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Effects of grazing on plant species diversity and carbon partitioning in semiarid rangelands of northeastern China

Efectos del pastoreo en la diversidad de especies vegetales y particionamiento del carbono en áreas semiáridas de vegetación natural en el noreste de China

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Abstract. Grasslands are one of the most widespread landscapes worldwide, covering approximately one-fifth of the world's land surface, where grazing is a common practice. How carbon storage responds to grazing in steppes remains poorly understood. We quantified the effects of grazing on community composition and species diversity, and carbon storage in two typical grasslands of northeastern China, one in Horqin and the other one in Hulunbeier. In both grasslands, grazing did not influence plant species diversity. However, it substantially decreased aboveground carbon by 31% and 54% in Horqin and Hulunbeier, respectively. Fenced and grazing treatments showed a similar belowground carbon at both locations. The predominant carbon pool in the study grassland ecosystem was found in the upper 100 cm soil depth, from 98.2 to 99.1% of the total carbon storage. There were no significant effects of grazing on soil carbon neither in the whole profile nor in the uppermost 20 cm soil depth in the two study grasslands. Studies on the effects of varying rangeland management, such as region disparity and grazing systems, may have important consequences on species diversity and carbon partitioning, and thus on rangeland stability and ecosystem functioning.

Keywords: Species diversity; Carbon allocation; Carbon stock; Optimal partitioning; Community heterogeneity; Soil depth.

Resumen. Las áreas de vegetación natural son unos de los paisajes más ampliamente distribuidos en el mundo, cubriendo aproximadamente un quinto de la superficie terrestre mundial, donde al pastoreo es una práctica común. Se conoce poco en relación a como el pastoreo modifica el almacenamiento de carbono en las estepas. En este estudio se cuantificaron los efectos del pastoreo en la composición y diversidad de especies en la comunidad, y el almacenamiento de carbono en dos áreas típicas de vegetación natural del noreste de China, una en Horqin y la otra en Hulunbeier. En ambas áreas, el pastoreo no afectó la diversidad de especies vegetales. Sin embargo, este redujo substancialmente el carbono en la parte aérea en un 31 y 54% en Horqin y Hulunbeier, respectivamente. El carbono en la parte subterránea fue similar en clausuras y sitios pastoreados en ambos lugares. La mayor cantidad de carbono en las áreas estudiadas se encontró en los primeros 100 cm de profundidad del suelo, desde 98,2 a 99,1% del almacenamiento total de carbono. No hubo efectos significativos del pastoreo en el carbono de todo el perfil y de los primeros 20 cm de profundidad del suelo. Variaciones en el manejo de las áreas de vegetación natural, como resultado de distintas áreas de estudio o sistemas de pastoreo, pueden tener importantes consecuencias en la diversidad y el particionamiento de carbono de las especies, y así en la estabilidad y funcionamiento del ecosistema en dichas áreas.

Palabras clave: Diversidad de especies; Distribución del carbono; Cantidad de carbono; Particionamiento óptimo; Heterogeneidad de la comunidad; Profundidad de suelo.

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INTRODUCTION

Grasslands are one of the most widespread landscapes worldwide, covering approximately 20% of the world's land surface (Scurlock & Hall, 1998). China's grasslands cover 6 to 8% of that surface area and have from 9 to 16% of the total carbon in the world grasslands (Ni, 2002). Because of the importance in regulating the nutrient and carbon cycles, much emphasis has been placed in estimating biomass of the world's grasslands (Klaus et al., 2012; Flanagan et al., 2013). However, overgrazing has contributed to desertification and degradation of more than two-thirds of these fragile ecosystems because of human activities (Karl & Trenberth, 2003; Li et al., 2012). When grasslands are either grazed by livestock or fenced to prevent long-term grazing, above- (AGB) and belowground (BGB) biomasses, and soil organic carbon (SOC), may respond differently, thus influencing the global carbon cycle (Cox et al., 2000; Amthor, 2006). Therefore, understanding the effects of grazing on carbon storage of grasslands is crucial to help making predictions on global C budgets.

There has been some progress in monitoring and understanding the factors influencing carbon partitioning (Bultynck & Lambers, 2004). Nevertheless, the effects of species composition and diversity in affecting carbon partitioning remain unclear. Many studies have shown that grazing might increase (Manley et al., 1995) or decrease (Wiesmeier et al., 2012) soil carbon accumulation compared to adjacent, fenced soils. The fact that plant and soil properties have not shown a consistent increase or decrease response to grazing has been attributed to the fact that a certain threshold level has been reached (Baron et al., 2002; Han et al., 2008; Silveira et al., 2013). Some studies have been conducted on the Tibetan Plateau or Loess Plateau of China to assess carbon sequestration (Zhao et al., 2006; Feng et al., 2013). However, little has been done to address the influences of grazing on species diversity and carbon allocation in China's grasslands.

We determined how plant species composition and diversity, and ecosystem carbon storage, responded to grazing in the Horqin and Hulunbeier grasslands of northeastern China. Grazing-induced changes in community composition determine in turn changes in aboveground net primary production (ANPP). This study was carried out on both fenced and grazed grasslands in two regions of northeastern China to determine (1) to what extent grazing affects plant community and ecosystem carbon storages, (2) if plant carbon storage differs between the two study regions.

MATERIALS AND METHODS

Study area. This study was conducted in two grasslands in Inner Mongolia, China (Fig.1). One of them was in southwestern Horqin Sandy Land (42° 56′ N - 43° 20′ N, 119° 29′ E - 119° 41′ E; 428 to 494 m.a.s.l.). This is characterized by sand dunes alternating with interdune lowlands, where overgrazing and extensive deforestation are the major factors leading to its desertification (Zhang et al., 2004). This area has a combination of temperate, semiarid, and continental monsoonal climate. Average annual precipitation is 340 mm, with 70-80% of which occurring between May and September. The mean annual open-pan evaporation is approximately 1935 mm. Annual temperature averages approximately 6.4 °C, with a mean minimum monthly temperature of -13.1 °C in January, and a maximum of 23.7 °C in July. The dominant species are sagebrush (*Salsola ruthenica* Iljin) and wheat grasses (*Cyperus rotundus* L.). Horqin steppe is also exposed to severe winds (Liu et al., 2007).

The other grassland was located in central Hulunbeier (47° 20′ N - 50° 12′ N, 118° 31′ E - 121° 03′ E; 599 to 618 m.a.s.l.). The mean annual precipitation is 308 mm; about 70% of annual precipitation occurs in summer and autumn. Total annual evaporation can reach 1371 mm. The mean annual wind velocity is 3.5 m/s, and soils are classified as sandy chestnut. The dominant plant species on the typical steppe are *Stipa grandis* and *Leymus chinensis*. Recently, agriculture has resulted in heavier grazing pressure and farm cultivation leading to an apparent deterioration in rangeland quality and productivity (Tang et al., 2004).

Experimental design. On the two study sites, sampling was carried out in mid-July 2010 on 5 to 6 year-old enclosures to grazing by domestic herbivores. At each sampling area of the Horqin and Hulunbeier regions, six plots (500 m × 500 m) were randomly established within the grazed and fenced treatments (Fig. 1). Plots were at least 2 km apart. In each plot, five 1 m × 1 m subplots were set (Fig. 1). Subplots were 15 m away one from each other. In each subplot (Fig.1), aboveground biomass and litter were harvested, and species richness and density were recorded. After litter was collected, three replicates of soil samples were taken at 0-10, 10-20, 20-40, 40-60, 60-80, and 80-100 cm soil depth using a 7 cm-diameter soil auger. Roots were also collected at each soil depth at locations 0.5 to 1 m from places where the soil samples were obtained.

Roots were thoroughly washed manually free from soil in deionized water using a 35-mesh screen (Williams & Baker, 1957). Aboveground plant litter and roots were first dried at 75 °C to a constant weight in an oven, and weighed thereafter. Soil samples were air-dried, and then sieved (2-mm mesh) to remove roots and other debris. Before air-drying, one subsample was obtained from each soil sample, which was first weighed and then oven-dried at 105 °C to determine gravimetric soil moisture following Brown (1995). Another subsample from each soil sample, after air-drying, was ground to pass a 0.15-mm sieve; this subsample was analyzed for soil organic carbon by the dichromate oxidation method of Walkey and Black (Nelson & Sommers, 1996).

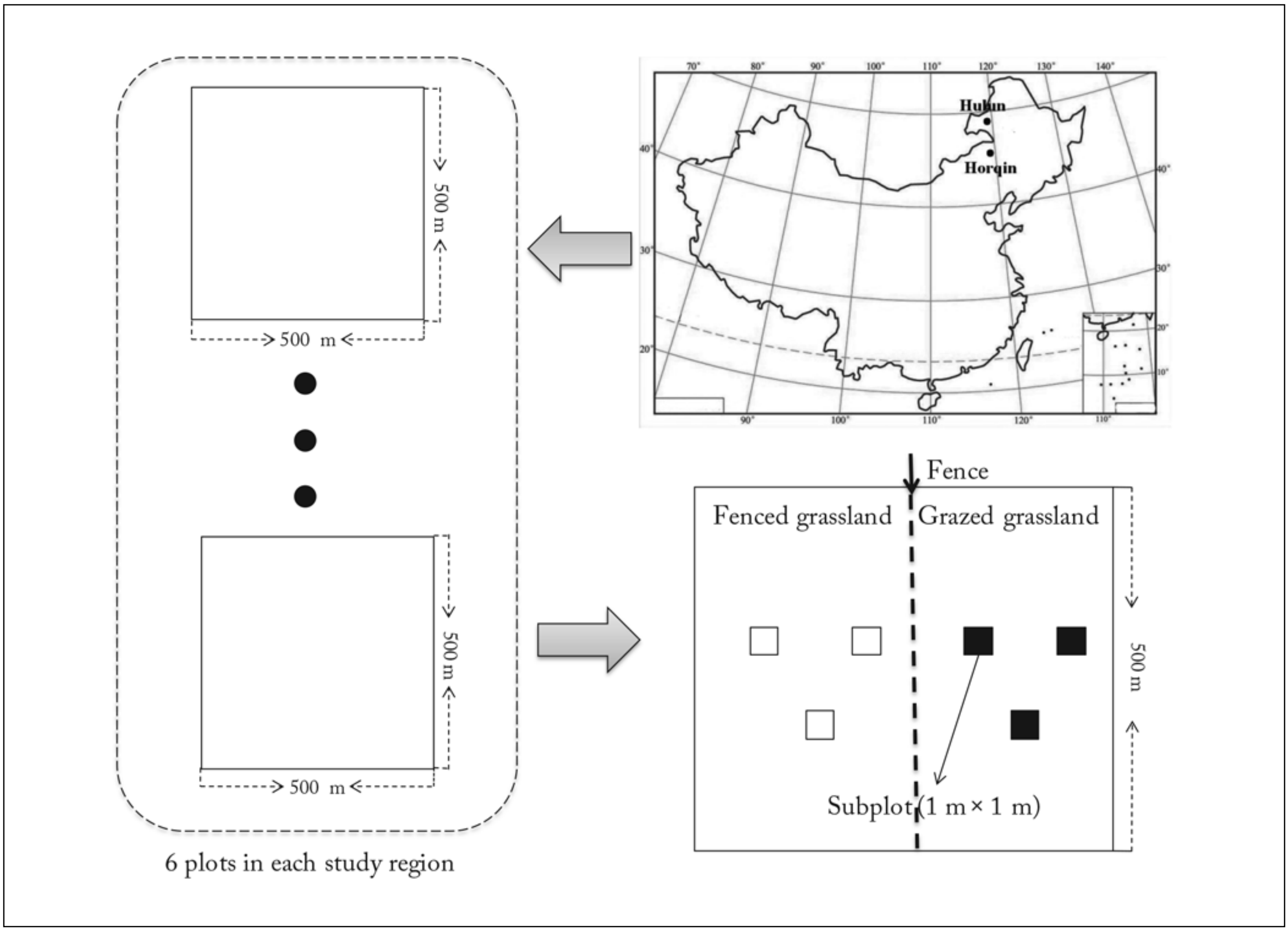

Fig. 1. Schematic diagram indicating the study sites (Horqin and Hulunbeier) in northern China, and the experimental design. Half of each 500 x 500 m plot (n=6) was grazed while the other half remained ungrazed (i.e., fenced). Sampling was conducted within each of five 1 x 1 m subplots within each plot.

Fig. 1. Diagrama indicando los sitios de estudio (Horqin y Hulunbeier) en el norte de China, y el diseño experimental. La mitad de cada parcela de 500 x 500 m (n=6) fue pastoreada mientras que la otra mitad permaneció sin pastorear (es decir, alambrada). El muestreo se condujo dentro de cada una de cinco subparcelas de 1 m x 1m dentro de cada parcela.

Species diversity was calculated using the Simpson's Diversity Index (D) as:

$$D = 1 - \sum_{i=1}^{s} (P_i)^2$$

where P_i is the proportion of the ith species in the community containing s species (Simpson, 1949). This index represents the probability that two individuals randomly selected from a sample will belong to different species. The proportion (i.e., percentage) of each species biomass within each sample plot was first calculated with respect to the total biomass contribution of all species within that plot. This proportion was then expressed as a fraction (i.e., P) to use it in the formula of the Simpson´s Diversity Index.

Carbon storage in plants was expressed as:

$$B' = B \times 45\%$$

where B' is carbon in the plant biomasses of the aboveground, belowground and litter components (g C/cm^2), and B is the dry weight of the biomass samples (Crutzen & Andreae, 1990).

Soil organic carbon (SOC) was calculated following Tian et al. (2009) as:

$$SOC_t = \Sigma[C_i D_i E_i (1 - G_i)] \times 100$$

where SOC_t is the total value of soil organic carbon storage (g C/m^2); C_i is the concentration of soil organic carbon at the soil depth i (%); D_i is the soil bulk density (g/cm^3); E_i is the thickness of the soil layer (cm), and G_i is the portion of gravel whose diameter is greater than 2 mm (%).

Statistical analysis. Detrended correspondence analysis (DCA) of different plots was performed by Canoco (version 4.5, Canoco, Netherlands). Data analysis was performed using ANOVA on a windows-based SPSS (version 13, SPSS, Chicago, IL, USA) with significance at $p<0.05$. When F tests were significant, means were compared using the LSD test of Fisher (Steel & Torrie, 1960). Regression analysis was used to compare the relationship between AG- and BGC in both grazing systems and sites following Neter et al. (1985).

RESULTS

Species composition and diversity. Species composition and density were quite different in the study regions (Tables 1 and 2). The numbers of species in the Horqin and Hulunbeier regions were 53 and 25, respectively (Tables 1 and 2). However, plant density appeared to be greater at the Hulunbeier (e.g., *Cyperus fuscus*, *Agropyron cristatus*) than at the Horqin site (Tables 1 and 2). Fenced and grazed grasslands showed some common species in each region (Tables 1 and 2). Some of them were *Corispermum stauntonii* Moq., *Salsola ruthenica* Iljin and *Setaria viridis* (L.) P. Beauv.

Table 1. Species composition and density (# individuals/m^2) on fenced and grazed plots in Horqin region. Each value is the mean ± 1 SE of n=6.

Tabla 1. Densidad (número de individuos/m^2) y composición de especies en clausuras y parcelas pastoreadas en la región de Horqin. Cada valor es el promedio ± 1 E.E. de n=6.

Abbreviation	Species	Fenced grassland	Grazed grassland
AgroMats	*Agrostis matsumurae*	8 ± 3	0
ArguSibi	*Argusia sibirica*	11 ± 5	3 ± 1
ArteAbsi	*Artemisia absinthium*	6 ± 2	1 ± 0
ArteLava	*Artemisia lavandulaefolia*	0	14 ± 5
ArthHisp	*Arthraxon hispidus*	4 ± 2	56 ± 23
AspaCoch	*Asparagus cochinchinensis*	9 ± 4	0
AstrAdsu	*Astragalus adsurgens*	1 ± 0	0
CalaEpig	*Calamagrostis epigejos*	161 ± 60	20 ± 8
ChloVirg	*Chloris virgata*	65 ± 22	79 ± 21
ConvFrut	*Convolvulus fruticosus*	2 ± 1	12 ± 4
CoriStau	*Corispermum stauntonii*	51 ± 9	20 ± 5
CypeFusc	*Cyperus fuscus*	49 ± 20	87 ± 25
EchiOryz	*Echinochloa oryzoides*	2 ± 1	0
EnneBore	*Enneapogon borealis*	17 ± 7	45 ± 15
EquiRamo	*Equisetum ramosissimum*	0	2 ± 1
GlauMari	*Glaux maritima*	2 ± 1	1 ± 0
GlycUral	*Glycyrrhiza uralensis*	2 ± 1	2 ± 1
HaloStro	*Halocnemum strobilaceum*	0	23 ± 10
HemaAlti	*Hemarthria altissima*	5 ± 2	7 ± 3
HeteAlta	*Heteropappus altaicus*	1 ± 0	0
InulJapo	*Inula japonica*	15 ± 6	6 ± 2
KengSqua	*Kengia squarrosa*	10 ± 3	1 ± 0
KochScop	*Kochia scoparia*	20 ± 8	0
LappMyos	*Lappula myosotis*	24 ± 10	0
LespBico	*Lespedeza bicolor*	33 ± 13	4 ± 1
LeymChin	*Leymus chinensis*	13 ± 5	0

MediFalc	*Medicago falcata*	1 ± 0	0
PennCent	*Pennisetum centrasiaticum*	30 ± 12	5 ± 2
PhraAust	*Phragmites australis*	37 ± 9	7 ± 3
PlanDepr	*Plantago depressa*	2 ± 1	0
PolyLapa	*Polygonum lapathifolium*	2 ± 1	0
PoteFrey	*Potentilla freyniana*	35 ± 14	22 ± 9
RanuJapo	*Ranunculus japonicus*	11 ± 5	8 ± 3
SalsRuth	*Salsola ruthenica*	7 ± 2	22 ± 5
SausAuri	*Saussurea auriculata*	2 ± 1	1 ± 0
ScutGuil	*Scutellaria guilielmi*	31 ± 12	97 ± 39
SetaPumi	*Setaria pumila*	31 ± 13	1 ± 0
SetaViri	*Setaria viridis*	69 ± 25	9 ± 4
SoncOler	*Sonchus oleraceus*	5 ± 2	0
TaraOffi	*Taraxacum officinale*	2 ± 1	2 ± 1
TherLupi	*Thermopsis lupinoides*	0	2 ± 1
TribTerr	*Tribulus terrestris*	11 ± 4	8 ± 2

Table 2. Species composition and density (# individuals/m^2) on fenced and grazed plots in Hulunbeier region. Each value is the mean ± 1 SE of n=6.

Tabla 2. Densidad (número de individuos/m^2) y composición de especies en clausuras y parcelas pastoreadas en la región de Hulunbeier. Cada valor es el promedio ± 1 E.E. de n=6.

Abbreviation	**Species**	**Fenced grassland**	**Grazed grassland**
AgroCris	*Agropyron cristatum*	2215 ± 327	398 ± 105
AlliSene	*Allium senescens*	84 ± 20	12 ± 4
ArteAbsi	*Artemisia absinthium*	2 ± 1	6 ± 3
ArteFrig	*Artemisia frigida*	72 ± 10	12 ± 4
ArteJapo	*Artemisia japonica*	2 ± 1	5 ± 2
ChenAcum	*Chenopodium acuminatum*	3 ± 1	3 ± 1
ChenGlau	*Chenopodium glaucum*	1 ± 0	2 ± 0
CoriStau	*Corispermum stauntonii*	3 ± 1	13 ± 3
CypeFusc	*Cyperus fuscus*	1415 ± 179	2787 ± 312
DianChin	*Dianthus chinensis*	0	1 ± 0
EragPilo	*Eragrostis pilosa*	0	1 ± 0
IrisLact	*Iris lactea*	1 ± 0	0
KengSqua	*Kengia squarrosa*	186 ± 23	328 ± 30
LeymChin	*Leymus chinensis*	76 ± 31	13 ± 4
MattStr	*Matteuccia struthiopteris*	1 ± 0	0
PortOler	*Portulaca oleracea*	0	1 ± 1
SalsRuth	*Salsola ruthenica*	1 ± 0	5 ± 1
SerrCent	*Serratula centauroides*	1 ± 0	4 ± 1
SetaViri	*Setaria viridis*	16 ± 4	46 ± 14
StipCapi	*Stipa capillata*	35 ± 4	37 ± 6
TeloAris	*Teloxys aristatum*	200 ± 35	281 ± 54

Detrended corresponded analysis on the study species supported that species composition contributed a wider range in the Horqin than in the Hulunbeier grassland. A similar trend between grazed and fenced grasslands was shown in each region (Fig. 2). However, plant species diversity was similar (p>0.05) between fenced and grazed grasslands in either the Horqin or Hulunbeier region (Fig. 3).

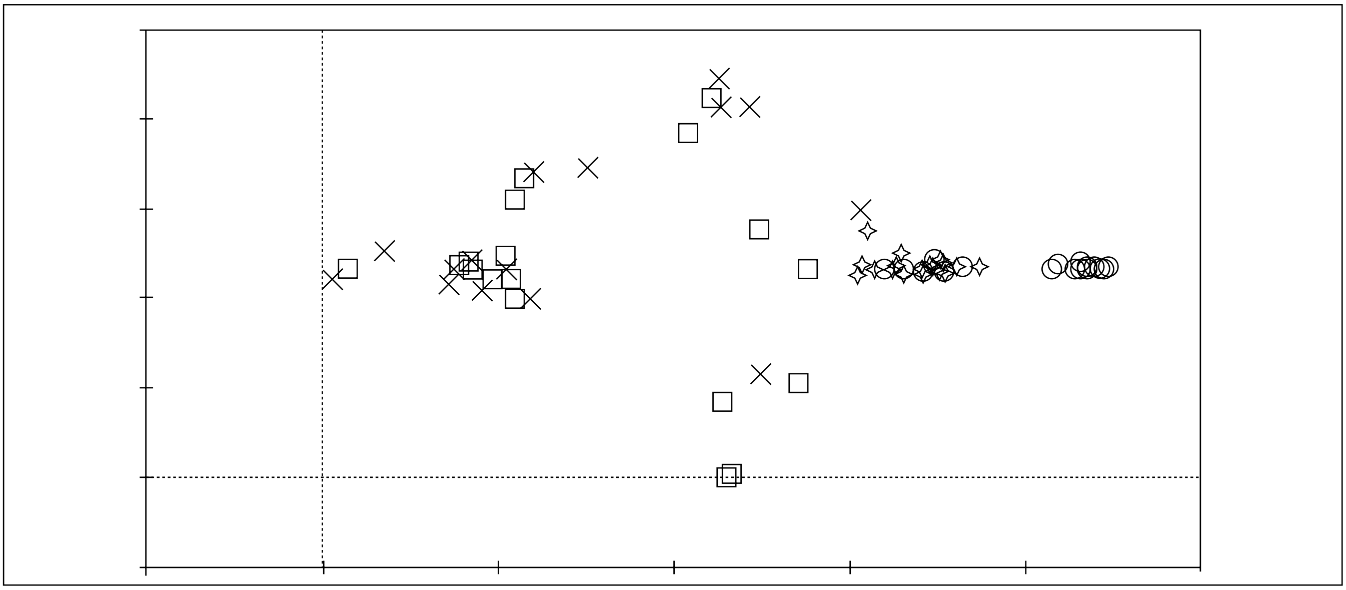

Fig. 2. Detrended correspondence analysis (DCA) of different plots, where "×" represents grazed grasslands in Horqin (Hor-G), "□" represents fenced grasslands in Horqin (Hor-F), "✧" represents grazed grasslands in Hulunbeier (Hul-G), and "O" represents fenced grasslands in Hulunbeier (Hul-F).

Fig. 2. Análisis de correspondencia de diferentes parcelas, donde "x" representa los pastizales pastoreados en Horqin (Hor-G), "□" representa los pastizales alambrados en Horqin (Hor-F), "✧" representa los pastizales pastoreados en Hulunbeier (Hul-G), y "O" representa los pastizales alambrados en Hulunbeier (Hul-F).

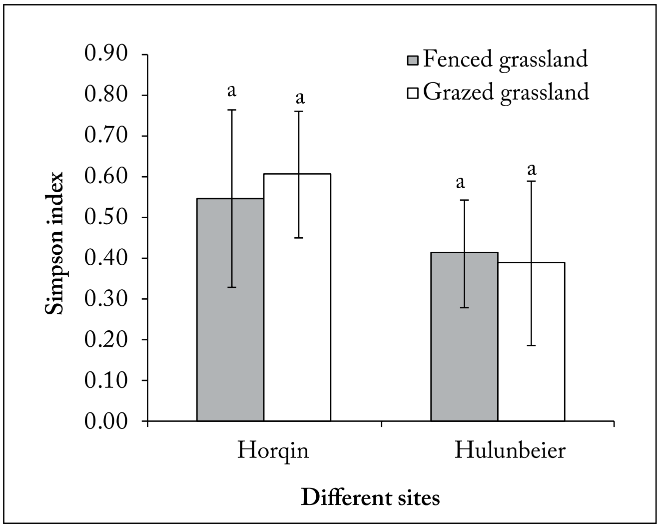

Fig. 3. Variation of the Simpson´s index of diversity between different sites or grazing treatments. Each histogram is the mean ± 1 SE of n=6. Equal letters above histograms indicate not significant differences at p<0.05.

Fig. 3. Variación del índice de diversidad de Simpson entre diferentes sitios o tratamientos de pastoreo. Cada histograma es el promedio ± 1 EE de n=6. Letras iguales sobre los histogramas indican no diferencias significativas a p<0,05.

Proportion of aboveground- and belowground carbon. In Horqin, grazing significantly decreased (p<0.05) aboveground carbon, while it had no effect (p>0.05) on belowground carbon (Table 3). Aboveground carbon in the grazed plots was 36% that in the fenced plots (Table 3). Litter carbon was also lower (p<0.05) in the grazed than fenced plots (Table 3).

A similar pattern was found in the Hulunbeier region, where aboveground carbon on the grazed plots was 38% of that in the fenced grasslands. Furthermore, the proportion of BGC in Hul-G reached 75.1% (p>0.05) of that in Hul-F (Table 3). Once again, LC was higher (p<0.05) in the fenced than grazed plots (Table 3).

While the percentage of aboveground carbon was greater (p<0.05) at the grazed than at the fenced area in Horqin, no differences (p>0.05) were found in that percentage between the grazed and fenced areas in Hulunbeier (Fig. 4).

Relationship between AG- and BGC at the study regions. At the Horqin site, there was a significant decrease in BGC as AGC increased at both the grazed (p=0.092) and the fenced (p=0.005) sites (Fig. 5). In the Hulunbeier region, however, even though it appeared to be a positive tendency at both study grazing treatments, the relationship was only significant at p=0.073 in the fenced area (Fig. 5).

Table 3. The contribution of each vegetation component (ABC= aboveground carbon, BGC= belowground carbon, LC= litter carbon) and the soil (SOC= soil organic carbon) to carbon storage (g C/m^2) on fenced or grazed grasslands at the Horqin or Hulunbeier sites in northern China. Hor-F: Horqin-fenced; Hor-G: Horqin-grazed. Each value is the mean ± 1 SE of n=6. Within each column and study site, different letters indicate significant differences between grazing treatments at p<0.05. Percentage refers to the contribution of each vegetation component and the soil to total carbon storage.

Tabla 3. Contribución de cada componente de la vegetación (ABC= carbono en la parte aérea; BGC = carbono en la parte subterránea; LC= carbono en la broza) y el suelo (SOC= carbono orgánico del suelo) al almacenamiento de carbono (g C/m^2) en áreas de vegetación natural pastoreadas o clausuradas al pastoreo en Horqin o Hulunbeier en el norte de China. Hor-F: clausura en Horqin; Hor-G: pastoreo en Horqin. Cada valor es el promedio ± 1 EE de n=6. Dentro de cada columna y sitio de estudio, letras diferentes indican diferencias significativas entre tratamientos de pastoreo a p<0,05. El porcentaje se refiere a la contribución de cada componente de la vegetación y el suelo al almacenamiento total de carbono.

Grazing treatment	Vegetation			Soil	Total Carbon
	AGC	BGC	LC	SOC	
Hor-F	52.8 ± 12.3a	33.4 ± 16.1a	20.5 ± 7.3a	8672.1 ± 5460.1a	8778.8 ± 5464.6a
Percentage	0.60%	0.38%	0.23%	98.78%	
Hor-G	19.3 ± 9.3b	28.2 ± 5.9a	13.0 ± 3.1b	6487.3 ± 2800.2a	6515.6 ± 2804.0a
Percentage	0.29%	0.43%	0.20%	99.08%	
Hul-F	71.2 ± 18.8a	42.2 ± 28.1a	32.5 ± 7.1a	8179.4 ± 960.1a	8325.3 ± 979.1a
Percentage	0.86%	0.51%	0.39%	98.20%	
Hul-G	27.0 ± 9.9b	31.7 ± 14.8a	25.0 ± 4.6b	8355.8 ± 590.7a	8439.5 ± 592.1a
Percentage	0.32%	0.38%	0.30%	99.00%	

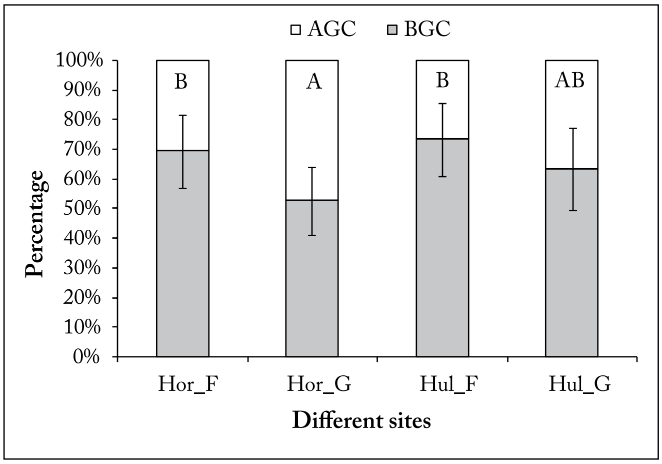

Fig. 4. Proportion of AGC and BGC in the grazed and fenced grasslands at each of the two study sites. "Hor_F" represents fenced grasslands in Horqin; "Hor_G" represents grazed grasslands in Horqin; "Hul_F" represents fenced grasslands in Hulunbeier, and "Hul_G" represents grazed grasslands in Hulunbeier. Different capital letters within each site represent significant differences (p<0.05) in aboveground carbon. Histograms are the mean ± 1 SE of n=6.

Fig. 4. Proporción de AGC y BGC en los pastizales pastoreados o clausurados al pastoreo en cada uno de los dos sitios de estudio. "Hor_F" representa pastizales alambrados en Horqin; "Hor_G" representa pastizales pastoreados en Horqin; "Hul_F" representa pastizales alambrados en Hulunbeier, y "Hul_G" representa pastizales pastoreados en Hulunbeier. Diferentes letras mayúsculas dentro de cada sitio representan diferencias significativas (p<0,05) en el carbono de la parte aérea. Los histogramas son el promedio ± 1 E.E. de n=6.

Soil organic carbon (SOC). There were no significant differences (p>0.05) in SOC storage in the whole soil profile between grazed and fenced grasslands in either the Horqin or Hulunbeier grassland (Table 3). Further analysis showed that in three of six paired plots (plot 3, plot 4 and plot 6) of Horqin region (Fig. 6), soil organic C storage was significantly lower (p<0.05) in the grazed (by 32-95%) than in the fenced plots. Such difference along the soil profile, however, was not observed in the Hulunbeier region (Fig. 7).

Soil at 20-40 cm soil depth contributed the highest carbon storage most of the times among the different soil depths at both study regions and grazing treatments (Figs. 6 and 7). In the Horquin region, the 20-40 cm soil depth produced 70.86% and 71.39% of the total soil carbon storage at the fenced and grazed grasslands, respectively. Similarly, in the Hulunbeier region, that soil depth produced 72.23% and 75.35% of the total soil carbon storage at the fenced and grazed grasslands, respectively (Figs. 6 and 7).

The contribution of soil to the total carbon pool. The greatest (p<0.05) carbon pool in both study regions was in the soil, where it ranged from 98.2 to 99.08% at the Horqin and Hulunbeier study sites (Table 3). In the Horqin region, soil contributed 8672.09 g C/m^2 which represented approximately 98.78% of the total carbon in fenced grasslands (Table 3). At the same site, AGC + LC contributed 0.83% which was twice that of the BGC (Table 3). Compared with measurements at the fenced grasslands, AGC + LC in the grazed grasslands contributed a relatively lower percentage (0.49% in

Horqin and 0.62% in Hulunbeier, respectively), while BGC contributed 0.43% at the Horqin, and 0.38% at the Hulunbeier study sites, respectively.

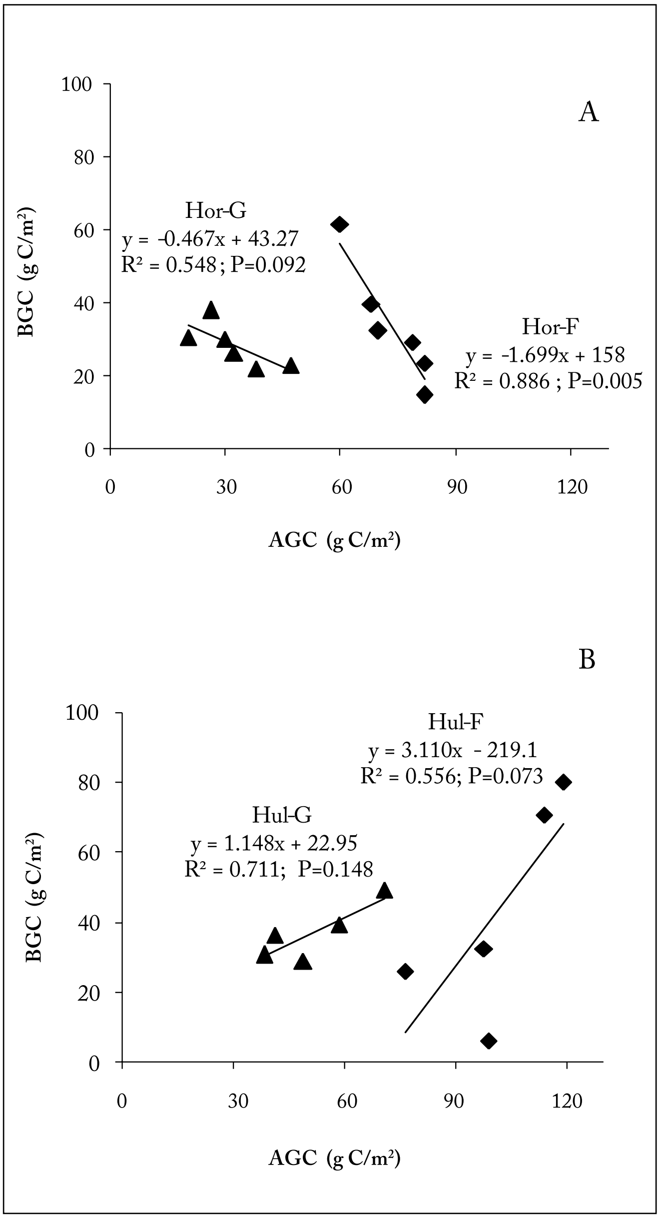

Fig. 5. The relationship of AGC/BGC at the either grazed (Hor-G) or fenced (Hor-F) grassland in Horqin or the grazed (Hul-G) of fenced (Hul-F) grassland in Hulunbeier. Each symbol represents individual values within 1 x1 m subplots distributed at random within a 500 x 500 m area. Half of this area was grazed while the other half remained ungrazed.

Fig. 5. Relación AGC/BGC en pastizales pastoreados (Hor-G) o alambrados (Hor-F) en Horqin o pastoreados (Hul-G) o alambrados (Hul-F) en Hulunbeier. Cada símbolo representa valores individuales dentro de subparcelas de 1 x 1 m distribuídas al azar dentro de un área de 500 x 500 m. La mitad de esta área fue pastoreada mientras que la otra mitad permaneció sin pastorear.

DISCUSSION

Effects of grazing on community composition. Grazing can affect the abundance, richness, and spatial heterogeneity of vegetation (Hilbert et al., 1981; Adler et al., 2001; Fuhlendorf & Engle, 2004). However, the effects of grazing at different regions may depend on its intensity and history (Austrheim & Eriksson, 2001; Díaz et al., 2001). Some studies have indicated that heavy grazing caused degradation of the alpine meadows (Zhou et al., 2005). Meanwhile, other studies have shown that moderate to heavy grazing by a combination of herbivore species resulted in similar plant communities (Allred et al., 2012; Wang et al., 2012). In our study, the plant species of the study regions showed indeed differences by DCA. However, the plant communities were similar between grazed and fenced grasslands within the same region; species diversity, expressed by the Simpson index, also showed no significant $(p<0.05)$ differences between grazed versus fenced grasslands in the same region. Dominant species were *Setaria viridis* (L.) P. Beauv. and *Arthraxon hispidus* (Thunb.) Makino in Horqin, and *Cyperus fuscus* L., *Agropyron cristatum* (L.) *Gaertn.* and *Stipa capillata* L. in Hulunbeier. Thus, grazing showed little influence on plant species diversity at the two study locations.

Effects of grazing on BGC and its relationship with AGC. Grazing can stimulate the productivity of vegetation in a wide range of ecosystems (McNaughton, 1985; Hadar et al., 2009; Smith et al., 2012), such as in forests and grasslands (Lohmann et al., 2012). However, the effects of grazing on BGC are rather elusive. Some studies have showed that grazing negatively impacted BGC (Rodriguez et al., 2007). Other findings, however, revealed that BGC increased under grazing as compared to control plants (Huhta et al., 2009). Our results indicated that grazing significantly decreased AGC, while BGC remained similar on grazed *versus* ungrazed sites in both study regions (Table 3).

Optimal partitioning and isometric allocation are two important hypotheses in biomass allocation of plants (Gedroc et al., 1996; Yang et al., 2009; Chan, 2012). The optimal partitioning hypothesis suggests that plants respond to environmental conditions by allocating biomass among various organs which contributes to capture nutrients, water, and light to maximize their growth rate (Kobe et al., 2010; Nair et al., 2013). In annual species, AGB/BGB partitioning is partially consistent with the optimal partitioning theory, but it might be also highly ontogenetically constrained (Gedroc et at, 1996). By comparison, the isometric allocation hypothesis predicts that the relationship between AGB and BGB is isometric across different plant species (Worley & Harder, 1996; Gray et al., 2006).

In our study, as AGC increased, BGC decreased at the Horqin region, which is consistent with the theory of optimal partitioning (Fig. 5). If a plant allocates more biomass be-

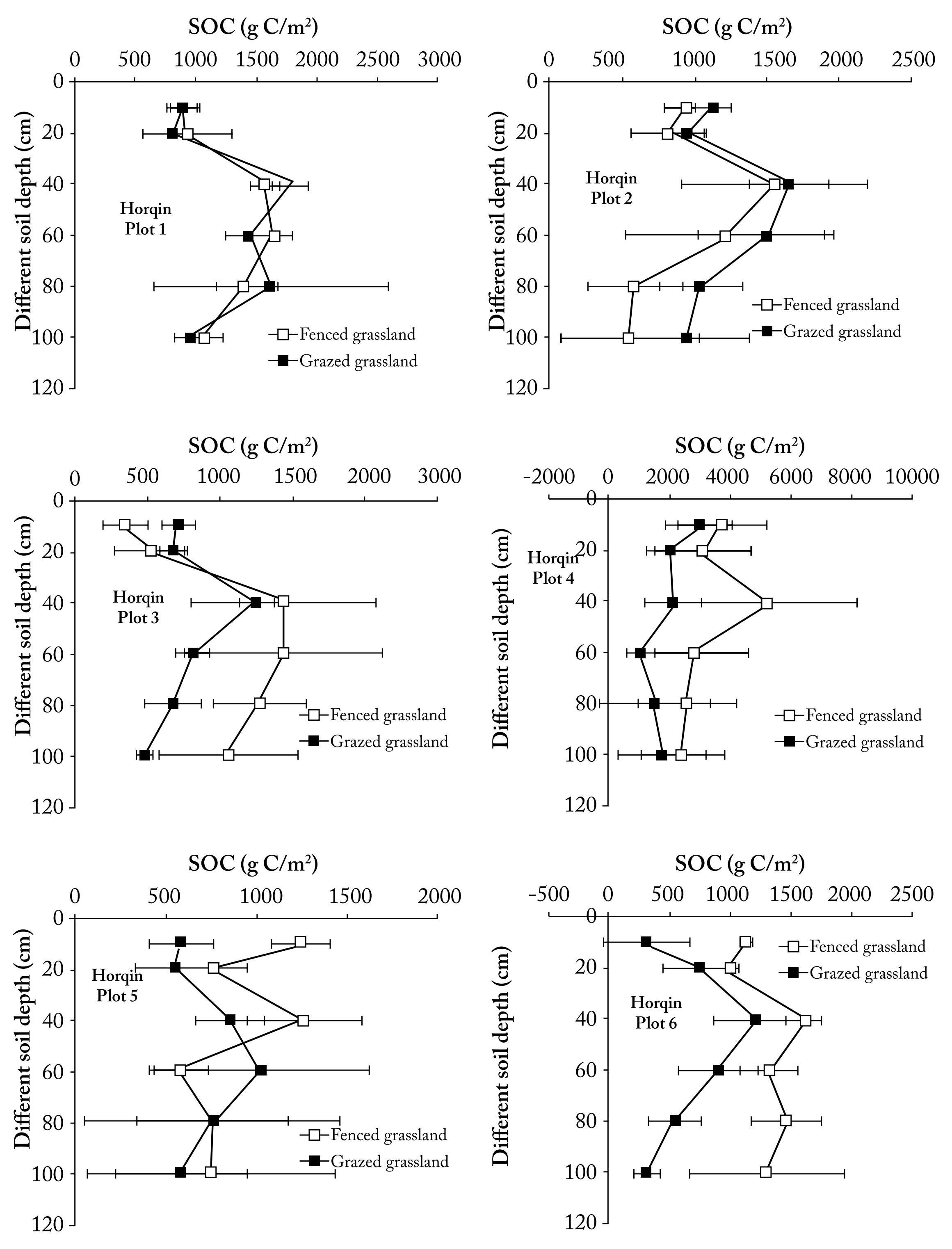

Fig. 6. SOC distribution at different soil depths at either grazed or fenced grasslands in Horqin region. Each symbol is the mean ± 1 SE of n=5 subplots within each study plot. Notice the change of scale in Plot 4.

Fig. 6. Distribución del SOC a diferentes profundidades del suelo en pastizales pastoreados o alambrados en Horqin. Cada símbolo es el promedio ± 1 E.E. de n=5 subparcelas dentro de cada parcela estudiada. Note el cambio de escala en la Parcela 4.

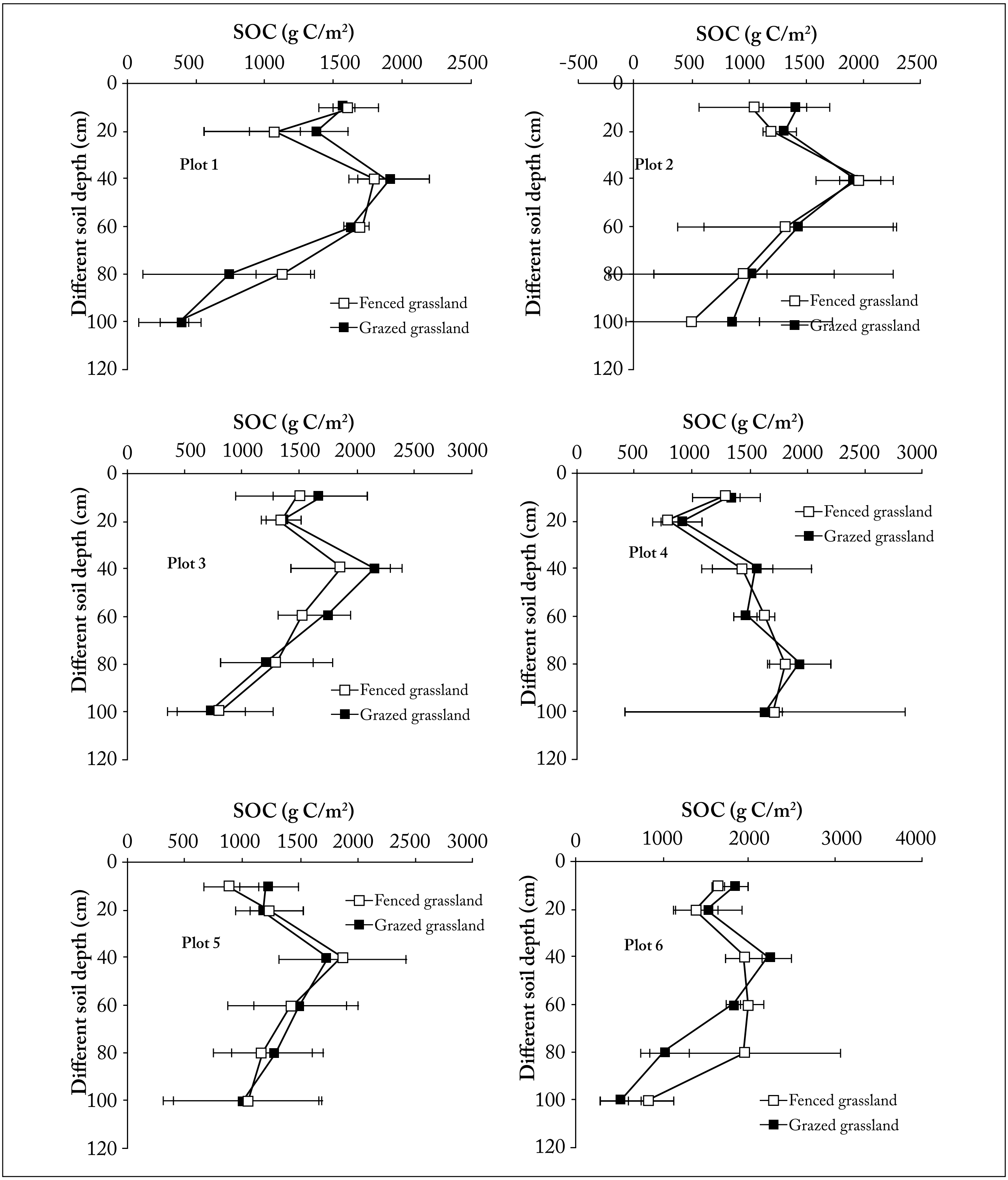

Fig. 7. SOC distribution at different soil depths at either grazed or fenced grasslands in Hulunbeier region. Each symbol is the mean ± 1 SE of n=5 subplots within each study plot. Notice the change of scale in the study plots.

Fig. 7. Distribución del SOC a diferentes profundidades del suelo en pastizales pastoreados o alambrados en Hulunbeier. Cada símbolo es el promedio ± 1 E.E. de n=5 subparcelas dentro de cada parcela estudiada. Note el cambio de escala en las parcelas estudiadas.

lowground to acquire more moisture and/or nutrients, it may decline its resource partitioning to aboveground plant parts. Meanwhile, if a plant develops more biomass aboveground to contribute capturing of more light, resource partitioning to roots may decline. On the contrary, the AG- and the BGC showed a positive relationship in the Hulunbeier region. Different community composition may cause different growth strategies to generate different AG- and BGC relationships at both study sites. In our study, plant species showed a greater difference at the Hulunbeier than at the Horqin region (Fig.2). In addition, different thermal conditions may cause different plant growth levels (Lambers et al., 1998). Horqin (42° 56' - 43° 20' N, 119° 29' E - 119° 41' E) and Hulunbeier (47° 20' - 50° 12' N, 118° 31' E - 121° 03' E) lied along a similar longitude but a different latitude, indicating a similar hydrological constraint but different thermal conditions. The mean annual open-pan evaporation was 1935 mm in Horqin, and 1371 mm in Hulunbeier. A lower evaporation in Hulunbeier grasslands could maintain higher AGC values when BGC increased. Thus, differences in plant species composition and mean annual evaporation could help explain why plant and soil variables did not show a consistent response to grazing in both the Horqin and the Hulunbeier regions.

Effects of grazing on SOC. In our study, grazing exclusion for 8-10 years did not change the total mass of C in the plant-soil system compared to values obtained under grazing conditions both at the Horqin and Hulunbeier regions. However, it did change the distribution of C among the plant components in those systems. This result is consistent with many studies that soils and ecosystems will not accumulate sufficient C when an area is fenced to herbivory grazing for a short time period (Schuman et al., 1999). Other studies have found that after a 20-year grazing exclusion, grasslands in northern China were stable in their productivity (Kawamura et al, 2005; Pei et al, 2008), spatial pattern of soil properties (Su et al, 2006) and C storage (Wu et al, 2008; He et al, 2008).

Our study also demonstrated that soil organic C was significantly lower in grazed than fenced plots (by 32-95%) in three out of six paired plots in Horqin region. At the same time, no differences were observed along the soil profile between fenced and grazed plots in the Hulunbeier region (Fig. 6 and Fig. 7). Also, soil carbon in the topsoil (0-20 cm) approached 1000 g C/m^2 in Horqin, and 1500 g C/m^2 in Hulunbeier. Several authors reported that variations in SOC levels can be due to climate, soil or vegetation type differences (Jonasson et al., 1986; Dec et al., 2010; Crowther & Bear, 2012). Variations in SOC could also be due to differences in grazing history or in the history of grazing intensity before and after grazing exclusion (Eckstut et al., 2011). A major problem in our study was the community heterogeneity between the two study regions. In Horqin, habitats were more fragile than those in Hulunbeier, with higher evaporation and less vegetation, which contributed to make a greater difference on carbon storage along the various study soil depths. The soil, however, was the largest "carbon pool" in the study grassland ecosystems, where it contributed with more than 98% of the total carbon. This is consistent with previous studies (Conant et al, 2001; Chen et al, 2012). Fenced grasslands in both Horqin and Hulunbeier steppes provided twice as much litter carbon as grazed ones, which would be transformed into soil organic matter and make the soil more productive.

MANAGEMENT IMPLICATIONS

The rangeland management profession has clearly advanced the natural resource conservation worldwide (James et al, 2013). Numerous experimental studies have demonstrated that grazing intensity has been the most important principle of grazing management (Hickman et al, 2004; Briske et al, 2008). However, the potential contribution to it from different regions has largely been ignored. While grazing decreased the proportion of aboveground carbon, it showed little influence on plant species diversity in both the Horqin and Hulunbeier regions. Therefore, for the restoration of plant species diversity at the study sites, it appears unnecessary to take into account the relationship between grazing practice and regional disparity.

Relationships between precipitation versus soil nutrient or regional disparity in relevant decision-making approaches have yielded different for rangeland management (Derner & Schuman, 2007; Gillingham et al, 2012). Our results showed that as aboveground carbon increased, belowground carbon decreased in Horqin, while positive correlations between the two plant parts were found in the Hulunbeier region. This suggests that plant photosynthesis might be enhanced in Hulunbeier to produce more aboveground carbon, while more soil nutrients should be provided for rangeland restoration in Horqin. Management plans for conservation and restoration of grasslands under grazing should therefore focus on the specific site conditions, and take several abiotic and biotic factors into account.

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