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Effect of clipping on aboveground biomass and nutrients varies with slope position but not with slope aspect in a hilly semiarid restored grassland

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ABSTRACT

Clipping is a common management option in semiarid grasslands, but whether topography mediates the effects of clipping on plant and soil nutrients is poorly studied. We examined the interacting effects of clipping and topography (slope aspect and slope position) on the aboveground biomass and carbon (C) and nutrient concentration of graminoid and forb, as well as on soil organic carbon (OC) and nutrient content in a restored grassland under long-term grazing exclusion. Clipping increased the aboveground biomass of forb and total community, and decreased most C and nutrient concentration in aboveground biomass, but did not influence the aboveground biomass of graminoid or the content of soil OC and nutrient. Slope aspect did not change the effects of clipping on most plant aboveground biomass, or soil OC and nutrients. However, slope position altered the effects of clipping on soil inorganic nitrogen, total phosphorus, and available potassium, with lower nutrient levels on the upper slope but higher nutrient levels on the middle and lower slopes. The results demonstrate that slope position should be considered in predicting the response of soil biogeochemical processes to clipping in hilly semiarid restored grasslands.

1. Introduction

Clipping is one of the most prevalent management operations in semiarid grasslands and affects many ecological characteristics of that ecosystem (Carlyle et al., 2014; Dickson and Foster, 2008; Shahzad et al., 2012; Zhong et al., 2017). The use of clipping has increased because grazing exclusion, although initially benefiting plant productivity and ecosystem stability (Cheng et al., 2016; Deng et al., 2017), has a negative effect on plant productivity and diversity over the long-term (Borer et al., 2014; Jing et al., 2013). Clipping is thought to mimic natural grazing and can potentially reshape long-term grazing-excluded grasslands through its effects on plant productivity, species composition, and nutrient cycling (Li et al., 2015; Li et al., 2017). However, studies of the effects of clipping on plant and soil nutrients in restored grasslands are actually rare. This lack of knowledge limits our understanding of nutrient cycling and the long-term sustainable management of restored grasslands.

Clipping can greatly affect plant productivity and nutrient cycles. Clipping directly reduces green leaf area, and thus suppresses plant photosynthesis and the accumulation of primary productivity (Bai et al., 2015; Tuffa et al., 2017). Meanwhile, clipping can cause compensatory growth and even over-compensatory growth (Alhamad and Alrababah, 2008; Loeser et al., 2004; Zhao et al., 2008). But this effect largely depends on vegetation type, clipping intensity, and habitat conditions (He et al., 2017; Stevens and Gowing, 2014; van Staalduinen et al., 2010). Clipping influences nutrient cycling by (1) promoting root exudation, which is quickly assimilated by soil microbes and positively feeds back on soil inorganic nitrogen (N) pools and plant N uptake (Hamilton and Frank, 2001); (2) reallocating more plant nutrients from belowground to aboveground biomass (Wei et al., 2016; Zhao et al., 2008); (3) changing the rate of litter decomposition and soil organic matter mineralization (Bai et al., 2010; Brandt et al., 2010; Shahzad et al., 2012); (4) accelerating nutrient losses through leaching or runoff as canopy cover and litter decline (Castillo et al., 1997; Qian et al., 2003); and (5) reducing soil nutrients due to the lower input from aboveground parts (Belay-Tedla et al., 2009; Du et al., 2014). These processes can accelerate nutrient cycling in long-term grazing-excluded grasslands (Li et al., 2017; Semmartin et al., 2008).

Topography impacts microclimate, modifying vegetation and soil properties, and influencing ecosystem structure and function (Burnett

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Table 1
Details of sampling plots.

Treatment	Slope aspect	Altitude (m)	Slope length (m)	Slope degree	Number of sampling plots		
					Upper	Middle	Lower
Control	North	2054–2075	80	12°	3	3	3
	South	2038–2075	140	15°	5	5	5
Clipping	North	2054–2075	80	12°	3	3	3
	South	2038–2075	140	15°	5	5	5

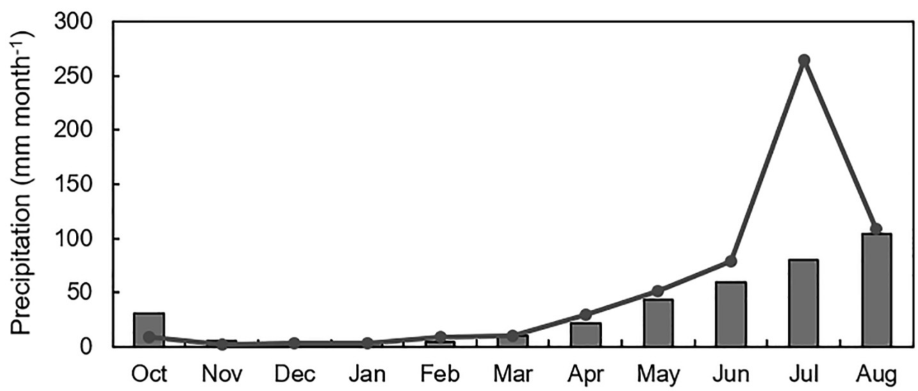

Fig. 1. Monthly precipitation during Oct. 2012 to Aug. 2013 (line) and mean monthly precipitation during 1981 to 2010 (bars) in the Yunwu Mountain National Natural Grassland Protection Zone in the Loess Plateau, China.

Table 2
Multi-way analysis of variance for aboveground biomass and carbon (C), nitrogen (N), phosphorus (P), and potassium (K) concentration in the aboveground biomass of two functional groups (graminoid and forb) and total community as affected by clipping (CL), slope aspect (SA), and slope position (SP) in a semiarid restored grassland.

		CL	SA	SP	CL × SA	CL × SP	SA × SP	CL×SA×SP
	Graminoid	3.74	9.40**	30.88**	4.83*	10.38**	11.21**	2.15
Biomass	Forb	14.07**	5.97	7.44	0.02	4.49	16.69**	0.20
	Community	15.84**	17.97**	12.14*	4.34	4.06	3.87	1.16
	Graminoid	16.05**	26.04**	0.13	0.21	3.79	0.18	4.38
C	Forb	0.75	10.79*	9.84*	1.35	17.99**	4.61	5.26
	Community	12.96**	27.13**	0.85	0.58	4.93	1.32	4.06
	Graminoid	23.42**	3.47	10.74*	0.30	3.75	8.76	0.59
N	Forb	25.56**	11.76**	5.21	0.09	1.87	11.86*	0.06
	Community	23.44**	5.40*	14.99**	2.19	4.79	6.93	0.30
	Graminoid	0.00	0.24	5.11	8.52**	9.98*	10.22*	14.96**
P	Forb	4.62	0.41	14.67*	0.00	8.15	2.58	12.09*
	Community	4.74	0.00	9.76*	0.81	2.17	18.83**	12.47*
	Graminoid	8.21*	12.67**	1.08	2.93	0.06	13.26*	1.16
K	Forb	21.46**	11.85*	5.26	1.48	0.12	1.68	1.47
	Community	1.63	4.07	15.34**	2.13	6.58	26.30**	0.23

All the values present here is the variance contribution of each factor and their interaction according the result of the MANOVA by GLM model; * and ** represent the *P* value < 0.05 and < 0.01, respectively.

et al., 2008; Hook and Burke, 2000; Hoylman et al., 2018; Milchunas et al., 1989; Sebastiá, 2004). North-facing slopes usually have lower temperatures, higher soil moisture, higher soil nutrient content, and more vegetation cover than south-facing slopes (Bennie et al., 2008; Gong et al., 2008; Huang et al., 2015; Wang et al., 2011). This is mainly because north-facing slopes (in the northern hemisphere) receive less solar radiation than south-facing slopes. Slope position also greatly affects microclimate, vegetation, and soil properties through its effect on the amount of solar radiation, wind speed, and the movement of soil particles and water (Chen et al., 2002; Fu et al., 2004; Nahidan et al., 2015; Sariyildiz et al., 2005). Previous studies have found that topographic factors interact with clipping to influence plant productivity (Belesky et al., 2002; Carlyle et al., 2014). However, this interactive effect on plant and soil nutrients remains poorly characterized, hindering our understanding of fine-scale biogeochemical cycles in hilly characterized grasslands.

Based on these prior studies of plant and soil responses to clipping and topography, our hypotheses were: (1) clipping enhances aboveground biomass and plant carbon (C) and nutrient concentration, and that this effect would be greater on the north slopes and lower slopes than the south slope and upper slopes, respectively; (2) clipping increases soil inorganic N, extractable phosphorus (P), and available potassium (K), but decreases soil organic C (OC), total N, and total P, and that these effects would also be greater on north slopes and lower slopes than south slopes and upper slopes, respectively. To test these hypotheses, we compared plant aboveground biomass, C, and nutrients and soil OC and nutrients on restored grassland slopes that had been clipped in the previous autumn and on adjacent unclipped restored grassland slopes. Plants and soils samples were collected from two slope aspects (north and south) and from three slope positions on each slope

Table 3
Effects of clipping on the aboveground biomass and carbon (C), nitrogen (N), phosphorus (P), and potassium (K) concentration in the aboveground biomass of two functional groups (graminoid and forb) and total community in a semiarid restored grassland.

	Treatment	Biomass ($g\,m^{-2}$)	C ($g\,kg^{-1}$)	N ($g\,kg^{-1}$)	P ($g\,kg^{-1}$)	K ($g\,kg^{-1}$)
Graminoid	Control	82.0 ± 4.1^{a}	470.4 ± 3.9^{a}	13.9 ± 0.2^{a}	0.58 ± 0.02^{a}	10.6 ± 0.2^{a}
	Clipping	91.8 ± 9.1^{a}	454.9 ± 2.9^{b}	12.8 ± 0.2^{b}	0.56 ± 0.04^{a}	9.7 ± 0.3^{b}
Forb	Control	46.8 ± 4.1^{b}	474.8 ± 2.9^{a}	19.7 ± 0.3^{a}	1.08 ± 0.03^{a}	26.5 ± 0.6^{a}
	Clipping	63.9 ± 4.5^{a}	471.4 ± 3.0^{a}	17.9 ± 0.3^{b}	1.13 ± 0.02^{a}	24.1 ± 0.4^{b}
Community	Control	128.8 ± 5.5^{b}	472.6 ± 3.1^{a}	15.9 ± 0.2^{a}	0.76 ± 0.02^{a}	16.3 ± 0.5^{a}
	Clipping	155.8 ± 8.8^{a}	461.0 ± 2.5^{b}	14.8 ± 0.2^{b}	0.81 ± 0.03^{a}	15.8 ± 0.5^{a}

Values represent the means ± standard error; different lowercase letters indicate significant ($P < 0.05$) between control and clipping treatments of each functional group and total community.

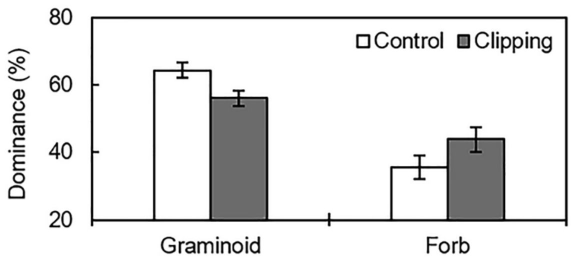

Fig. 2. Effects of clipping on the dominance of graminoid and forb in a semiarid restored grassland. The dominance was calculated by comparing the aboveground biomass of graminoid or forb with the aboveground biomass of total community. Error bars denote two standard errors of the mean. No significant difference ($P > 0.05$) was found between control and clipping treatments.

aspect to test whether the effects of clipping varied with slope aspect and slope position.

2. Material and methods

2.1. Study area

This study was conducted in the Yunwu Mountain National Natural Grassland Protection Zone in the Loess Plateau (106°21′–106°27′E, 36°10′–36°17′N, altitude 1800–2148 m), near Guyuan City, Ningxia Hui Autonomous Region, China. To protect grassland from overgrazing and soil erosion, the protection zone excluded grazing and has been in natural restoration since 1982. Long-term meteorological data (1957–2011) indicates that the mean annual temperature is 6.9 °C, with an annual maximum temperature (22–25 °C) in July and minimum (−14 °C) in January. Mean annual precipitation is 448 mm, with 60–75% occurring in July–September. According to the Chinese taxonomic system, the soil in the study area is a mountain grey-cinnamon soil classified as a Calci-Orthic Aridisol, equivalent to a Haplic Calcisol in the FAO/UNESCO system (Qiu et al., 2015). The vegetation is dominated by the perennial graminoid— *Stipa grandis*, *S. przewalskyi*, and *Carex aridula*. Forbs account for the majority of plant species diversity, including *Artemisia sacrorum*, *Dendranthema lavandulifolium*, *Thymus mongolicus*, and *Potentilla bifurca*.

2.2. Field investigation, sampling design, and laboratory analysis

To test the effects of clipping, we chose one clipped hill as the clipping treatment, and one adjacent unclipped hill as the control. The clipped hill was clipped using a mower in September 2012. Plants were clipped to a height of 3 cm above the soil surface, with most litter removed. Both control and clipping treatments had been in a natural restoration condition (excluded from grazing, fire, clipping, and any other human disturbances) for 30 years before the experiment. To examine the effects of slope aspect and position, we established two sampling slopes (north and south) in both control and clipping treatments, with each slope containing 3 slope positions (upper, middle, and lower). We established 3 (in north slope) or 5 (in south slope) plots (1 m × 1 m) in each slope position (see details in Table 1). The number of plots in each slope position were limited by slope length. Because of the relatively higher canopy cover (> 93%), no significant soil erosion was observed in the grasslands before clipping. The monthly precipitation after clipping was greater than the long-term average, especially in July (Fig. 1). The vegetation type and soil condition of the plots in same slope aspect × position were similar before clipping according to the previous investigation. Therefore, any differences in aboveground biomass and nutrients should be ascribed to the effects of clipping and topography.

In August 2013, when the grassland reached its peak aboveground biomass, we cut all the aboveground biomass (without stand/fall litter) at ground level in each plot. Plants were separated into two functional groups—graminoid and forb. Plant samples were transported to the laboratory, and dried at 65℃ for 48 h, and then weighted. Dried plant samples were ground finely enough to pass through a 1 mm sieve in order to measure plant C, N, P, and K concentration. After aboveground biomass removal, three soil samples from two soil depth (0–10 and 10–20 cm) was collected in each plot with an auger (0–20 cm depth and 5 cm diameter) and mixed into one composite sample per depth and per plot. Soil samples were air-dried after removing the visible roots and litter, and ground to pass through a 2 mm sieve in order to measure soil inorganic N, extractable P, and available K. Then soil samples were ground to pass through a 0.25 mm sieve in order to measure soil OC, total N, and total P.

Nutrients in plants and soils were measured according to standard methods described by Page and Miller (1982). Plant C concentration was determined by the Walkley-Black method. After plant samples were digested in a solution of H_2SO_4-H_2O_2, plant N concentration was determined using the Kjeltec method, plant P concentration was measured colorimetrically with blue phosphor-molybdate, and plant K concentration was analyzed by flame photometry. The stocks of plant C and nutrients were calculated using their concentrations multiplied by aboveground biomass. Soil OC was analyzed using the Walkley-Black method, total N was determined by the Kjeldahl method, total P was analyzed colorimetrically after wet digestion with sulphuric acid and perchloric acid, extractable P was measured by the Olsen method, and available K was measured by flame photometry after extraction by ammonium acetate. Soil inorganic N were determined by a Lachat Flow Analyzer (AutoAnalyzer3-AA3, Seal Analytical, Mequon, WI) after extraction by potassium chloride (Kachurina et al., 2000).

2.3. Data analysis

Multi-way analysis of variance (MANOVA) with a GLM model was conducted to test the independent and interactive effects of clipping, slope aspect, and slope position on plant aboveground biomass and the nutrient concentration in aboveground plants and soils. Correlation analysis was used to examined the relationships between aboveground biomass and soil available nutrients. Data analyses were performed

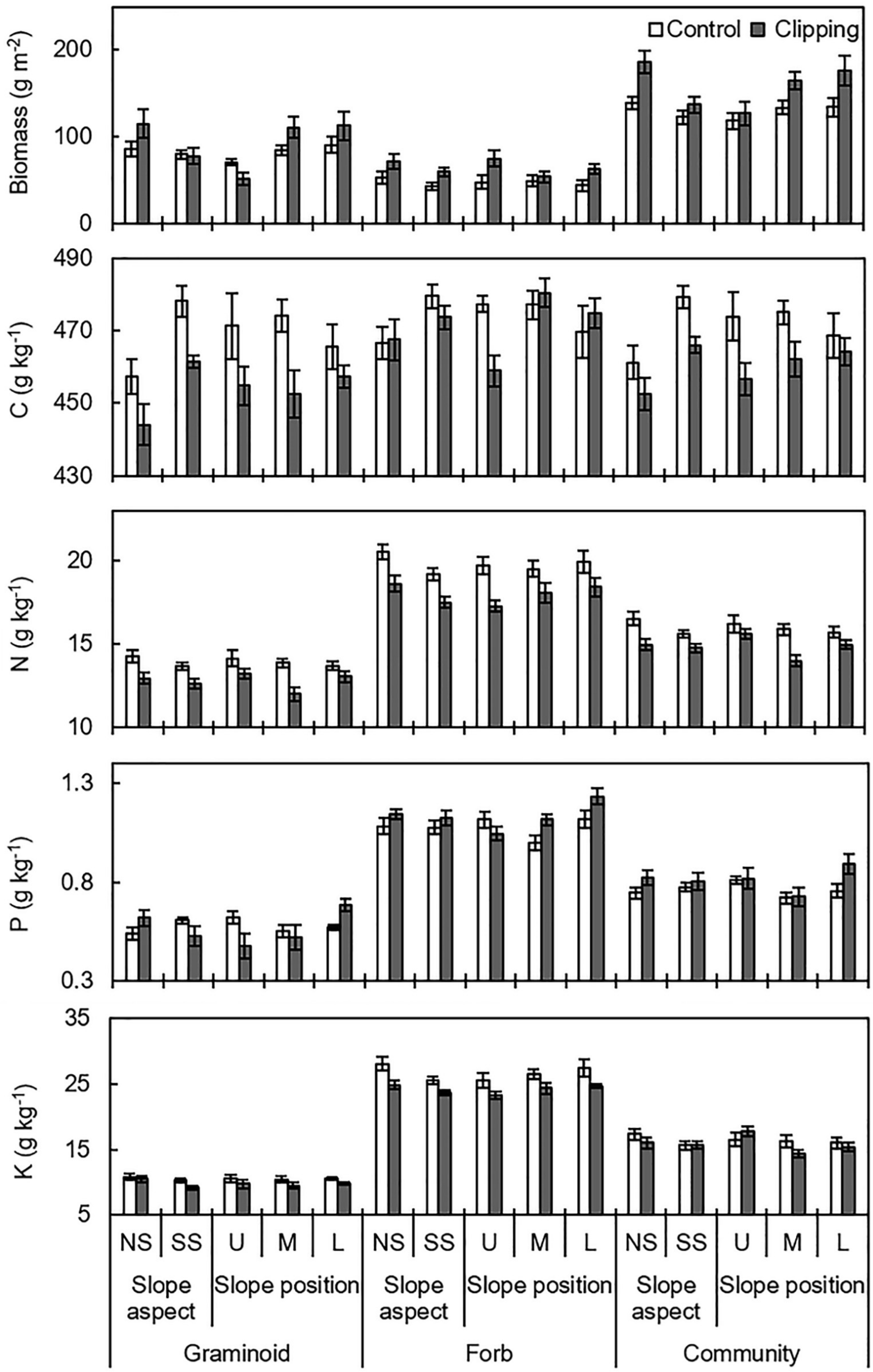

Fig. 3. Effects of clipping on plant aboveground biomass and carbon (C), nitrogen (N), phosphorus (P), and potassium (K) concentration in the aboveground biomass of two functional groups (graminoid and forb) and total community as affected by slope aspect (north (NS) and south (SS)) and slope position (upper (U), middle (M), and lower (L)) in a semiarid restored grassland. Error bars denote the standard errors of the mean.

Table 4
Multi-way analysis of variance (MANOVA) for soil organic carbon (OC), total nitrogen (N), inorganic N, total phosphorus (P), extractable P and available potassium (K) as affected by clipping (CL), slope aspect (SA), slope position (SP), and soil depth (D) in a semiarid restored grassland.

	OC	Total N	Inorganic N	Total P	Extractable P	Available K
CL	1.14	1.09	0.26	0	0.53	0.27
SA	59.50**	62.43**	46.22**	39.37**	37.91**	37.91**
SP	2.38*	2.11*	3.89*	6.30**	4.10**	2.69*
D	12.76**	9.68**	5.01**	8.66**	29.26**	21.92**
CL × SA	0.04	0.10	0.02	0.00	0.06	0.22
CL × SP	1.26	1.28	5.18**	5.25**	1.55	2.89*
CL × D	0.23	0.01	5.46**	0.00	1.02	0.00
SA × SP	1.24	1.51	1.35	0.79	2.33*	0.84
SA × D	0.45	0.28	0.35	0.52	0.02	0.72
SP × D	0.05	0.12	0.12	0.26	0.70	0.62
CL × SA × SP	0.14	0.00	2.69*	0.00	0.14	0.34

All the values present here is the variance contribution of each factor and their interaction according the result of the MANOVA by GLM model; * and ** represent the P value < 0.05 and < 0.01, respectively.

Table 5
Effects of clipping on soil organic carbon (OC), total nitrogen (N), inorganic N, total phosphorus (P), extractable P, and available potassium (K) at 0–10 and 10–20 cm depth in a semiarid restored grassland.

	OC	Total N	Inorganic N	Total P	Extractable P	Available K
	(g kg^{-1})	(g kg^{-1})	(mg kg^{-1})	(g kg^{-1})	(mg kg^{-1})	(mg kg^{-1})
0–10 cm						
Control	27.4 ± 1.3^a	2.7 ± 0.1^a	13.3 ± 0.8^a	0.66 ± 0.01^a	13.4 ± 0.6^a	262.9 ± 14.2^a
Clipping	29.3 ± 1.2^a	2.8 ± 0.1^a	11.6 ± 0.6^a	0.67 ± 0.01^a	14.7 ± 0.6^a	266.9 ± 14.0^a
10–20 cm						
Control	24.0 ± 1.0^a	2.4 ± 0.1^a	13.6 ± 0.6^a	0.63 ± 0.01^a	10.4 ± 0.5^a	197.7 ± 11.0^a
Clipping	24.7 ± 1.0^a	2.5 ± 0.1^a	14.6 ± 0.7^a	0.63 ± 0.01^a	10.1 ± 0.6^a	205.1 ± 11.3^a

Values represent the means ± standard error; different lowercase letters indicate the significant differences ($P < 0.05$) between control and clipping treatments at same soil depth.

with SPSS for Windows (Version 23.0, SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Aboveground biomass and plant C and nutrients

Clipping increased plant aboveground biomass, and this effect varied by plant functional group (Tables 2 and 3). The aboveground biomass of forb was 37% higher in the clipping treatment than the control ($P < 0.05$), while the aboveground biomass of graminoid was only 12% higher ($P > 0.05$). At the community level, clipping significantly increased aboveground biomass (+21%, $P < 0.05$). Furthermore, clipping decreased the dominance of graminoid (from 64% to 56%, $P = 0.061$) and increased that of forb (from 36% to 44%, $P = 0.061$) (Fig. 2).

Clipping significantly decreased the concentration of most C and nutrient in aboveground biomass (Table 3). For example, the concentration of N and K were significantly decreased by clipping across graminoid (−8% for both N and K, $P < 0.05$) and forb (−9% for both N and K, $P < 0.05$). The effects of clipping on plant C was impacted by plant functional group, with a 3% decrease ($P < 0.05$) in graminoid but no significant response in forb (−1%, $P > 0.05$). The concentration of P was not affected by clipping in either graminoid or forb ($P > 0.05$). At the community level, clipping significantly reduced the concentration of C (−2%, $P < 0.01$) and N (−7%, $P < 0.01$), but did not affect the concentration of P (+6%, $P > 0.05$) or K (−3%, $P > 0.05$).

Slope aspect and position also dramatically affected aboveground biomass and plant C, N, and K, and these effects varied with functional group (Table 2). However, the interaction between clipping and slope aspect or clipping and slope position had less influence on aboveground biomass and plant C and nutrient concentration (Table 2). Significant interactions were only observed in aboveground biomass and P concentration of graminoid and in C concentration of forb (only significant for the interaction between clipping and slope position). For example, clipping significantly increased the aboveground biomass of graminoid on the north slope (+34%, $P < 0.05$) but had no effect on the south slope (−2%, $P > 0.05$) (Fig. 3). Therefore, the effects of clipping on most aboveground biomass and plant C and nutrient concentration were consistent across slope aspect and slope position for both plant functional group and the community level.

3.2. Soil organic carbon and nutrients

Clipping did not affect the content of soil OC and nutrient consistently across soil depth (Table 5). For example, soil OC was similar between control and clipping treatments at both 0–10 (27.4 vs. 29.3 g kg^{-1}, $P > 0.05$) and 10–20 cm (24.0 vs. 24.7 g kg^{-1}, $P > 0.05$) depths. Soil inorganic N was also similar between control and clipping treatments at both 0–10 (13.3 vs. 11.6 mg kg^{-1}, $P > 0.05$) and 10–20 cm (13.6 vs. 14.6 mg kg^{-1}, $P > 0.05$) depths.

Slope aspect strongly affected soil OC and nutrient content (Table 4), with higher levels on the north slope than that on the south slope (Fig. 4). Nonetheless, slope aspect did not change the effects of clipping on soil OC and nutrient content (Table 4). For example, soil OC content was similar between control and clipping treatments across slope aspect at 0–10 cm depth on north (34.8 vs. 35.2 g kg^{-1}, $P > 0.05$) and south (23.6 vs. 25.8 g kg^{-1}, $P > 0.05$) slopes, and at 10–20 cm depth on north (29.2 vs. 29.9 g kg^{-1}, $P > 0.05$) and south (20.9 vs. 21.6 g kg^{-1}, $P > 0.05$) slopes (Fig. 4).

Slope position also affected soil OC and nutrient content, but its effects were much smaller than the effects of slope aspect or soil depth (Table 4). However, slope position significantly altered the effects of clipping on soil OC and nutrient content (Table 4). Most soil nutrients decreased following clipping on the upper slope but increased on the middle and lower slopes (Fig. 4), especially for soil inorganic N, total P, and available K ($P < 0.05$ for the interaction between clipping and slope position) (Table 4). For example, the content of soil total P was

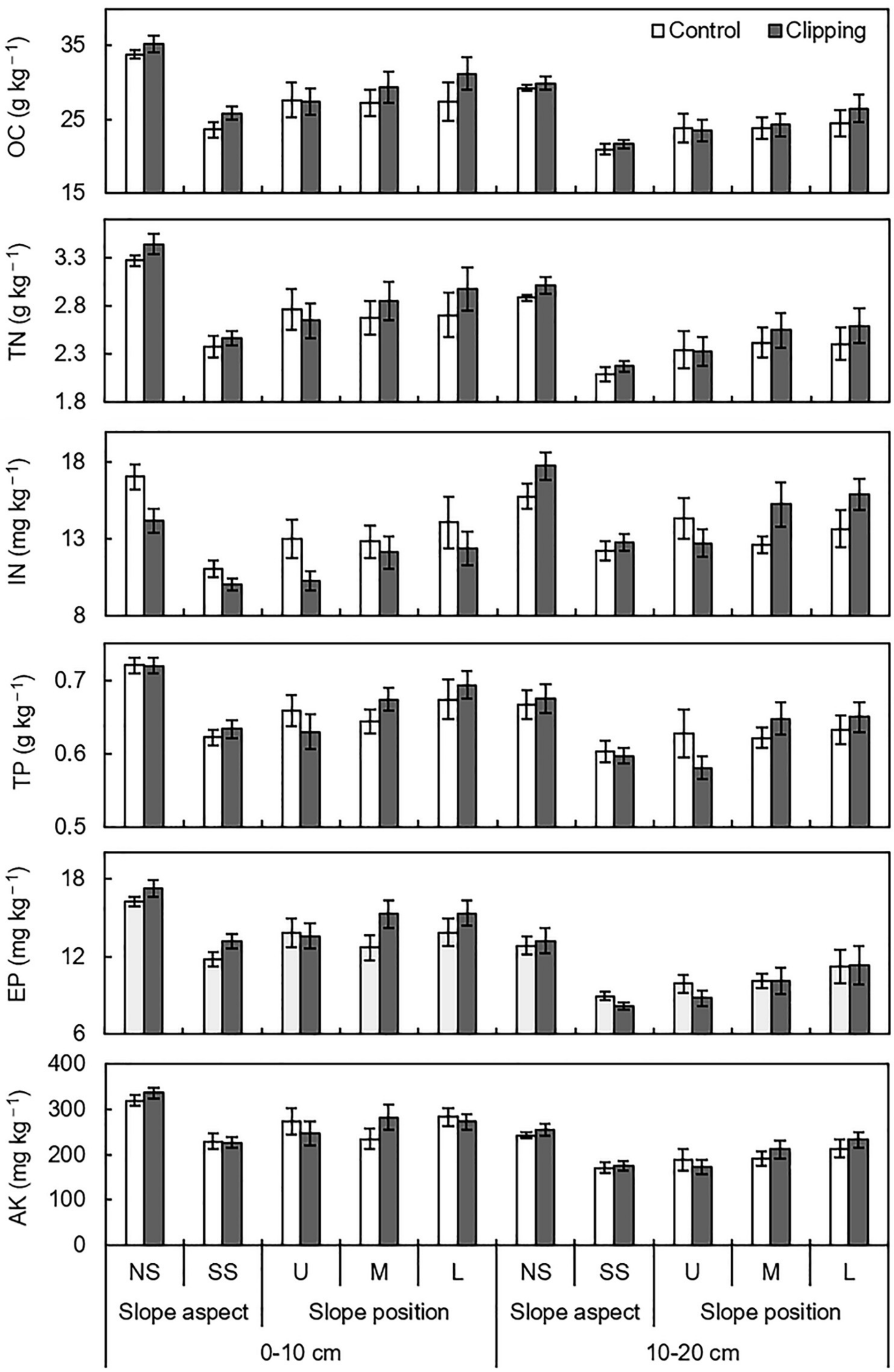

Fig. 4. Effects of clipping on soil organic carbon (OC), total nitrogen (TN), inorganic nitrogen (IN), total phosphorus (TP), extractable phosphorus (EP), and available potassium (AK) at 0–10 and 10–20 cm depth as affected by slope aspect (north (NS) and south (SS)) and slope position (upper (U), middle (M), and lower (L)) in a semiarid restored grassland. Error bars denote the standard errors of the mean.

decreased on the upper slope (−4% and −7% for 0–10 and 10–20 cm, respectively, $P > 0.05$) but was increased on the middle (+5% and + 4%, for 0–10 and 10–20 cm, respectively, $P > 0.05$) and lower slope (+3% for both 0–10 and 10–20 cm, $P > 0.05$) (Fig. 4).

4. Discussion

4.1. Aboveground biomass and plant C and nutrients

Supporting our hypotheses, the clipping treatment increased aboveground biomass. This response is a common feature in clipped grasslands and possibly because plants have the capacity to compensate or even over-compensate for clipping (Loeser et al., 2004; Wallace

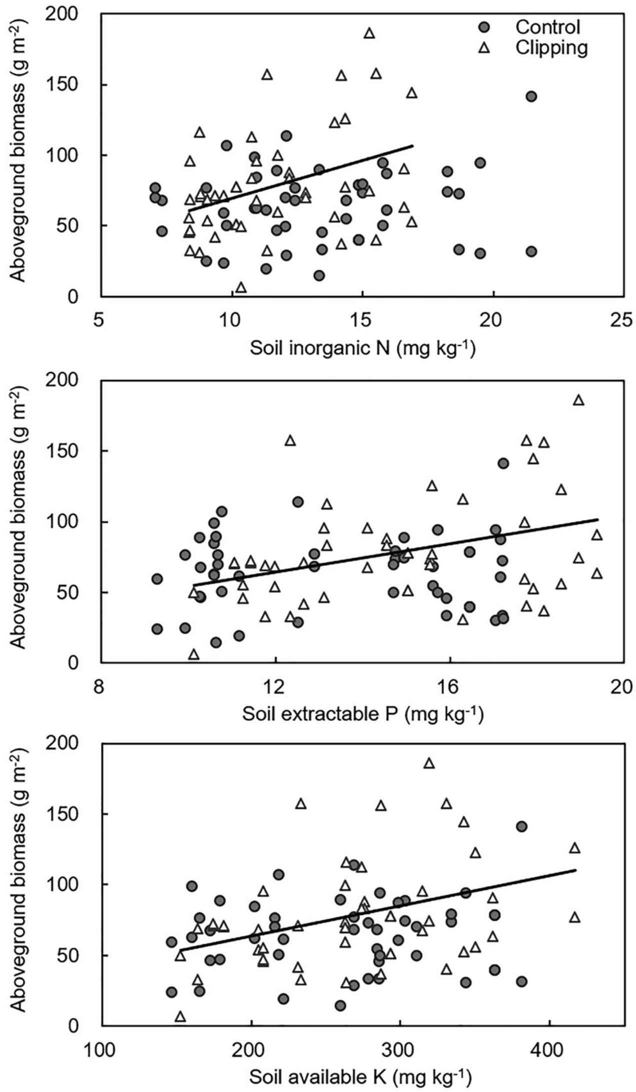

Fig. 5. Effects of clipping on the relationships between soil available nutrients (inorganic nitrogen (N), extractable phosphorus (P), and available potassium (K)) and aboveground biomass (across graminoid and forb) in a semiarid restored grassland. Full line is the trendline between soil available nutrients and aboveground biomass in the clipping treatment (r = 0.385, 0.375, and 0.385 of correlation analyses between aboveground biomass and soil inorganic N, extractable P, and available K, respectively; $P < 0.01$). But such a significant correlation was not found in control ($P > 0.05$).

et al., 1984; Zhao et al., 2008). However, the compensate growth is usually controlled by the availability of soil moisture (van Staalduinen and Anten, 2005). For example, temporal variation in precipitation resulted in variable compensatory growth in an Inner Mongolian steppe ecosystem (Schoenbach et al., 2011). In our study, the greater precipitation than the average (Fig. 1) supported strong regrowth, but this situation may be different in a dry growing season. Therefore, long-term observation of clipping effects is needed.

Another likely reason for strong compensatory growth is the increased light availability following clipping (Niu et al., 2010), because grazing-excluded grasslands are often light limited (Borer et al., 2014; Li et al., 2017). In addition, the positive correlation between aboveground plant biomass and soil available nutrients (in the clipping treatment, Fig. 5) indicated that soil available nutrients might limit the compensatory growth. Grazing animals are an important source of external nutrients for grassland plants (De Mazancourt et al., 1998). Therefore, soil nutrients management is likely to be important in clipped grasslands (Hicks and Reader, 1995), especially when grasslands are clipped for many years.

Clipping influences plant competition through its effects on microclimate, soil nutrients, litter, and allelochemicals (Alhamad and Alrababah, 2008; Ruprecht et al., 2016). In our study, clipping decreased the dominance of graminoid in favor of forb, consistent with previous studies (Koerner et al., 2014; Lavorel et al., 1997; Wu et al., 2010). This effect was because the higher light availability and lower litter under the clipping treatment aided seedling recruitment (Goldberg and Werner, 1983; Ruprecht et al., 2016), resulting in the greater numbers of forb (Koerner et al., 2014). Furthermore, the increased forb dominance may further improve the light availability as the less litter is produced by forb than graminoid (Niu et al., 2010).

Clipping is well-documented to increase nutrient concentration in plant aboveground biomass. The increased nutrients usually derive from the reallocation of nutrients from belowground, the negative dilution effect, rhizosphere priming effects, or an increase in photosynthesis (Hamilton and Frank, 2001; Hamilton et al., 2008; Hiernaux and Turner, 1996; Van de Vijver et al., 1999). However, in contrast to these ideas, our study found that clipping significantly decreased plant C and most nutrient concentration, rejecting the hypotheses. These negative effects could be attributed to the dilution effect (Elser et al., 2010; Hejcman et al., 2010). Clipping induced increases of 18% in C, 12% in N, 28% in P, and 14% in K stocks in the plant aboveground biomass (Fig. 6), as well as a 21% increase in the aboveground biomass (Table 3). Thus, plant C, N, and K concentration in clipped grassland were diluted by the great increase of aboveground biomass, while plant P was not affected.

Slope aspect and slope position did not change the effects of clipping on aboveground biomass and plant C and nutrient concentration, rejecting the hypotheses. The effects of clipping on plants in semiarid grasslands are strongly influenced by the availability of water and soil nutrients (Tuffa et al., 2017; van Staalduinen et al., 2010). In our study, differences in soil moisture and nutrients among slope aspect and position were likely insufficient to modify the effects of clipping. For example, even though soil inorganic N, extractable P, and available K were 48%, 34% and 44% higher, respectively, in the north slope than the south slope, the effects of clipping were not affected by slope aspect and exhibited consistently higher aboveground biomass and lower plant nutrient concentration across north and south slopes. Therefore, most effects of clipping on aboveground biomass and plant nutrient concentration were consistent across slope aspect and position in this restored grassland.

4.2. Soil organic carbon and nutrients

Clipping did not affect soil OC and nutrient content, partly supporting our hypotheses. A lack of response of soil nutrients to clipping is observed in many clipped grasslands (Cheng et al., 2011; Marion et al., 1991; Van de Vijver et al., 1999). For example, Cheng et al. (2011) found that 9 years of annual clipping did not affect soil OC and total N in a North American tallgrass prairie. Clipping could decrease soil OC and nutrient content through increasing nutrient uptake by plants (Fig. 6), promoting the mineralization of soil organic matter (Kirschbaum, 1995; Wan et al., 2002), and accelerating nutrients leaching (Castillo et al., 1997; Qian et al., 2003). However, these negative effects could be offset by positive effects that could increase soil nutrients, including stimulation of root exudation and soil microbial activities (Hamilton et al., 2008), increased photodegradation (Austin and Vivanco, 2006), and decreased soil respiration (Wei et al., 2016). Moreover, this equilibrium might not be affected by a single clipping, which may explain why our results differ from other studies (Du et al., 2014; Li et al., 2017).

Slope aspect did not change the effects of clipping on soil OC and nutrients, rejecting our hypotheses. Previous study in this area demonstrated that slope aspect moderated the effects of fire on soil

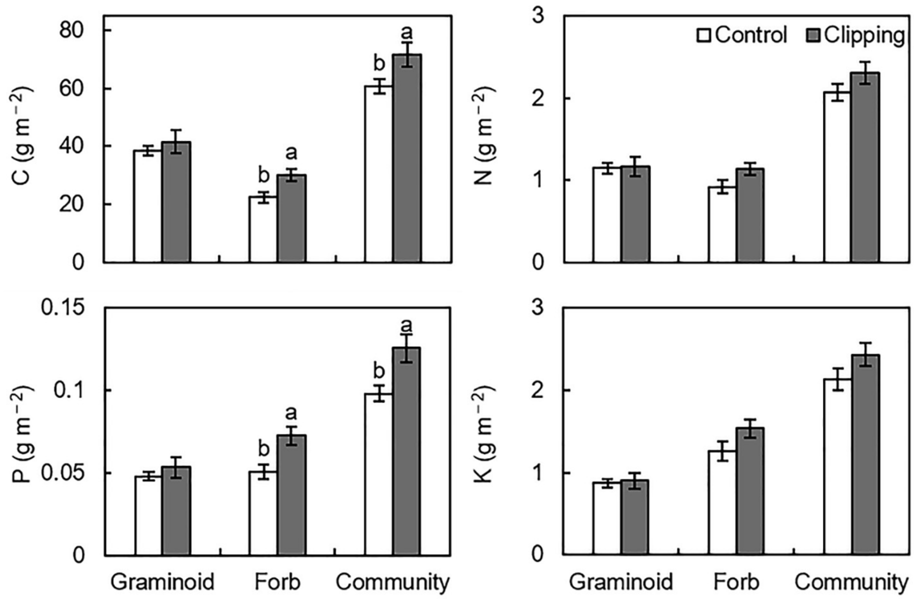

Fig. 6. Effects of clipping on the stock of carbon (C), nitrogen (N), phosphorus (P), and potassium (K) in the aboveground biomass of two functional groups (graminoid and forb) and total community in a semiarid restored grassland. Error bars denote the standard errors of the mean; means with different lowercase letters indicate significant (P < 0.05) between control and clipping treatments.

nutrients, which was attributed to the different nutrient uptake by plants in the north and south slopes (Liu et al., 2018). In our study, the equilibrium between the positive and the negative effects of clipping on soil OC and nutrients was not altered by slope aspect, suggesting that clipping affects soil OC and nutrients independent of slope aspect.

However, slope position did change the effects of clipping on soil inorganic N, total P, and available K in our study. Clipping decreased these soil nutrients in the upper slope but increased them in the middle and lower slopes, possibly through differences in nutrient uptake, organic matter mineralization, root exudation, and soil microbial activities (Hook and Burke, 2000; Northup et al., 1999; Zhang et al., 2012). Moreover, clipping appears to accelerate the nutrient transport by soil particles or runoff along slopes (Castillo et al., 1997) due to the decreased canopy cover and litter following clipping, exacerbated in our case by the higher than average rainfall in July 2013 (Fig. 1). This transport favors the accumulation of soil nutrients in the middle and lower slopes. Research on the effects of extreme precipitation events on (clipped) grasslands is urgently needed.

5. Conclusion

Experimental clipping of a grazing-excluded grassland significantly increased the aboveground biomass of forb, but decreased the concentration of plant C and most plant nutrient, without affecting the aboveground biomass of graminoid or soil OC and nutrient content. These effects were consistent across slope aspect. However, slope position changed the effects of clipping on soil inorganic N, total P, and available K content. Therefore, slope position should be taken account into when analyzing the responses of plant and soil nutrients to clipping. Clipping may be an applicable management for a long-term grazing-excluded grassland. However, our study was of one especially wet growing season. Semiarid grassland ecosystems vary greatly in precipitation from year to year, and drier years may not show the same effects. Experimental clipping of restored grasslands at multiple-sites over many years is therefore needed to adequately assess the long-term effects of clipping on plant and soil nutrient cycling and its use for the sustainable management of semiarid grasslands.

6. Declarations of interest

None

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