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Effect of Grazing Types on Community-Weighted Mean Functional Traits and Ecosystem Functions on Inner Mongolian Steppe, China

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Abstract: The relationships between community-weighted mean (CWM) functional traits and ecosystem functions have been extensively studied. However, how CWM traits and ecosystem functions respond to grazing types and whether the relationships between CWM traits and ecosystem functions mediate the response of ecosystem functions to grazing types remains controversial. In the present study, we set up a seven-year grazing experiment with four grazing types: no grazing (NG), cattle grazing (CG), sheep grazing (SG), and mixed grazing by sheep and cattle (MG) on Inner Mongolia grassland. Nine functional traits of dominant species and five ecosystem functions under different grazing types were determined, and the relationships between CWM traits and ecosystem functions were analyzed. The results showed that the CWM height decreased after grazing, while the CWM nitrogen and phosphorus contents increased after CG. SG caused a greater decrease in aboveground biomass (AGB) and a greater increase in the net ecosystem CO_2 exchange (NEE) of grassland ecosystems than did CG. This result may be partially because the CWM nutrient content and NEE were more negatively related after CG; and the increase in the CWM nitrogen and phosphorus contents suppressed NEE after CG. Therefore, to protect the sustainability of grassland ecosystem functions, SG should be reduced. Additionally, our work emphasizes that the relationships between plant functional traits and ecosystem functions may mediate the response of ecosystem functions to grazing types.

Keywords: functional traits; biomass; carbon sequestration capacity; grazing types

1. Introduction

Functional trait-based methodologies have created new ways to link plant and ecosystem processes and functions and can be used to solve problems related to global climate change, biodiversity loss and ecological protection [1–4]. Many scholars have focused on the relationships between plant functional traits and environmental factors. On the one hand, they have explored the relationships between

different functional traits of plants [1,4,5]. On the other hand, they have focused on the relationship between plant functional traits and environmental gradients and disturbance intensity [6–9]. The results show that the study of plant functional traits not only helps clarify the internal mechanism of community species' coexistence but also reflects and predicts the maintenance mechanism of plant communities on ecosystem function [8,10,11].

The study of plant functional traits involves multiple scales, such as species level, community level and ecosystem level [12–15]. At the community level, the study of the plant functional traits can reveal the underlying mechanism of ecosystem function [13,16,17]. Functional diversity and community-weighted average are two main approaches used to study the relationships between community-level plant functional traits and ecosystem function [18–20]. It has been hypothesized that functional diversity operates through functional complementarity [17], can describe ecosystem functions with multiple functional traits, and links functional traits with ecosystem functions [10,21,22]. Based on the biomass ratio hypothesis, in which the contribution of a species determines the extent of its influence on the characteristics of the ecosystem [23], community-weighted mean (CWM) traits focus on the importance of dominant species and are useful for explaining the litter decomposition rate, aboveground net primary productivity, and soil moisture [13,24–26].

Grazing is the main type of disturbance in grassland ecosystems [27]. Livestock feeding, trampling, and excretion can change the composition, structure, function, and physical and chemical properties of plant communities in grassland ecosystems [28–30]. Recently, with the development of functional ecology, the use of plant functional traits to study the adaptability of species and predict the responses of communities and ecosystem functions to human grazing disturbances has become a trend in ecological research. Studies have shown that long-term grazing can reduce the leaf area and height of plants, shorten the internodes and lead to a shallow root distribution of plants [12,20]. At medium and low grazing intensities, selective feeding by grazing animals resulted in a reduction in the abundance of tall plants with high specific leaf area (SLA) and an increase in the abundance of short plants with low SLA [9,31].

The aboveground biomass (AGB) and belowground biomass of grassland communities are important indicators for evaluating the grassland carbon cycle, grassland ecological protection and grassland restoration, and these indicators are of great importance for understanding grassland productivity and ecosystem function [32,33]. Many studies have shown that the AGB of plant communities tends to decrease with increasing grazing intensity or duration [34–37]. Ecosystem net carbon exchange (NEE) is determined by the balance between photosynthetic carbon absorption and respiration carbon release, which reflects the carbon source or carbon sink capacity of an ecosystem. A positive NEE value indicates that the ecosystem is a carbon source (net carbon release), and a negative NEE value indicates that the ecosystem is a carbon sink (net carbon absorption) [38–41]. Changes in terrestrial carbon exchange can cause obvious fluctuations in atmospheric CO_2 concentrations and thus affect global climate change [42]. Studies have shown that leaf nitrogen content has a strong effect on the plant photosynthetic rate, and the ratio of nitrogen to phosphorus is often used to assess whether nitrogen or phosphorus is more restricted in the carbon cycle [43]. Therefore, the circulation of chemical elements in plants is an important part of energy flow and material circulation, which have significant effects on the ecosystem carbon cycle [44,45].

There have been some related studies on the impact of grazing intensity on the productivity and biodiversity of typical grasslands in Inner Mongolia [30,46]. However, most existing studies have focused on the effects of grazing intensity on plant functional traits [12,29]. From the perspective of community-level plant functional traits, there has been little research on the impact of different livestock combinations (e.g., sheep and cattle) on grassland ecosystems. In fact, the effects of different grazing types on vegetation are quite different. Studies have shown that sheep generally require more energy than cattle because smaller-sized herbivores have a shorter retention time of food in the gastrointestinal tract, which leads to lower digestion efficiency [47]. In addition, sheep have a narrow mouth and have a higher ability to select plant parts with high quality (e.g., pods, young twigs and

flowers) than cattle [43,48]. Besides, sheep can ingest plants from the turf and bite them close to the ground, which may be not conducive to the regeneration of plants [49,50]. Therefore, we conducted a systematic exploration from the aspect of plant functional traits and analyzed the effects of grazing treatments on CWM traits and ecosystem functions. We would like to further propose the following hypotheses through this study: (1) sheep will cause greater damage to the function of the grassland ecosystem than cattle and (2) the relationships between plant functional traits and ecosystem functions can mediate the response of ecosystem functions to grazing types.

2. Methodology

2.1. Field Description and Experimental Design

The National Climate Observatory in Xilinhot (NCOX) was selected as the study area for the present study, and the site is located at 44°07′–44°09′ N, 116°19′–116°20′ E in Inner Mongolia, northern China. This climate observatory is at an elevation of approximately 1129 m. The climate type belongs to a semi-arid continental climate, with cold and dry winters but wet and warm summers. The mean average annual rainfall is 281 mm (based on meteorological data from 1953 to 2013), and most precipitation events occur during the growing season (May–September). The annual average temperature in this area is 2.4 °C, with an annual accumulated temperature $\geq$10 °C of 2700.5 °C [51]. According to the Chinese Soil Taxonomy system, the soil in the study area is chestnut soil [52], which is similar to Haplic Kastanozem in the FAO system. The dominant species in the study area are *Stipa grandis* P. Smirn. and *Leymus chinensis* (Trin.) Tzvel, and additional main species are *Agropyron cristatum* (L.) Gaertn and *Cleistogenes squarrosa* (Trin.) Keng. The mean proportion of aboveground biomass contributed by each species is shown in Table 1.

Table 1. Mean proportion of aboveground biomass (%) contributed by species at twelve sites on typical steppe, Inner Mongolia, with different grazing types.

Species	Mean ± Std. Error				*p*-Value
	Site NG	Site SG	Site CG	Site MG	
Stipa grandis	9.50 ± 1.90 [c,*]	50.40 ± 9.00 [b]	44.50 ± 7.00 [b]	70.20 ± 3.6 [a]	<0.001
Leymus chinensis	46.00 ± 7.00 [a]	8.10 ± 2.60 [c]	22.00 ± 4.00 [b]	6.40 ± 1.40 [c]	<0.001
Anemarrhena asphodeloides	29.40 ± 6.50 [a]	1.40 ± 0.60 [b]	8.60 ± 2.00 [b]	2.90 ± 0.80 [b]	<0.001
Cleistogenes squarrosa	5.30 ± 1.20 [b]	13.30 ± 4.20 [a]	7.50 ± 2.40 [a,b]	8.60 ± 1.60 [a,b]	0.189
Agropyrom cristatum	6.90 ± 3.80	1.30 ± 1.30	6.40 ± 3.80	0.30 ± 0.30	0.243
Salsola collina	2.40 ± 1.30	5.30 ± 1.70	2.50 ± 1.70	4.50 ± 1.50	0.476
Chenopodiaceae aristatum	0 [b]	3.00 ± 0.80 [a]	0.10 ± 0.10 [b]	2.20 ± 0.60 [a]	<0.001
Allium mongolicum	0.20 ± 0.20	0.90 ± 0.50	0.40 ± 0.20	1.00 ± 0.60	0.411
Allium condensatum	0.20 ± 0.10	0	1.20 ± 0.90	0	0.212
Allium tenuissimum	0	0	0.30 ± 0.30	0.30 ± 0.20	0.466
Allium polyrhizum	0 [b]	7.00 ± 4.40 [a]	0.40 ± 0.40 [b]	2.00 ± 1.00 [a,b]	0.134
Allium bidentatum	0 [b]	3.80 ± 2.00 [a]	0.70 ± 0.60 [b]	0 [b]	0.046
Setaria viridis	0 [b]	1.10 ± 0.50 [a]	0 [b]	0.10 ± 0.10 [b]	0.010
Eragrostis pilosa	0 [b]	2.80 ± 1.80 [a]	0 [b]	0.60 ± 0.20 [a,b]	0.114
Portulaca oleracea	0 [b]	0.70 ± 0.40 [a]	0 [b]	0.40 ± 0.20 [a,b]	0.049
Astragalus galactites	0	0.50 ± 0.50	1.00 ± 0.80	0.40 ± 0.30	0.643
Convolvulus ammannii	0	0	1.10 ± 0.80	0	0.201
Caragana microphylla	0	0	3.50 ± 3.50	0	0.405
Thalictrum petaloideum	0	0.30 ± 0.30	0	0.10 ± 0.10	0.569
Carex korshinskyi	0	0	0	0.04 ± 0.04	0.405
Euphorbia humifusa	0.10 ± 0.10	0	0	0	0.405

NG, no grazing; CG, cattle grazing; SG, sheep grazing; and MG, mixed grazing by sheep and cattle. 0 indicates that the species was present at the site but did not occur in the nine quadrats. Within rows, small alphabetical letters were provided based on post-hoc test (Turkey) after analysis of variance (ANOVA); * means followed by the same letter are not significantly different (*p* > 0.05).

The grazing experiment used to assess different grazing types was established in 2013, and four grazing types were established: no grazing (NG), cattle grazing (CG), sheep grazing (SG), and mixed grazing by sheep and cattle (MG) [43]. Each grazing type included 3 replicate sites, and the location distribution of the sites was completely random. The area of the NG, CG, and SG sites was each 50 × 25 m, and the area of the MG sites was twice the area of the other sites, i.e., 50 × 50 m. The feed intake of one head of cattle in the grasslands of Inner Mongolia is approximately equal to the feed intake of 8.5 sheep [53]. Therefore, we grazed 10 cattle on the CG site, 85 sheep on the SG site, and 10 cattle and 85 sheep on the MG site; the NG site was not grazed. The stocking rate was controlled to a moderate intensity level, and livestock were expelled from the sites when approximately half of the aboveground biomass was removed [43]. Grazing experiments were carried out from early June to late August each year, with grazing intervals of 1 month starting at the beginning of the experiment (total length of 7 years).

2.2. Measurement of Ecosystem Function

Ecosystem function measurements were conducted during mid-August, when the standing AGB reached its annual peak [54]. Within each site, three 1 × 1 m quadrats were randomly selected, and all living vascular plants in the quadrats were harvested by clipping to 1 cm stubble height, sorted to species, dried in an oven at 60 °C for 48 h and then weighed. After harvesting the aboveground portion, the belowground biomass was obtained by extracting a cylindrical soil core with a depth of 0–70 cm, and then soil samples were collected after removing the plant roots [55]. After washing the soil on the surface, the collected roots were dried in an oven at 60 °C to a constant weight.

The ecosystem net carbon exchange (NEE) and ecosystem respiration (ER) were determined by a static chamber system. The system included a cube made of transparent acrylic, with an open static chamber at the bottom of 0.5 × 0.5 × 0.6 m and a square stainless-steel soil collar. One week before the measurement, the square stainless-steel soil collar was smashed 6 cm into the ground to ensure tightness. A pair of 0.1 × 0.1 m fans were installed diagonally on the inner wall of the static chamber to ensure that the internal environment was close to the natural state. The CO_2 flux was monitored using a LI-8100 soil CO_2 analyzer (LI-COR, Lincoln, NE, USA) connected to the static chamber after grazing was completed in mid-August. The monitoring was divided into "open box" and "dark box" processes. The "open box" process monitored NEE under sunlight exposure; and the "dark chamber" process monitored ER by covering the static chamber with a double layer of opaque insulating cloth to prevent photosynthesis by the plant. The gross ecosystem productivity (GEP) was calculated from the NEE and ER. Each observation was performed between 8:00 and 10:00 a.m. on a cloudless day, and data were recorded every second for 120 s to measure the CO_2 flux.

2.3. Measurement of Plant Functional Traits

In mid-August 2019, we randomly collected most dominant species (*S. grandis, C. leymus chinensis, A. asphodeloides, and C. squarrosa*) at our study area for the measurement of plant functional traits (Table 2). The CWM traits calculated using the functional traits of these species can describe the community property accurately and allow us to compare the response of common species to different grazing types. For each selected species within each site, 2 well-grown (non-shaded, non-damaged) mature individuals were randomly selected (6 replicates per species per grazing type in total). Following Cornelissen et al. [45], height (H) was measured in the field and then all the selected individuals containing the root system were excavated. After cleaning and removing the soil, all plants were separated into different organs, e.g., leaves, stems and roots, to measure the chemical traits of each organ. The nitrogen concentrations of these samples were measured with an elemental analyzer (CHN-600, LECO, St. Joseph, MI, USA). The total p concentration of these samples was measured by the H_2SO_4-$HClO_4$ fusion method [56]. The SLA and leaf dry matter content (LDMC) were determined following standardized protocols [45]. The measurements of these two traits were also conducted on 6 replicate samples per species per site. After collecting the aboveground parts of the plant, they were

quickly placed in a box filled with water and rehydrated for at least 6 h in the dark. After removing twigs and the water on the surface of the blade, the leaf fresh mass was weighed, and the leaf area was measured with a leaf area meter (Li-3000, LI-COR, Superior St. Lincoln, NE, USA); the leaves were then oven-dried at 60 °C for 48 h and weighed.

Table 2. Community-weighted mean traits, ecosystem function, abbreviations, units and method description.

Relevant Variables	Abbreviations	Unit	Definition ([45,58])
	Community-weighted mean traits		
Mean height	CWM_H	cm	Average plant height
Mean leaf dry matter content	CWM_LDMC	$mg\ g^{-1}$	Ratio of average leaf dry weight to saturated fresh weight
Mean specific leaf area	CWM_SLA	$m^2\ kg^{-1}$	Ratio of average leaf area to dry leaf weight
Mean root nitrogen concentration	CWM_RNC	$mg\ g^{-1}$	Average nitrogen content per root dry mass
Mean root phosphorus concentration	CWM_RPC	$mg\ g^{-1}$	Average phosphorus content per unit of root dry mass
Mean stem nitrogen concentration	CWM_SNC	$mg\ g^{-1}$	Average nitrogen content per stem mass
Mean stem phosphorus concentration	CWM_SPC	$mg\ g^{-1}$	Average phosphorus content per stem mass
Mean leaf nitrogen concentration	CWM_LNC	$mg\ g^{-1}$	Average nitrogen content of the leaf stem mass
Mean leaf phosphorus concentration	CWM_LPC	$mg\ g^{-1}$	Average phosphorus content per unit of leaf dry mass
	Ecosystem function		
Aboveground biomass	AGB	$g\ m^{-2}$	Total dry weight of plants on the ground per unit area
Below-ground biomass	BGB	$g\ m^{-2}$	Biomass of herbaceous roots and rhizomes under grassland vegetation per unit area
Net ecosystem CO_2 exchange	NEE	$\mu mol\ m^{-2}\ s^{-1}$	Carbon absorbed or emitted by the ecosystem
Ecosystem respiration	ER	$\mu mol\ m^{-2}\ s^{-1}$	Sum of aboveground respiration and soil respiration in the ecosystem
Gross ecosystem productivity	GEP	$\mu mol\ m^{-2}\ s^{-1S}$	Amount of photosynthetic products fixed by organisms through photosynthesis in a unit of time

2.4. Calculation Method

$$SLA = \frac{Leaf\ area}{Dry\ leaf\ weight} \tag{1}$$

$$LDMC = \frac{Dry\ leaf\ weight}{Saturated\ fresh\ leaf\ weight} \tag{2}$$

$$GEP = NEE - ER \tag{3}$$

Community-weighted mean traits [13,57].

$$CWM_{trait} = \sum_{i=1}^{n} P_i \times X_i \tag{4}$$

where CWM_{trait} is the community-weighted mean traits of a site, n is the number of common species at the quadrats, P_i is the relative AGB of species i at the quadrats, and X_i is the trait value of species i at the quadrats.

2.5. Data Analyses

Statistical analyses were performed with R x64 3.6.1 [59]. One-way analysis of variance (ANOVA) was used to analyze the effects of grazing treatments on community-level plant functional traits and ecosystem functions. To analyse the CWM plant functional traits affecting ecosystem functions, we applied linear regression models (LRMs) to analyze the relationships between CWM plant functional traits and ecosystem functions under grazing treatments.

3. Results

3.1. Community-Weighted Mean Traits

Grazing had a significant effect on CWM_H, of which NG had the highest CWM_H (Figure 1a). There was no significant difference in grazing on CWM_LDMC and CWM_SLA (Figure 1b,c). Grazing treatments had significant effects on the CWM_LNC and leaf phosphorus content. The CWM_LNC of the MG site was significantly higher than that of the NG and SG sites, but it was not significantly different from the CG sites (Figure 1d). The CWM_LPC of MG and CG was significantly higher than that of the control (NG), and there was no significant difference from SG (Figure 1e). The grazing treatments had significant effects on CWM_SNC, and the CWM_SNC of MG and CG was significantly higher than that of SG and NG (Figure 1f). The CWM_SPC of CG alone was significantly higher than that of the control (NG), but there was no significant difference between SG and MG (Figure 1g). The CWM_LNC and CWM_LPC values were the highest in MG sites, while the CWM_RNC, CWM_RPC, CWM_SNC and CWM_SPC were the highest in CG sites. The impact of CG on CWM_RNC was significantly greater than that of SG, and there was no significant difference between MG and NG (Figure 1h). There was no significant difference in the effect of the grazing treatments on the community-level root phosphorus content (Figure 1i).

3.2. Ecosystem Functions

Grazing significantly reduced the AGB, with SG and MG having greater impacts on biomass (Figure 2a). Compared with the control, grazing significantly increased the community's belowground biomass, with the belowground biomass of CG and MG increasing significantly (Figure 2b). Grazing increased the NEE and GEP and reduced the ER (Figure 2c–e).

3.3. Relationship between Community-Weighted Mean Traits and Ecosystem Functions

The relationships between CWMs and ecosystem functions under SG are shown in Table 3. The relationships between ecosystem functions and CWM traits showed that the higher the CWM_H, the higher the ER under SG. The relationships between CWMs and ecosystem functions under CG are shown in Table 3. No variables had a significant effect on AGB. Belowground biomass increased with the nitrogen and phosphorus concentrations in roots and stems. NEE and ER were significantly positively correlated, and their relationships with community-weighted traits were similar. The higher the community-weighted LDMC, leaf nitrogen and phosphorus concentrations, SLA, and root nitrogen

and phosphorus concentrations, the lower the NEE. The relationships between ER and CWM traits showed that with the increase of community-weighted LDMC, SLA, root nitrogen and phosphorus concentrations, and stem phosphorus concentrations, ER shows a downward trend. GEP was positively associated with the community-weighted root nitrogen concentrations and stem nitrogen and phosphorus contents.
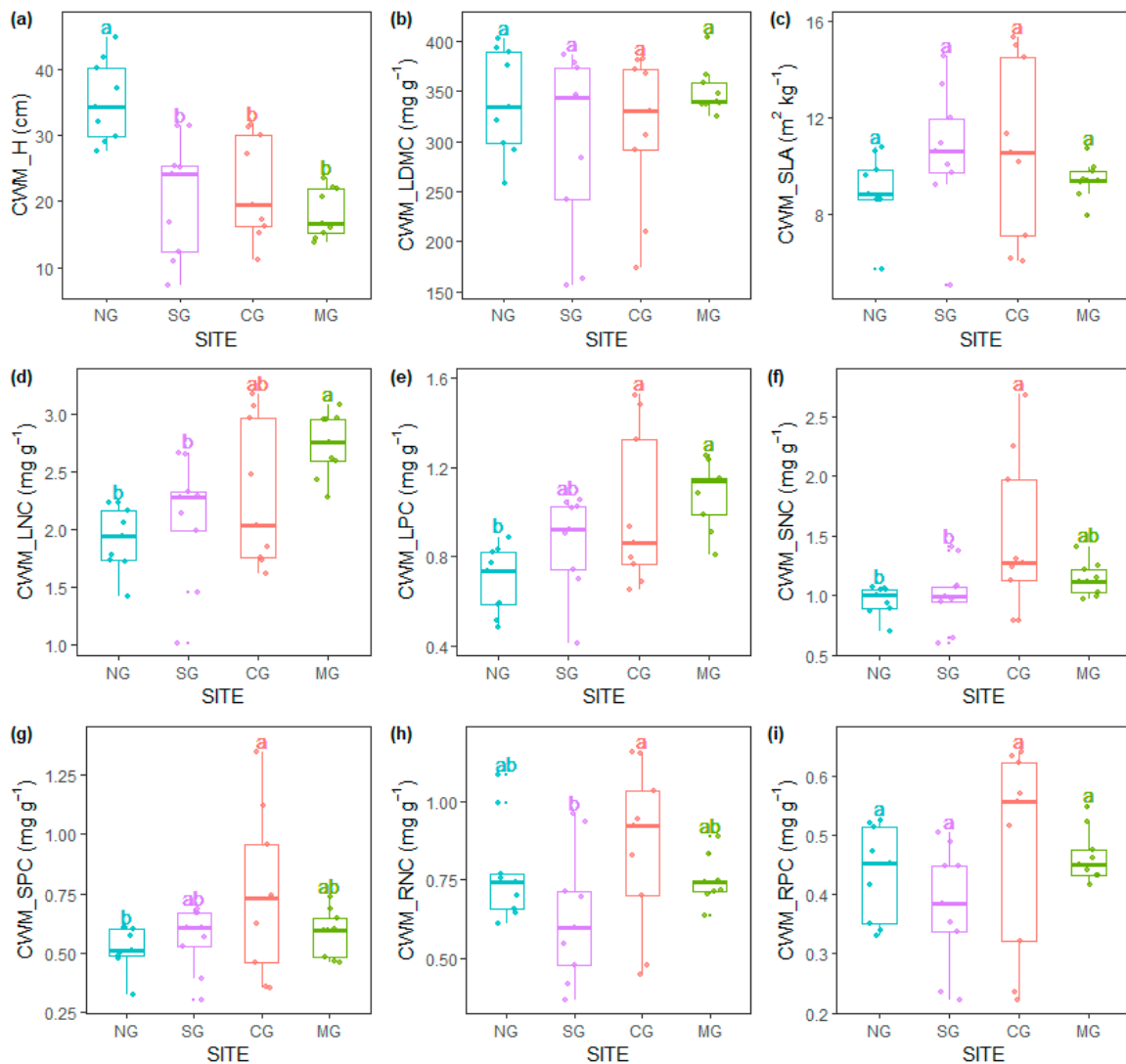
Figure 1. Effects of grazing types on community-weighted mean (CWM) (**a**) height (H), (**b**) leaf dry matter content (LDMC), (**c**) specific leaf area (SLA), (**d**) leaf nitrogen concentration (LNC), (**e**) leaf phosphorus concentration (LPC), (**f**) stem nitrogen concentration (SNC), (**g**) stem phosphorus concentration (SPC), (**h**) root nitrogen concentration (RNC), (**i**) root phosphorus concentration (RPC). One-way ANOVA was used to examine the effects of grazing types on CWM traits; significant differences ($p < 0.05$) are marked with different letters. Error bars are standard errors. (NG: no grazing; CG: cattle grazing; SG: sheep grazing; MG: mixed grazing by sheep and cattle).
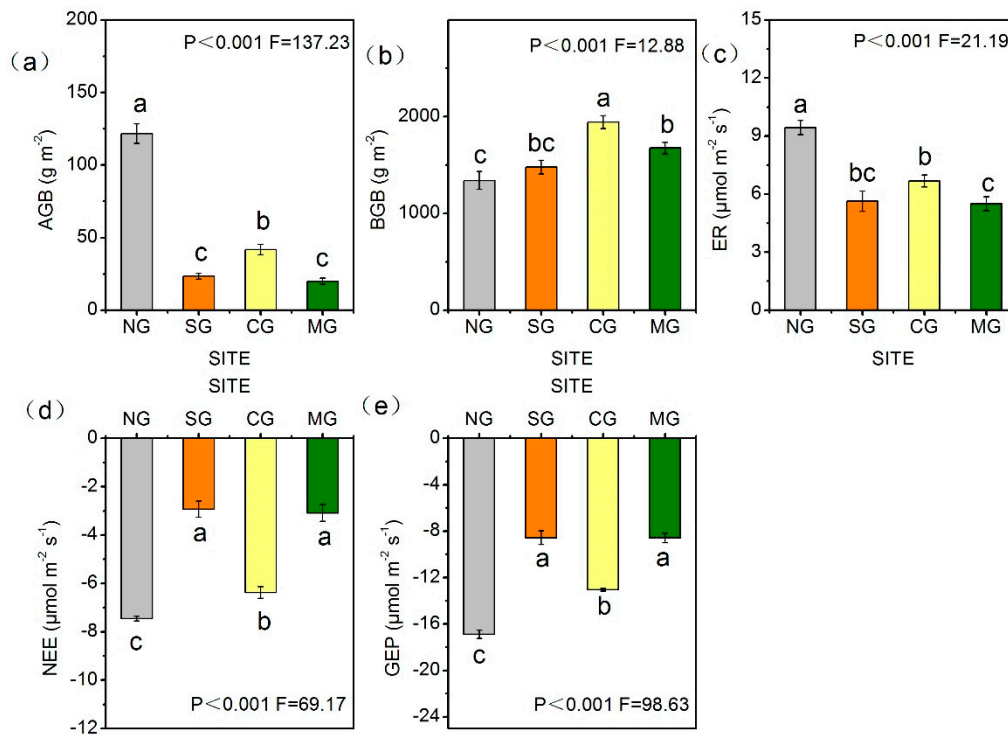
Figure 2. Effects of grazing types on (**a**) aboveground biomass (AGB), (**b**) below-ground biomass (BGB), (**c**) ecosystem respiration (ER), (**d**) net ecosystem CO_2 exchange (NEE), (**e**) gross ecosystem productivity (GEP). One-way ANOVA was used to examine the effect of different grazing types on ecosystem function; significant differences ($p < 0.05$) are marked with different letters. Error bars are standard errors. (NG: no grazing; SG: sheep grazing; CG: cattle grazing; MG: mixed grazing by sheep and cattle).

Table 3. Selected factors from the LRMs for community-weighted traits and ecosystem functions. Only significant factors are shown.

Traits	ER ($\mu mol\ m^{-2}\ s^{-1}$)	NEE ($\mu mol\ m^{-2}\ s^{-1}$)	GEP ($\mu mol\ m^{-2}\ s^{-1}$)	BGB ($g\ m^{-2}$)	AGB ($g\ m^{-2}$)
			Site SG		
CWM_H (cm)	0.687 *				
			Site CG		
CWM_RNC ($mg\ g^{-1}$)	−0.876 **	−0.682 *	0.862 **	0.948 ***	
CWM_RPC ($mg\ g^{-1}$)	−0.961 ***	−0.897 **		0.863 **	
CWM_SNC ($mg\ g^{-1}$)			0.95 ***	0.892 **	
CWM_SPC ($mg\ g^{-1}$)	−0.765 *		0.932 ***	0.983 ***	
CWM_LDMC ($mg\ g^{-1}$)	−0.737 *	−0.801 **			
CWM_LNC ($mg\ g^{-1}$)		−0.695 *			
CWM_LPC ($mg\ g^{-1}$)		−0.794 *			
CWM_SLA ($m^2\ kg^{-1}$)	−0.846 **	−0.982 ***			

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4. Discussion

4.1. Effect of Grazing Types on Community-Weighted Mean Values

In the present study, we found that the CWM height showed a decreasing trend regardless of grazing types (Figure 1a). This result is consistent with previous studies that found, under overgrazing conditions, plants showed a trend towards miniaturization, which was characterized by a lower height, shorter and narrower leaves, shorter internodes, and shallower root distribution [9,60,61]. Plant miniaturization after grazing is a defence strategy plants use to avoid being fed upon by livestock, which may lead to a decrease in community productivity [62]. In this study, we found that grazing could significantly promote the nitrogen and phosphorus contents at the community level. This trend was more obvious after CG, with site CG and site MG having higher nitrogen and phosphorus contents in the roots, stems, and leaves (Figure 1). Under the same grazing experiment used in the our research, Wang et al. (2018) studied nitrogen mineralization in cattle and sheep faeces and found that the amount of nitrogen released by the decomposition of cattle faeces was almost twice that of sheep faeces, which led to a significant increase in soil mineral nitrogen after cattle grazing [43]. In addition, because of the difference in the lignin:N ratio, cattle faeces decay quickly [63]. Therefore, the difference in faeces nitrogen release between cattle and sheep may be the main reason for the increased leaf N with cattle grazing relative to sheep grazing. Leaf P and N usually show a consistent increase with increases of soil fertility [64], which results in the same response of leaf P to grazing types as leaf N. There was a trade-off between the distribution of nutritional elements and the supply of resources. Among them, leaf nitrogen content is known to affect components of the nutrient cycles and has a high correlation with the maximum photosynthesis rate of plants; that is, the higher the leaf nitrogen content, the higher the maximum photosynthesis rate of the plant [5]. In addition, the nitrogen content of plants was inversely related to the lignin content, and plants with a higher leaf nitrogen content have a higher litter quality and a high litter decomposition rate, which accelerates the cycling rate of the ecosystem [3]. In short, the plant community can restore the lost tissues by increasing the plant photosynthetic efficiency and growth ability, allowing plants to adapt to grazing disturbances [65].

4.2. Effect of Grazing Types on Ecosystem Functions

Our study showed that grazing significantly reduced the AGB, and this result was strengthened after SG, with the AGB being lower at site SG and site MG (Figure 2a). Many studies have shown that grazing reduces the AGB of the community [66]; here, we highlighted that compared with CG, SG consumes more grassland AGB. This result may be caused by the differences in body size, physiological structure, and morphological structure of mouth and teeth between cattle and sheep. Cattle are more efficient at feeding on plants with a community height greater than 12 cm, while sheep stay closer to the ground and chew on plants, which greatly damages the growth point of plants, resulting in the inability of the remaining stalks to continue to grow and causing more serious inhibition of plant growth [67]. Unlike AGB, belowground biomass had a tendency to increase after grazing, especially after CG (Figure 2b). Belowground biomass occupies an important proportion of the total biomass of grasslands. Studies have shown that most of the biomass in grassland ecosystems is distributed below ground [68]. Biomass plays an important role in the formation of an ecosystem, and it is the main manifestation of energy harvesting by ecosystems. Ecosystem productivity is one of the most important components of ecosystem functions and can be used to explain the consequences of land-use change [8]. Our results revealed that compared with CG, SG under the same grazing intensity was not conducive to the accumulation of biomass. Therefore, to maintain the healthy and sustainable development of a grassland ecosystem, it is recommended to reduce the level of SG.

NEE is determined by the imbalance between photosynthetic carbon absorption and respiration carbon release, which reflects the carbon source or carbon sink capacity of an ecosystem [38,39]. We also found significant increases in NEE and GEP after grazing, and this trend resulted in a decrease in the carbon sequestration capacity of grassland. Li et al. (2004) found that in the past 40 years, overgrazing

has caused the soil organic carbon of *L. chinensis* grassland in the Xilin River basin to decrease by approximately 12.4% [69]. With the deterioration of climatic conditions and the further increase in grassland grazing intensity, it is possible that Inner Mongolia grassland will change from a carbon sink to a carbon source [70]. In addition, we found that ER decreased after grazing, which may have been caused by the decrease in AGB caused by grazing; however, the increase in belowground biomass meant that the increase in root respiration compensated for the decrease in aboveground respiration [71]. Livestock trampling compacts the soil, and the ability to release CO_2 is weakened, which in turn lowers ER [72].

The increase in NEE and GEP in our study was more obvious after SG, with the SG and MG sites having higher NEE and GEP. The increase in GEP can provide more substrate for root growth and microbial activity and plays a leading role in the NEE change [73]. Community photosynthesis and respiration are the main processes of ecosystem carbon exchange and maintain the relative balance of ecosystem organic carbon pools. Although ER decreased after SG, the increase in GEP was greater than the decrease in ER, resulting in a significant increase in NEE. In our research, the maximum NEE value was -1.62 μmol m^2 s^{-1} in the SG site, while the average NEE value in the NG site was -7.46 μmol m^2 s^{-1}. Wang et al. (2007) showed that the stronger the grazing disturbance intensity is, the more obvious the decrease in carbon sequestration ability is [74]. The results revealed that compared with other grazing treatments, SG has a greater impact on grassland ecosystem carbon sequestration capacity; furthermore, if the intensity of SG continues to increase, it is possible to change the grassland ecosystem from a carbon sink to a carbon source (NEE > 0). Therefore, from the perspective of protecting the carbon sequestration capacity of grassland ecosystems, we recommend reducing the level of SG.

4.3. Linking CWM Traits to Explain the Effect of Grazing Types on Ecosystem Functions

Community-weighted traits can comprehensively reflect the changes in plant functional traits and species composition and can scale up functional traits from the species level to the community level; thus, community-weighted traits are appropriate for explaining ecosystem functions [8,13,75]. In this study, grazing, especially cattle grazing, promoted an increase in the nitrogen and phosphorus contents of plants. We found that after cattle grazing, plant nutrients and NEE showed a very significant negative correlation; however, at site SG, plant nutrients and NEE showed a positive correlation. Therefore, the increase in nutrients decreased the NEE of site CG, which may partly explain why cattle grazing will have less of an impact on the carbon sequestration capacity. Previous research proved that leaf nitrogen content has a greater effect on the plant photosynthetic rate [43], and why the opposite result appears after cattle grazing requires additional research in the future. In addition, the presence of the root system increases the activity of soil microorganisms, and the secretions released by the rhizosphere contain active organic carbon, which increases the carbon emission from the soil through mineralization [76]. Thus, higher belowground biomass appears to result in a higher ER; however, in our study, although the belowground biomass was significantly higher at site CG than at site SG, the ER was not significantly different between the two sites. This result was partly attributed to the different relationships between ER and belowground biomass and partly attributed to the different relationships between ER and nutrient content (a positive relationship at site SG but a negative relationship at site CG). Therefore, our study revealed that the relationships between plant functional traits and ecosystem functions will largely affect the response of ecosystem functions to grazing types.

5. Conclusions

Our study showed that the CWM height presented a decreasing trend regardless of grazing types. Grazing can significantly increase the nitrogen and phosphorus contents at the community level, and this trend was more pronounced after cattle grazing. Grazing sheep caused the greatest damage to the AGB and carbon sequestration capacity of the grassland ecosystem. Therefore, to protect the sustainability of the function of the grassland ecosystem, sheep grazing should be reduced.

After grazing, especially after cattle grazing, the CWM nitrogen and phosphorus contents were significantly increased, which was conducive to the accumulation of belowground biomass. We found that plant nutrients and NEE showed a very significant negative correlation after cattle grazing. The increase in nutrients promoted the NEE and suppressed the NEE under cattle grazing, which may partly explain why cattle grazing will have less of an impact on carbon sequestration capacity. Our work highlights that the relationships between plant functional traits and ecosystem functions will largely affect the response of ecosystem functions to grazing types.

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