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REGULAR ARTICLE

Effects of grazing management system on plant community structure and functioning in a semiarid steppe: scaling from species to community

Hongwei Wan · Yongfei Bai · Philipp Schönbach · Martin Gierus · Friedhelm Taube

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Abstract Under the aim of searching for a more sustainable grazing management system, a mixed management system (grazing and haymaking alternate annually) was proposed and tested against traditional management system (used consistently either for grazing or haymaking) in the semiarid grassland of Inner Mongolia with a field manipulation experiment. The responses of aboveground biomass to the two grazing management systems were examined across different levels of organization (i.e., species, plant functional group, and community) and in five consecutive years from 2005 to 2009. The effects of the two systems on seed production potential of four dominant species (*Leymus chinensis*, *Stipa grandis*, *Agropyron cristatum*, *Cleistogenes squarrosa*) were also investigated. Our results demonstrate that, in the traditional system, aboveground biomass production across all the levels of organization was reduced by grazing. In mixed system, however, no significantly negative relationship between the biomass response and stocking rate was detected at all organization levels. Precipitation fluctuation had strong influence on biomass responses, and compared to the traditional system the slope of the biomass-precipitation relationship tends to be higher in the mixed system. This effect might be attributed to the more positive response of *L. chinensis* and *A. cristatum* to increase in precipitation. In the traditional system, both the ratio and the density of reproductive tillers of the grazing subplots were significantly reduced compared to the haymaking or ungrazed control plots. In the mixed system, there was no significant difference between the haymaking subplots and the ungrazed control plots, regardless of the grazing pressures imposed on the haymaking subplots in the previous growing season. Our findings suggest that the mixed system mitigates the sheep grazing-induced species shift and it tends to be more responsive to increasing precipitation as compared to the traditional system. Therefore, replacement of the traditional grazing strategy with the mixed system could provide an important contribution to sustainable land-use of the Inner Mongolia grasslands.

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H. Wan (✉) · P. Schönbach · M. Gierus · F. Taube
Institute of Crop Science and Plant Breeding - Grass
and Forage Science/Organic Agriculture,
Christian-Albrechts-University,
Hermann-Rodewald-Str. 9,
24118 Kiel, Germany
e-mail: hwan@email.uni-kiel.de

Y. Bai
State Key Laboratory of Vegetation and Environmental
Change, Institute of Botany, Chinese Academy of Sciences,
Beijing 100093, China

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Abbreviations

AB	Aboveground biomass
AS	Annuals and biennials
IRT	Intact reproductive tiller
PB	Perennial bunchgrasses
PF	Perennial forbs
PR	Perennial rhizomes
RB	Relative aboveground biomass

Introduction

Grazing is a major factor influencing biodiversity and ecosystem functioning of grasslands (Diaz et al. 2007; Fernandez-Gimenez and Allen-Diaz 2001; Li 1989; Sala et al. 2000). However, abundant evidence demonstrates that grazing leads to shifts in species composition, alters community structure, and reduces ecosystem functioning across a wide range of arid and semiarid grasslands (Anderson and Briske 1995; Archer 1989; Belsky 1992; Bosch 1989; Ellison 1960; Noy-Meir et al. 1989). Grazing generally causes the replacement of tall-grasses by short-grasses or palatable species by unpalatable species (Augustine and McNaughton 1998; Diaz et al. 2007). Following such structural and compositional changes, both the herbage productivity and quality of the system would, therefore, be greatly influenced. The mechanisms of such shifts have been extensively studied in natural and semi-natural grasslands of North America, Africa, and Europe, or by simulated defoliation experiments both in fields or greenhouses (Anderson and Briske 1995; Milchunas et al. 1988; Milton and Dean 1995; Mitchley 1988; Noy-Meir et al. 1989). Grazing may influence plant communities in both direct and indirect ways, i.e., directly through defoliation and trampling on plant's survival, growth, and fecundity and indirectly by altering the intra- and interspecific interactions or the water and nutrient availability by affecting soil physical and chemical properties (Hodgson and Illius 1996). From the perspective of herbivores, three major components have to be clearly considered, i.e., grazer species, number of grazers, and patterns of grazing (continuous or intermittent). Different combinations of these three components provide great potential options for sustainable grassland management. An optimal management system, however, needs the basic knowledge about the predominant grazing resistance mechanisms (avoidance or tolerance) of dominant species within a certain community from the perspective of vegetation and diet preference of the grazers from the animal perspective (Hodgson and Illius 1996).

The Eurasian steppe is the largest contiguous terrestrial biome in the world (Bai et al. 2007; Coupland 1993). While many previous studies demonstrate that poor management and overgrazing causes shifts in dominant species and consequently leads to grassland degradation across a wide range of ecosystems in the Eurasian steppe (Li 1988; Tong et al. 2004; Wang and Ripley 1997; Wang et al. 2002). And the shortage of sustainable management alternatives was partly attributed to the lack of systematic studies on the underpinning mechanisms of grazing induced species shift (Harris 2010). Under the aim of searching for a more sustainable grazing management system and exploring the mechanisms of plant community structure and functioning changes induced by sheep grazing, a field grazing experiment with two management systems and seven stocking rates and two land use types was established on a typical steppe community dominated by *Leymus chinensis* and *Stipa grandis*, a widely distributed community type in the Eurasian steppe (Bai et al. 2004).

In the traditional management system, the pastures were used consistently either for grazing or haymaking, whilst in the mixed management system, grazing and haymaking alternate annually. A previous study from the same experiment documented that the herbage quality on offer increased, but the herbage productivity decreased with increasing stocking rate (Schönbach et al. 2009). The comparison of two management systems, i.e. traditional and mixed system showed marked effects (Schönbach et al. 2010). Comparing with the traditional system, the mixed system was more resilient to grazing, especially at the high stocking rates (Schönbach et al. 2010). However, a fundamental question is yet to be fully answered regarding how does the management system shape the community structure and functioning? To address this question, a detailed analysis on plant responses to stocking rate of the two management systems at different levels of organization (i.e., at species, plant functional group, and community level) is particularly necessary. We hypothesized that the species shift could be mitigated substantially in the mixed system compared to the traditional system. The mixed system might reduce the seed depletion rate because it had the chance to get seed compensation from the haymaking year run. In order to test this hypothesis, the seed production potential indicated as intact reproductive tiller ratio and density, was also investigated and examined to address following three research questions: 1) How does land use type (grazing and haymaking) influence the seed production potential in the traditional system? 2) Is the influence enhanced by increasing stocking rates? 3) Are there carryover effects of grazing on seed production potential in the mixed system?

Materials and methods

Experimental site

This study was conducted at the Inner Mongolia Grassland Research Station (IMGERS, 43° 38′ N, 116° 42′ E) of the Chinese Academy of Sciences, which is located in the Xilin River Basin of Inner Mongolia, China (Bai et al. 2004). The topography consists of low rolling hills, with an elevation ranging from 1,200 m to 1,280 m above sea level. The mean annual precipitation is 346.1 mm, with about 60–80% falling as rainfall in the growing season (April to September). The mean annual temperature is 0.3°C. The soil is classified as dark chestnut (Calcic Chernozem according ISSS Working Group RB, 1998). *Stipa grandis* (perennial bunchgrass) and *Leymus chinensis* (perennial rhizomatous grass) are two dominant species in the study area, which altogether account for 60–80% of total aboveground biomass (AB). The experimental area has been used for sheep grazing before the experiment was established, and in order to make an equal starting point, the whole area was cut to 3–5 cm in stubble height at end of the growing season in 2004.

Experimental design

Our experimental site, which covers a total area of 128 ha, was established in 2005 with a split–split plot in a random complete block design. The main plot factor is management system, i.e., traditional versus mixed systems. The subplot factor is stocking rate (0 to ~9 sheep ha^{-1}, by an increment of ~1.5) and the sub-subplot factor is land use type (grazing and haymaking). The 128 ha area was first divided topographically into two blocks (block slope and flat, Fig. 1a), and each block was divided into two paddocks (management system was randomly assigned into each block, Fig. 1b), and each paddock were further divided into 7 plots (stocking rate was randomly assigned into each paddock, Fig. 1c), and each plot was then divided into 2 subplots (land use type was randomly assigned into each plot, Fig. 1d). In the mixed system, the land use for each subplot had a shift between haymaking and grazing year after year (Fig. 2a), whereas, the haymaking and grazing subplots were used continuously for haymaking and grazing each year in the traditional system (Fig. 2b). The layout of experiment in 2005 and 2006 were showed in the supplementary figures 1 and 2. In total 56 experimental units were established in which the smallest unit is 2 ha in size. In order to ensure herds of at least 6 sheep, the experimental unit of lower stocking rate (1.5 sheep/ha) was enlarged to 4 ha. Grazing started from the beginning of June until end of September and haying was done once a year at the middle of August. Due to spatial heterogeneity of vegetation, plots with the same stocking rate were exposed to different grazing pressure. In order to keep the same grazing pressure on the sward under target grazing intensity, we switched grazing management from the fixed stocking rates to herbage allowance in 2007. The number of sheep was then adjusted monthly in each grazing plot according to the herbage on offer. In this paper, the averaged stocking rate was used to describe the grazing intensity because of its quantitative attribute. A detailed description of herbage allowance application for this grazing experiment is given in Schönbach et al. (2010).

Aboveground biomass sampling and response index calculation

Within each plot, three (in the 2 ha plot) or six (in the 4 ha plot) representative sampling points were selected and marked. In all grazing plots, grazing exclosures (3 m×2 m) were established at the previously chosen sampling points prior to sheep

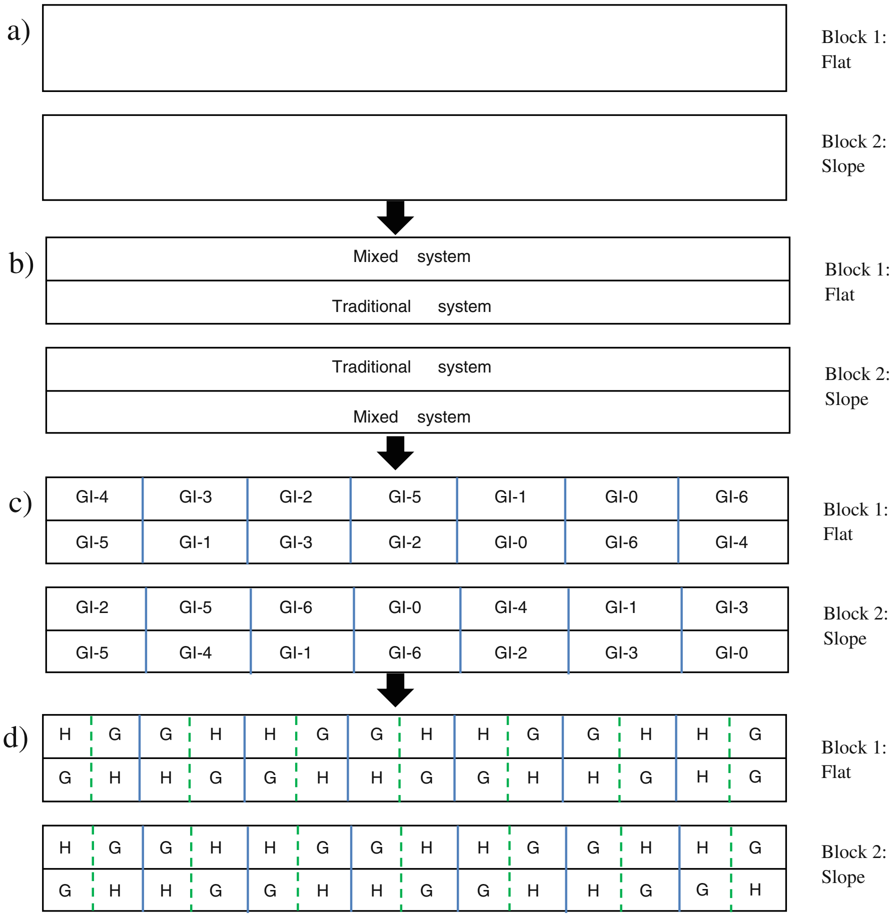

Fig. 1 Illustration of the experimental design. The experiment is a split–split plot in a random complete block design. **a** The area was first divided topographically into two blocks (slope and flat); **b** each block was divided into two paddocks (mixed and traditional system were randomly assigned to each block); **c** each paddock was further divided into 7 plots (stocking rate was randomly assigned to each paddock); **d** each plot was then divided into 2 subplots (land use type was randomly assigned to each plot). GI denotes stocking rate, 0–6 denotes the seven stocking rates, H and G denotes the land use of haymaking and grazing respectively

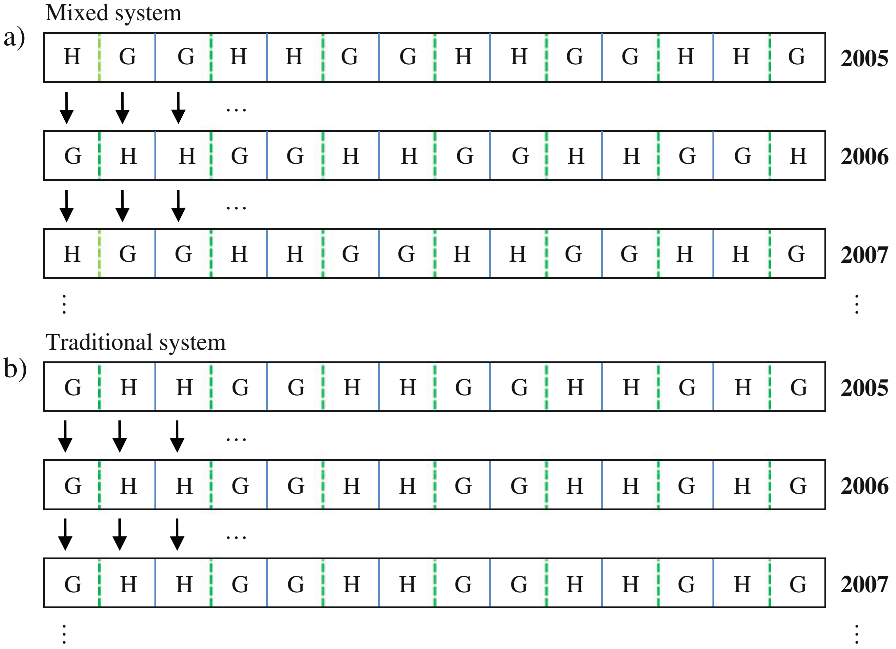

Fig. 2 Illustration of the differences between the mixed and traditional management system from 2005 to 2007. *Black arrows* show the successional land use of the same plot over years. H and G are derived from Fig. 1

grazing started in June. In July, a 0.25 m×2 m transect was sampled either inside of each exclosure in the grazing plot or close to each of the marked points in the haymaking plots to determine the botanical composition and aboveground biomass (AB) of the community. All plants within the transect were clipped to 1 cm stubble height, separated to species, oven dried at 60°C for 24 h to constant weight, and weighed.

AB response was calculated by the following formula:

$$R_{AB} = \mathrm{Ln}(ABt/ABi) \tag{1}$$

Where R_{AB} represents the AB response, t represents year of 2006, 2007, 2008, 2009, i represents year 2005, AB could be of a community, a plant functional group or a species. Plant species were classified into five plant functional groups based on Bai et al. (2004), i.e., perennial rhizomes (PR), perennial bunchgrasses (PB), perennial forbs (PF), annuals and biennials (AS), shrub and semi-shrubs.

Reproductive tiller and species frequency measurement

For each management system, intact reproductive tiller (IRT) and vegetative tiller of four dominant species was counted at four stocking rates (0, 1.5, 4.5, 7.5 sheep/ha) in mid-August of 2007, when most of species start flowering and seeding. These species were: *L. chinensis* (perennial rhizome grass), *S. grandis* (tall bunchgrass), *Cleistogenes squarrosa* (short bunchgrass), and *Agropyron cristatum* (bunchgrass with short rhizomes). Together, these species account for about 80% of the total community AB (Table 1). In each subplot, a total number of 30 individuals (ramet for clonal plant) or bunches of each species were chosen randomly along a 150-m zigzag shaped transect, and the number of IRT and vegetative tiller were recorded at individual level. Tillers which could be recognized as reproductive tillers but the heads were grazed by sheep were also recorded separately.

Species frequency was measured with point sampling method after the IRT investigation (Whalley and Hardy 2000). For each subplot, 50 points were randomly chosen and investigated with a 10 cm-diameter circle at each point. The number of bunches or individuals of each species within the circle was recorded. Species density was expressed as the number of bunches or individuals per unit of area. For each species, the ratio of IRT was calculated as the number of IRT divided by the total amount of tillers of 30 bunches or ramets. The density of IRT was determined by the ratio of IRT and the density of each species.

Table 1 Botanical composition of the plant community (mean ± SE) of the experiment area in the initial experimental year 2005 before any treatment started

	PR	PB	PF	AS	*L. c.*	*S. g.*	*A. c.*	*C. s.*
Aboveground biomass (g m^{-2})								
Mf	27.35 ± 1.89^{b}	58.81 ± 2.97^{a}	8.06 ± 1.75^{a}	0.13 ± 0.09^{a}	18.19 ± 1.47^{b}	31.13 ± 3.77^{ab}	12.92 ± 2.41^{a}	13.18 ± 0.76^{a}
Ms	40.71 ± 4.48^{b}	48.49 ± 3.59^{b}	2.91 ± 1.15^{b}	0.02 ± 0.01^{a}	29.24 ± 4.19^{b}	22.86 ± 3.67^{ab}	12.86 ± 1.65^{a}	7.08 ± 1.16^{b}
Tf	69.16 ± 6.71^{a}	57.97 ± 2.69^{a}	4.07 ± 0.70^{b}	0.03 ± 0.01^{a}	59.57 ± 6.01^{a}	31.57 ± 2.44^{a}	8.88 ± 1.82^{ab}	11.77 ± 1.14^{a}
Ts	35.21 ± 4.46^{b}	41.11 ± 3.74^{b}	1.56 ± 0.31^{b}	0.02 ± 0.01^{a}	25.30 ± 3.58^{b}	21.42 ± 2.95^{b}	5.94 ± 0.93^{b}	8.60 ± 1.28^{b}
Relative biomass (%)								
Mf	29.07 ± 1.82^{b}	62.07 ± 2.21^{a}	8.79 ± 2.02^{a}	0.07 ± 0.07^{a}	19.50 ± 1.64^{c}	32.43 ± 3.29^{a}	13.86 ± 2.53^{ab}	14.00 ± 0.88^{a}
Ms	43.00 ± 3.72^{a}	53.71 ± 3.59^{ab}	3.07 ± 1.09^{b}	0.00 ± 0.00^{a}	30.00 ± 3.16^{b}	24.21 ± 3.23^{a}	15.14 ± 2.36^{a}	8.50 ± 1.97^{b}
Tf	51.29 ± 2.89^{a}	45.50 ± 2.87^{b}	3.00 ± 0.38^{b}	0.00 ± 0.00^{a}	44.07 ± 2.60^{a}	24.64 ± 1.89^{a}	7.29 ± 1.72^{c}	9.21 ± 0.84^{b}
Ts	44.21 ± 3.84^{a}	53.71 ± 3.87^{ab}	2.00 ± 0.44^{b}	0.00 ± 0.00^{a}	31.86 ± 3.50^{b}	27.29 ± 2.73^{a}	8.21 ± 1.75^{bc}	11.29 ± 1.56^{ab}

Values with the same superscript letters within each column are not significantly different in Duncan's Multiple range test from one-way ANOVA ($P > 0.05$). Abbreviations: Mf = mixed flat, Ms = mixed slope, Tf = traditional flat, Ts = traditional slope; *L. c.* = *Leymus chinensis*, *S. g.* = *Stipa grandis*, *A. c.* = *Agropyron cristatum*, *C. s.* = *Cleistogenes squarrosa*; PR = Perennial rhizome grasses, PB = Perennial bunchgrasses, PF = Perennial forbs, AS = Annuals and biennials

Statistical analyses

Statistical analysis was performed using SAS Version 9.1 (SAS Institute Inc., Cary, NC, USA). Duncan's Multiple range test from one way ANOVA proceeded with general linear model (GLM) was used to compare AB, relative aboveground biomass (RB) of each organization level of the four paddocks, and to see significant differences before any experimental treatment started. For management system comparison, each pair of grazing and haymaking subplots was considered as a unit, the response index was calculated on this unit basis. Linear regression was used to analyze the responses of AB to stocking rate and to variation in precipitation (calculated as the natural logarithm transformed ratios of effective precipitation from 2006 to 2009 to the initial year 2005). To address the three questions the two management systems are considered separately when examining the land use type (grazing and haymaking) and stocking rate effects on seed production potential.. In order to address the first two questions regarding the land use type and stocking rate effects on the seed production potential, the IRT ratio and density of the haymaking plots were averaged for each block, and then compared with the ungrazed control and other three levels of stocking rate in the traditional system. Furthermore, multiple comparisons of reproductive tiller ratio and density between the control and three haymaking plots in the mixed system were made to clarify the third question regarding the carryover effects of grazing on seed production potential. Tukey's test from ANOVA proceeded with mixed model were used for multiple comparisons.

Results

Effective precipitation

Correlations between January to July, October-through-July, and August-through-July precipitation and community AB showed that August-through-July precipitation was most correlated with community and AB (R^2=0.08, 0.12, 0.25 between the precipitation of January to July, October-through-July, and August-through-July to community AB, respectively) and was defined as the effective precipitation. This finding highlights the importance of precipitation in late autumn and during the winter time for July AB formation. The effective precipitation was 317, 230, 281, 327 and 289 mm in 2005, 2006, 2007, 2008 and 2009, respectively (Fig. 3). While its long-term mean was 322 mm (1982–2009). As compared with the long-term mean, effective precipitation from 2005 to 2009 was characterized by a standard initial starting year (98%, 2005) followed by a drought year (71%, 2006), a substandard years (87%, 2007), a normal year (102%, 2008) and a substandard year (90%, 2009).

Initial state of plant community of the experimental grassland in 2005

At plant functional group level, PR and PB were two dominant functional groups in our experimental site, which together accounted for more than 90% of the total community AB. At species level, about 80% of the total community AB was composed of four dominant species, i.e., *Leymus chinensis*, *Stipa grandis*, *Agropyron cristatum*, *Cleistogenes squarrosa* (Table 1).

The AB and RB of the dominant species and functional groups and the total community AB differed significantly between established paddocks at the start of the experiment. Among the four

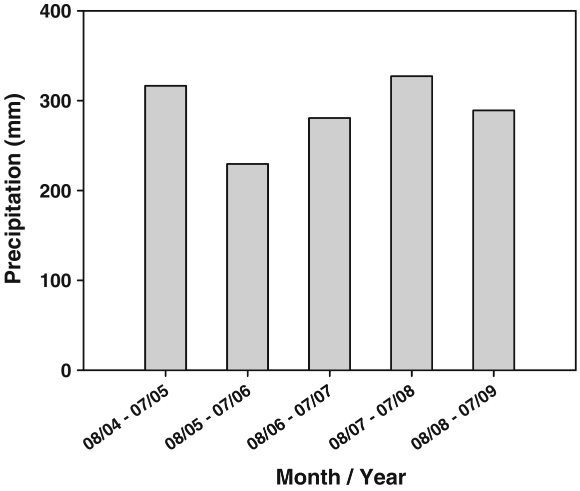

Fig. 3 The effective precipitation (sum of the precipitation from August of previous year to July of the current year) during 2005 to 2009

paddocks, the traditional flat showed the highest AB production, with more PR (such as *L. chinensis*) and less PB (such as *A. cristatum* and *C. squarrosa*). The mixed flat had lower productivity, with more PB, PF and AS, but less PR. The traditional slope and the mixed slope paddocks were quite similar in terms of plant species and functional type composition and community AB production, except that both the AB and RB of *A. cristatum* were significantly higher at the mixed slope than that of the traditional slope paddock (Table 1). The heterogeneity in the botanical composition and community AB was also found between plots within each paddock, but it was stochastically distributed along the gradient of stocking rate, with no correlation being found between AB of each organization level and stocking rate at the beginning of the experiment in 2005 (data not shown). Due to these background variations in the botanical composition at the beginning of the experiment, the response index (relative changes) of each organization level for each plot was used for comparison rather than the absolute AB data.

Aboveground biomass responses to stocking rate across different levels of organization

At the community level, total AB decreased linearly with increasing stocking rates in traditional system (R^2 = 0.20, P < 0.0001) when all data were pooled across the four years (2006–2009) and two blocks (flat versus slope) (Fig. 4). In the mixed system, however, no significant relationship between community AB response and stocking rate was found (R^2= 0.02, P > 0.10) (Fig. 4). At plant functional group level, the AB of PR and PB declined linearly with increasing stocking rate in the traditional system, while the other two functional groups showed no significant responses to grazing (Table 2). In the mixed system, the AB of AS increased with stocking rate, while the AB of the other functional groups remained largely unchanged (Table 2).

At species level, the AB of *L. chinensis* and *C. squarrosa* was negatively correlated with stocking rate in the traditional system, while *S. grandis and A. cristatum* exhibited no significant responses to grazing (Table 2). In the mixed system, all the four dominant species remained unchanged across the seven stocking rates (Table 2).

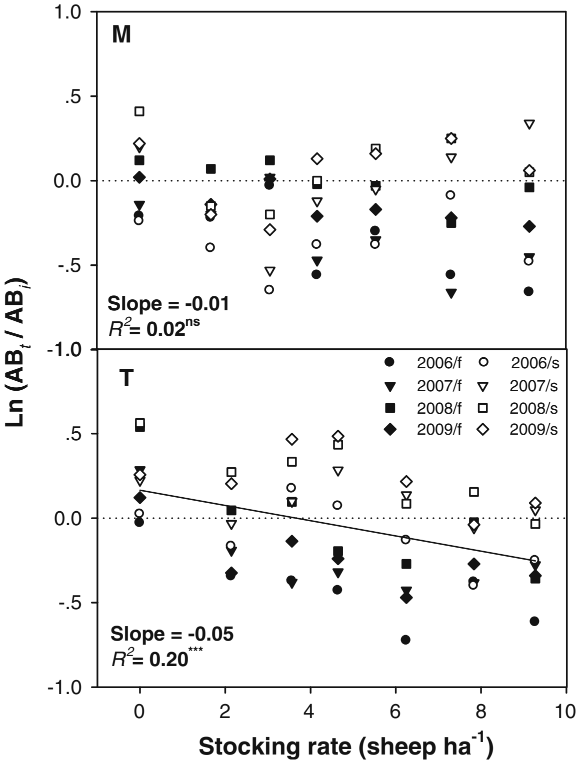

Fig. 4 Relationship between total community level aboveground biomass (AB) response and stocking rate in mixed system (M) and traditional system (T). $RI = \ln(AB_t/AB_i)$, t represents year of 2006, 2007, 2008, 2009, i represents year 2005. Symbol followed by year/blocks, "f" denotes block flat and "s" denotes block slope

Relationship between aboveground biomass response and variation in precipitation

At the community level, the total AB increased linearly with the August-through-July precipitation in both the traditional system and the mixed system, with the slope in the mixed system showing a tendency to be higher than that of the traditional system (Table 3).

At plant functional group level, only the AB of PB increased with the August-through-July precipitation in both the traditional and mixed systems (P < 0.001, Table 3). At species level, AB of *S. grandis* was positively correlated with the August-through-July precipitation in both the traditional and mixed systems (P < 0.001). Among the other three dominant species examined, the AB of *L. chinensis* and *A. cristatum* also increased with the August-through-July precipitation in the mixed system, although the level of significance was at $0.05 < P < 0.1$ due to the small sample size per plot (Table 3).

Table 2 Relationships between biomass response and stocking rate for plant functional groups (PFG) and dominant species under two management systems

		Mixed system			Traditional system		
		Slope	R^2	P	Slope	R^2	P
PFG	PR	−0.03	0.03	ns	−0.04	0.10	*
	PB	−0.02	0.03	ns	−0.04	0.10	*
	PF	0.01	0.00	ns	−0.11	0.06	#
	AS	0.28	0.15	**	0.00	0.00	ns
Species	*L. c.*	0.00	0.00	ns	−0.06	0.14	**
	S. g.	0.01	0.00	ns	−0.02	0.02	ns
	A. c.	−0.06	0.03	ns	0.00	0.00	ns
	C. s.	−0.05	0.04	ns	−0.12	0.16	**

Regression parameters were estimated by linear model with stocking rate (SR) as independent variable and RI [$\ln(AB_t/AB_i)$] as dependant variable, i.e. *RI* = Intercept + *Slope* × *SR*. Abbreviations of *L. c., S. g., A. c., C. S.*, PR, PB, PF, AS are the same as in Table 1

Significant differences are reported as ns, $P > 0.10$; #, $0.05 < P < 0.10$; *, $0.01 < P < 0.05$; **, $0.001 < P < 0.01$; ***, $P < 0.001$ ($n = 56$)

Table 3 Relationship between the biomass response and variation in precipitation (Vprec) for community, four plant functional groups (PFG) and dominant species in each management system

		Mixed system			Traditional system		
		Slope	R^2	P	Slope	R^2	P
Community	AB	1.17	0.33	***	1.06	0.20	***
PFG	PR	0.69	0.04	ns	0.34	0.01	ns
	PB	1.35	0.25	***	1.45	0.20	***
	PF	−0.68	0.01	ns	−2.08	0.04	ns
	AS	0.57	0.00	ns	1.77	0.01	ns
Species	*L. c.*	1.06	0.07	#	0.25	0.00	ns
	S. g.	1.91	0.20	***	1.99	0.22	***
	A. c.	1.74	0.05	#	1.61	0.03	ns
	C. s.	−0.73	0.02	ns	−1.49	0.04	ns

Regression parameters were estimated by linear model with variation in precipitation as independent variable and AB response as dependant variable, i.e. *RI* = Intercept + *Slope* × *Vprec*; AB represents community level aboveground biomass. Abbreviations of *L. c., S. g., A. c., C. s.*, PR, PB, PF, AS are the same as in Table 1

Significant differences are reported as ns, $P > 0.10$; #, $0.05 < P < 0.10$; *, $0.01 < P < 0.05$; **, $0.001 < P < 0.01$; ***, $P < 0.001$ ($n = 56$)

Intact reproductive tiller ratio and density

In the traditional system, control and haymaking plots had both the high ratio and density of the IRT for all the three investigated bunchgrasses (*S. grandis, A. cristatum, C. squarrosa*). As compared with control, the ratio and density of IRT of the dominant species were all significantly reduced in the lightly grazed (1.5 sheep/ha), moderately grazed (4.5 sheep/ha), and heavily grazed (7.5 sheep/ha) plots (Table 4). In the mixed system, however, no significant reduction in the ratio and density of IRT was observed in haymaking subplots, which had experienced light, moderate and heavy grazing in previous year (Table 5).

Table 4 Effect of grazing on the ratio (R_{IRT},%) and density (D_{IRT}, tillers m^{-2}) of intact reproductive tiller of the four dominant species in traditional system observed in 2007

	Control	HM	LG	MG	HG	*S.E.M*
R_{IRT} (%)						
L. c.	7.5^a	10.5^a	0.0^a	0.0^a	0.0^a	*5.5*
S. g.	12.5^a	10.5^{ab}	8.5^{abc}	3.5^{bc}	1.0^c	*1.2*
A. c.	15.5^a	20.5^a	3.0^b	1.5^b	0.0^b	*1.8*
C. s.	12.5^{ab}	13.5^a	3.5^{ab}	1.5^{ab}	0.5^b	*1.9*
D_{IRT} (tillers m^{-2})						
L. c.	22^a	24^a	0^a	0^a	0^a	*17*
S. g.	333^a	208^b	131^{bc}	62^{cd}	21^d	*17*
A. c.	26^b	71^a	4^c	4^c	0^c	*3*
C. s.	250^a	345^a	22^b	15^b	10^b	*21*

Values with the same superscript letters (a,b,c,d) within each row are not significantly different ($P > 0.05$). *L. c., S. g., A. c., C. s.* are the same as in Table 1. HM = haymaking, LG = light grazing (1.5 sheep/ha), MG = moderate grazing (4.5 sheep/ha), HG = heavy grazing (7.5 sheep/ha)

Discussion

Vegetation responses to stocking rate under fluctuating environment

Different responses of the total community level AB to stocking rate were observed between the traditional

Table 5 Effect of grazing on the ratio (R_{IRT},%) and density (D_{IRT}, tillers m^{-2}) of intact reproductive tiller of the four dominant species at control and haymaking plots in the mixed system observed in 2007

	Control	LH	MH	HH	*S.E.M*
R_{IRT} *(%)*					
L. c.	0.0	0.0	0.0	0.0	–
S. g.	8.5^a	8.0^a	11.5^a	8.5^a	*1.11*
A. c.	35.0^a	19.5^a	16.0^a	15.0^a	*3.84*
C. s.	4.5^a	7.0^a	5.5^a	9.0^a	*3.48*
D_{IRT} *(tillers* m^{-2}*)*					
L. c.	0	0	0	0	–
S. g.	91^a	122^a	243^a	160^a	*57*
A. c.	112^a	75^a	73^a	66^a	*17*
C. s.	177^a	99^a	102^a	136^a	*97*

Means with the same superscript letters within each row are not significantly different ($P > 0.05$). *L. c., S. g., A. c., C. s.* are the same as in Table 1. LH, MH, HH are the haymaking plots in 2007, which had experienced Light (1.5 sheep/ha), moderate (4.5 sheep/ha) and heavy grazing (7.5 sheep/ha) in 2006, respectively

and the mixed systems (Fig. 4). Theoretically, the response of plant community to grazing disturbance might be attributed to three interacting factors, i.e., disturbance regimes (timing, intensity, and frequency of grazing), plant community composition (proportion of species with different grazing resistance ability and strategies), and environmental stress (Grime 1974; Harris 1978; Milchunas et al. 1988; Sample 1970). In our study, the significant negative relationship between stocking rate and AB response in the traditional system was attributed to the strong negative effect of grazing disturbance on *L. chinensis*, *C. squarrosa,* and the perennial forbs. However, the negative correlations between the AB response and stocking rate was not observed for the four dominant species in the mixed system, indicating that plants in the mixed system may benefit from the recovery time during the haymaking year run. Compared with the species level responses to grazing in the traditional system, species in the mixed system were more persistent and less affected by grazing even at the moderate to high stocking rates. Our results further showed that no consistent decline in the total community AB was found in response to increasing stocking rate throughout the study in the mixed system. Thus, these findings support our original hypothesis that the mixed system exhibits the advantage of mitigating the species shift and consequently sustaining the grassland productivity as compared to the traditional system. And these findings also support the general conclusions of the hypothesis regarding detrimental effect of continuous heave grazing on plant growth (Briske et al. 2008).

The clearly different biomass response patterns between the flat and slope block within each system were observed as well. This is likely due to the original differences in both species and plant functional group composition between the paddocks and the diet preference of the sheep. Previous studies on sheep diet selection have proposed that sheep prefer *C. squarrosa, L. chinensis*, and *A. cristatum,* but not *S. grandis* when there is enough herbage for selection (Wang 2000, 2001). In this study, the plant species level responses to increasing stocking rate further revealed that the responses of the two most abundant species differed significantly. The AB of *L. chinensis* declined with increasing stocking rate, whereas the AB of *S. grandis* remained unchanged along the gradient of stocking rate. Therefore, the block originally with more *S. grandis* showed a less community level aboveground biomass response to stocking rate in both management systems (Fig. 4).

The negative response of *C. squarrosa* and *L. chinensis* to grazing in the traditional system might be partly attributed their higher palatability, because the relatively unpalatable species *S. grandis* show neutral response to the increasing stocking rates. These findings support the hypothesis regarding grazing favors the unpalatable species by preference intake of the palatable species (Augustine and McNaughton 1998). However, the negative response of the short statue *C. squarrosa* to increasing stocking rate rejects the hypothesis regarding grazing favors short statue species over high statue species and contradict to the frequently observed phenomena that *C. squarrosa* was also abundant in the overgrazed area (Diaz et al. 2007; Li 1988). Under the consideration of that the seed production of *C. squarrosa* was significantly reduced in the grazed plots in traditional system, and its seed dispersal channel (*C. squarrosa* is wind rolling plant, its seed are majorly dispersed by wind) was also blocked by the fences, so the continuous grazing plots might suffer from the seed limitation. Whereas, the seeds might not be a problem for the large overgrazed area, because it could get seed replenishment from the wind rolling body of *C. squarrosa*.

Plant persistence could be weakened by the continuously high level of disturbance, and consequently plant response to rainfall or recovery after drought may be reduced by grazing (Del-Val and Crawley 2005; McPherson and Williams 1998; Sample 1970). In the present study, the vegetation did suffer from one extreme drought event in 2005, and then the precipitation gradually increased from 2006 to 2008, and the precipitation in 2008 was slighter higher than the long-term mean. Therefore, it provided us a chance to look into the effects of management systems on plant persistence after the extreme drought in 2005. When the plant response at each organization level was plotted against the variation of precipitation, a strong correlation between community level AB response and variation in precipitation was identified in both mixed and traditional systems. Our findings corroborate with previous studies, suggesting that water is the primary limiting factor for plant growth in semiarid grassland ecosystems (Bai et al. 2008; Biondini et al. 1998; Patton et al. 2007). The slope of the regression line tends to be higher in the mixed system than the traditional system. This further confirms our original hypothesis that the mixed system has the advantage to sustain the high production of plants than the traditional system. The more positive community level AB responses in mixed system were attributed to the significantly positive responses of *L. chinensis* and *A. cristatum* to precipitation pulse in the mixed system but not in the traditional system. In addition, we found the response of *S. grandis* to precipitation pulse was more positive than the other three species. This is more likely due to the higher grazing avoidance and drought tolerance of *S. grandis*.

Effects of management system on seed production potential

Seeds play an important role in population regeneration and persistence (Adams et al. 2005; Fenner and Thompson 2005; Kalamees and Zobel 2002; O'Connor 1991). Continuous heavy grazing might lead to the reduction of seed production of the palatable species and consequently influence their fitness (Noy-Meir and Briske 1996; O'Connor and Pickett 1992; Sternberg et al. 2003), particularly for the species with limited clonal mobility (the ability of a plant to move in space using its vegetative organs and to alter the location of its ramets) and are dependent on the seedling to colonize newly formed gap by the grazing animals (Schmid 1985). In our study, both the ratio and density of IRT were greatly diminished by grazing for the continuous grazing plots in the traditional system. These findings are in consistent with previous studies regarding the negative effects of grazing on seed production (Noy-Meir and Briske 1996; O'Connor and Pickett 1992). And there were no carry-over effects of grazing on ratio and density of IRT were found in the mixed system. These findings again, although measured only one year, support our hypothesis that the mixed management system may improve population persistence by balance the seed bank from seed production in the haymaking year run.

Implications for grassland management

Our findings demonstrate that, after the five years of field experiment, the AB at species, plant functional groups, and community levels were all reduced by grazing in the traditional system particularly at the high stocking rates, whereas the negative effects of grazing were greatly lessened in the mixed system. The advantages of the mixed system were also confirmed from the high annual aboveground net primary productivity, high litter accumulation, and low soil erosion potential (Schönbach et al. 2010). The mixed system with the change between plots of haymaking and grazing year after year provides higher sustainability for the management of the native grassland in Inner Mongolia. Therefore, based on the findings of the current study, we propose that the mixed system could be served as a promising strategy to balance the negative effects of continuous grazing and haymaking and, thus, promote a more sustainable land use of the Inner Mongolia grassland.

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