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Impact of grazing intensity and grazing system on herbage quality and performance of sheep in the Inner Mongolian steppe, China

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List of Abbreviations

ADF	Acid detergent fiber
ADL	Acid detergent lignin
B	Block
C	Carbon
CA	Crude ash
CG	Continuous grazing
CP	Crude protein
d	Day
DG	Daytime grazing
DM	Dry matter
dOM	Digestibility of organic matter
DOMI	Digestible organic matter intake
GI	Grazing intensity
h	Hour of the day
ha	Hectare
HA	herbage allowance
HM	Herbage mass
IVdOM	In vitro digestibility of organic matter
kg	Kilogram
$kg^{0.75}$ LW	Metabolic liveweight
LSMeans	Least square means
LW	Live weight
LWG	Live weight gain
ME	Metabolizable energy
MEI	Intake of metabolizable energy
MJ	Megajoule
N	Nitrogen
NDF	Neutral detergent fiber
OM	Organic matter
OMI	Organic matter intake
P	Period
SD	Standard deviation
SE	Standard error of the mean
SR	Stocking rate
TiO_2	Titanium dioxide
TR	Treatment
Y	Year

Chapter 1 General Introduction

1.1 Grassland utilization in the Inner Mongolian steppe ecosystem

Inner Mongolia is the third largest province of the People’s Republic of China with an area of approximately 1.2 million km^2 and is an autonomous region (Figure 1.1). The dominant landscape in China with around 40 % of the national land are grasslands (Kang *et al.* 2007) and the grassland steppe in Inner Mongolia is one of the largest grassland ecosystems of the world. It covers around 791 000 km^2, 68 % of the total land area of Inner Mongolia (Kawamura *et al.* 2005).

Figure 1.1: Map of China with its provinces

The Inner Mongolian steppe is a major livestock husbandry region of China, providing important source of animal products such as meat, milk, wool and pelts (Kang *et al.* 2007).

Traditionally, the grassland steppe has been used for grazing by nomadic tribes in a sustainable way. However, in the past 50 - 60 years predominant land use in Inner Mongolia has shifted from an extensive use by nomadic pastoralists to settled livestock farming where rangelands close to the settlements are used more intensively and land further away is often used extensively once a year for hay-making. Additionally, the increasing demand for agricultural land has resulted in a conversion of grasslands to agriculture land reducing the size of grassland available for livestock grazing (Wang and Ripley 1997). Furthermore, since human populations sharply increased the increasing demand for natural resources and livestock products has placed a tremendous pressure on the grassland ecosystem (Kang *et al.* 2007; Tong *et al.* 2004). According to Yiruhan *et al.* (2001) grassland available per sheep decreased from 6.8 ha per sheep in the 1950's to 1.6 ha in the 1980's. In the mid 1980's Chinese land-use policy changed. While the land still belongs to the government, farmers are allowed to make their own profit out of farming by using the land for livestock farming but only for short periods. Thus, having only short-time contracts the farmers are not interested in a sustainable utilization of the grassland. Instead, they aim for the highest short-term outcome per area. Thus, with the implementation of the land reform the number of livestock has rapidly increased and free grazing systems were adopted (Li *et al.* 2008) but no control over livestock numbers and distribution exists. Overgrazing was the consequence leading to severe grassland degradation (Li *et al.* 2000). The increasing human population and the targets of the local herdsmen to improve their standard of living entail rapidly increasing livestock numbers and a more intensive grassland utilization resulting in a heavy grazing pressure and hence, in grassland degradation. Livestock numbers in the Xilin River Basin almost doubled from 618.000 in 1985 to 1.133.000 in 1999 (Tong *et al.* 2004) and livestock density exceeds the carrying capacity in large areas of the Inner Mongolian steppe (Yu *et al.* 2004).

1.2 Effects of overgrazing in the Inner Mongolian steppe

Kang *et al.* (2007), Kawamura *et al.* (2003) and Li *et al.* (2000) identified overgrazing by livestock and the irrational use of grasslands as primary causes for desertification and as important factors for diminishing the grassland condition (Figure 1.2a). The changes in management practices to cope with the rising demands play an important role in improving economic returns of livestock production in a short-term. But this intensive grassland utilization is not sustainable and might result in long-term declining ecosystem production (Christensen *et al.* 2003). Rangelands in Inner Mongolia provide about most of the forage supply for livestock in the region. The large areas of degraded grassland due to

overgrazing are the major constraints to the regional animal industry and economy and limits the economical development of the whole area (Sun *et al.* 2008).
Especially during low precipitation years heavy grazing may bring this system to a threshold beyond which there can be a shift to an alternative stable state (Christensen *et al.* 2003). Xiao *et al.* (1995) showed that there is a high interannual variation in grassland productivity due to the high variability of precipitation and temperature within the growing season. This leads to the assumption that water is the growth-limiting factor in this region (Giese *et al.* 2009). However, increasing grazing pressure is very detrimental to soil and vegetation cover (Li *et al.* 2000). It changes species composition and plant functional groups (Giese 2007), the diversity of plant communities (Zhao *et al.* 2007a), the vegetation structure and to some extent activates sand dunes (Wang and Ripley 1997).
According to Tong *et al.* (2004) and Kang *et al.* (2007) steppe degradation reduces grassland productivity and biodiversity, leads to desertification, and thereby accelerates the occurrence of dust storms (Figure 1.2b). Consequences of dust storms are already apparent in large parts of China and also outside of the country with economical damages and health injuries. The frequently occurring dust storms since the end of the last century are considered a direct consequence of degradation and desertification of the northern temperate grassland ecosystem of China (Wang *et al.* 2004). Li *et al.* (2000) found that wind speeds are high in heavily grazed steppe areas where sheep trampling and grazing reduce vegetation cover and therefore offers optimal conditions for soil erosion. Similarly, Hoffmann *et al.* (2008) found a strong influence of grazing on wind erosion. While ungrazed sites were well protected against wind and storms, dust emissions were observed on all grazed plots (Hoffmann *et al.* 2008). Especially, below a certain threshold of 4-9 cm vegetation height wind erosion of top soil layers occurs (Hoffmann *et al.* 2008). Sustained overgrazing reduces surface roughness length so that wind can act directly on sandy grassland surface and provoke severe grassland desertification (Li *et al.* 2000). Furthermore, wind erosion resulting in a coarseness in surface soil, loss of organic C and N, and depletion in soil biological properties (Su *et al.* 2005).

Overgrazing is reported to be one of the major contributions increasing atmospheric CO_2 concentrations (Li *et al.* 1997). A large proportion of soil carbon (C) is stored in the soil of grassland ecosystems, indicating that they have a high capacity to sequestrate C. However, grassland ecosystems are fragile and the C stock in grassland soil may become a source of large C emissions under improper management that would contribute to global greenhouse effect (Cui *et al.* 2005). Steffens *et al.* (2008) found a strong negative influence of grazing intensity on soil organic C. Since 1850, about one-third of the total C loss from soils in the world occurred in the grasslands of the temperate zone (Houghton

1995) due to overgrazing and the cultivation of grasslands to cropland. In absence of livestock grazing Su *et al.* (2005) found an enhanced vegetation recovery, litter accumulation, development of annual and perennial grasses and higher soil organic C and N concentrations.

Moreover, heavy grazing has a strong influence on soil texture, structure and stability and consequently, on saturated hydraulic conductivity and in a long-term on the water-household of the soil (Krummelbein *et al.* 2006). In particular after heavy rain, a decrease in saturated hydraulic conductivity reduces the infiltration capacity of the soil, increases the surface water runoff, and hence, soil erosion (Figure 1.2c). Additionally, animal trampling, especially after rain, compacts the top soil, increases bulk density, and reduces soil porosity and water infiltration (Zhao *et al.* 2007b). Since soil water is a limiting factor for the grassland productivity Krummelbein *et al.* (2006) argued that a reduced hydraulic conductivity due to soil deformation caused by heavy grazing is a limiting factor for future grassland productivity. The reduced availability of water capacity reduces plant growth, decreases input of litter and influences again soil organic C (Zhao *et al.* 2007b).

Figure 1.2a: Heavy grazing Figure 1.2b: Sandstorm Figure 1.2c: Water erosion

1.3 Previous grazing studies in the Inner Mongolian steppe

Rapidly increasing stock numbers and changes in the grassland vegetation show a lack of understanding for management practices and their consequences. The current management practices and land tenure arrangements have left the system vulnerable to changes such as vegetation changes due to heavy grazing. An improved grassland management with appropriate grazing regimes is necessary to restore the degraded steppe ecosystem. To develop systems for a sustainable pasture use the knowledge of interaction between steppe productivity and livestock grazing including their forage intake and grazing behaviour is important (Kawamura *et al.* 2005).

Research studies to determine optimal stocking rates and long-term effects of grazing management on grassland productivity are highly welcome. Recently, Zhang *et al.* (2004) conducted a grazing experiment in the Inner Mongolian steppe and analysed the effect of four different grazing intensities on grassland vegetation. The authors suggested stocking rates of 2 - 3 sheep equivalents per hectare for a sustainable grassland use. Instead, Li *et al*. (2000) recommended a critical stocking rate of 3 - 4 sheep per hectare to meet requirements of grazers in a sustainable way. However, Han *et al.* (2000) carried out a one-year grazing experiment on a *Stipa breviflora* desert in Inner Mongolia with five different stocking rates. Based on live weight gains, they recommend a stocking rate of 1.1 sheep per hectare. For long-term effects of grazing on grassland productivity further research work is needed.

1.4 MAGIM-Project

The present work was carried out as a Sino-German cooperation project in the framework of the research group MAGIM (**M**atter fluxes of **G**rasslands in **I**nner **M**ongolia as influenced by Stocking Rate; FG 536) and supported by the German Research Foundation (DFG). The project was set up in 2004. The first phase lasted until 2007 and the second phase from 2007 - 2010. The ecological problems of grassland degradation as background this research group was aimed to analyse the impacts of grazing on the natural grassland vegetation, soil and animal performance and to develop concepts for a sustainable grassland utilization. Eleven sub-projects working on sites as well as on a regional scale are part of the project focusing on the following subjects:

P1 Amount, composition, and turnover of organic matter pools in grassland soils under typical steppe vegetation types of the Xilin River Basin influenced by different grazing intensities

P2 Effects of grazing intensity on net primary production and nutrient dynamics

P3 Impact of grazing management on yield performance, herbage quality and persistence of grassland ecosystems of Inner Mongolia

P4 Impact of grazing intensity on herbage quality, feed intake and animal performance of grazing sheep in the grassland steppe of Inner Mongolia

P5 Quantification and biogeochemical modelling of C and N turnover processes and biosphere-atmosphere exchange of C and N compounds

P6 Quantification of water and carbon exchange by micrometeorology and remote sensing in managed steppe ecosystems of Inner Mongolia

P7 Regional water fluxes and coupled C and N transport

P8 Influence of various grazing intensities on soil stability and water balance on the plot scale

P9 Dynamics of wind erosion in the Xilin River Catchment area in Inner Mongolia

P10 Influence of grazing pressure on the carbon isotope composition of the grassland of China: spatio-temporal variations at multiple scales

P11 Surface and satellite based remote sensing to infer rain rates within the Xilin catchment

The present dissertation belongs to the sub-project P4 and focuses on the influence of grazing systems and grazing intensities on amount and composition of the grassland and animal performance. A grazing experiment was carried out by the Institute of Animal Nutrition and Physiology of the Christian-Albrechts-University of Kiel in close cooperation with the sub-project P3 by the Institute of Crop Science and Plant Breeding of the Christian-Albrechts-University of Kiel and the Institute of Botany, Chinese Academy of Sciences.

1.5 The Xilin River catchment

The grassland ecosystems in China are classified according to the precipitation patterns into four major steppe types: (i) Meadow steppes, (ii) typical steppes, (iii) desert steppe, and (iv) alpine steppes (Kang *et al.* 2007). The Xilingol grasslands of Inner Mongolia are dominated by typical and meadow steppes and is a distinguish husbandry region with livestock grazing dominated by sheep farming. This area is situated in the north-eastern part of Inner Mongolia, approximately 600 km north of Beijing and covers about 10000 km^2. Grassland degradation is already well documented. In 1985, 67 % of the Xilin River Basin were degraded increasing to 72 % in 1999 (Tong *et al.* 2004).

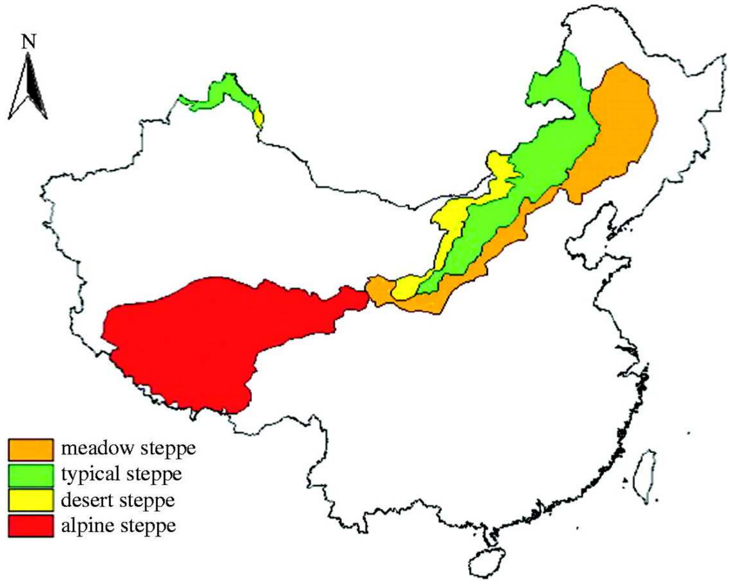

Figure 1.3: The steppe ecosystem of China (Kang *et al.* 2007)

Study area

The experimental area is situated in the Xilin River catchment approximately 600 km north of Beijing (Figure 1.4). Experiments were conducted on the experimental area of the Inner Mongolia Grassland Ecosystem Research Station (IMGERS), which is located 70 km south-east of the city of Xilinhot at an average altitude of 1200 m above sea level.

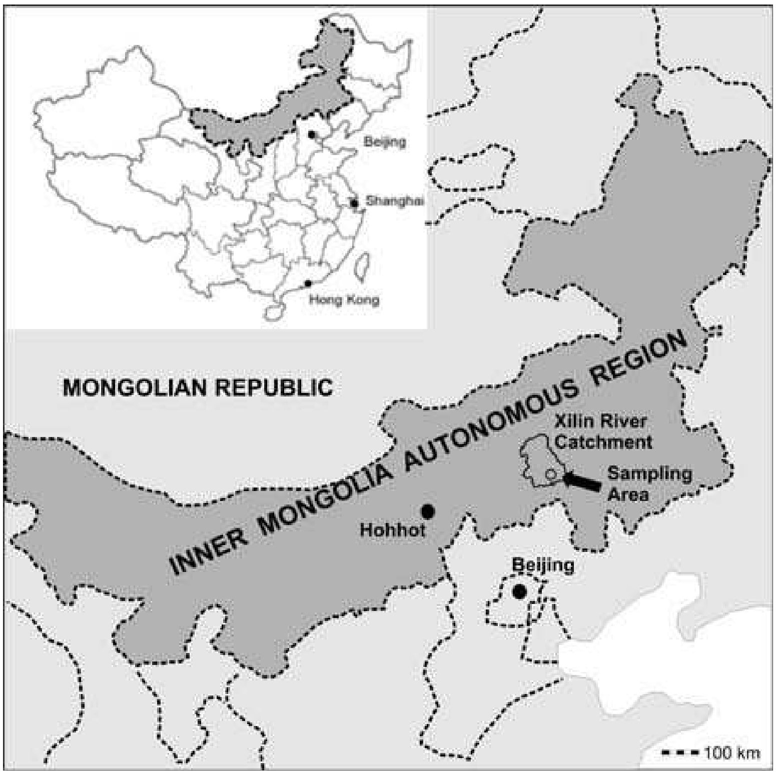

Figure 1.4: The Xilin River catchment

The climate in the Xilin River Basin is typical for the temperate steppe region. Mean annual temperature is 0.8℃. The highest monthly temperature is 19.1℃ in July, and the lowest monthly temperature is -20.9℃ in January (Figure 1.5). Long-term mean annual precipitation is 335 mm (1982 -2008), but it is highly variable between seasons and years (Xiao *et al.* 1995). The coefficient of variation is 22 % (Xiao *et al.* 1995). Approximately 85 % of rainfall occurred between May-September which coincides with the highest temperatures. Low snow rates occur during winter months from November until March (Schneider *et al.* 2007). The growing season lasts for 5 months (May - September). *Stipa grandis* and *Leymus chinensis* steppes are the dominant plant communities in the Xilin River Basin. But, overgrazing has introduced additional succession communities (Tong *et al.* 2004). The dominant soil types are Chestnut and Chernozem (Li *et al.* 1997).

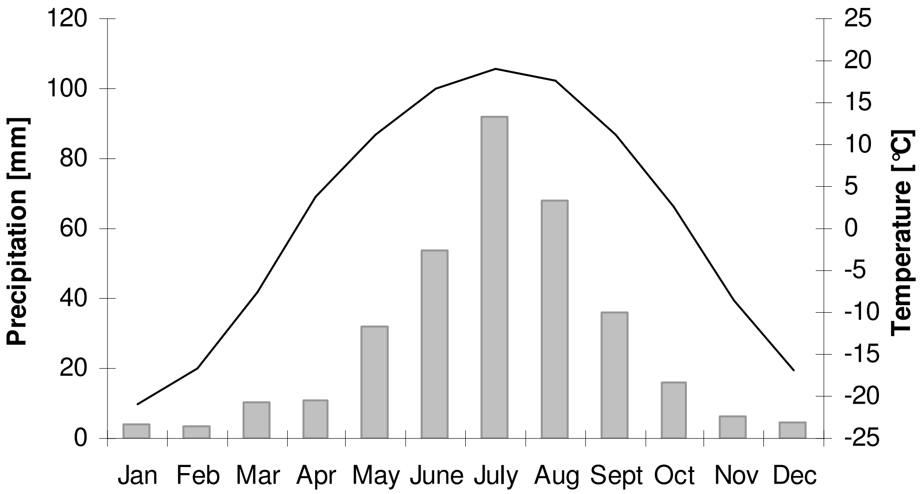

Figure 1.5: Long-term mean annual temperature (line) and precipitation (columns) during 1982-2008 at IMGERS (Inner Mongolia Grassland Ecosystem Research Station).

1.6 Grazing experiment

A grazing experiment with sheep was conducted in the Xilin River Basin to determine the influence of grazing intensity on herbage mass, quality of ingested herbage, feed intake and animal performance. The experiment was initiated in 2005 on a total study area of 200 ha. It comprises two grazing systems with six different grazing intensities. While in the so-called “Traditional System” grazing and hay-making takes place on the same plot every year, the two adjacent plots were used alternately one year for grazing and one year for hay-making in the “Mixed System”, which is called in the studies comparing systems with each other “Continuous System”. Two additional grazing systems moderately grazed were set up to determine the differences between rotational and continuous grazing and between daytime and continuous grazing. In the rotational treatment, the 2-ha plots were divided in 4 sub-paddocks and the sheep are rotationally grazing for 10 day on each sub-paddock. Each sub-paddock has an ungrazed re-growth period of 30 days after grazing. In the daytime treatment grazing time is restricted to the daytime and animals are kept in yards during night. This practice is typical in the region where the research area is located. In all grazing systems there are two paddocks per grazing intensity class: one for grazing and one for hay-making. In 2005 and 2006, six stocking rates from 1.5; 3.0; 4.5; 6.0; 7.5 and 9.0 sheep/ha for very light, light, light-moderate, moderate, heavy, and very heavy grazing were set up. To account for the differences in herbage mass productivity in the experimental area the system was changed in 2007 from fixed stocking rates throughout the grazing season to monthly adjusted herbage allowance levels (kg DM (dry matter)/kg LW(live weight)), which were defined by the following herbage allowance classes: >12, 6-12, 4.5-6, 3-4.5, 1.5-3, <1.5 kg DM/kg LW for the very light, light, light-moderate, moderate, heavy, and very heavy grazing intensity treatments. Every grazing intensity treatment were carried out with two replications, one in a flat and one in a moderately slope area. A local fat-tailed breed was used and sheep were 15 month old at the beginning of the trial in each year and six sheep per plot were used for sampling.

The impact of grazing intensity – Chapter 2

A grazing experiment with six different grazing intensities was carried out in the vegetation periods of 2005, 2006, and 2007 to analyse quality of ingested herbage, feed intake and animal performance influenced by different grazing intensities. Therefore, the mixed system where the two adjacent plots alternating annually between grazing and hay-making, was used. All plots had a size of 2 ha except of the lowest grazing intensity plots with 4 ha each. Sheep were transferred to the grazing plots in the middle of June each year and were continuously kept on the plots throughout the grazing season until the middle of September. The grazing season lasted for 98, 90, and 97 days in 2005, 2006, and 2007, respectively.

Based on the results of the first experimental year in 2005 observed by Glindemann *et al.* (2009) the hypothesis of this study was that animal performance increased with decreasing grazing intensity, but that the outcome per area is higher with increasing number of sheep per hectare. While these results based on a one-year study, and especially 2005 was a very dry year, Chapter 2 of this dissertation analyses 3-year-data from this grazing experiment and aimed to provide recommendations for an optimal grazing management regime which allows high animal productivity in a sustainable way.

Figure 1.6a: Heavy *versus* light grazing

Figure 1.6b: Rare vegetation covers the soil

The impact of grazing system – Chapter 3

Besides the influence of different grazing intensities the grazing system also plays an important role for grassland productivity and hence, animal performance. Wang *et al.* (2009) compared the rotational and the continuous system in a two-year-study and showed that although feed intake and digestibility of ingested herbage was lower in the rotational system, no effect could be observed on animal performance. This experiment was continued for another two years to account for the annual variability between years and to determine mid-term effects of different grazing systems on grassland vegetation and animal performance.

In Chapter 3 we tested the two grazing systems continuously *versus* daytime grazing. For the continuously grazed system sheep were kept on the plots all day and all night throughout the whole grazing season, whereas sheep of the daytime treatment were removed from the pasture in the evening and kept in pens over night according to the common practice of local sheep farmers in Inner Mongolia. The research questions were i) if sheep that have the possibility to graze at day and at night increase their daily feed intake due to longer available grazing time and thus, show a higher live weight gain than sheep that graze during the daytime only, and ii) if closing the nutrient cycling on continuously grazed treatments where sheep faeces remained on the pasture has a remarkable influence on grassland productivity.

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Chapter 2 Impact of grazing intensity on herbage composition, feed intake, and performance of sheep in the steppe of Inner Mongolia, China

Abstract

The grassland steppe of Inner Mongolia in the north of China is traditionally used for grazing. In the last three decades, overgrazing by livestock led to a spare vegetation cover in winter and caused soil erosion and hence grassland degradation. The aim of this study was to evaluate the effect of grazing intensity (GI) of sheep on grassland and animal performance and to determine an optimal grassland use, which realizes a high but sustainable animal and grassland productivity. Grazing experiments were conducted in this typical steppe ecosystem from July until September in 2005, 2006, and 2007 to analyse the effect of six different GI from very light (GI 1), light (GI 2), light-moderate (GI 3), moderate (GI 4), heavy (GI 5), and very heavy (GI 6) on herbage mass (HM), herbage quality as well as digestibility of ingested organic matter (dOM), organic matter intake (OMI) and live weight gain (LWG) of grazing sheep. Each GI consisted of an adjacent grazing and hay-making plot altering annually and was carried out with two replications. Faeces samples were taken from six sheep per plot.

Herbage mass on offer (HM) decreased with increasing GI ($P = 0.005$) from 1006 (GI 1) to 448 kg DM/ha (GI 6). A significant influence of GI on the concentrations of crude protein (CP), neutral detergent fibre (NDF) and acid detergent lignin (ADL) were observed ($P < 0.05$).

Diet dOM, OMI, digestible organic matter intake (DOMI) and metabolizable energy intake (MEI) were not different between GI's. However, OMI and DOMI per ha increased with increasing GI ($P < 0.001$) from 2.21 kg at lowest to 10.36 kg at highest GI and from 1.3 kg to 5.9 kg at lowest and highest GI, respectively.

LWG per sheep ranged between 84 and 103 g/d and was not influenced by GI ($P = 0.34$). Corresponding to the increase of OMI and DOMI per ha, LWG per ha increased with increasing GI ($P < 0.001$), reaching a maximum of 730 g/d at GI 6 compared to 181 g/d at GI 1.

Vegetation period had a negative influence on dOM, OMI, DOMI, MEI and LWG as well as on HM and CP while NFD, ADF and ADL increased with proceeding vegetation period. Great variability in precipitation between years affected HM and herbage quality parameters as well as dOM, DOMI per sheep, MEI and LWG per sheep and per area.

The results showed that intensive grazing does not reduce performance of individual animals but increases productivity per area and therefore, income for farmers. However, in dry years a lack of HM on offer on heavy grazed pastures requires the purchase of

additional forage for animals at the end of the vegetation period or the untimely sale of animals. Long-term negative effects of high GI's on grassland productivity are likely and therefore, this study is continued to obtain further information on long-term effects of intensive livestock grazing.

To be submitted to Archives of Animal Nutrition

2.1 Introduction

The Inner Mongolia Province comprises one of the largest grassland regions of the world, which covers an area of 791,000 km^2 equivalent to 68 % of the province (Kawamura *et al.* 2005). However, 20 % of this area is already unusable due to severe degradation (Yu *et al.* 2004). The study of Tong *et al*. (2004), which focused on the Xilin River Basin, showed that extent and intensity of degradation severely increased in the last 15 years and that grassland degradation is a major environmental and economic problem in Inner Mongolia. The total area of degraded steppe in the Xilin River catchment due to overgrazing increased from 67 % in 1985 to 72 % in 1999 (Tong *et al.* 2004).

The Xilingol steppe is a major livestock husbandry region in Inner Mongolia and the grassland steppe is traditionally used for sheep grazing (Kawamura *et al.* 2003). Since the 1980's, land tenure changed and farmers were allowed to make their own profit. Stock numbers increased and available land per sheep decreased from 6.8 ha per sheep in the 1950's to 1.6 ha per sheep in the 1980's (Yiruhan *et al.* 2001) and further to 1.05 ha per sheep in 1990 (Li *et al.* 2007).

Moreover, irrigated cropping land increased lowering the groundwater level and amplifying the deterioration of the grassland. The improper grassland management lead to a decreased vegetation cover and vegetation height resulting in a decrease in ground cover and surface roughness length (Li *et al.* 2000). The unprotected soil especially in winter enables soil erosion in the dry and windy seasons of winter and spring (Zhao *et al.* 2005) and increased the diminishing of the fertile top soil. The enhanced wind erosion causes desertification and therefore increases sandstorm frequency.

Many studies such as those of Tong *et al.* (2004) and Kawamura *et al.* (2005) have shown that rangeland degradation caused by overgrazing is a serious problem. Zhang *et al.* (2004) reported that livestock grazing is one of the major factors disturbing the Inner Mongolian grassland. Since forage supply for livestock is provided mainly of the grassland, rangeland degradation withdraws important resources not only for the animal production but also the livelihoods of the local people.

The critical problems farmers have to face are the prevention of overgrazing and at the same time the enhancement of the grazing efficiency of ruminants. The great challenge of the latter is to provide forage in an adequate amount and of sufficient quality to meet the animals' requirements without adverse impacts on the environment (Garcia *et al.* 2003). The herders in the Xilin River Basin are still struggling to make a living out of grassland resources. However, the current land tenure arrangements seem vulnerable to further steppe degradation and economic interests force farmers to maximise their short-term benefits regardless of long-term steppe degradation. Although several studies (McNaughton 1979; Sharrow *et al.* 1981) have shown that moderate grazing is beneficial for grassland productivity and improves its nutritional quality, the degree of disturbance depends on the grazing intensity. Many studies deal with the interaction between grazing intensity and animal production and grazing intensity is still the most important factor in pasture management. However, no standardized stocking rate for grasslands in China has been determined yet (Wang *et al.* 2005). An optimal stocking rate should realize the efficient use of the available forage as well as the conservation and sustainable use of the grassland.

Therefore, a grazing experiment with different grazing intensities was conducted in the Inner Mongolian grassland steppe. The aim of this study was to evaluate the effect of different grazing intensities by sheep on pastures which are continuously grazed throughout the grazing season and alternatively used for grazing and hay-making year by year on grassland and animal productivity and to determine an optimal rangeland utilization, which realizes a high animal and grassland production in a sustainable way.

2.2 Materials and methods

2.2.1 Study site

In 2005, a grazing trial was established in the Xilin River catchment (E116°42' N43°38') of the Inner Mongolian steppe, approximately 600 km north of Beijing, P.R. China. The study area is about 1200 m above sea level in the Mongolian Plateau and belongs to the Inner Mongolia Grassland Ecosystem Research Station (IMGERS), which is administered by the Botany Institute of the Chinese Academy of Sciences, Beijing.

The study area belongs to the continental middle temperate semi-arid zone (Yu *et al.* 2004). While winters are cold and dry, summers are warm and show the highest precipitation. The long-term mean annual precipitation (1982-2007) is 335 mm, 85 % of which occurs between May and September, coinciding with the highest temperatures. Mean annual temperature is 0.8°C, the coldest and the warmest monthly temperatures

are – 20.9°C in January and 19.0°C in July, respectively (Figure 2.1). The first experimental year 2005 was very dry with only 158 mm rainfall. Whereas, average amount of precipitation was recorded in 2006 and 2007. The vegetation period lasts on average 150 days from May-September with a non-frost period of about 100 days.
The dominant soil type is Calcic Chernozem (Li *et al.* 1997) and the natural vegetation is characterised by the perennial bunchgrass S*tipa grandis* and the perennial rhizome grass *Leymus chinensis* (Xiao *et al.,* 1995; Bai *et al.,* 2004).

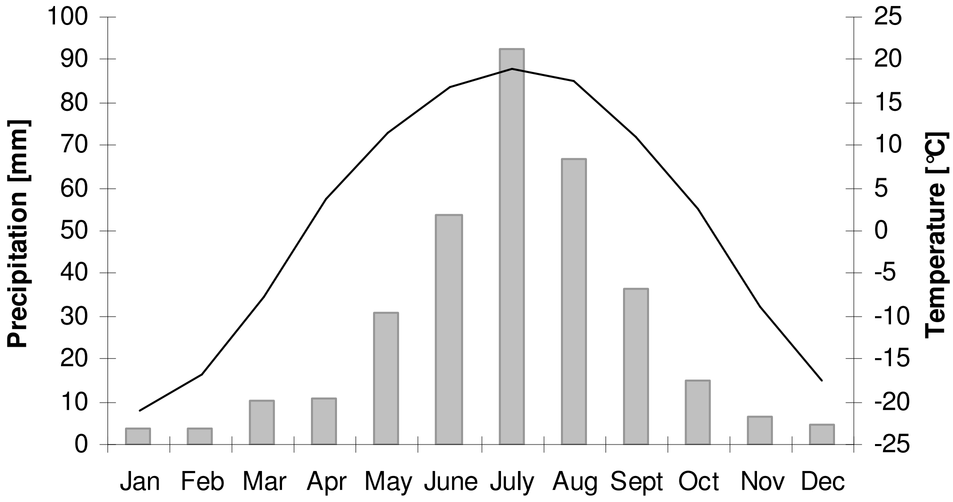

Figure 2.1: Long-term mean annual precipitation (mm, columns) and monthly mean temperatures (°C, line) at IMGERS (1982 – 2007).

2.2.2 Experimental design

The grazing experiment was carried out in the vegetation periods of 2005, 2006, and 2007. Grazing started around 10th June and ended around 12th September each year and lasted for 98, 90, and 93 days in 2005, 2006, and 2007, respectively. The experiment consisted of six different grazing intensity (GI) treatments from very light (GI 1), light (GI 2), light-moderate (GI 3), moderate (GI 4), heavy (GI 5), and very heavy (GI 6) grazing which were defined by the following herbage allowance (HA) classes, respectively: >12, 6-12, 4.5-6, 3-4.5, 1.5-3, <1.5 kg herbage dry matter (DM)/kg live weight (LW; Table 2.1). To achieve the target HA ranges the numbers of sheep were monthly adjusted according to the standing biomass subsequent to animal weighing and biomass measurements in the respective plots.
Each treatment was replicated in two blocks, a flat and a moderately sloped area and consisted of an adjacent grazing and hay-making plot altering annually. All plots were not

grazed the year before the trial started in 2004 and had a size of 2 hectares (ha) except the GI 1; sheep of this treatment were offered a paddock of a size of 4 ha to achieve a minimum of six sheep per plot. Faeces sampling took place in the three sampling periods July, August, and September.

In 2006, GI 5 and GI 6 sheep had to be removed from the pasture after the second sampling period in the end of August to avoid animal losses due to the lack of forage. Additionally, live weight could not be determined in the last period of this year because of an early winter onset.

Table 2.1: Live weight (LW), stocking rate (SR), and herbage allowance (HA) in the grazing intensity (GI) treatments, in the experimental years 2005, 2006, and 2007 (means ± SE).

	GI[1]											
	1		2		3		4		5		6	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Mean 2005-2007												
LW (kg)	34.7	0.8	34.4	0.7	34.4	0.8	34.8	0.7	35.1	0.6	35.3	0.6
SR (sheep/ha)	1.7	0.2	3.1	0.1	4.3	0.2	5.6	0.4	7.2	0.2	8.9	0.5
HA (kg DM[2]/kg LW)	18.3	2.0	8.4	0.7	4.0	0.5	3.6	0.5	2.0	0.2	1.6	0.2
2005												
LW (kg)	34.2	1.2	33.8	1.3	33.5	1.6	35.0	0.8	35.6	0.7	36.7	0.6
SR (sheep/ha)	1.5	0.0	3.0	0.0	4.5	0.0	6.0	0.0	7.5	0.0	9.0	0.0
HA (kg DM/kg LW)	27.6	3.3	11.4	1.00	5.5	1.1	4.8	1.1	2.5	0.3	2.2	0.3
2006												
LW (kg)	32.3	0.9	34.4	1.2	33.2	0.9	32.7	1.0	32.9	0.7	33.2	1.0
SR (sheep/ha)	1.5	0.0	3.0	0.0	4.5	0.0	6.0	0.0	7.5	0.0	9.0	0.0
HA (kg DM/kg LW)	16.7	0.7	7.6	0.6	2.2	0.2	1.8	0.4	1.5	0.4	0.9	0.2
2007												
LW (kg)	36.9	1.6	35.0	1.2	36.2	1.5	36.0	1.6	36.3	1.5	35.5	1.1
SR (sheep/ha)	2.1	0.3	3.3	0.3	3.8	0.4	4.8	1.1	6.7	0.4	8.6	1.5
HA (kg DM/kg LW)	10.4	1.1	6.2	0.3	4.3	0.4	4.3	0.7	2.0	0.3	1.9	0.4

[1] Defined over HA with GI 1: >12, GI 2: 6-12, GI 3: 4.5-6, GI 4:3-4.5, GI 51.5-3, GI 6: <1.5 kg DM / kg LW
[2] DM, dry matter

2.2.3 Animal management

Approximately 132 female, non pregnant sheep of the "Mongolian fat-tailed" breed were used each year. The animals were around 15 months old at the beginning of each experiment with a mean initial live weight of 31.2 ± 0.3 kg. All sheep were ear-tagged for identification and treated against internal and external parasites. The treatment against parasites was repeated once after the first sampling period in July. The animals were evenly allocated to the plots to equalize mean live weight per plot. They were weighed again after an adaptation period of ten days to determine their initial live weight at the

beginning of the grazing study. Six sheep per plot were randomly chosen at the beginning of the trial each year to determine digestibility of ingested organic matter (dOM), organic matter intake (OMI) and live weight gain (LWG). Sheep were continuously kept on the plots throughout the grazing season. Water and mineral lick stones were freely available to all animals during the whole grazing experiment.
Sheep were weighed on two consecutive days at the beginning of the grazing study in June and at the end of each sampling period in the middle of July, August, and September to calculate the daily live weight gain for each period.

2.2.4 Determination of digestibility of the ingested herbage, organic matter and energy intake

Dietary organic matter digestibility (dOM) was estimated from the faecal crude protein concentration (CP = N*6.25) according to the regression equation developed by Wang *et al.* (2009b).
Organic matter intake (OMI) was estimated by determining the total faecal excretion and (dOM). Faecal excretion was determined using the external marker TiO_2, assuming a faecal recovery rate of 100 % (Glindemann *et al.* 2009a). On ten consecutive days in the beginning of each sampling period in July, August, and September, a gelatine capsule containing 2.5 g TiO_2 was orally administered to six sheep per plot once a day always at the same time. From day 6 - 10 faecal grab samples were obtained once daily from the rectum and samples were frozen immediately. After each sampling period, samples were pooled by sheep and one subsample was analysed for nitrogen (N), dry matter (DM) and organic matter (OM) content. A second subsample was oven-dried at 60℃ for 48 h ground to pass a 1 mm sieve and analysed for TiO_2 concentration using the procedure as described by Brandt and Allam (1987) modified by Glindemann *et al.* (2009a). In 2005 and 2006, samples of each sheep were analysed for TiO_2 concentration individually with repeated determination. To reduce the number of samples analyses were simplified in the following year, the evaluation took place on a plot level. Samples of the six sheep per plot were pooled in 2007 and analysed with three replicates each.
Digestible organic matter intake (DOMI) was calculated by multiplying dOM by OMI and concentration of metabolizable energy intake (MEI) according to the formula of Aiple (1992):

$$\text{ME (MJ/kg OM)} = -0.9 + 0.170 \cdot \text{dOM (\%)} \qquad (1)$$

2.2.5 Determination of herbage mass and herbage quality

Herbage mass (HM) was determined by cutting the sward at 1 cm above ground level in three representative areas per plot. Sampling took place in the beginning of the experiment in June and in each period subsequent to the faeces sampling in the beginning of July, August, and September, respectively. The collected herbage material was pooled by plot, dried at 60°C for 24 h and ground to pass a 1 mm sieve. Contents of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), cellulase digestible organic matter (CDOM), and metabolizable energy (ME) were determined by Near-Infrared-Spectroscopy system (NIRS) after calibration. For the chemical laboratory analysis calibration (2005: n = 138, 2006: n = 44, 2007: n = 31) and validation (2005: n = 25, 2006: n = 10, 2007: n = 15; Schönbach *et al.* 2009 and personal communication) subsets of the herbage samples were chosen. Herbage DM content was determined by drying at 105°C until a constant dry weight was reached and OM content was calculated as the difference between the dry sample and the residue (ash) after incineration of the dry sample at 550°C over night. CP concentration was calculated from the nitrogen (N) concentration (CP = N x 6.25). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analysed sequentially by a semiautomated Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA) according to the procedures described by Van Soest *et al*. (1991). The in vitro digestibility of organic matter (IVdOM) was estimated by calculating EULOS by the pepsin-cellulase technique described by De Boever *et al.* (1986) using equations (2) developed by Weissbach *et al.* (1999):

$$\text{IVdOM (\% of OM)} = 100*(940 - \text{CA} - 0.62\text{EULOS} - 0.000221\text{EULOS}^2)/(1000 - \text{CA}) \qquad (2)$$

(CA = crude ash, EULOS = enzyme insoluble OM; CA and EULOS in g kg/DM)

2.2.6 Statistical analyses

Data were analysed using mixed model procedures of SAS (2000). The model included the fixed effects year (Y), block (B), grazing intensity (GI), and the interactions GI x P and GI x Y. Period (P: July, August, and September) was treated as repeated effect. Probabilities were determined for all effects and their interactions. Heterogeneous auto-regression covariance structure was chosen. When effects were significant ($P < 0.05$), the Tukey-Test (Steel and Torrie 1980) was used to compare least square means.

2.3 Results

2.3.1 Effect of grazing intensity

Herbage mass (HM) on offer decreased with increasing GI (*P* = 0.005) from 1006 (GI 1) to 448 (GI 6) kg DM/ha (Table 2.2). A significant influence of GI on CP, NDF and ADL content was observed (*P* < 0.05). While CP content was highest (*P* = 0.004) and NDF content was lowest (*P* = 0.023) at light-moderate and moderate grazed plots, ADL content was lowest at GI 1 treatment (*P* = 0.009).

Diet digestibility (dOM) was not different between GI (*P* = 0.34). However, dOM was lower (0.56 - 0.58) than digestibility of herbage on offer (IVdOM) (0.60 - 0.62; Table 2.2). OMI (1.1 - 1.3 kg/d) and MEI per sheep (9.6 – 11.7 MJ/d) as well as OMI per $kg^{0.75}$ LW (74.5 - 88.3 g/$kg^{0.75}$ LW) were not affected by GI (*P* > 0.05), although all were numerically higher in animals of low compared to animals of heavy GI groups. OMI per ha increased with increasing GI (*P* < 0.001) from 2.21 kg/ha at GI 1 to 10.36 kg/ha at GI 6.

LWG per sheep was not significantly different between GI treatments (*P* > 0.05) but a decrease from 103 to 82 g/d was observed from lowest to highest GI with the exception of GI 2. At one of these plots a high abundance of *Stipa grandis* was observed. Since this grass species develops needles at a mature state, it is assumed that sheep of the GI 2 plots might have suffered from stress induces by the stings of this species resulting in a reduced LWG. GI did not differ between years or sampling periods and no significant interaction between GI and year and GI and period was found. In contrast, LWG per ha increased with increasing GI (*P* < 0.001).

Table 2.2: Effect of grazing intensity (GI) and probabilities of fixed effects on digestibility of ingested organic matter (dOM), organic matter intake (OMI), live weight gain (LWG) and energy intake (MEI) of sheep and herbage mass (HM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) concentration and digestibility of offered herbage (IVdOM) in the grazing seasons of 2005 - 2007 (LSMeans ± SE).

	GI							Probabilities[ab]					
Parameter[c]	1	2	3	4	5	6	SE	GI	P	Y	B	GI*P	GI*Y
HA (kg DM/kg LW)	18.2	8.4	4.0	3.6	2.0	1.6	1.04						
HA (kg DM/kg$^{0.75}$ LW)	44.4	20.4	9.6	8.7	4.8	3.9	2.55						
Animal													
dOM	0.58^{a}	0.57^{a}	0.58^{a}	0.57^{a}	0.57^{a}	0.56^{a}	0.01	n.s.	***	***	n.s.	n.s.	n.s.
OMI (kg/d/sheep)	1.30^{a}	1.22^{a}	1.23^{a}	1.26^{a}	1.09^{a}	1.14^{a}	0.06	n.s.	**	n.s.	n.s.	n.s.	n.s.
OMI (kg/d/ha)	2.21^{a}	3.78^{ab}	5.31^{bc}	7.09^{cd}	7.83^{d}	10.36^{e}	0.51	***	n.s.	n.s.	n.s.	n.s.	n.s.
OMI (g/kg$^{0.75}$ LW)	88.3^{a}	83.8^{a}	84.6^{a}	85.6^{a}	74.5^{a}	77.0^{a}	4.13	n.s.	***	*	n.s.	n.s.	n.s.
DOMI (kg/d/sheep)	0.76^{a}	0.70^{a}	0.71^{a}	0.73^{a}	0.62^{a}	0.64^{a}	0.04	n.s.	**	*	n.s.	n.s.	n.s.
DOMI (kg/d/ha)	1.3^{a}	2.2^{ab}	3.1^{bc}	4.1^{cd}	4.5^{d}	5.9^{e}	0.28	***	n.s.	n.s.	*	n.s.	n.s.
MEI (MJ/kg$^{0.75}$ LW)	0.79^{a}	0.73^{a}	0.75^{a}	0.76^{a}	0.64^{a}	0.67^{a}	0.043	n.s.	***	*	*	n.s.	n.s.
MEI (MJ/d/sheep)	11.7^{a}	10.8^{a}	11.0^{a}	11.2^{a}	9.6^{a}	9.9^{a}	0.55	n.s.	**	*	0.07	n.s.	n.s.
LWG (g/d/sheep)	103^{a}	94^{a}	102^{a}	95^{a}	89^{a}	82^{a}	7.29	n.s.	**	***	n.s.	n.s.	n.s.
LWG (g/d/ha)	181^{a}	288^{ab}	431^{bc}	525^{cd}	631de	730^{e}	39.3	***	**	***	n.s.	n.s.	**
Herbage													
HM (kg/DM ha)	1006^{a}	861^{ab}	569^{ab}	656^{ab}	467^{b}	448^{b}	100	**	**	**	n.s.	n.s.	n.s.
CP (g/kg DM)	105^{a}	110^{ab}	125^{b}	122^{b}	119^{b}	119^{b}	3.4	**	***	***	n.s.	n.s.	n.s.
NDF (g/kg DM)	697^{ab}	697^{ab}	694^{ab}	681^{b}	703^{ab}	709^{a}	5.1	*	***	***	n.s.	*	n.s.
ADF (g/kg DM)	335^{a}	331^{a}	328^{a}	326^{a}	334^{a}	334^{a}	3.2	n.s.	***	***	*	n.s.	n.s.
ADL (g/kg DM)	44^{a}	46^{ab}	45^{ab}	46^{ab}	48^{b}	48^{b}	0.7	**	***	***	n.s.	n.s.	n.s.
IVdOM	0.61^{a}	0.61^{a}	0.62^{a}	0.62^{a}	0.61^{a}	0.60^{a}	0.005	n.s.	***	***	*	**	n.s.

Within a row means with a common superscript are not significantly different at $P > 0.05$.
[a] $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, n.s. not significant.
[b] GI, grazing intensity; P, period; Y, year; B, block.
[c] HA, herbage allowance; DM, dry matter.
Number of observations for animal related parameters: 18; for LWG and GI 5 and 6: 16; for herbage related parameters: 24.
For definitions of GI treatments see table 2.1.

2.3.2 Effect of vegetation period

Herbage mass and herbage quality differed between sampling periods (Table 2.3). In September, HM, CP and IVdOM contents were lower than in July ($P < 0.01$), whereas NDF, ADF and ADL contents in the herbage increased with advancing vegetation period ($P < 0.001$).

Diet dOM decreased with proceeding sampling period with 0.59, 0.58, and 0.55 in July, August, and September, respectively (Table 2.3; $P < 0.001$). Sheep consumed more OM per day in July (1.26 kg, 90.3 g/kg$^{0.75}$ LW) than in August (1.17 kg, 78.5 g/kg$^{0.75}$ LW; $P = 0.005$; $P < 0.001$) and September (1.19 kg, 78.1 g/kg$^{0.75}$ LW; $P > 0.05$, $P < 0.001$). However, OMI per ha was similar throughout the whole vegetation period ($P = 0.51$). MEI per sheep was higher in July than in September and decreased from 11.4 – 10.2 MJ/d ($P = 0.002$).

Similarly, overall mean LWG per animal and LWG per ha were highest in July and decreased with advancing vegetation period ($P = 0.002$; $P = 0.003$). In 2005 and 2007, LWG per sheep was lower in September as in July ($P = 0.003$; $P = 0.005$) and tended to decrease from July to August ($P = 0.10$, $P = 0.06$). In 2006, LWG per sheep did not differ between July and August; no data could be recorded for the last period because of early onset of winter.

Table 2.3: Effect of period on digestibility of ingested organic matter (dOM), intake of organic matter (OMI), intake of digestible organic matter (DOMI), intake of metabolizable energy (MEI), live weight gain (LWG), herbage mass (HM), and herbage composition (LSMeans ± SE).

Parameter[a]	Period				
	June	July	August	September	SE
HA (kg DM/kg LW)	.	6.53	6.58	5.79	0.47
HA (kg DM/kg $^{0.75}$ LW)	.	15.6	16.0	14.4	1.17
Animal					
dOM	.	0.59^{a}	0.58^{a}	0.55^{b}	0.004
OMI (kg/sheep/d)	.	1.26^{a}	1.17^{b}	1.19^{ab}	0.03
OMI (kg/ha/d)	.	6.17^{a}	5.95^{a}	6.17^{a}	0.26
OMI (g/kg $^{0.75}$ LW)	.	90.3^{a}	78.5^{b}	78.1^{b}	2.13
DOMI (kg/sheep/d)	.	0.74^{a}	0.68^{b}	0.66^{b}	0.02
DOMI (kg/ha/d)	.	3.61^{a}	3.45^{a}	3.40^{a}	0.15
MEI (MJ/kg$^{0.75}$ LW)	.	0.82^{a}	0.70^{b}	0.65^{c}	0.024
MEI (MJ/sheep/d)	.	11.4^{a}	10.5^{b}	10.2^{b}	0.30
LWG (g/sheep/d)	.	108.1^{a}	97.5^{ab}	76.7^{b}	6.63
LWG (g/ha/d)	.	541^{a}	473^{ab}	379^{b}	35.6
Herbage					
HM (kg DM/ha)	654^{ab}	756^{a}	698^{a}	563^{b}	52.0
CP (g/kg DM)	135^{a}	119^{bc}	115^{c}	97^{d}	0.3
NDF (g/kg DM)	682^{a}	697^{b}	702^{b}	707^{b}	2.6
ADF (g/kg DM)	322^{a}	325^{a}	334^{b}	344^{c}	21.3
ADL (g/kg DM)	36^{a}	42^{b}	52^{c}	56^{d}	0.2
IVdOM	0.66^{a}	0.62^{b}	0.59^{c}	0.57^{d}	0.002

Within a row means with a common superscript are not significantly different at $P > 0.05$.
[a] HA, herbage allowance; DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; IVdOM, digestibility of offered herbage.
Number of observations for animal related parameters in July and August: 36, in September except for LWG: 32, in September for LWG: 24; for herbage related parameters: 36.

2.3.3 Effect of year

Herbage quality and HM differed between experimental years. CP content and IVdOM were highest in 2006 ($P < 0.001$). In 2005, when NDF and ADF contents were highest, ADL content was lowest but increased over the years ($P < 0.001$; Table 2.4).
Diet digestibility (dOM) was lower in the low rainfall year of 2005 than in the two following years when annual precipitation was comparable to the long-term average ($P < 0.001$). Daily OMI per animal did not differ between years ($P = 0.13$) with 1.15, 1.27, and 1.20 kg/sheep in 2005, 2006, and 2007 respectively. However, daily DOMI as well as MEI

were lower in 2005 (0.64 kg and 9.8 MJ/sheep) compared to 2006 (0.75 kg, $P = 0.015$; 11.5 MJ/sheep, $P = 0.014$) but did not differ from 2007 (0.69 kg, $P = 0.24$; 10.7 MJ/sheep, $P = 0.22$). No difference in OMI per ha was observed between years ($P = 0.22$).

Daily LWG was different between years and was lower in 2005 (60 g/sheep) than in 2006 (101 g/sheep, $P < 0.001$) and 2007 (121 g/sheep, $P < 0.001$). Similarly, LWG per ha was lower ($P < 0.001$) in 2005 (268 g/ha) compared to 2006 (545 g/ha) and 2007 (580 g/ha). The effect of GI on LWG per ha differed between years ($P = 0.003$) and increased significantly in 2006 (146 – 1012 g/d) and 2007 (274 – 852 g/d) whereas in 2005 (124 – 326 g/d) the increase was not significant.

Table 2.4: Effect of year on digestibility of ingested organic matter (dOM), intake of organic matter (OMI), intake of digestible organic matter (DOMI), live weight gain (LWG), intake of metabolizable energy (MEI), herbage mass (HM), and herbage composition (LSMeans ± SE).

Parameter[a]	Year			
	2005	2006	2007	SE
HA (kg DM/kg LW)	8.79	5.04	5.07	0.73
HA (kg DM/kg$^{0.75}$ LW)	21.3	12.2	12.5	1.79
Animal				
dOM	0.55^{a}	0.58^{b}	0.58^{b}	0.004
OMI (kg/d/sheep)	1.15^{a}	1.27^{a}	1.20^{a}	0.04
OMI (kg/d/ha)	5.87^{a}	6.63^{a}	5.80^{a}	0.36
OMI (g/kg $^{0.75}$ LW)	78.5^{a}	88.8^{a}	79.6^{a}	2.93
DOMI (kg/d/sheep)	0.64^{a}	0.75^{b}	0.69^{ab}	0.03
DOMI (kg/d/ha)	3.22^{a}	3.89^{b}	3.34^{ab}	0.20
MEI (MJ/kg$^{0.75}$ LW)	0.67^{a}	0.80^{b}	0.71^{ab}	0.029
MEI (MJ/d/sheep)	9.8^{a}	11.5^{b}	10.7^{ab}	0.37
LWG (g/d/sheep)	60.4^{a}	100.9^{b}	121.0^{c}	6.17
LWG (g/d/ha)	268^{a}	545^{b}	580^{b}	33.2
Herbage				
HM (kg DM/ha)	851^{a}	456^{b}	695^{b}	71
CP (g/kg DM)	92^{a}	135^{b}	123^{c}	2.3
NDF (g/kg DM)	721^{a}	681^{b}	688^{b}	3.5
ADF (g/kg DM)	345^{a}	323^{b}	326^{b}	2.2
ADL (g/kg DM)	44^{a}	45^{a}	49^{b}	0.5
IVdOM	0.59^{c}	0.64^{a}	0.62^{b}	0.003

Within a row means with a common superscript are not significantly different at $P > 0.05$.
[a] HA, herbage allowance; DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; IVdOM, digestibility of offered herbage.
Number of observations for animal related parameters in 2005 and 2007: 36, in 2006 except for LWG: 32, in 2006 for LWG: 24; for herbage related parameters: 48.

2.4 Discussion

2.4.1 Effect of grazing intensity

Effect of grazing intensity on herbage mass and herbage composition

Increasing GI reduces standing HM on offer, an effect which is well established in the literature (Ackerman *et al.* 2001; Animut *et al.* 2005) and also confirmed in our study. On very intensively grazed pastures with sparse vegetation cover the lack of protection against dust storms especially in winter and spring enhances desertification and might reduce grassland productivity on the long-term (Li *et al.* 2000). Moreover, HM on heavily grazed plots (GI 5 and 6) decreased in the present study in September 2006 to a level where survival of sheep could not be ensured anymore and the animals had to be removed from pastures indicating that the impact of intensive grazing might vary between years depending on the amount and distribution of rainfall.

Furthermore, an improved forage quality is expected on pastures with increasing grazing pressure because plant re-growth is enhanced by livestock grazing, the mean age of the plant tissues is reduced and forage is maintained in a more immature state (Roth *et al.* 1990; Schlegel *et al.* 2000). While herbage CP contents as well as IVdOM increased with increasing GI in a study by Schlegel *et al*. (2000) highest CP and IVdOM contents in our study were determined on moderately grazed plots. This indicates that plant re-growth on the very heavily grazed plots could not occur at all or could not compensate for the amount of herbage consumed by sheep, resulting in a declining proportion of leaf mass and hence increasing herbage lignin content. These findings suggest that there is a minimum as well as a maximum GI to achieve a high forage quality as well as a high and sustainable forage production which is in agreement with observations by Sharrow *et al.* (1981) who found highest productivity on moderately stocked pastures. Since the authors found a short-term decline at heaviest GI and a long-term decline of HM at lowest GI they recommended a moderate stocking rate for optimal pasture utilization in a long-term. Based on herbage quality data of our study optimum grazing intensities were determined at moderately grazed plots of GI 3 and GI 4. This would equalize 1.1 to 1.5 sheep, with an average liveweight of 35 kg, per ha per year.

Effect of grazing intensity on organic matter intake and digestibility of ingested herbage

Sheep's OMI of 75 - 88 g/kg$^{0.75}$ LW fits within the range of OMI values given by Cordova *et al*. (1978) for grazing cattle and sheep (40 to 90 g/kg$^{0.75}$ LW) and is similar to the daily feed intake of 74 g/kg$^{0.75}$ LW by sheep described by Moore and Mott (1973). Zoby and Holmes (1983) and Langlands and Bennett (1973) found a linear decline in OMI with increasing GI and also a close relationship between HM and herbage intake of cattle grazing at high GI with low HM on offer was observed (Zoby and Holmes 1983). In contrast, on pastures with sufficient herbage availability no effect of a further increase of HM on feed intake was determined in our study. These results were confirmed by other authors (Allison 1985; Hodgson *et al.* 1982; Langlands and Bennett 1973) who showed that OMI increased asymptotically with increasing HM until a maximum level where it remained independent of further increases in HM. In our study a significant decrease in HM with increasing GI was observed. However, animals' OMI was similar between GI treatments which agrees with results of Ackerman *et al.* (2001) and Animut *et al.* (2006). This could be due to the fact that animals grazing on low productive steppe pastures select for areas with higher biomass concentration rather than for patches of biomass with higher nutrient concentration to maintain a sufficient energy and nutrient intake (Wang *et al.* 2005).

Moreover, CP deficiencies can limit herbage intake (Minson 1990). Many authors revealed a strong relationship between herbage CP contents and OMI (Boval *et al.* 2007; Coleman and Moore 2003). Since dietary CP contents in our study averaged 105 to 122 g/kg DM for animals of all GI treatments and were thus higher than the minimum CP content in the diet of 80 g/kg DM recommended by Coleman and Moore (2003) animals' CP requirements can be assumed to be met and a depression of OMI due to a low herbage CP content is unlikely in our experiment.

Beside the CP content of the herbage, NDF concentrations and dOM are important factors influencing voluntary feed intake because rumen fill remains fairly constant; therefore, differences in the filling effect of ingested herbage and retention time of the fibrous fraction in the rumen determines intake (Allison 1985). Low quality herbage with high in NDF content and low degradation rate reduces passage rate (Ketelaars and Tolkamp 1992). This in turn reduces feed intake due to physical limitation of rumen fill by roughage intake (Van Soest 1994).

Langlands and Bennet (1973) determined a decrease in dOM and OMI with increasing GI. However, no decrease in dOM with increasing GI was detected in our study which agrees with results of Zoby and Holmes (1983). The constant NDF concentration across the treatments in the present study, may explain the similar OMI of sheep of different GI groups despite differences in HM.

Garcia *et al.* (2003) suggested that the ability of sheep to select for higher quality herbage in order to maximise the quality of their ingested diet and to meet their nutritional requirements might offer a possible explanation for a similar dOM across all GI treatments. In particular at light GI with low herbage quality sheep decrease their intake rates and spend more time for selection (Garcia *et al.* 2003; Zoby and Holmes 1983). However, if sheep grazed selectively for higher quality patches, dOM of ingested herbage should be higher than IVdOM of herbage on offer. IVdOM and dOM in our study varied only little between GI treatments and a relationship between dOM and IVdOM was determined ($P < 0.001$; $r^2 = 0.50$; Figure 2.2). This contradicts the assumption of selection. Similarly, Schiborra (2007) found only slight and inconsistent differences in IVdOM of offered herbage in the vertical structure of the sward on ungrazed plots within our study area implicating that only minor selection can occur.

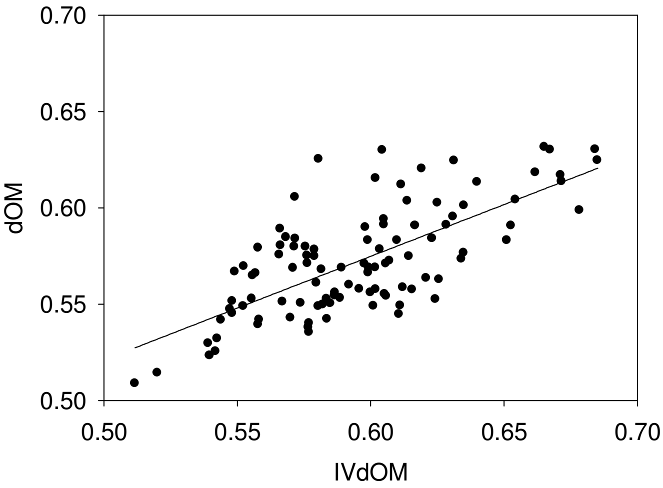

Figure 2.2: Relationship between dOM and IVdOM

Effect of grazing intensity on live weight gain of individual sheep

LWG numerically decreased with increasing GI ($P = 0.34$) which is in accordance with the slight and insignificant differences in OMI between animals in GI 1 and GI 6 treatments. Similarly, a decrease in HM and LWG with increasing stocking rates is often reported in the literature (Ackerman *et al.* 2001; Glindemann *et al.* 2009b; Sharrow *et al.* 1981; Zoby and Holmes 1983). This could be due to the limited herbage availability on heavy grazed pastures with minor proportion of young re-grown and a high proportion of mature plant parts and hence, lower dOM and lower nutrient contents leading to a decrease of herbage quality (Allison 1985; Bryant *et al.* 1970). Besides the nutritive value of herbage the most important factor influencing LWG is the decrease in HM with increasing GI (Animut *et al.* 2005; Animut *et al.* 2006) resulting in a lower OMI and MEI. But only small and insignificant differences in OMI (1.1 – 1.3 kg/d) and MEI (9.6 – 11.7 MJ/d) were observed between GI treatments in our study and therefore explain the minor effect of GI on sheep's LWG. This is in contrast to observations by Wang *et al.* (2009a) who found similar LWG despite higher OMI and MEI of sheep grazing on pastures with higher HM. They assumed that this might be caused by an increased energy demand for walking and selecting reducing energy available for growth.

Effect of grazing intensity on live weight gain per area

Animut *et al.* (2005) stated that LWG per area increases with increasing GI up to a certain point when herbage mass becomes the limiting factor for LWG of the individual animal and in studies by Ackerman *et al.* (2001), LWG per ha increased linearly with increasing GI, suggesting that GI did not exceed the potential increase in LWG per ha at any GI. In our study, a plateau was reached at GI 5 in 2005 and 2007, whereas in 2006, LWG per ha increased continuously. Heavy grazing appears to be profitable for farmers. Since the land still belongs to the government and farmers have only short-term contracts for pastures the current ownership support the common practice of highly intensive grazing irrespective of negative effects on long-term productivity and increasing risk of soil erosion. However, while increasing GI resulted in an increase in LWG per area, LWG per individual animal decreased. Hence, a trade-off exists between LWG per animal and LWG per ha (Ackerman *et al.* 2001; Animut *et al.* 2005; Han *et al.* 2000; Holechek *et al.* 1999). Maximum gain per ha is never achieved when maximum gain per animal is reached (Jones and Sandland 1974). But focusing on the highest possible animal production per area would lead in a long-term (20 to 40 years) to grassland degradation due to soil erosion and changes in the botanical composition of the pasture and thus to decreasing LWG per area (Holechek *et al.* 1999). These long-term consequences due to overgrazing are already well documented (Kawamura *et al.* 2005; Tong *et al.* 2004). The trade-off between LWG per animal and LWG per ha can be determined by two curvilinear regression equations (Han *et al.* 2000). The point where both curves cross is taken as the optimal stocking rate for animal production (Wang *et al.* 2005). Increasing GI from this point onwards negatively influences individual animal performance, HM and sustainability of grassland. Han *et al.* (2000) suggested that experimental determination of this optimal stocking rate can be made within one or two years of grazing experiments. However, Wang (2005) and Fynn and O'Connor (2000) recommended to use either opportunistic stocking rates or data from long-term experiments, to account for the intra- and interannual variability in temperature and precipitation leading to changes in HM and herbage composition, OMI, and LWG. LWG per animal and LWG per ha as well as the intersection between both curves in our study strongly differed between years (Figure 2.3a-b) supporting the recommendations of these authors. Maximum LWG per sheep was found in all experimental years at very light - light-moderate grazed plot. In 2005 LWG per sheep was highest at light, in 2006 at very light, and in 2007 at moderate grazed plots. Contrary, LWG per ha was highest in the two heaviest grazing treatments (GI 5 and GI 6) explaining the farmers interest in a high grazing pressure. It should be noted that in 2006, sheep had to be removed from the pasture in the end of August due to herbage shortage. No intersection was observed in the dry year 2005, whereas the curves intersected at very high grazing intensities in 2007 (Figure 2.3a-b). Thus, short-term experiments such as recommended by Han *et al.* (2000) are not sufficient to give a recommendation for a stocking rate that achieves highest sheep productivity and sustainable rangeland utilization. Rather long-term data of at least 10 years should be collected to account for the annual variability in precipitation to make a useful statement and to determine a range of stocking densities for optimum pasture utilization. The intersection between LWG per sheep and LWG per ha shows an economic optimum for animal production, but does not give any information about ecological consequences. Thus, such high variability in precipitation in this ecosystem leads to annual changes in herbage availability and influences animal performance. On the basis of three-year dataset light-moderate to moderate grazing intensity is recommended by the present study. This grazing experiment is continued to extend the dataset to validate the ecological and economical sustainability of light-moderate to moderate grazing intensity.

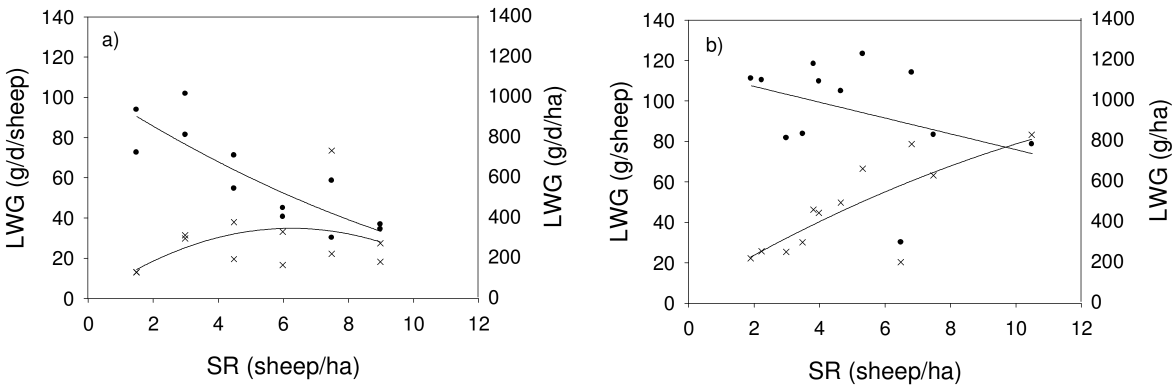

Figure 2.3: Trade-off between LWG per ha (x) and LWG per sheep (●) as influenced by different grazing intensities in a dry year as in 2005 (a) and in a year with average precipitation as in 2007 (b).

2.4.2 Effect of vegetation period

Vegetation period strongly influences HM and herbage quality and decrease as grazing season progresses (Bailey 2004). Intake and digestibility of offered herbage declines with advancing maturity of the plants (Cordova *et al.* 1978; Garcia *et al.* 2003). In our study herbage ADL and NDF contents increased with advancing vegetation period most likely due to forage maturation (Vavra *et al.* 1973; Jung and Sahlu, 1989). Correspondingly, CP content, IVdOM and dOM significantly decreased with progressing vegetation period which is confirmed in studies by Jung and Sahlu (1989) and Garcia *et al.* (2003). A decrease in herbage intake as a result of plant maturation was observed by Langlands and Bennett (1973) and Reardon (1977) and confirmed in the present study from July to August. However, a decrease in September could not be determined most likely due to data missing in 2006 for the two highest GI's. The decreasing nutritive value is also assumed to be the important factor for decreasing LWG with ongoing vegetation period (Animut *et al.,* 2005; Glindemann *et al*., 2009b).

2.4.3 Effect of year

Annual precipitation strongly varied between the study years, resulting in differences in herbage quality, IVdOM, dOM and OMI. Similar observations were reported by Ackerman et al. (2001) and Langlands and Bennett (1973) who found that the effects of GI on dOM differed according to the amount and distribution of annual rainfall. In our study, LWG significantly increased from 2005 until 2007. Lowest LWG per sheep occurred in 2005 associated with lowest dOM and IVdOM, however numerically lower OMI and DOMI in 2007 compared to 2006 did not coincide with highest LWG in 2007 and as mentioned above, probably caused by missing data in September 2006.

The alternating use of pastures in our study might have lowered the effect of heavy grazing on HM, herbage quality, and on animal performance. Schönbach *et al.* (2009) found a strong negative impact of grazing intensity on HM in the same experimental area when analysing continuously grazed plots. Accordingly, strong negative effects of current year grazing on following year's herbage mass are reported. Schönbach *et al.* (submitted) also showed that especially at heavy grazed pastures higher litter accumulation and higher soil coverage in an annual rotating system reduce the risk of erosion and hence, reduce the risk of degradation.

2.5 Conclusions

The results showed that in general intensive grazing does not reduce dOM of ingested herbage, feed intake and hence, growth of individual sheep in the Inner Mongolia steppe, but strongly increases LWG per area and, therefore, income for farmers. Thus, high grazing intensities are more profitable and the current system of land ownership supports the practice of overgrazing. Because of uncertainties in land management the main interests of farmers are the maximisation of short-term concerns. But it is necessary to mention, that the results of this study show short- to mid-term effects only.

However, in dry years or in years with an unequal distribution of rainfall a lack of HM requires the purchase of additional forage for animals at the end of the vegetation period or the untimely sale of animals. Therefore, it can be concluded, that light and moderately grazing intensities can be realized in a sustainable way in a mid-term which agrees with

highest herbage quality at moderately grazed pastures. Furthermore, with increasing GI HM decreased and left the soil with a sparse vegetation cover vulnerable for wind erosion in winter and in spring, whereas higher HM at the end of the grazing season at pastures moderately stocked act as positive factor for grassland and soil protection.
Long-term negative effects of high GI's on grassland productivity may also occur in alternating grassland use systems, therefore, this study is continued to provide further information on long-term effects of intensive livestock.

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Chapter 3 Effect of continuous *versus* daytime grazing on feed intake and growth of sheep in the steppe of Inner Mongolia, China

Abstract

Grazing of livestock has a long history in the Inner Mongolian steppe, China and is still the dominant grassland use. Generally, sheep graze during daytime and are kept in yards over night to protect them and to collect their manure used as fuel. However, this leads to an interruption of the nutrient cycling and might on a long-term negatively impact grassland productivity. Furthermore, reduced grazing time may limit forage intake and performance of sheep. The aim of this study was therefore, to evaluate the impact of continuous 24 h grazing (CG) *versus* the common daytime-grazing (DG) system on herbage mass (HM), feed quality, feed organic matter intake (OMI), and live weight gain (LWG) of sheep in the Inner Mongolian steppe.

The experiments were carried out in 2005, 2006, and 2007 with two replications each on the Inner Mongolia Grassland Experimental Research Station, Xilinhot and measurements were performed in July, August, and September. Titanium dioxide (TiO_2) as a marker were given to the sheep daily during ten days within each month and faecal grab samples were obtained from day 6 to 10. Faeces were analysed for crude protein to estimate the organic matter digestibility (dOM) and for TiO_2 to estimate the total faecal output, and hence the OMI. LWG of all sheep and HM were determined within each month.

HM and herbage quality were not different between treatments. However, as season progressed, herbage's concentration of neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) increased ($P = 0.012$, $P = 0.008$, $P < 0.001$), while HM and crude protein (CP) concentration declined ($P = 0.024$, $P < 0.001$). HM ($P = 0.064$) and herbage quality parameters ($P < 0.05$) were different between years. Digestibility of organic matter (dOM) did not differ between treatments with 0.577 in CG and 0.572 in DG, but decreased from 0.583 in July to 0.558 in September ($P = 0.003$) and differed between years ($P = 0.032$). OMI per sheep and per ha were not influenced by TR and remained fairly constant over the grazing season and study years.

Mean LWG of animals was almost identical in CG (101.5 g/day) and DG (101.8 g/day), but LWG per sheep and LWG per ha differed between grazing periods ($P = 0.004$, $P = 0.005$) and years ($P = 0.001$).

The results show that additional grazing time offered to sheep during night does not lead to an increased feed intake or improved animal productivity. Positive effects of closing the nutrient cycling could not be determined in this study, but are not expected. Our

observations confirm the common practice of penning sheep over night to be an adequate management practice for the pastoralists in the Inner Mongolian steppe.

3.1 Introduction

Worldwide, there are big variations in ruminant production systems including intensive feeding systems with zero-grazing as well as pastoral systems using extensive rangelands. From an economic point of view it is important for all production systems to maximise feed intake in order to minimise feed to live weight gain ratio and to improve productivity (Baumont *et al.* 2000). Daily feed intake is generally assumed to be closely related to total daily foraging time (Newman *et al.* 1995). Allden and Whittaker (1970) and Penning *et al.* (1991a) showed that herbivores compensate a decrease in available fodder by increasing their daily foraging time. Ayantunde *et al.* (2002) and Wigg and Owen (1973) identified positive effects of additional night time grazing on cattle performance and Fernandez-Rivera *et al.* (1996) showed a decrease in forage intake and higher live weight losses when cattle were corralled at night. For grazing sheep that were corralled over night supplementation was necessary in the dry season with concentrate feeds to maintain good animal performance (Ayantunde *et al.* 2000). However, night grazing became common in East (Nicholson 1987; Wigg and Owen 1973) and in West Africa (Ayantunde *et al.* 2002; Bayer 1990) to increase the time available for grazing, to minimise heat stress on the animals and to increase forage intake and, therefore, animal performance. Another benefit of additional night grazing is the deposition of manure on the grassland and its positive effects on the nutrient cycling.

In Inner Mongolia, the use of rangelands by grazing sheep is an important component of agriculture and traditionally nomadic pastoralists moved through large catchment areas. Since the 1950’s the pastoralists settled down and consequently grasslands close to the settlements are used intensively by grazing whereas distant areas are used extensively for hay-making without nutrient reflux. In the common system sheep have access to the pastures during the daytime and are kept in sheep yards at night. Thus, farmers are able to collect the manure for fuel and to prevent animal losses due to theft. An interruption of the nutrient cycling with negative long-term impacts on grassland productivity might occur and grazing restricted to daytime may negatively affect feed intake and animal performance. Considering the increasing number of ruminants in the Inner Mongolian steppe without an increase in grazing land it might be interesting for farmers to change the common practice to day-and-night grazing to use distant land to increase pasture area and implement the rotation between hay-making and grazing with positive effects on the nutrient cycling and thus, the productivity of the grassland. Hence, the present study focused on the effect of a continuous day and night grazing (CG) *versus* daytime grazing (DG) on herbage mass, quality and intake, and live weight gain of sheep in the Inner Mongolian steppe.

3.2 Materials and methods

3.2.1 Study area

The grazing experiment was conducted nearby the Inner Mongolia Grassland Ecosystem Research Station (IMGERS). The station is located in the Xilin river watershed in the autonomous region Inner Mongolia about 600 km north of Beijing (116°42'E; 43°38'N) at an average altitude of 1200 m above sea level and is characterised by a continental, semi-arid climate. The long-term average annual precipitation (1982 – 2003) was 343 mm, 85 % of which occurred in the vegetation period between May and September. However, annual precipitation in the study years in 2005 - 2007 was highly variable with 158 mm in 2005, 312 mm in 2006, and 367 mm in 2007 (Figure 3.1). The daily mean annual air temperature in 2005 – 2007 was 0.7°C ranging from -21.2°C in January to 19.0°C in July. The vegetation periods last for approximately 150 with only 100 days without frost. Climatic data were provided by the Institute of Botany, Chinese Academy of Sciences (IB-CAS), Beijing and measured at IMGERS.

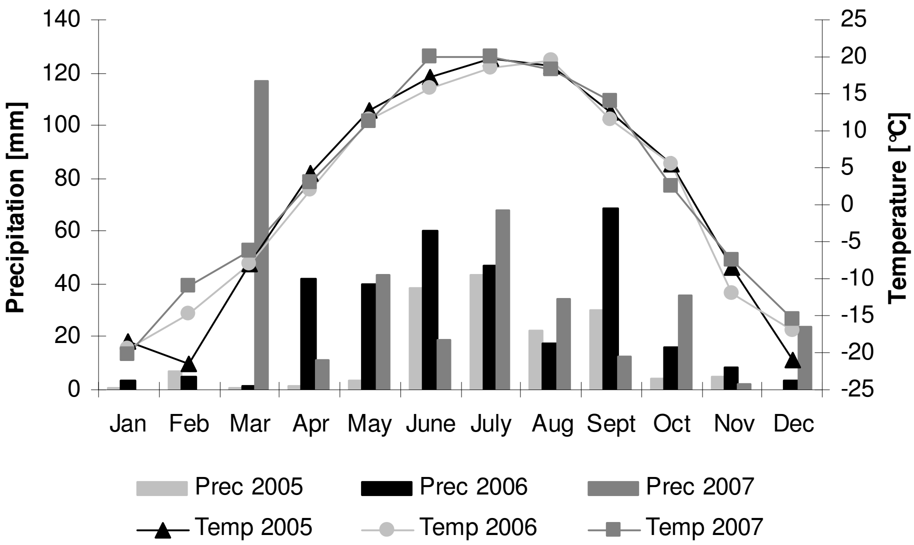

Figure 3.1: Monthly precipitation (mm, bars) and air temperature (°C, lines) in 2005 – 2007

The experimental site is located within the typical steppe zone (Yu *et al.* 2004). Dominant plant species are C_3-grasses, including the perennial bunchgrass *Stipa grandis* and the perennial rhizome grass *Leymus chinensis* (Bai *et al.* 2004; Xiao *et al.* 1995). Plant species composition on the continuous and daytime grazing plots is given in Table 3.1. The dominant soil type is classified as Chestnut and Calcic Chernozem (IUSS 2007).

Table 3.1: Diversity of plant species on the continuous and daytime grazing plots, means and standard deviation (SD) of above ground dry matter herbage mass in percentages determined at the beginning of July (means of the years 2005-2007).

Plant species	Continuous grazing				Daytime grazing			
	Flat		Slope		Flat		Slope	
	Means	SD	Means	SD	Means	SD	Means	SD
Stipa grandis	22.7	5.8	28.2	4.8	22.1	8.6	17.4	3.2
Leymus chinensis	28.9	19.6	28.8	10.6	37.4	17.9	29.8	16.9
Achnatherum sibiricum	0.1	0.2	2.1	0.2	0.3	0.5	1.8	2.6
Agropyron michnoi	19.0	7.8	14.5	7.7	4.3	2.5	24.3	5.8
Carex korshinskyi	6.8	4.3	8.2	5.7	8.0	4.0	4.4	1.5
Cleistogenes squarossa	10.8	8.5	7.8	4.8	10.8	4.2	4.5	1.8
Others	11.8	9.2	10.3	8.5	17.2	12.8	17.7	16.3

3.2.2 Experimental design

During the grazing seasons which last from mid of June to mid of September of 2005, 2006, and 2007 two grazing treatments (TR), continuous grazing (CG) and daytime grazing (DG), were tested with two replications each evenly allotted to two blocks, the flat and the moderately slope area to account for any heterogeneity of the study area. CG sheep were allowed to graze continuously 24 h per day throughout the grazing seasons whereas DG sheep were allowed to graze during daytime only and were kept in a pen without herbage cover from sunset to sunrise. Sunrise was at 0400 am in July, at 0430 am in August, and at 0500 am in September. Sunset was at 2030 pm in July, 2000 pm in August, and 1900 pm in September. Therefore, grazing time lasted 16.5 h in July, 15.5 h in August, and 14 h in September. Experimental measurements took place in the beginning of each month in July, August, and September, respectively. The grazing season lasted for 98, 90, and 93 days in 2005, 2006, and 2007, respectively. The size of the experimental plots was two hectares (ha). Grazing plots were used for hay-making in the preceding years. The plots were grazed at a moderate herbage allowance (HA) level with 5.3, 2.6 and 4.6 kg dry matter (DM) /kg live weight (LW) in 2005, 2006, and 2007, respectively. In 2005 and 2006, nine sheep per plot were used. In 2007 the number of sheep per plot was adjusted monthly to the actual herbage mass on offer in order to achieve a moderate HA level over the vegetation period. On average eight sheep per plot were used. The details of the experimental scheme are given in Table 3.2.

Table 3.2: Experimental schema over the three years 2005 – 2007.

		Year of experiment											
		2005				2006				2007			
		period				period				period			
	TR	June[1]	July	Aug.	Sept.	June[1]	July	Aug.	Sept.	June[1]	July	Aug.	Sept.
Herbage mass on offer	CG	830	999	716	499	348	450	283	210	554	494	698	813
(kg DM/ha)	DG	675	891	852	575	535	503	475	284	733	610	837	503
Live weight (LW)	CG	29.9	32.9	34.7	36.2	31.6	33.6	37.0	37.5	31.4	34.1	36.5	41.3
(kg/animal)	DG	31.7	34.3	36.0	37.8	31.4	34.7	39.1	37.6	31.9	33.9	37.3	40.9
Stocking rate	CG	-	4.5	4.5	4.5	-	4.5	4.5	4.5	-	3.5	3.8	4.0
(sheep/ha)	DG	-	4.5	4.5	4.5	-	4.5	4.5	4.5	-	5.0	3.8	4.0
Grazing period	CG	-	30	28	35	-	26	30	31	-	28	30	31
(days)	DG	-	30	28	35	-	26	30	31	-	28	30	31
Herbage allowance	CG	-	6.4	5.4	3.7	-	2.6	2.3	1.4	-	4.9	4.1	5.2
(kg DM/kg LW)	DG	-	5.5	5.7	4.4	-	3.7	3.6	2.5	-	4.2	5.7	4.5
Herbage allowance	CG	-	15.8	14.0	9.5	-	6.5	5.7	3.6	-	12.1	8.4	11.3
(kg DM/kg$^{0.75}$ LW)	DG	-	12.6	13.4	10.6	-	8.4	7.3	5.5	-	10.5	14.0	11.5

[1] adaptation period
DM, dry matter; LW, live weight

3.2.3 Animals and animal management

In this study non-pregnant, non-lactating female sheep of the local breed "Mongolian fat-tailed sheep" were used. The sheep were approximately 15 months old in the beginning of the trials in each year. Before the experiments started, the sheep were weighed, ear-tagged, treated against internal and external parasites and randomly allocated to the four experimental plots. After the first sampling period in July, the treatment against parasites was repeated. After an adaptation period of approximately 10 days on the plots, the individual animal weights were determined on two consecutive days. They averaged 31.3 kg ± 0.53 over all three years. All sheep were weighed again on two consecutive days after every sampling period to determine monthly live weight gain (LWG) for each period. In 2006, no weight data were available in September, because of an early onset of winter resulting in additional hay feeding on the plots. CG sheep had continuous access to water and mineral lick stones, whereas DG sheep had access to water and minerals during daytime only.

3.2.4 Determination of feed intake and digestibility

In the beginning of each annual experiment six sheep were randomly chosen in each plot and used to determine digestibility of ingested herbage, feed intake and LWG. On 10 consecutive days per sampling period (days 1 – 10 in July, August, and September), the selected sheep were orally dosed a gelatine capsule containing 2.5 g titanium dioxide (TiO_2) as an inert marker. Dosing was carried out at the same time each day and immediately after dosing, faecal grab samples were obtained from rectum on days 6 - 10. Faecal samples of each animal were pooled and analysed for crude protein (CP) and organic matter (OM) concentration to estimate OM digestibility (dOM) according to the regression equation of Wang *et al.* (2009b).
OM intake (OMI) was estimated by dOM of ingested feed and by the faecal organic matter output. The latter was calculated based on the TiO_2 concentration in faecal OM assuming a faecal recovery of TiO_2 of 100 % (Glindemann *et al.* 2009). Intake of digestible organic matter (DOMI) was calculated by multiplying OMI with dOM.

3.2.5 Herbage mass, botanical composition and laboratory analyses

Concomitant to faeces collection, herbage mass (HM) was measured in each plot by clipping herbaceous plants within three representative areas (each 0.5 m^2) to 1 cm stubble height.

The herbage samples were pooled, dried at 60°C for 24 h and weighed. After grinding to pass a 1 mm sieve by a Cyclotec Mill (Tecator, Sweden), samples were analysed by Near Infrared Reflectance Spectroscopy (NIRS) for neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), crude protein (CP), dry matter (DM), organic matter (OM), cellulase digestible organic matter (CDOM), and metabolizable energy (ME). The calibration (2005: n = 138, 2006: n = 44, 2007: n = 31) and validation (2005: n = 25, 2006: n = 10, 2007: n = 15; Schönbach *et al.,* 2009 and personal communication) of NIRS was carried out by laboratory analyses of subsets of the herbage samples. DM concentration was determined by drying at 105°C to constant mass. OM concentration was calculated as the difference between dry sample weight and the residue weight (ash) after incineration of the sample at 550°C over night. CP concentration was calculated from nitrogen (N) concentration (CP = N x 6.25), which was analysed by a C/N-analyser based on the DUMAS-combustion method (vario Max CN, Elementar Analysensysteme, Hanau, Germany). NDF, ADF, and ADL were analysed sequentially by semi-automatic ANKOM 200 Fiber Analyzer (Ankom technology, Macedon, NY, USA) according to the procedures described by Van Soest *et al.* (1991). EULOS was estimated by the pepsin-cellulase technique described by De Boever *et al.* (1986) and used to calculate IVdOM by the equation of Weissbach *et al.* (1999). Faecal samples were frozen immediately after collection and samples taken from each sheep on the five sampling days were pooled and homogenised. One sub-sample was frozen to analyze N, DM and OM concentration. The other sub-sample was oven-dried at 60°C for 36 h, ground to pass a 1 mm screen and analysed for TiO_2 concentration using the procedure of Brandt and Allam (1987) modified by Glindemann *et al.* (2009). In 2005 and 2006, samples of each sheep were analysed for TiO_2 concentration individually with repeated determination. To reduce the number of samples analyses were simplified in the following year, the evaluation took place on a plot level. Samples of the six sheep per plot were pooled in 2007 and analysed with three replicates each.

3.2.6 Statistical analysis

Data were analysed using mixed model procedures of SAS version 9.1 (SAS 2000). The model included the fixed effects year (Y), block (B), and treatment (TR) and the repeated effect period (P). Interactions TR x P, TR x Y and TR x P x Y were also analysed. For analysing the data obtained from the animals and from the herbage samples the subsequent model was used:

$$Y_{ijkl} = \mu + Y_i + B_{ij} + TR_{ijk} + P_{ijkl} + TR_{ijk}*P_{ijkl} + TR_{ijk}*Y_i + TR_{ijk}*P_{ijkl}*Y_i + e_{ijkl}$$

where μ is the overall Means, Y_i year (2005, 2006, and 2007), B_{ij} block (flat and slope area), TR_{ijk} treatment (continuous and daytime grazing), P_{ijkl} period (July, August, and September). Probabilities for all effects and their interactions were determined. Heterogeneous auto-regression covariance structure was chosen. When effects were significant ($P < 0.05$), Tukey's t Test was used to test differences of least square means.

3.3 Results

3.3.1 Herbage mass and chemical composition

HM and chemical composition during the vegetation period from June to September for the experimental years 2005, 2006, and 2007 are shown in Table 3.3. HM and herbage quality parameters were not influenced by TR ($P > 0.05$; Table 3.4). However, as season progressed, herbage's concentration of NDF, ADF, and ADL increased ($P = 0.012$, $P = 0.008$, $P < 0.001$), while CP concentration and IVdOM declined from 141 g/kg and 0.670 in June to 103 g/kg and 0.584 in September ($P < 0.001$). Due to different climatic conditions the effect of period on TR varied among years. HM was also different between periods ($P = 0.024$). A threefold interaction of TR x year x period on HM ($P = 0.022$) was observed but it seemed not appropriate to further discuss it. HM tended to be different between years ($P = 0.064$), whereas herbage quality parameters were affected by year ($P < 0.05$).

Table 3.3: Herbage mass (HM), concentration of organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) as well as in vitro digestibility of organic matter (IVdOM) in June, July, August, and September in 2005, 2006, and 2007 on continuously (CG) and daytime (DG) grazed pastures (LSMeans ± SE).

		2005					2006					2007					2005-2007
		period					Period					period					
	TR	June	July	Aug.	Sept.	Mean	June	July	Aug.	Sept.	Mean	June	July	Aug.	Sept.	Mean	
HM	CG	830	999	716	499	761	348	450	283	210	323	594	529	494	870	622	569
(kg DM/ha)	DG	675	891	852	575	748	535	503	475	284	449	785	653	896	538	718	639
	SE	130	152	177	108	122	130	152	177	108	122	130	152	177	108	122	70
OM	CG	941	944	944	948	944	915	926	931	925	924	934	933	932	943	935	935
(g/kg DM)	DG	944	948	949	947	947	925	922	928	943	930	942	938	944	939	941	939
	SE	6.0	4.3	3.1	3.6	2.7	6.0	4.3	3.1	3.6	2.7	6.0	4.3	3.1	3.6	2.7	1.5
CP	CG	106	101	87	82	94	168	153	144	124	147	171	127	129	104	133	125
(g/kg DM)	DG	102	93	89	79	90	157	136	117	123	133	142	112	130	105	122	115
	SE	12.7	5.7	7.8	9.5	7.3	12.7	5.7	7.8	9.5	7.3	12.7	5.7	7.8	9.5	7.3	4.2
NDF	CG	703	725	724	722	719	661	656	690	688	674	657	692	702	701	688	694
(g/kg DM)	DG	701	736	735	716	722	672	675	685	681	678	686	700	708	674	692	697
	SE	14.0	5.6	11.1	5.1	5.4	14.0	5.6	11.1	5.1	5.4	14.0	5.6	11.1	5.1	5.4	3.1
ADF	CG	337	336	342	341	339	315	310	320	331	319	301	322	332	347	325	328
(g/kg DM)	DG	330	348	352	350	345	332	327	329	317	326	318	326	339	328	328	333
	SE	10.5	4.0	8.4	6.0	5.8	10.5	4.0	8.4	6.0	5.8	10.5	4.0	8.4	6.0	5.8	3.3
ADL	CG	31.3	40.9	49.6	50.4	43.0	35.5	37.9	53.3	51.1	44.4	37.1	47.4	52.2	57.9	48.7	45.4
(g/kg DM)	DG	33.0	41.1	51.4	48.5	43.5	34.7	41.0	43.6	52.6	42.9	39.9	50.6	57.1	54.3	50.5	45.6
	SE	1.4	2.4	2.1	0.9	1.2	1.4	2.4	2.1	0.9	1.2	1.4	2.4	2.1	0.9	1.2	0.7
IVdOM	CG	0.65	0.60	0.58	0.56	0.60	0.70	0.67	0.62	0.61	0.65	0.69	0.62	0.59	0.56	0.61	0.62
	DG	0.64	0.57	0.55	0.57	0.58	0.69	0.65	0.64	0.61	0.65	0.66	0.63	0.59	0.59	0.62	0.62
	SE	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01

DM, dry matter

Table 3.4: Levels of significance of the effects of TR on herbage mass (HM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), and in vitro digestibility of OM (IVdOM).

	Level of significance[ab]						
	TR	period	year	block	TR*P	TR*year	year*TR*P
HM	n.s.	*	0.06	n.s.	*	n.s.	*
OM	0.09	0.06	**	n.s.	n.s.	n.s.	0.05
CP	n.s.	***	**	n.s.	n.s.	n.s.	**
NDF	n.s.	*	***	**	**	n.s.	*
ADF	n.s.	**	*	0.07	**	n.s.	n.s.
ADL	n.s.	***	**	0.06	n.s.	n.s.	**
IVdOM	n.s.	***	**	*	n.s.	n.s.	0.08

[a] $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, n.s. not significant.
[b] TR, treatment; P, period.

3.3.2 Herbage digestibility and intake

Digestibility of OM (dOM) was not different between TR with 0.577 in CG and 0.572 in DG (Table 3.5). As vegetation period proceeded, dOM for both TR decreased from 0.583 in July to 0.558 in September *(P* = 0.003, Table 3.6 and 3.7). Differences were also observed between years (*P* = 0.032) with 0.554, 0.580, and 0.587 for both TR in 2005, 2006, and 2007, respectively.

OM intake (OMI) per sheep with 1.23 kg/d (CG) and 1.20 kg/d (DG) and OMI per ha with 5.31 kg/d (CG) and 5.32 kg/d (DG) were not influenced by TR. Likewise, there was no difference in OMI per $kg^{0.75}$ LW with 85 g/$kg^{0.75}$ LW (CG) and 81 g/$kg^{0.75}$ LW (DG). OMI per sheep and OMI per ha remained fairly constant over the grazing season. However, OMI per $kg^{0.75}$ LW varied between grazing seasons (*P* = 0.010) with the highest intake in July, decreasing to the following period (*P* = 0.007) and similar to the last period (*P* = 0.82; Table 3.5). No differences in OMI per sheep and OMI per ha as well as OMI per $kg^{0.75}$ LW were observed between years (*P* = 0.230*, P* = 0.138 and *P* = 0.178; Table 3.6).

A close relationship between NDF concentration of herbage and OMI per sheep was detected (*P* < 0.001; r^2 0.294; Figure 3.2). The respective equation did not differ between both treatments.

Table 3.5: Digestibility of organic matter (dOM), organic matter intake (OMI), digestible organic matter intake (DOMI) per sheep and per ha, and live weight gain (LWG) per sheep and per ha during the periods July, August, and September in 2005, 2006, and 2007 in continuously (CG) and daytime (DG) grazed pastures (LSMeans ± SE).

			2005				2006				2007				2005-2007
			period				period				period				
	TR		July	Aug.	Sept.	Mean	July	Aug.	Sept.	Mean	July	Aug.	Sept.	Mean	
dOM	CG		0.56	0.56	0.54	0.55	0.63	0.58	0.62	0.59	0.57	0.63	0.58	0.59	0.58
	DG		0.57	0.56	0.55	0.56	0.62	0.56	0.55	0.58	0.56	0.61	0.59	0.58	0.57
		SE	0.010	0.009	0.014	0.008	0.010	0.009	0.014	0.008	0.009	0.014	0.008	0.008	0.005
OMI	CG		1.09	1.21	1.11	1.14	1.48	1.29	1.37	1.38	1.15	1.12	1.26	1.18	1.23
(kg/d/sheep)	DG		1.10	1.07	1.31	1.10	1.48	1.17	1.30	1.32	1.13	1.19	1.27	1.20	1.20
		SE	0.08	0.14	0.18	0.12	0.08	0.14	0.18	0.12	0.08	0.14	0.18	0.12	0.07
OMI	CG		79.9	84.3	76.5	80.2	108.6	87.9	91.8	96.1	81.5	74.1	76.5	77.4	84.6
(g/kg$^{0.75}$ LW)	DG		76.7	71.9	73.3	74.0	105.4	76.1	86.8	89.5	81.5	79.9	80.3	80.6	81.3
		SE	6.20	9.33	10.59	7.69	6.20	9.33	10.59	7.69	6.20	9.33	10.59	7.69	4.44
OMI	CG		4.92	5.43	5.02	5.12	6.68	5.80	6.15	6.21	3.98	4.82	5.04	4.61	5.31
(kg/d/ha)	DG		4.94	4.82	5.09	4.95	6.67	5.25	5.85	5.92	5.66	4.47	5.12	5.08	5.32
		SE	0.43	0.78	0.67	0.54	0.43	0.78	0.67	0.54	0.43	0.78	0.67	0.54	0.31
DOMI	CG		0.62	0.67	0.60	0.63	0.92	0.75	0.75	0.81	0.65	0.71	0.73	0.70	0.71
(kg/d/sheep)	DG		0.62	0.60	0.61	0.61	0.91	0.65	0.72	0.76	0.64	0.72	0.75	0.70	0.69
		SE	0.04	0.08	0.10	0.07	0.04	0.08	0.10	0.07	0.04	0.08	0.10	0.07	0.04
DOMI	CG		2.78	3.01	2.70	2.83	4.16	3.39	3.40	3.65	2.25	3.03	2.91	2.73	3.07
(kg/d/ha)	DG		2.79	2.69	2.76	2.75	4.08	2.93	3.24	3.42	3.19	2.70	3.00	2.96	3.04
		SE	0.22	0.46	0.40	0.30	0.23	0.42	0.41	0.29	0.23	0.42	0.41	0.29	0.18
LWG	CG		96.7	62.3	34.0	64.3	115.6	110.6	n.d.[2]	113 [1]	146.7	104.9	145.5	132.3	102 [1]
(g/d/sheep)	DG		79.6	62.8	48.5	63.7	171.6	140.5	n.d.[2]	156 [1]	100.2	100.1	112.5	104.3	102 [1]
		SE	8.4	13.6	10.5	8.2	8.4	13.6	-	-	8.4	13.6	10.5	8.2	-
LWG	CG		435	280	153	289	520	498	n.d.[2]	509 [1]	513	447	582	514	420 [1]
(g/d/ha)	DG		358	283	218	286	772	632	n.d.[2]	702 [1]	501	372	450	441	448 [1]
		SE	37	58	39	24	37	58	-	-	37	58	39	24	-

[1] arithmetic means; [2] n.d = not determined; n= 12 sheep

Table 3.6: Significance levels of the effects of grazing system on digestibility (dOM), organic matter intake (OMI), digestible organic matter intake (DOMI), and live weight gain (LWG) per sheep and per ha.

		Level of significance[ab]						
		year	block	TR	period	TR*P	TR*year	year*TR*P
dOM	(g/g)	*	n.s.	n.s.	**	n.s.	n.s.	***
OMI	(kg/d/sheep)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
OMI	(g/kg $^{0.75}$ LW)	n.s.	n.s.	n.s.	**	n.s.	n.s.	0.08
OMI	(kg/d/ha)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DOM	(kg/d/sheep)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*
DOMI	(kg/d/ha)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LWG	(g/d/sheep)	**	0.09	n.s.	**	n.s.	*	*
LWG	(g/d/ha)	***	**	n.s.	**	n.s.	*	*

[a] *P* < 0.05, ** *P* < 0.01, *** *P* < 0.001, n.s. not significant.
[b] TR, treatment; P, period.

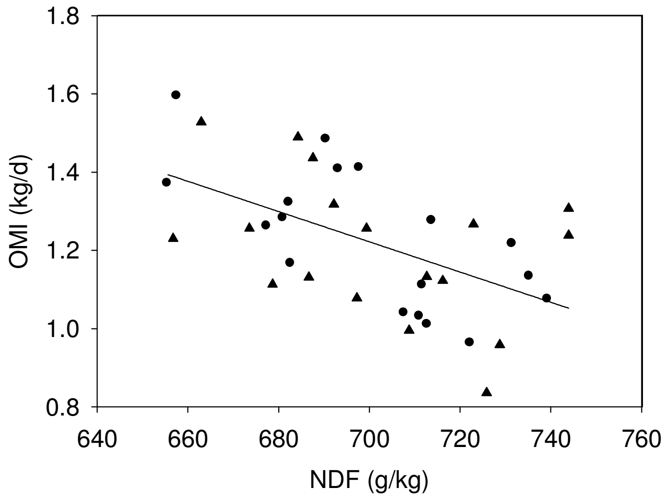

Figure 3.2: Relationship between OMI of sheep of both treatments and NDF concentration of herbage (● = CG; ▲= DG), OMI = – 3.93 + 0.004 x NDF.

Table 3.7: Effects of vegetation period on digestibility (dOM), organic matter intake (OMI), digestible organic matter intake (DOMI), and live weight gain (LWG) per sheep and per ha (LSMeans ± SE).

		period								
		July		SE	August		SE	September		SE
dOM	(g/g)	0.583	a	0.004	0.580	a	0.004	0.558	b	0.006
OMI	(kg/d/sheep)	1.24	a	0.03	1.17	a	0.06	1.24	a	0.07
OMI	(g/kg $^{0.75}$ LW)	88.9	a	2.5	79.0	b	3.8	80.9	ab	4.3
OMI	(kg/d/ha)	5.47	a	0.18	5.10	a	0.32	5.38	a	0.27
DOM	(kg/d/sheep)	0.73	a	0.02	0.68	a	0.03	0.69	a	0.04
DOMI	(kg/d/ha)	3.21	a	0.09	2.96	a	0.19	3.00	a	0.16
LWG	(g/d/sheep)	118	a	3	97	b	6	85		[1]
LWG	(g/d/ha)	517	a	15	419	b	24	351		[1]

Within a row Means with a common superscript are not significantly different at $P > 0.05$

[1] no standard error could be estimated due to missing values in September 2006

3.3.3 Live weight gain

Overall mean LWG of the animals was almost identical in CG (101.5 g/day) and DG (101.8 g/day; Table 3.5). LWG per sheep and LWG per ha differed between sampling periods *(P* = 0.004, *P* = 0.005), and were higher in the first than in the second period. In 2005, LWG decreased from the first continuously to the last period (*P* = 0.005). In 2006, no BW data were available for the last period, because of an early onset of winter and the resultant necessity to take the sheep of the plots. However, in 2007 no differences could be observed for LWG. Moreover, LWG differed between years *(P* = 0.001) and a significant interaction between TR and year on LWG per sheep and LWG per ha were observed *(P* = 0.026, *P* = 0.019). As expected from the relationship between NDF concentration and OMI, LWG was negatively affected by herbage NDF concentration ($P = 0.001$; $r^2 = 0.290$; Figure 3.3).

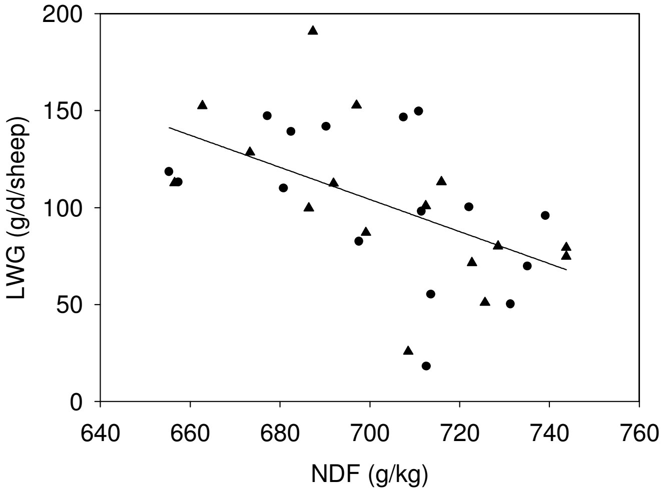

Figure 3.3: Relationship between LWG of sheep of both treatments and NDF concentration of herbage (● = CG; ▲= DG), LWG = 684.02 - 0.83 x NDF.

3.4 Discussion

3.4.1 Herbage mass and chemical composition

Additional grazing of sheep during night on pasture did not have a significant influence on HM and, because of similar OM intake, on herbage growth. The larger amounts of nutrients excreted by animals when present on pastures at night did not affect plant growth or composition, probably due to the following two reasons: (i) it could clearly be shown that water is the first limiting factor for herbage growth in this region (Xiao *et al.* 1995), and in experiments on the same experimental area with irrigation and N-fertilization Gong (personal communication). (ii) Furthermore, at night, sheep stay most of the time close together in certain places of the plots, preventing an even distribution of excreted nutrients. The effect of vegetation period on HM and herbage quality varied between years probably due to annual variation in precipitation. In 2005, precipitation was very low with only 158 mm compared to 312 mm in 2006 and 367 mm in 2007 causing a serious drought. This had a severe influence on the productivity of the grassland (Bai *et al.* 2004; Schönbach *et al.* 2009; Xiao *et al.* 1995). High temperatures in combination with lower soil moisture not only affect the grassland productivity but also the herbage quality by a rapid maturation of plants.

Plant development stage influenced herbage quality and led to a decrease in CP concentration as vegetation period progressed which was also observed in other studies by Minson (1990) and in studies in the same experimental area by Schiborra (2007). CP concentration averaged 129 g/kg DM in the studies of Minson (1990) and ranged between

87 and 156 g/kg DM on the same experimental sites in the studies of Schiborra (2007). In the present study, CP concentration of the offered herbage averaged 120 g/kg DM, decreasing from 141 to 102 g/kg DM with advancing vegetation period. These values were consistently above 60-80 g/kg DM which is regarded as the minimum concentration for grazing sheep fed at maintenance level (Minson 1990; Van Soest 1994). Therefore, it is unlikely that the variations in CP concentration led to nitrogen deficiencies for rumen microbial activity and, as a consequence, affected digestibility of the diet (Van Soest 1994) or feed intake (Moore and Mott 1973). With advancing maturity, NDF and ADL concentration increased and IVdOM declined. Van Soest (1994) found a relationship between lignification and digestibility of forages, which supported earlier findings of Moore and Mott (1973) or very recent ones of Schiborra (2007) and Schönbach *et al.* (2009) in the same experimental area.

3.4.2 Digestibility of ingested herbage

The results of digestibility of ingested herbage show that diets selected during the daytime did not differ from that selected by sheep having additional time for grazing at night ($P = 0.45$). Similar findings were reported for cattle (Ayantunde *et al.* 2001; Iason *et al.* 1999; Nicholson 1987). This could be due to the fact that (i) herbage quality was similar in both treatments and/or that (ii) sheep in both treatments did not select. Similar species composition in all swards and the low variability of digestibility of the swards in our experiment limited animals' possibility to select plants of different quality, suggesting that selection did not play a major role. Moreover, only slight and inconsistent differences in digestibility in the vertical structure of the sward exists in ungrazed plots within our study area (Schiborra 2007) underlining the assumption of limited selection. Additionally, IVdOM was mostly higher than dOM, which further contradicts the assumption of selection of higher digestible plant tissues or species. In swards with high plant heterogeneity and low forage availability it is necessary for animals to graze selectively in order to maintain diet quality (Breman *et al.* 1978; Garcia *et al.* 2003). Also high selection for material with the highest N concentration was observed in grazing sheep consuming diets that were inadequate in energy (Arnold 1960; Ramirez 1999).

In our study, relatively small but significant differences in the digestibility of ingested herbage were found between vegetation periods, which are typical for swards dominated by annual grasses (Ayantunde *et al.* 2001). NDF and ADL concentrations increased with proceeding sampling period resulting in a decrease in dOM, which is in agreement with measurements of in vitro digestibility (see section 3.4.1).

3.4.3 Organic matter intake

Different authors revealed that additional grazing time at night lead to an increase in forage intake (Ayantunde *et al.* 2000; Fernandez-Rivera *et al.* 1996; Nicholson 1987). These observations could not be confirmed in the present study. This could be due to the fact that sheep continuously present on pastures decreased their intake during daytime in exchange for grazing at night (Ayantunde *et al.* 2002). According to several studies two main grazing periods exist: the first near dawn in the morning until midday and the second in the evening close to sunset (Van Soest 1994). In several studies where animals had the possibility for night grazing they did not show significant grazing activity at night (Arnold 1985; Ayantunde *et al.* 2002; Champion *et al.* 1994; Penning *et al.* 1991b). Prache *et al.* (1998) assumed that sheep graze rapidly in the morning to avoid night grazing. These findings were confirmed by observations in our experimental area (Lin, personal communication) where grazing behaviour of sheep was measured by chewing activity recorders, showing that sheep did hardly graze during darkness. Similarly, Hughes and Reid (1951) reported that 95 – 100 % of the time sheep spent grazing was observed during daylight from June to August and declined to 60 % in December. It is necessary to note that in the present study the time available for grazing ranged from 14 to 16.5 h/d for DG sheep, which is higher than the average grazing time of 9.5 h/d of free-ranging beef cattle as given by Arnold and Dudzinski (1978) on the basis of a literature review.

In contrast, several authors reported that additional night grazing can become an important factor for intake, if forage availability is limited. These findings were made by Iason *et al.* (1999) with un-restricted *versus* time-restricted grazing sheep having access to taller or shorter swards. Joblin (1960) stated that night grazing can make an important contribution to animal performance if forage quality is low, whereas, in moderate to high quality forage no differences in feed intake were observed.

However, if grazing time is the limiting factor for feed intake, animals are able to adapt their behaviour and graze more efficiently, by increasing bite mass due to heavier bites, and by spending less time per bite (Prache *et al.* 1998), by reducing mastication rates (Prache 1997; Prache *et al.* 1998) or increasing intake rates (Ayantunde *et al.* 2001; Greenwood and Demment 1988; Newman *et al.* 1995). Iason *et al* .(1999) and Smith (1961) reported that ruminants with restricted grazing time increased their intake rate for longer periods without interruption and delayed their resting and ruminating activities until night. Similarly, studies with tethered goats (Romney *et al.* 1996) showed the ability of animals to change their behaviour in response to restricted access to grazing in order to maintain herbage intake by increasing their intake rate and by spending proportionally more time for grazing. Moreover, sheep are able to learn which amount of forage causes minimal total discomfort by using information from a certain feeding period to instruct their behaviour in following feeding periods (Forbes 2001; 2009).

OMI in the present experiment averaged 83 g OM/kg$^{0.75}$ LW (1.2 kg OM/d). This is relatively high compared to 74 g OM/kg$^{0.75}$ LW suggested by Moore and Mott (1973) as a daily consumption level of standard forage for sheep, 75.9 g OM/kg$^{0.75}$ LW (ranging from 51 - 119 g OM/kg$^{0.75}$ LW) observed by Pfander (1970), and 70 g OM/kg$^{0.75}$ LW found by Reid *et al.* (1988) for rations of C_3 and C_4 grasses with NDF concentrations of 560 and 720 g/kg DM, respectively. In particular, in forages with low quality and high fibre concentrations structural volume as well as restricted capacity of the digestive tract act as limiting factor for feed intake (Mertens 1994). Vallentine (2001) suggested that animals' intake capacity reaches a plateau and cannot be further increased due to the low digestibility of the offered herbage, which results in longer retention times and slow passage rates of ingested herbage.

Baumont *et al.* (2004) found that the NDF concentration of the sward is the most sensitive parameter affecting daily intake. A reduction in feed intake with increasing fibre concentration observed in different studies confirms our findings (Figure 3.3). But daily feed intake in our study still remained at a high level. Similar findings of a high intake even at high NDF concentration of the forage were reported by Schlecht *et al.* (1999), who referred that ruminants under semi-arid range conditions are able to maintain a high intake level by adaption mechanism to low quality feed.

In contrast to findings of Ayantunde *et al.* (2001), who reported a decrease in forage intake with proceeding vegetation period due to a decrease in herbage availability, no significant influence of the vegetation period on OMI was determined in our study. This could be due to a compensatory response to declining HM with proceeding vegetation period. This was shown by Hodgson (1985), who stated that ruminants increase their biting rate during grazing or by Bayer (1990), who reported an increase of grazing time in response to low forage availability up to 7.8 h in his study and up to 13 h in other studies. This is still within the range of grazing time available to sheep in the present study. Arnold (1981; 1985) reported about the ability of sheep to adjust their grazing behaviour to climatic conditions to be able to maintain feed intake and demonstrated how diurnal grazing patterns changed with day length.

3.4.4 Live weight gain

LWG per sheep and LWG per ha was not different between TR which confirms results of others studies by Nicholson (1987) and Bayer (1990). In contrast, other authors revealed that animal performance decreases when grazing time is restricted (Ayantunde *et al.* 2002;

Kyomo *et al.* 1972; Wigg and Owen 1973). However, Ayantunde *et al*. (2001) and Joblin (1960) found that in periods with low herbage availability additional time for grazing at night becomes an important factor for feed intake. Furthermore, no differences between TR were observed in forage and energy intake, suggesting that time for grazing during the daytime was not likely to be a major factor limiting animal productivity. This assumption is confirmed by Smith (1961), who found no further feed intake of sheep that are allowed to graze at least 11 h per day. Sheep in the DG treatment in the present study were allowed to graze 14 – 16.5 h.

While energy intake and DOMI were not influenced by vegetation period, LWG decreased with advancing vegetation period. Although, the influence was not significant, this leads to the assumption that with proceeding vegetation period and decreasing HM more energy is required for walking and other grazing activities. Lachica and Aguilera (2005) observed longer grazing times and hence, increasing walking times in pastures with low herbage availability which resulted in higher energy demand for activity in sheep. This is confirmed by Lin (personal communication) who observed increasing grazing times and decreasing LWG of sheep on pastures with higher grazing intensity and decreasing herbage availability in our experimental area. Other authors reported longer mastication and ruminating times with decreasing quality of ingested herbage, which also increases energy demand. However, comparing two different grazing systems in our experimental area, Wang *et al.* (2009a) and Lin (personal communication) concluded that sheep grazing larger areas with higher forage quality have the possibility to select more palatable herbage and increase their energy intake. They walked longer distances and spent less time for ruminating and more time for grazing, resulting in higher energy requirements.

3.5 Conclusions

The present study showed that no enhancement in animal performance or by nutrient cycling is expected if in contrast to the traditional practice additional time for grazing is offered to sheep during night. Even though grazers stay 24 h on pasture no positive effect regarding nutrient return is expected, because sheep crowed together during darkness in one corner where they dispose the faeces so that no even distribution of the manure occurred. Considering the risk of animal losses and the lack of fuel, the common practice of penning sheep over night in yards near the farm appears to be an adequate management practice for the pastoralists and their families in the Inner Mongolian steppe of China.

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Chapter 4 General discussion

Since the livelihoods of farmers and their families in Inner Mongolia strongly rely on the resources provided by the grassland steppe, this ecosystem should be conserved to assure people's future income from pastoral sheep husbandry. However, a conflict between farmers' economical interests and a sustainable resource management maintaining the ecological stability of the natural grassland steppe ecosystem exists. The current grassland utilization in Inner Mongolia is not sustainable. Different grazing management systems, with diverging grazing time, duration and intensity, play a major role for the determination of the optimal grassland utilization. So far, a few studies were carried out in the Inner Mongolian steppe ecosystem to determine the impact of different grazing intensities on the grassland vegetation, herbage production and animal performance (Glindemann *et al.* 2009; Li *et al.* 2000; Wang and Ripley 1997; Zhang *et al.* 2004). However, since they are based on short-term observation, no prediction for long-term consequences of livestock grazing on grassland herbage production and animal performance could be derived.

4.1 Grazing management practices for a sustainable grassland utilization

4.1.1 Grazing intensity

Overgrazing causes grassland degradation and desertification in large areas of Inner Mongolia (Chapter 1). Therefore, a grazing experiment was conducted to test the effects of different grazing intensities on grassland vegetation and animal performance. Our hypothesis was that moderate grazing can combine economic interests of local farmers and maintain fodder production of the natural grassland in a long-term.

In particular in the last years, prices for sheep in Inner Mongolia rapidly rose, encouraging farmers to increase their number of animals. Although, at animal level several authors revealed a negative impact of grazing intensity on live weight gain per sheep (Ackerman *et al.* 2001; Glindemann *et al.* 2009; Han *et al.* 2000), but this decrease can be compensated by an increase in the number of sheep per area. Hence, according to our results heavy grazing is more profitable for farmers, because animal production per area increases, which agrees with observations made by several authors (Ackerman *et al.* 2001; Holechek *et al.* 1999). But these observations only count as long as the amount and distribution of annual rainfall do not deviate from the long-term average. We could also show that in years with less than average precipitation, farmers might have to remove their sheep from heavily grazed pastures, sell them untimely or buy additional fodder due to the lack of herbage on pastures. This would result in additional costs for farmers or a lower income from sheep husbandry. Instead, a change in pricing to a payment per sheep according to body condition and live weight of individual animals or the meat quality might provide an incentive for farmers to improve the performance of individual animals instead of increasing their herd sizes.

4.1.2 Grazing systems

Mixed versus traditional grazing system

In the Inner Mongolian steppe, farming comprises grazing and hay-making areas. Grasslands close to farms are commonly used for livestock grazing, while land which is further away is only used for hay-making. Thus, pastures might be over-grazed, whereas no nutrient input occurs and the nutrient cycle is interrupted on hay-making areas which may lead to a nutrient deficiency in a long-term. In the current research project the traditional management system was compared to a mixed system, where hay-making and grazing were alternated annually on the same plots. While in the latter system grazing land has the possibility to recover from grazing in the following year a return of nutrients through livestock manure can occur on hay-making plots. Schönbach *et al.* (submitted) analysed data from four years collected within the same grazing experiment and determined a greater grazing tolerance of the vegetation to sheep grazing and a higher grassland productivity in the mixed system than in the traditional system, especially on heavily grazed plots. Furthermore, the risk of soil erosion is reduced on grazed plots in mixed systems, since vegetation coverage of the soil can recover during hay making years (Schönbach *et al.,* submitted). These results suggest that a shift from an unilateral to an alternating use of pastures might offer a possibility for more sustainable grassland utilization.

Continuous versus rotational grazing system

In the continuous grazing system sheep graze on the same pasture throughout the whole vegetation period. Continuous grazing allows unrestricted selective grazing of available plants throughout the growing season which might reduce the abundance of preferred fodder plants (Stuth *et al.* 1987). In contrast thereto, rotationally grazed pastures are divided into paddocks and sheep graze rotationally on each paddock for a certain time period. Hence, rotational grazing allows periods for undisturbed herbage re-growth. Since diet selection is lower if animals graze on a paddock for a short period at high grazing intensity, herbage is grazed more uniformly, and the grassland vegetation can evenly re-grow until the next grazing period starts (Vallentine 2001).

Walton *et al.* (1981) found a higher in vitro digestibility, a higher feed intake, a decrease in grazing time and hence, a higher live weight gain in grazing cattle at rotational grazing. Wang *et al.* (2009) compared the rotational *versus* the continuous system within the current research project. While the authors found a higher herbage mass production due to an undisturbed plant re-growth, digestibility of ingested herbage and feed intake of sheep were reduced at rotationally grazed pastures. However, live weight gain remained similar between both grazing systems. Similar to Walton *et al.* (1981) Wang *et al.* (2009) suggested that animals' energy requirements for physical activity to select preferred plants are higher at continuous than at rotational grazing and that therefore sheep performance is limited despite higher feed intake. Hence, this study is continued for another two years to include years with higher annual precipitation and to determine mid-term impacts of both systems on pasture production and herbage nutritional composition as well as on animal performance.

Continuous versus daytime grazing

Farmers generally keep their sheep in confinements over night in order to protect them and to collect the manure to use it as fuel. In contrast to this common practice, sheep in the continuously grazed system had the possibility to graze day and night. Constraints in grazing time reduce animals' feed intake and hence, decrease their live weight gain (Ayantunde *et al.* 2002; Wigg and Owen 1973). Furthermore, removing sheep from the pasture over night leads to an interruption of the nutritive cycling with possible negative effects on pasture productivity.

When the continuous grazing is compared to the common grazing system, no differences in feed intake or animal performance could be determined in our study. Since sheep crowd together in one corner of the plots during darkness and faecal and urinary excretion were concentrated on such "hotspots", no equal distribution of faeces and urine over the whole pasture occurs. Thus, no beneficial effects of closed nutrient cycles on pasture production in the continuously grazed system are expected and could not be confirmed in our study. Since no disadvantages for pasture or animal production were observed when sheep remained on pastures over night, more distant pastures, where it is impossible to drive animals back home for the night, could therefore be used for grazing. However, considering the importance of sheep manure as fuel, the common system of local farmers in the Inner Mongolian steppe appears to be an adequate management practice for the pastoralists and their families.

Grazing behaviour

A profound knowledge of grazing behaviour is needed to improve grazing management, because herbage energy contents and animals' energy expenditure during grazing are major factors determining animal production.

Many observations exist which could offer the basis for an efficient grassland utilization (Animut *et al.* 2005a). On pastures with high herbage availability sheep can easily select preferred plants than on pastures with low herbage on offer but spend more energy for walking and searching the preferred plant species (Garcia *et al.* 2003; Zoby and Holmes 1983). In 2008, a study was carried out within the current grazing experiment to determine grazing activity of sheep kept at different grazing intensities as well as in different grazing systems and to calculate energy requirements for grazing depending on the management regime. Grazing time increased with increasing grazing intensity (Lin, personal communications), supporting observations by Animut *et al.* (2005b) who reported that sheep compensate for a decrease in HM by increasing their grazing time. When comparing sheep's grazing behaviour in rotational *versus* continuously grazed system Lin (personal communication) found a decrease in gazing time and walking distances. These observations confirmed the assumptions of Walton *et al.* (1981) and Wang *et al.* (2009) that energy requirements are higher at continuously compared to rotationally grazed pastures due to the extra energy needed for walking and selecting. Therefore, it can be concluded, that rotational grazing systems grazed at moderate intensity might be beneficial for animal performance, herbage quality and grassland productivity in a short-term as well as in a long-term.

Supplementation

Recently, the local government has defined limits for the maximum animal stocking density per area. Thus, since livestock farmers might have to reduce their herd sizes in order to keep to these limits, they have to search for possibilities to maintain their income. Supplementation of grazing sheep with concentrate feeds is so far not a common practice in Inner Mongolia. However, since prices for meat and milk rapidly increased in the last years, it might become profitable to supplement grazing sheep. Performance of an individual animal can be improved by feeding concentrates (Ayantunde *et al.* 2000) and thus, could compensate for a reduced herd size. But, profitability of a supplement feeding depends on the costs for the amount of concentrate feeds needed and on the additional price obtained per animal due to the feeding of concentrates at the time of sale (Schlecht 1995).

Moreover, supplementation might reduce animals' herbage intake resulting in higher herbage mass on pastures at the end of the growing season and hence, limiting the risk of wind erosion by protecting the soil due to an improved vegetation cover. However, Ayantunde *et al*. (2000) did not find any or only a minor substitution effect of herbage by supplementing grazing cattle with concentrate feeds on pastures with low herbage availability or low quality. Instead, supplementation lead to an increase in feed intake and hence, in animal performance. Supporting supplementation and reducing grazing pressure at moderate grazing intensity might also have positive long-term effects on grassland productivity and hence, assure future income for farmers and a sustainable use of the grasslands.

Finally, since meat production per individual animal could be improved by feeding concentrates, methane emission per kg of meat produced is reduced, which plays an important role for the green house effect. Hence, to get further information on the impact of supplementation on herbage intake and animal performance with and without supplementation a grazing experiment will be carried out in a two year study within the same research project.

4.2 Conclusions

In the current grazing experiment it could be shown that different grazing management systems affect animal performance as well as grassland productivity. However, productive sheep husbandry is not in contradiction to a sustainable use of the grassland ecosystem. Although a higher animal production can be achieved at high grazing intensities in a short-term, grazing on pastures with high grazing intensity in years with unfavourable or low precipitation is not possible throughout the whole grazing season and alternatives to compensate for the lack of HM on the pastures have to be found. Whereas, sheep grazing at moderate grazing intensities showed a medium production per area that was independent from inter- and intra-annual variability in precipitation. Moreover, a higher HM at the end of the grazing season was observed which might be beneficial for the protection of the grassland against wind erosion in winter and in spring.

Furthermore, different grazing systems, that offer pastures a time to recover due to an alternating use between hay-making or grazing or due to a rotational grazing utilization appears to be more beneficial for the protection of the grassland and hence, for animal production.

The involvement of the government and their efforts to conserve the steppe ecosystem in Inner Mongolia might be necessary to assure the livelihood of the local people. Recently, the government changed the land use policy and farmers can lease land for longer periods. Moreover, limits for the herd size per area were established to adapt stocking densities of livestock to the natural carrying capacity of the steppe region. However, scientific results are needed to confirm these guidelines and inspections are hardly realised yet.

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5 Summary

In Inner Mongolia, China, grassland degradation due to overgrazing reduces grassland and animal productivity as well as biodiversity, leads to desertification, and thereby accelerates the occurrence of dust storms with ecological and economical consequences to the whole country. The present dissertation was carried out within the framework of the Sino-German research group MAGIM (**M**atter fluxes of **G**rasslands in **I**nner **M**ongolia as influenced by Stocking Rate), supported by the German Research Foundation (DFG). The objectives of this dissertation were to evaluate the effect of different grazing intensities and different grazing management regimes on grassland and animal performance.

A grazing experiment with six different grazing intensities was conducted in the vegetation periods of 2005, 2006, and 2007 to analyse herbage mass and quality as well as quality of ingested herbage, feed intake and animal performance influenced by different grazing intensities. Therefore, a system with two adjacent plots, alternating annually between grazing and hay-making, were used. Sheep were transferred to the grazing plots in the middle of June each year and were continuously kept on the plots throughout the grazing season until the middle of September.

Grazing intensity strongly influences herbage mass and quality. Diet digestibility of organic matter, feed intake, metabolizable energy intake, and live weight gain were not different between grazing intensities. However, feed intake per ha as well as live weight gain per ha increased with increasing grazing intensity.

The results show that intensive grazing does not reduce performance of individual animals but increases productivity per area and therefore, income for farmers. However, in dry years a lack of herbage mass on offer on heavy grazed pastures requires the purchase of additional forage for animals at the end of the vegetation period or the untimely sale of animals. Long-term negative effects of high grazing intensities on grassland productivity are likely and therefore, this study is continued to obtain further information on long-term effects of intensive livestock grazing.

To determine the impact of a continuously 24 h grazing system compared to the common daytime grazing system an experiment with these two systems were carried out in 2005, 2006, and 2007 at a moderate grazing intensity. For the continuously grazed system sheep were kept on the plots all day and all night throughout the whole grazing season, whereas sheep of the daytime treatment were removed from the pasture in the evening and kept in pens over night according to the common practice of local sheep farmers in Inner Mongolia. The research question were (i) if sheep that have the possibility to graze

at day and at night increase their daily feed intake due to longer available grazing time and thus, show a higher live weight gain than sheep that graze during the daytime only, and (ii) if closing the nutrient cycling on continuously grazed treatments where sheep faeces remained on the pasture has a remarkable influence on grassland productivity.

Grazing treatment of continuous and daytime grazing did not influence herbage mass and herbage quality parameters. Similarly, digestibility of organic matter as well as feed intake and animal performance did not differ between treatments, but digestibility of ingested herbage and live weight gain decreased with proceeding vegetation period, whereas herbage intake remained fairly constant over the grazing season.

The results show that additional grazing time offered to sheep during night does not lead to an increase in feed intake or animal productivity. Furthermore, no beneficial effects for continuous grazing of closing the nutrient cycling on pasture production could be determined in this study. Hence, considering the importance of sheep manure as fuel, our observations confirm the common practice of penning sheep over night to be an adequate management practice for the pastoralists and their families in the Inner Mongolian steppe.

5 Zusammenfassung

In der Inneren Mongolei, China, hat die Degradierung des Graslandes durch Überbeweidung eine Verringerung der Grasland- und Tierproduktivität sowie der Artenvielfalt zur Folge, führt zur Desertifikation und beschleunigt dadurch das Vorkommen von Staubstürmen mit ökologischen und ökonomischen Konsequenzen für das gesamte Land.
Die vorliegende Dissertation wurde im Rahmen der deutsch-chinesischen Forschergruppe MAGIM (Stoffflüsse im Grasland der Inneren Mongolei beeinflusst durch Beweidungsdichte), finanziert durch die Deutsche Forschungsgemeinschaft (DFG), durchgeführt. Gegenstand dieser Arbeit war es, den Einfluss unterschiedlicher Beweidungsintensitäten sowie Managementsysteme auf das Weideland und die Tierleistung zu untersuchen.

In der Vegetationsperiode 2005, 2006 und 2007 wurde ein Weideexperiment mit sechs unterschiedlichen Beweidungsintensitäten durchgeführt, welches die Menge und Qualität des angebotenen Futters, Menge und Qualität des von den Tieren aufgenommenen Futters sowie die Tierleistung, beeinflusst durch unterschiedliche Beweidungsintensitäten, untersucht. Es wurde ein Beweidungssystem mit zwei zusammengehörigen Parzellen, deren Nutzung sich jährlich zwischen Beweidung und Schnittnutzung abwechselte, für diese Untersuchung ausgewählt. Die Schafe wurden Mitte Juni aufgetrieben und blieben durchgängig während der gesamten Weidesaison bis Mitte September auf den Parzellen.
Die Beweidungsintensität hat einen starken Einfluss auf das Futterangebot und die Qualität des angebotenen Futters. Hingegen waren die Verdaulichkeit des aufgenommenen Futters, die Futter- und Energieaufnahme sowie die Lebendgewichtszunahmen nicht unterschiedlich zwischen den Beweidungsintensitäten, Futteraufnahme und Lebendgewichtszunahme pro Hektar nahmen aber mit höherer Beweidungsintensität zu.
Die Ergebnisse zeigen, dass die Tierleistung des einzelnen Tieres nicht durch die Beweidungsintensität beeinflusst wird, die Leistung pro Fläche aber deutlich mit zunehmende Beweidungsintensität gesteigert werden kann, welches seinerseits zu einer Steigerung des Einkommens der Landwirte führt. Jedoch konnte auch gezeigt werden, dass in trockenen Jahren durch ein zu geringes Futterangebot der Zukauf von zusätzlichem Futter oder ein verfrühter Verkauf der Tiere erforderlich wird. Langfristige negative Auswirkungen durch hohe Beweidungsdichten auf die Graslandproduktivität sind wahrscheinlich. Für weitere Informationen über die langfristigen Auswirkungen durch intensive Beweidung wird der Versuch fortgesetzt.

Die Analyse des Einfluss durchgängiger 24-stündiger Beweidung im Vergleich zu der üblichen Praxis der Tagesbeweidung wurde mit einem Beweidungsversuch der beiden Beweisungssysteme in den Vegetationsperioden 2005, 2006 und 2007 bei moderater Beweidungsintensität durchgeführt. Im System der 24-stündigen Beweidung blieben die Tiere Tag und Nacht durchgängig während der gesamten Beweidungssaison auf den Flächen, während Tiere im System der Tagesbeweidung abends von den Flächen abgetrieben und über Nacht in Pferchen gehalten wurden, wie es in der gängigen Praxis der ortsansässigen Landwirte üblich ist.

Ziel dieser Studie war es zu untersuchen, ob zum einen Schafe, die die Möglichkeit haben Tag und Nacht zu grasen, ihre Futteraufnahme aufgrund der höheren Weidezeit steigern und dadurch eine höhere Tierleistung erzielen im Vergleich zu Tieren, die nur tags weiden und zum anderen ob der geschlossene Nährstoffkreislauf auf Flächen, die durchgängig beweidet werden und auf denen die gesamten Schafexkremente verbleiben, einen positiven Einfluss auf die Produktivität des Graslandes hat.

Das Beweidungssystem hatte keinen Einfluss auf Futterangebot oder Qualität des angebotenen Futters. Gleichermaßen wurden keine Unterschiede zwischen den Systemen bei der Verdaulichkeit des aufgenommenen Futters, der Futteraufnahme oder der Gewichtsentwicklung beobachtet. Allerdings nahmen die Verdaulichkeit sowie die Lebendgewichtszunahme mit fortschreitender Vegetationsperiode ab, während die Futteraufnahme über die gesamte Weideperiode hinweg konstant blieb.

Die Resultate zeigen, dass zusätzliche Weidezeit für Schafe über Nacht, nicht zu einer Zunahme der Futteraufnahme oder der Tierleistung führt. Außerdem konnte in dieser Studie kein vorteilhafter Effekt durch einen geschlossenen Nährstoffeskreislauf auf die Produktivität des Graslandes festgestellt werden. Demzufolge, und unter Berücksichtigung des Wertes des Schafkotes als Brennstoff, bestätigen unsere Untersuchungen die übliche Praxis, die Schafe über Nacht im Pferch zu halten, als ein geeignetes Beweidungsregime für die Viehhalter und ihre Familien in der inneren mongolischen Steppe.

Lebenslauf

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