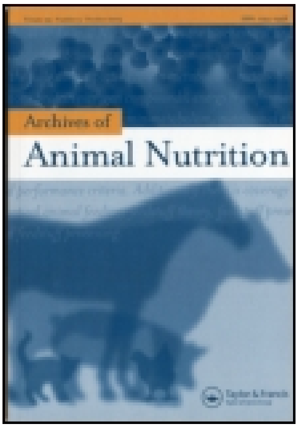

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Effects of rotational and continuous grazing on herbage quality, feed intake and performance of sheep on a semi-arid grassland steppe

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Compared to continuous grazing (CG), rotational grazing (RG) increases herbage production and thereby the resilience of grasslands to intensive grazing. Results on feed intake and animal performance, however, are contradictory. Hence, the objective of the study was to determine the effects of RG and CG on herbage mass, digestibility of ingested organic matter (dOM), organic matter intake (OMI) and live weight gain (LWG) of sheep in the Inner Mongolian steppe, China. During June–September 2005–2008, two 2-ha plots were used for each grazing system. In RG, plots were divided into four 0.5-ha paddocks that were grazed for 10 days each at a moderate stocking rate. Instead, CG sheep grazed the whole plots throughout the entire grazing season. At the beginning of every month, dOM was estimated from faecal crude protein concentration. Faecal excretion was determined using titanium dioxide in six sheep per plot. The animals were weighed every month to determine their LWG. Across the years, herbage mass did not differ between systems ($p = 0.820$). However, dOM, OMI and LWG were lower in RG than in CG ($p \leq 0.005$). Thus, our study showed that RG does not improve herbage growth, feed intake and performance of sheep and suggests that stocking rates rather than management system determine the ecological sustainability of pastoral livestock systems in semi-arid environments.

Keywords: continuous grazing; feed intake; weight gain; rotational grazing; sheep; steppe

1. Introduction

Several grazing systems were developed to lower the grazing pressure on the natural fodder resources without reducing animal performance. In a continuous grazing (CG) system, animals graze the same area during the whole vegetation period (Hodgson 1979). In contrast, in a rotational grazing (RG) system, the grazing area is divided into several paddocks that are grazed in sequence (Frame 1992). Although RG increases stocking densities in a short term, it includes resting periods when the vegetation is allowed to recover from grazing. This may maintain or even increase the short-term as well as

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long-term grassland productivity (Virgona et al. 2000) and, as a consequence, the animal production (Allan 1997). However, in a literature review (Briske et al. 2008), 87% of the 32 studies on vegetation response reported a similar or lower herbage production in RG than in CG. On the other hand, 92% of 38 experiments that analyse the effects of grazing systems on animal performance determined a similar or lower animal live weight gain (LWG) in RG than in CG. Hence, the effects of RG on the quantity and quality of herbage and animal LWG are inconsistent. Amongst other reasons, this may be caused by differences in the studied ecosystem, the animal species used and the applied stocking rates (Vanpoollen and Lacey 1979; Warner and Sharrow 1984; Nicol and Kitessa 2001). Moreover, Schönbach et al. (2009) concluded that short-term experiments are inadequate to compare system effects, when measuring the effects of different grazing systems on herbage quality and production in the Inner Mongolian steppe. Within the same research project, Wang et al. (2009a) suggested that very low precipitation might curtail the positive effects of RG on herbage and animal performance. Therefore, their study was continued to analyse the effects of RG and CG on herbage as well as on feed intake and LWG of sheep. We aimed to determine whether they depend on the duration of the experiment and differ between the study years or throughout the grazing seasons due to changing climatic conditions.

2. Materials and methods

2.1. Site of study and current land use system

This study was conducted in the Inner Mongolian steppe (43°38′N, 116°42′E) at an approximate altitude of 1200 m above sea level. In the past six decades, human population as well as the number of grazing cattle, sheep in particular, rapidly increased in this region, which strongly reduced the available grassland per animal (Jiang et al. 2006). Moreover, the sedentarisation of the formerly nomadic pastoralists increased the grazing pressure close to settlements, whereas distant grassland areas are nowadays only used for hay making. Although high grazing intensities could increase animal production per unit of land area in a short term (Glindemann et al. 2009b), this excessive utilisation is not sustainable and might result in a long-term decline in ecosystem production (Christensen et al. 2003). The climate in the Inner Mongolian steppe is a semi-arid, continental temperate steppe climate. Annual precipitation averages 343 mm and the mean annual air temperature is 0.7°C (climate data was collected at a weather station close to the experimental areas from 1982 to 2004). Monthly precipitations and mean monthly air temperatures in the years 2005–2008 are shown in Figure 1. Rainfall mainly occurs from June to August and the vegetation period lasts from April to September for about 150 to 180 days per year. The dominant soil type in the region is chestnut soil (Chen and Wang 2000). The steppe vegetation is dominated by *Leymus chinensis* Trin. and *Stipa grandis* P.A. Smirn (Bai et al. 2004). Vegetation cover is about 30–40% and may reach 60–70% in wet years (Chen and Wang 2000). From 2005 to 2008, annual yields of herbage mass range between 152 and 240 g dry matter (DM)/m^2 (Schönbach et al. 2011).

2.2. Experimental design

The experiments lasted from mid of June to mid of September (grazing season) for 98, 90, 93 and 95 days in 2005, 2006, 2007 and 2008, respectively. Two different grazing management systems were tested: an RG and a CG system. The latter is similar to the current grazing system in Inner Mongolia. Each system was tested on two permanently

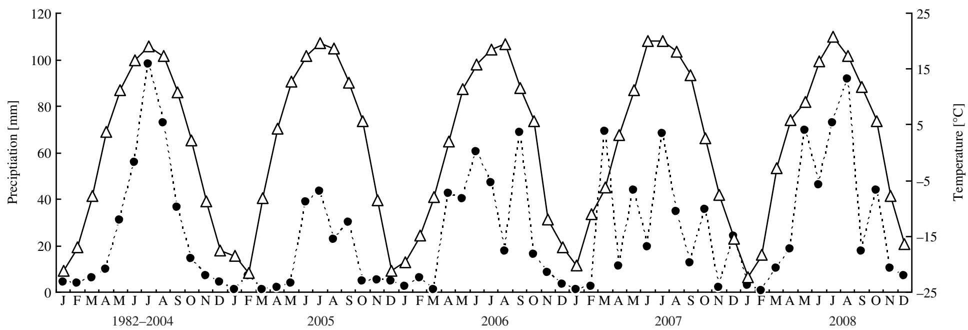

Figure 1. Mean monthly temperature (Δ, ——) and precipitation (●, - - - - - -) at the experimental site during 1982–2004 and in the study years 2005, 2006, 2007 and 2008.

fenced plots, a flat and a moderately sloped plot, to account for the differences in the geographical setting. For RG, the plots (2 ha each) were divided into four equally sized paddocks that were grazed sequentially for 10 days each, followed by a resting period of 30 days (i.e. each paddock was grazed two to three times per grazing season). For CG, sheep were allowed to graze the whole plots throughout the grazing season. Outside of the grazing seasons, the plots remained ungrazed. Nine sheep per plot (i.e. 4.5 sheep/ha) were used in 2005 and 2006, whereas sheep numbers were adjusted every month to herbage mass on offer and the total live weight (LW) of all animals per plot in 2007 and 2008 to maintain a similar herbage allowance of 4.5–6 kg DM/kg LW across the grazing season. Across 2007 and 2008, mean stocking rates were 4.0 sheep/ha in RG and 3.9 sheep/ha in CG. In this region, this equals a moderate grazing intensity (4.5 sheep/ha) for the grasslands (Wang et al. 2001). In addition to the reduced grazing intensities, moderate stocking rates were used in both systems to test whether RG can contribute to a more sustainable grassland use in Inner Mongolia. Details on implemented stocking rates and resulting herbage allowance during experimental years are given in Table 1.

2.3. Herbage mass and quality

After removing the litter, herbage mass on offer was measured by cutting the sward to 1 cm above ground level in $2.0 \cdot 0.25\ m^2$ frames ($n = 3$) at the beginning of June, July, August and September each year. To account for the differences in the sward composition within each plot, representative areas were chosen. Mean herbage mass on RG and CG plots was 653 ± 51, 442 ± 136, 631 ± 92 and 616 ± 50 kg DM/ha in June 2005, 2006, 2007 and 2008, respectively. For RG, samples were taken in grazed paddocks at the beginning of each 10-day grazing period and the mean herbage mass on offer was calculated for every month and experimental year. The collected herbage material was oven-dried for 24 h at 60°C, weighed and pooled by plot for milling. After grinding to pass a 1-mm mesh by a Cyclotec 1093 Sample Mill (Tecator, Sweden), herbage samples were analysed for DM, crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), cellulase digestible organic matter (OM) and metabolisable energy (ME) by near-infrared reflectance spectroscopy (NIRS). For details on calibration and validation of NIRS as well as the analytical procedures, see Schönbach et al. (2009).

Table 1. Mean live weight (LW) of sheep, stocking rate and herbage allowance on continuously (CG) and rotationally grazed (RG) plots during the grazing seasons of the years 2005–2008 (n = 2).

		2005					2006					2007					2008				
		June	July	Aug.†	Sept.#	Mean	June	July	Aug.	Sept.	Mean	June	July	Aug.	Sept.	Mean	June	July	Aug.	Sept.	Mean
LW [kg/sheep]	CG	30.0	33.1	34.9	36.3	33.6	31.6	33.6	37.1	37.5	35.0	30.7	34.1	36.5	41.3	35.7	30.3	36.9	39.9	44.1	37.8
	RG	32.1	34.9	36.7	38.5	35.6	31.1	33.3	36.7	37.8	34.7	31.4	33.3	36.9	41.0	35.7	30.2	35.9	38.5	40.4	36.3
Stocking rate [sheep/ha]	CG	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	3.5	4.0	4.3	3.8	3.9	3.8	3.8	3.8	3.8	3.8
	RG	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	3.5	3.5	3.5	3.3	3.5	4.3	4.5	4.3	4.3	4.4
Herbage allowance [kg DM*/kg LW]	CG	–	7.1	4.7	3.2	5.0	–	3.1	1.7	1.3	2.0	–	4.6	3.2	5.3	4.4	–	5.7	5.5	5.4	5.5
	RG	–	4.9	2.5	3.5	3.6	–	4.0	3.7	1.7	3.1	–	4.5	5.4	3.1	4.3	–	3.4	4.2	6.2	4.6
Herbage allowance [kg DM/kg$^{0.75}$ LW]	CG	–	16.6	11.3	7.6	11.8	–	7.2	4.2	3.1	4.8	–	11.0	7.8	13.4	10.7	–	14.1	13.8	13.8	13.9
	RG	–	11.9	6.0	8.6	8.8	–	9.5	9.0	4.3	7.6	–	10.5	12.7	7.4	10.2	–	8.0	10.3	15.3	11.2

Notes: *DM, Dry matter; †Aug., August; #Sept., September.

2.4. Animals and live weight gain

In 2005, 2006, 2007 and 2008, the numbers of female sheep of the local fat-tailed breed used were 36, 36, 31 and 33, respectively. The animals were about 15 months old and were neither pregnant nor lactating. Sheep were randomly assigned to the grazing plots after shearing and anthelmintic treatments. During the grazing seasons, they had free access to water and mineral lick stones and were allowed to graze for the whole day. All sheep were weighed on two consecutive days at the beginning of the grazing seasons, using an electronic platform scale (0.1 kg accuracy). Their initial LW was 31.1 ± 5.7, 31.4 ± 4.6, 31.1 ± 2.4 and 30.2 ± 4.6 kg in June 2005, 2006, 2007 and 2008, respectively. Thereafter, the animals were weighed again on the 11th and 12th of every month. The mean LW of the two days was used to calculate the animals' LWG during each month according to Equation (1):

$$\mathrm{LWG}\ [\mathrm{g/d}] = (\mathrm{LW}_m - \mathrm{LW}_{m-1})/D_m \cdot 1000, \tag{1}$$

where LWG is the daily LWG, LW is the mean LW [kg] of the two weightings per month and D is the number of days between weighing dates; m and $m - 1$ indicate two consecutive months (m = June, July, August and September). Daily LWG per hectare [g] was calculated from the mean daily LWG of individual sheep [g] and the stocking rate [sheep/ha] in the respective plots.

2.5. Feed intake and digestibility of ingested herbage

At the beginning of the grazing seasons, six sheep per plot were randomly chosen to determine organic matter intake (OMI) and digestibility of ingested herbage organic matter (dOM). Daily OMI of sheep was calculated from dOM and daily faecal organic matter excretion [g/d]. The latter was measured using the external marker titanium dioxide (TiO_2). For this, one gelatine capsule filled with 2.5 g TiO_2 was orally administered to the six sheep per plot at about 10:30 h each day for the first ten days of July, August and September. Immediately after marker application, faecal samples (approximately 25 g fresh matter per sheep) were taken from the rectum on days 6 to 10 (sampling period) and frozen. At the end of each sampling period, all faecal samples were thawed and pooled to one sample per sheep (150 g fresh matter). The pooled samples were divided into two sub-samples. One sub-sample was oven-dried at 60°C for 48 h and used to determine faecal TiO_2 concentration analysis according to Glindemann et al. (2009a), using the marker recovery rate of 100%. The other sample was analysed for DM, crude ash (CA) and nitrogen (N) concentrations according to the methods of the Chinese Technical Committee for Feed Industry Standardization and the Chinese Association of Feed Industry (2000). Briefly, DM is determined by drying the samples at 105°C for 24 h, CA by incineration at 550°C and N by the Kjeldahl procedure.

According to the equation suggested by Wang et al. (2009b), dOM was calculated as follows (Equation (2)):

$$\mathrm{dOM}\,[\%] = 89.9 - 64.4 \cdot \exp\left(-0.5774 \cdot \mathrm{Faecal\,CP}/100\right), \tag{2}$$

where dOM is the digestibility of ingested organic matter (OM) and CP is the CP concentration in faecal organic matter (= N · 6.25) [g/kg OM].

Subsequently, OMI was estimated by Equation (3):

$$\text{OMI}\,[\text{g/d}] = \text{Faecal OM} \,/\, (100 - \text{dOM}), \tag{3}$$

where OMI is the daily OMI of sheep, faecal OM is faecal organic matter [g/d] and dOM is the digestibility of ingested organic matter [%].

Intakes of digestible organic matter (DOMI) and ME (MEI) were calculated by multiplying OMI by dOM or ME concentrations, respectively. The latter was estimated according to Equation (4) derived by Aiple (personal communication) on the basis of the data published by Aiple et al. (1992):

$$\text{ME}\,[\text{MJ/kg OM}] = -0.9 + 0.170 \cdot \text{dOM}, \tag{4}$$

where ME is the dietary ME concentration and dOM is the digestibility of ingested organic matter [%].

2.6. *Statistical analysis*

Mean values of the six selected sheep per plot were used for statistical analyses. Hence, in total, 48 observations (2 systems · 4 years · 3 months · 2 plots) were obtained for all animal and herbage parameters. Data were analysed using the Mixed Model procedure of SAS version 9.1 (SAS Institute Inc., Cary, NC, USA) to test the effect of grazing system, year and month on herbage mass, herbage composition, dOM, OMI, DOMI, MEI and LWG. The following model was used:

$$y_{ijkl} = \mu + \text{GS}_i + \text{YE}_j + \text{M}_k + (\text{GS} \cdot \text{YE})_{ij} + (\text{GS} \cdot \text{M})_{ik} + (\text{YE} \cdot \text{M})_{jk} + (\text{GS} \cdot \text{YE} \cdot \text{M})_{ijk} + \text{P}_l + e_{ijkl},$$

where y is the dependent variable, μ is the overall mean, GS_i is the grazing management system (RG and CG), YE_j is the year (2005, 2006, 2007 and 2008), M_k is the month (July, August and September), P_l is the plot (flat and sloped) and e_{ijkl} is the random experimental error. Year was treated as repeated measurement. All other factors and their interactions were treated as fixed effects. Probabilities for all effects and their interactions were determined. When effects were significant ($p \leq 0.05$), the Tukey test was used for pair-wise comparisons of least squares means.

3. Results

3.1. *Herbage mass and quality*

The effects of grazing system on herbage mass and herbage quality are shown in Table 2. Across the four study years, mean herbage mass on offer in RG and CG was 641 and 628 kg DM/ha, respectively, and it did not differ between grazing systems. Chemical composition of herbage was influenced by grazing system. Concentrations of CP ($p < 0.001$), cellulase digestible OM ($p = 0.034$) and ME ($p = 0.019$) were lower in RG than in CG, whereas concentrations of ADF were greater in RG (33.4% of DM) than in CG (32.8% of DM, $p = 0.025$). Grazing system did not affect concentrations of NDF and ADL. Moreover, there were no significant interactions between grazing system and year and grazing system and month for herbage mass and quality parameters.

Table 2. Mean herbage mass and chemical composition on continuously and rotationally grazed plots during the grazing seasons of 2005–2008 (least squares means; n = 6).

		Continuous grazing				Rotational grazing						*p*-value						
	Year	July	Aug.‡	Sept.#	Mean	July	Aug.	Sept.	Mean	Mean	SEM+	GS†	YE§	M¶	GS×YE	GS×M	YE×M	GS×YE×M
Herbage mass [kg DM*/ha]	2005	999	716	499	738	769	406	603	592	665^{B}	34.3	0.820	0.001	0.836	0.268	0.550	0.013	0.166
	2006	450	283	210	314	590	601	293	494	404^{A}								
	2007	529	494	870	631	561	797	585	648	640^{AB}								
	2008	786	823	901	837	544	779	1,161	828	832^{B}								
Crude protein [% DM]	2005	10.1	8.7	8.2	9.0	9.3	8.5	6.6	8.1	8.6^{A}	0.34	<0.001	<0.001	<0.001	0.419	0.660	0.129	0.385
	2006	15.3	14.4	12.5	14.0^{b}	13.4	10.8	11.0	11.7^{a}	13.0^{C}								
	2007	12.7	12.7	10.4	11.9	11.5	12.6	8.9	11.0	11.5^{B}								
	2008	13.9	13.9	12.9	13.6	13.5	10.9	12.9	12.4	13.0^{C}								
Neutral detergent fibre [% DM]	2005	72.5	72.4	72.2	72.4	72.4	74.1	73.3	73.3	72.8^{C}	0.36	0.442	<0.001	0.044	0.557	0.369	0.094	0.086
	2006	65.6	69.0	68.8	67.8	66.9	69.4	65.6	67.3	67.5^{A}								
	2007	69.2	71.6	70.1	70.3	70.6	70.8	70.6	70.6	70.5^{B}								
	2008	68.6	69.1	67.0	68.2	70.0	67.4	68.4	68.6	68.4^{A}								
Acid detergent fibre [% DM]	2005	33.6	34.2	34.1	33.9^{a}	34.4	35.3	37.0	35.5^{b}	34.7^{C}	0.22	0.025	<0.001	0.013	0.068	0.967	0.032	0.034
	2006	31.0	32.0	33.1	32.0	31.5	33.4	31.1	32.0	32.0^{A}								
	2007	32.2	32.8	34.7	33.2	32.7	32.8	34.0	33.2	33.2^{B}								
	2008	32.6	32.1	31.6	32.1	33.5	31.9	33.4	32.9	32.5^{AB}								

(*continued*)

Table 2. (*Continued*).

	Year	Continuous grazing				Rotational grazing				Mean	SEM[+]	*p*-value						
		July	Aug.[‡]	Sept.[#]	Mean	July	Aug.	Sept.	Mean			GS[†]	YE[§]	M[¶]	GS×YE	GS×M	YE×M	GS×YE×M
Acid detergent lignin [% DM]	2005	4.1	5.0	5.0	4.7^{a}	4.3	5.4	5.7	5.1^{b}	4.9^{AB}	0.08	0.257	0.001	<0.001	0.081	0.304	0.007	0.251
	2006	3.8	5.3	5.1	4.7	3.8	4.8	5.4	4.7	4.7^{A}								
	2007	4.7	5.1	5.8	5.2	4.9	5.2	5.4	5.1	5.2^{B}								
	2008	4.3	4.9	4.7	4.6	4.4	4.7	5.0	4.7	4.7^{A}								
Cellulase digestible organic matter [% organic matter]	2005	60.1	57.8	56.3	58.1	58.4	54.6	54.1	55.7	56.9^{A}	0.46	0.034	<0.001	<0.001	0.109	0.458	0.078	0.726
	2006	66.9	62.0	60.8	63.2^{b}	63.4	59.4	61.6	61.5^{a}	62.3^{C}								
	2007	61.7	58.9	56.0	58.9	62.5	59.9	57.7	60.0	59.5^{B}								
	2008	62.7	60.2	62.1	61.7	59.4	60.0	60.6	60.0	60.8^{BC}								
Metabolisable energy [MJ/kg DM]	2005	8.3	7.9	7.7	8.0	8.1	7.4	7.3	7.6	7.8^{A}	0.07	0.019	<0.001	<0.001	0.120	0.474	0.061	0.614
	2006	9.4	8.7	8.5	8.9	9.0	8.4	8.7	8.7	8.8^{C}								
	2007	8.5	8.3	7.9	8.2	8.6	8.4	8.0	8.3	8.3^{B}								
	2008	8.7	8.3	8.4	8.5^{b}	8.1	8.2	8.3	8.2^{a}	8.3^{B}								

Notes: [‡]Aug., August; [#]Sept., September; *DM, Dry matter; [+]SEM, Standard error of the mean; [†]GS, Grazing system; [§]YE, Year; [¶]M, Month; [a,b]Means within rows without a common superscript differ ($p \leq 0.05$) for each grazing system and year; [A,B,C]Means within columns without a common superscript differ ($p \leq 0.05$) between the overall means for each year. Significant differences between months within each grazing system are not shown.

Mass and chemical composition of herbage on offer strongly differed between years ($p \leq 0.001$). Whereas herbage mass on offer was lowest in 2006 (405 kg DM/ha, $p \leq 0.036$), it reached 665, 640 and 828 kg DM/ha in 2005, 2007 and 2008, respectively. In contrast thereto, concentrations of ME ($p \leq 0.001$) and cellulase digestible OM ($p = 0.051$) were highest in 2006, whereas NDF ($p = 0.085$) and ADF ($p = 0.149$) contents were lowest in this year.

Herbage quality differed between months. Concentrations of CP, cellulase digestible OM and ME were greater in July (12.4% of DM, 61.9% of OM and 8.6 MJ/kg DM, respectively) than in September (10.4% of DM, 58.7% of OM and 8.1 MJ/kg DM, respectively; $p < 0.001$ for all parameters). In contrast thereto, concentrations of ADF and ADL were lower in July (32.7% of DM, $p = 0.013$; 4.3% of DM, $p < 0.001$) than in September (33.6% of DM; 5.3% of DM). Across the four study years, herbage mass did not differ between months.

3.2. Digestibility of ingested herbage and feed intake

Across the four study years, dOM, OMI, DOMI and MEI were lower in RG than in CG ($p \leq 0.002$) and there were no significant interactions between grazing system and year for these parameters (Table 3). Nevertheless, the differences in dOM between the two systems were only significant in 2006 ($p = 0.029$) and 2007 ($p = 0.001$). On the contrary, OMI, DOMI and MEI were lower in RG than in CG in 2005 ($p \leq 0.045$ for all parameters) and 2006 ($p \leq 0.007$), whereas no differences were found in 2007 and 2008.

Moreover, dOM, OMI, DOMI and MEI differed between years ($p \leq 0.018$). With preceding study years, dOM increased from 0.55 in 2005 to 0.61 in 2008. Lowest OMI, DOMI and MEI were observed in 2005 and 2007, whereas respective values were highest in 2006 and 2008.

Across the study years, dOM ($p < 0.001$), OMI ($p = 0.028$), DOMI ($p = 0.003$) and MEI ($p = 0.003$) were greater in July than in September, which was due to significantly greater digestibility and intake values determined in July 2006 ($p \leq 0.047$ for all parameters). No differences between months were determined in any of the other years, except for dOM, which was greater in July and August than in September in 2007 ($p \leq 0.034$).

3.3. Live weight gain

Across the study years, LWG per sheep was lower in RG (80 g/d) than in CG (104 g/d; $p = 0.005$). However, there was a tendency of an interaction between grazing system and year ($p = 0.051$); the difference was only due to a lower LWG per sheep of RG in 2008 ($p = 0.013$; Table 3). On the contrary, grazing system did not affect the LWG per hectare across the study years ($p = 0.248$). A significant effect of the interaction between grazing system and month on LWG of sheep was found ($p = 0.036$) as it was greater in CG than in RG in July ($p = 0.023$), but not in August ($p = 0.999$) and September ($p = 0.253$).

Both LWG per sheep and per hectare differed between years ($p \leq 0.001$) and months ($p \leq 0.016$) and significant interactions between year and month were found ($p < 0.001$ for all parameters). Hence, LWG per sheep and per hectare were lower in 2005 ($p \leq 0.004$) and 2006 ($p \leq 0.036$) than in 2007 and 2008. Across the study years, LWG per sheep and per hectare were greater in July than in September ($p \leq 0.018$), which was due to significant differences between the two months in 2006 ($p = 0.001$). Instead, no

Table 3. Mean digestibility of ingested organic matter (OM), daily OM intake, digestible OM intake and metabolisable energy intake as well as daily live weight (LW) gain of sheep and per hectare in rotationally and continuously grazed plots during the grazing seasons of 2005–2008 (least squares means; n = 12).

		Continuous grazing				Rotational grazing						*p*-value						
Parameter	Year	July	Aug.‡	Sept.#	Mean	July	Aug.	Sept.	Mean	Mean	SEM+	GS†	YE§	M¶	GS×YE	GS×XM	YE×M	GS×YE×XM
Digestibility of ingested OM	2005	0.57	0.55	0.54	0.55	0.54	0.56	0.52	0.54	0.55[A]	0.01	<0.001	<0.001	<0.001	0.383	0.425	<0.001	0.016
	2006	0.62	0.58	0.55	0.59[b]	0.58	0.58	0.54	0.57[a]	0.58[B]								
	2007	0.57	0.63	0.58	0.59[b]	0.56	0.57	0.55	0.56[a]	0.58[B]								
	2008	0.63	0.61	0.60	0.61	0.60	0.59	0.61	0.60	0.61[C]								
OM intake [g/kg$^{0.75}$ LW*]	2005	79.8	84.2	76.0	80.0[b]	71.4	63.9	72.2	69.2[a]	74.6[A]	3.68	0.002	0.018	0.007	0.512	0.665	0.402	0.704
	2006	106	85.9	90.1	94.0[b]	89.4	66.4	79.3	78.4[a]	86.2[B]								
	2007	82.0	75.8	77.4	78.4	79.4	74.2	62.1	71.9	75.1[A]								
	2008	92.1	79.3	75.9	82.4	83.5	69.7	78.4	77.2	79.8[AB]								
Digestible OM intake, [g/kg$^{0.75}$ LW]	2005	45.0	46.6	40.5	44.1[b]	38.4	34.7	37.9	36.9[a]	40.5[A]	2.15	<0.001	0.001	0.001	0.442	0.506	0.130	0.634
	2006	66.2	50.1	50.0	55.3[b]	52.1	38.1	42.4	44.2[a]	49.8[C]								
	2007	46.5	47.6	44.8	46.3	44.7	42.2	34.3	40.4	43.3[AB]								
	2008	58.1	48.1	46.9	50.6	50.1	41.1	48.1	46.5	48.5[BC]								
Metabolisable energy intake [MJ/kg$^{0.75}$ LW]	2005	0.69	0.72	0.63	0.68[b]	0.59	0.55	0.57	0.57[a]	0.62[A]	0.03	<0.001	0.002	0.002	0.473	0.481	0.135	0.640
	2006	1.03	0.77	0.77	0.86[b]	0.81	0.59	0.65	0.68[a]	0.77[C]								
	2007	0.72	0.74	0.69	0.72	0.69	0.65	0.53	0.62	0.66[AB]								
	2008	0.91	0.75	0.71	0.79	0.78	0.64	0.75	0.72	0.75[BC]								
LW gain [g/sheep]	2005	94	64	39	65	85	65	48	66	66[A]	10	0.005	<0.001	0.007	0.051	0.036	<0.001	0.363
	2006	114	114	17	81	111	112	–6	72	77[A]								
	2007	145	90	154	130	71	113	130	104	117[B]								
	2008	173	97	151	140[b]	75	95	68	79[a]	109[B]								
LW gain [g/ha]	2005	423	286	174	294	382	293	215	296	295[A]	30	0.248	0.001	0.016	0.412	0.032	<0.001	0.344
	2006	513	511	75	366	497	503	–27	324	345[A]								
	2007	507	380	615	500	277	630	637	514	507[B]								
	2008	654	355	565	525	352	466	339	385	455[AB]								

Notes: ‡Aug., August; #Sept., September; *LW, Live weight; +SEM, Standard error of the mean; †GS, Grazing system; §YE, Year; ¶M, Month; Significant differences between months within each GS are not shown; Means within rows without a common superscript differ ($p \leq 0.05$) between means for each GS and year; A,B,CMeans within columns without a common superscript differ ($p \leq 0.05$) between the overall means for each year.

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differences in LWG per sheep and per hectare were found between July and September in any of the other study years.

4. Discussion

4.1. Effect of grazing system

In contrast to CG, RG allows the vegetation to recover from animal grazing and thereby increases vegetation cover, avoids water and soil erosion and reduces the risk of grassland degradation (Teague and Dowhower 2003). Thus, it may offer a valuable management strategy for the sustainable use of the Inner Mongolian steppe for pastoral livestock production (Su et al. 2005). Hence, Virgona et al. (2000) reported that RG increased phalaris herbage mass compared to CG under sheep grazing. Moreover, Han et al. (1990) determined a higher nutritional quality of herbage in RG than in CG in the Inner Mongolian steppe, although the authors did not find a positive effect on herbage mass. In contrast thereto, Walker et al. (1989) studied the effect of management system on herbage in Southern United States and reported that RG by cattle did not increase herbage quality. Similarly, Popp et al. (1997) found no difference in CP, cellulase digestible OM and ME concentrations between the two grazing systems for an alfalfa-grass pasture grazed by cattle in Southern United States. In our study, we also did not observe a positive effect of RG on herbage mass on offer. Moreover, CG, not RG, increased concentrations of CP, cellulase digestible OM and ME across the four study years. This confirms the findings of Sharrow (1983) who studied the effect of sheep grazing on an annual grass-clover sward in Western United States during the dry summer period. Nicol and Kitessa (2001), who studied LWG of cattle and sheep co-grazing temperate pastures, found that LWG of cattle was lower in CG than in RG, whereas LWG of sheep was similar in both grazing systems. The authors suggested that this was due to the greater ability of sheep to select for a higher quality diet. Moreover, Warner and Sharrow (1984) stated that RG is only superior to CG at relatively high stocking rate (in this study a minimum of five ewes and nine lambs were used in 0.8 ha/plots). Hence, the reasons for the contradicting study results might be the differences in the climatic and environmental conditions, the animal species used as well as the applied stocking rates (Warner and Sharrow 1984; Nicol and Kitessa 2001; Bailey and Brown 2011).

Stocking densities during the 10-day grazing periods were greater in RG paddocks than in CG plots. This might have limited the ability of RG sheep to select for preferred plant species or plant parts (Stuth et al. 1987), thereby reducing the nutritional quality of the animals' diets (Vallentine 2001). Hence, together with the lower herbage quality, this might explain the lower dOM and consequently the lower OMI, DOMI and MEI of sheep in RG than in CG. Results confirm those obtained by Hafley (1996) in a study with cattle grazing a ryegrass pasture in Southern United States. In accordance with the lower digestibility and intake values, LWG per sheep was lower in RG than in CG sheep. This did not lead to a lower LWG per hectare due to higher stocking rates in RG than in CG in 2008 (4.4 vs. 3.8 sheep/ha). However, it complies with the results of Derner et al. (2008), who reported that RG reduces LWG of cattle by 6% as compared to CG. Other studies indicated that grazing system has no effect on animal LWG (Gammon 1987; Manley et al. 1997; Wang et al. 2009a). In a literature review, Briske et al. (2008) showed that 92% of the grazing studies (n = 38) reported a similar or greater LWG of sheep in CG than in RG, whereas 84% of them (n = 32) determined a similar or greater LWG per unit of land area. Hence, it appears that animal performance is primarily determined by grazing intensity rather than by grazing system (Heitschmidt et al. 1987; Manley et al. 1997; McCollum et al. 1999; Derner et al. 2008) and that it might even be lower in RG systems due to a poorer quality of herbage.

4.2. *Effect of year*

The difference in LWG per sheep in CG or RG was pronounced in 2008, whereas no significant differences between grazing systems were found during the other study years. In 2008, precipitation during the grazing period was 297 mm, which was higher than in 2005 (138 mm) and 2007 (178 mm). However, the lack of continuous forage removal as well as the maturation of plants during the resting periods of 30 days in RG plots might have limited the positive effect of rainfall on re-growth and thus nutritional quality of herbage. Instead, herbage offered to CG sheep might have been less mature. Hence, herbage ME concentrations were lower in RG than in CG, which might partly explain the lower LWG of RG sheep. Although the differences in dOM, DOMI and MEI were not significant, mean MEI was 1.5 MJ/d lower in RG than in CG in 2008 (Figure 2). According to Jeroch et al. (1996), sheep need on average 23 kJ ME for each gram of LWG at 35 kg LW. The additional MEI of CG sheep would therefore have allowed for an extra gain of 65 g/d, which is similar to the measured difference in animal performance (61 g/d).

When compared with 2008, a similar precipitation was recorded in the grazing season of 2006 (233 mm). In this study year, CP and cellulase digestible OM concentrations as well as dOM, OMI, DOMI and MEI were significantly lower in RG than in CG. Nevertheless, LWG of sheep was similar in both systems. Herbage mass as well as herbage allowance was lowest in 2006, probably due to a carry-over effect of the very

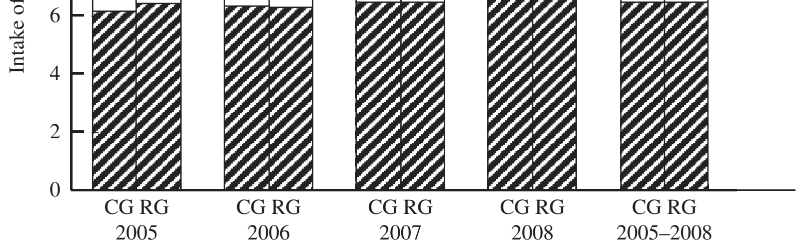

Figure 2. Daily intake of metabolisable energy (ME) and ME expenditure for maintenance (ME$_m$), live weight gain (ME$_g$) and other purposes than maintenance and gain (ME$_x$) of sheep in continuous grazing (CG) and rotational (RG) grazing in 2005–2008. ME intake [in MJ/d] was calculated by multiplying the mean ME intake [in MJ/kg LW] of sheep in each year (see Table 3) by the animals' respective metabolic live weight [kg$^{0.75}$ LW] (see Table 1).
Note: *Indicate significant ($p \leq 0.05$) differences between the ME intake of CG and RG sheep. Bars indicate standard deviations from the mean ME intake.

low rainfall in 2005. The lower herbage allowance might have increased the animals' physical activity and hence their daily energy expenditures (Lin et al. 2011). The proportion of the MEI used for purposes other than maintenance and LWG (ME_x) can be estimated by deducting the animals' ME requirements for maintenance (ME_m) and gain (ME_g) from their daily MEI. Growing sheep require 430 kJ ME/kg$^{0.75}$LW for maintenance, and at 35 kg LW, for each gram of LWG 23 kJ ME (Jeroch et al. 1996). Hence, in our study ME_m, ME_g and ME_x of RG sheep were 6.45 MJ, 1.85 MJ and 1.37 MJ/d, respectively, whereas those of CG sheep were 6.46 MJ, 2.40 MJ and 2.49 MJ/d, respectively. The differences in ME_x between CG and RG were 1.5, 2.4, 0.9 and −0.2 MJ ME/d in the respective study years and were significant in 2005 ($p = 0.034$) and 2006 ($p = 0.002$), but not in the following two years ($p > 0.909$). This seems to explain why LWG per sheep was similar in RG than in CG in the dry year 2005 and in 2006 when herbage allowance was very low, despite lower die digestibility and intake values.

4.3. *Effect of month*

Herbage quality decreased with proceeding vegetation period, which is consistent with the findings of previous studies conducted within the frame of the same research project (Schönbach et al. 2009). As a consequence, dOM, feed intake and LWG per sheep decreased from July to September. However, in 2006, dOM, MEI and LWG per sheep across both systems were lower in September than in July, whereas the differences were not significant in 2005, 2007 (except LWG per sheep) and 2008. This was most likely due to greater herbage allowance in these years (see previous section), which enabled the animals to compensate for the negative effects of herbage maturation by selecting for plants or plant parts of higher nutritional quality towards the end of the grazing season.

If RG is only beneficial at high stocking rate and low herbage allowance (Warner and Sharrow 1984), one would expect that feed intake and performance of animals might be greater in RG than in CG towards the end of the grazing season when herbage mass and herbage quality decline. An interaction between grazing system and month was observed for LWG of sheep. Across the four study years, LWG of CG sheep was lower in September than in July, whereas no difference in animal performance was found between the two months in RG. The latter was mainly due to the LWG of RG sheep in 2007 that was nearly twice as high in September than in July (130 vs. 71 g/d), indicating a compensatory growth of sheep in this study year. In none of the other study years, RG was superior to CG towards the end of the grazing season. Hence, the pronounced decrease in herbage quality found in our study did not alter the system effect. This suggests that the moderate grazing intensity used in our study, the adjustment of stocking rates to herbage mass on offer in 2007 and 2008, and the similar decreases in herbage quality in both systems might have hampered the beneficial effect of RG on feed intake and LWG per sheep at the end of the grazing season.

5. Conclusions

The results of four study years showed that herbage quality, feed intake and weight gain of sheep grazing the Inner Mongolian steppe at a moderate grazing intensity is inferior in RG than in CG. However, higher energy intake in CG did not result in a corresponding increase in weight gain, because animals used a greater amount of ingested energy for purposes other than maintenance and growth, likely for grazing and walking. The differences between grazing systems may vary between years according to the amount of rainfall and thus herbage mass on offer. The pronounced decreases in herbage quality with advancing vegetation period due to plant maturation do not alter the system effects. The lack of herbage re-growth during grazing seasons, the animals' selective feeding behaviour and the moderate grazing intensity appear to hamper any beneficial effect of RG on pasture vegetation and sheep performance. Hence, further studies are required to test whether an RG system is superior at grazing intensities higher than those used in our study.

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