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Christian-Albrechts-Universität zu Kiel

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**Effect of grazing intensity on behavior and liveweight  
gain of sheep in the Inner Mongolian steppe, China**

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## List of abbreviations

ANPP	Aboveground net primary productivity
CV	Coefficient of variation
DM	Dry matter
DOM	Digestibility of organic matter
ESSB	End-of-season standing biomass
GI	Grazing intensity
GPS	Global Positioning System
HA	Herbage allowance
IDOM	Intake of digestible organic matter
LW	Liveweight
LWG	Liveweight gain
ME	Metabolizable energy
OMI	Organic matter intake
SEM	Standard error of the means
SR	Stocking rate

*Chapter 1*

**General Introduction**



# **1 General introduction**

## **1.1 The typical steppe in Inner Mongolia**

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

Grasslands in China cover an area of about 400 million hectares, about 42% of the country's territory. They are mainly located in the arid and semi-arid mountain and plateau regions of Northwest China, including those in Tibet, Inner Mongolia, Xinjiang, Qinghai, Sichuan, and Gansu, which account for 21, 20, 15, 9, 6, and 5% of the total grassland area in China, respectively (Liu et al., 2008). Livestock production is the main agricultural activity in the Inner Mongolia steppe, and the yield of cow milk, mutton, and cashmere is highest in this region.

Since 1950, the human population of the Xilingol League, where the experimental site was located, rapidly increased, especially due to the immigration of Han people in the 1970s (Figure 1.1). Simultaneously, the number of grazing animals increased by 18 folds compared to 1949 and strongly reduced the available grassland per animal. Moreover, the predominant land use pattern has shifted from a nomadic rangeland utilization to sedentary livestock operations, which intensively uses the rangelands close to farmers' settlements for livestock grazing and the distant grassland for hay-making once a year (Christensen et al., 2003). Grazing pressure on the Inner Mongolian steppe has therefore continuously increased, causing severe ecological and economic problems. Hence, the Inner Mongolian steppe has experienced wide-spread degradation during the last decades, so that in the 1990s more than 20% of the grassland area were unusable for farming and about 30% were degraded (Yu et al., 2004). Recent surveys have shown that nowadays nearly 90% of the grasslands are degraded to varying degrees (Jiang et al., 2006).

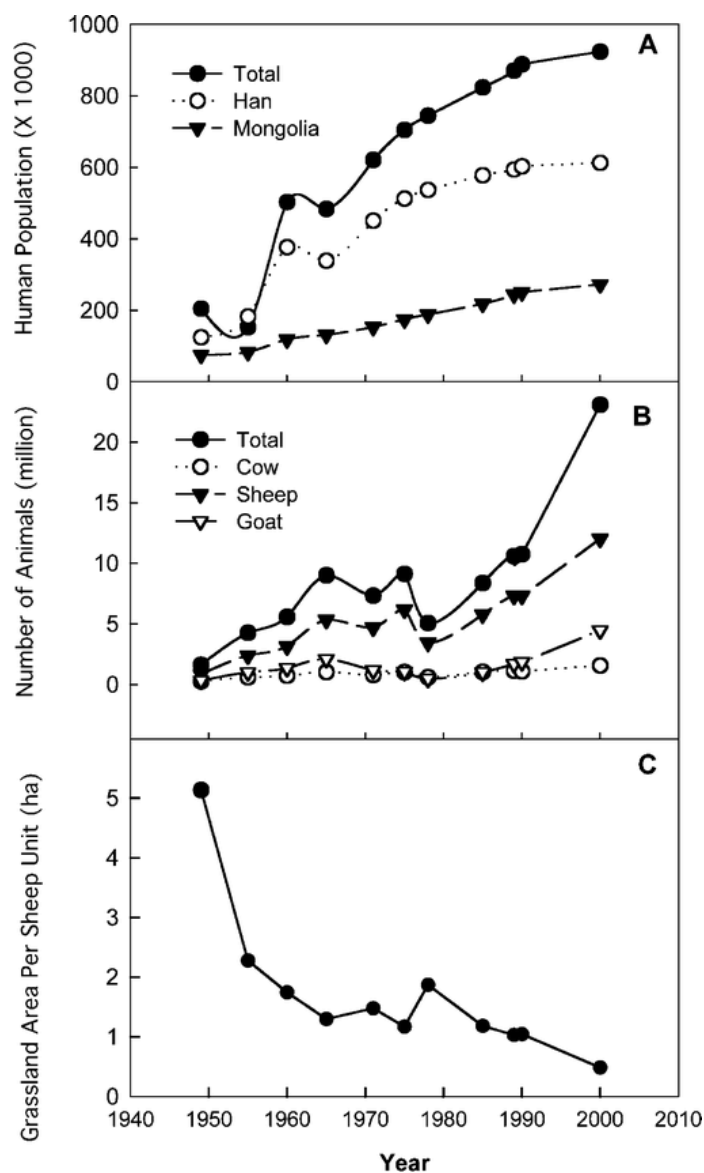


Figure 1.1. Human population (A), the number of grazing animals (B), and the grassland area per sheep unit (C) in the Xilingol League of Inner Mongolia in 1947-2000 (Jiang et al., 2006).

### 1.1.2 Ecological consequences of overgrazing

High grazing intensities may maximize short-term animal production per unit area (Glindemann et al., 2009); however, they decrease long-term grassland productivity and therefore animal production (Jiang et al., 2006). World-wide, many studies have revealed the negative effects of grazing on above-ground net primary production of

semi-arid grasslands on the community as well as on plant species level (Ferraro and Oesterheld, 2002; Schönbach, 2009). Continuous heavy grazing considerably decreases vegetation cover, vegetation height, standing biomass, and root biomass, and increases the negative impacts of animal trampling (Zhao et al., 2005). Hence, in the American Missouri Coteau, Biondini et al. (1998) found that seven years of heavy grazing (removal of 90% of aboveground net primary production) strongly reduced standing dead biomass, litter biomass, and peak root biomass on semi-arid rangelands. Similarly, recent surveys in Inner Mongolia showed that above ground primary biomass production of the grassland degraded by livestock grazing is currently only 50% of the biomass production of the undegraded steppe grassland (Jiang et al., 2006). Moreover, overstocking reduces soil surface roughness length and increases surface albedo in semi-arid zones of the world such as the Inner Mongolian steppe. At co-occurrence of drought and strong winds, it thus creates favorable conditions for wind erosion and hence, leads to desertification (Li et al., 2000). A 5-year grazing experiment in Inner Mongolia indicated that continuous heavy grazing enlarged bare areas in the rangeland (Zhao et al., 2005). Total bare area reached up to 52% and the average depth of wind erosion increased to 25 cm in the fifth year of the study, indicating that heavy grazing of such rangeland should be avoided (Zhao et al., 2005). In Inner Mongolia, land degradation is generally believed to be the main cause for the increasing frequency of severe sand and dust storms in the last years. In North China, sandstorms occurred once every two years in the 1960s and 1970s, while there were storms every year in the 1990s. The frequency even increased to 18 dusty weather periods in 2001. Simultaneously, land desertification rate in China more than doubled from 1,560 km<sup>2</sup> per year in the 1970s to 3,436 km<sup>2</sup> per year in the 2000s (Zhu et al., 1999).

Furthermore, overgrazing is proved to be the main reason for the shift of grasslands from sinks to sources for the atmospheric carbon (Li et al., 2006), since it destroys vegetation cover and thus reduces photosynthesis of grassland plants. Therefore, overgrazing not only results in severe ecological problems in the region, but also has

negative impacts on the global greenhouse effect.

Nevertheless, Jiang et al. (2006) recently stressed that, with the aid of scientific knowledge and advanced technological means, most of the grassland in Inner Mongolia could be restored, if proper measures are rigorously implemented.

## **1.2 Effect of stocking rate on behavior of grazing ruminants**

Increasing stocking rate decreases herbage mass on offer (Wang, 2004; Schönbach et al., 2009) and reduces the quantity of herbage taken per bite (Forbes, 1988). As a consequence, beef steers (Seman et al., 1991; Ackerman et al., 2001), heifers (Hejcmanova et al., 2009), goats and sheep (Wang, 1997; Animut et al., 2005) grazing at high stocking rates increase their grazing time and take more bites per minute to compensate for the decrease in forage availability and to maintain their feed intake. Moreover, Animut et al. (2005) showed that the number of steps of sheep linearly increases with increasing stocking rate, implying that walking distances of animals grazing at high stocking rates are longer. However, stocking rate does not affect ruminating time of goats and sheep on grass/forb pastures (Animut et al., 2005) as well as of heifers grazing species-rich pastures (Hejcmanova et al., 2009). Animals on range spend considerably more time walking, eating, and foraging for food than confined animals (Osuji, 1974). These activities increase the animals' energy expenditures and may therefore reduce the amount of energy available for growth and production. Physical activities can account for 25%-50% of the daily energy requirement of grazing animals (Osuji, 1974), so that energy requirements for maintenance and activity of grazing ruminants can be more than twice as high as of confined animals (Lachica and Aguilera, 2008). NRC (1981) assumes an increase in the metabolizable energy requirements for maintenance by 25% in goats with light activity, by 50% in goats grazing slightly hilly, semi-arid rangelands, and by 75% in goats grazing sparsely vegetated mountain pastures. An efficient utilization of available feed resources requires a profound knowledge of animal behavior in order to determine the energy expenditure of grazing animals for physical activity. Understanding livestock behavior in response to varying environmental conditions

and forage dynamics is therefore important in evaluating management strategies for pastoral livestock production (Hejcmanova et al., 2009).

### **1.3 Effect of stocking rate on liveweight gain of grazing ruminants**

Stocking rate has a major impact on animal performance and overall profitability of livestock production systems (Biondini et al., 1998). Understocking results in patch-grazing, since animals repeatedly graze the same areas as soon as plant regrowth is available. The immature plant material is more palatable and has a higher nutritive value, while herbage in ungrazed pasture areas matures, becomes less palatable, and loses its nutritive value. Therefore, forage in ungrazed areas is wasted and profit from pastoral livestock husbandry decreases. Conversely, overstocking of rangelands typically reduces desirable forage species and leads to an invasion of impalatable plant species. As a consequence, the carrying capacity of the grassland declines. The knowledge about the relationship between liveweight gain of grazing ruminants and the corresponding stocking rate is therefore of essential importance for an economically sustainable management of grassland systems (Li et al., 2000).

Earlier studies with steers (Hull et al., 1961), cattle (Fynn and O'Connor, 2000), and sheep (Han et al., 2000) showed that with increasing grazing intensity, liveweight gain per animal decreased, while liveweight gain per ha increased up to a certain threshold above which it declined again (Jones and Sandland, 1974; Kemp and Michalk, 2007). Jones and Sandland (1974) proposed a simple model to describe the effect of stocking rate on animal production. The basis of this model is the linear relationship between stocking rate and individual animal performance expressed as  $y_1 = a - bx$ , where  $y_1$  is the liveweight gain of an individual animal,  $x$  the stocking rate,  $a$  and  $b$  the constant (Allan and Neil, 1991). Based on this linear model, the relationship between total liveweight gain per unit area and stocking rate can be expressed as  $y_2 = ax - bx^2$ , where  $y_2$  is the liveweight gain per unit area and  $a$ ,  $b$ , and  $x$  are parameters defined above.

From a livestock production point of view, a stocking rate that allows for a maximum liveweight gain per hectare was commonly seen as the optimum stocking rate (Jones and Sandland, 1974; Edye et al., 1978; Allan and Neil, 1991; Kemp and Michalk, 2007). However, it does not consider monetary values of the inputs and outputs of a grazing system (Allan and Neil, 1991). Moreover, Kemp and Michalk (2007) suggested that the number of animals should be kept within a range close to the stocking rate, at which the maximum production per unit area is achieved. This does not result in great losses in the productivity of a livestock system, but eases pressure on the ecosystem and is also easier to implement than aiming at maximum values (Kemp and Michalk, 2007). According to outcomes from discussions with scientists and livestock producers, it appears that the costs for the maintenance of grassland production (re-sowing, destocking, etc.) will be higher, if a grazing system is managed with the aim of a maximum production per area. The authors therefore recommended that farmers should rather aim for 75% of the maximum production per area at a lower stocking rate, since it is closer to the economic optimum in many grazing systems and further relieves grazing pressure on the grassland.

According to the most accepted model describing the relationship between stocking rate and animal production proposed by Jones and Sandland (1974), 75% of the maximum outcome per hectare can be achieved at two instances represented by points A and B in Figure 1.2. Compared to A, the stocking rate at point B is nearly three times as high than at point A, but liveweight gain of individual animals is only about 30% and production per unit of area is similar. Obviously, net profit is distinctly higher at point A than at point B. Moreover grazing at a stocking rate close to point A is more ecological friendly because of the lighter grazing pressure (Kemp and Michalk, 2007).

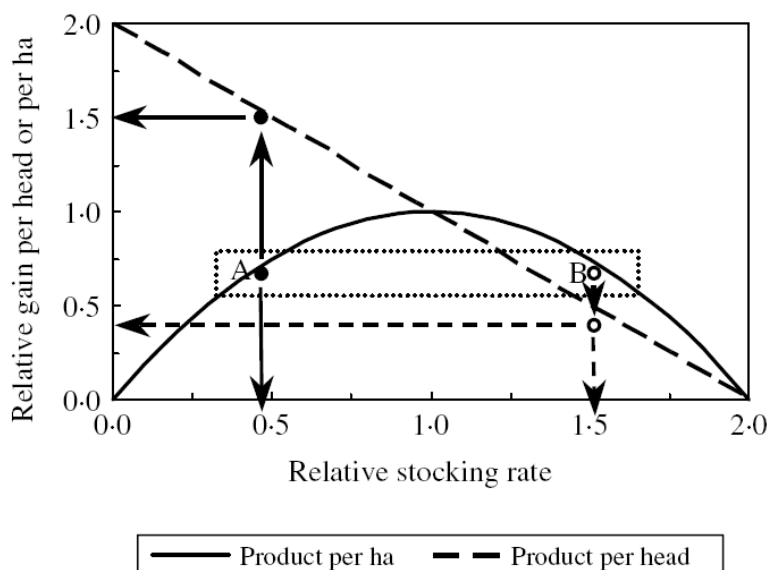


Figure 1.2. Relationships between relative stocking rate and relative animal production per head and per hectare according to Jones and Sandland (1974). Relative stocking rate means the actual stocking rate divided by the stocking rate for maximum production per area. At points A and B production per hectare equals 75% of the maximum output per hectare (Kemp and Michalk, 2007). The dashed line represents  $y = 2 - x$  and the solid line  $y = (2 - x) \times x$ .

However, the economic optimum stocking rate depends on the variations in both, costs (input) and product prices (output) of a grazing system (Allan and Neil, 1991). While the fixed costs have no direct effect on the economic optimum stocking rate, the ratio of fixed to variable costs is important. For a given level of total cost per hectare, the economic optimum stocking rate will increase as the ratio of fixed to variable costs increases. In an extreme case, in which all costs are fixed costs, the economic optimum stocking rate would equal the stocking rate at maximum production per area, while increasing variable costs will decrease the economic optimum stocking rate (Allan and Neil, 1991). Hence, besides the restoration of vegetation cover and biomass production, animal behavior and performance as well as costs and prices of the grazing system should be considered when defining an optimum grazing system and intensity for the Inner Mongolian steppe.

#### 1.4 Objectives and structure of this dissertation

This study is part of a long-term research project that evaluates the multiple effects of grazing on the typical steppe of Inner Mongolia. The Sino-German research collaboration “**M**atter fluxes of **G**rasslands in **I**nnner **M**ongolia as influenced by stocking rate” (MAGIM) was funded by the German Research Foundation (DFG, research unit no. 536). The research collaboration aimed to investigate the interaction between grazing of steppe ecosystems and matter fluxes, and then to develop concepts for a sustainable grassland utilization. Eleven sub-projects contributed to the overall aim of the research group on site as well as on a regional scale:

1. Amount, composition, and turnover of organic matter pools in grassland soils under typical steppe vegetation types of the Xilin River Basin as influenced by different grazing intensities.
2. Effects of grazing intensity on net primary production and nutrient dynamics.
3. Impact of grazing management on yield performance, herbage quality, and persistence of grassland ecosystems of Inner Mongolia.
4. Impact of grazing intensity on herbage quality, feed intake, and animal performance of grazing sheep in the grassland steppe of Inner Mongolia.
5. Quantification and biogeochemical modeling of C and N turnover processes and biosphere-atmosphere exchange of C and N compounds.
6. Quantification of water and carbon exchange by micrometeorology and remote sensing in managed steppe ecosystems of Inner Mongolia.
7. Regional water fluxes and coupled C and N transport.
8. Influence of various grazing intensities on soil stability and water balance on the plot scale.
9. Dynamics of wind erosion in the Xilin River Catchment area in Inner Mongolia.
10. Influence of grazing pressure on the carbon isotope composition of the grassland



of China: spatio-temporal variations at multiple scales.

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

The present study was carried out within the frame of sub-project 4 of the Institute of Animal Nutrition and Physiology, Christian-Albrechts-University of Kiel. In close cooperation with the Institute of Crop Science, Christian-Albrechts-University of Kiel (sub-project 3), a grazing experiment was set up in the Xilin River catchment area of Inner Mongolia in 2004 (Figure 1.3). The main aim of the sub-projects 3 and 4 was to investigate the impacts of different grazing systems and intensities on animal performance and grassland production and to develop strategy concepts for a sustainable utilization of the grassland resources.



Figure 1.3. Location of the Xilin River catchment.

This dissertation focused on the grazing behavior and liveweight gain of sheep as affected by grazing intensity and grazing system in the steppe of Inner Mongolia. After a general introduction to economical and ecological problems associated with sheep grazing in the Inner Mongolian steppe (Chapter 1), Chapter 2 of this dissertation discusses the effect of grazing intensity on grazing behavior and thus energy requirement of grazing sheep. Chapter 3 analyzes the impact of grazing system, grazing intensity, and year on liveweight gain and discusses sustainable grazing management strategies for the Inner Mongolian steppe. Chapter 4 reviews different methods for measuring behavior and walking distance of free-ranging animals and, based on own measurements, evaluates the potential use of global positioning system technologies for the determination of the behavior of grazing sheep in Inner Mongolia.

## **1.5 References**

- Ackerman, C. J., H. T. Purvis, G. W. Horn, S. I. Paisley, R. R. Reuter, and T. N. Bodine. 2001. Performance of light vs heavy steers grazing Plains Old World bluestem at three stocking rates. *Journal of Animal Science* 79:493-499.
- Allan, D. W., and D. M. Neil. 1991. Overgrazing: Present or absent? *Journal of Range Management* 44:475-482.
- Animut, G., A. L. Goetsch, G. E. Aiken, R. Puchala, G. Detweiler, C. R. Krehbiel, R. C. Merkel, T. Sahlu, L. J. Dawson, Z. B. Johnson, and T. A. Gipson. 2005. Grazing behavior and energy expenditure by sheep and goats co-grazing grass/forb pastures at three stocking rates. *Small Ruminant Research* 59:191-201.
- Biondini, M. E., B. D. Patton, and P. E. Nyren. 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecological Applications* 8:469-479.
- Christensen, L., M. B. Coughenour, J. E. Ellis, and Z. Z. Chen. 2003. Sustainability of Inner Mongolian grasslands: Application of the savanna model. *Journal of*

Range Management 56:319-327.

Edye, L. A., W. T. Williams, and W. H. Winter. 1978. Seasonal relations between animal gain, pasture production and stocking rate on 2 tropical grass-legume pastures. *Australian Journal of Agricultural Research* 29:103-113.

Ferraro, D. O., and M. Oesterheld. 2002. Effect of defoliation on grass growth. A quantitative review. *Oikos* 98:125-133.

Forbes, T. D. A. 1988. Researching the plant-animal interface - the investigation of ingestive behavior in grazing animals. *Journal of Animal Science* 66:2369-2379.

Fynn, R. W. S., and T. G. O'Connor. 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. *Journal of Applied Ecology* 37:491-507.

Glindemann, T., C. Wang, B. M. Tas, A. Schiborra, M. Gierus, F. Taube, and A. Susenbeth. 2009. Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe. *Livestock Science* 124:142-147.

Han, G., B. Li, Z. Wei, and H. Li. 2000. Live weight change of sheep under 5 stocking rates in *Stipa breviflora* desert steppe. *Grassland of China* 38:4-6.

Hejcmanova, P., M. Stejskalova, V. Pavlu, and M. Hejcman. 2009. Behavioural patterns of heifers under intensive and extensive continuous grazing on species-rich pasture in the Czech Republic. *Applied Animal Behaviour Science* 117:137-143.

Hull, J. L., R. Kromann, and J. H. Meyer. 1961. Influence of stocking rate on animal and forage production from irrigated pasture. *Journal of Animal Science* 20:46-52.

Jiang, G. M., X. G. Han, and J. G. Wu. 2006. Restoration and management of the Inner Mongolia grassland require a sustainable strategy. *Ambio* 35:269-270.

Jones, R. J., and R. L. Sandland. 1974. Relation between animal gain and stocking

- rate - derivation of relation from results of grazing trials. *Journal of Agricultural Science* 83:335-342.
- Kemp, D. R., and D. L. Michalk. 2007. Towards sustainable grassland and livestock management. *Journal of Agricultural Science* 145:543-564.
- Lachica, M., and J. F. Aguilera. 2008. Methods to estimate the energy expenditure of goats: From the lab to the field. *Small Ruminant Research* 79:179-182.
- Li, J., S. H. Liu, Y. H. Mao, C. Y. Zhang, L. C. Liu, F. M. Liang, G. J. Xin, and J. H. Wang. 2006. Characteristics of CO<sub>2</sub> flux and concentration in different ecosystems. *Chinese Journal of Geophysics-Chinese Edition* 49:1298-1307.
- Li, S. G., Y. Harazono, T. Oikawa, H. L. Zhao, Z. Y. He, and X. L. Chang. 2000. Grassland desertification by grazing and the resulting micrometeorological changes in Inner Mongolia. *Agricultural and Forest Meteorology* 102:125-137.
- Liu, J., Y. Zhang, Y. Li, D. Wang, G. Han, and F. Hou. 2008. Overview of grassland and its development in China. In: 2008 XXI International Grassland and VIII International Rangelands Congress Proceedings, Hohote, China. p 3-10.
- NRC (Editor), 1981. Nutrient requirements of domestic animals. National Academy Press, Washington, DC.
- Osuji, P. O. 1974. Physiology of eating and energy expenditure of ruminant at pasture. *Journal of Range Management* 27:437-443.
- Schönbach, P. 2009. Grazing effects on productivity and herbage quality of an Inner Mongolian steppe ecosystem. PhD Thesis, Christian-Albrechts-University, Kiel, Germany.
- Schönbach, P., H. Wan, A. Schiborra, M. Gierus, Y. Bai, K. Muller, T. Glindemann, C. Wang, A. Susenbeth, and F. Taube. 2009. Short-term management and stocking rate effects of grazing sheep on herbage quality and productivity of Inner Mongolia steppe. *Crop & Pasture Science* 60:963-974.
- Seman, D. H., M. H. Frere, J. A. Stuedemann, and S. R. Wilkinson. 1991. Simulating the influence of stocking rate, sward height and density on steer productivity

and grazing behavior. *Agricultural Systems* 37:165-181.

Wang, R. Z. 2004. Responses of *Leymus chinensis* (Poaceae) to long-term grazing disturbance in the Songnen grasslands of north-eastern China. *Grass and Forage Science* 59:191-195.

Wang, S. P. 1997. Behavior ecology of grazing sheep II influence of stocking rates on foraging behavior of wether. *Acta Prataculturae Sinica* 6:10-17.

Yu, M., J. E. Ellis, and H. E. Epstein. 2004. Regional analysis of climate, primary production, and livestock density in Inner Mongolia. *Journal of Environmental Quality* 33:1675-1681.

Zhao, H. L., X. Y. Zhao, R. L. Zhou, T. H. Zhang, and S. Drake. 2005. Desertification processes due to heavy grazing in sandy rangeland, Inner Mongolia. *Journal of Arid Environments* 62:309-319.

Zhu, J., Z. Zhu, and Y. Shen. 1999. Combating sandy desertification in China. Chinese Forestry Press, Beijing.

*Chapter 2*

**Behavior of sheep at different grazing intensities in the Inner  
Mongolian steppe, China**

## **2 Behavior of sheep at different grazing intensities in the Inner Mongolian steppe, China**

### **2.1 Abstract**

This study evaluated the effect of grazing intensity (GI) on behavior and the distance walked in sheep grazing the Inner Mongolian steppe, China. Seventy female fat-tailed breed sheep were randomly assigned to one of six GI plots, which were defined by different herbage allowance (HA) classes included very light (GI1), light (GI2), light-moderate (GI3), moderate (GI4), heavy (GI5), and very heavy (GI6) with standing biomass allowances of >12, 6-12, 4.5-6, 3-4.5, 1.5-3, and <1.5 kg dry matter kg<sup>-1</sup> LW. The sheep continuously stocked throughout the grazing season from June till October 2008. Behavior of two sheep per plot was monitored by visual observation during daylight. At the same time walking distance of sheep at different GI's was recorded by global positioning system technology.

Two main grazing periods of sheep were observed at all GI's with afternoon grazing being longer than morning grazing. With increasing GI animals spent more time grazing, whereas resting time during daylight decreased. GI had no effect on ruminating time and 12 h-walking distance (12:00 h-24:00 h). Although HA was low at high GI, sheep succeeded in maintaining their daily organic matter intake (OMI) as GI increased from GI1 to GI5, while sheep in GI6 had lower OMI than that in GI2 and GI3. When daylight became shorter with advancing vegetation period, sheep tended to decrease their resting time in order to maintain their grazing time. Therefore, it can be concluded that the strategy taken by sheep to avoid negative effects of increasing GI or shorter daylight on their daily feed intake was to increase or at least maintain their grazing time at the expense of their resting time. Despite a similar feed intake it is likely that performance of sheep at high GI is reduced, since higher energy expenditures for physical activity reduce energy available for growth or production.

## 2.2 Introduction

Compared to confined animals, behavior of free-ranging animals is considerably different, such as that they show higher activities related to eating and walk longer distances (Osuji, 1974). These activities increase the animals' energy expenditures and may therefore reduce the amount of energy available for growth and production. Physical activities can account for 25%-50% of grazing animals' daily energy requirements (Osuji, 1974), and NRC (1981) supposed increased metabolizable energy (ME) requirements for maintenance by 25% in goats with light activity, by 50% grazing slightly hilly, semiarid rangelands, and by 75% grazing sparsely vegetated rangelands or mountainous transhumance pastures. Understanding livestock behavior in response to varying environmental conditions and forage dynamics is therefore important in evaluating management strategies for pastoral livestock production (Hejcmanova et al., 2009).

The steppe grassland in Inner Mongolia is an important part of the world's grassland ecosystems and is the most important grazing land with highest production of cow milk, mutton, and cashmere in China. However, in the last decades, this natural grassland was extensively degraded due to the continuously increasing grazing pressure that allows for higher economic returns for farmers (Wang, 2000; Glindemann et al., 2009). Therefore, it is of essential ecological and economical importance to search for the optimal grazing intensity (GI) for the typical steppe of Inner Mongolia. Several studies have been carried out to evaluate the effect of different GI's or stocking rates (SR) on grassland productivity (Schönbach et al., 2009) and animal performance (Wang, 2000; Glindermann et al., 2009) in this region. However, little quantitative data is so far available on the effect of GI on sheep behavior (Wang, 1997), although this should be taken into account when defining an optimal GI. Therefore, the objective of this study was to evaluate the effect of GI on the behavior of sheep grazing the Inner Mongolian steppe.



## 2.3 Materials and methods

In 2008, the study was conducted at the Inner Mongolia Grassland Ecosystem Research Station (IMGERS), which is located in the Xilin River Basin, Inner Mongolia Autonomous Region of China (116° 42' E, 43° 38' N) and is administered by the Institute of Botany, Chinese Academy of Sciences, Beijing.

### 2.3.1 Experimental design and animals

Seventy 15-month-old female sheep of the local fat-tailed breed with an initial liveweight (LW) of  $30.8 \pm 0.7$  kg were purchased from local farms, blocked by LW into three groups, and randomly assigned to one of six GI plots. GI was defined by herbage allowance (HA): very light (GI1), light (GI2), light-moderate (GI3), moderate (GI4), heavy (GI5), and very heavy (GI6) with standing biomass allowances of >12, 6-12, 4.5-6, 3-4.5, 1.5-3, and <1.5 kg dry matter  $\text{kg}^{-1}$  LW (Schönbach et al., 2009), corresponding to SR of approximately 2, 3, 4, 6, 8, and 11 sheep  $\text{ha}^{-1}$ , respectively. Experimental plots had a size of 2 ha each, with the exception of the GI1 paddock, which covered 4 ha in order to maintain a minimum of six sheep per plot (Penning et al., 1993). The animals were treated for internal parasites before the grazing experiment started, were kept continuously on the plots throughout the grazing season (June till October 2008), and had free access to water and mineral lick stones.

### 2.3.2 Animal behavior recording

Two sheep from each GI plot were randomly selected and marked with a colored ribbon for behavioral observations. On two days during the first ten days of each month (observing period), behavior of these two sheep per plot was monitored by visual observation at 3 min-intervals from sunrise to sunset. Twelve well-trained farmers were employed for visual observation and randomly divided into two groups (group A and group B). Group A observers were randomly assigned to the six GI plots and alternated with group B observers in 2 h-intervals. Daily observing time was 16.0 h (4:30 h-20:30 h), 16.0 h (4:30 h-20:30 h), and 13.5 h (5:30 h-19:00 h) in July, August, and September, respectively. Recorded activities included grazing, ruminating while

standing (Rumi-S), ruminating while lying (Rumi-L), resting while standing (Rest-S), resting while lying (Rest-L), walking without grazing (walking), and other activities (other). Grazing was defined as biting, chewing, and swallowing herbage, or walking with the muzzle close to the sward. Rumi-S was defined as chewing the cud while standing, Rumi-L as chewing the cud while lying, and total ruminating time was calculated as the sum of Rumi-S and Rumi-L. Rest-S was defined as standing without any activity and Rest-L as lying without any activity. Total resting time was calculated as the sum of Rest-S and Rest-L. Standing was defined as the sum of Rumi-S and Rest-S, and lying as the sum of Rumi-L and Rest-L. "Other" included activities such as drinking, salt licking, and social interactions (Hejcmanova et al., 2009). Total time spent for each activity was calculated by multiplying the frequency of observations of each behavioral activity by the 3-min interval.

One of the two observed sheep per GI plot was randomly selected to determine walking distance. GPS receivers (Garmin eTrex H) were housed in plastic containers and mounted on collars. The collars were fitted to the sheep three days before and retrieved directly after each observing period. The animals' position was recorded at 30-second intervals on the two observing days per month. The animals accepted and wore the GPS collars without any obvious irritation. Since we lost some 24-h GPS data due to technical problems, only 12 h-walking distances (12:00 h-24:00 h) of sheep were analyzed.

Organic matter intake (OMI) of sheep was calculated from fecal organic matter excretion and digestibility of organic matter (DOM) ingested by sheep. Fecal organic matter excretion was determined using the inert marker titanium dioxide (TiO<sub>2</sub>), while DOM was calculated from crude protein concentration in fecal organic matter using the regression equation of Wang et al. (2009). A detailed description of these methods was presented by Glindemann et al. (2009).

### **2.3.3 Statistical analyses**

All data were analyzed using the SAS version 9.1 (SAS Institute Inc., Cary, NC, USA).

Animal behavioral responses to GI treatment were analyzed by ANOVA using the Mixed Model procedure. The model consisted of GI, month, and their interactions. Fixed factors were GI and month was the repeated measurement. The best fit covariance structure was compound symmetry. The following model was used:  $y_{ij} = \mu + GI_i + M_{ij} + GI \times M_{ij} + e_{ij}$ , where  $y$  is the target variable,  $\mu$  is the overall mean, GI and M is the grazing intensity and month, respectively, and  $e$  is the random experimental error. Multiple comparisons of least squares means were done by the Tukey test. To analyze the effect of GI on the OMI of sheep, months were treated as replication and the General Linear Model was applied. Regression analyses were performed to determine the relationships between HA (independent variable) and grazing and resting time (dependent variables).

## **2.4 Results**

### **2.4.1 Diurnal behavioral pattern**

Two main grazing periods were observed in all GI with the first grazing period from 5:00 h to 9:30 h (morning grazing) and the second grazing period from 15:00 h to 20:30 h (afternoon grazing; Figure 2.1). Throughout the whole grazing season, animals at all GI's grazed longer in the afternoon than in the morning. Sheep at higher GI's (GI3-GI6) grazed throughout daylight, while sheep at lower GI's (GI1-GI2) rested or ruminated after morning grazing and started to graze again after 14:00 h. Of the daily daylight duration, sheep spent on average 49% for grazing, 24% for ruminating, 24% for resting, 3% for walking, and 1% for other activities.

### **2.4.2 Effect of grazing intensity**

With increasing GI, the time animals spent grazing increased ( $P < 0.01$ ), while total resting time ( $P = 0.05$ ) and especially Rest-S decreased ( $P < 0.05$ ; Figure 2.1, Table 2.1). Similarly, when analyzed by regression analysis, sheep tended to spend more time grazing and less time resting with decreasing HA (Figure 2.2). This effect was most pronounced when HA was below 1 kg dry matter  $kg^{-1}$  LW, such as at GI5 in

September and GI6 in August and September. Sheep's OMI was similar from GI1 to GI5 ( $P > 0.05$ ), but was lower in GI6 animals than of those at GI2 and GI3 ( $P < 0.05$ ).

GI had no effect on total ruminating time ( $P > 0.05$ ); however, time spent Rumi-S decreased ( $P < 0.05$ ) and Rumi-L tended to decrease ( $P = 0.06$ ) with increasing GI (Table 2.1). Total standing time decreased as GI increased, while no effect of GI on lying time was found. In addition, GI had no effect on 12 h-walking distance ( $P = 0.84$ ).

### **2.4.3 Effect of month**

Depending on the length of daylight, observing time was 16 h, 16 h, and 13.5 h in July, August, and September, respectively. However, month and thus daylight duration had no effect on the time animals spent grazing ( $P > 0.05$ ). Sheep spent 61% less time on Rest-L in September than in July and August ( $P < 0.05$ ). Total ruminating time tended to decrease as season progressed ( $P = 0.05$ ), while no effect of month on Rumi-S or Rumi-L was detected ( $P > 0.05$ ). During observation time, sheep spent less time lying in September than in July and August ( $P < 0.05$ ). For all GI's, shortest 12 h-walking distance was found in August followed by September and July ( $P < 0.05$ ).

When expressed as percentages of the total observation time, both grazing and resting were affected by month (Table 2.2). In September, sheep of all GI's spent 56 % of daylight time grazing, while in July and August, grazing time only accounted for 46% and 45%, respectively. In contrast thereto, sheep spent approximately 10% less of the daylight for resting in September than in July and August.

Table 2.1. Herbage allowance (HA, kg dry matter kg<sup>-1</sup> live weight), organic matter intake (OMI, kg d<sup>-1</sup>), 12 h-walking distance (distance, km), and the time sheep spent for different behavioral activities during daylight (h during daylight) for different grazing intensity treatments (least squares means; n=6).

	Grazing intensity (GI)						SEM	P-value		
	1	2	3	4	5	6		GI	Month	GI*Month
HA*	18.77 ± 2.65 <sup>d</sup>	9.44 ± 0.59 <sup>c</sup>	4.93 ± 0.09 <sup>b</sup>	3.30 ± 0.37 <sup>ab</sup>	1.56 ± 0.81 <sup>a</sup>	0.87 ± 0.61 <sup>a</sup>		<b>&lt;0.01</b>		
OMI*	1.23 ± 0.07 <sup>ab</sup>	1.32 ± 0.13 <sup>b</sup>	1.39 ± 0.15 <sup>b</sup>	1.16 ± 0.01 <sup>ab</sup>	1.20 ± 0.06 <sup>ab</sup>	1.04 ± 0.06 <sup>a</sup>		<b>0.01</b>		
Grazing	6.41 <sup>a</sup>	5.87 <sup>a</sup>	7.45 <sup>abc</sup>	7.15 <sup>ab</sup>	8.27 <sup>bc</sup>	8.96 <sup>c</sup>	0.36	<b>&lt;0.01</b>	0.82	0.75
Ruminating	4.19 <sup>a</sup>	3.83 <sup>a</sup>	3.76 <sup>a</sup>	3.73 <sup>a</sup>	3.80 <sup>a</sup>	2.86 <sup>a</sup>	0.27	0.10	<b>0.05</b>	0.10
Resting	4.04 <sup>ab</sup>	5.09 <sup>b</sup>	3.28 <sup>ab</sup>	3.77 <sup>ab</sup>	2.74 <sup>a</sup>	2.89 <sup>ab</sup>	0.47	0.05	<b>&lt;0.01</b>	1.00
Walking	0.44 <sup>a</sup>	0.31 <sup>a</sup>	0.42 <sup>a</sup>	0.29 <sup>a</sup>	0.19 <sup>a</sup>	0.38 <sup>a</sup>	0.10	0.55	0.07	0.39
Other	0.09 <sup>a</sup>	0.07 <sup>a</sup>	0.20 <sup>a</sup>	0.23 <sup>a</sup>	0.17 <sup>a</sup>	0.08 <sup>a</sup>	0.03	<b>0.03</b>	<b>0.03</b>	0.16
Distance	3.18 <sup>a</sup>	2.90 <sup>a</sup>	2.67 <sup>a</sup>	2.33 <sup>a</sup>	2.68 <sup>a</sup>	3.13 <sup>a</sup>	0.31	0.84	<b>0.04</b>	0.26
Rumi-Stand	1.03 <sup>ab</sup>	1.39 <sup>b</sup>	1.33 <sup>ab</sup>	0.54 <sup>a</sup>	0.72 <sup>ab</sup>	0.79 <sup>ab</sup>	0.15	<b>0.02</b>	0.32	<b>0.07</b>
Rumi-Lying	3.15 <sup>a</sup>	2.44 <sup>a</sup>	2.49 <sup>a</sup>	3.19 <sup>a</sup>	3.09 <sup>a</sup>	2.07 <sup>a</sup>	0.26	0.06	0.20	0.29
Rest-Stand	1.92 <sup>b</sup>	1.73 <sup>ab</sup>	1.12 <sup>ab</sup>	1.23 <sup>ab</sup>	0.80 <sup>a</sup>	0.88 <sup>ab</sup>	0.20	<b>0.02</b>	0.35	0.56
Rest-Lying	2.12 <sup>a</sup>	3.36 <sup>a</sup>	2.16 <sup>a</sup>	2.54 <sup>a</sup>	1.94 <sup>a</sup>	2.01 <sup>a</sup>	0.40	0.21	<b>&lt;0.01</b>	0.88
Standing (total)	2.95 <sup>ab</sup>	3.12 <sup>b</sup>	2.45 <sup>ab</sup>	1.77 <sup>ab</sup>	1.52 <sup>a</sup>	1.67 <sup>a</sup>	0.27	<b>0.01</b>	0.26	0.16
Lying (total)	5.27 <sup>a</sup>	5.80 <sup>a</sup>	4.65 <sup>a</sup>	5.73 <sup>a</sup>	5.02 <sup>a</sup>	4.09 <sup>a</sup>	0.37	0.07	<b>&lt;0.01</b>	0.62

\* Mean ± S.E., n=3. Statistical analysis using General Linear Model, GI as fixed factor

Effects in bold characters were significant at the level  $P < 0.05$

Within a row, means without a common superscript differ at  $P < 0.05$

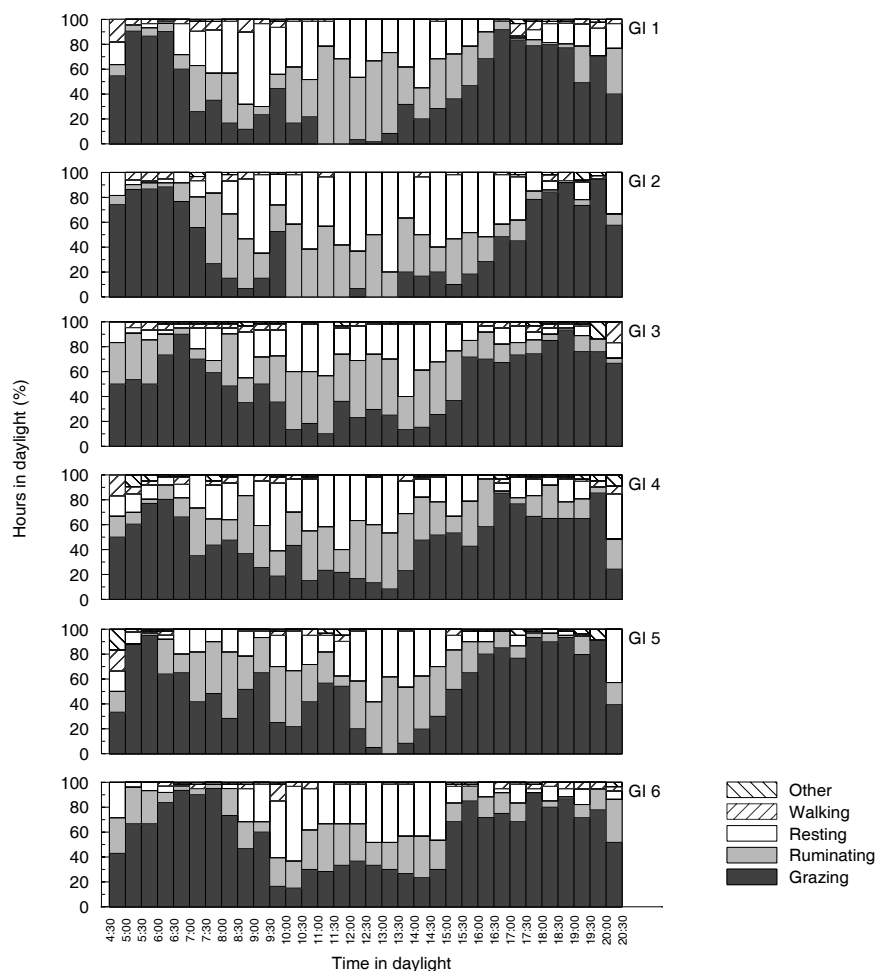


Figure 2.1. Diurnal behavioral pattern of sheep grazing at different grazing intensities (GI) (means across the whole grazing period). GI was defined by herbage allowance: very light (GI1), light (GI2), light-moderate (GI3), moderate (GI4), heavy (GI5), and very heavy (GI6), corresponding to stocking rates of approximately 2, 3, 4, 6, 8, and 11 sheep  $\text{ha}^{-1}$ , respectively.

## 2.5 Discussion

### 2.5.1 Diurnal behavioral pattern

The diurnal behavioral pattern of sheep observed in the present study confirms previous reports that two major grazing periods exist during the day, a longer afternoon grazing (5.5 h) and a shorter morning grazing period (4.5 h) (Fierro and Bryant, 1990; Birrell, 1991; Wang, 1997). Studies indicated that tall fescue or alfalfa

(cool-season grass) and switchgrass or luka gamagrass (warm-season grass) harvested in the late afternoon (PM) versus the early morning (AM) have greater concentrations of total non-structural carbohydrates (TNC) (Fisher et al., 1999, 2002; Huntington and Burns, 2008; Sauve et al., 2009). Forages with increased TNC had higher apparent dry matter digestibilities when offered to goats (Burns et al., 2005) or steers (Huntington and Burns, 2008); and compared to AM harvested forages, cattle, sheep, and goats preferred PM harvested tall fescue (Fisher et al., 1999) and alfalfa (Fisher et al., 2002). The longer afternoon grazing could therefore be caused by the accumulation of TNC in the herbage within the course of the day.

Table 2.2. Behavioral activities of sheep during daylight in July, August, and September 2008 (least squares means; n=12).

Activities	Month			SEM	P-value Month
	July	August	September		
Grazing (h)	7.39 <sup>a</sup>	7.18 <sup>a</sup>	7.49 <sup>a</sup>	0.31	0.82
Ruminating (h)	4.02 <sup>b</sup>	3.73 <sup>ab</sup>	3.34 <sup>a</sup>	0.18	0.05
Resting (h)	3.92 <sup>b</sup>	4.70 <sup>b</sup>	2.29 <sup>a</sup>	0.35	<b>&lt;0.01</b>
Walking (h)	0.45 <sup>a</sup>	0.28 <sup>a</sup>	0.28 <sup>a</sup>	0.06	0.07
Other (h)	0.19 <sup>b</sup>	0.12 <sup>a</sup>	0.11 <sup>a</sup>	0.02	<b>0.03</b>
Distance (km)	3.70 <sup>b</sup>	2.79 <sup>a</sup>	3.06 <sup>ab</sup>	0.24	<b>0.04</b>
Grazing (% of daylight)	46.2 <sup>a</sup>	44.9 <sup>a</sup>	55.5 <sup>b</sup>	2.0	<b>&lt;0.01</b>
Ruminating (% of daylight)	25.1 <sup>a</sup>	23.3 <sup>a</sup>	24.7 <sup>a</sup>	1.1	0.42
Resting (% of daylight)	24.5 <sup>ab</sup>	29.4 <sup>b</sup>	16.9 <sup>a</sup>	2.3	<b>&lt;0.01</b>
Walking (% of daylight)	2.8 <sup>a</sup>	1.8 <sup>a</sup>	2.1 <sup>a</sup>	0.4	0.12
Other (% of daylight)	1.0 <sup>a</sup>	0.7 <sup>a</sup>	0.8 <sup>a</sup>	0.1	0.09

Effects in bold characters were significant at the level  $P < 0.05$

Within a row, means without a common superscript differ at  $P < 0.05$ .

Sheep mainly ruminate during darkness (Fierro and Bryant, 1990), whereas daylight ruminating only accounts for about 36% of the total daily ruminating time (Animut et al., 2005). In contrast thereto, sheep (Birrell, 1991), dairy cows (Stockdale and King, 1983), heifers (Hessle et al., 2008), or beef steers (Huber et al., 1995) avoid grazing during darkness, which relates to the anti-predator theory that herbivores will

avoid foraging during darkness due to a perceived risk of predation (Rutter, 2006). While the grazing time observed during daylight in the present study therefore equals total daily grazing time of sheep, ruminating and resting time during daylight might only account for less than 50% of the total daily ruminating and resting time (Animut et al., 2005). During daytime, grazing time of sheep in our experiment was comparable to that of sheep grazing alone (Fierro and Bryant, 1990; Han, 1993), or of sheep and goats grazing together (Animut et al., 2005). While animals spent more time ruminating and resting than those in studies by Fierro and Bryant (1990) and Wang (1997), ruminating and resting time was consistent with findings of Animut et al. (2005).

Animals tended to ruminate and rest more while lying than while standing, and total lying time was about twice as high as total standing time in the daylight. This is in agreement with results of a previous study carried out with animals of the same breed in the study area (Wang, 1997). In contrast thereto, Fierro and Bryant (1990) reported that Corriedale ewes showed a tendency to rest more on foot than lying down. This different habit could be caused by the different animal breed used in the studies.

### **2.5.2 Effect of grazing intensity**

Increasing GI decreases herbage mass on offer (Wang, 2004; Schönbach et al., 2009) and reduces the quantity of herbage taken per bite (Forbes, 1988). As a consequence, beef steers (Seman et al., 1991; Ackerman et al., 2001), heifers (Hejcmanova et al., 2009), goats and sheep (Wang, 1997; Animut et al., 2005) grazing at high GI's increased their grazing time to compensate for a decrease in forage availability. However, GI did not affect ruminating time of goats and sheep on grass/forb pastures (Animut et al., 2005) as well as of heifers grazing on a species-rich pasture (Hejcmanova et al., 2009). Similarly, sheep in the present study spent more time grazing and less time resting and standing with increasing GI, indicating that sheep tended to increase their grazing time to compensate for reduced forage availability by decreasing their resting time. Although HA was lower at high GI, OMI did not differ between GI1 to GI5, implying that sheep in the present study succeeded in



maintaining their OMI by increasing their grazing time (except GI6).

According to the 8, 9, and 9 days of 24 h-GPS data obtained in July, August, and September, respectively, the ratios of distances walked between 0:00 h - 12:00 h and between 12:00 h-24:00 h were  $0.79 \pm 0.05$ ,  $1.06 \pm 0.10$  and  $0.98 \pm 0.05$  in the three months, respectively. Therefore, 12 h-walking distances represent about half of the total distances covered by sheep per day. Walking distances of sheep in the present study ranged from 2.3 to 3.2 km per 12 h, and thus about 4.7 to 6.4 km d<sup>-1</sup>, which was within the range reported in a similar study by Fierro and Bryant (1990). Walking distance was lowest at GI4 ( $P > 0.05$ ); however, because of a high variation between measurement days, the effect of GI on walking distance was not significant. Nevertheless, Animut et al. (2005) showed that the number of steps of sheep linearly increases with increasing SR, indicating that sheep in high SR may walk further distances. Hence, further studies should be carried out to evaluate the effect of GI on the walking distance of sheep.

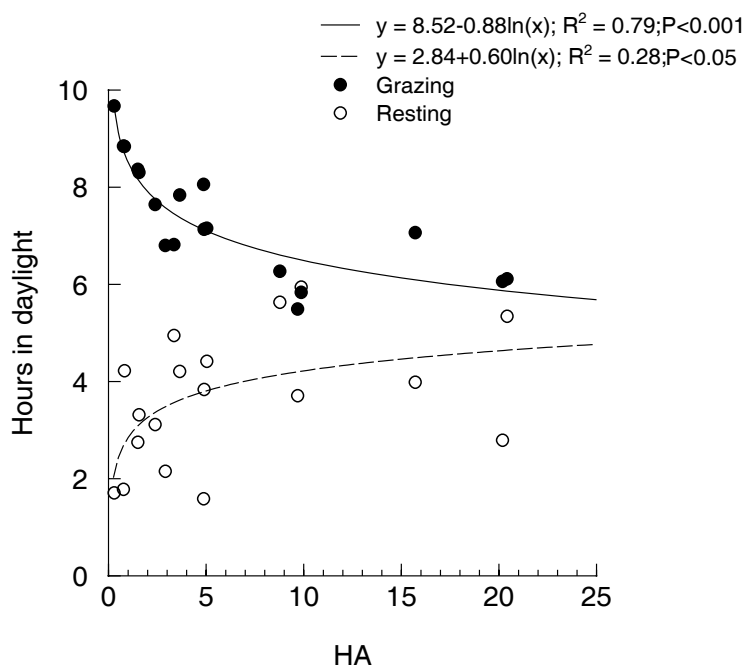


Figure 2.2. Effect of herbage allowance (HA, kg dry matter kg<sup>-1</sup> live weight) on the time sheep spent grazing and resting during daylight.

### 2.5.3 Effect of month

In the present study, sheep maintained their grazing time as season progressed even though daylight in September was 2.5 h shorter than in July and August. In contrast thereto, resting time was approximately 2.0 h shorter in September than in July and August, indicating that sheep tended to decrease their resting time in order to maintain their grazing and ruminating time when daylight became shorter. In recent studies, Hesse et al. (2008) and Hejzmanova et al. (2009) found that heifers decreased their resting time but increased their grazing time as season progressed from spring to autumn. There was no difference in the standing biomass in each of our study plots between months (unpublished data), which might explain why in contrast to findings of Hesse et al. (2008) and Hejzmanova et al. (2009) absolute grazing time was not affected by month in the present study.

### 2.5.4 Energy expenditure of grazing behavior

Higher requirements of grazing sheep than of those kept in confinement might be due to increased muscular efforts for walking and eating, whereas contributions of other activities such as ruminating and resting are considered low or negligible (Lachica and Aguilera, 2005). Osuji (1974) indicated that grazing and walking account for 47% and 42%, respectively, of the additional energy expenditure for muscular activity of sheep on range compared to similar animals kept indoors. Similarly, Fierro and Bryant (1990) reported that grazing and walking each accounted for 45% of the energy expended on behavioral activities of sheep during daytime. In order to evaluate the effect of GI on energy requirements for activity of sheep in the present study, energy costs for grazing and walking were estimated by the sum of the absolute grazing time (h during daylight) multiplied by the mean heat production of eating ( $40 \text{ J min}^{-1} \text{ kg}^{-1} \text{ LW}$ ) proposed by Susenbeth et al. (1998) as well as the measured walking distance ( $\text{m d}^{-1}$ ) multiplied by the heat production of walking of  $2.47 \text{ J m}^{-1} \text{ kg}^{-1} \text{ LW}$  determined by Osuji (1974). Assuming the average LW of sheep of 37 kg, total energy expenditure for grazing and walking were 1.15, 1.05, 1.15, 1.06, 1.22, and 1.37  $\text{MJ d}^{-1}$  at GI1 to GI6, respectively, accounting for 25.4%, 19.6%, 18.2%, 26.6%, 28.8%, and 45.2% of the

corresponding ME above maintenance, which was calculated as the ME intake (unpublished data) minus the ME requirements for maintenance of  $410 \text{ kJ kg}^{-1} \text{ LW}^{-0.75}$  (NRC, 1975). Therefore, GI6 sheep spent about 20% ( $0.2 \text{ MJ day}^{-1}$ ) more of their ME above maintenance for grazing and walking than those at GI1 - GI5, implying that less ME is available for growth. This complies with results of Animut et al. (2005) who reported that ME requirements of grazing sheep for maintenance and activity increased with increasing SR.

## 2.6 Conclusion

It can be concluded that sheep increase or at least maintain their grazing time at the expense of their resting time to avoid the negative impacts of an increasing GI or shorter daylight duration on their daily feed intake. However, higher energy expenditures for grazing and walking may reduce the energy available for growth of animals at high GI.

## 2.7 References

- Ackerman, C. J., H. T. Purvis, G. W. Horn, S. I. Paisley, R. R. Reuter, and T. N. Bodine. 2001. Performance of light vs heavy steers grazing Plains Old World bluestem at three stocking rates. *Journal of Animal Science* 79:493-499.
- Animut, G., A. L. Goetsch, G. E. Aiken, R. Puchala, G. Detweiler, C. R. Krehbiel, R. C. Merkel, T. Sahlu, L. J. Dawson, Z. B. Johnson, and T. A. Gipson. 2005. Grazing behavior and energy expenditure by sheep and goats co-grazing grass/forb pastures at three stocking rates. *Small Ruminant Research* 59:191-201.
- Birrell, H. A. 1991. The effect of stocking rate on the grazing behavior of Corriedale sheep. *Applied Animal Behaviour Science* 28:321-331.
- Burns, J. C., H. F. Mayland, and D. S. Fisher. 2005. Dry matter intake and digestion of alfalfa harvested at sunset and sunrise. *Journal of Animal Science* 83:262-270.

- Fierro, L. C., and F. C. Bryant. 1990. Grazing activities and bioenergetics of sheep on native range in Southern Peru. *Small Ruminant Research* 3:135-146.
- Fisher, D. S., H. F. Mayland, and J. C. Burns. 1999. Variation in ruminants' preference for tall fescue hays cut either at sundown or at sunup. *Journal of Animal Science* 77:762-768.
- Fisher, D. S., H. F. Mayland, and J. C. Burns. 2002. Variation in ruminant preference for alfalfa hays cut at sunup and sundown. *Crop Science* 42:231-237.
- Forbes, T. D. A. 1988. Researching the plant-animal interface - the investigation of ingestive behavior in grazing animals. *Journal of Animal Science* 66:2369-2379.
- Glindemann, T., C. Wang, B. M. Tas, A. Schiborra, M. Gierus, F. Taube, and A. Susenbeth. 2009. Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe. *Livestock Science* 124:142-147.
- Glindemann, T., C. Wang, B. M. Tas, A. Schiborra, M. Gierus, F. Taube, and A. Susenbeth. 2009. Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe. *Livestock Science* 124:142-147.
- Han, G. D. 1993. A comparative study of grazing behaviors of sheep in rotational and seasonal continuous grazing system. *Grassland of China* 2:1-4.
- Hejcmanova, P., M. Stejskalova, V. Pavlu, and M. Hejcman. 2009. Behavioural patterns of heifers under intensive and extensive continuous grazing on species-rich pasture in the Czech Republic. *Applied Animal Behaviour Science* 117:137-143.
- Hessle, A., M. Rutter, and K. Wallin. 2008. Effect of breed, season and pasture moisture gradient on foraging behaviour in cattle on semi-natural grasslands. *Applied Animal Behaviour Science* 111:108-119.

- Huber, S. A., M. B. Judkins, L. J. Krysl, T. J. Svejcar, B. W. Hess, and D. W. Holcombe. 1995. Cattle grazing a riparian mountain meadow: Effects of low and moderate stocking density on nutrition, behavior, diet selection, and plant growth response. *Journal of Animal Science* 73:3752-3765.
- Huntington, G. B., and J. C. Burns. 2008. The interaction of harvesting time of day of switchgrass hay and ruminal degradability of supplemental protein offered to beef steers. *Journal of Animal Science* 86:159-166.
- Lachica, M., and J. F. Aguilera. 2005. Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* 59:105-121.
- NRC (Editor), 1975. Nutrient requirements of sheep, fifth ed. National Academy Press, Washington, DC.
- Osuji, P. O. 1974. Physiology of eating and energy expenditure of ruminant at pasture. *Journal of Range Management* 27:437-443.
- Penning, P. D., A. J. Parsons, J. A. Newman, R. J. Orr, and A. Harvey. 1993. The effects of group-size on grazing time in sheep. *Applied Animal Behaviour Science* 37:101-109.
- Rutter, S. M. 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: Current theory and future application. *Applied Animal Behaviour Science* 97:17-35.
- Sauve, A. K., G. B. Huntington, and J. C. Burns. 2009. Effects of total nonstructural carbohydrates and nitrogen balance on voluntary intake of goats and digestibility of gamagrass hay harvested at sunrise and sunset. *Animal Feed Science and Technology* 148:93-106.
- Schönbach, P., H. Wan, A. Schiborra, M. Gierus, Y. Bai, K. Muller, T. Glindemann, C. Wang, A. Susenbeth, and F. Taube. 2009. Short-term management and stocking rate effects of grazing sheep on herbage quality and productivity of Inner Mongolia steppe. *Crop & Pasture Science* 60:963-974.

- Seman, D. H., M. H. Frere, J. A. Stuedemann, and S. R. Wilkinson. 1991. Simulating the influence of stocking rate, sward height and density on steer productivity and grazing behavior. *Agricultural Systems* 37:165-181.
- Stockdale, C. R., and K. R. King. 1983. Effect of stocking rate on the grazing behavior and fecal output of lactating dairy-cows. *Grass and Forage Science* 38:215-218.
- Susenbeth, A., R. Mayer, B. Koehler, and O. Neumann. 1998. Energy requirement for eating in cattle. *Journal of Animal Science* 76:2701-2705.
- Wang, C. J., B. M. Tas, T. Glindemann, G. Rave, L. Schmidt, F. Weissbach, and A. Susenbeth. 2009. Fecal crude protein content as an estimate for the digestibility of forage in grazing sheep. *Animal Feed Science and Technology* 149:199-208.
- Wang, R. Z. 2004. Responses of *Leymus chinensis* (poaceae) to long-term grazing disturbance in the Songnen grasslands of north-eastern China. *Grass and Forage Science* 59:191-195.
- Wang, S. P. 1997. Behavior ecology of grazing sheep II influence of stocking rates on foraging behavior of wether. *Acta Prataculturae Sinica* 6:10-17.
- Wang, S. P. 2000. Relationships between body gains and stocking rates of grazing sheep on typical Inner Mongolian grassland. *Acta Prataculturae Sinica* 9:10-16.

*Chapter 3*

**Growth of sheep as affected by grazing system and grazing intensity in the steppe of Inner Mongolia, China**

### **3 Growth of sheep as affected by grazing system and grazing intensity in the steppe of Inner Mongolia, China**

#### **3.1 Abstract**

The Inner Mongolian grassland steppe is the most important grazing land in China in terms of cow milk, mutton, and cashmere production. However, sheep grazing has severely degraded the steppe grassland. Defining an optimum grazing system and grazing intensity (GI) is therefore essential for an economically viable use of the Inner Mongolian grassland without amplifying its desertification. The objective of this study was to evaluate the effects of different grassland use systems and GI's on liveweight gain (LWG) of sheep grazing the Inner Mongolian steppe in order to derive recommendations for a sustainable grassland use, which considers both, farmers' interests of a profitable livestock production as well as environmental goals. A 5-year grazing experiment was conducted in June-September of 2005-2009, in which six different GI's (2, 3, 4, 6, 8, and 9 sheep ha<sup>-1</sup>) and two different grazing systems were installed. The two systems included an alternating grazing system where grazing and hay-making alternated annually between the two plots, and a continuous grazing system where the same plots were used either for hay-making or for grazing each year. Results indicated that grazing system had no or only minor effects on sheep's LWG. However, LWG per sheep linearly decreased with increasing stocking rate, while there were quadratic relationships between stocking rate and LWG per ha. LWG per sheep and per ha differed between years and months. LWG per sheep and per ha were lowest in a dry year and decreased with advancing vegetation period. In view of our earlier published data regarding the effect of GI on the steppe vegetation, it is concluded that grazing at ecologically acceptable SR's that account for inter- and intra-annual variations in herbage growth also can satisfy farmers' economical interests and thus assure the sustainable use of the Inner Mongolian grassland.



### 3.2 Introduction

The Inner Mongolian grassland steppe is one of the largest grassland regions in the world and is the most important grazing land in China in terms of cow milk, mutton, and cashmere production. It has experienced wide-spread degradation during the last century, so that in the 1990s, about 30% of the grassland area was degraded and more than 20% were considered unusable for farming (Yu et al., 2004). More recent surveys have shown that nearly 90% of the Inner Mongolian grassland is degraded to varying degrees (Lu et al., 2006). Rangeland degradation not only reduces grassland productivity, but also increases the risk of wind and water erosion as well as sand storms during the dry winter months. The latter induce severe economic and health problems for the population in Central China (Lu et al., 2005; Zhang et al., 2006). Overgrazing is one of the primary causes for grassland degradation and desertification in Inner Mongolia (Li et al., 2000; Yu et al., 2004; Li et al., 2005). Therefore, it is of essential economical and ecological importance to develop a framework that considers both, agricultural productivity as well as environmental aspects, and from which guidelines can be derived for pastoral livestock keepers (Kemp and Michalk, 2007).

The current grassland management in the Inner Mongolian steppe is characterized by a strict functional and spatial delimitation of hay-making and grazing: grasslands close to farmers' settlements are intensely used for grazing, whereas distant areas are used moderately for hay-making without any nutrient reflexes. This may negatively affect long-term grassland productivity in both areas (Müller, 2009; Schönbach, 2009) and thus economical viability of livestock system. An alternative to the current grassland management could be an annual rotation of the use of individual areas for hay-making and grazing. This would allow for a recovery of grazed swards during hay-making years and nutrient returns to grassland through animal excrements during grazing years. Moreover, there are so far no recommendations of a sustainable grazing intensity (GI) for the Inner Mongolian grasslands (Wang et al., 2005). However, GI is one of the most important management decisions determining the sustainability

and efficiency of the use of the key resources pasture and labor force in pastoral livestock systems (Li et al., 2000; Alcock, 2006). It strongly influences biomass production and nutritional quality of the vegetation and consequently, animal behavior and performance (Kemp and Michalk, 2007). Hence, this paper analyzes the results of a 5-year grazing experiment, in which two grazing systems (continuous grazing vs. alternating hay-making and grazing) and six different GI treatments were tested in order to evaluate their impacts on liveweight gain (LWG) of individual sheep as well as on the output of pastoral sheep husbandry in the Inner Mongolian steppe.

### **3.3 Materials and methods**

#### **3.3.1 Study area**

The study was conducted at the Inner Mongolia Grassland Ecosystem Research Station (IMGERS), which is located in the Xilin River Basin in the Inner Mongolia Autonomous Region of China (116° 42' E, 43° 38' N) and is administered by the Institute of Botany, Chinese Academy of Sciences, Beijing. The climate is semi-arid, continental with mean annual precipitations and temperatures of 342 mm and 0.7°C, respectively (1982-2004). More than 80% of the rainfall occurs in the vegetation period from April-September. In the study years of 2005, 2006, 2007, 2008, and 2009, mean annual temperature was 1.1, 1.1, 2.4, 1.6, and 1.6 °C and annual precipitation was 162, 312, 371, 369, and 313 mm, respectively (measured by IMGERS near the experimental plots; Figure 3.1). Hence, while precipitation in 2006-2009 was similar to the long-term average, 2005 was the only year since 1982 when rainfall was below 200 mm. Long-term inter-annual coefficient of variation (CV) in rainfall is 19% (1982-2004), but was higher in the study years (28%). The dominant soil type of the study area is a calcic chernozem (IUSS Working Group WRB, 2006) and the natural vegetation is dominated by two grass species: the perennial rhizome grass *Leymus chinensis* and the perennial bunchgrass *Stipa grandis*.

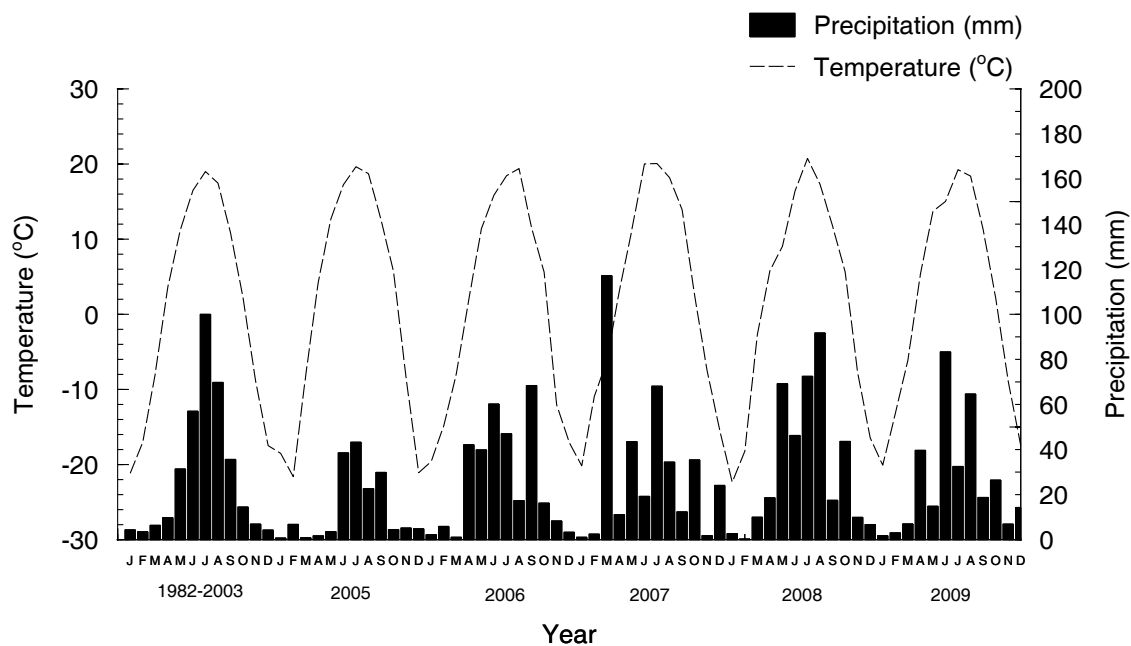


Figure 3.1. Mean monthly temperature (dotted line) and precipitation (bars) at the experimental site across 1982-2002 and in 2005-2009. Mean annual temperature was 1.1, 1.1, 2.4, 1.6, and 1.6 °C and annual precipitation was 162, 312, 371, 369, and 313 mm in 2005, 2006, 2007, 2008, and 2009, respectively.

### 3.3.2 Experimental design

The experiment was conducted in the grazing periods (June-September) and lasted for 98, 90, 93, 94, and 92 days in the respective study years. It was established on a 200 ha site, which had been moderately used for sheep grazing until October 2003. Thereafter, swards were not grazed until the experiment started in June 2005.

Six different GI treatments were established. GI was defined by herbage allowance (HA), which better described GI than SR, since herbage mass varied between plots. HA was expressed as kg dry matter (DM) of standing biomass per kg of liveweight (LW) per plot. HA target ranges were >12, 6-12, 4.5-6, 3-4.5, 1.5-3, and <1.5 kg DM kg<sup>-1</sup> LW for GI treatments very-light (GI1), light (GI2), light-moderate (GI3), moderate (GI4), heavy (GI5), and very-heavy (GI6) grazing. It corresponded to SR's of approximately 2, 3, 4, 6, 8, and 9 sheep ha<sup>-1</sup>, respectively. Each GI treatment was replicated in two blocks, a flat and a moderately sloped area, to account for any

differences in herbage mass and composition due to different geographical settings. In each block, each GI treatment comprised two adjacent plots, one hay-making plot and one grazing plot, which were considered as one production unit. Each plot had a size of 2 ha, with the exception of the GI1 plots, which covered 4 ha in order to maintain a minimum of 6 sheep per plot. Two grazing management systems were tested: an alternating system (ALT), where grazing and hay-making were alternated annually between the two plots, and a continuous grazing system (CON), where the same plots were used for hay-making or for grazing at the same GI every year, which is similar to the current grazing system in Inner Mongolia. Hence, in total measurements were carried out on 24 grazing plots (6 GI's x 2 blocks x 2 systems) during the 3-month-grazing periods of each of the five study years.

### **3.3.3 Animals and herbage allowance**

Each year, about 300 non-pregnant and non-lactating 15-month-old female sheep of the Inner Mongolian fat-tailed breed were purchased from local farms in the beginning of the grazing periods ( $30.1 \pm 0.8$  kg LW). The animals were treated for internal parasites and had free access to water and mineral lick stones throughout the entire grazing period. After sheep had been on the grazing plots for 1-2 weeks for adaptation, they were weighed on two consecutive days and their average LW was calculated (initial LW  $30.8 \pm 0.7$  kg). Subsequently, they were divided into three LW groups (light, medium, and heavy). Out of each LW group animals were randomly allocated to one of the 24 plots to equalize mean LW per plot. LW measurements were repeated on two consecutive days between 10<sup>th</sup> and 15<sup>th</sup> of July, August, and September, respectively, to determine average LW and to calculate daily LWG per sheep for the respective months. LWG per ha was calculated by multiplying LWG per sheep by the respective SR. In 2005, sheep's LW was only measured in July and September. Therefore, LWG per sheep and LWG per ha could not be calculated for each individual month that year. In 2006, sheep at GI5 and GI6 had to be removed from the grazing plots at the end of August due to a lack of forage. For calculating average LWG per sheep and LWG per ha across the whole grazing period, LWG of GI5 and

GI6 sheep in September 2006 was estimated by extrapolating the linear regression equation between SR and LWG per sheep at GI1 to GI4 to GI5 and GI6.

HA's were determined by the following formula (Sollenberger et al., 2005):  $HA = (SB_1/LW_1 + SB_2/LW_2)/2$ , where HA is the herbage allowance in kg DM kg<sup>-1</sup> LW, SB the standing biomass (kg DM per plot), which was estimated by a calibrated height-platemeter (Schönbach et al., 2008), and LW (kg) the total LW of all animals per plot. Indices 1 and 2 represent two consecutive sampling days in the beginning of July, August, and September, respectively. Based on these instantaneous measurements, the number of sheep per plot was adjusted each month in order to maintain the HA's at defined target ranges and mean HA's were calculated across the entire grazing period.

### 3.3.4 Statistical analyses

All data were analyzed using the SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). Least squares means and standard error of the means of LWG per sheep and LWG per ha were calculated for each year and GI using the Mixed Model procedure (Proc Mixed). The model consisted of system ( $S_i$ : CON and ALT), block ( $B_j$ : flat and sloped), GI ( $GI_k$ : 1, 2, 3, 4, 5, and 6), year ( $YE_l$ : 2005, 2006, 2007, 2008, and 2009), and their interactions. Fixed factors were block, GI, and system, and year was the repeated measurement. The best fit was the autoregressive co-variance structure. The following model was used:

$$Y_{ijkl} = \mu + S_i + B_j + GI_k + S \times GI_{ik} + YE_l + S \times YE_{il} + GI \times YE_{kl} + GI \times S \times YE_{jkl} + e_{ijkl},$$

where  $\mu$  is the overall mean and  $e_{ijkl}$  is the random experimental error.

Multiple comparisons of least squares means were done by the Tukey-test. Regression analyses were applied to analyze the relation between SR (dependent variable) and LWG per sheep or LWG per ha (independent variables) across the whole grazing period. Since a similar LWG was found in 2006, 2008, and 2009 (Table 3.1, 3.2), data were pooled, while data from 2005 showing low LWG and from 2007 with exceptionally high LWG were analyzed separately.

The effect of month on LWG within years was investigated using the General Linear Model procedure for 2007, 2008, and 2009. The model was:

$$Y_i = \mu + M_i + e_i,$$

where  $\mu$  is the overall mean,  $M$  is the fixed effect of month  $i$  (July, August, and September), and  $e$  the random experimental error. Data from 2005 and 2006 were not included in this analysis because of missing data in these years (see 3.3.3).

### 3.4 Results

LWG per sheep determined across the entire grazing period ranged between 36 and 131 g d<sup>-1</sup>, while LWG per ha was 132 - 852 g d<sup>-1</sup> (Table 3.1). Except in 2008, when LWG was higher in CON than in ALT sheep ( $P < 0.05$ ; Table 3.2), LWG per sheep was similar in animals grazing CON and ALT plots ( $P > 0.05$ ). Across all study years, LWG per ha was slightly, but significantly higher on CON than on ALT plots ( $P < 0.05$ ). However, this difference was not significant within individual study years ( $P > 0.05$ ).

There were significant effects of GI on LWG per sheep and LWG per ha ( $P < 0.01$ ). LWG per sheep was similar at GI1-GI4 ( $P > 0.05$ ), but significantly lower at GI5 and GI6 than at the lighter GI's ( $P < 0.05$ ). In contrast thereto, LWG per ha increased from GI1 to GI4 and was similar at GI4 to GI6 ( $P > 0.05$ ). LWG per sheep and LWG per ha were lower in 2005 and higher in 2007 than in 2006, 2008, and 2009 ( $P < 0.05$ ). The effect of GI on LWG per sheep differed between years ( $P < 0.05$ ). While a significant effect of GI on LWG per sheep was found in 2005, 2008, and 2009 ( $P < 0.05$ ), LWG per sheep grazing at different GI's was similar in 2006 and 2007 ( $P > 0.05$ ). The CV in LWG per sheep and LWG per ha increased with increasing GI, indicating the higher year-to-year variation in LWG of sheep grazing at high GI's.

Table 3.1. Effect of year, grazing system (S), and grazing intensity (GI) on liveweight gain (LWG) per sheep and LWG per ha of sheep grazing the Inner Mongolian steppe in 2005-2009.

Year	GI						SEM <sup>3</sup>	S			Total
	1	2	3	4	5	6		ALT <sup>1</sup>	CON <sup>2</sup>	SEM	
LWG per sheep (g d <sup>-1</sup> )											
2005	88 <sup>bc</sup>	103 <sup>c</sup>	70 <sup>abc</sup>	57 <sup>ab</sup>	57 <sup>ab</sup>	36 <sup>a</sup>	8	61	76	5	68 <sup>A</sup>
2006	90 <sup>a</sup>	92 <sup>a</sup>	85 <sup>a</sup>	88 <sup>a</sup>	75 <sup>a</sup>	75 <sup>a</sup>	8	78	91	5	85 <sup>B</sup>
2007	120 <sup>a</sup>	108 <sup>a</sup>	122 <sup>a</sup>	131 <sup>a</sup>	110 <sup>a</sup>	97 <sup>a</sup>	8	119	110	5	115 <sup>C</sup>
2008	84 <sup>ab</sup>	93 <sup>ab</sup>	104 <sup>b</sup>	84 <sup>ab</sup>	81 <sup>ab</sup>	56 <sup>a</sup>	8	97*	70	5	84 <sup>B</sup>
2009	105 <sup>b</sup>	88 <sup>ab</sup>	90 <sup>ab</sup>	85 <sup>ab</sup>	63 <sup>ab</sup>	55 <sup>a</sup>	8	83	80	5	81 <sup>AB</sup>
Total	98 <sup>c</sup>	97 <sup>c</sup>	94 <sup>c</sup>	89 <sup>bc</sup>	77 <sup>ba</sup>	64 <sup>a</sup>	4	88	85	2	87
CV (%) <sup>4</sup>	15	9	21	30	26	37					
LWG per ha (g d <sup>-1</sup> )											
2005	132 <sup>a</sup>	309 <sup>a</sup>	314 <sup>a</sup>	339 <sup>a</sup>	430 <sup>a</sup>	320 <sup>a</sup>	53	270	346	31	308 <sup>A</sup>
2006	136 <sup>a</sup>	277 <sup>ab</sup>	384 <sup>abc</sup>	529 <sup>bc</sup>	563 <sup>bc</sup>	678 <sup>c</sup>	53	405	450	31	428 <sup>B</sup>
2007	288 <sup>a</sup>	398 <sup>a</sup>	529 <sup>ab</sup>	715 <sup>bc</sup>	797 <sup>bc</sup>	852 <sup>c</sup>	53	564	629	31	596 <sup>C</sup>
2008	174 <sup>a</sup>	333 <sup>ab</sup>	429 <sup>abc</sup>	490 <sup>bc</sup>	647 <sup>c</sup>	532 <sup>bc</sup>	53	441	427	31	434 <sup>B</sup>
2009	232 <sup>a</sup>	353 <sup>ab</sup>	435 <sup>ab</sup>	534 <sup>b</sup>	518 <sup>ab</sup>	551 <sup>b</sup>	53	407	466	31	437 <sup>B</sup>
Total	192 <sup>a</sup>	334 <sup>b</sup>	418 <sup>b</sup>	522 <sup>c</sup>	591 <sup>c</sup>	587 <sup>c</sup>	23	418	464*	14	441
CV (%)	35	14	19	26	24	33					

Within a row (a, b, and c) or within a column (A, B, and C) means without a common superscript differ at  $P < 0.05$

\* Within the same row means for the two grazing systems differ at  $P < 0.05$ .

<sup>1</sup> ALT: Alternating grazing system, where grazing and hay-making alternated annually between two plots

<sup>2</sup> CON: Continuous grazing system, where the same plots were used either for hay-making or for grazing at the same GI each year

<sup>3</sup> SEM: Standard error of the mean

<sup>4</sup> CV: Coefficient of variation

LWG per sheep and LWG per ha differed between months ( $P < 0.05$ ; Table 3.3). In 2007 and 2009, LWG per sheep and LWG per ha decreased as grazing season progressed from July to September ( $P < 0.05$ ), while in 2008, lowest LWG was found in August ( $P < 0.05$ ). The CV in LWG per sheep and LWG per ha in 2007 was 14% and lower than that in 2008 (41%) and 2009 (50%), indicating the lower monthly variation in LWG of sheep and SR's in 2007 than in the other two years.

In all study years, LWG per sheep linearly decreased with SR, while there were

quadratic relationships between SR and LWG per ha (Figure 3.2). According to the regression equation for 2006, 2008, and 2009 (see Figure 3.2), LWG per ha increased when SR increased to about 9 sheep ha<sup>-1</sup> in years with an annual rainfall similar to the long-term average. Maximum LWG per ha derived from this equation was 613 g d<sup>-1</sup> at a SR of 9.6 sheep ha<sup>-1</sup>. In 2005 and 2007, maximum LWG per ha was 383 and 868 g d<sup>-1</sup>, which was reached at SR's of 6.7 and 9.8 sheep ha<sup>-1</sup>, respectively.

Table 3.2. Results of ANOVA analysis of the effects of block (flat vs. sloped), grazing system (S: continuous vs. alternating grazing system), grazing intensity (GI1-6), and year (2005-2009) on liveweight gain (LWG) per sheep and per ha.

Effect	LWG per sheep		LWG per ha	
	<i>F</i> -value	<i>P</i> -value	<i>F</i> -value	<i>P</i> -value
S	0.71	0.41	5.79	<b>0.02</b>
Block	0.05	0.83	1.49	0.23
GI	13.92	<b>&lt;0.001</b>	45.14	<b>&lt;0.001</b>
S x GI	2.17	0.09	0.43	0.82
Year	27.57	<b>&lt;0.001</b>	22.59	<b>&lt;0.001</b>
Year x S	6.86	<b>&lt;0.001</b>	0.66	0.62
Year x GI	1.95	<b>0.04</b>	1.79	0.06
Year x S x GI	1.22	0.29	0.88	0.61

*F*-value: *F*-statistics for the test of particular analysis

*P*-value: Probability values

Effects in bold characters were significant at  $P < 0.05$



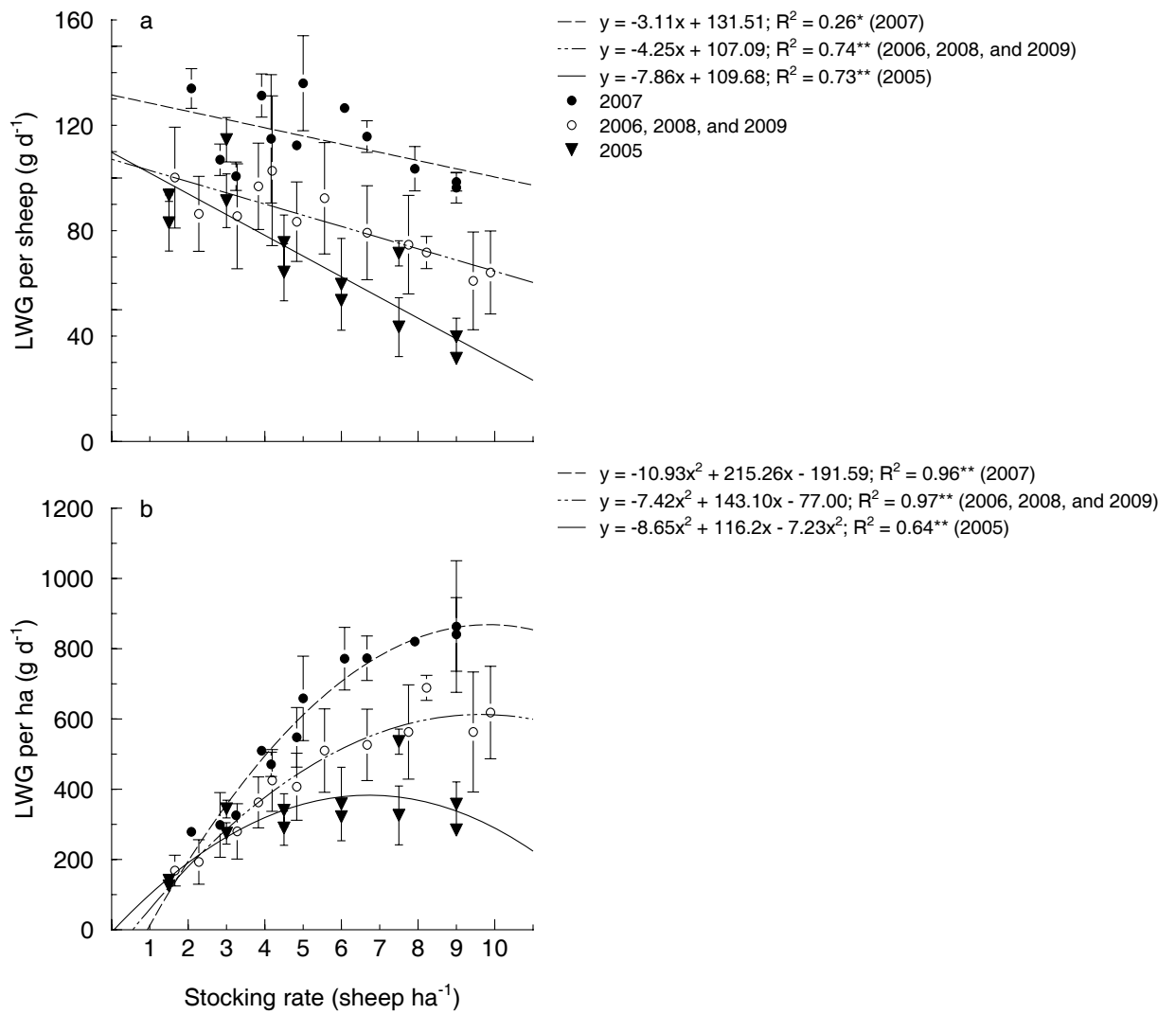


Figure 3.2. Relationships between stocking rate and liveweight gain (LWG) per sheep (a) and between stocking rate and LWG per ha (b) in 2007, in 2006, 2008, and 2009, and in 2005. \* and \*\* regressions are significant at  $P < 0.05$  and  $P < 0.01$ , respectively.

Table 3.3. Effect of month (July, August, and September) on liveweight gain (LWG) per sheep and LWG per ha of sheep grazing the Inner Mongolian steppe in 2007-2009.

Year	Month	GI						Total	CV (%) <sup>1</sup>	SEM <sup>2</sup>
		1	2	3	4	5	6			
LWG per sheep (g d <sup>-1</sup> )										
2007	July	136	133	124	150	117	121	130 <sup>b</sup>	9	18
	August	119	129	115	123	107	105	116 <sup>ab</sup>	8	18
	September	107	61	126	121	104	66	98 <sup>a</sup>	28	18
	CV (%)	12	38	5	12	6	29	14		
2008	July	68	82	112	73	72	105	85 <sup>b</sup>	22	18
	August	55	69	75	57	39	-5	48 <sup>a</sup>	60	18
	September	129	130	124	121	133	68	117 <sup>b</sup>	21	18
	CV (%)	47	35	25	40	59	99	41		
2009	July	104	110	139	109	107	104	112 <sup>b</sup>	12	18
	August	123	77	75	85	60	71	82 <sup>ab</sup>	26	18
	September	90	76	58	62	22	-10	50 <sup>a</sup>	74	18
	CV (%)	16	22	47	28	68	106	39		
LWG per ha (g d <sup>-1</sup> )										
2007	July	314	537	461	787	800	925	638 <sup>a</sup>	37	103
	August	302	455	565	652	799	987	627 <sup>a</sup>	39	103
	September	249	202	559	704	780	644	525 <sup>a</sup>	47	103
	CV (%)	12	44	11	10	1	22	11		
2008	July	125	274	446	397	564	1067	479 <sup>b</sup>	68	103
	August	111	253	309	330	320	-67	209 <sup>a</sup>	76	103
	September	287	473	531	744	1056	630	620 <sup>b</sup>	42	103
	CV (%)	56	36	26	45	58	106	48		
2009	July	248	440	677	663	853	1020	650 <sup>b</sup>	43	103
	August	288	309	359	523	479	712	445 <sup>b</sup>	36	103
	September	158	309	270	417	218	-79	216 <sup>a</sup>	78	103
	CV (%)	29	21	49	23	62	103	50		

a, b, c Within columns of the same item, means followed by different lower-case letters are significantly different ( $P < 0.05$ )

<sup>1</sup> CV: Coefficient of variation

<sup>2</sup> SEM: Standard error of the means

### **3.5 Discussion**

#### **3.5.1 Effect of grazing system, grazing intensity, and year on liveweight gain**

LWG of sheep in the present study is similar to that of grazing sheep of the same breed determined in earlier studies in this region (Han et al., 2000; Wang, 2000). No effect of grazing system on LWG of individual sheep was found in our study, because digestibility and nutrient concentrations of the herbage on offer did not differ between ALT and CON plots (Schönbach, 2009) and the number of animals was monthly adjusted to herbage mass to maintain similar HA's in the two systems. Across all study years, LWG per ha was slightly higher in CON than in ALT plots due to a higher standing biomass and consequently higher SR's on these plots. However, above-ground net primary production (ANPP) as well as ground coverage were higher at ALT than at CON plots in 2008 after four study years (Schönbach, 2009), indicating that, in the long term, an alternating use of the steppe grassland for animal grazing and hay-making may positively affect grassland as well as livestock productivity.

LWG per sheep was similar in sheep grazing at GI1-GI4 despite the decrease in HA from GI1 to GI4. As discussed in earlier studies, beef steers (Seman et al., 1991; Ackerman et al., 2001), heifers (Hejcmanova et al., 2009) as well as goats and sheep (Wang, 1997; Animut et al., 2005) grazing at high GI's increase their grazing time or the intake rate to compensate for a decrease in herbage availability. By this they are able to maintain their DM intake and consequently their LWG to a certain extent. However, Müller (2009) reported that digestible organic matter intake (DOMI) of GI5 and GI6 sheep in our experiment was lower than of those grazing at GI1-GI4, although the animals spent 37% more time during daylight for grazing than sheep at lighter GI's (Lin et al., 2010). Similarly, Hull et al. (1961) found that total forage consumption per ha increases with increasing GI up to a critical point, when feed intake of individual animals starts to decline. The prolonged grazing time increased their energy expenditure for physical activity and thus together with the lower feed intake reduced energy available for growth (Lin et al., 2010), which explains the lower

LWG of GI5 and GI6 sheep than of animals grazing at lighter GI's observed in this study. Due to the increasing SR's LWG per ha increased from GI1 to GI4, nevertheless, it was similar on GI4, GI5, and GI6 plots. Similarly, other studies with grazing steers and sheep showed that LWG per ha increases up to a certain SR threshold, above which any increases in the number of animals per area do not affect or even lead to a declining LWG per area due to the decreasing LWG of individual animals (Jones and Sandland, 1974; Kemp and Michalk, 2007).

Variations in the amount and distribution of rainfall result in inter- and intra-annual differences in the herbage production of natural grasslands (Harrington et al., 1984; Yu et al., 2004) and consequently in animal performance (Bird et al., 1989). In our study, annual precipitation in 2005 was only 47% of the 22-year mean precipitation, while it was similar to the long-term average in 2006-2009 (Figure 3.1). As a consequence, herbage quality and thus DOMI of sheep were lower in 2005 ( $P < 0.05$ ) than in any of the other study years (Müller, 2009; Schönbach, 2009), explaining the very low LWG per sheep and per ha in this year. However, although annual rainfall did not differ between 2006, 2007, 2008, and 2009, LWG per sheep and per ha were distinctly higher in 2007. There are two specific circumstances in 2007, which might offer some possible explanation for this higher animal performance. Firstly, rainfall was more evenly distributed in 2007 than in the other years and heavy rain and snow fall occurred in March, so that germination of herbage species in early April was improved (Bai et al., 2004). Soil water content remained high until the beginning of the grazing season in June (Zhao et al., 2010). Nevertheless, ANPP and DOMI in 2007 did not differ from those in 2006, 2008, and 2009. Secondly, initial LW with 31.8 kg was lowest in 2007 (32.4 kg in 2006, 34.6 kg in 2008, and 35.9 kg in 2009), so that the animals' growth potential might have been higher. However, we did not find this effect in 2006, when initial LW of sheep was similar to that in 2007.

Several models were developed to describe the relationship between SR and livestock production (Jones and Sandland, 1974; Kemp and Michalk, 2007). The model, which has received most attention, was proposed by Jones and Sandland

(1974) who examined published results from several grazing experiments. The authors concluded that over a wide range of SR's, a linear regression best describes the effect of SR on LWG per animal, while a quadratic regression best fits the relationship between SR and LWG per ha. Similarly, the relationships between SR and LWG per sheep and between SR and LWG per ha in our study were best described by linear and quadratic regression equations, respectively. In 2007, LWG per sheep decreased with  $4.3 \text{ g d}^{-1}$  per unit of SR, which is similar to the value of  $3.1 \text{ g d}^{-1}$  determined for the pooled dataset of 2006, 2008, and 2009. In contrast thereto, the decrease was more pronounced in the very dry year 2005 ( $7.9 \text{ g d}^{-1}$ ), which underlines that low rainfall not only decreases herbage mass and quality and consequently overall LWG per sheep and per ha, but also amplifies the effect of GI on animal performance.

### **3.5.2 Effect of month on liveweight gain**

LWG per sheep and LWG per ha differed between months ( $P < 0.05$ ). Similarly, Wang (2000) showed a clear decrease in LWG of Inner Mongolian sheep with advancing grazing season. Herbage quality data for the plots used in our experiment in 2005-2007 are presented by Müller (2009). At all GI's, digestibility of herbage on offer decreased as vegetation period progressed. The consequently lower digestible organic matter and energy intake of sheep towards the end of the grazing season thus explains the decrease in LWG per sheep from July to September. The exceptionally low LWG of sheep in August 2008 might have been the result of a decrease in herbage quality due to an uneven rainfall distribution in July 2008, when most of the precipitation happened during only a few heavy rainfall events (e.g. 46 mm within 12 h on 31 July 2008). Since most water is lost due to surface run-off, heavy rainfall events may cause severe soil erosion on sloped areas and thus rather damage the grassland vegetation than enhance herbage regrowth and quality.

### 3.5.3 Optimum grazing intensity

GI has a major impact on animal performance and profitability of grazing livestock systems (Biondini et al., 1998). Understocking results in patch-grazing, since animals repeatedly graze the same areas as soon as plant regrowth has occurred. The young plant material is more palatable and has a higher nutritive value than the mature herbage in ungrazed areas of the pastures. The left-over forage remains is wasted, reducing potential profit from livestock production. Conversely, overstocking of rangelands typically suppresses desirable forage species and leads to an invasion of weeds and impalatable plant species (Todd and Hoffman, 1999). In semi-arid zones such as the Inner Mongolian steppe, it reduces soil surface roughness length and increases surface albedo, which favors wind erosion in times of low rainfall and strong winds and thus leads to desertification (Li et al., 2000). As a consequence, carrying capacity of the rangeland decreases, so that overstocking may imperil long-term livestock production. Hence, an optimum GI should avoid negative effects of under- as well as of overgrazing and thereby allow for a long-term sustainable and productive use of grasslands for animal production.

Schönbach (2009) showed that in our study area sheep grazing reduced ANPP, litter accumulation, and soil coverage at all GI's, which indicates that even GI's of less than 1.5 sheep ha<sup>-1</sup> may negatively affect the vegetation of the Inner Mongolian steppe. However, since livestock production is the main source of income for local residents, farmers' economical interests need to be considered. Hence, recommendations for an ecologically and economically sustainable GI, which does not impair ecosystem functions as well as long-term animal and grassland productivity, are urgently needed. Christensen et al. (2003) who modeled long-term root biomass and ANPP of the ligneous and herbaceous vegetation in the Inner Mongolian steppe concluded that a GI that leads to a removal of less than 51% of ANPP does not lead to a decrease in long-term biomass production. According to the average ANPP of the grassland in our study area of 140 g DM m<sup>-2</sup> (Schönbach, 2009) this would equal an end-of season standing biomass (ESSB) of about 70 g DM m<sup>-2</sup>. Taking this value as a

minimum threshold, an ecologically acceptable GI can be derived from the regression equations between the SR's and the ESSB determined by Schönbach (2009) on the experimental plots used in our study (Figure 3.3). Accordingly, a minimum ESSB of 70 g DM m<sup>-2</sup> was reached at SR's of  $\leq 3.7$ ,  $\leq 2.9$ ,  $\leq 5.7$ ,  $\leq 7.1$ , and  $\leq 7.1$  sheep ha<sup>-1</sup> in 2005, 2006, 2007, 2008, and 2009, respectively (Table 3.4). Given the regression equations between SR and LWG per ha (see Figure 3.2), LWG per ha at these SR's would amount to 302, 276, 676, 565, and 565 g d<sup>-1</sup>, equivalent to 79%, 45%, 78%, 92%, and 92% of the maximum LWG per ha in the respective years. This indicates that in most years, LWG per ha at an ecologically acceptable SR is not much lower than the maximum possible LWG per ha.

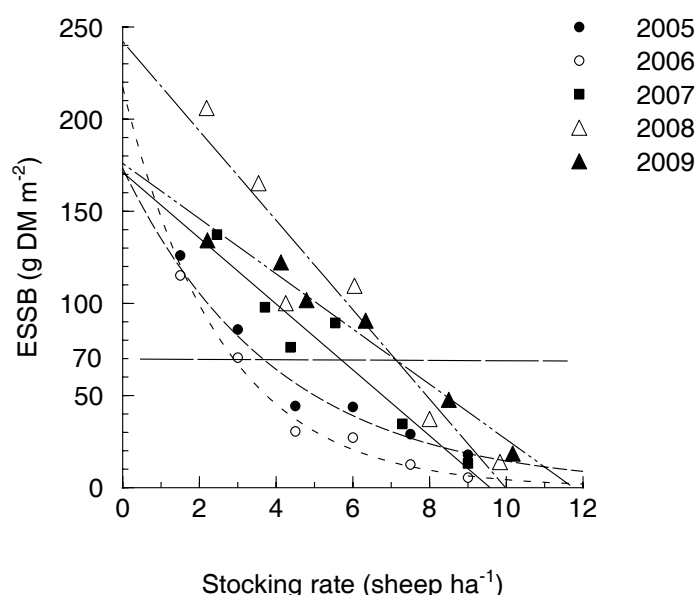


Figure 3.3. Effect of stocking rate on end-of-season standing biomass (ESSB) in 2005-2008 (Published by Schönbach et al., 2009) and in 2009. Regression equations of stocking rate vs. ESSB were  $y = 173.29e-0.25x$ ,  $R^2 = 0.97$ ,  $P < 0.01$  in 2005 (- - -);  $y = 217.46e-0.39x$ ,  $R^2 = 0.98$ ,  $P < 0.01$  in 2006 (- - -);  $y = -17.86x + 171.11$ ,  $R^2 = 0.92$ ,  $P < 0.01$  in 2007 (—);  $y = -24.26x + 242.14$ ,  $R^2 = 0.91$ ,  $P < 0.01$  in 2008 (- -); and  $y = -14.98x + 175.97$ ,  $R^2 = 0.97$ ,  $P < 0.01$  in 2009 (- · -).

Moreover, managing a grazing system with the aim of a maximum production per area may maximize short-term economical output (Jones and Sandland, 1974; Allan

and Neil, 1991; Kemp and Michalk, 2007), but does not consider any inputs into a grazing system (Allan and Neil, 1991) and may thus overestimate the long-term economical optimum SR. Hence, for pastoral livestock systems in Australia, Kemp and Michalk (2007) recommended that farmers should rather aim for 75% of the maximum production per area at a lower SR, since it is closer to the long-term economical optimum SR in many grazing systems and relieves the grazing pressure on the grassland. Although variable costs of sheep husbandry in Inner Mongolia are lower than in these systems, the economical optimum SR is nevertheless closer to an ecologically acceptable SR.

Table 3.4. Maximum live weight gain (LWG) per ha and LWG at an ecologically acceptable stocking rate (SR) that lead to a minimum end-of-season standing biomass of 70 g DM m<sup>-2</sup> on the study plots in the Inner Mongolian steppe in 2005-2009.

Year	2005	2006	2007	2008	2009	Mean
SR at maximum LWG per ha (sheep ha <sup>-1</sup> )	6.7	9.6	9.8	9.6	9.6	9.1
Maximum LWG per ha (g d <sup>-1</sup> )	383	613	868	613	613	618
Ecologically acceptable SR (sheep ha <sup>-1</sup> )	3.7	2.9	5.7	7.1	7.1	5.3
LWG per ha at ecologically acceptable SR (g d <sup>-1</sup> )	302	276	676	565	565	477
LWG per ha at ecologically acceptable SR vs. maximum LWG per ha (%)	79	45	78	92	92	77

### 3.6 Conclusion

Given the studied management scheme (3-month continuous grazing by sheep of 30-35 kg LW), the economical optimum SR in the Inner Mongolian steppe is close to an ecologically acceptable SR, indicating that by a sophisticated grazing management it is possible to fulfill both, farmers' economical interests as well as the requirements for a conservative resource use. Complementary measures such as an alternating use of the grassland for hay-making and grazing or the supplement feeding of sheep may compensate for the inter- and intra-annual changes in herbage mass and quality and thus further contribute to a sustainable use of Inner Mongolian steppe. However,



more information on ecological threshold values as well as prices and costs for in- and outputs of the system are needed to evaluate the practical implications for the pastoral sheep husbandry.

### 3.7 References

- Ackerman, C. J., H. T. Purvis, G. W. Horn, S. I. Paisley, R. R. Reuter, and T. N. Bodine. 2001. Performance of light vs heavy steers grazing Plains Old World bluestem at three stocking rates. *Journal of Animal Science* 79:493-499.
- Alcock, D. J. 2006. Using grazing systems modelling to assess economic, production and environmental risks to aid in selecting appropriate stocking rates. *Australian Journal of Experimental Agriculture* 46:841-844.
- Allan, D. W., and D. M. Neil. 1991. Overgrazing: Present or absent? *Journal of Range Management* 44:475-482.
- Animut, G., A. L. Goetsch, G. E. Aiken, R. Puchala, G. Detweiler, C. R. Krehbiel, R. C. Merkel, T. Sahl, L. J. Dawson, Z. B. Johnson, and T. A. Gipson. 2005. Grazing behavior and energy expenditure by sheep and goats co-grazing grass/forb pastures at three stocking rates. *Small Ruminant Research* 59:191-201.
- Bai, Y. F., X. G. Han, J. G. Wu, Z. Z. Chen, and L. H. Li. 2004. Ecosystem stability and compensatory effects in the Inner Mongolia grassland. *Nature* 431:181-184.
- Biondini, M. E., B. D. Patton, and P. E. Nyren. 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecological Applications* 8:469-479.
- Bird, P. R., M. J. Watson, and J. W. D. Cayley. 1989. Effect of stocking rate, season and pasture characteristics on liveweight gain of beef steers grazing perennial pastures. *Australian Journal of Agricultural Research* 40:1277-1291.
- Bransby, D. I., B. E. Conrad, H. M. Dicks, and J. W. Drane. 1988. Justification for

- grazing intensity experiments - analyzing and interpreting grazing data. *Journal of Range Management* 41:274-279.
- Costin, A. B. 1980. Runoff and soil and nutrient losses from an improved pasture at Ginninderra, Southern Tablelands, New-South-Wales. *Australian Journal of Agricultural Research* 31:533-546.
- Garcia, F., P. Carrere, J. Soussana, and R. Baumont. 2003. The ability of sheep at different stocking rates to maintain the quality and quantity of their diet during the grazing season. *The Journal of Agricultural Science* 140:113-124.
- Glindemann, T., C. Wang, B. M. Tas, A. Schiborra, M. Gierus, F. Taube, and A. Susenbeth. 2009. Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe. *Livestock Science* 124:142-147.
- Han, G., B. Li, Z. Wei, and H. Li. 2000. Live weight change of sheep under 5 stocking rates in *Stipa breviflora* desert steppe. *Grassland of China* 38:4-6.
- Harrington, G. N., A. D. Wilson, and M. D. Young (Editors). 1984. Management of Australia's rangelands. Land and water processes. CSIRO, Melbourne, 25-40 pp.
- Hejcmanova, P., M. Stejskalova, V. Pavlu, and M. Hejcman. 2009. Behavioural patterns of heifers under intensive and extensive continuous grazing on species-rich pasture in the Czech Republic. *Applied Animal Behaviour Science* 117:137-143.
- Hull, J. L., R. Kromann, and J. H. Meyer. 1961. Influence of stocking rate on animal and forage production from irrigated pasture. *Journal of Animal Science* 20:46-52.
- Jiang, G. M., X. G. Han, and J. G. Wu. 2006. Restoration and management of the Inner Mongolia grassland require a sustainable strategy. *Ambio* 35:269-270.
- Jones, R. J., and R. L. Sandland. 1974. Relation between animal gain and stocking

- rate - derivation of relation from results of grazing trials. *Journal of Agricultural Science* 83:335-342.
- Kemp, D. R., and D. L. Michalk. 2007. Towards sustainable grassland and livestock management. *Journal of Agricultural Science* 145:543-564.
- Lachica, A., and J. F. Aguilera. 2005. Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* 59:105-121.
- Li, F. R., L. F. Kang, H. Zhang, L. Y. Zhao, Y. Shirato, and I. Taniyama. 2005. Changes in intensity of wind erosion at different stages of degradation development in grasslands of Inner Mongolia, China. *Journal of Arid Environments* 62:567-585.
- Li, S. G., Y. Harazono, T. Oikawa, H. L. Zhao, Z. Y. He, and X. L. Chang. 2000. Grassland desertification by grazing and the resulting micrometeorological changes in Inner Mongolia. *Agricultural and Forest Meteorology* 102:125-137.
- Lin, L., U. Dickhoefer, K. Müller, Wurina, and A. Susenbeth. 2010. Behavior of sheep at different grazing intensities in the Inner Mongolian steppe, China. *Applied Animal Behaviour Science* (under review).
- Lu, Z. J., X. S. Lu, and X. P. Xin. 2005. Present situation and trend of grassland desertification of North China. *Acta Agrestia Sinica* 13:24-27.
- Müller, K. 2009. Impact of grazing intensity and grazing system on herbage quality and performance of sheep in the Inner Mongolian steppe, China. PhD Thesis, Christian-Albrechts-University, Kiel, Germany.
- Osuji, P. O. 1974. Physiology of eating and energy expenditure of ruminant at pasture. *Journal of Range Management* 27:437-443.
- Schönbach, P. 2009. Grazing effects on productivity and herbage quality of an Inner Mongolian steppe ecosystem. PhD Thesis, Christian-Albrechts-University, Kiel, Germany.

- Schönbach, P., H. W. Wan, M. Gierus, Y. Bai, and F. Taube. 2008. Relationship between sward surface height and agronomic traits in the typical steppe of Inner Mongolia. In: 2008 XXI International Grassland and VIII International Rangelands Congress Proceedings, Hohote, China. 1160 pp.
- Seman, D. H., M. H. Frere, J. A. Stuedemann, and S. R. Wilkinson. 1991. Simulating the influence of stocking rate, sward height and density on steer productivity and grazing behavior. *Agricultural Systems* 37:165-181.
- Sollenberger, L. E., J. E. Moore, V. G. Allen, and C. G. S. Pedreira. 2005. Reporting forage allowance in grazing experiments. *Crop Science* 45:896-900.
- Thompson, A. N., P. T. Doyle, and M. Grimm. 1994. Effects of stocking rate in spring on liveweight and wool production of sheep grazing annual pastures. *Australian Journal of Agricultural Research* 45:367-389.
- Todd, S. W., and M. T. Hoffman. 1999. A fence-line contrast reveals effects of heavy grazing on plant diversity and community composition in Namaqualand, South Africa. *Plant Ecology* 142:169-178.
- Wang, D. L., G. D. Han, and Y. G. Bai. 2005. Interactions between foraging behaviour of herbivores and grassland resources in the eastern Eurasian steppes. *Grassland: A Global Resource*:97-110.
- Wang, S. P. 1997. Behavior ecology of grazing sheep II influence of stocking rates on foraging behavior of wether. *Acta Prataculturae Sinica* 6:10-17.
- Wang, S. P. 2000. Relationships between body gains and stocking rates of grazing sheep on typical Inner Mongolian grassland. *Acta Prataculturae Sinica* 9:10-16.
- Yu, M., J. E. Ellis, and H. E. Epstein. 2004. Regional analysis of climate, primary production, and livestock density in Inner Mongolia. *Journal of Environmental Quality* 33:1675-1681.
- Zhang, Z., S. P. Wang, P. Nyren, and G. M. Jiang. 2006. Morphological and

reproductive response of caragana microphylla to different stocking rates.  
Journal of Arid Environments 67:671-677.

Zhao, Y., S. Peth, A. Reszkowska, L. Gan, J. Krümmelbein, X. Peng, and R. Horn.  
2010. Response of soil moisture and temperature to grazing intensity in a  
*Leymus chinensis* steppe, Inner Mongolia. Plant and Soil (under review).

*Chapter 4*

**Determining the behavior of grazing livestock**

## **4 Determining the behavior of grazing livestock**

### **4.1 Visual observation**

Although grazing behavior can nowadays easily be measured by automatic recording devices such as video or audio recorders (Penning, 1983; Penning et al., 1994; Goetsch et al., 2010), visual observation is still the most common means for assessing the activity of animals during daylight, both in confined as well as in grazing animals (Schlecht et al., 2004; Goetsch et al., 2010). During observation, the time animal spent for different activities is estimated either by continuous monitoring or by recording the behavior of animals at certain time intervals. For the latter the total time an animal spends for an individual activity is calculated by multiplying the frequency of a certain activity by the length of the time interval. Interval observations are less difficult to conduct, less laborious, and can be as accurate as the continuous monitoring of the animals depending on the length of the time interval chosen. Gary et al. (1970) showed that observations at 15 min-intervals allowed for an accurate determination of continuous activities such as grazing, ruminating, and resting, but did not capture those behaviors occurring as discrete events such as walking, drinking, defecation, and urination. Hodgson (1982) also suggested shorter recording intervals of 5-10 min in case the periodicity of grazing activities is of interest. Hence, the frequency of recordings needed in order to obtain reliable estimates mainly depends on the kind of activities (continuous or discrete event, Hirata et al., 2002).

### **4.2 Pedometers**

Pedometers have been and still are useful tools in grazing experiments to determine the moving distance and behavior of free-ranging animals (Lachica and Aguilera, 2005). Moving distances are calculated from the number of steps and the average step length. Calibration factors must be used to reduce instrument bias. Although these factors are similar for different animal species, they vary between types of pedometers because of differences in their sensitivity to movement and/or the tightness of the case around the animal's leg (Lachica and Aguilera, 2005). Hence, by

correcting pedometer readings by their individual calibration factor allowed for an accurate measurement of the traveling distance of free-ranging cattle in studies by Walker et al. (1985) and Anderson and Urquhart (1986).

### **4.3 Head and jaw movement recorders**

A number of mechanical and electronic devices have been developed to automatically record the feeding behavior of grazing animals (Stobbs and Cowper, 1972; Penning, 1983; Anderson and Urquhart, 1986; Matsui and Okubo, 1991). These systems monitor head or jaw movements in digital or analogue form based on the following techniques: (1) Head movement: grazing moves a pendulum and these movements are logged by a vibrarecorder (Penning, 1983). This method allows for a differentiation of grazing, ruminating, or walking, and idling time. (2) Jaw movements are measured by placing balloons or a tube in the sub-mandibular space, which record a change in air pressure when the jaw is opened (Penning, 1983). This method allows for estimates of the time spent grazing, ruminating, and idling (Figure 4.1). (3) Head position: Mercury tilt-switches are used to record the time when an animal's head is down or up (Jones and Cowper, 1975). This method estimates the time an animal is grazing (head down) or not grazing (head up).

All techniques have limitations, which might be improved by simultaneous measurements by a combination of the techniques. Measuring the animal's jaw movement and head position, Stobbs and Cowper (1972) succeeded in estimating their grazing and ruminating time. Chambers et al. (1981) used a combination of head movement and head position recorders to estimate the animals' grazing time, assuming that it is grazing when its head is down and at least one head movement was observed each 5 seconds. However, many studies showed that none of these techniques or their combinations allowed for an accurate description of animal behavior (Penning, 1983). For example, errors of up to 18% for grazing were found in vibrarecorders. Combined measurements of head positions and jaw movements overestimated ruminating time in a study by Chacon et al. (1976), because during an average of 20% of the grazing time the animal's head was in an upright position.



Furthermore, some techniques for the measurement of jaw movements, such as balloons or tubes require extremely careful placement of the transmitters on the animals (Penning, 1983) which is especially difficult in free-ranging animals.

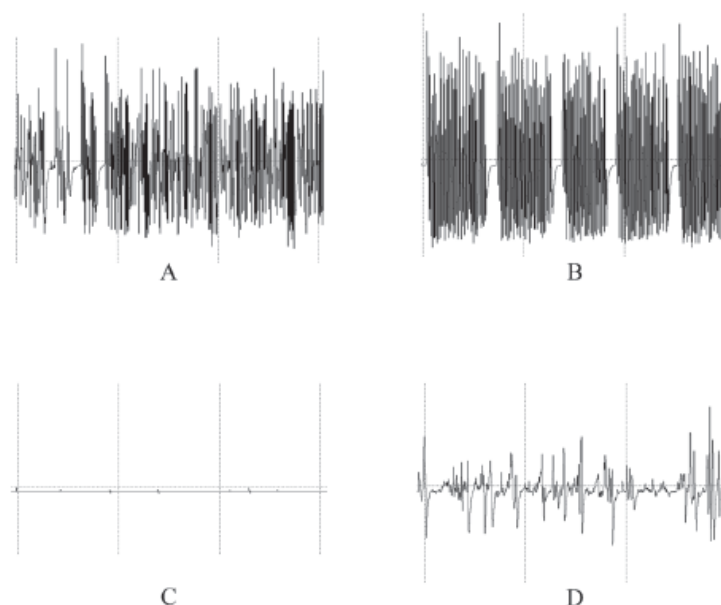


Figure 4.1. Exemplary jaw movement patterns for eating (A), ruminating (B), remaining idle (C), and an unknown activity requiring deletion or a subjective decision (D) The interval between vertical lines represents 1 min (Goetsch et al., 2010).

#### 4.4 Acoustic recorders

The use of acoustic signals in animal studies was pioneered by Alkon and Cohen (1986) in their study of the nocturnal behavior of porcupines and by Delagarde et al. (1999) in studies of grazing ruminants. The acoustic method includes an inward-facing microphone mounted to the forehead of an animal. Sounds can be recorded using remote recording devices (Laca and WallisDeVries, 2000) or small recorders that are fixed directly to the animal (Matsui and Okubo, 1991). To most listeners, the ripping sound of a bite and the grinding sound of a chew were readily distinguishable (Ungar and Rutter, 2006). Previous studies found that biting and chewing actions could be more easily identified and counted by inspecting sound

records (Figure 4.2) rather than by visual observation. Studies from Laca and WallisDevries (2000) and Galli et al. (2006) indicated that the classification of jaw movements from acoustic signals could be automated using special software. Hence, acoustic measurements may overcome many of the problems associated with other methods used to describe the ingestive behavior in free-ranging and stabled ruminants. Moreover, it was shown to be a promising method to estimate voluntary feed intake (Galli et al., 2006). However, further research and refinement is required to extend its use to estimate DM intake and to quantify chewing activity over a wide range of feeds.

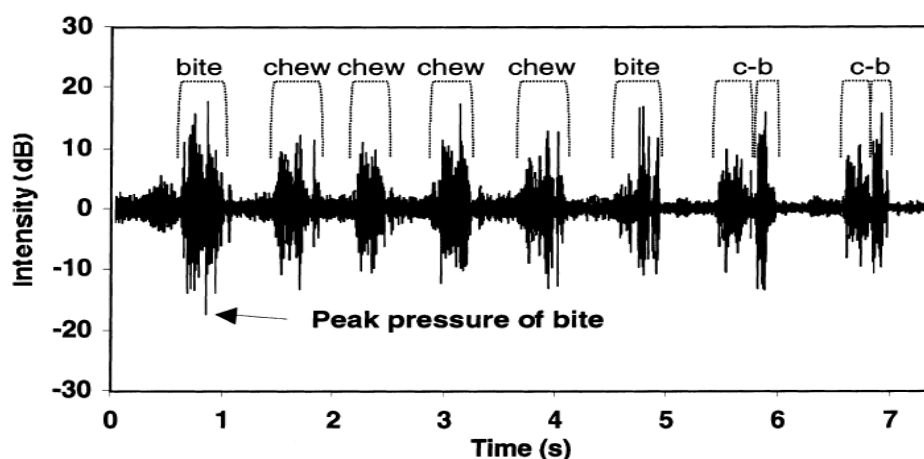


Figure 4.2. Example of sound waves of a series of bites and chews taken of steers grazing a tall sward (Laca and WallisDevries, 2000).

#### 4.5 Global positioning system technology

The global positioning system (GPS) is a navigation satellite system that provides position information anywhere on or near the earth. The system is maintained by the United States government and freely accessible to anyone with a GPS receiver. Over the time signals from three or more satellites need to reach a GPS receiver, its horizontal (minimum of 3 satellites) and vertical (minimum of four satellites) position is determined. However, even under good measurement conditions (clear sky, no

obstacles), the position error can be as much as 15 m in regular GPS devices. By ex post differential correction of GPS data (DGPS) the accuracy of position information can be enhanced. DGPS uses GPS data collected by a fixed reference station to correct for system-inherent errors using the difference between the positions indicated by the satellite system and the known position of the reference station. Moreover, satellite based augmentation systems (SBAS) are nowadays available in North America, Europe, and parts of Asia, which allow for a reduction in position errors to less than 3 m.

GPS has long been used for wildlife research (Gordon, 1995), while the use of GPS techniques in studies of the behavior of grazing livestock was pioneered by Rutter et al. (1997). They rapidly became the standard method for tracking routes and determining grazing areas of cattle (Ganskopp, 2001; Schlecht et al., 2004; Lachica and Aguilera, 2005), sheep (Hulbert et al., 1998), and goats (Schlecht et al., 2009). When used in combination with animal activity recorders, for example those monitoring jaw movements or vertical body positions (see above), they allow for a spatial and temporal characterization of activity patterns of free-ranging animals (Schlecht et al., 2004; Goetsch et al., 2010). Since the distance travelled and the traveling speed are zero when an animal is resting, ruminating, drinking, or cleaning itself and increases when an animal is grazing or walking, the distance and the speed calculated from GPS recordings can be used to distinguish different behavioral activities of animals at pasture (Schlecht et al., 2004). However, the accuracy of these estimations depend on the distance and the speed thresholds defined for the different behavioral activities and it is still impossible to distinguish between resting and ruminating by GPS only. Based on visual observations, Putfarken et al. (2008) assumed that the distance an animal moves within 5 minutes is lower than or equal to 6.0 m (equivalent to a walking speed  $0.02 \text{ m s}^{-1}$ ) when an animal is resting, while the authors considered walking distances between  $> 6.0$  to  $100.0$  m per 5 minutes ( $> 0.02$ - $0.33 \text{ m s}^{-1}$ ) as grazing and of  $> 100.0$  m per 5 minutes ( $> 0.33 \text{ m s}^{-1}$ ) as walking or running without grazing. According to this classification, they succeeded in

distinguishing resting, grazing, and walking activities by GPS data (94.3% and 89.4% of the behavioral activities determined by visual observations of cattle and sheep, respectively, were identified by GPS data).

The simultaneous monitoring of the activity of grazing animals by visual observation and GPS loggers in this study not only allows for an evaluation of the effect of different management parameters on their behavior and walking distance as was done earlier (Chapter 2), but also offers the opportunity to assess to which extent GPS data can be used to estimate the grazing activities of sheep in Inner Mongolia (Figure 4.3). The movement of two sheep per GI plot was recorded by GPS loggers every 30-second during daylight on two days each in July, August, and September 2008 (for a detailed description of the methods see Chapter 2). The distance traveled within 3 min-intervals was calculated from the GPS data and sheep behavior was classified for six different distance thresholds. Hence, when animals covered more than 6, 7, 8, 9, 10, or 11 m within 3 min, their activity was defined as grazing, while they were assumed to be resting, when walking distance was less than the respective thresholds. Subsequently, the time sheep spent grazing during daylight was calculated according to each threshold value (Table 4.1).

Animal behavior was simultaneously monitored by visual observation at 3 min-intervals. Recorded activities included grazing, ruminating, resting, walking without grazing (walking), and other activities. For the purpose of this study, grazing and walking were combined to "grazing". Paired-sample t-test was carried out to evaluate the difference between grazing time estimated from GPS data and by visual observation. Linear regression analyses between the observed (independent variable) and the estimated (dependent variable) grazing time were performed to evaluate the accuracy of animal behavior estimates derived from GPS data (Figure 4.4).

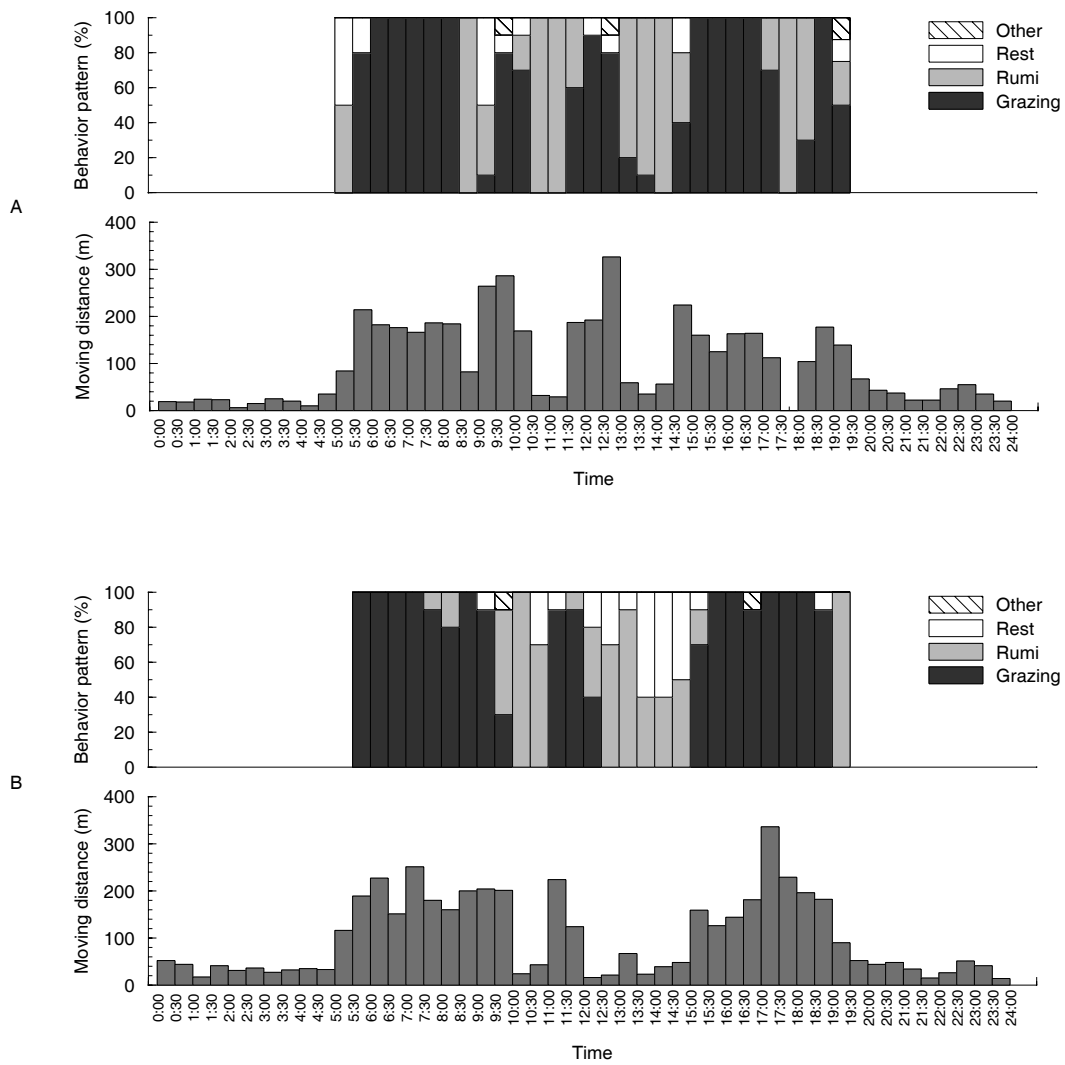


Figure 4.3. Exemplary comparison of the observed behavioral pattern and the moving distance estimated from simultaneous GPS measurements with sheep grazing at grazing intensity 4 (A) and 5 (B) in September 2008. Rest is resting, Rumi ruminating “Other” included activities such as drinking, salt licking, and social interactions.

Table 4.1. Comparison of the grazing time (minutes, means  $\pm$  standard error) determined during visual observation and estimated from GPS measurements when the distance covered during grazing was considered to be  $\geq 6$ ,  $\geq 7$ ,  $\geq 8$ ,  $\geq 9$ ,  $\geq 10$ , or  $\geq 11$  m per 3 min.

Method	Grazing time
Observed	363 $\pm$ 17.2
Estimated by GPS	
$\geq 6$ m	478 $\pm$ 19.6*
$\geq 7$ m	430 $\pm$ 18.6*
$\geq 8$ m	404 $\pm$ 17.9*
$\geq 9$ m	371 $\pm$ 17.0
$\geq 10$ m	345 $\pm$ 16.1*
$\geq 11$ m	320 $\pm$ 15.4*
N	42

\* Values significantly differ from the observed grazing time ( $P < 0.05$ ).

Linear regressions between the grazing time estimated from GPS data and that determined by visual observation were highly significant with  $R^2$ -values ranging from 0.79 to 0.87 (Figure 4.4). Hence, GPS data may not only provide information about the walking distance of animals (Chapter 2), but also allow for an accurate determination of their grazing time. Since walking and grazing account for as much as 90% of the additional energy expenditure of sheep on range compared to similar animals kept indoors (Osuji, 1974; Fierro and Bryant, 1990), GPS may thus be a very useful tool for evaluating the nutritional situation of grazing sheep in the Inner Mongolian steppe. However, estimates derived from GPS data overestimated the time animals spent grazing when distance thresholds were 6, 7, and 8 m per 3 min, while grazing time was underestimated when the threshold was set to 10 and 11 m per 3 min. The difference between observed and estimated grazing time was smallest when the distance threshold was set to 9 m per 3 min. This indicates that care should be taken when defining the distance thresholds for different behavioral activities or that suitable regression equation must be developed by simultaneous visual observation to correct for the bias in the estimations (Goetsch et al., 2010).

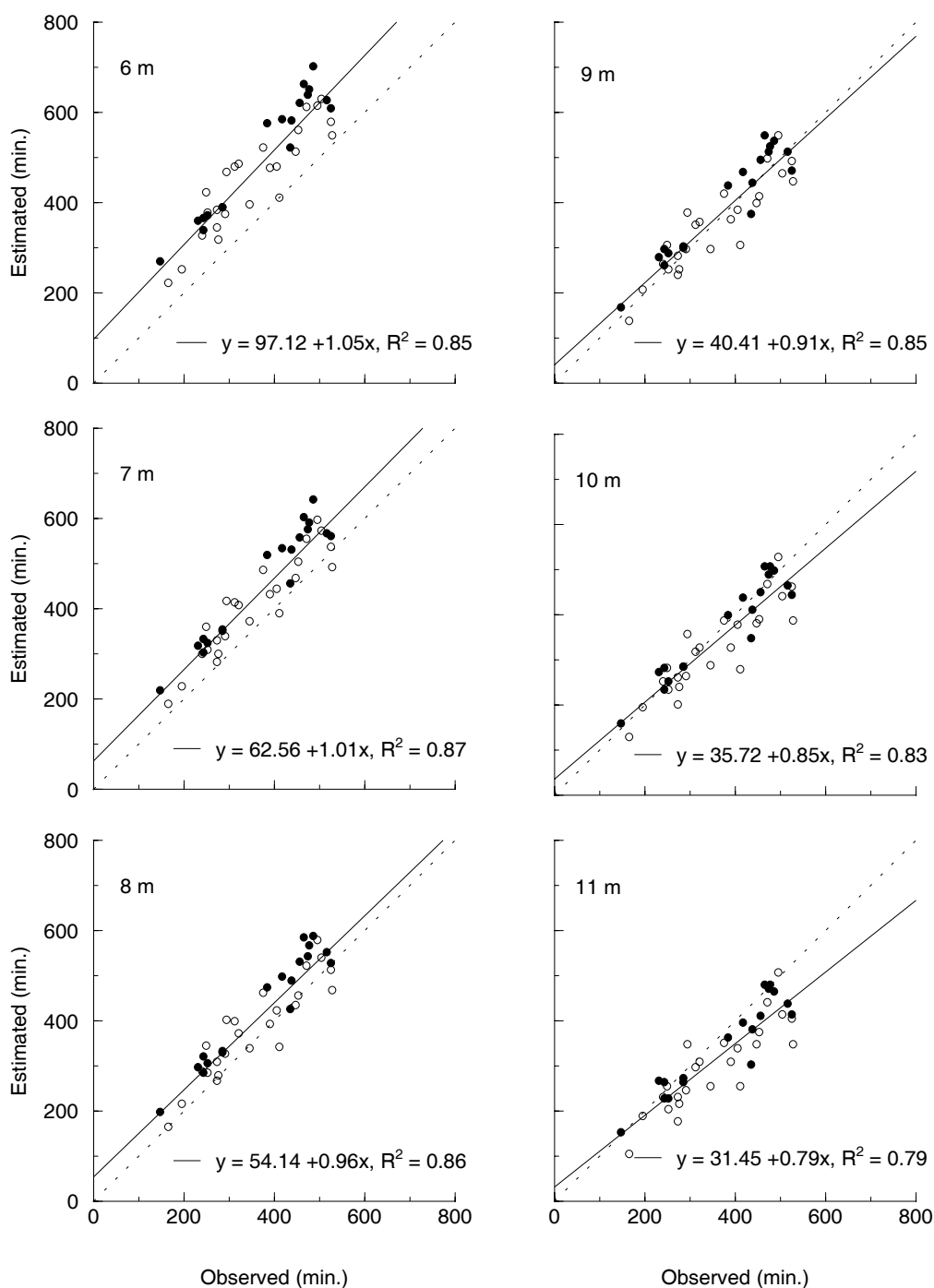


Figure 4.4. Relationship (solid line) between the grazing time determined by visual observation (Observed) and estimated from GPS measurements (Estimated) in August (●) and September (○) 2008, when moving distances was assumed to be  $\geq 6$ ,  $\geq 7$ ,  $\geq 8$ ,  $\geq 9$ ,  $\geq 10$ , or  $\geq 11$  m per 3 min during grazing. The dotted line represents  $y = x$ .

Furthermore, patch-selective grazing of sheep in Inner Mongolia may result in an uneven distribution of grazing pressure and thus the progressive degradation of the grassland, which cannot easily be reversed (Fuls and Bosch, 1991; Kellner and Bosch, 1992; Norton, 1998). Hence, besides the potential application in animal nutrition research, GPS measurements of the spatial and temporal activity patterns of grazing sheep may also provide useful information for rangeland scientists and may thus largely contribute to the development of an economically and ecologically sustainable use of the grasslands in the future.

#### 4.6 References

- Alkon, P. U., and A. Cohen. 1986. Acoustical biotelemetry for wildlife research - a preliminary test and prospects - comments. *Wildlife Society Bulletin* 14:193-196.
- Anderson, D. M., and N. S. Urquhart. 1986. Using digital pedometers to monitor travel of cows grazing arid rangeland. *Applied Animal Behaviour Science* 16:11-23.
- Chacon, E., T. H. Stobbs, and R. L. Sandland. 1976. Estimation of herbage consumption by grazing cattle using measurements of eating behaviour. *Journal of the British Grassland Society* 31:81-87.
- Chambers, A. R. M., J. Hodgson, and J. A. Milne. 1981. The development and use of equipment for the automatic recording of ingestive behavior in sheep and cattle. *Grass and Forage Science* 36:97-105.
- Delagarde, R., J. P. Caudal, and J. L. Peyraud. 1999. Development of an automatic bitemeter for grazing cattle. *Annales de Zootechnie* 48:329-339.
- Fierro, L. C., and F. C. Bryant. 1990. Grazing activities and bioenergetics of sheep on native range in Southern Peru. *Small Ruminant Research* 3:135-146.
- Fuls, E. R., and O. J. H. Bosch. 1991. The influence of below-average rainfall on the vegetational traits of a patch-grazed semiarid grassland. *Journal of Arid Environments* 21:13-20.



- Galli, J. R., C. A. Cangiano, M. W. Demment, and E. A. Laca. 2006. Acoustic monitoring of chewing and intake of fresh and dry forages in steers. *Animal Feed Science and Technology* 128:14-30.
- Ganskopp, D. 2001. Manipulating cattle distribution with salt and water in large arid-land pastures: A GPS/GIS assessment. *Applied Animal Behaviour Science* 73:251-262.
- Gary, L., G. Sherritt, and E. Hale. 1970. Behavior of Charolais cattle on pasture. *Journal of Animal Science* 30:203.
- Goetsch, A. L., T. A. Gipson, A. R. Askar, and R. Puchala. 2010. Invited review: Feeding behavior of goats. *Journal of Animal Science* 88:361-373.
- Gordon, I. J. 1995. Animal-based techniques for grazing ecology research. *Small Ruminant Research* 16:203-214.
- Hirata, M., T. Iwamoto, W. Otozu, and D. Kiyota. 2002. The effects of recording interval on the estimation of grazing behavior of cattle in a daytime grazing system. *Asian-australasian journal of animal sciences* 15:745-750.
- Hodgson, J. 1982. Ingestive behaviour. In: J. D. Leaver (ed.) *Herbage intake handbook*. p 113-138. British Grassland Society, Hurley, UK.
- Hulbert, I. A. R., J. T. B. Wyllie, A. Waterhouse, J. French, and D. McNulty. 1998. A note on the circadian rhythm and feeding behaviour of sheep fitted with a lightweight GPS collar. *Applied Animal Behaviour Science* 60:359-364.
- Jones, J. R., and L. J. Cowper. 1975. A lightweight, electronic device for measurement of grazing time in cattle. *Tropical Grasslands* 9:235-241.
- Kellner, K., and O. J. H. Bosch. 1992. Influence of patch formation in determining the stocking rate for Southern African grasslands. *Journal of Arid Environments* 22:99-105.
- Laca, E. A., and M. F. WallisDeVries. 2000. Acoustic measurement of intake and

- grazing behaviour of cattle. *Grass and Forage Science* 55:97-104.
- Lachica, A., and J. F. Aguilera. 2005. Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* 59:105-121.
- Matsui, K., and T. Okubo. 1991. A method for quantification of jaw movements suitable for use on free-ranging cattle. *Applied Animal Behaviour Science* 32:107-116.
- Norton, B. E. 1998. The application of grazing management to increase sustainable livestock production. *Animal Production in Australia* 22:15-26.
- Osuji, P. O. 1974. Physiology of eating and energy expenditure of ruminant at pasture. *Journal of Range Management* 27:437-443.
- Penning, P. D. 1983. A technique to record automatically some aspects of grazing and ruminating behaviour in sheep. *Grass and Forage Science* 38:89-96.
- Penning, P. D., A. J. Parsons, R. J. Orr, and G. E. Hooper. 1994. Intake and behavior responses by sheep to changes in sward characteristics under rotational grazing. *Grass and Forage Science* 49:476-486.
- Putfarken, D., J. Dengler, S. Lehmann, and W. Hardtle. 2008. Site use of grazing cattle and sheep in a large-scale pasture landscape: A GPS/GIS assessment. *Applied Animal Behaviour Science* 111:54-67.
- Rutter, S. M., N. A. Beresford, and G. Roberts. 1997. Use of GPS to identify the grazing areas of hill sheep. *Computers and Electronics in Agriculture* 17:177-188.
- Schlecht, E., U. Dickhoefer, E. Gumpertsberger, and A. Buerkert. 2009. Grazing itineraries and forage selection of goats in the Al Jabal al Akhdar mountain range of northern Oman. *Journal of Arid Environments* 73:355-363.
- Schlecht, E., C. Hulsebusch, F. Mahler, and K. Becker. 2004. The use of differentially corrected global positioning system to monitor activities of cattle at pasture. *Applied Animal Behaviour Science* 85:185-202.

Stobbs, T. H., and L. J. Cowper. 1972. Automatic measurement of the jaw movements of dairy cows during grazing and rumination. *Tropical Grasslands* 6:107-112.

Ungar, E. D., and S. M. Rutter. 2006. Classifying cattle jaw movements: Comparing IGER behaviour recorder and acoustic techniques. *Applied Animal Behaviour Science* 98:11-27.

Walker, J. W., R. K. Heitschmidt, and S. L. Dowhower. 1985. Evaluation of pedometers for measuring distance traveled by cattle on 2 grazing systems. *Journal of Range Management* 38:90-93.

*Chapter 5*

**General discussion and conclusion**

## 5 General discussion and conclusion

### 5.1 Methodology

#### 5.1.1 Visual observation

Physical activity may largely increase energy requirements of grazing livestock, and it is thus essential to consider the behavior of animals when evaluating the effects of different grazing management parameters on livestock performance. Although different technologies are available to easily record animal behavior, visual observation is still the standard method commonly used (see Chapter 4). Hence, to study the activity of Inner Mongolian sheep grazing at different intensities and to thereby derive estimates of their energy expenditures, two animals per plot were observed during two days each in July, August, and September 2008. Animal behavior might be modified by the presence of an observer (Goetsch et al., 2010). However, since sheep in Inner Mongolia are familiar with and at ease in human presence, a modification of the normal behavior of the animal groups was unlikely. Moreover, behavior of the observed sheep at all GI's was very similar to that of the rest of the group, and since the two chosen sheep per plot were marked with a colored ribbon, there was no problem in keeping them in constant view. However, visual observation is only possible at daylight, so that daily observing time was only 16.5 h in July and August and 13.5 h in September. Results therefore do not account for possible activities of animals at night. Nevertheless, according to the anti-predator theory herbivores will avoid foraging during darkness due to a perceived risk of predation (Rutter, 2006). Moreover, walking distance recorded by GPS receivers during darkness was small and the animals' walking speed was similar to that determined during resting and ruminating periods at daylight (see Figure 4.3). Hence, the grazing time of sheep observed during daylight in our study should equal their total daily grazing time. Since furthermore walking and grazing account for most of the animals' energy expenditure for physical activity and other activities such as ruminating, standing or lying are negligible (Lachica and Aguilera, 2005), estimates for

the behavior-related energy needs of sheep in our study appear to be close to their total energy requirements for activity.

### **5.1.2 Global positioning system technique**

Global positioning system (GPS) recorders are useful tools for monitoring behavioral patterns and moving distances of grazing animals (see Chapter 4). In many parts of the world such as North America, Europe, Australia, and Japan, different satellite-based differential correction systems are available that allow for highly accurate position measurements. Eventually, GPS receivers around the world will have access to these or other compatible systems (Goetsch et al., 2010), and will be able to describe the spatial and temporal movement of free-grazing animals even more accurately than it is already possible nowadays. GPS data used in this study did not receive any differential correction, so that positions logged with the GPS receivers might have deviated as much as 15 m from the true positions of the animals (according to the manufacturer). However, given the flat and open landscape in Inner Mongolia as well as the cloudless weather conditions on measurement days, strength and quality of satellite signals were likely to be high, which would have significantly improved the accuracy of the GPS data.

Few published studies discussed the daily variation in the moving distance of grazing animals. However, the high day-to-day variation in the moving distance measured by GPS receivers in the present study (see Chapter 2) suggested that behavior of sheep grazing the Inner Mongolian steppe may largely differ between different measurement days. Sheep tended to spend more time for grazing and walking when the weather conditions were favorable, while sheep spent more time for resting and lying or standing on days when it was windy, rainy or when temperatures were high. Therefore, two recording days per month might not be enough to obtain a representative measurement of the moving distance of sheep. Instead, Schlecht et al. (2004) used GPS receivers to monitor cattle grazing itineraries on three consecutive days of GPS every 5-6 weeks over a period of 12 months. Recently, Putfarken et al. (2008) even recorded the positions of cattle and sheep continuously over the study

period of 10 months to determine the site use patterns of the animals. Similarly, Rutter et al. (1997) suggested that GPS records from at least seven measurement days should be used to describe the grazing patterns of sheep.

Therefore, in order to obtain representative data on the moving distance and activity of Inner Mongolian sheep in future studies, GPS measurements should be carried out on at least 4-5 days. Moreover, the position data should be differentially corrected ex post using a fixed reference station to improve the accuracy of the regular GPS measurements (Schlecht et al., 2004).

## **5.2 Behavior and liveweight gain of sheep grazing at different grazing intensities in the Inner Mongolian steppe**

In the grazing period of 2005, Glindemann et al. (2009) found that with increasing GI, digestible organic matter and energy intake of sheep only tended to decrease, while liveweight gain (LWG) per sheep significantly decreased. Similarly, the present study found that, across the five grazing periods of 2005-2009, LWG per sheep linearly decreased with increasing GI (Chapter 3). A possible reason for this bias is an increased activity of sheep at high GI's with low herbage allowances, which increases their energy requirements for physical activity and therefore reduces energy available for growth (Glindemann et al., 2009). Results from the visual observations and GPS measurements presented in Chapter 2 of this study showed that grazing time of sheep at high GI's was indeed longer than of animals at lighter GI's. Hence, sheep increased their grazing time at the expense of their resting time in order to compensate for the decreasing herbage allowance and to maintain their daily feed intake (Garcia et al., 2003; Lin et al., 2010). Higher energy expenditures for grazing activity thus explain why LWG of sheep at very high GI's strongly decreased (Osuji, 1974; Lachica and Aguilera, 2005; Lin et al., 2010).

Moreover, feed efficiency of animals in the present study can be calculated by dividing their daily LWG ( $\text{g d}^{-1}$ ) by their intake of digestible organic matter ( $\text{g d}^{-1}$ ) (Figure 5.1). In 2007, the efficiency in converting feed mass to body mass was similar

in sheep grazing at different GI's, most likely due to a lower initial liveweight of the experimental animals used in this year as well as an more evenly distributed rainfall pattern during the vegetation period (see Chapter 3). In the other study years, however, there were quadratic relationships between the stocking rate and the feed efficiency of sheep. According to the curve regression, the highest feed efficiency would be achieved at 2.5 sheep ha<sup>-1</sup> (0.13), while at very high stocking rates, feed efficiency clearly decreased to about 0.09 at 9.0 sheep ha<sup>-1</sup>. Instead it was 0.12 at the economically optimum GI recommended in Chapter 3 of 4.5 sheep ha<sup>-1</sup> and thus close to the maximum feed efficiency in this grazing system.

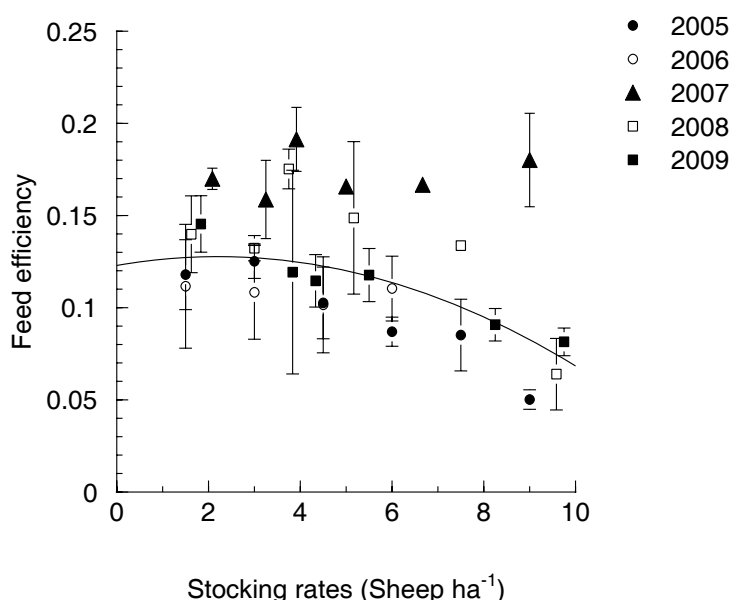


Figure 5.1. Relationship between stocking rate and feed efficiency of sheep in the five grazing periods of 2005-2009. The regression line ( $y = 0.123 + 0.005x - 0.001x^2$ ;  $R^2 = 0.51$ ) was estimated based on the feed efficiency data of 2005, 2006, 2008, and 2009 only (for explanation see text).



### 5.3 Conclusion

Sheep in the Inner Mongolian steppe increase or at least maintain their grazing time at the expense of their resting time to compensate for the negative impacts of an increasing GI or shorter daylight duration on their daily feed intake. By this, they succeed in maintaining their digestible organic matter intake to some extent. However, prolonged grazing time at high GI's increases the animals' energy expenditures for physical activity and therefore reduces the energy available for growth and production. Thus, LWG per sheep linearly decreased with increasing stocking rate, although a similar digestible organic matter intake was found in sheep grazing at light to moderate GI's. There were quadratic relationships between stocking rate and LWG per ha, indicating that the increasing number of sheep per plot could compensate for the decrease in LWG of individual sheep at some extent. LWG of sheep was lower in the dry study year than in years with average rainfall and decreased with advancing vegetation period from July to September. In view of our earlier published data regarding the effect of GI on the steppe vegetation, it is concluded that grazing at ecologically acceptable SR's that account for inter- and intra-annual variations in herbage growth also can satisfy farmers' economical interests and thus assure the sustainable use of the Inner Mongolian grassland..

### 5.4 References

- Garcia, F., P. Carrere, J. Soussana, and R. Baumont. 2003. The ability of sheep at different stocking rates to maintain the quality and quantity of their diet during the grazing season. *The Journal of Agricultural Science* 140:113-124.
- Glindemann, T., C. Wang, B. M. Tas, A. Schiborra, M. Gierus, F. Taube, and A. Susenbeth. 2009. Impact of grazing intensity on herbage intake, composition, and digestibility and on live weight gain of sheep on the Inner Mongolian steppe. *Livestock Science* 124:142-147.
- Goetsch, A. L., T. A. Gipson, A. R. Askar, and R. Puchala. 2010. Invited review: Feeding behavior of goats. *Journal of Animal Science* 88:361-373.

- Lachica, A., and J. F. Aguilera. 2005. Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* 59:105-121.
- Lin, L., U. Dickhoefer, K. Müller, Wurina, and A. Susenbeth. 2010. Behavior of sheep at different grazing intensities in the Inner Mongolian steppe, China. *Applied Animal Behaviour Science* (under review).
- Osuji, P. O. 1974. Physiology of eating and energy expenditure of ruminant at pasture. *Journal of Range Management* 27:437-443.
- Putfarken, D., J. Dengler, S. Lehmann, and W. Hardtle. 2008. Site use of grazing cattle and sheep in a large-scale pasture landscape: A GPS/GIS assessment. *Applied Animal Behaviour Science* 111:54-67.
- Rutter, S. M. 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: Current theory and future application. *Applied Animal Behaviour Science* 97:17-35.
- Rutter, S. M., N. A. Beresford, and G. Roberts. 1997. Use of GPS to identify the grazing areas of hill sheep. *Computers and Electronics in Agriculture* 17:177-188.
- Schlecht, E., C. Hulsebusch, F. Mahler, and K. Becker. 2004. The use of differentially corrected global positioning system to monitor activities of cattle at pasture. *Applied Animal Behaviour Science* 85:185-202.

*Chapter 6*

**Summary / Zusammenfassung**

## 6 Summary / Zusammenfassung

### Summary

The present dissertation was conducted within the frame of the Sino-German research project MAGIM (**M**atter fluxes of **G**rasslands in Inner **M**ongolia as influenced by stocking rate) funded by the German Research Foundation (DFG), which analyzed the effects of different grazing management parameters on the grassland vegetation as well as the feed intake and performance of sheep in the Inner Mongolian steppe of China.. For this, a grazing experiment was carried out in the grazing periods (June - September) of 2005 – 2009, which included six different grazing intensity treatments (GI: 2, 3, 4, 6, 8, and 11 sheep ha<sup>-1</sup>) and two different grazing systems, an alternating system, where grazing and hay-making alternated annually between two plots, and a continuous grazing system, where the same plots were used either for hay-making or for grazing every year. The main objectives of this thesis were to investigate the effects of different grazing systems and GI's on the behavior and the liveweight gain (LWG) of sheep in the Inner Mongolian steppe.

Understanding livestock behavior in response to varying environmental conditions and forage dynamics is important in evaluating management strategies for pastoral livestock production. Hence, during the grazing period of 2008, behavior of two sheep per GI plot was monitored by visual observation during daylight on two days per month. Simultaneously, sheep's walking distance was measured by global positioning system recorders. With increasing GI animals spent more time grazing, whereas resting time during daylight decreased. GI had no effect on the animals' ruminating time and walking distance. Similarly, sheep tended to decrease their resting time in order to maintain their grazing time when daylight became shorter with advancing vegetation period. Therefore, it can be concluded that the strategy taken by sheep to avoid negative effects of an increasing GI or shorter daylight on their daily feed intake was to increase or at least maintain their grazing time at the expense of their resting time. However, this may increase their energy expenditures for physical activity and

thus reduce the amount of energy available for growth or production.

Hence, using weight data collected during the 5-year grazing experiment, the effects of grazing system and GI on LWG of sheep grazing the Inner Mongolian steppe were analyzed. Results indicated that grazing system had no or only minor effects on sheep's LWG; however, significant effects of GI on LWG per sheep and LWG per ha were found. With increasing stocking rate, LWG per sheep linearly decreased while LWG per ha increased but stagnated or even decreased at highest stocking rates despite a larger number of animals per plot. In view of our earlier published data regarding the effect of GI on the steppe vegetation, it is concluded that grazing at ecologically acceptable SR's that account for inter- and intra-annual variations in herbage growth also can satisfy farmers' economical interests and thus assure the sustainable use of the Inner Mongolian grassland.

## Zusammenfassung

Die vorliegende Dissertation wurde im Rahmen der chinesisch-deutschen Forschergruppe MAGIM (**M**atter fluxes of **G**rasslands in **I**nnner **M**ongolia as influenced by stocking rate), finanziert durch die Deutsche Forschungsgemeinschaft (DFG), durchgeführt, welche die Auswirkungen unterschiedlicher Beweidungsparameter auf die Grünlandvegetation und die Futteraufnahme und Leistung von Schafen in der Inneren Mongolei Chinas analysierte. In den Vegetationsperioden (Juni – September) von 2005 bis 2009 wurde ein Weideexperiment mit sechs unterschiedlichen Beweidungsintensitäten (BI: 2, 3, 4, 6, 8 und 11 Schafe ha<sup>-1</sup>) und zwei verschiedenen Managementsystemen durchgeführt: einem alternierenden System, in dem Beweidung und Schnittnutzung jährlich abwechselten, und einem kontinuierliche Beweidungssystem, in dem die gleichen Flächen jedes Jahr entweder für Schnittnutzung oder für Beweidung genutzt wurden. Ziel dieser Arbeit war es, den Einfluss der verschiedenen Beweidungssysteme und der unterschiedlichen BI auf das Verhalten und den Lebendgewichtszuwachs von Schafen in der Steppe der Inneren Mongolei zu untersuchen.

Das Verständnis des Verhaltens von Tieren in Reaktion auf veränderte Umweltbedingungen und Futterangebote ist wichtig für die Bewertung von Managementstrategien für pastorale Viehhaltungssysteme. Aus diesem Grund wurden in der Weidperiode des Jahres 2008 das Verhalten von jeweils zwei Schafen pro Plot an je zwei Tagen pro Monat durch visuelle Beobachtung erfasst. Gleichzeitig wurden die durch die Schafe zurückgelegten Distanzen mit Hilfe von GPS-Geräten aufgezeichnet. Mit zunehmender BI erhöhte sich die Weidezeit der Schafe, während Ruhephasen während des Tages abnahmen. Die BI hatte keinen Effekt auf die Wiederkäuzeit und die täglich zurückgelegten Distanzen..

Außerdem zeigten die Schafe die Tendenz ihre Ruhephasen mit fortschreitender Vegetationsperiode und abnehmender Tageslichtdauer, zu verringern, um somit ihre Fresszeit konstant zu halten. Daraus kann geschlossen werden, dass Schafe auf Kosten ihrer Ruhephasen ihre Fresszeiten konstant halten oder sogar erhöhen, um

den negativen Auswirkungen einer zunehmenden BI oder einer kürzeren Tageslichtdauer auf ihre tägliche Futteraufnahme entgegenzuwirken. Dennoch kann dies ihren Energieaufwandes für körperliche Aktivität erhöhen und somit die für Wachstum oder Produktion verfügbare Energie verringern.

Überbeweidung ist eine der hauptsächlichen Ursachen für Degradation und Desertifikation in der Inneren Mongolei. Somit sind ein angemessenes Beweidungssystem und angepasste Beweidungsintensitäten eine kluge Strategie für die Nutzung der Innermongolischen Steppe, ohne die Desertifikation zu verstärken. Basierend auf Gewichtsdaten aus dem 5-jährigen Beweidungsexperiment wurden daher die täglichen Lebengewichtszunahmen (LGZ) der Schafe ermittelt und der Einfluss des Managementsystems und der BI auf die LGZ weidender Schafe in der Steppe der Inneren Mongolei untersucht.

Die Ergebnisse zeigten keinen oder einen nur sehr geringen Einfluss des Managementsystems auf die LGZ der Tiere. Doch waren die Auswirkungen der BI auf die LGZ pro Schaf und pro ha signifikant. Die LGZ pro Schaf verringerten sich linear mit zunehmender Besatzdichte, während die LGZ pro ha bei moderater Besatzdichte am höchsten waren und trotz der größeren Zahl an Tieren pro Fläche bei sehr hohen Besatzdichten stagnierten oder sogar abnahmen. Diese Ergebnisse untermauern daher die essentielle Bedeutung der Bestimmung einer optimalen Beweidungsintensität, die sowohl den Schutz des Steppenökosystems, der ökonomischen Interessen der Bauern als auch die inter- und intra-annualen Schwankungen in dem Futterangebot und der Futterqualität berücksichtigt.

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