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Christian-Albrechts-Universität zu Kiel

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**Influence of grazing system on herbage production and animal  
performance in the Inner Mongolian steppe, China**

Dissertation

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## List of abbreviation

ADF	Acid detergent fiber
ADL	Acid detergent lignin
ALT	Alternating
ANPP	Above-ground net primary production
CON	Continuous
CP	Crude protein
CDOM	Cellulase digestible organic matter
DM	Dry matter
dOM	Digestibility of ingested organic matter
DOMI	Digestible organic matter intake
FOM	Fecal organic matter
GI	Grazing intensity
GS	Grazing system
HA	Herbage allowance
HM	Herbage mass
LW	Live weight
LWG	Live weight gain
LWGs	Live weigh gain per sheep
LWGh	Live weight gain per hectare
M	Month
ME	Metabolizable energy
MEI	Metabolizable energy intake
NDF	Neutral detergent fiber
NIRS	Near-infrared reflectance spectroscopy
OM	Organic matter
OMI	Organic matter intake
ROT	Rotational
SE	Standard error
SEM	Standard error of mean
SR	Stocking rate
TiO <sub>2</sub>	Titanium dioxide
YE	Year

*Chapter 1*

**General introduction**



## **1 General introduction**

### **1.1 Grasslands in Inner Mongolia**

Grasslands in Inner Mongolia cover around 791,000 km<sup>2</sup> (Kawamura et al., 2005), and are thus one of the largest grassland ecosystems in China (approximately 20% of the total grasslands area; Liu et al., 2008). The Inner Mongolian steppe is under a semi-arid temperate climate, with annual rainfall of around 350 mm and dominated by drought tolerant plant species (Kang et al., 2007). The dominant soil type in this region is the chestnut soil (Chen and Wang, 2000). The steppe vegetation is dominated by twelve plant species. Among these species, *Leymus chinensis* Tzvel, *Stipa grandis* P.A. Smirn, *Festuca sulcata* Beck, and *Artemisia frigida* Willd are the most common ones (Sun, 2005).

### **1.2 Grassland utilization in the Inner Mongolian steppe**

Livestock production is the main agricultural activity in Inner Mongolian steppe (Thwaites et al., 1998). Farmers used the nomadic grazing systems several decades ago, which avoid continuous grazing in the same area due to the shift according to grassland conditions (Thwaites et al., 1998).

Human impacts are one of the main causes for the grassland degradation and desertification in Northern China in recent years (Yu et al., 2004). Sharply rising human populations increased demands for the animal products and pressures on grassland ecosystems in the last five decades (Suttie et al., 2005). Since 1950, human population as well as the number of grazing cattle and in particular sheep in Inner Mongolia rapidly increased, which strongly reduced the ratio of available grassland per animal (Jiang et al., 2006). Yiruhan et al. (2001) reported that the available land area per sheep decreased from 6.8 ha in the 1950s to 1.6 ha in the 1980s in Inner Mongolia. For example, the human population in the Xilingol League, one of the biggest livestock areas in the Inner Mongolia, increased from 200,000 in 1949 to

approximately 950,000 in 2000 (Jiang et al., 2006). Correspondingly, the livestock numbers increased by 18-folds from 1949 to 2000, so that the available grassland area decreased from 5 ha to 1 ha/sheep (Jiang et al., 2006). Meanwhile, the current grazing system in the Inner Mongolian steppe consists of grasslands close to farms being utilized for intensive sheep and cattle grazing. Other, distant areas are only used for hay-making (Christensen et al., 2003). Farmers typically focus on the short-term economic output and neglect the long-term grassland productivity. Hence, they prefer to increase stocking rate with the goal of maximizing profit in a short-term. As a result, the grazing pressure on the Inner Mongolian steppe has therefore continuously increased, leading to severe ecological and economic problems (Jiang et al., 2006). Due to the increasing human population and the strong incentive by government for the nomadic families to settle and abandon their traditional utilization way of steppe, the grazing system in the Inner Mongolia steppe is characterized by spatial distinction between continuous grazed areas and hay-making sites (Christensen et al., 2003). Pastures nearby the farms are generally used for grazing throughout the whole grazing season. On the other hand, hay-making sites are often located farther away from farms and utilized for collecting hay for winter feeding (Schönbach et al., 2009). The continuous grazing in the same areas might reduce vegetation cover, standing biomass, and also root biomass. Consequently, the risk of water and wind erosion significantly increased (Lu et al., 2005; Zhao et al., 2005). Moreover, grassland in hay-making areas may lead to degradation due to the lack of nitrogen from animals' excretions. This has significant influences on the long-term grassland production (Owens and Shipitalo, 2009). The consequences of this grassland utilization change are the degradation and desertification of the Inner Mongolian steppe. More than 20% of the grassland areas in Inner Mongolia are not suitable for grazing and about 30% were degraded in the 1990s (Yu et al., 2004). Furthermore, the area of degraded grasslands in China has increased by about 2 million ha every year since 1990 (Li, 1999a). In 2004 about approximately 90% of the grasslands in China suffered to various degrees of degradation (Jiang et al., 2006). Tong et al. (2004) reported that the degradation and desertification of grasslands in Northern China, particularly in Inner Mongolia, is

the driving factor for the frequent sand and dust storms in China. Furthermore, the current grazing system in the Inner Mongolian steppe is far away from being of sustainable use. Future research efforts are necessary to combine the economic and ecological revenues of grasslands to evaluate the grazing management success (Yu et al., 2004).

Fortunately, the Chinese government attempted to protect the grasslands with land-use policies at the end of the 1990s. The policies focus on four aspects: (1) seasonal grazing: dividing the grasslands into several areas by different seasons and grazing sequentially, based on the climate, species composition, water resources, and grazing management; (2) grazing ban: forbidding grazing activities in the heavily destroyed grasslands; (3) financial compensation: providing food and money refund to farmers in grazing ban areas; (4) legal protection: establishing the “Grassland Law” for rational protection and utilization of grassland in 2002 (Chen and Wang, 2006; Zhang, 2008).

### **1.3 Effect of stocking rate on the grassland vegetation and animal production**

Stocking rate is a critical factor affecting vegetation conditions and livestock production from the grasslands. Too low stocking rate results in waste herbage and low animal gain per unit area, while an over-stocking rate leads to degradation of grassland conditions and lower live weight gain per animal (Ralphs et al., 1990).

World-wide, many studies evaluated the vegetation responses to increasing stocking rates. The increasing grazing pressure changes its species composition on a rough fescue grassland in Canada (Willms et al., 1985) and on a semi-arid typical steppe in Inner Mongolia, China (Zhao et al., 2007). Chen et al. (2003) and Wang and Li (1999) indicated that the vegetation species in Xilin River Basin, Inner Mongolia are *Leymus chinensis* Tzvel and *Stipa grandis* P.A. Smirn are replaced by *Cleistogenes squarrosa* Keng under continuously heavy grazing, and then finally replaced by *Artemisia frigida* Willd. These changes in the botanical composition of

the vegetation may decrease the nutritional quality of the forage available for livestock grazing (Chen et al., 2003). Hence, the study by Chen et al. (2003) in Inner Mongolia indicated that crude protein content in forage samples decreased due to the species composition changes with increasing stocking rate by grazing sheep. Similarly, vegetation cover and standing biomass decreased with increasing stocking rate (Ralphs et al., 1990; Li et al., 2000). Moreover, Ferraro and Oesterheld (2002), Jiang et al. (2006), and Schönbach et al. (2011) reported that negative effects of grazing on above-ground net primary production of grasslands in different areas.

Due to the changes of vegetation caused by increasing stocking rate, the digestibility of ingested herbage, intake of organic matter, and the live weight gain of animal would be affected. According to different chemical compositions of standing forage and greater capability of selection for higher quality herbage at low stocking rate, Garcia et al. (2003) speculated that digestibility of organic matter should be affected by stocking rates. The hypothesis was consistent with earlier study by Lu (1988), who reported that goats ingested herbage of a higher digestibility when stocking rate is low. However, these results contradict observations of Glindemann et al. (2009) and Müller et al. (2012), who conducted their studies in sheep in the Inner Mongolian steppe. This discrepancy may be explained by Schiborra (2007) who stated that diet selection was limited in this region due to a small difference in the digestibility of the herbage at different heights above ground level. Many studies reported that reduced organic matter intake is correlated with increasing stocking rate (Hull et al., 1961; Langlands and Bennett, 1973). Nevertheless, some studies determined that stocking rate did not affect animals' feed intake (Ackerman et al., 2001; Aharoni et al., 2004; Glindemann et al., 2009; Müller et al., 2012). Wang et al. (2005) concluded that animals prefer areas with a higher biomass to maintain their feed intake when grazing on a low herbage production grassland. Stocking rate largely influences live weight gain of animals and overall profitability of grazing management systems (Biondini et al., 1998). Quite a few studies estimated the effects of stocking rate on animal production with different species (cattle, sheep, and goat)

and concluded that increasing stocking rate may maximize live weight gain per unit of land in the short-term, however, reduced live weight gain per animal (Hull et al., 1961; Fynn and O'Connor, 2000; Han et al., 2000; Glindemann et al., 2009; Lin et al., 2012). Furthermore, Kemp and Michalk (2007) suggested that there might be a certain threshold, above which any increases in stocking rates do not contribute to or even reduce the total output per unit of land area due to the decreasing performance of individual animal. After five years of their study, Lin et al. (2012) concluded that in the Inner Mongolia steppe this threshold is approximately 5.3 sheep/ha across the study years for the 3 months continuous grazing period, which ensure the long-term animal and grassland productivity as well as the ecosystem functions.

Grazing system is considered to be important for maintaining or even increasing the long-term grassland productivity and animal performance (Long, 1986). Therefore, the use of suitable grazing systems might mitigate the reported negative effects of heavy grazing. Allan (1997) compared rotational grazing, alternating grazing, and continuous grazing and concluded that rotational and alternating grazing were superior to continuous grazing with increasing stocking rate. Moreover, Schönbach et al. (2011) reported that the above-ground net primary production was higher at alternating grazing system than at continuous grazing system in a moderate to heavy stocking rate after a four years study in the Inner Mongolian steppe. Similarly, Müller et al. (2012) evaluated the impacts of alternating grazing system and stocking rates on herbage quality and live weight gain of grazing sheep and suggested that alternating counteract the negative effects of heavy stocking rate on herbage and animal performance. However, they also mentioned that the positive effects of alternating system were limited by the low rainfall in the grazing season.

Table 1.1 Common grazing systems used in the livestock management studies.

Grazing systems	Definition and characteristic
Continuous grazing	grazing in a particular pasture the whole year or an entire grazing season (Hodgson, 1979)
Rotational grazing	animals are sequentially grazed from one pasture to another during an entire grazing season (Campbell, 1966)
Alternating grazing	grazing and hay-making areas are alternated between two or more than two pastures, the period of hay-making continuous for more than 12 consecutive months until next grazing period (Merrill, 1954)
Strip grazing	pasture is grazed in strips to enhance the utilization rate, giving livestock allocation to fresh pasture each day (Jamieson and Hodgson, 1979)
Rationed grazing	a predetermined amount of forage is allotted to the animal on a daily, weekly, or longer basis (Geus, 1950)
Extended grazing	grazing season is lengthened by utilization of hay filed for pasture (D'souza et al., 1990)
Time limiting grazing	livestock graze a limited amount of high quality forage for a short period, usually once or twice daily, as a supplement to lower quality forage (Gerrish, 1993)

#### 1.4 Grazing systems

World-wide, continuous heavy grazing has caused different degree of grasslands degradation (Gebremedhin et al., 2004). Managers attempt to find several methods to maintain and improve the grassland production, and thus enhance the animal performance. Specialized grazing systems (Table 1.1) with rest periods during the grazing season are considered to be effective to achieve the goals (Long, 1986). Periods with absence of animal grazing allow the vegetation to re-grow, to produce more seeds, and thus, to increase forage production and herbage nutrient quality

(Heady, 1961). Li (1999b) suggested that efficient grazing management in the grassland ecosystems may protect the grassland from degradation and thereby maintain or even improve the long term grassland production and animal performance.

Many studies compared continuous (CON) grazing with specialized grazing system and attempted to obtain a more efficient grazing system to increase the grassland and livestock production. Several studies evaluated CON and rotational (ROT) grazing and reported that ROT increased herbage production (Virgona et al., 2000) and live weight gain (LWG) of individual animals (McMeekan and Walshe, 1963; Allan, 1997). On the contrary, Hafley (1996) and Derner et al. (2008) reported that lower LWG was observed at ROT than at CON. Furthermore, some studies stated that no differences were found in forage and animal parameters between ROT and CON by cattle (Manley et al., 1997; Popp et al., 1997) and sheep (Wang et al., 2009) grazing. Hence, Briske et al. (2008) reviewed the previous studies and concluded that ROT is not superior to CON. Similarly, inconsistent results have been also reported in the comparison of CON and alternating (ALT) system. The forage production and litter accumulation were observed to be higher at ALT than at CON (Clarke et al., 1943; Reardon and Merrill, 1976), and the above-ground net primary production of the grassland in Inner Mongolian steppe increased comparing ALT to CON at stocking rate from 6.0 to 9.0 sheep/ha (Schönbach et al., 2011). However, studies reported that ALT did not affect herbage nutrient quality (Schönbach et al., 2009) and productivity (Allan, 1985; Grant et al., 1988), and hence, live weight gain of individual sheep (Allan, 1997; Lin et al., 2012). As mentioned above, the effects of specialized grazing systems on herbage and animal parameters as well as grassland ecology were inconsistent in the previous studies. Results indicate that the specialized systems are not always better than CON. Positive effects of specialized grazing systems might be dependent on animal species used (Kitessa and Nicol, 2001), disparity of stocking rate applied (Warner and Sharrow, 1984), and differences in climates and ecosystems in the study areas (Van Poollen and Lacey, 1979).

## 1.5 The research project

This study is part of a long-term research project that evaluates the multiple effects of grazing on the typical steppe of Inner Mongolia. The goal is to elucidate the interaction between grazing of steppe ecosystems and matter fluxes, and to develop concepts for sustainable grassland utilization. The Sino-German research collaboration “Matter fluxes of Grasslands in Inner Mongolia as influenced by stocking rate” was funded by the German Research Foundation (No. 536). Eleven sub-projects contributed to the overall aim of the research group on site as well as on a regional scale:

1. Amount, composition, and turnover of organic matter pools in grassland soils under typical steppe vegetation types of the Xilin River Basin as influenced by different grazing intensities. (German partner: Department of Soil Science, Technical University of Munich; Chinese partner: Department of Soil and Water Science, China Agricultural University, Beijing, and Institute of Botany, Chinese Academy of Science, Beijing).
2. Effects of grazing intensity on net primary production and nutrient dynamics. (German partner: Institute of Plant Nutrition and Soil Science, Christian-Albrechts-Universität zu Kiel; Chinese partner: Department of Plant Nutrition, China Agricultural University, Beijing).
3. Impact of grazing management on yield performance, herbage quality, and persistence of grassland ecosystems of Inner Mongolia. (German partner: Institute of Grass and Forage Science/Organic Agriculture, Christian-Albrechts-Universität zu Kiel; Chinese partner: Institute of Botany, Chinese Academy of Sciences, Beijing).
4. Impact of grazing intensity on herbage quality, feed intake, and animal performance of grazing sheep in the grassland steppe of Inner Mongolia. (German partner: Institute of Animal Nutrition and Physiology, Christian-Albrechts-Universität zu Kiel; Chinese partner: College of Animal Science and Technology, China Agricultural University, Beijing)



5. Quantification and biogeochemical modeling of C and N turnover processes and biosphere-atmosphere exchange of C and N compounds. (German partner: Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology; Chinese partner: Institute for Atmospheric Physics, Chinese Academy of Sciences, Beijing).
6. Quantification of water and carbon exchange by micrometeorology and remote sensing in managed steppe ecosystems of Inner Mongolia. (German partner: Institute for Hydrology and Meteorology, Technical University Dresden; Chinese partner: Institute for Atmospheric Physics, Chinese Academy of Sciences, Beijing).
7. Regional water fluxes and coupled C and N transport. (German partner: Institute for Landscape Ecology and Resources Management, Justus-Liebig- Universität Gießen).
8. Influence of various grazing intensities on soil stability and water balance on the plot scale (German partner: Institute for Plant Nutrition and Soil Science, Christian-Albrechts-Universität zu Kiel; Chinese partner: Institute of Soil Science, Chinese Academy of Sciences, Beijing).
9. Dynamics of wind erosion in the Xilin River Catchment area in Inner Mongolia. (German partner: The Leibniz Centre for Agricultural Landscape Research; Chinese partner: Institute of Agricultural Environment and Sustainable Development, Chinese Academy of Agricultural Sciences, Beijing).
10. Influence of grazing pressure on the carbon isotope composition of the grassland of China: spatio-temporal variations at multiple scales. (German partner: Center of Life and Food Sciences Weihenstephan, Technical University of Munich; Chinese partner: Institute of Botany, Chinese Academy of Sciences, Beijing).
11. Surface and satellite based remote sensing to infer rain rates within the Xilin catchment. (German partner: German Meteorological Service, Meteorological Observatory Lindenberg – Richard Ahmann Observatory; Chinese partner: Institute for Atmospheric Physics, Chinese Academy of Sciences and Chinese

Meteorological Administration, Dept. of Observations and Telecommunication, Division of Upper Air Observations).

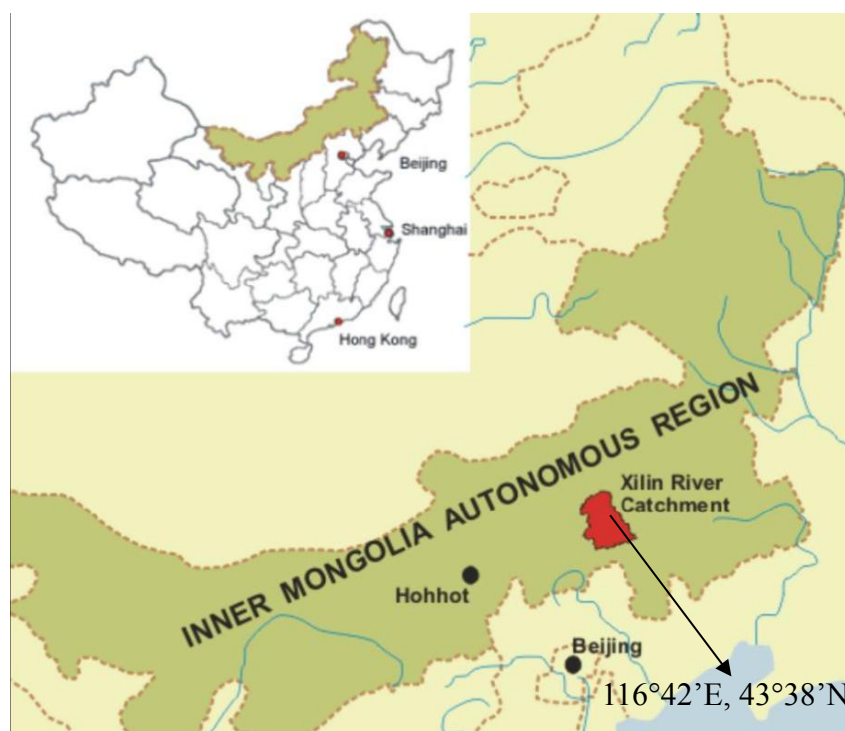


Figure 1.1: Location of the study site in the Xilin River Basin, Inner Mongolia, China

The present study was carried out within the frame of sub-project 4 of the Institute of Animal Nutrition and Physiology, Christian-Albrechts-Universität zu Kiel. In close cooperation with the Institute of Crop Science, Christian-Albrechts-Universität zu Kiel (sub-project 3), a field grazing trial had been established in 2005 on a *Leymus chinensis* Tzvel and *Stipa grandis* P. A. Smirn dominated plant community in the typical steppe of Inner Mongolia (Figure 1.1). The main aims of the sub-projects 3 and 4 were to investigate the impacts of different grazing management systems and stocking rates on herbage species composition, herbage quality and quantity, digestibility of ingested herbage, feed intake, and live weight gain of sheep and to develop management concepts for a sustainable utilization of the grassland resources.

This dissertation focuses on the effects of grazing systems on digestibility of ingested organic matter, feed intake, and live weight gain of grazing sheep in the steppe of Inner Mongolia. Chapter 1 documents a general introduction for the

utilization of the steppe in the Inner Mongolia, and hence, the negative effects of high stocking rates on herbage and animal production. Chapter 2 describes a study where the impacts of ROT and CON on herbage chemical composition, herbage mass on offer, digestibility of ingested organic matter, feed intakes, and live weight gain of grazing sheep were measured. Chapter 3 presents results of an experiment investigating the effects of ALT and CON on digestibility of organic matter, intakes of organic matter and metabolizable energy, and live weight gain of sheep in the Inner Mongolian steppe. Chapter 4 discusses the measured parameters which are appropriate to evaluate the special grazing management system effects and to summarize factors that affect the effects of systems on herbage and animals. The general discussion provides recommendations for a proper grazing system applied in the Inner Mongolian steppe to maintain or even increase animal performance and long-term grassland productivity.

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*Chapter 2*

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

Archives of Animal Nutrition (in press)

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

### **2.1 Abstract**

Compared to continuous (CON) grazing, rotational (ROT) grazing 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 was to determine the effects of ROT and CON on herbage mass (HM), 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. At ROT, plots were divided into four 0.5-ha paddocks that were grazed for 10 d each at a moderate stocking rate. Instead, CON sheep grazed the whole plots throughout the entire grazing season. In the beginning of every month, dOM was estimated from fecal crude protein concentration. Feces excretion was determined using titanium dioxide in six sheep per plot. The animals were weighed every month to determine their LWG. Across the years, HM did not differ between systems ( $P = 0.820$ ). However, dOM, OMI, and LWG were lower at ROT than at CON ( $P \leq 0.005$ ). Our study thus showed that ROT 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.

### **2.2 Introduction**

Several grazing systems were developed to lower grazing pressure on the natural fodder resources without reducing animal performance. In a continuous grazing (CON) system, animals graze the same area during the whole vegetation period (Hodgson,

1979). Instead, the grazing area is divided into several paddocks that are grazed in sequence in the rotational grazing (ROT) system (Frame, 1992). Although ROT 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 short-term as well as long-term grassland productivity (Virgona et al., 2000) and as a consequence, animal production (Allan, 1997). However, in a literature review Briske et al. (2008) found that 87% of the 32 considered studies on vegetation responses reported a similar or lower herbage production at ROT than at CON, whereas 92% of the 38 experiments that analyzed grazing system effects on animal performance determined a similar or lower animal live weight gain (LWG) at ROT than at CON. Hence, the effects of ROT on the quantity and quality of herbage and animal LWG are inconsistent. This may be, amongst other reasons, caused by differences in the studied ecosystem, the animal species used, and the applied stocking rates (Van Poolen and Lacey, 1979; Warner and Sharrow, 1984; Kitessa and Nicol, 2001). Moreover, Schönbach et al. (2009) who 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 ROT on herbage and animal performance. Their study was therefore continued to analyze the effects of ROT and CON on herbage as well as feed intake and LWG of sheep. We aimed to determine whether they depend on the duration of the experiment and differ between study years or throughout the grazing seasons due to changing climatic conditions.

## **2.3 Materials and methods**

### **2.3.1 Site of study and current land use system**

The 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 and in particular sheep in this

region rapidly increased, which strongly reduced the available grassland per animal (Jiang et al., 2006). Moreover, the sedentarization of the formerly nomadic pastoralists increased 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 utilization is not sustainable and might result in a long-term decline in ecosystem production (Christensen et al., 2003). The climate is a semi-arid, continental temperate steppe climate. Annual precipitation averages 343 mm and mean annual air temperature is 0.7 °C (climate data was collected at a weather station close to our experimental areas in 1982–2004). Monthly precipitations and mean monthly air temperatures in 2005–2008 are shown in Figure 2.1. Rainfall mainly occurs from June to August and the vegetation period lasts from April to September for about 150 to 180 d per year. The dominant soil type in the region is a 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). Annual yields of herbage mass (HM) range between 152 and 240 g dry matter (DM)/m<sup>2</sup> in 2005–2008 (Schönbach et al., 2011).

### **2.3.2 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: a ROT and a CON system. The latter is similar the current grazing system in Inner Mongolia (see previous section). Each system was tested on two permanently fenced plots: a flat and a moderately sloped plot to account for differences in the geographical setting. For ROT, plots (2 ha each) were divided into four equally sized paddocks that were grazed sequentially for 10 d each, followed by a resting period of 30 d (i.e. each paddock was grazed 2–3 times per grazing season). For CON, 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 HM on offer and the total live weight (LW) of all animals per plot in 2007 and 2008 to maintain a similar herbage allowance (HA) of 4.5 – 6 kg DM/kg LW across the grazing season. Across 2007 and 2008, mean stocking rates were 4.0 sheep/ha at ROT and 3.9 sheep/ha at CON. This equals a moderate grazing intensity (4.5 sheep/ha) for the grasslands in this region (Wang et al., 2001). Moderate stocking rates were used in both systems to test whether in addition to reduced grazing intensities, ROT can contribute to a more sustainable grassland use in Inner Mongolia. Details on implemented stocking rates and resulting HA values during experimental years are given in Table 2.1.

### **2.3.3 Herbage mass and quality**

After removing the litter, HM on offer was measured by cutting the sward to 1 cm above ground level in 2.0 × 0.25 m<sup>2</sup> frames (n=3; representative areas were chosen to account for differences in the sward composition within each plot) at the beginning of June, July, August, and September each year. Mean HM on ROT and CON plots was 653 ± 51, 442 ± 136, 631 ± 92, and 616 ± 50 kg DM/ha in June 2005, 2006, 2007, and 2008, respectively. For ROT, samples were taken in grazed paddocks at the beginning of each 10-d grazing period and the mean HM 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 analyzed for DM, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), cellulase digestible organic matter (CDOM), and metabolizable 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).

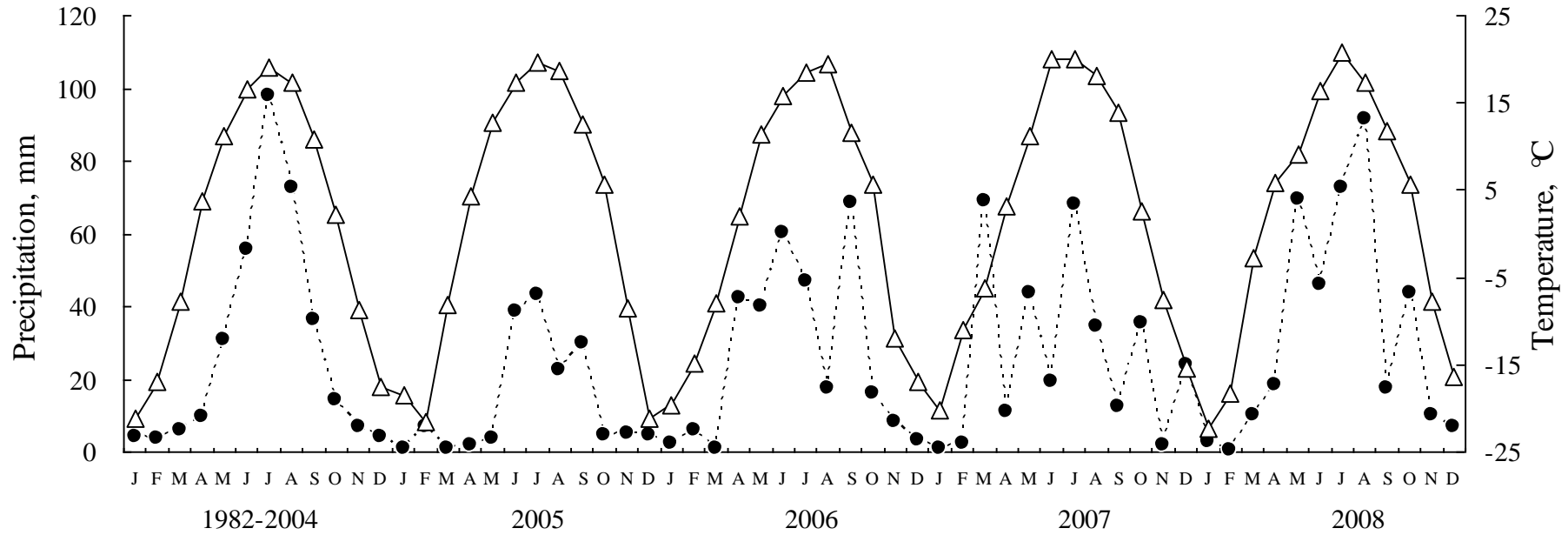


Figure 2.1 Mean monthly temperatures ( $\Delta$ , —) and precipitations ( $\bullet$ , -----) at the experimental site during 1982–2004 and in the study years 2005, 2006, 2007, and 2008.



Table 2.1 Mean live weight (LW) of sheep, stocking rate (SR), and herbage allowance (HA) on continuously (CON) and rotationally grazed (ROT) plots during the grazing seasons of 2005–2008 (n = 2).

Parameter	GS	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,	CON	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
kg/sheep	ROT	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
SR,	CON	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
sheep/ha	ROT	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
HA,	CON	-	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
kg DM/kg	ROT	-	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
HA,	CON	-	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
kg	ROT	-	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

Aug., August; GS, grazing system; Sept., September.

### 2.3.4 Animals and live weight gain

In 2005, 2006, 2007, and 2008, 36, 36, 31, and 33 female sheep of the local fat-tailed breed were used. The animals were about 15 months old and 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  $31.1 \pm 5.7$ ,  $31.4 \pm 4.6$ ,  $31.1 \pm 2.4$ , and  $30.2 \pm 4.6$  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:

$$\text{LWG [g/d]} = (\text{LW}_m [\text{kg}] - \text{LW}_{m-1} [\text{kg}]) / \text{D}_m \cdot 1000, \quad (1)$$

where LWG is the daily LWG, LW the mean LW of the two weighings per month, and D the number of days between weighing dates.  $m$  and  $m-1$  indicate two consecutive months ( $m = \text{June, July, August, and September}$ ). Daily LWG per hectare (LWG<sub>h</sub>, g/ha) was calculated from the mean daily LWG of individual sheep (LWG<sub>s</sub>, g/d) and the stocking rate (sheep/ha) in the respective plot.

### 2.3.5 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 fecal organic matter excretion (g/d). The latter was measured using the external marker titanium

dioxide (TiO<sub>2</sub>). For this, one gelatine capsule filled with 2.5 g TiO<sub>2</sub> was orally administered to the six sheep per plot about 10:30am each day for the first ten days 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 six to 10 (sampling period) and frozen. At the end of each sampling period, all fecal 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 fecal TiO<sub>2</sub> concentration analysis according to Glindemann et al. (2009a) using the marker recovery rate of 100%. The other sample was analyzed 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):

$$\text{dOM [\%]} = 89.9 - 64.4 \cdot \exp(-0.5774 \cdot \text{fecal CP}[\text{g/kg organic matter}]/100), \quad (2)$$

where dOM is the digestibility of ingested organic matter and CP the CP concentration in fecal organic matter (= N · 6.25). Subsequently, OMI was estimated by equation 3:

$$\text{OMI [g/d]} = \text{fecal organic matter [g/d]} / (100 - \text{dOM [\%]}), \quad (3)$$

where OMI is the daily OMI of sheep and dOM 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):

$$\text{ME [MJ/kg organic matter]} = -0.9 + 0.170 \cdot \text{dOM [\%]}, \quad (4)$$

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

### 2.3.6 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 analyzed 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 HM, herbage composition, dOM, OMI, DOMI, MEI, and LWG, respectively. The following model was used:

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

where  $y$  is the dependent variable,  $\mu$  the overall mean,  $\text{GS}_i$  grazing management

system (ROT and CON),  $YE_j$  the year (2005, 2006, 2007, and 2008),  $M_k$  the month (July, August, and September),  $P_1$  the plot (flat and sloped), and  $e_{ijkl}$  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 pairwise comparisons of least squares means.

## 2.4 Results

### 2.4.1 Herbage mass and quality

The effects of grazing system on HM and herbage quality are shown in Table 2.2. Across the four study years, mean HM on offer at ROT and CON was 641 and 628 kg DM/ha, respectively, and did not differ between grazing systems ( $P = 0.820$ ). Chemical composition of herbage was influenced by grazing system. Concentrations of CP ( $P < 0.001$ ), CDOM ( $P = 0.034$ ), and ME ( $P = 0.019$ ) were lower at ROT than at CON, whereas concentrations of ADF were greater at ROT (33.4 % DM) than at CON (32.8 % DM,  $P = 0.025$ ). Grazing system did not affect concentrations of NDF and ADL ( $P \geq 0.257$ ). Moreover, there were no significant interactions between grazing system and year ( $P \geq 0.068$ ) and grazing system and month ( $P \geq 0.304$ ) for herbage mass and quality parameters.

Mass and chemical composition of herbage on offer strongly differed between years ( $P \leq 0.001$ ). Whereas HM 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 CDOM ( $P \leq 0.051$ ) were highest in 2006, whereas NDF ( $P \leq 0.085$ ) and ADF ( $P \leq 0.149$ ) contents were lowest in this year.

Chapter 2 Effects of rotational and continuous grazing system

Table 2.2 Mean herbage mass (HM) and chemical composition on continuously (CON) and rotationally grazed (ROT) plots during the grazing seasons of 2005–2008 (least squares means; n = 2).

Parameter	Year	CON				ROT				Mean	SEM	<i>P</i> -value						
		July	Aug.	Sept.	Mean	July	Aug.	Sept.	Mean			GS	YE	M	GS×YE	GS×M	YE×M	GS×YE×M
HM, kg DM/ha	2005	999	716	499	738	769	406	603	592	665 <sup>B</sup>	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 <sup>A</sup>								
	2007	529	494	870	631	561	797	585	648	640 <sup>AB</sup>								
	2008	786	823	901	837	544	779	1,161	828	832 <sup>B</sup>								
CP, % DM	2005	10.1	8.7	8.2	9.0	9.3	8.5	6.6	8.1	8.6 <sup>A</sup>	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 <sup>b</sup>	13.4	10.8	11.0	11.7 <sup>a</sup>	13.0 <sup>C</sup>								
	2007	12.7	12.7	10.4	11.9	11.5	12.6	8.9	11.0	11.5 <sup>B</sup>								
	2008	13.9	13.9	12.9	13.6	13.5	10.9	12.9	12.4	13.0 <sup>C</sup>								
NDF, % DM	2005	72.5	72.4	72.2	72.4	72.4	74.1	73.3	73.3	72.8 <sup>C</sup>	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 <sup>A</sup>								
	2007	69.2	71.6	70.1	70.3	70.6	70.8	70.6	70.6	70.5 <sup>B</sup>								
	2008	68.6	69.1	67.0	68.2	70.0	67.4	68.4	68.6	68.4 <sup>A</sup>								
ADF, % DM	2005	33.6	34.2	34.1	33.9 <sup>a</sup>	34.4	35.3	37.0	35.5 <sup>b</sup>	34.7 <sup>C</sup>	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 <sup>A</sup>								
	2007	32.2	32.8	34.7	33.2	32.7	32.8	34.0	33.2	33.2 <sup>B</sup>								
	2008	32.6	32.1	31.6	32.1	33.5	31.9	33.4	32.9	32.5 <sup>AB</sup>								
ADL, % DM	2005	4.1	5.0	5.0	4.7 <sup>a</sup>	4.3	5.4	5.7	5.1 <sup>b</sup>	4.9 <sup>AB</sup>	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 <sup>A</sup>								
	2007	4.7	5.1	5.8	5.2	4.9	5.2	5.4	5.1	5.2 <sup>B</sup>								
	2008	4.3	4.9	4.7	4.6	4.4	4.7	5.0	4.7	4.7 <sup>A</sup>								
CDOM, % organic matter	2005	60.1	57.8	56.3	58.1	58.4	54.6	54.1	55.7	56.9 <sup>A</sup>	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 <sup>b</sup>	63.4	59.4	61.6	61.5 <sup>a</sup>	62.3 <sup>C</sup>								
	2007	61.7	58.9	56.0	58.9	62.5	59.9	57.7	60.0	59.5 <sup>B</sup>								
	2008	62.7	60.2	62.1	61.7	59.4	60.0	60.6	60.0	60.8 <sup>BC</sup>								
ME, MJ/kg DM	2005	8.3	7.9	7.7	8.0	8.1	7.4	7.3	7.6	7.8 <sup>A</sup>	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 <sup>C</sup>								
	2007	8.5	8.3	7.9	8.2	8.6	8.4	8.0	8.3	8.3 <sup>B</sup>								
	2008	8.7	8.3	8.4	8.5 <sup>b</sup>	8.1	8.2	8.3	8.2 <sup>a</sup>	8.3 <sup>B</sup>								

<sup>a, b</sup> Within rows means without a common superscript differ ( $P \leq 0.05$ ) between means for each GS and year. <sup>A, B, C</sup> Within columns means without a common superscript differ ( $P \leq 0.05$ ) between the overall means for each years. ADF, acid detergent fiber; ADL, acid detergent lignin; Aug., August; CDOM, cellulase digestible organic matter; CP, crude protein; DM, dry matter; GS, grazing system; M, month; ME, metabolizable energy; NDF, neutral detergent fiber; SEM, standard error of the mean; Sept., September; YE, year.

Herbage quality differed between months. Concentrations of CP, CDOM, and ME were greater in July with 12.4 % DM, 61.9 % organic matter, and 8.6 MJ/kg DM in than in September with 10.4 % DM, 58.7 % organic matter, and 8.1 MJ/kg DM in September ( $P < 0.001$  for all parameters). In contrast thereto, concentrations of ADF and ADL were greater in July (32.7 % DM,  $P = 0.013$ ; 4.3 % DM,  $P < 0.001$ ) than in September (33.6 % DM; 5.3 % DM). Across the four study years, HM did not differ between months ( $P = 0.836$ ).

#### **2.4.2 Digestibility of ingested herbage and feed intake**

Across the four study years, dOM, OMI, DOMI, and MEI were lower at ROT than at CON ( $P \leq 0.002$ ) and there were no significant interactions between grazing system and year for these parameters ( $P \geq 0.384$ ; Table 2.3). 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 at ROT than at CON in 2005 ( $P \leq 0.045$  for all parameters) and 2006 ( $P = 0.007$ ,  $P = 0.002$ ,  $P = 0.002$ ), whereas no differences were found in 2007 ( $P \geq 0.070$ ) and 2008 ( $P \geq 0.189$ ).

Moreover, dOM ( $P < 0.001$ ), OMI ( $P = 0.018$ ), DOMI ( $P = 0.001$ ), and MEI ( $P = 0.002$ ) differed between years. 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 ( $P \leq 0.034$ ).

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Table 2.3 Mean digestibility of ingested organic matter (dOM), daily organic matter intake (OMI), digestible OMI (DOMI), and metabolizable energy intake (MEI) as well as daily live weight gain of sheep (LWGs) and per hectare (LWGH) at rotationally (ROT) and continuously grazed (CON) plots during the grazing seasons of 2005–2008 (least squares means; n = 2).

Parameter	Year	CON				ROT				Mean	SEM	P-value						
		July	Aug.	Sept.	Mean	July	Aug.	Sept.	Mean			GS	YE	M	GS×YE	GS×M	YE×M	GS×YE×M
dOM	2005	0.57	0.55	0.54	0.55	0.54	0.56	0.52	0.54	0.55 <sup>A</sup>	0.01	< 0.001	< 0.001	< 0.001	0.384	0.425	< 0.001	0.016
	2006	0.62	0.58	0.55	0.59 <sup>b</sup>	0.58	0.58	0.54	0.57 <sup>a</sup>	0.58 <sup>B</sup>								
	2007	0.57	0.63	0.58	0.59 <sup>b</sup>	0.56	0.57	0.55	0.56 <sup>a</sup>	0.58 <sup>B</sup>								
	2008	0.63	0.61	0.60	0.61	0.60	0.59	0.61	0.60	0.61 <sup>C</sup>								
OMI, g/kg <sup>0.75</sup> LW	2005	79.8	84.2	76.0	80.0 <sup>b</sup>	71.4	63.9	72.2	69.2 <sup>a</sup>	74.6 <sup>A</sup>	3.68	0.002	0.018	0.007	0.512	0.665	0.402	0.704
	2006	106	85.9	90.1	94.0 <sup>b</sup>	89.4	66.4	79.3	78.4 <sup>a</sup>	86.2 <sup>B</sup>								
	2007	82.0	75.8	77.4	78.4	79.4	74.2	62.1	71.9	75.1 <sup>A</sup>								
	2008	92.1	79.3	75.9	82.4	83.5	69.7	78.4	77.2	79.8 <sup>AB</sup>								
DOMI, g/kg <sup>0.75</sup> LW	2005	45.0	46.6	40.5	44.1 <sup>b</sup>	38.4	34.7	37.9	36.9 <sup>a</sup>	40.5 <sup>A</sup>	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 <sup>b</sup>	52.1	38.1	42.4	44.2 <sup>a</sup>	49.8 <sup>C</sup>								
	2007	46.5	47.6	44.8	46.3	44.7	42.2	34.3	40.4	43.3 <sup>AB</sup>								
	2008	58.1	48.1	46.9	50.6	50.1	41.1	48.1	46.5	48.5 <sup>BC</sup>								
MEI, MJ/kg <sup>0.75</sup> LW	2005	0.69	0.72	0.63	0.68 <sup>b</sup>	0.59	0.55	0.57	0.57 <sup>a</sup>	0.62 <sup>A</sup>	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 <sup>b</sup>	0.81	0.59	0.65	0.68 <sup>a</sup>	0.77 <sup>C</sup>								
	2007	0.72	0.74	0.69	0.72	0.69	0.65	0.53	0.62	0.66 <sup>AB</sup>								
	2008	0.91	0.75	0.71	0.79	0.78	0.64	0.75	0.72	0.75 <sup>BC</sup>								
LWGs, g	2005	94	64	39	65	85	65	48	66	66 <sup>A</sup>	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 <sup>A</sup>								
	2007	145	90	154	130	71	113	130	104	117 <sup>B</sup>								
	2008	173	97	151	140 <sup>b</sup>	75	95	68	79 <sup>a</sup>	109 <sup>B</sup>								
LWGH, g/ha	2005	423	286	174	294	382	293	215	296	295 <sup>A</sup>	30	0.248	0.001	0.016	0.412	0.032	< 0.001	0.349
	2006	513	511	75	366	497	503	-27	324	345 <sup>A</sup>								
	2007	507	380	615	500	277	630	637	514	507 <sup>B</sup>								
	2008	654	355	565	525	352	466	339	385	455 <sup>AB</sup>								

<sup>a, b</sup> Within rows means without a common superscript differ ( $P \leq 0.05$ ) between means for each GS and year. <sup>A, B, C</sup> Within columns means without a common superscript differ ( $P \leq 0.05$ ) between the overall means for each year. Aug., August; GS, grazing system; LW, live weight; M, month; SEM, standard error of the mean; Sept., September; YE, year.



### 2.4.3 Live weight gain

Across the study years, LWGs was lower at ROT (80 g/d) than at CON (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 LWGs of ROT sheep in 2008 ( $P = 0.013$ ; Table 2.3). On the contrary, grazing system did not affect LWGh across the study years ( $P = 0.248$ ). A significant effect of the interaction between grazing system and month on LWGs was found ( $P = 0.036$ ) as LWGs was greater at CON than at ROT in July ( $P = 0.023$ ) but not in August ( $P = 0.999$ ) and September ( $P = 0.253$ ).

Both, LWGs and LWGh differed between years ( $P < 0.001$ ,  $P = 0.001$ ) and months ( $P = 0.007$ ,  $P = 0.016$ ) and significant interactions between year and month were found ( $P < 0.001$  for all parameters). Hence, LWGs and LWGh were lower in 2005 ( $P \leq 0.003$ ,  $P \leq 0.004$ ) and 2006 ( $P \leq 0.031$ ,  $P \leq 0.036$ ) than in 2007 and 2008. Across the study years, LWGs and LWGh were greater in July than in September ( $P = 0.005$ ,  $P = 0.018$ ), which was due to significant differences between the two months in 2006 ( $P = 0.001$ ,  $P = 0.001$ ). Instead, no differences between July and September in LWGs and LWGh were found in any of the other study years ( $P \geq 0.266$ ).

## 2.5 Discussion

### 2.5.1 Effect of grazing system

In contrast to CON, ROT allows the vegetation to recover from animal grazing, thereby increases vegetation cover, avoids water and soil erosion, and reduces the risk of grassland degradation (Teague and Dowhower, 2003). It may thus 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 ROT increased phalaris herbage mass compared to CON under sheep grazing. Moreover, Han et al. (1990) determined a higher nutritional quality of herbage at ROT than at CON in the Inner Mongolian steppe, although the authors did not find a

positive effect on HM. In contrast thereto, Walker et al. (1989) studied the effect of management system on herbage in Southern United States and reported that ROT by cattle did not increase herbage quality. Similarly, Popp et al. (1997) found no difference in CP, CDOM, 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 ROT on HM on offer. Moreover, CON not ROT increased concentrations of CP, CDOM, and ME across the four study years. This confirms 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. Kitessa and Nicol (2001) who studied LWG of cattle and sheep co-grazing temperate pastures found that LWG of cattle was lower at CON than at ROT, whereas LWG of sheep was similar at 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 ROT is only superior to CON 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 differences in the climatic and environmental conditions, the animal species used as well as the applied stocking rates (Warner and Sharrow, 1984; Kitessa and Nicol, 2001; Bailey and Brown, 2011).

Stocking densities at ROT paddocks during the 10-d grazing periods were greater than at CON plots. This might have limited the ability of ROT 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 at ROT than at CON. Results confirm those obtained by Hafley (1996) in a study with cattle grazing a ryegrass pasture in Southern United States. In accordance to the lower digestibility and intake values, LWGs was lower in ROT than in CON sheep. This did not lead to a lower LWG<sub>h</sub> due to higher stocking rates at ROT than at CON in 2008 (4.4 vs. 3.8 sheep/ha). However, it complies with results of Derner et al. (2008) who reported that ROT reduces LWG of cattle by 6%

compared to CON. 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 LWGs at CON than at ROT, 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 ROT systems due to a poorer quality of herbage.

### **2.5.2 Effect of year**

The difference in LWGs at CON or ROT 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 and 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 d at ROT plots might have limited the positive effect of rainfall on re-growth and thus nutritional quality of herbage. Instead, herbage offered to CON sheep might have been less mature. Hence, herbage ME concentrations were lower at ROT than at CON, which might partly explain the lower LWGs of ROT sheep. Although the differences in dOM, DOMI, and MEI were not significant, mean MEI was 1.5 MJ/d lower at ROT than at CON in 2008 (Figure 2.2). 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 CON 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).

Compared with 2008, a similar precipitation was recorded in the grazing season of 2006 (233 mm). In this study year, CP and CDOM concentrations as well as dOM, OMI, DOMI, and MEI were significantly lower at ROT than at CON. Nevertheless, LWGs was similar at both systems. HM as well as HA were lowest in 2006, probably

due to a carry-over effect of the very low rainfall in 2005. The lower HA 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<sup>0.75</sup> LW for maintenance and at 35 kg LW, 23 kJ ME for each gram of LWG (Jeroch et al., 1996). Hence,  $ME_m$ ,  $ME_g$ , and  $ME_x$  requirements of ROT sheep in our study were 6.45 MJ, 1.85 MJ, and 1.37 MJ/d, respectively, whereas at CON sheep required 6.46 MJ, 2.40 MJ, and 2.49 MJ/d for  $ME_m$ ,  $ME_g$ , and  $ME_x$ . The differences in  $ME_x$  between CON and ROT 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 ( $P = 0.909$ ;  $P = 0.997$ ). This seems to explain why LWGs was similar at ROT than at CON in the dry year 2005 and in 2006 when HA was very low, despite lower die digestibility and intake values.

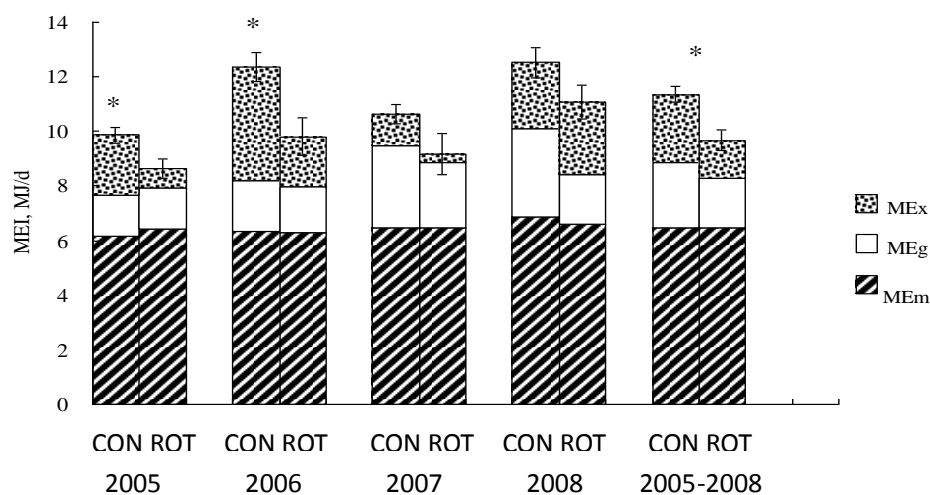


Figure 2.2 Daily intakes of metabolizable energy (ME) and ME expenditures for maintenance ( $ME_m$ ), live weight gain ( $ME_g$ ), and purposes other than maintenance and gain ( $ME_x$ ) of sheep at continuous (CON) and rotational (ROT) grazing in 2005–2008. MEI [in MJ/d] was calculated by multiplying the mean ME intake [in MJ/kg live weight] of sheep in each year (see table 2.3) by the animals' respective metabolic live weight [kg<sup>0.75</sup> live weight] (see Table 2.1). \* indicate significant ( $P \leq 0.05$ ) differences between the MEI of CON and ROT sheep. Bars indicate standard deviations from the mean ME intake.

### **2.5.3 Effect of month**

Herbage quality decreased with proceeding vegetation period, which is consistent with findings of previous studies conducted within the frame of the same research project (Schönbach et al., 2009). As a consequence, dOM, feed intake, and LWGs decreased from July to September. However, in 2006, dOM, MEI, and LWGs across both systems were lower in September than in July, whereas the differences were not significant in 2005, 2007 (except LWGs), and 2008. This was most likely due to greater HA 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 grazing season.

If ROT is only beneficial at high stocking rate and low HA (Warner and Sharrow 1984), one would expect that feed intake and performance of animals might be greater at ROT than at CON towards the end of the grazing season when HM and herbage quality decline. An interaction between grazing system and month was observed for LWGs. Across the four study years, LWGs of CON sheep was lower in September than in July, whereas no difference in animal performance was found between the two months at ROT. The latter was mainly due to the LWGs of ROT 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, ROT was superior to CON 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 HM on offer in 2007 and 2008, and the similar decreases in herbage quality at both systems might have hampered the beneficial effect of ROT on feed intake and LWGs at the end of the grazing season.

## **2.6 Conclusions**

Results of four study years showed that herbage quality, feed intake, and LWG of

sheep grazing the Inner Mongolian steppe at a moderate grazing intensity is inferior at ROT than at CON. However, higher energy intake in CON did not result in a corresponding increase in LWG, 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. 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 behavior, and the moderate grazing intensity appear to hamper any beneficial effect of ROT on pasture vegetation and sheep performance. Hence, further studies are required to test whether a ROT system is superior at grazing intensities higher than those used in our study.

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*Chapter 3*

**The effect of grazing system on feed intake and performance  
of sheep in a semi-arid grassland steppe**

Submitted to Agricultural Systems

### **3 The effect of grazing system on feed intake and performance of sheep in a semi-arid grassland steppe**

#### **3.1 Abstract**

Many studies evaluated the effects of different grazing management systems (GS) on biomass production and the nutritional quality of the rangeland vegetation in semi-arid regions of the world. However, less work has been done regarding their effects on diet digestibility, feed intake, and performance of grazing livestock. We therefore analyzed digestibility of ingested organic matter (dOM), organic matter intake (OMI), and live weight gain (LWG) of sheep grazing at two different GS's and determined whether GS effects may vary between grazing intensities (GI) due to differences in the amount and quality of herbage on offer. A grazing experiment was established in the Inner Mongolian steppe of China (E116°42', N43°38') in spring 2005. Two GS's were tested at six different GI's from very light to very heavy grazing. While in the alternating grazing system, grazing and hay-making were alternated annually between two adjacent plots, sheep grazed the same plots every year in the continuous grazing system. In July, August, and September 2009 and 2010, four sheep per plot were selected to determine feces excretion on 5 d per month using the external marker titanium dioxide, while dOM was estimated from fecal crude protein concentrations. OMI was calculated and sheep were weighed at the beginning of each month to determine their LWG.

GS did not affect dOM ( $P = 0.101$ ), OMI ( $P = 0.381$ ), and LWG of sheep ( $P = 0.701$ ). Across both GS's LWG decreased from 98 g/d at GI1 to 62 g/d at GI6 ( $P < 0.001$ ;  $R^2 = 0.42$ ). Nevertheless, there were no significant interactions between GS and GI for all measured parameters ( $P \geq 0.061$ ), indicating that differences between GS's were similar at all GI's and that alternating grazing was not able to compensate for the negative effects of very high GI on animal performance. In summary, our study showed that irrespective of GI alternating grazing does not increase dOM, OMI,

and hence, LWG of sheep in this environment even after four years of grazing. Nevertheless, in the long term, improvements in the productivity and feeding value of the steppe vegetation by an alternating pastoral grassland use might enhance revenues and ecological sustainability when compared to the common practice of continuous grazing at very high stocking rates.

### **3.2 Introduction**

Grazing system (GS) is considered 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's were conceptualized. Their main aims are (i) to maintain rangelands in a productive state and (ii) to make 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 and nutrients to the rangelands in grazing years through the disposal of animal feces and urine (Owens et al., 1989). 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 at ALT than at 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 than the presented study, Schönbach et al. (2011) determined a higher above-ground net primary production (ANPP) of the grassland steppe in Inner Mongolia at ALT than at CON at heavy grazing intensities (GI).

Moreover, Wan et al. (2011) concluded that above-ground biomass of the herbage species preferably grazed by sheep was less affected by moderate to high GI at ALT than at CON. Instead, few studies were conducted to clarify the effects of ALT on grazing livestock, and most of them rather focused on measuring animal performance 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. We aimed to determine whether it can compensate for the negative effects of increasing GI and advancing plant maturation with proceeding vegetation period 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.

### **3.3 Materials and methods**

#### **3.3.1 Study area**

The study site (116°42'E, 43°38'N) is located in the Xilin River Basin, Inner Mongolia Autonomous Region of China. The average altitude is approximately 1200 m above sea level. The semi-arid 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 3.1. The dominant soil type is a chestnut soil (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 yield of ANPP is 140 g dry matter (DM)/m<sup>2</sup> (Schönbach et al., 2011).

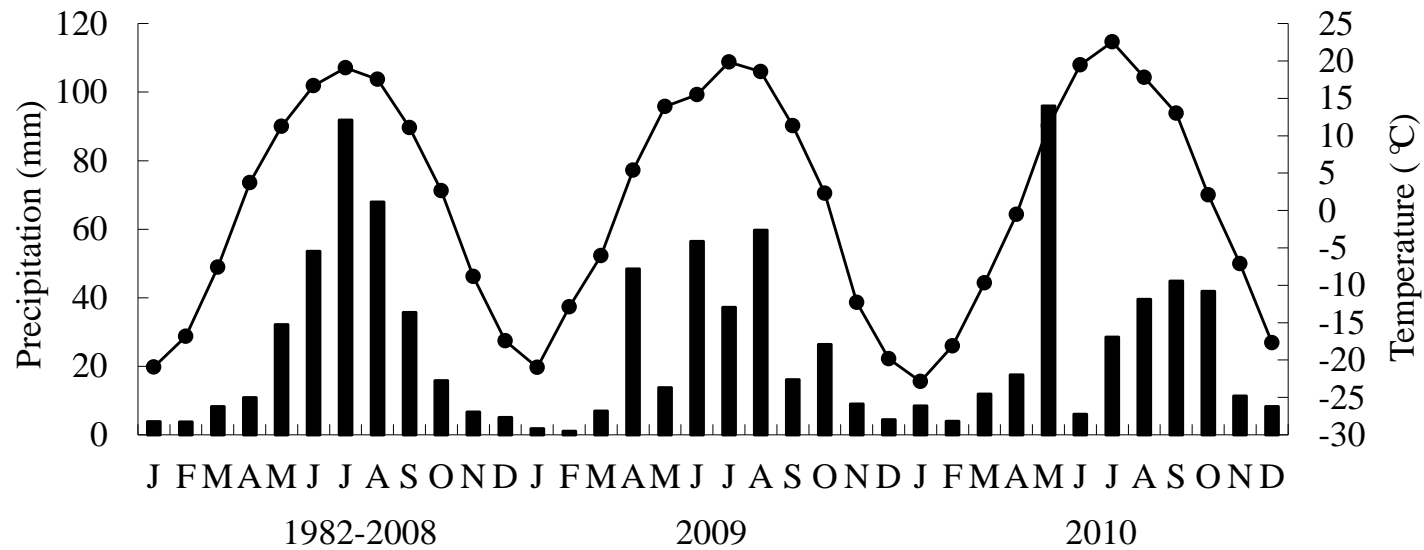


Figure 3.1 Monthly precipitation (mm, bars, primary y-axis) and mean monthly air temperature (°C, line and points, secondary y-axis) measured near the experimental area across 1982-2008 and in 2009 and 2010.

Livestock production has been and still is the main agricultural activity in Inner Mongolia. In the past, the land was extensively used for nomadic sheep production. Since 1950, the human population of the Xilingol league (202,580 km<sup>2</sup>) 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-folds from 1949 to 2000, so that the available grassland area decreased from 5 ha to 1 ha/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 disposal and thus nutrient inputs to the grassland may negatively affect its long-term productivity (Owens and Shipitalo, 2009; Schönbach et al., 2009).

### **3.3.2 Experimental design**

Two grazing experiments were conducted from mid of June to mid of September in 2009 and 2010 lasting for 92 d and 91 d, respectively. Outside of the grazing seasons, the grassland remained ungrazed. Two GS's 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. GI was defined by herbage allowance (HA) which will better describe GI than merely SR's, if herbage mass (HM) on offer strongly differs between experimental plots, years, or throughout the vegetation period (Sollenberger et al., 2005). 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/kg live weight (LW) for GI1 to GI6, respectively. The numbers of sheep per plot were adjusted to HM on offer at the middle of June, July, and August in order to maintain similar HA's across the grazing



seasons and in both study years. Details of the experimental scheme are given in Table 3.1. 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's · 6 GI's · 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.

### 3.3.3 Animals live weight gain

In 2009 and 2010, 315 and 337 female sheep of the Inner Mongolia fat-tailed breed were purchased from two local farmers. In both study years, the animals were about 15 months 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 ten days of adaptation, sheep were weighed again to determine their initial LW in the middle of June. Across all GI's and GS's, it averaged  $34.8 \pm 4.0$  and  $30.2 \pm 1.9$  kg LW in June 2009 and 2010, respectively.

All animals were weighed again on the 11th and 12th of July, August, and September. The mean LW of the two days was used to calculate their daily LWG during each month according to the following equation:

$$\text{LWG [g/d]} = (\text{LW}_m [\text{kg}] - \text{LW}_{m-1} [\text{kg}]) / \text{D}_m \cdot 1000,$$

where LW is the mean LW of the two weighings per month and D the number of days between weighing dates. m and m-1 indicate two consecutive months (June, July, August, and September). Daily LWG per hectare (LWG<sub>h</sub>, g/ha) was calculated by multiplying the mean LWG of individual sheep (LWG<sub>s</sub>, g/d) by the SR (sheep/ha) in

the respective plot.

Table 3.1 Mean live weight (LW) of sheep in the beginning of grazing season, stocking rates (SR), 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).

Parameter	GS	Grazing intensity						SE	Mean	SEM
		1	2	3	4	5	6			
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	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 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	ALT	1144	968	882	916	662	660	39	872	22
	CON	2103	1801	1443	893	752	426	93	1236	77
	Mean	1624	1384	1162	905	707	543	52	1054	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

ADF, 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; SEM, standard error of mean.

For further descriptions of the GS and grazing intensity treatments see text.

### 3.3.4 Herbage allowance

Standing herbaceous biomass was determined by cutting the sward at 1 cm above ground level within a 2.0 m · 0.25 m-frame in three representative areas per plot. The collected herbage material was oven-dried for 24 h at 60 °C and weighed to determine its DM content. Subsequently, HA's were calculated according to the formula given by Sollenberger et al. (2005):

$$\text{HA [kg DM/kg LW]} = (\text{SB}_1 \text{ [kg DM]/LW}_1 \text{ [kg]} + \text{SB}_2 \text{ [kg DM]/LW}_2 \text{ [kg]})/2,$$

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.

### 3.3.5 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 organic matter (FOM) excretion. FOM excretion was determined using the external marker titanium dioxide (TiO<sub>2</sub>) assuming a fecal recovery rate of 100% (Glindemann et al., 2009a). For this, one gelatin capsule filled with 2.5 g TiO<sub>2</sub> (electronic balance with 0.001 g accuracy) was orally administered to the four sheep per plot each day for the first ten days 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 sub-samples. One sub-sample was oven-dried at 60 °C for 48 h, milled by a mixer, and used to determine fecal TiO<sub>2</sub> concentration according to procedures described by Glindemann et al. (2009a). The other sub-sample 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).

dOM was estimated from CP ( $= N \cdot 6.25$ ) in FOM according to the non-linear regression equation given by Wang et al. (2009b):

$$\text{dOM [\%]} = 89.9 - 64.4 \cdot \exp(-0.5774 \cdot \text{CP[g/kg FOM]}/100)$$

Subsequently OMI of sheep was calculated using the following equation:

$$\text{OMI [g/d]} = \text{FOM [g/d]} / (100 - \text{dOM [\%]}).$$

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 of Aiple et al. (1992) :

$$\text{ME [MJ/kg organic matter]} = -0.9 + 0.170 \cdot \text{dOM [\%]}.$$

### 3.3.6 Statistical analysis

In total, 144 observations (2 GS's  $\cdot$  6 GI's  $\cdot$  2 plots  $\cdot$  2 years  $\cdot$  3 months) were obtained for all parameters. Data were analyzed using the Mixed Model procedure of SAS version 9.2 (SAS Institute Incorporated, Cary, NC, USA) to test for the effects of GS, GI, year, month, and their interactions. The following model was used:

$$y_{ijkl} = \mu + \text{GS}_i + \text{GI}_j + \text{YE}_k + \text{M}_l + \text{GS} \times \text{GI}_{ij} + \text{GS} \times \text{YE}_{ik} + \text{GS} \times \text{M}_{il} + \text{GI} \times \text{YE}_{jk} + \text{GI} \times \text{M}_{jl} + \text{YE} \times \text{M}_{kl} + \text{GS} \times \text{GI} \times \text{YE}_{ijk} + \text{GS} \times \text{YE} \times \text{M}_{ikl} + \text{GI} \times \text{YE} \times \text{M}_{jkl} + e_{ijkl},$$

where  $\mu$  is the overall mean,  $\text{GS}_i$  the grazing system ( $i = \text{ALT}$  and  $\text{CON}$ ),  $\text{GI}_j$  the grazing intensities ( $j = 1, 2, 3, 4, 5,$  and  $6$ ),  $\text{YE}_k$  the year ( $k = 2009$  and  $2010$ ),  $\text{M}_l$  the month ( $l = \text{July, August, and September}$ ), 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 co-variance 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 a total number of 24 observations for each parameter. Moreover, regression analysis were performed separately for each year using the mean values across the three months ( $n = 12$ ).

### 3.4 Results

#### 3.4.1 Effects of grazing system and grazing intensity

The effects of GS and GI on measured parameters are presented in Table 3.2. GS did not affect dOM ( $P = 0.101$ ), OMI ( $P = 0.381$ ), DOMI ( $P = 0.209$ ), and MEI ( $P = 0.195$ ) as well as LWGs ( $P = 0.701$ ) and LWGh ( $P = 0.390$ ).

Mean dOM across both GS's, both years, and all months ranged from 0.546 at GI4 to 0.562 at 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 3.3). Moreover, no differences between GI's were determined for OMI ( $P = 0.327$ ), DOMI ( $P = 0.266$ ), and MEI ( $P = 0.258$ ). Although daily LWGs linearly decreased ( $P < 0.001$ ,  $R^2 = 0.42$ ), daily LWGh increased with increasing SR ( $P < 0.001$ ,  $R^2 = 0.80$ ). However, the decrease in LWGs 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 3.2).

Chapter 3 Effects of alternating and continuous grazing system

Table 3.2 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) at different grazing intensities (GI) in 2009 and 2010 (Least squares means; n = 12).

Parameter	GS	GI						SE	Mean	SEM	P-value*		
		1	2	3	4	5	6				GS	GI	GS×GI
SR, sheep/ha	ALT	1.9	3.9	4.8	6.3	8.5	10.2	0.1	6.0				
	CON	2.4	4.4	5.8	7.0	8.9	10.2	0.2	6.4				
	Mean	2.2	4.2	5.3	6.6	8.7	10.2	0.2	6.2	0.2			
HA, kg DM/kg LW	ALT	15.6	6.8	4.8	3.9	2.0	1.8	2.3	5.8				
	CON	22.1	10.8	6.6	3.2	2.4	1.1	3.5	7.7				
	Mean	18.9	8.8	5.7	3.6	2.2	1.5	2.1	6.8	1.4			
dOM	ALT	0.563	0.550	0.558	0.549	0.555	0.555	0.003	0.555				
	CON	0.552 <sup>ab</sup>	0.544 <sup>a</sup>	0.544 <sup>a</sup>	0.543 <sup>a</sup>	0.551 <sup>ab</sup>	0.569 <sup>b</sup>	0.003	0.551				
	Mean	0.557 <sup>ab</sup>	0.547 <sup>a</sup>	0.551 <sup>ab</sup>	0.546 <sup>a</sup>	0.553 <sup>ab</sup>	0.562 <sup>b</sup>	0.002	0.553	0.006	0.101	<b>0.010</b>	0.061
OMI, g/kg <sup>0.75</sup> 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
DOMI, g/kg <sup>0.75</sup> 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	0.21	0.209	0.266	0.405
MEI, MJ/kg <sup>0.75</sup> 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	0.03	0.195	0.258	0.456
LWGs, g	ALT	105	79	87	92	73	69	6	84				
	CON	91	94	92	87	72	55	5	82				
	Mean	98 <sup>b</sup>	86 <sup>b</sup>	89 <sup>b</sup>	89 <sup>b</sup>	72 <sup>ab</sup>	62 <sup>a</sup>	4	83	13	0.701	<b>0.003</b>	0.501
LWGh, g/ha	ALT	199 <sup>a</sup>	305 <sup>ab</sup>	416 <sup>abc</sup>	573 <sup>bc</sup>	595 <sup>bc</sup>	678 <sup>c</sup>	44	461				
	CON	223 <sup>a</sup>	410 <sup>ab</sup>	515 <sup>ab</sup>	630 <sup>b</sup>	623 <sup>b</sup>	570 <sup>b</sup>	38	495				
	Mean	211 <sup>a</sup>	357 <sup>ab</sup>	465 <sup>bc</sup>	601 <sup>c</sup>	609 <sup>c</sup>	624 <sup>c</sup>	29	478	96	0.390	<b>&lt; 0.001</b>	0.660

<sup>a, b, c</sup> Within rows means without a common superscript differ at  $P \leq 0.05$ .

\* Effects in bold characters were significant at  $P \leq 0.05$ .

There were no significant differences ( $P > 0.05$ ) between ALT and CON at the same GI for any of the measured parameters.

GS, grazing system; HA, herbage allowance; LW, live weight; ; SE, standard error; SEM, standard error of mean; SR, stocking rate.

Table 3.3 Parameters of the linear and non-linear 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) at an alternating (ALT) and continuous (CON) grazing system in 2009 and 2010.

Parameter	Grazing system	Type of regression	a	b	c	P-value*	adjusted R <sup>2</sup>
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)	< <b>0.001</b>	0.80
	Mean	Quadratic	0.0001 (0.001)	-0.009 (0.003)	0.575 (0.008)	<b>0.007</b>	0.31
OMI, g/kg <sup>0.75</sup> 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/kg <sup>0.75</sup> 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)	<b>0.029</b>	0.33
	CON	Linear	-	-4.32 (1.37)	110.2 (9.8)	<b>0.010</b>	0.45
	Mean	Linear	-	-3.90 (0.93)	107.1 (6.3)	< <b>0.001</b>	0.42
LWGh, g/ha	ALT	Linear	-	59.5 (7.4)	109.3 (48.2)	< <b>0.001</b>	0.85
	CON	Linear	-	47.6 (11.6)	180.9 (82.4)	<b>0.002</b>	0.69
	Mean	Linear	-	53.7 (6.6)	142.3 (44.9)	< <b>0.001</b>	0.74

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

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

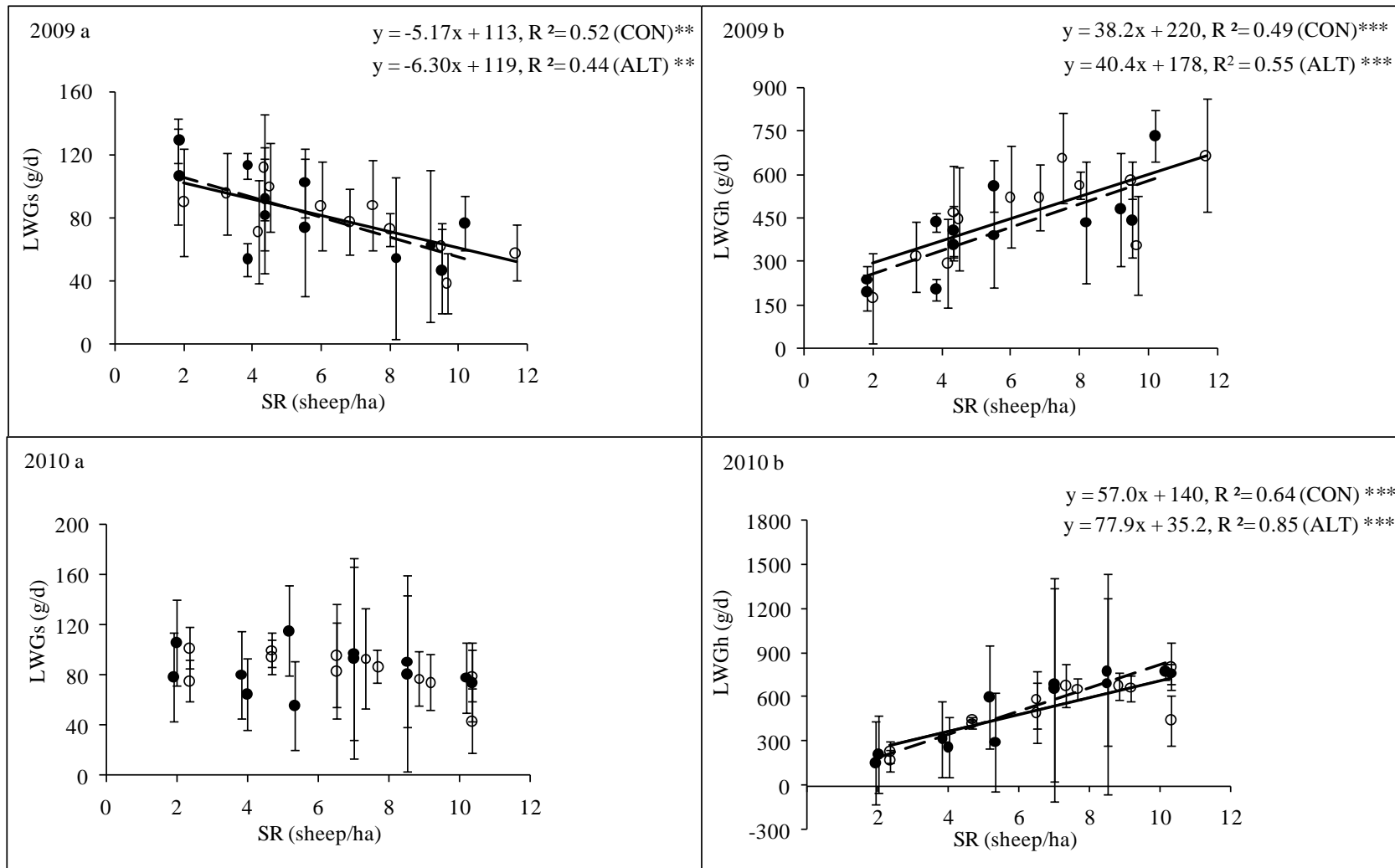


Figure 3.2 Linear relationships between stocking rate (SR; independent variable) and live weight gain (LWG) of individual sheep (LWGs, a; dependent variable) and per hectare (LWGh, b; dependent variable) in 2009 and 2010. Circles (○) and points (●) represent the mean LWGs and LWGh at continuous (CON) and alternating (ALT) grazing, respectively, across the entire grazing seasons. Bars indicate standard errors from the means. “—” and “- - -” indicate the linear regression lines for CON and ALT, respectively. \*, \*\*, and \*\*\* highlight regressions that are significant at a level of  $P \leq 0.05$ ,  $P \leq 0.01$ , and  $P \leq 0.001$ , respectively. The regression analysis is not significant in 2010a.



Interactions between GS and GI for feed intake ( $P \geq 0.112$ ) and performance parameters did not occur ( $P \geq 0.501$ ; Table 3.2). However, a tendency of an interaction between GS and GI was observed for dOM ( $P = 0.061$ ). While dOM was similar at all GI treatments at ALT ( $P \geq 0.605$ ), it was higher at GI6 (0.569) than at GI2 – GI4 (0.543 – 0.544;  $P \leq 0.011$ ) at 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, 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 at both GS's and all GI treatments.

### 3.4.2 Effects of year and month

Across both GS's 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/kg<sup>0.75</sup> LW, and 0.71 MJ/kg<sup>0.75</sup> LW, respectively, and higher than in 2010 when corresponding values averaged 0.533 ( $P < 0.001$ ), 67.6 g/kg<sup>0.75</sup> LW ( $P < 0.001$ ), and 0.55 MJ/kg<sup>0.75</sup> LW ( $P < 0.001$ ). However, at 81 g/d (2009) and 84 g/d (2010), no difference in LWGs was found between years ( $P = 0.600$ ). Daily LWGh was lower in 2009 (437 g/ha) than in the 2010 (519 g/ha;  $P = 0.022$ ) due to slight differences in the mean SR.

All parameters were affected by month ( $P < 0.001$  for all measured parameters; Table 3.4). dOM, OMI, and MEI were higher in July than in September ( $P < 0.001$  for all three parameters). Correspondingly, a higher daily LWGs and LWGh were found in July (115 g, 678 g/ha) than in September (46 g, 230 g/ha;  $P < 0.001$  for both parameters).

Table 3.4 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).

Parameter	GS	Month			SE	Mean	SEM	<i>P</i> -value*						
		Jul.	Aug.	Sept.				M	YE	M×YE	GS×M	GS×YE	GI×YE	GI×M
SR, sheep/ha	ALT	5.8	5.9	6.0	0.3	6.0								
	CON	6.1	6.5	6.8	0.3	6.4								
	Mean	6.0	6.2	6.4	0.2	6.2	0.1							
HA, kg DM/kg LW	ALT	6.2	6.4	4.9	0.2	5.8								
	CON	9.0	8.1	5.9	0.2	7.7								
	Mean	7.6	7.3	5.4	0.2	6.8	0.2							
dOM	ALT	0.566 <sup>b</sup>	0.554 <sup>a</sup>	0.545 <sup>a</sup>	0.002	0.555								
	CON	0.562 <sup>b</sup>	0.547 <sup>a</sup>	0.542 <sup>a</sup>	0.002	0.551								
	Mean	0.564 <sup>b</sup>	0.551 <sup>a</sup>	0.544 <sup>a</sup>	0.002	0.553	0.004	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.860	0.054	0.086	0.340
OMI, g/kg <sup>0.75</sup> LW	ALT	81.2 <sup>b</sup>	74.7 <sup>b</sup>	67.1 <sup>a</sup>	1.5	74.3								
	CON	80.7 <sup>b</sup>	71.1 <sup>a</sup>	66.8 <sup>a</sup>	1.3	73.0								
	Mean	80.9 <sup>c</sup>	73.2 <sup>b</sup>	66.9 <sup>a</sup>	1.0	73.7	2.53	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.689	0.764	<b>0.027</b>	0.938
DOMI, g/kg <sup>0.75</sup> LW	ALT	46.2 <sup>c</sup>	41.1 <sup>b</sup>	36.8 <sup>a</sup>	0.98	41.5								
	CON	45.5 <sup>b</sup>	39.2 <sup>a</sup>	36.4 <sup>a</sup>	0.87	40.4								
	Mean	45.8 <sup>c</sup>	40.3 <sup>b</sup>	36.6 <sup>a</sup>	0.66	40.9	1.48	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.674	0.454	<b>0.015</b>	0.862
MEI, MJ/kg <sup>0.75</sup> LW	ALT	0.71 <sup>c</sup>	0.64 <sup>b</sup>	0.57 <sup>a</sup>	0.02	0.64								
	CON	0.70 <sup>b</sup>	0.60 <sup>a</sup>	0.56 <sup>a</sup>	0.01	0.62								
	Mean	0.71 <sup>c</sup>	0.62 <sup>b</sup>	0.56 <sup>a</sup>	0.01	0.63	0.02	< <b>0.001</b>	< <b>0.001</b>	< <b>0.001</b>	0.684	0.421	<b>0.014</b>	0.945
LWGs, g	ALT	114 <sup>c</sup>	87 <sup>b</sup>	50 <sup>a</sup>	6	84								
	CON	116 <sup>c</sup>	88 <sup>b</sup>	42 <sup>a</sup>	5	82								
	Mean	115 <sup>c</sup>	87 <sup>b</sup>	46 <sup>a</sup>	4	83	9	< <b>0.001</b>	0.600	0.474	0.647	0.843	0.664	0.173
LWGh, g/ha	ALT	682 <sup>b</sup>	413 <sup>b</sup>	218 <sup>a</sup>	44	461								
	CON	674 <sup>b</sup>	569 <sup>b</sup>	242 <sup>a</sup>	38	495								
	Mean	678 <sup>c</sup>	526 <sup>b</sup>	230 <sup>a</sup>	29	478	48	< <b>0.001</b>	<b>0.010</b>	0.178	0.617	0.416	0.249	< <b>0.001</b>

<sup>a,b,c</sup> Within rows means without a common superscript differ at  $P \leq 0.05$ . There were no significant differences ( $P \leq 0.05$ ) between ALT and CON.

\* Effects in bold characters were significant at  $P \leq 0.05$ . None of the effects of the triple interactions between GS, GI, YE, and M were significant at  $P \leq 0.05$  and were thus not included in the table. Aug., August; GI, grazing intensity; GS, grazing system; HA, herbage allowance; Jul., July; LW, live weight; M, month; ; SE, standard error; SEM, standard error of mean; Sept., September; SR, stocking rate; YE, year.

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). While 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).

### **3.5 Discussion**

#### **3.5.1 Effect of grazing system**

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, litter accumulation of the steppe vegetation at ALT grazing (defined as “mixed grazing” in their study), in particular at very high GI. However, the number of sheep was adjusted to HM on offer to maintain similar HA’s between GS’s, study years, and across the grazing seasons. Moreover, GS did not affect chemical composition of the pasture plants in 2005 and 2006 (Schönbach et al., 2009) and herbage CP, ME, neutral detergent fiber, and acid detergent fiber concentrations were also very similar at both GS’s in the present study (Table 3.1). Altogether, this might explain why no differences in dOM, OMI, and hence, MEI and LWGs were found between ALT and CON sheep. To our knowledge, little information is available in literature on the effect of GS on dOM and OMI of grazing ruminants. The lack of a GS effect on LWGs confirms results of Lin et al. (2012) who analyzed the performance of sheep at both GS’s within the frame of the same research project during 2005 – 2009. The authors suggested that LWGs was similar at ALT and CON because of similar digestibility and nutrient concentrations of the herbage on offer and the monthly adjustment of SR’s at both GS’s. Similarly, Allan (1997) found no differences between GS’s 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 six years was too short to clearly establish GS effects on herbage and thus, animal performance. 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 North-Eastern Israel. Altogether, this might explain why the expected advantage of ALT was not found in our study.

Across both study years and all GI's, HM on offer was 42% higher at CON than at ALT. However, this did not lead to a higher LWGh, since mean SR's were only slightly different between CON ( $6.5 \pm 0.3$  sheep/ha) and ALT ( $5.9 \pm 0.3$  sheep/ha). The lower HM on offer across all GI's at ALT was solely due to differences in HM at GI1 – 3. As a consequence, HA's at these GI's were higher at ALT than at CON. Nevertheless, they were within the defined HA classes (except GI3) so that effects of the higher HA's at ALT on the measured parameters appear unlikely.

### **3.5.2 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 at very high GI with low HM on offer, ALT is not superior to CON. Results contradict conclusions drawn in earlier studies within the frame of the same research project. Schönbach et al. (2012) found that LWGs clearly decreased with increasing SR at CON in 2005 and 2006. Instead, Müller et al. (2012) reported that LWGs of ALT sheep only decreased with increasing SR in 2005 when annual rainfall was very low, whereas in 2006 and 2007, it was similar at all GI's. The authors therefore speculated that ALT might have mitigated the negative effects of heavy GI on LWGs. Likewise, increasing SR strongly reduced ANPP at CON in 2005 – 2008, whereas grassland at ALT appeared to be more resilient to heavy grazing (Schönbach et al., 2011). Moreover, above-ground 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 at high than at moderate to low GI's at CON in July 2005 – 2009 (Wan et al., 2011). Instead GI did not affect above-ground biomass of this species at ALT (Wan et al., 2011). Hence, ANPP and botanical composition data underline the advantage of ALT grassland use.

Despite a strong decline in HA with increasing GI, there were only minor or no effects of GI on dOM, OMI, and MEI of sheep, neither at ALT nor at CON. Moreover, no significant relationships between SR and digestibility and intake parameters were determined according to the regression analyses for both GS's. 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 at different HA's (Garcia et al., 2003). Altogether this explains why no differences between GI's in dOM and feed intake of sheep and thus, no interactions between GI and GS were found for these parameters.

Nevertheless, a strong decline in LWGs with increasing SR was observed at both GS's in 2009, indicating elevated ME requirements for grazing activities of sheep at higher GI's in this year (Animut et al., 2005; Lin et al., 2011). Such decreases in LWGs were not observed in 2010 or in most of the previous study years within the research project (Müller et al., 2012; Schönbach et al., 2012) which was related to differences in the amount and distribution of annual precipitation and hence, the quantity and quality of herbage re-growth during the grazing season (Bai et al., 2008; Schönbach et al., 2009). Despite the clear decline in LWGs with increasing GI in 2009, no effects of the interactions between GS and GI or GS, GI, and year were determined for LWGs and LWGh. Moreover, estimates of the intercept values and slopes of the linear regressions were almost identical at both GS's which not only contradicts our hypothesis and the conclusions drawn by Müller et al. (2012) 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's 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's on animal performance. This underlines that changes in the rangeland vegetation 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.

### **3.5.3 Effect of month**

Due to advanced plant maturation, limited plant re-growth (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., 2012) in the same project and Garcia et al. (2003) who analyzed dOM and OMI of sheep in a semi-arid highland area in Central France. As a consequence, LWGs and LWGh strongly declined from July to September. 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). Since HA's was 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, increased ground cover and hence, soil water contents might not only enhance overall

nutritional quality of the grassland vegetation, but also lower the rate of plant maturation (Ferraro and Oesterheld, 2002; Schönbach et al., 2011).

### 3.6 Conclusions

ALT grazing does not improve feed intake and LWG of sheep grazing semi-arid 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 comprehensively evaluate GS effects in pastoral ecosystems. 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.

### 3.7 References

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*Chapter 4*

General discussion

## **4 General discussion**

### **4.1 Grazing management systems**

Application of improved and adapted management techniques may alter current livestock grazing systems and thereby ensure the sustainability of rangeland use (Bailey, 2004). Besides stocking rate (SR), supplementation, duration of grazing period, fertilization, and burning, grazing system (GS) is also considered as a main management tool that can enhance grassland production and animal performance. However, as mentioned in Chapter 1.4, results of previous studies about effects of GS on herbage and animal parameters are inconsistent (Table 4.1). The concern of the present thesis is the comparison of rotational (ROT; Chapter 2) and alternating (ALT; Chapter 3) grazing with continuous (CON) grazing, respectively. The study aims to identify important factors which define a suitable grazing system to maintain or even increase long term animal productivity but without reducing grassland productivity in the Inner Mongolian steppe. Digestibility of ingested herbage (dOM), feed intake, and live weight gain (LWG) of animals were measured in the present study. Combing the results of presented and previous studies that evaluated GS effects (Table 4.1), we conclude that SR, climate conditions, the animals' age and species, and the duration of practicing a specific GS might influence the extent of these effects.

Table 4.1 Literature review of studies that compared different grazing systems with the continuous grazing system.

Author	Year	GS	Duration		SR	Annual rainfall	Species	Age	Study site	Digestibility of ingested herbage (%)	OMI (g/sheep/d)	LWG (g/sheep/d)	Milk (kg/animal/d)	HM (DM/m <sup>2</sup> )
			Year	M	(animal/ha)	(mm)		month						
Clarke et al.	1943	ALT, CON	-	-	-	~334	cattle	-	Alberta and Saskatchewan, Canada	-	-	-	-	ALT>CON
Campling et al.	1958	STR, CON	2	4	-	-	cow	-	-	-	-	-	STR=CON	-
Holmes and Osman	1960	STR, CON	1	4	-	-	cow	-	-	STR=CON	STR<CON	STR=CON	STR=CON	-
Reardon and Merrill	1976	ALT, CON	20	-	-	~700	sheep/ cattle	-	Texas, USA	-	-	-	-	ALT>CON
Jamieson and Hodgson	1979	STR, ROT	3	1.5	-	-	calve	4-9	Alaska, USA	-	-	-	STR=CON	-
Warner and Sharrow	1984	ROT, CON	3	-	-	530	ewe	-	Oregon, USA	-	-	ROT=CON	-	ROT=CON
Hodgson	1985	TLG, CON	-	-	-	-	-	-	-	-	TLG<CON	TLG>CON	-	-
Holechek et al.	1987	ALT, CON	5	4	2.5	530	heifer	12	Oregon, USA	ALT=CON	-	ALT=CON	-	-

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Grant et al.	1988	ALT, CON	-	-	-	-	sheep	-	-	-	-	-	-	ALT=CON
Heitschmidt et al.	1990	ALT, CON	4	12	5.3	~700	cow/ calf	-	Texas, USA	-	-	ALT=CON	-	-
Dowling et al.	1996	ALT, CON	6	-	5-7	~600	sheep/ cattle	-	New South Wales, Australia	-	-	-	-	ALT>CON
Hafley	1996	ROT, CON	2	3	3.0, 6.0	~1526	steer	12	Louisiana, USA	ROT<CON	-	ROT<CON	-	-
Allan	1997	ROT, ALT, CON	6	6	1.9, 3.0, 4.1	500	wether	12	New Zealand	-	-	ROT=ALT =CON	-	ROT>ALT =CON
Popp et al.	1997	ROT, CON	3	-	2.2, 1,1	~ 450	cattle	-	Brandon, Canada	-	ROT=CON	-	-	ROT=CON
Virgona et al.	2000	ROT, CON	3	12	-	>600	sheep	-	New South Wales and Victoria, Australia	-	-	-	-	ROT>CON
Davies et al.	2001	ALT, CON	3	-	-	580	ewe	-	Bakers Hill, Western Australia	-	-	ALT=CON	-	ALT>CON
Lodge et al.	2003	ALT, CON	4	12	4.0, 6.0, 8.0	~689	wether	-	New South Wales, Australia	-	-	-	-	ALT>CON
Alvarez-Rodriguez et al.	2007	RAT, CON	1	3	-	-	ewe/ lamb	-	Spain	-	-	RAT>CON	RAT=CON	-

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Briske et al.	2008	ROT, CON	-	-	-	-	sheep/ cattle	-	-	-	-	ROT≤CON	-	-
Derner et al.	2008	ROT, CON	16	4	0.2, 0.3, 0.4	381	steer	12	Wyoming, USA	-	-	ROT<CON	-	-
Joy et al.	2008	RAT, CON	1	4	-	-	ewe/ lamb	-	Spain	-	-	-	RAT=CON	-
Schönbach et al.	2009	ALT, CON	2	3	1.5–9.0	330	ewe	15	Inner Mongolia, China	-	-	-	-	ALT=CON
Wang et al.	2009	ROT, CON	2	3	4.5	330	ewe	15	Inner Mongolia, China	ROT<CON	ROT<CON	ROT=CON	-	ROT=CON
Miller et al.	2010	ROT, CON	1	1.5	-	-	lamb	-	Tasmania, Australia	-	-	ROT=CON	-	-
Nie and Zollinger	2011	ALT, CON	5	12	-	451	sheep	-	Southern Australia	-	-	-	-	ALT>CON

ALT, alternating grazing; CON, continuous grazing; DM, dry matter; GS, grazing system; HM, herbage mass; LWG, live weight gain per animal; OMI, organic matter intake; ROT, rotational grazing; SR, stocking rate during the study period; STR, strip grazing; TLG, time limited grazing.



According to results of Chapter 2, ROT is inferior to CON at a moderate SR ( $4.2 \pm 0.3$  sheep/ha) regarding herbage mass and chemical compositions of herbage on offer, as well as feed intake and LWG of individual sheep. SR is frequently discussed as an important factor determining the effects of GS on herbage quality and production, and thus animal performance (Hacker and Richmond, 1994; Simon et al., 1995; Schönbach et al., 2009; Schönbach et al., 2011). Due to the fact that relative growth rate of herbage production increases with increasing SR (Schönbach et al., 2011), the positive effects of resting periods regarding herbage regrowth as well as animal production might be impaired when a low SR is used (Warner and Sharrow, 1984). This seems to be the reason why LWG of individual sheep was lower at ROT than at CON at relative lower SR in the present study. Similarly, Allan (1985, 1997) reported that herbage regrowth and animal performance increased with increasing SR at ROT. Warner and Sharrow (1984) stated that LWG of animal was higher at ROT than at CON plots at a higher SR, while they were identical at both systems at a lower SR (see Table 4.1). Information given by the publications were used to explain why ROT was identical or even inferior to CON in the first experiment with 4.2 sheep/ha. Likewise, no positive effect of ALT on feed intake and LWG at high SR were observed in the second experiment while above-ground net primary production (ANPP) was higher at ALT than at CON at a moderate to heavy SR (Schönbach et al., 2011). Therefore, it is concluded that the effect of SR on animal performance vary between different GS.

Besides SR, amount of rainfall is another important factor which influences the system effects. Many studies have shown positive effects of rainfall on herbage production (Fynn and O'Connor, 2000; Patton et al., 2007; Bai et al., 2008; Schönbach et al., 2009) and herbage quality (Schönbach et al., 2009) on semi-arid grasslands. However, Heitschmidt et al. (1987) reported that herbage quality in rest areas at ROT might decrease at higher rainfall than the average of 682 mm due to the lack of continuous forage removal. This might have led to a high proportion of mature and dead herbage (Heitschmidt et al., 1987). Furthermore, herbage regrowth is limited

by a low rainfall. Therefore, it is evident that positive effects of ROT on herbage quality and thus, animal feed intake and LWG might vary between years due to the different amounts of precipitation. The results were consistent with our finding that metabolizable energy content of herbage and LWG of sheep were lower at ROT than at CON in the last study year at a relatively high annual rainfall (389 mm; average rainfall of other three years was 266 mm), while LWG was identical at both GS in the previous three study years. In the last year, higher precipitation increased regrowth of herbage by grazing and thus was less mature in CON plots. Hence, herbage quality was lower at ROT than at CON, which caused a lower LWG at ROT. Similarly, lower LWG of cattle was observed at ROT than at CON in Louisiana, USA at annual rainfall of 1526 mm (Halfey, 1996). Hence, level of rainfall is an important factor for herbage production but not the sole main determinant for dOM, feed intake, and LWG of animals.

According to Manley et al. (1997), longer time periods are necessary to indicate plant botanical composition changes caused by grazing on rangelands. However, most of the studies evaluating that herbage quality and quantity and performance of grazing animals at different GS's were conducted for a relatively short term of three to five years (see Table 4.1). Perhaps the positive effects of specialized GS's may become manifest after long term grazing (Derner et al., 2008). Hence, Reardon and Merrill (1976) reported that ALT increased the herbage production after 20 years of grazing sheep and cattle, which is probably due to the recovery phases for grazed swards and the seed production during un-grazed years (Derner et al., 2008). This argument was used to explain why no differences in LWG (Allan, 1997) and herbage mass (Schönbach et al., 2009) were found between ALT and CON in the six- and the two-years study, respectively. Similarly, no positive effects of ALT on animal LWG in the present study (Chapter 3) might be caused by the short duration of experiment. Hence, the benefits of an ALT system on animal performance are expected after more study years due to a higher ANPP compared to CON plots. However, the experiment did not show any advantage of ROT on animal productivity due to the fact that herbage

production was identical between years. Furthermore, extended grazed periods per year must cause a lower herbage allowance due to a continuously reduction in herbage mass on offer, which will, decrease feed intake and LWG of animals. Therefore, not only the duration of grazing years but also the duration of grazing within a year might alter the GS effects. A relative long grazing period per year might more clearly show the advantage of resting periods in sophisticated GS.

NRC (1975) stated that the requirement for metabolizable energy for maintenance and growth differ according age and species. Furthermore, Blaxter and Wainman (1964) and Garrett et al. (1959) concluded that the utilization of energy for maintenance and gain were different between sheep and cattle. Moreover, the capability for selecting of plants and plant parts is different between animals (Grant et al., 1985) and Animut et al. (2005) showed that diets of goats contain higher proportions of forbs than in sheep. Similarly, Kitessa and Nicol (2001) stated that the greater ability of sheep for selection might explain why LWG of sheep were similar, whereas for cattle higher at ROT than at CON in a cattle-sheep-co-grazed temperate pasture. Therefore, the choice of animal species and age could affect the effects of GS on animal feed intake and LWG, irrespective of herbage botanical composition and herbage quality.

As discussed above, many factors may alter the effects of GS on herbage production and nutritional quality of herbage as well as feed intake and performance of grazing animals. Climate conditions in the studied ecosystem, the botanical composition of the grassland vegetation, the species and age of animal used, the SR, and the duration of grazing season should be considered when comparing GS effects. According to results of the present study and the literature review (Table 4.1), positive effects of sophisticated GS might be more pronounced under high SR, at a relative short duration of resting periods, and at long-term grazing.

### **4.2 Choice of measured parameters**

Schönbach et al. (2011) showed a higher ANPP of herbage at ALT grazing plots, however no improvements in dOM, feed intake as well as LWG of sheep were found after two years grazing in the present study (Chapter 3). Lower metabolizable energy concentration of herbage on offer was observed in 2008 while animal feed intakes were nearly identical (Chapter 2). Similarly, Davies et al. (2001) reported that herbage mass was higher at ALT than at CON while LWG of sheep was similar at both GS (Table 4.1). This might be explained by the ability of grazing animals to maintain their feed intake and thus, ingest enough energy for maintenance and growth by increasing grazing time (Animut et al., 2005; Lin et al., 2011) even at lower herbage allowances. Hence, animals may change their grazing behavior to compensate for the negative impacts of heavy grazing pressure. However, many studies compared effects of GS either on herbage (Clarke et al., 1943; Reardon and Merrill, 1976; Grant et al., 1987; Dowling et al., 1996) or on animal (Holechek et al., 1987; Heitschmidt et al., 1990) parameters while only in few studies both aspects were simultaneously considered (Table 4.1). Neither animal productivity nor ecological parameters can be ignored when a sustainable utilization of grasslands is intended.

### **4.3 Grazing systems for Inner Mongolia**

As mentioned in Chapter 1, degradation and desertification of grassland in the Inner Mongolian steppe increased in last five decades due to the increasing human population and thus the decrease in the available grassland area for grazing (Lu et al., 2005; Zhao et al., 2005; Jiang et al., 2006). Hence, the purpose of the project “Matter fluxes of grasslands in Inner Mongolia as influenced by stocking rate” was to test concepts discussed to affect a sustainable grassland utilization in Inner Mongolia. It could be shown that ANPP increased by 15% in response to an ALT grassland use when compared to CON grazing at moderate to heavy grazing intensity. Moreover, herbage ground cover was 35% higher at ALT than at CON under grazing intensity 6 after four study years (Schönbach et al., 2011). Similarly, ALT did not change the species composition of herbage on offer while the above biomass of *Leymus chinensis* Tzvel, one of the dominant species in the study area, declined with increasing SR in CON grazing plots (Wan et al., 2011). However, results presented in Chapter 3 did not

show any advantage of ALT regarding animal feed intake and performance. As discussed in section 4.2, herbage parameters cannot be ignored when considering long-term grasslands production. The positive effects of ALT on ANPP and herbage botanical composition were evidenced by previous data, which might lead to higher herbage allowances and herbage quality available for grazing. Therefore, although results in the present study did not show any positive effects of ALT on animal feed intake and LWG, it is still recommend that ALT systems should be applied in the Inner Mongolian steppe, since it may lead to higher LWG per area in the long-term due to preventing soil erosion compared to the current grassland use system. Herbage quality, dOM as well as animal feed intake and LWG were lower at ROT than at CON across the four years while herbage mass was similar at both GS (Chapter 2). Furthermore, it is discussed that grazing under higher SR might show the positive effects of ROT on animal performance. However, as mentioned in Chapter 1, increasing SR led to degradation and desertification of grassland in Inner Mongolia (Jiang et al., 2006). Hence, ROT cannot be seen as a sophisticated GS which to maintain or even increase long term grassland production and animal productivity in this region. It has to be mentioned that in addition to the factors discussed here, grazing time, SR, animal species and age, and climate conditions should be considered as well when sophisticated and region-specific GS are developed. Furthermore, the change of the GS solely is not sufficient to resolve the ecological problems in Inner Mongolia. Combing the grassland protection policies mentioned in Chapter 1 with a suitable GS may save the grassland and maintain agricultural production in the future.

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*Chapter 5*

**General conclusions**

## 5 General conclusions

Herbage quality, digestibility of ingested organic matter, feed intake, and live weight gain of sheep decreased at rotational (ROT) grazing system. This might be due to greater stocking densities at ROT paddocks, which might have limited the selected behavior of grazing sheep and thus reduced the nutritional quality of the diet. Results showed that ROT is not a suitable management system for the Inner Mongolian steppe to maintain or even increase herbage production and animal performance. Ground cover and above-ground net primary production (ANPP) of herbage were higher at alternating (ALT) than continuous (CON) grazing at a moderate to heavy grazing intensity. In contrast thereto, grazing effects on animal parameters were similar at both systems. The limited duration of the present studies, the variable distribution and amount of rainfall, and the relative short term duration might explain why the ALT neither improved feed intake and live weight gain of sheep nor compensated for the negative effects of moderate to high stocking rate on animal performance in 2009. It is recommended that ALT should be applied in the Inner Mongolian steppe due to the advantage of ALT on herbage ground cover, ANPP as well as botanical composition. By this, ALT may increase the long-term animal productivity. In view of previous literature, it is concluded that long term duration of grazing practice and sufficient precipitation are benefits to show the advantages of sophisticated grazing systems in Inner Mongolia. Moreover, a study should measure herbage and animal parameters simultaneously and be performed for a long duration to comprehensively compare the effects of different grazing systems.

*Chapter 6*

**Summary / Zusammenfassung**

## **6 Summary / Zusammenfassung**

### **Summary**

Increasing human population decreased the available grassland area per sheep in the Inner Mongolian steppe in last 60 years. Due to the sedentarization of nomadic families, grassland close to settlements is currently used for intensive sheep and cattle grazing, while distant areas are only used for hay-making in this region. The consequences of this grassland utilization change are the degradation and desertification of the Inner Mongolian steppe. World-wide, grassland managers considered that sophisticated grazing management systems (GS) are an important tool for maintaining or even increasing long-term grassland production and animal performance. Therefore, many studies compared herbage production, herbage quality, and change of species composition at sophisticated GS with continuous (CON) grazing. However, few studies measured the influence of GS on digestibility of ingested herbage organic matter (dOM) and feed intake or only evaluated live weight gain (LWG) of animals. Hence, the main objectives of the thesis were to analyze effects of GS on dOM, organic matter intake (OMI), and LWG of grazing sheep in the Inner Mongolian steppe.

Two sophisticated GS's, a rotational (ROT) and an alternating (ALT) GS, were tested with regard to their effects on dOM, feed intake, and LWG of sheep. In ROT, sheep sequentially grazed in four 0.5-ha paddocks for 10 d each at a moderate stocking rate of 4.2 sheep/ha. Instead, in CON sheep grazed the whole plots throughout the entire grazing season. Across the four study years from 2005 to 2008, dOM, OMI, and LWG were lower at ROT than at CON. However, differences could not be observed every year. Hence, it can be concluded that ROT was not superior or even inferior to CON in Inner Mongolia. In the ALT system, grazing and hay-making were alternated annually between two adjacent plots, while sheep grazed the same plots every year in CON. Six different grazing intensities (GI) were established from

very light to very heavy grazing. Data were collected in 2009 and 2010, and the results showed that GS did not affect dOM, OMI, and LWG of sheep. Nevertheless, in view of published data of the same project, ALT might improve the long term productivity and feeding value of the steppe vegetation. Hence, it is recommended that ALT might enhance revenues and ecological sustainability of grassland when compared to the common practice of CON grazing at very high stocking rates.



## **Zusammenfassung**

Aufgrund einer stetig wachsenden Weltbevölkerung sanken in der Steppe der Inneren Mongolei die pro Schaf nutzbaren Grünlandflächen in den letzten 60 Jahren stark ab. Dadurch, dass die Nomaden sesshaft wurden, werden heute die Grünlandflächen in unmittelbarer Nähe der Siedlungen intensiv von Schafen und Rindern beweidet, während die Heuproduktion in entfernteren Bereichen stattfindet. Die Folgen dieser veränderten Grünlandnutzung sind Degradierung und Desertifikation der Steppe in der Inneren Mongolei. Weltweit betrachtet ist Grünlandmanagement mit angepassten Beweidungssystemen (GS) ein wichtiges Instrument für die Aufrechterhaltung oder sogar der Steigerung einer langfristigen Grünlandproduktion sowie der Leistung der Tiere. Viele Studien verglichen die Produktion und die Qualität des Grünfutters und die Veränderung der Artenzusammensetzung zwischen angepassten GS oder kontinuierlichen (CON) Beweidungssystemen miteinander. Allerdings, befassten sich nur wenige Studien mit dem Einfluss von GS auf die Verdaulichkeit der aufgenommenen organischen Substanz des Grünfutters (dOM) und der Futteraufnahme oder sie werteten nur die Gewichtszunahmen von Tieren (LWG) aus. Daher waren die Hauptziele dieser Arbeit, die Auswirkungen von GS auf Produktion und Qualität des Grünfutters, dOM, Aufnahme der organischen Substanz (OMI) und LWG von weidenden Schafen in der Steppe der Inneren Mongolei herauszustellen.

Zwei angepasste GS's, eine rotierendes (ROT) und ein alternierendes (ALT) GS wurden getestet und deren Auswirkungen auf dOM, die Futteraufnahme und LWG erfasst. Im ROT System, weideten die Schafe nacheinander in einem der vier 0,5 ha große Weiden für jeweils 10 Tage bei einer moderaten Besatzdichte von 4,2 Schafen/ha. Bei CON stattdessen beweideten die Schafe alle Parzellen während der gesamten Weidesaison. Über die vier Untersuchungsjahre von 2005 bis 2008 waren dOM, OMI und LWG bei ROT niedriger als bei CON. Diese Unterschiede konnten jedoch nicht jedes Jahr beobachtet werden. Daraus lässt sich schließen, dass das ROT- gegenüber dem CON-System nicht über- oder unterlegen ist. Im ALT-System wechselten die

benachbarten Weide- und Heuflächen jährlich, während in diesem CON-System die Schafe jedes Jahr die gleichen Parzellen beweideten. Sechs verschiedene Beweidungsintensitäten (GI) wurden etabliert, von sehr geringer bis starker Beweidung. Die Daten wurden in den Jahren 2009 und 2010 erhoben, und die Ergebnisse zeigten, dass das GS keinen Einfluss auf dOM, OMI und LWG von Schafen hat. Dennoch weisen bereits veröffentlichte Ergebnisse weiterer Studien aus demselben Projekt darauf hin, dass ALT die langfristige Produktivität sowie den Futterwert des Steppenaufwuchses verbessern kann. Es ist daher zu erwarten, dass ALT-Systeme mit mittlerer Beweidungsintensität verglichen mit der üblichen Praxis von CON-Systemen bei sehr hoher Tierbesatzdichten die Erlöse für die Farmer langfristig erhalten und zu einer nachhaltigen Nutzung des Grünlandes beitragen können.

## Lebenslauf

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Jun Hao

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