003; Gass & Binkley, 2011; Wu *et al*., 2012; Fivez *et al*., 2014). Finally, the WGs had a higher plant density and plant diversity, which were the principal factors determining soil nutrient dynamics via enhancing N mineralization through the diversity of substrates and habitats they provide (Porazinska *et al*., 2003; De Deyn *et al*., 2008; Cong *et al*., 2014). Plant trait composition influenced soil decomposer diversity, and decomposer diversity in turn can affect soil nutrient cycling through functional complementarity (Hättenschwiler *et al*., 2005; Wardle, 2006). The CG meadows had the higher soil C, N contents at the depth of 10–100 cm soil than the WG meadows, which might be caused by the greater root density, higher rates of root exudate (Frank *et al*., 1995; Augustine *et al*., 2003; Klumpp *et al*., 2009). This indicated that the topsoil was more active in carbon and nitrogen sequestering at the WGs but it was the deep soil in the CGs.

Seasonal grazing also influenced the soil physical characteristics and soil pH and soil water content, and those effects might change the soil carbon and nitrogen. Soil bulk density were lower at the CGs because of the reduction of compaction influence from animal trampling for the frozen soil, compared with the WGs (Shi *et al*., 2013). The marginally decreased of soil water content at the CGs was in line with previous studies, as the cold-season grazing often decreased surface roughness length and snow capture resulted in a reduction of the insulation of the soil, snow cover and wintertime water retention (Wu *et al*., 2012). Our results found that pH was higher at the WGs at the top 50-cm soil, while larger at the CGs at the 50- to 100-cm soil. The pH difference caused by seasonal grazing might result from different root biomass and the livestock dung deposition and urine input (Van der Wal *et al*., 2004).

Soil Nutrient Habitats Response to Seasonal Grazing

The decreasing in soil C, N, water contents and soil C, N, water densities in the alpine meadow with the increase of soil depth was in agreement with the previous published results on the Qinghai–Tibetan Plateau (Yang *et al*., 2010; Liu *et al*., 2012). The root was also mainly distributed at the top 20 cm and sharply decreased with soil depth. The vertical distribution of soil nutrients was attributed to the distribution of roots in the soil and the related soil processes (Chen *et al*., 2007; Liu *et al*., 2014), which was illustrated by the increased rhizodeposition at the topsoil and subsequent increase in soil organic matter turnover (Hafner *et al*., 2012). Root turnover was faster in surface than in deeper soil layers and played an important role in carbon storage and turnover in alpine meadow ecosystem (Wu *et al*., 2011). Furthermore, soil water content was the most important parameter for the vertical variation of soil nutrients, and the belowground biomass was the main source of soil C, N (Liu *et al*., 2014). As a consequence, the significantly higher C, N density in the upper 30-cm soil layers was due to the higher root biomass, soil water content and subsequently enhanced C, N stocks in soil (Rasse *et al*., 2005). Soil C, N contents and densities declined dramatically with depth deepening suggested that the large potential for improving soil C, N contents existing in alpine meadow of the Qinghai–Tibetan Plateau by grassland regime adjustment, particularly in the topsoil.

The cumulative soil C, N and water stocks vertical distribution revealed that the cumulative C and N stocks were significantly distributed at the top 30-cm soil in both CG and WG and the carbon and nitrogen sequestrations might be mainly concentrated at the topsoil after the suitable grassland regimes (Liu *et al*., 2012). And the cumulative soil C and N stocks at depths of 0–10, 0–20 and 0–30 cm soil layers were larger at WG than CG, but at depths of 0–50, 0–70 and 0–100 cm soil layers, they were higher at CG than WG. When we compared the soil C, N and water stocks, deep soil cannot be neglected. Finally, soil water stocks were larger under WG than CG at all soil layers, and the warm-season grazing was beneficial for the soil water stock.

CONCLUSIONS

Seasonal grazing is a key factor for the plant biomass, plant height, plant diversity and plant function groups on the Qinghai–Tibetan Plateau. The warm-season grazing is more suitable for the species diversity conservation and the nutrient sequestration at the topsoil. However, the cold-season grazing is more suitable for the nutrient sequestration at the deep soil. The WGs and the CGs should be used alternatively yearly or more for protecting plant diversity and improving soil texture and soil C and N stocks. The warm-season and cold-season grazing might be exchanged regularly to practice continuous carbon and nitrogen sequestration. Periodic cold-season and warm-season grazing would be the suitable grazing regime to achieve sustainability of alpine grassland ecosystems. Further researches should be carried out to derive optimal prescribed rotation grazing strategies at different seasons, and which should incorporate more holistic evaluations of the effects of management change on the social and economic viability.

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