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Feed Intake and Performance of Sheep Grazing Semiarid Grassland in Response to Different Grazing Systems

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Abstract

Effects of grazing management systems (GS) on biomass production and nutritional quality of rangeland vegetation in semiarid regions are extensively studied; however, limited information is available regarding their effects on diet digestibility and feed intake of grazing livestock. We therefore analyzed digestibility of ingested organic matter (dOM), organic matter intake (OMI), and live weight gain (LWG) of sheep in a grazing experiment established in the Inner Mongolian steppe of China, where two GS were tested for six different grazing intensities (GI) from very light to heavy grazing. For the continuous grazing system, sheep grazed the same plots each year, and for the alternating system, grazing and hay making were alternated annually between two adjacent plots. In July, August, and September 2009 and 2010, feed intake and live weight of sheep were determined. The GS did not affect dOM ($P=0.101$), OMI ($P=0.381$), and LWG of sheep ($P=0.701$). Across both GS LWG decreased from 98 $g \cdot d^{-1}$ for GI1 to 62 $g \cdot d^{-1}$ for GI6 ($P < 0.001$; $R^2=0.42$). There were no interactions between GS and GI for all measured parameters ($P \geq 0.061$), indicating that alternating grazing did not compensate for negative effects of heavy grazing even after 4 yr of grassland use. In summary, our study showed that irrespective of GI, alternating grassland use does not improve dOM, OMI, and hence, LWG of sheep. However, it might enhance revenues and ecological sustainability in the long term when compared to the common practice of continuous grazing at very high stocking rates.

Key Words: alternating grazing, continuous grazing, grazing intensity, live weight gain, Inner Mongolia, steppe

INTRODUCTION

Grazing systems (GS) are considered as an important management tool that can maintain or even increase long-term rangeland and livestock production in pastoral farming systems (Long 1986). In addition to the continuous (CON) grazing system in which a particular area is used for livestock grazing every year, several improved GS have been conceptualized. Their main aims are maintaining rangelands in a productive state and making the most effective use of natural feed resources to generate income from animal products (Clark 1994). In the alternating (ALT) grazing system hay-making and animal grazing are regularly alternated between two or more paddocks or areas (Merrill 1954). This enables the vegetation to recover from grazing during hay-making years and returns organic matter (OM) and nutrients to the rangelands in grazing years through the deposition of animal feces and urine (Owens et al. 1989). The ALT grazing might thus provide higher quantity and quality of herbage to grazing livestock, and could therefore increase the animals' nutrient and energy intakes, and thus their performance level (Heady 1961).

Many studies analyzed the effects of ALT and CON on herbage production and quality. Reardon and Merrill (1976) stated that forage yields and litter accumulation were higher for ALT than for CON. Similarly, Clarke et al. (1943) showed in an earlier study that ALT grazing increased herbage production and was more favorable for the seasonal development and life cycle of the main forage species than CON grazing. Within the same research project as the presented study, Schönbach et al. (2011) determined a higher aboveground net primary production (ANPP) of the grassland steppe in Inner Mongolia for ALT than for CON heavy grazing intensities (GI). Moreover, Wan et al. (2011) concluded that aboveground biomass of the herbage species preferably grazed by sheep was less affected by moderate to high GI for ALT than for CON. Instead, few studies were conducted to clarify the effects of ALT on grazing livestock, and most of them focused on measuring animal performance rather than feed intake and quality. The objectives of our experiment were therefore to investigate the effects of ALT versus CON grazing on diet digestibility, feed intake, and live weight gain (LWG) of grazing sheep in the semiarid grassland steppe of Inner Mongolia. We aimed to determine whether GS can compensate for the negative effects of increasing GI and plant maturation with advancing vegetation

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on these parameters. It was hypothesized that ALT increases energy intake and hence, animal performance by a higher mass and nutritional quality of the herbage on offer.

MATERIALS AND METHODS

Study Area

The study site (lat 116°42′E, long 43°38′N) is located in the Xilin River Basin, Inner Mongolia Autonomous Region of China. The average altitude is approximately 1 200 m above sea level. The semiarid continental temperate steppe climate is characterized by a mean annual precipitation of 335 mm and a mean annual air temperature of 0.9°C (weather data were collected at a station located close to our experimental areas in 1982–2008). Rainfall mainly occurs during May to August, and the vegetation period lasts for approximately 150 d from April to September (Bai et al. 2004). Monthly precipitations and mean monthly temperatures in 2009 and 2010 are shown in Figure 1. The dominant soil type is a chestnut soil (chernozem with high humus content and fertility; Chen and Wang 2000). The steppe vegetation is dominated by the perennial rhizome grass *Leymus chinensis* Trin., and the perennial bunchgrass *Stipa grandis* P.A. Smirn (Bai et al. 2004). Annual ANPP is 140 g dry matter (DM) $\cdot$ m^{-2} (Schönbach et al. 2011).

Livestock production has been and still is the main agricultural activity in Inner Mongolia. Before the 1950s (Jiang et al. 2006), the land was used by transhumant and nomadic pastoralists who subsisted largely upon sheep production. Since then, the human population of the Xilingol league (202 580 km^2) rapidly increased from 200 000 in 1949 to approximately 950 000 in 2000 (Jiang et al. 2006). Correspondingly, the number of grazing animals increased by 18-fold from 1949 to 2000, so that the available grassland area decreased from 5 ha to 1 ha per sheep (Jiang et al. 2006). Moreover, the government strongly encouraged the nomadic families to settle and abandon their traditional way of steppe use. Hence, grassland close to farms is currently used for intensive sheep and cattle grazing, while distant areas are only used for hay-making (Christensen et al. 2003). The constant removal of herbage on grazing areas reduces vegetation cover and hence, increases the risk of soil erosion. On hay-making areas, the lack of dung deposition and thus, nutrient inputs to the grassland may negatively affect its long-term productivity (Owens and Shipitalo 2009; Schönbach et al. 2009).

Experimental Design

A grazing experiment was conducted from middle of June to middle of September in 2009 and 2010 lasting for 92 and 91 d, respectively. Outside of the grazing seasons, the grassland remained ungrazed. Two GS were tested that had already been established in June 2005. For the ALT system, grazing and hay making were alternated annually between two adjacent plots, whereas sheep grazed the same plots every year in the CON system. In each GS, six different GI treatments from very light (GI1), light (GI2), light–moderate (GI3), and moderate (GI4) to heavy (GI5) and very heavy (GI6) grazing were established. The GI was defined by herbage allowance (HA), which describes GI

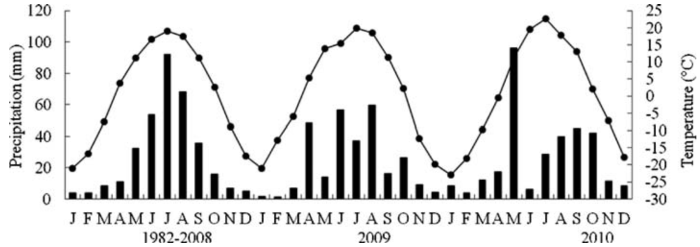

Figure 1. Monthly precipitation (mm, bars, primary y axis) and mean monthly air temperature (°C, line and points, secondary y axis) measured near the experimental area across 1982–2008 and in 2009 and 2010.

better than stocking rates (SR) alone if herbage mass on offer strongly differs between experimental plots, years, or throughout the vegetation period (Sollenberger et al. 2005). The HA target ranges were > 12.0, $> 6.0–12.0$, $> 4.5–6.0$, $> 3.0–4.5$, $> 1.5–3.0$, and ≤ 1.5 kg DM $\cdot$ kg^{-1} live weight (LW) for GI1 to GI6, respectively. The numbers of sheep per plot were adjusted to herbage mass on offer in the middle of June, July, and August in order to maintain similar HAs across the grazing seasons and in both study years. Values for actual HAs and SR are given in Table 1. Each treatment was replicated on two plots, a flat and a moderately sloped plot. Hence, measurements were carried out on a total of 24 plots (2 GS $\times$ 6 GI $\times$ 2 plots). Each plot had a size of 2 ha, except the GI1 plots, which covered 4 ha to be able to keep a minimum of eight sheep per plot.

Animals and Live Weight Gain

In 2009 and 2010, 315 and 337 female sheep, respectively, of the Inner Mongolia fat-tailed breed were purchased from two local farmers. In both study years, the animals were about 15 mo old when they were obtained, and neither pregnant nor lactating. Sheep were treated for internal parasites and sheared before the experiments started. During the grazing seasons, they had free access to water and mineral in lick stones and were allowed to graze day and night. Immediately after purchase, all sheep were weighed on two consecutive days using a portable electronic platform balance (0.1-kg accuracy). Subsequently, they were divided into four different LW groups (light < 30 kg LW, moderate $> 30–35$ kg LW, heavy $> 35–40$, and very heavy > 40 kg LW). Out of each LW group sheep were randomly allocated to the grazing plots to equalize mean LW per plot. After 10 d of adaptation, sheep were weighed again to determine their initial LW on the 12th and 13th of June. Mean LWs at these moments were 34.8 kg $\pm$ 4.0 and 30.2 kg $\pm$ 1.9 in 2009 and 2010, respectively. All animals were weighed again on 11 and 12 July, August, and September. The mean LW of the 2 d was used to calculate their daily LWG during each month. Total LWG of all sheep per hectare (LWGh, g $\cdot$ ha^{-1} $\cdot$ d^{-1}) was calculated by multiplying the mean LWG of individual sheep (LWGs, g $\cdot$ d^{-1}) by the SR (sheep $\cdot$ ha^{-1}) in the respective plot.

Herbage Allowance

Standing herbaceous biomass was determined by cutting the sward at 1 cm above ground level within a 2.0 $\times$ 0.25 m^2-frame in three representative areas per plot. The collected herbage material was oven-dried for 24 h at 60°C and weighed to

Table 1. Mean initial live weight (LW) of sheep, stocking rates (SR), and herbage allowances (HA), as well as herbage mass (HM) and chemical composition on the experimental plots during the grazing seasons in 2009 and 2010 (least squares means; $n = 12$).[1]

Parameter	GS	Grazing intensity 1	2	3	4	5	6	SE	Mean	SEM
Initial LW (kg)	ALT	32.8	32.2	32.8	32.4	32.4	32.6	0.1	32.5	0.1
	CON	32.5	32.6	32.7	33.0	32.5	32.4	0.1	32.6	0.1
	Mean	32.6	32.4	32.7	32.7	32.4	32.5	0.1	32.5	0.1
SR (sheep · ha^{-1})	ALT	1.9	3.9	4.8	6.3	8.4	10.1	0.3	5.9	0.2
	CON	2.4	4.4	5.9	7.0	8.9	10.4	0.3	6.5	0.2
	Mean	2.2	4.2	5.4	6.7	8.7	10.3	0.2	6.2	0.2
HA (kg DM · kg^{-1} LW)	ALT	15.6	6.8	4.8	3.9	2.0	1.8	2.3	5.8	1.5
	CON	22.1	10.8	6.6	3.2	2.4	1.1	3.5	7.7	2.3
	Mean	18.9	8.8	5.7	3.6	2.2	1.5	2.1	6.8	1.4
HM (kg DM · ha^{-1})	ALT	1144	968	882	916	662	660	39	872	22
	CON	2103	1 801	1 443	893	752	426	93	1 236	77
	Mean	1624	1 384	1 162	905	707	543	52	1 054	48
CP (% DM)	ALT	10.2	10.4	11.0	10.9	10.7	10.8	0.2	10.6	0.1
	CON	8.9	8.7	9.4	9.7	11.6	13.4	0.3	10.3	0.2
	Mean	9.5	9.6	10.2	10.3	11.2	12.1	0.2	10.5	0.1
NDF (% DM)	ALT	69.7	69.7	69.4	69.8	70.0	69.4	0.2	69.7	0.1
	CON	70.8	71.2	70.8	70.7	69.2	67.5	0.2	70.1	0.2
	Mean	70.3	70.4	70.1	70.3	69.6	68.5	0.2	69.9	0.1
ADF (% DM)	ALT	33.8	32.6	32.9	32.9	33.7	33.8	0.2	33.3	0.1
	CON	35.3	34.6	33.7	34.4	31.9	31.2	0.3	33.5	0.2
	Mean	34.5	33.6	33.3	33.7	32.8	32.5	0.2	33.4	0.1
ADL (% DM)	ALT	4.8	4.8	4.8	4.9	5.0	4.9	0.1	4.9	0.1
	CON	5.1	5.0	4.8	5.1	4.7	4.6	0.1	4.9	0.1
	Mean	4.9	4.9	4.8	5.0	4.9	4.8	0.1	4.9	0.1
CDOM (% OM)	ALT	63.8	63.8	64.0	63.3	62.8	63.3	0.3	63.5	0.1
	CON	61.2	60.9	61.9	61.2	64.4	66.0	0.4	62.6	0.3
	Mean	62.5	62.4	62.9	62.3	63.6	64.7	0.2	63.1	0.1

[1]ADF indicates acid detergent fiber; ADL, acid detergent lignin; ALT, alternating grazing; CDOM, cellulase digestible organic matter; CON, continuous grazing; CP, crude protein; DM, dry matter; GS, grazing system; NDF, neutral detergent fiber; OM, organic matter; SE, standard error; and SEM, standard error of mean. For further descriptions of the GS and grazing intensity treatments see text.

determine its DM content. Subsequently, HA was calculated according to the formula given by Sollenberger et al. (2005):

$$\mathrm{HA}\left[\mathrm{kg\ DM}\cdot\mathrm{kg}^{-1}\mathrm{LW}\right] = (\mathrm{SB}_1[\mathrm{kg\ DM}]/\mathrm{LW}_1[\mathrm{kg}] + \mathrm{SB}_2[\mathrm{kg\ DM}]/\mathrm{LW}_2[\mathrm{kg}])/2, \quad [1]$$

where SB is the standing herbaceous biomass per plot, DM is the dry matter concentration in herbage, and LW is total live weight of all sheep per plot. Indices 1 and 2 represent two consecutive sampling days at the beginning of June, July, August, and September, respectively.

Digestibility of Ingested Herbage and Feed Intake

At the beginning of the grazing seasons, four sheep per plot were randomly chosen to determine digestibility of ingested organic matter (dOM) and organic matter intake (OMI). Daily OMI of sheep was calculated from dOM and daily fecal OM excretion. Fecal OM excretion was determined with the use of the external marker TiO_2 assuming a fecal recovery rate of 100% (Glindemann et al. 2009a). For this, one gelatin capsule filled with 2.5 g TiO_2 (electronic balance with 0.001 g accuracy) was orally administered to the four sheep per plot once per day during the first 10 d of July, August, and September, respectively. Immediately after marker application, fecal samples (approximately 25 g fresh matter per sheep) were taken from the rectum on days 6–10 (sampling period) and frozen. At the end of each sampling period, all samples were thawed and pooled to one sample per sheep (100 g fresh matter). The pooled samples were divided into two subsamples. One subsample was oven dried at 60°C for 48 h, milled by a mixer, and used to determine fecal TiO_2 concentration according to procedures described by Glindemann et al. (2009a). The other subsample was analyzed for DM, crude ash, and crude protein (CP) concentrations. DM, crude ash, and nitrogen (N) were determined according to the methods of the Chinese Technical Committee for Feed Industry Standardization and the Chinese Association of Feed Industry (2000).

The dOM was estimated from CP ($N \cdot 6.25$) in fecal OM according to the nonlinear regression equation given by Wang et al. (2009b):

$$\mathrm{dOM}[\%] = 89.9 - 64.4 \times \exp\left(-0.5774 \times \mathrm{CP}\left[\mathrm{g}\cdot\mathrm{kg}^{-1}\mathrm{fecal\ OM}\right]/100\right). \quad [2]$$

Table 2. Effect of alternating (ALT) and continuous (CON) grazing on digestibility of ingested organic matter (dOM), daily intakes of organic matter (OMI), digestible organic matter (DOMI), and metabolizable energy (MEI), as well as daily live weight gain (LWG) of individual sheep (LWGs) and per hectare (LWGh) for different grazing intensities (GI) in 2009 and 2010 (least squares means; $n=12$).[1]

		GI[2]									*P* value[3]						
Parameter	GS	1	2	3	4	5	6	SE	Mean	SEM	GS	GI	GS × GI	GS × Yr	GI × Yr	GS × Mo	GI × Mo
dOM	ALT	0.563	0.550	0.558	0.549	0.555	0.555	0.003	0.555								
	CON	0.552ab	0.544a	0.544a	0.543a	0.551ab	0.569b	0.003	0.551								
	Mean	0.557ab	0.547a	0.551ab	0.546a	0.553ab	0.562b	0.002	0.553	0.001	0.101	**0.010**	0.061	0.054	0.086	0.860	0.340
OMI ($g \cdot kg^{-0.75}$ LW)	ALT	74.9	73.1	71.9	76.2	70.4	79.8	1.5	74.4								
	CON	76.7	71.3	72.7	76.1	72.7	68.7	1.3	73.1								
	Mean	75.8	72.2	72.3	76.1	71.5	74.2	1.0	73.7	0.36	0.381	0.327	0.112	0.764	**0.027**	0.689	0.938
DOMI ($g \cdot kg^{-0.75}$ LW)	ALT	42.4	40.5	40.4	42.1	39.2	44.3	0.98	41.5								
	CON	42.4	39.1	39.7	41.7	40.2	39.2	0.87	40.4								
	Mean	42.4	39.8	40.0	41.9	39.7	41.8	0.66	40.9	0.32	0.209	0.266	0.405	0.454	**0.015**	0.674	0.862
MEI ($MJ \cdot kg^{-0.75}$ LW)	ALT	0.65	0.62	0.62	0.64	0.60	0.68	0.02	0.64								
	CON	0.65	0.60	0.61	0.64	0.62	0.60	0.01	0.62								
	Mean	0.65	0.61	0.61	0.64	0.61	0.64	0.01	0.63	0.01	0.195	0.258	0.456	0.421	**0.014**	0.684	0.945
LWGs (g)	ALT	105	79	87	92	73	69	6	84								
	CON	91	94	92	87	72	55	5	82								
	Mean	98b	86b	89b	89b	72ab	62a	4	83	1	0.701	**0.003**	0.501	0.843	0.664	0.647	0.173
LWGh ($g \cdot ha^{-1}$)	ALT	199a	305ab	416abc	573bc	595bc	678c	44	461								
	CON	223a	410ab	515ab	630b	623b	570b	38	495								
	Mean	211a	357ab	465bc	601c	609c	624c	29	478	10	0.390	**< 0.001**	0.660	0.416	0.249	0.617	**< 0.001**

[1]GS indicates grazing system; LW, live weight; Mo, month; SE, standard error; SEM, standard error of mean; and Yr, year.
[2]Within-rows means without a common letter differ at $P \leq 0.05$.
[3]Effects in bold characters were significant at $P \leq 0.05$. None of the effects of the triple interactions between GS, GI, Yr, and Mo were significant at $P \leq 0.05$ and were thus not included in the table. There were no significant differences ($P > 0.05$) between ALT and CON for the same GI for any of the measured parameters.

Table 3. Parameters of the linear and nonlinear regressions between stocking rate (SR; sheep/ha) and the digestibility of ingested organic matter (dOM), daily intakes of organic matter (OMI), and metabolizable energy (MEI), as well as the daily live weight gain (LWG) of individual sheep (LWGs) and per hectare (LWGh) for an alternating (ALT) and continuous (CON) grazing system in 2009 and 2010.[1]

Parameter	Grazing system	Type of regression	a	b	c	*P* value[2]	Adjusted R^2
dOM	ALT	Linear	–	−0.001 (0.001)	0.559 (0.006)	0.446	−0.04
	CON	Quadratic	0.0005 (0.001)	−0.011 (0.002)	0.575 (0.007)	< **0.001**	0.80
	Mean	Quadratic	0.0001 (0.001)	−0.009 (0.003)	0.575 (0.008)	**0.007**	0.31
OMI ($g \cdot kg^{-0.75}$ LW)	ALT	Quadratic	0.0002 (0.001)	−0.003 (0.002)	0.079 (0.007)	0.384	0.01
	CON	Linear	–	−0.001 (0.001)	0.074 (0.002)	0.369	−0.01
	Mean	Linear	–	0.001 (0.001)	0.075 (0.002)	0.818	−0.05
MEI ($MJ \cdot kg^{-0.75}$ LW)	ALT	Quadratic	0.0018 (0.002)	−0.029 (0.019)	0.701 (0.052)	0.297	0.07
	CON	Linear	–	−0.002 (0.004)	0.636 (0.029)	0.593	0.03
	Mean	Linear	–	−0.001 (0.003)	0.633 (0.019)	0.829	−0.04
LWGs (g)	ALT	Linear	–	−3.54 (1.38)	104.6 (9.0)	**0.029**	0.33
	CON	Linear	–	−4.32 (1.37)	110.2 (9.8)	**0.010**	0.45
	Mean	Linear	–	−3.90 (0.93)	107.1 (6.3)	< **0.001**	0.42
LWGh ($g \cdot ha^{-1}$)	ALT	Linear	–	59.5 (7.4)	109.3 (48.2)	< **0.001**	0.85
	CON	Linear	–	47.6 (11.6)	180.9 (82.4)	**0.002**	0.69
	Mean	Linear	–	53.7 (6.6)	142.3 (44.9)	< **0.001**	0.74

[1]Means for each plot across the two study years and 3 mo were used. The number of observations was, therefore, $n=12$ for each grazing system and $n=24$ across both grazing systems. Regression equations are $y=bx+c$ for linear and $y=ax^2+bx+c$ for quadratic regressions. Only parameters of the regressions with the highest adjusted R^2 values are given. Numbers inside parentheses represent one standard error. LW, live weight.

[2]Probability values of the linear or quadratic relationships. Effects in bold characters were significant at $P \leq 0.05$.

Subsequently, OMI of sheep was calculated with the use of the following equation:

$$\mathrm{OMI}\left[\mathrm{g \cdot d^{-1}}\right] = \mathrm{fecal\ OM}\left[\mathrm{g \cdot d^{-1}}\right] / (100 - \mathrm{dOM}[\%]). \quad [3]$$

Intakes of digestible organic matter (DOMI) and metabolizable energy (MEI) were calculated by multiplying OMI by dOM or dietary metabolizable energy (ME) concentrations, respectively. The latter was estimated from dOM according to the formula derived by Aiple (personal communication) on the basis of the data published by Aiple et al. (1992):

$$\mathrm{ME}\left[\mathrm{MJ \cdot kg^{-1} OM}\right] = -0.9 + 0.170 \times \mathrm{dOM}[\%]. \quad [4]$$

Statistical Analysis

In total, 144 observations (2 GS × 6 GI × 2 replicates × 2 yr × 3 mo) were obtained for all parameters. Data were analyzed using the Mixed Model procedure of SAS version 9.2 (SAS Institute Incorporated, Cary, NC) to test for the effects of GS, GI, year, month, and their interactions. The following model was used:

$$\begin{aligned} y_{ijkl} = \mu &+ \mathrm{GS}_i + \mathrm{GI}_j + \mathrm{Yr}_k + \mathrm{Mo}_1 + \mathrm{GS} \times \mathrm{GI}_{ij} + \mathrm{GS} \times \mathrm{Yr}_{ik} \\ &+ \mathrm{GS} \times \mathrm{Mo}_{il} + \mathrm{GI} \times \mathrm{Yr}_{jk} + \mathrm{GI} \times \mathrm{Mo}_{jl} + \mathrm{Yr} \times \mathrm{Mo}_{kl} \\ &+ \mathrm{GS} \times \mathrm{GI} \times \mathrm{Yr}_{ijk} + \mathrm{GS} \times \mathrm{Yr} \times \mathrm{Mo}_{ikl} + \mathrm{GI} \times \mathrm{Yr} \times \mathrm{Mo}_{jkl} \\ &+ e_{ijkl}, \end{aligned} \quad [5]$$

where μ is the overall mean, GS_i the grazing system (i = ALT and CON), GI_j the grazing intensities (j=1, 2, 3, 4, 5, and 6), Yr_k the year (k=2009 and 2010), Mo_l the month (l=July, August, and September), and e_{ijkl} the random experimental error. All factors and their interactions were treated as fixed effects. Year was treated as repeated measurement. An autoregressive covariance structure was chosen. When effects were significant ($P \leq 0.05$), the Tukey test was used for pairwise comparisons of least-squares means. Linear or quadratic regression analyses were applied to analyze the effects of SR (independent variable) on dOM, OMI, LWGs, and LWGh (dependent variables). For this, means for each plot across the two study years were calculated and treated as one observation resulting in 24 observations (2 GS × 6 GI × 2 replicates) for each parameter. Moreover, regression analyses were performed separately for each year using the mean values across the three months (n=12).

RESULTS

Grazing System and Grazing Intensity

The effects of GS and GI on measured parameters are presented in Table 2. Interactions between GS and GI for feed intake ($P \geq 0.112$) and performance parameters did not occur ($P \geq 0.501$). The GS did not affect dOM (P=0.101), OMI (P=0.381), DOMI (P=0.209), MEI (P=0.195), LWGs (P=0.701), or LWGh (P=0.390).

Mean dOM across both GS, both years, and all months ranged from 0.546 for GI4 to 0.562 for GI6 (P=0.001). It differed between individual GI treatments (P=0.010) and according to the quadratic regression equation, first declined then increased with increasing SR (P=0.007, R^2=0.31; Table 3). Moreover, no differences between GI were determined for OMI (P=0.327), DOMI (P=0.266), or MEI (P=0.258). Although daily LWGs linearly decreased ($P < 0.001$, $R^2 = 0.42$), daily LWGh increased with increasing SR ($P < 0.001$, R^2=0.80; Table 3). However, the linear

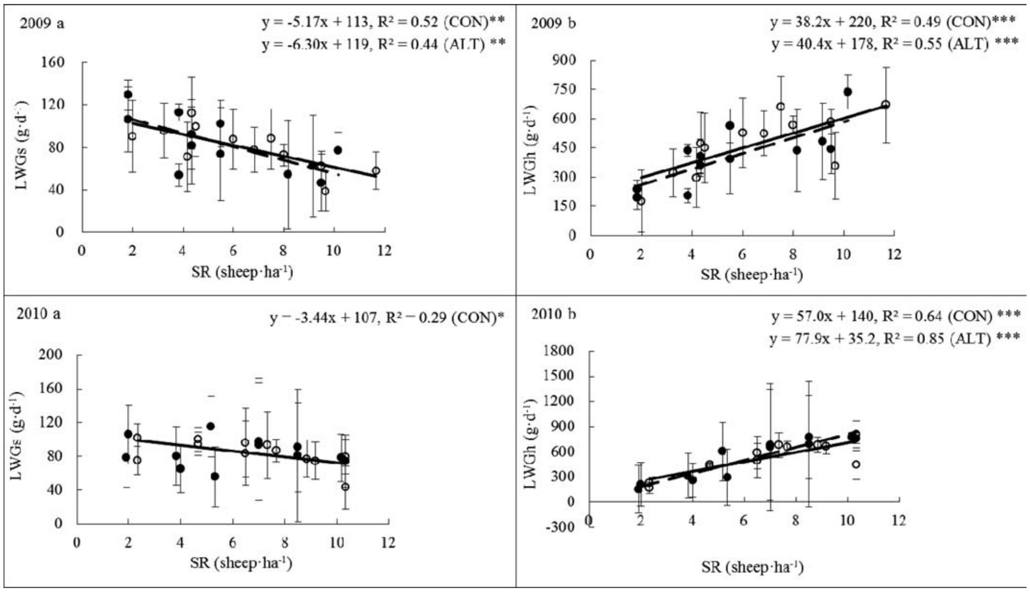

Figure 2. Linear relationships between stocking rate (SR; independent variable) and live weight gain (LWG) of individual sheep (LWGs, a; dependent variables) and per hectare (LWGh, b; dependent variables) in 2009 and 2010. Open and solid circles represent the mean LWGs and LWGh for continuous (CON) and alternating (ALT) grazing, respectively, across the entire grazing seasons. Bars indicate standard errors from the means. Solid and dashed lines indicate the linear regression lines for CON and ALT, respectively. Single, double, and triple asterisks highlight regressions that are significant at a level of $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

decrease in LWGs with increasing SR was only pronounced in 2009 ($P=0.011$, $R^2=0.44$ for ALT; $P=0.005$, $R^2=0.52$ for CON), whereas in 2010, LWGs was unaffected by SR ($P=0.731$, $R^2=-0.09$ for ALT; $P=0.041$, $R^2=0.29$ for CON; Figure 2).

Interactions between GS and GI for feed intake ($P \geq 0.112$) and performance parameters did not occur ($P \geq 0.501$; Table 2). However, a tendency of an interaction between GS and GI was observed for dOM ($P = 0.061$). Although dOM was similar for all GI treatments for ALT ($P \geq 0.605$), it was higher for GI6

Table 4. Effect of alternating (ALT) and continuous (CON) grazing on digestibility of ingested organic matter (dOM), daily intakes of organic matter (OMI), digestible organic matter (DOMI), and metabolizable energy (MEI) as well as daily live weight gain (LWG) of individual sheep (LWGs) and per hectare (LWGh) during different months of grazing seasons in 2009 and 2010 (least squares means; $n=24$).[1]

Parameter	GS	Mo[2] July	Mo[2] August	Mo[2] September	SE	Mean	SEM	Mo[3]	Yr	Mo × Yr
dOM	ALT	0.566b	0.554a	0.545a	0.002	0.555				
	CON	0.562b	0.547a	0.542a	0.002	0.551				
	Mean	0.564b	0.551a	0.544a	0.002	0.553	0.004	< **0.001**	< **0.001**	< **0.001**
OMI (g · kg$^{-0.75}$ LW)	ALT	81.2b	74.7b	67.1a	1.5	74.3				
	CON	80.7b	71.1a	66.8a	1.3	73.0				
	Mean	80.9c	73.2b	66.9a	1.0	73.7	3.49	< **0.001**	< **0.001**	< **0.001**
DOMI (g · kg$^{-0.75}$ LW)	ALT	46.2c	41.1b	36.8a	0.98	41.5				
	CON	45.5b	39.2a	36.4a	0.87	40.4				
	Mean	45.8c	40.3b	36.6a	0.66	40.9	2.8	< **0.001**	< **0.001**	< **0.001**
MEI (MJ · kg$^{-0.75}$ LW)	ALT	0.71c	0.64b	0.57a	0.02	0.64				
	CON	0.70b	0.60a	0.56a	0.01	0.62				
	Mean	0.71c	0.62b	0.56a	0.01	0.63	0.04	< **0.001**	< **0.001**	< **0.001**
LWGs (g)	ALT	114c	87b	50a	6	84				
	CON	116c	88b	42a	5	82				
	Mean	115c	87b	46a	4	83	1	< **0.001**	0.600	0.474
LWGh (g · ha^{-1})	ALT	682b	413b	218a	44	461				
	CON	674b	569b	242a	38	495				
	Mean	678c	526b	230a	29	478	24	< **0.001**	**0.010**	0.178

[1]GI indicates grazing intensity; GS, grazing system; HA, herbage allowance; LW, live weight; Mo, month; SE, standard error; SEM, standard error of the mean; SR, stocking rate; and Yr, year.
[2]Within-rows means without a common letter differ at $P \leq 0.05$. There were no significant differences ($P \leq 0.05$) between ALT and CON.
[3]Effects in bold characters were significant at $P \leq 0.05$.

(0.569) than for GI2–GI4 (0.543–0.544; $P \leq 0.011$) for CON. No interactions between GS and month ($P \geq 0.617$) and between GI and month ($P \geq 0.173$) were found for any of the measured parameters (Table 2), indicating that the effects of GS or GI did not differ between months and that changes in dOM, feed intake, and LWGs with proceeding grazing season were similar for both GS and all GI treatments.

Year and Month

Across both GS and all GI treatments, dOM and feed intake of sheep differed between years ($P < 0.001$ for all measured parameters; data not shown). In 2009, dOM, OMI, and MEI were 0.574, 79.7 $g \cdot kg^{-0.75}$ LW, and 0.71 $MJ \cdot kg^{-0.75}$ LW, respectively, and higher than in 2010 when corresponding values averaged 0.533 ($P < 0.001$), 67.6 $g \cdot kg^{-0.75}$ LW ($P < 0.001$), and 0.55 $MJ \cdot kg^{-0.75}$ LW ($P < 0.001$). However, at 81 $g \cdot d^{-1}$ (2009) and 84 $g \cdot d^{-1}$ (2010), no difference in LWGs was found between years ($P = 0.600$). Daily LWGh was lower in 2009 (437 $g \cdot ha^{-1}$) than in 2010 (519 $g \cdot ha^{-1}$; $P = 0.022$), which was due to slight differences in the mean SR.

All parameters were affected by month ($P < 0.001$ for all measured parameters; Table 4). The dOM, OMI, and MEI were higher in July than in September ($P < 0.001$ for all three parameters). Correspondingly, higher daily LWGs and LWGh were found in July (115 g, 678 $g \cdot ha^{-1}$) than in September (46 g, 230 $g \cdot ha^{-1}$; $P < 0.001$ for both parameters).

With the exception of LWGs ($P = 0.474$) and LWGh ($P = 0.178$), the interactions between year and month influenced all measured parameters ($P < 0.001$ for dOM, OMI, and MEI; data not shown). Although dOM ($P \leq 0.002$), OMI ($P < 0.001$), and MEI ($P < 0.001$) were higher in July than in August and September in 2009, dOM and feed and energy intakes were higher in July and August than in September in 2010 ($P < 0.001$ for all three parameters; data not shown).

DISCUSSION

Grazing System

No differences in dOM, OMI, and hence, MEI and LWGs were found between ALT and CON sheep. Previous studies within the frame of the same research project analyzed the effects of GS on biomass production and plant community structure of the grassland vegetation, as well as the nutritional quality of herbage. Based on data collected during 2007 and 2008, Schönbach et al. (2011) found a higher ANPP, soil coverage, and litter accumulation of the steppe vegetation for ALT grazing (defined as "mixed grazing" in their study), in particular for very high GI. However, the number of sheep was adjusted to herbage mass on offer to maintain similar HAs between GS, study years, and across the grazing seasons. Moreover, herbage CP, ME, neutral detergent fiber, and acid detergent fiber concentrations were very similar for both GS in the present study (Table 1). This might have limited the positive effect of ALT grassland use on animal feed intake and performance. To our knowledge, little information is available in the literature on the effect of GS on dOM and OMI of grazing ruminants. The lack of a GS effect on LWGs confirms results of Allan (1997), who found no differences between GS in LWGs and wool growth of sheep grazing a tussock pasture in New Zealand (760–930-m altitude, 500 mm annual rainfall). The author speculated that the duration of the experiment of only 6 yr was too short to establish GS effects on herbage and thus, animal performance, clearly. Moreover, the low and variable distribution in annual rainfall may greatly influence the effect of GS on herbage parameters, and hence, feed intake and animal performance (Schönbach et al. 2012). Hence, GS effects on the structure of the plant community were stronger in wet than in dry years in a study by Sternberg et al. (2000), who studied a Mediterranean rangeland vegetation in northeastern Israel. Altogether, this might explain why, despite positive effects on the steppe vegetation, the expected increase in feed intake and performance of sheep at an ALT grassland use were not found in our study.

Across both study years and all GI, herbage mass on offer was 42% higher for CON than for ALT. However, this did not lead to a higher LWGh, because mean SR were only slightly different between CON (6.5 ± 0.3 $sheep \cdot ha^{-1}$) and ALT (5.9 ± 0.3 $sheep \cdot ha^{-1}$). The lower herbage mass on offer across all GIs for ALT was solely due to differences in herbage mass for GI1–GI3. As a consequence, HAs for these GI were higher for CON than for ALT. Nevertheless, they were within the defined HA classes (except GI3), so that effects of the higher HAs for ALT on the measured parameters appear unlikely.

Interaction between Grazing System and Grazing Intensity

No interactions between GS and GI were found for any of the measured animal parameters, indicating that even for very high GI with low herbage mass on offer, ALT is not superior to CON. Results contradict conclusions drawn by Müller et al. (2013). The authors reported that in contrast to CON sheep (Schönbach et al. 2012), LWGs of ALT sheep were similar for all GI and speculated that ALT might have mitigated the negative effects of heavy GI on LWGs.

Results of previous studies within the frame of the same research project showed that increasing SR strongly reduced ANPP for CON, whereas grassland for ALT appeared to be more resilient to heavy grazing (Schönbach et al. 2011). Moreover, aboveground biomass of *L. chinensis*, one of the dominant grass species in the Inner Mongolian steppe that is preferably grazed by sheep (Wang 2000) was lower for high than for moderate to low GI for CON in July 2005–2009 (Wan et al. 2011). Instead GI did not affect aboveground biomass of this species for ALT (Wan et al. 2011). However, despite the inferior productivity and botanical composition of the vegetation for CON and the strong decline in HA with increasing GI, there were no or only minor effects of GI on dOM, OMI, and MEI of sheep, neither for ALT nor for CON. Moreover, no significant relationships between SR and digestibility and intake parameters were determined according to the regression analyses for both GS. Sheep can partly compensate for a decrease in herbage availability by increasing their grazing time and/or the frequency of their bites (Animut et al. 2005; Lin et al. 2011). Additionally, selective feeding behavior may enable sheep to maintain dOM for different HAs (Garcia et al. 2003). Altogether this could explain why no differences between GI in dOM and feed intake of sheep and thus, no interactions between GI and GS were found for these parameters.

Although not in 2010, a strong decline in LWGs with increasing SR was observed for both GS in 2009, confirming the elevated ME requirements for grazing activities of sheep at higher GI in this year (Animut et al. 2005; Lin et al. 2011). Nevertheless, no effects of the interactions between GS and GI or GS, GI, and year were determined for LWGs and LWGh in this year. Moreover, estimates of the intercept values and slopes of the linear regressions were almost identical for both GS. This not only contradicts our hypothesis and the conclusions drawn by Müller et al. (2013) and Schönbach et al. (2012), but is also not in line with the positive effect of ALT observed in herbage parameters (Schönbach et al. 2011). The limited duration of the research project, the inter- and intra-annual variability in precipitation and ambient temperatures (see previous section), and only minor differences in herbage quantity and quality parameters between GS in 2009 and 2010 (Ren et al. 2012; see Table 1) might explain why the ALT use of the grassland steppe neither improved feed intake and LWGs of sheep nor compensated for the negative effects of moderate to high SR on animal performance. This underlines that changes in the rangeland vegetation do not necessarily increase LWG of grazing livestock. Furthermore, solely measuring animal performance will not capture (initial) positive effects on the grassland vegetation which might, nevertheless, enhance overall livestock production in the long term.

Month

Because of advanced plant maturation, limited plant regrowth (Schönbach et al. 2009), and hence, a pronounced decline in the nutritional value of herbage on offer, dOM, OMI, and MEI decreased with proceeding grazing season. This is consistent with results of previous studies (Glindemann et al. 2009b; Wang et al. 2009a; Müller et al. 2013) within the same grazing experiment and Garcia et al. (2003) who analyzed dOM and OMI of sheep in a semiarid highland area in central France. As a consequence, LWGs and LWGh strongly declined from July to September in our study. In contrast to our expectations, no interactions between GS and month or GS, GI, and month were found. At such high dietary fiber concentrations (see Table 1), any further increases in NDF contents from July to September combined with decreases in fiber degradability and thus, overall diet digestibility will strongly reduce OMI and LWG of sheep (Siebert and Hunter 1977). Because HAs were kept constant across the grazing seasons, the decrease in herbage quality due to rapid plant maturation during the short vegetation period of only 150 d could outweigh any positive effects of GS on herbage and animal parameters. Nevertheless, long-term shifts in the botanical composition of herbage and increased ground cover as determined in previous studies within the same grazing experiment (e.g., Schönbach et al. 2011; Wan et al. 2011) might not only enhance overall nutritional quality grassland vegetation, but also lower the rate of plant maturation because of greater soil water content.

IMPLICATIONS

The ALT grazing does not improve feed intake and LWG of sheep grazing semiarid grassland steppes in the short term and cannot mitigate the negative effects of very high GI on animal performance. Besides study duration, low rainfall, and the variability in climatic conditions, the adaptive capacity of grazing livestock might explain the lack of direct effects. Nevertheless, ALT grazing enhanced production and ground coverage of herbage and its botanical composition in many studies. Hence, solely measuring either herbage or animal performance parameters is insufficient to evaluate GS effects in pastoral ecosystems comprehensively. Moreover, this suggests that an ALT use of grasslands in this and similar environments might increase revenues and ecological sustainability of livestock production in the long term when compared to the common practice of continuous grazing at high stocking rates.

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