

Aus dem Institut für Tierernährung und Stoffwechselphysiologie  
der Christian-Albrechts-Universität zu Kiel

**Development and Application of a Method to Estimate Feed  
Digestibility in Sheep Grazing Differently Managed Grasslands  
in Inner Mongolia, China**

Dissertation

Zur Erlangung des Doktorgrades der  
Agrar- und Ernährungswissenschaftlichen Fakultät  
der Christian-Albrechts-Universität zu Kiel

vorgelegt von

M.Sc. Chengjie Wang  
Aus Xinghe, Innere Mongolei, V.R. China

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## Abbreviations

ADF	Acid Detergent Fiber
ADSCP	Acid Detergent Soluble Crude Protein
ANPP	Aboveground Net Primary Productivity
CP	Crude Protein
DM	Dry Matter
dOM	Organic Matter digestibility
HM	Herbage Mass
HUE	Herbage Utilization Efficiency
IDM	Intake of Dry Matter
IDOM	Intake of Digestible Organic Matter
IME	Intake of Metabolisable Energy
IOM	Intake of Organic Matter
LWG	Live Weight Gain
ME	Metabolisable Energy
MPE	Mean Prediction Error
MSPE	Mean Square Prediction Error
N	Nitrogen
NDF	Neutral Detergent Fiber
NDN	Non-Dietary Nitrogen
NFE	Nitrogen Free Extract
NIRS	Near-Infrared Reflectance Spectroscopy
OM	Organic Matter
SD	Standard Deviation
SE	Standard Error
UDN	Undigested Dietary Nitrogen

## Chapter 1 General Introduction and Objectives

### 1.1 Introduction

In grazing systems, the digestibility of the ingested herbage by animals is one of the most important criterion evaluating grassland productivity as well as a characteristic of grasslands, which affects animal performances to a large extent (Croker and Watt, 2001). The amount of feed intake from grassland and its digestibility determine the level of metabolisable energy (ME) intake (McDonald et al., 1988) — a key factor affecting grazing animals' productivity when supplementation with other feedstuffs is limited. A great challenge in evaluating grassland systems is that in animals grazing on pasture as their main source of nutrients and energy it is very difficult to measure feed intake and digestibility (Freer and Dove, 2002). This, in turn, constrains our possibility to understand the interaction between animal production and grassland resource. These are not only academic issues, but issues of major economical importance for livestock farmers. However, both the quality and quantity of herbage selected by grazing animals are impossible to be measured directly, and difficult and expensive to estimate indirectly.

*Leymus chinensis* and *Stipa grandis* grassland, which represents the most widely distributed grassland types in the Eurasia steppe region, is used mainly as natural grazing lands providing forage for animals in the Inner Mongolian steppe, China (Zhao et al., 1988; Chen and Wang, 2000). This type of grassland also holds the largest area in the Xilin River basin of Inner Mongolia. The efficient utilization and sustainable resource management in the grassland ecosystems may improve animal performances as well as protecting grassland from degradation and maintaining ecological stability (Li et al., 1999). However, due to the high grazing intensity which has significant effects on plant composition and community characteristics of grassland (Li and Wang, 1999), the natural Inner Mongolia grassland was severely degraded during the last three decades. The balance of grassland resource and animal production was disturbed by improper management policies resulting over-utilization of grasslands. Currently the acceleration of degradation and desertification of grasslands is a major problem in large areas of the northern China (Chen and Wang, 2000).

Grassland degradation causes a high ecological damage in large parts of China (Lu et al., 2005). Climate warming was observed at the Inner Mongolia Grassland Ecosystem Research Station (IMGERS) in the last 20 years, especially in winter. Temperature increase in the winter has aggravated the drought in spring in this region (Chen et al., 2003). As a consequence, nutrition of animals based on herbage from grassland is inadequate. The economical perspective for livestock production on natural grasslands is not encouraging in the Inner Mongolia region. Understanding the effects of grazing system and grazing intensity on the interaction between grassland resource and animal production is the prerequisite for developing sustainable and productive grassland management systems. In addition, it is necessary to identify highly sensitive parameters reflecting grassland stability and long term productive use.

## 1.2 Estimating digestibility of herbage and feed intake of grazing animals

A challenge in grazing studies is the determination of the quality and quantity of the herbage ingested by animals because of their ability for selective intake of special plant fractions and species. Since the concentrations of nutrients can vary considerably among the different plant parts and species selected, this choice can markedly affect the nutrient intake of grazing animals (Dove et al., 1999). Therefore, accurate assessment of the nutritive value of herbage and its intake of grazing animals in grazing studies is critical.

The quality of a diet for ruminants is characterized first by diet organic matter (OM) digestibility. The direct measurement of OM digestibility requires the determination of the ingested feed amount and the total-collection of feces. The difference is taken as digested. Under grazing conditions, however, total-collection trails are difficult for measurement of feed intake and OM digestibility of herbage. Therefore, indirect methods, such as use of the internal and external markers, *in situ* procedures, *in vitro* systems (e.g. using rumen microorganisms, cellulolytic enzymes), and near-infrared reflectance spectroscopy (NIRS) are suggested (Menke et al., 1979; Ørskov and McDonald, 1979; Le Du and Penning, 1982; Armstrong et al., 1989; Leite and Stith, 1990 ; Dove and Mayes, 1991; Burns et al., 1994; Givens et al., 2000; Hendricksen et al., 2002; Lewis et al., 2003). A major problem of these indirect

methods when applied in grazing studies is the collection of representative samples of the ingested herbage, especially for heterogeneous pasture where plant species and chemical compositions vary greatly and diet selection occurs (Freer and Dove, 2002).

The eating behaviour of grazing animal has been clearly characterized as selective, with a strong preference for tender and green leaf and against dead and stem tissues (Minson, 1981), which may result in a greater feed intake and a higher quality of the diet. Large discrepancies between the quality of the standing biomass on offer (i.e. botanical composition, crude protein and fibre concentration, OM digestibility) and the quality of the effectively ingested material were reported by Steingäß et al. (2000) in sheep and by Lukas (2001) in dairy cows. Due to the pronounced ability of the animals for feed selection, ingested material shows higher crude protein and lower fibre concentrations and, as a consequence, higher digestibility than the material available to the animals and hence affecting accurate evaluation of OM digestibility of diets ingested by grazing animals.

Regression equations derived from data of feeding trials may be developed to predict nutritive value of herbage, expressed in terms of OM digestibility, based on herbage characteristics which included bioassays, chemical and structural characteristics (NRC, 1985). The methods involve two steps: (1) selection of a representative herbage sample database with known OM digestibility, and (2) development of predictive equation of OM digestibility based on certain characteristics of herbage. The two basic approaches in obtaining a representative herbage sample are a manual collection of herbage by observation of the selective eating behaviour or the use of animals with esophagus cannula (Le Du and Penning, 1982). Representative samples of the ingested herbage may be received by detecting those plant species and parts which are ingested by the grazing animal and attempting to mimic their selection manually that represent their grazing behavior. The use of animals with esophagus cannulae is intended to provide a sample of the diet similar to that consumed by the experimental animals (Mayes and Dove, 2000).

The fecal crude protein (CP) or nitrogen (N) method, which is based on the relationship between the concentration of CP ( $N \times 6.25$ ) in fecal OM and OM digestibility of the diet, can be used for estimating OM digestibility of the diet

ingested by grazing animals (Schmidt, 1993; Schmidt and Jentsch, 1994; Boval et al., 2003; Lukas et al., 2005; Schlecht and Susenbeth, 2006). This kind of method does not need collection of representative samples of the ingested herbage and reflects precisely the herbage truly selected by grazing animals. The regression equation describing the relationship between fecal CP concentration and OM digestibility is based on the biological relationship between fecal soluble CP and OM digestibility of diet. Total fecal CP is most highly related to the soluble CP fraction in feces, while the insoluble CP represents a smaller fraction which is not related to digestibility (Leite and Stuth, 1990). The soluble fecal CP originates mostly from indigestible microbial material, digestive secretion enzymes, and sloughed epithelial tissue (more than 80 %, Mason and Frederiksen, 1979). Jarrige (1989) developed a linear regression model in which the fecal CP excretion is divided into three main components (microbial, dietary and endogenous CP) using data from sheep experiments. The equation indicates that fecal microbial CP was proportional to the intake of fermentable organic matter and fecal endogenous CP was proportional to IDM. Based on these findings, prediction equations were developed using the fecal CP content for estimation of OM digestibility in grazing animals (Thomas and Campling, 1976; Schmidt and Jentsch, 1994; Boval et al., 2003; Lukas et al., 2005). In a comprehensive study using a large set of data, the relationship between faecal CP concentration and dietary OM digestibility in cattle was tested with regard to its predictive value (Lukas, 2001). This relationship is not influenced by diet composition, feed intake and animal species and is, therefore, valid for a large range of types of diets (Lukas et al., 2005; Schlecht and Susenbeth, 2006).

The accurate measurement of quantitative feed intake is necessary for application of nutritional requirement standards to achieve a desired animal response, and also essential for diet formulation (Burns et al., 1994). The direct measurements of forage intake involves that animals were weighed before and after they eat, and herbage disappearance were calculated as the difference between pregrazing and postgrazing herbage mass (Walton et al., 1981; Macoon et al., 2003). Most of the prediction equations for feed intake, based on in situ, in vitro and NIRS technique, describe empirical relationships between feed parameters (e.g. cell wall, acid detergent fiber (ADF), neutral detergent fiber (NDF), gas production, DM disappearance, leaf proportion, grinding energy, bulk density, NIRS) and potential intake (Van Soest,



1965; NRC, 1987; Ørskov et al., 1988; Minson, 1990; Kibon and Ørskov, 1993; Coleman et al., 1995; Blummel and Beck, 1997; Blummel and Bullerdieck, 1997). The equations result in reliable estimates, however, can be applied only for diets and feeds similar to those used for their development (Forbes and Beattie, 1987; Givens et al., 2000).

The simultaneous use of external markers and the fecal CP method is a strong and effective tool to measure feed intake and nutritive digestibility of herbage ingested by grazing animals. The OM digestibility of herbage is predicted by fecal CP concentration, and daily fecal output is calculated by the quantity of the external marker given divided by external marker concentration in feces. If recovery of the external marker is assumed to be 100 % OM intake can be calculated by the following equation:

$$\text{OM intake (g/day)} = \frac{\text{Daily output of fecal OM (g/day)}}{100 - \text{OM digestibility (\%)}} \times 100$$

The combination of both methods is innovative and allows research in grazed grasslands under semi-practical and difficult experimental conditions.

### 1.3 Grassland resources and utilization in the Inner Mongolian steppe

China is one of the countries with the most plentiful grassland resources in the world. There are 400 million hectares (Mha) of the natural grassland (FAO, 2004), of which 300 Mha are pastures and 100 Mha rolling rangelands, mountain slopes and coastal wetland. Livestock production is the main agricultural activity in the Inner Mongolia steppe. In recent decades, durative high grazing intensity has already led to a severe degradation and desertification of the natural grassland ecosystem that has also caused instability for agricultural activities (Chen et al., 2003). Currently there are 3.9 Mha of sandy deserted land, of which 28.3% are caused by heavy grazing (Zhang et al., 1998; Wang, 2000).

The resource of grassland is most readily affected by the land use strategy, which has a large effect on animal productivity. High grazing intensities may maximize feed intake and animal performance per area of land within a short time period, however,

decreases on long term grassland productivity, feed intake per animal, feed quality and as a consequence animal production (Bo and Shiping, 1993). Therefore, sustainable management of grazing animals and grassland systems depends on the understanding of the relationship between ecology of grasslands and animal production (Chen et al., 2003). About the 1950s, there were abundant grassland resources in the Inner Mongolia region. The nomadic land and livestock use system was characterized by the large scale pastoral movements alternating grazing with periods for regrowth and recover of grassland. Due to political decisions, the local farmers were forced to settle in small villages, hamlets or individual farms since 1960s which ended the large scale pastoral movements between seasonal pastures. This management system has increased grazing pressure due to the higher numbers of animals grazing in certain areas. From the 1980s, it was allowed for individual farmer to get profit directly from increased meat or wool production, which again sharply fostered the pressure on the grassland resources and resulted in intensified grassland use and large scale overgrazing.

In the Xilingol region the grassland consists of 11 Mha of the Inner Mongolia grassland (Hao et al., 1997). Currently 41% of the natural grassland is degraded (Wang et al., 2003). The essential attribute of grassland degradation is the deterioration of the entire steppe ecosystem. The vegetation change is one of the most important indicators of grassland degradation. The initial climax community of grassland in the region, *L. chinensis* and *S. grandis* community, is replaced by *Cleistogenes squarrosa* community under higher grazing intensity, which, in turn, is replaced finally by *Artemisia frigida* community under sustainable heavy grazing that decreases the quality of forages and productivity of grassland (Li et al., 1999; Wang and Li, 1999; Chen et al., 2003). Definitions of optimum grazing intensity are difficult, because the optimum depends to a certain extent on the criterion chosen (e.g. feed intake, forage quality or weight change), on climatic and other conditions (i.e. water and nutrient availability of the plants), and on grassland and grazing management systems (continuous versus rotational grazing within or between years). Currently the local government tries to reduce grazing pressure by regulations of herd size and grazing bans. However, these regulations are not specific and it is questionable whether it will help to find a sustainable balance between ecological needs and agricultural productivity.

## 1.4 Grazing studies in the Inner Mongolian steppe

The natural grassland degradation has become a major environmental and an economical problem in the Inner Mongolia region because it leads directly to grassland desertification, reduces grassland productivity and biodiversity, and accelerates the occurrence of dust storms (Liu and Wang, 1997; Wu and Overton, 2002; Lu et al., 2005; Zhao et al., 2005). Well-managed grasslands for livestock grazing lead to sustainable grassland and livestock production and high benefit to the farmer, as well as to the society (Heady, 1999). In order to obtain maximum profits from grassland, producers need to manage the grasslands for sufficient growth of livestock, and to prevent degradation of grassland. Numerous studies have been conducted to investigate the effects of grazing management systems on the dynamic change of degraded and desert grasslands in Inner Mongolia.

A long-term experimental site was set up by the Inner Mongolia Grassland Ecosystem Research Station in 1989, to study the effects of grazing management factors on community characteristics, degradation succession, production of grassland, and animal performance on a pasture dominated by *A. frigida*, *C. squarrosa* and *Potentilla acculis* in the Inner Mongolian steppe. The grazing management factors include grazing intensity (5 levels: 1.33, 2.47, 4.00, 5.33 and 6.67 sheep/ha in the vegetation period), high stocking rate (36 sheep/ha) for a short grazing period (5-10d), low stocking rate (4 sheep/ha) for long grazing period (during the whole vegetation period) and grazing season (spring, summer and autumn).

Botanical composition was significantly affected by stocking rate (Li et al., 1999). The proportion of *L. chinensis* and *A. michnoi* significantly increased at low stocking rate or in the ungrazed control paddock, implying a vegetation succession towards the *L. chinensis* community; the proportion of *P. acculis* increased largely at high stocking rate, indicating grassland degradation. Li and Wang (1998), Wang et al. (1998, 1999) and Wang (2000) concluded that lower stocking rates (1.33-2.67 sheep/ha) can increase the proportion of grasses, such as *L. chinensis*, *Stipa krylovii*, *Agropyron cristatum*, and the plant diversities index. Under heavy grazing condition, the *A. frigida* grassland is degraded to *P. acaulis* grassland where the proportion of grasses and diversity index decreases.

In degraded grasslands dominated by *A. frigida* herbage mass (HM) decreased and intake of herbage increases with increasing stocking rate, while the aboveground net primary productivity (ANPP) (above ground biomass + intake of animal) was the maximum at a stocking rate of 2.67 sheep/ha (Wang, 2003). This indicates improved regrowth and regeneration after grazing at lower stocking rates in degraded grassland. The dietary composition of grazing sheep had a significantly positive correlation with relative biomass (% DM) ( $r = 0.85$ ), height ( $r = 0.73$ ) and frequency ( $r = 0.91$ ) of different plant species. (Wang, 2000).

Grazing seasons affects plant diversity and composition of herbage. The proportion of grasses was maximum in July. *L. chinensis*, *Medicago ruthenica*, *Allium bidentatum*, *Kochia prostrate* and *Cleistogenes squarrosa* were the preferred species by grazing sheep, while others such as *Stipa grandis*, *Carex duruuscula* and *Potentilla acaulis* were usually avoided. Herbage utilization efficiency (HUE), which is calculated by total feed intake divided by total ANPP, is affected not only by stocking rate, but also by grazing season (Table 1.1) (Wang et al., 2003). HUE increases with an increase of stocking rate. Under the same stocking rate there is a high HUE of animal grazing in spring, indicating that overgrazing occurs easily in spring grazing. It is suggested that stocking rates should be reduced to prevent overgrazing in spring grazing.

**Table 1.1** The change of herbage utilization efficiency (%) under different stocking rate and grazing season (Wang et al., 2003).

Stocking rate (sheep/ha)	Spring	Summer	Autumn
1.33	25.4	17.2	16.7
2.67	44.9	31.9	31.6
4.00	72.7	44.5	44.7
5.33	72.6	48.1	62.8
6.67	84.2	64.7	74.3

The stocking rate is an important factor affecting on animal production. Wang (2000) stated that the individual animal body weight gain linearly decreased with increase of stocking rate, whereas body weigh gain per ha increased with decreasing increment. Under the same stocking rate, the body weight gain per ha was maximum

during July to August.

Zhao et al (2005) investigated the effect of heavy grazing on desertification of sandy rangeland in the Inner Mongolia region, and demonstrated that continuous heavy grazing resulted in a considerable decrease in vegetation cover and height, above ground and root biomass, and in a significant increase in animal hoof impacts on fragmentation of topsoil, which is susceptible to wind erosion (Faraggitaki, 1985). The desertification processes was caused by the increasing size of bare spots on the ground with grazing intensity. Heavy grazing resulted in a considerable decrease in ground cover, which accelerate soil erosion by wind, leading to a further coarseness in surface soil, loss of soil organic carbon and nitrogen, and deterioration of soil biological properties. It is suggested that a proper grazing intensity is 2-3 sheep (adult ewe, 50 kg of body weight) per ha in sandy rangelands of Inner Mongolia (Zhao et al., 2005). However, excluding grazing livestock is considered as a necessity to restore heavily degraded vegetation (Su et al. 2005).

A study carried out during a period of 11 year (1983-1993) at a *L. chinensis* site prevented from grazing since 1979 in the Inner Mongolian grassland in a restoration area of degraded grassland the characteristics of individual plants and of the root system distribution of major plant species were compared between the degraded community and primary community. Wang et al. (2000) conclude from this study that the plant individual miniaturization is the mechanistic intermediate link between over-grazing and degradation. Miniaturized plants showed the following characteristics: shortened internodes, contracted leaf blades and a shallowly distributed root system. Individual plant miniaturization reduced community productivity and regenerative ability of populations. The space released by the miniaturization of originally present plants may then be filled by abundant colonization of unpalatable plant species. The phenomenon of individual plant miniaturization and its ecological effects reveals the mechanism of underlying decreasing productivity and the replacement of dominant species that characterizes steppe community under overgrazing.

### **1.5 Continuous and rotational grazing systems**

Continuous grazing is defined as grazing of animals on the same area during the

whole period of the vegetation. In a rotational grazing system pasture is divided into several paddocks and animals are moved recurrently from one paddock to another paddock during grazing season. Therefore, each paddock is more intensively grazed for a short period, whereas the others remain un-grazed. A major objective of a rotational grazing system is to give plants a certain period of time to recover and for re-growth after grazing. Rotational grazing emphasizes the intensity of the management rather than the grazing intensity. Continuous grazing system has its benefit of lower capital investment, since few fencing and watering facilities are required and management is relatively simple. Rotational grazing requires more time to maintain the equipment and to manage the animals (Vallentine, 2001). However, no single grazing system can be taken as the general optimum, since grassland types, climate and management objectives vary which will lead to different optima for specific conditions (Heady, 1999; Vallentine, 2001). Grazing systems must be adapted to the local conditions, and comparison of different grazing system carried out in different areas should be made only with caution (Walton et al., 1981).

Holechek et al. (1999) demonstrated that there was much inconsistency regarding influences of continuous and rotational grazing on rangeland vegetation. In semi-arid and desert type grasslands, rotational grazing generally showed no advantage over continuous grazing. However, in more humid grassland types, forage production was 20-30% higher under rotational grazing. Animals often show equal or higher performance at continuous grazing than at rotational grazing. This is attributed to the opportunity at continuous grazing for selecting preferred plants or parts of plants with higher quality (Vallentine, 2001; Holechek et al., 1999). Mckown et al. (1991) compared grazing systems (continuous vs. rotational) and tested the effect of grazing intensity with regard to nutrient intake and observed that the differences in CP and ME intake between treatments were attributed primarily to differences in stocking rate rather than to the grazing system. Mathews et al. (1994) compared the effects of continuous and rotational grazing on animal weight gain, and found that there was no advantage of rotational over continuous grazing in LWG per animal or per hectare. However, Savory and Parsons (1980) stated that rotational grazing should be installed for an improvement of the grassland and its productivity in terms of livestock carrying capacity and to obtain a high economic return to the farmers. This increase in carrying capacity has been attributed generally to substantial increases in quantity and quality

of herbage produced as a result of the positive effects of plant growth and ecological succession. Zhang et al. (1989) and Han et al. (1990) also stated that at the same grazing intensity, rotational versus continuous grazing improved herbage quality and LWG of sheep in the Inner Mongolian steppe. The recovery periods of the grassland after grazing seems to be an important factor both on short term and on long term productivity of grasslands realized either by increasing the number of grazing periods within the season or by preventing grazing in critical time periods (Li et al, 2001). If the recovery period is too short, plants will not have time enough to produce larger amounts of photosynthetic active tissues which affects herbage mass and in some cases also the nutritive value. Thus, time length and frequency of the recovery periods play an important role for the effects of rotational grazing (Valentine, 2001).

### **1.6 Maintaining balance between grassland and livestock production**

Most of the management strategies (e.g. rotational grazing, seasonal grazing, and limited grazing) aim to improve grassland use efficiency (Li et al., 1999; Freer and Dove, 2002). However, grassland livestock producers and managers are often reluctant to implement management systems to resolve concerns associated with overgrazing in the Inner Mongolia region because of the high costs of some strategies. Currently it is urgent question to balance potential grassland production, nutritional requirement of grazing livestock, and protection of the fragile grassland ecosystem in the Inner Mongolia.

It is obvious that as stocking rate decreases herbage becomes more abundant for animal production. Therefore, the stocking rate is one of the most important factors affecting stability of grassland and animal productivity (O'Reagain and Turner, 1992). Most of the methods used for determination of optimum stocking rate in this region are based on herbage production and daily feed intake, however, they do not consider nutrient concentrations and digestibility of the feed. Therefore, it is necessary to evaluate herbage availability of the different types of grasslands for optimal determination of stocking rate.

Flexible stocking rates may be employed in the region, where animal numbers can be adapted to forage availability. The most important issue is to reduce grazing pressure at the start of flowering until seed maturity, which will be beneficial to plant

recruitment and vegetative reproduction (Vallentine, 2001). Managers need to be familiar with the variable climatic conditions primarily precipitation and temperature in the region. Whatever strategies are applied, stocking rates should be reduced in the drought seasons and years, in order to minimize animal losses and prevent overgrazing (Freer and Dove, 2002).

Herbage nutritive value is one important variable besides others when optimum grazing intensity and systems are evaluated. Intensive regrowth is a mean of maintaining high nutrient levels in herbage (Vallentine, 2001). Agricultural measures, such as fertilizing, irrigation and reseeded in degraded grasslands may result in high regrowth of plants and increase of plant species numbers, and change composition and improve herbage yield of grassland (Yao et al., 1997; Zheng et al., 2006). However, these measures cannot be applied to large areas due to the lack of scientific guidance and capital for the local farmers. Therefore, innovative and cost-effective approaches to match balance between grassland and animals production are needed.

In view of the grassland degradation in the Inner Mongolia steppe it is essential that degraded pasture has to be fenced to protect sensitive areas (Chen et al., 2003). Han et al. (2000) stated that conservation measures can be applied in two ways. One is to use a proper grassland utilization system at optimum stocking rate. This means that a rotational grazing system has to be implemented. The other way is to produce high quality hay using adapted forage species to provide herbage for grazing livestock when excluding grazing is taken for protection of grazed pastures in early spring and drought season.

Continuous hay production without supplementation of fertilizers will cause nutrient depletion of grassland. Therefore, a mixed grassland system, where grazing alternates with hay production each year, can be seen as better nutrient balanced, more productive and stable. Moreover, farmers need to retrench the grazed area when herbage mass is higher as earlier expected. Those ungrazed areas will show an undisturbed re-growth and can be for haymaking in autumn or grazing in winter.

Although some grazing grasslands may be suitable only to certain species of grazing animals due to palatability of forage and animal preference, most grazing grasslands tolerate several grazing animal species to adapt to the different grazing



behavior. Domestic livestock on the grassland of Inner Mongolia are sheep, goats, cattle, and horses. Therefore, a mix of grazing animals may be considered to utilize certain types of grassland and plant species more effectively and enhance farmers' income.

### **1.7 General objectives**

As mentioned above digestibility of herbage is the crucial information required for feed evaluation and to evaluate the different climatic and management factors that affect grassland and animal productivity. The fecal CP method does not require collection of representative herbage sample and shows great benefits as reliable, rapid and inexpensive method for estimating digestibility of herbage. In Chapter 2, the development and evaluation a prediction equation is described for estimating OM digestibility of herbage from CP concentration in fecal OM, using data from large number of in vivo digestibility trials in sheep with a large variation in herbage composition. In Chapter 3, the results of a grazing experiment with sheep are presented where the effects of two different grazing systems (rotational and continuous grazing) on HM, re-growth, feed intake and digestibility, and on LWG at moderate grazing intensity of 4.5 sheep/ha throughout two grazing seasons in the *L. chinensis* grassland of Inner Mongolia were investigated.

## References

- Armstrong, R. H., Common, T. G., Davies, G. J., 1989. The prediction of the in vivo digestibility of the diet of sheep and cattle grazing indigenous hill plant communities by in vitro digestion, faecal nitrogen concentration or indigestible acid-detergent fiber. *Grass and Forage Science* 44: 303-313.
- Blummel, M., Becker, K., 1997. The degradability characteristics of fifty four roughages and roughage neutral detergent fibres as described by in vitro gas production and their relationship to voluntary feed intake. *British Journal of Nutrition* 77: 757-768.
- Blummel, M., Bullerdieck, P., 1997. The need to component in vitro gas production measurements with residue determinations from in sacco degradabilities to improve the prediction of voluntary intake of hays. *Animal Science* 64: 71-76.
- Bo, L., Shiping, Y., 1993. Winter cold temperate grasslands: identifying problems. In: *Grassland for our World*. Baker, M. J. (ed.). SIR Publishing, Wellington, New Zealand. pp. 586-591.
- Boval, M., Archimede, H., Fleury, J., Xande, A., 2003. The ability of faecal nitrogen to predict digestibility for goats and sheep fed with tropical forage. *Journal of Agricultural Science* 140: 443-450.
- Burns, J. C., Pond, K. R., Fisher, D. S., 1994. Measurement of forage intake. In: *Fahey, G. C. (ed.). Forage quality, evaluation and utilization*. pp. 502.
- Chen, Z. Z., Wang, S. P., 2000. Typical steppe ecosystem of China. *Science Press*. pp. 9-45.
- Chen, Z. Z., Wang, S. P., Wang, Y. F., 2003. Update progress on grassland ecosystem research in Inner Mongolia steppe. *Chinese Bulletin of Botany* 20: 423-429.
- Coleman, S. W., Stuch, J. W., Holleway, J. W., 1995. Prediction of intake by near infrared spectroscopic analysis fecal sample. In: *Owen, F. N., Gill, D., Lusby, K., McCollum, T. (eds). Symposium: intake by feedlot cattle*. Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma. pp. 145-155.
- Crocker, K., Watt, P., 2001. *The good food guide for sheep*. Department of Agriculture, South Perth, Australia, pp. 20-49.
- Dove, H., Mayes, R. W., 1991. The use of plant max alkanes as marker substance in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* 42: 913-952.

- Dove, H., Wood, J. T., Simpson, R. J., Gatford, K. L., Siever-Kelly, C., Ciavarella, T. A., 1999. Spray-topping annual grass pasture with glyphosate to delay loss of feeding value during summer. Quantitative basis of the alkane-based procedures for estimating diet selection and herbage intake by grazing sheep. *Australian Journal of Agricultural Research* 50: 475-485.
- FAO, 2004. Statistical yearbook. In Food and Agricultural Organization, Rome, Italy.
- Faraggitaki, M. A., 1985. Desertification by heavy grazing in Greece: the case of Lesbos island. *Journal of Arid Environments* 9: 237-242.
- Forbes, T. D. A., Beattie, M. M., 1987. Comparative studies of ingestive behaviour and diet composition in oesophageal-fistulated and non-fistulated cows and sheep. *Grass and Forage Science* 42: 79-84.
- Freer, M., Dove, H., 2002. Sheep Nutrition. CABI publishing in association with CSIRO publishing, UK. pp. 1-70, pp. 263-281.
- Givens, D. I., Owen, E., Axford, R. F. E., Omed, H. M., 2000. Forage evaluation in ruminant nutrition. CABI publishing.
- Han, G. D., Xu, Z. X., Zhang, Z. T., 1990. Comparison of rotation and continuous season grazing systems. *Chinese Journal of Arid Land Resources and Environment* 3: 355-362.
- Han, G., Willms, W. D., Zhao, M., Gao, A., Jiao, S., Kemp, D., 2000. Effect of stocking rate on a stipa breviflore desert steppe community of Inner Mongolia. [www.paper.edu.cn](http://www.paper.edu.cn)
- Hao, D. Y., Liu, Z. L., Wang, W., Liang C. Z., 1997. Research on the Restoring Succession of the Degenerated Grassland in Inner Mongolia. III A Mathematical Model for Plant Community Succession. *Acta Phytocologica Sinica* 6: 503-511
- Heady, H. F., 1999. Perspectives on rangeland ecology and management. *Rangelands* 21: 23-33.
- Hendricksen, R. E., Reich, M. M., Robertson, R. F., Reid, D. J., Gazzola, C., Rideout, J. A., Hill, R. A., 2002. Estimating the voluntary intake and digestibility of buffel-grass and Lucerne hays offered to Brahman-cross cattle using n-alkanes. *Animal Science* 74: 567-577.
- Holechek, J. L., Gomea, H., Molinar, F., Galt, D., 1999. Grazing Studies: what we have learned. *Rangelands* 21: 12-16.
- Jarrige, R. (ed.). 1989. Ruminant Nutrition: recommended allowances and feed tables.

- John Libbey, Eurotext, London Paris. pp. 31-47.
- Kibon, A., Ørskov, E. R., 1993. The use of degradation characteristics of browse plants to predict intake and digestibility by goats. *Animal Production* 57: 247-251.
- Le Du, Y. L. P., Penning, P. D., 1982. Animal based techniques for estimating forage intake. In: Leaver, J. D. (Ed.). *Forage Intake Handbook*. The British Grassland Society, Hurley, Maidenhead, Berkshire, UK. pp. 37-75.
- Leite, E. R., Stuth, J. W., 1990. Value of multiple fecal indices for predicting diet quality and intake of steer. *Journal of Range Management* 43: 139-143.
- Lewis, R. M., Magadlela, A. M., Jessop, N. S., Emmans, G. C., 2003. The ability of the n-alkane technique to estimate intake and diet choice of sheep. *Animal Science* 77: 319-327.
- Li, B., 1999. Steppe degradation in northern China and preventing measures. In: Xu, R. (ed.). *Collected Papers of Li Bo*. Science Press, Beijing, pp. 513
- Li, Q. F., Li, F. S., Siri, G. L., Duan, X. Q., 2001. A preliminary study on spring prohibiting grazing on grassland vegetation and animal production in a sandy grassland area. *Grassland of China* 23: 41-46.
- Li, Y. H., Wang, S. P., 1999. Response of plant and plant community to different stocking rates. *Grassland of China* 3:11-19.
- Li, Y. H., Chen, Z. Z., Wang, S. P., Huang, D. H., 1999. Grazing experiment for sustainable management of grassland ecosystem of Inner Mongolia steppe: experimental design and the effect of stocking rates on grassland production and animal live weight. *Acta Agrestia Sinica* 3: 173-182.
- Li, Y. H., Wang, S. P., 1998. Grazing intake of Inner Mongolian fine wool sheep and their preference for grassland forage species. *Acta Prataculturas Sinica* 7: 50-53.
- Liu, Z., Wang, W., 1997. Status and succession pathways of the steppe degradation in Inner Mongolia. In: Chen, M. (ed.). *Research for improving degraded steppe and building artificial steppe*. Inner Mongolia Press, Huhhot, pp. 147.
- Lu, Z. J., Lu, X. S., Xin, X. P., 2005. Present situation and trend of grassland desertification of North China. *Acta Agrestia Sinica* 13: 24-27.
- Lukas, M., 2001. Fecal crude protein as an estimate of diet digestibility in cattle. PhD-Thesis, University of Kiel.
- Lukas, M., Südekum, K. H., Rave, G., Friedel, K., Susenbeth, A., 2005. Relationship between fecal crude protein concentration and diet organic matter digestibility in cattle. *Journal of Animal Science* 83: 1332-1344.

- Macon, B., Sollenberger, L. E., Moore, J. E., Staples, C. R., Fike, J. H., Portier, K. M., 2003. Comparison of three techniques for estimating the forage intake of lactating dairy cows on pasture. *Journal of Animal Science* 81: 2357-2366.
- Mason, V. C., Frederiksen, J. H., 1979. Partition of the nitrogen in sheep faeces with detergent solution, and its application to the estimation of the true digestibility of dietary nitrogen and the excretion of non dietary faecal nitrogen. *Z. Tierphysiol., Tierenahrg. u. Futtermittelkde.* 41: 121-131.
- Mathews, B. W., Sollenberger, L. E., Staples, C. R., 1994. Dairy heifer and bermudagrass pasture responses to rotational and continuous stocking. *Journal of Dairy Science* 77: 244-252.
- Mayes, R. W., Dove, H., 2000. Measurements of dietary nutrient intake in free-ranging mammalian herbivores. *Nutrition Research Review* 13: 107-138.
- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., 1988. *Animal Nutrition*. Copublished in United State with John Wiley and Sons, Inc., New York. pp. 257-259.
- Mckown, C. D., Walker, J. W., Stuth, J. W., Heitschmidt, R. K., 1991. Nutrient intake of cattle on rotational and continuous grazing treatments. *Journal of Range Management* 44: 596-601.
- Menke, H. K., Raab, L., Salewski, A., Steingass, H., Fritz, D., Schneider, W., 1979. The estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor in vitro. *Journal of Agricultural Science* 93: 217-222.
- Minson, D. J., 1981. Nutritional differences between tropical and temperate pastures. In: Morley, F. H. W. (ed.). *World Animal Science B1. Grazing Animals*. Elsevier Science Publication. New York. pp. 143.
- Minson, D. J., 1990. *Forage in Ruminant Nutrition*. Academic Press, San Diego, California, UAS.
- NRC (National Research Council). 1985. *Nutrient requirements of sheep*, 6th edn. National Academy Press, Washington, DC, pp. 97.
- NRC (National Research Council). 1987. *Sheep*. In: *predicting feed intake of food-producing animals*. National Academy Press, Washington, D. C. pp. 75-82.
- O'Reagain, P. J., Turner, J. R., 1992. An evaluation of the empirical basis for grazing management recommendations for grassland in southern Africa. *Journal of the Grassland Society of Southern Africa* 9: 38-49.

- Ørskov, E. R., McDonald, I., 1979. The estimation of crude protein degradability in the rumen incubation measurements weighted according to rate of passage. *Journal of Agricultural Science* 92: 499-503.
- Ørskov, E. R., Reid, G. W., Kay, M., 1988. Prediction of intake by cattle from degradation characteristics of roughages. *Animal Production* 46: 29-34.
- Savory, A., Parsons, S. D., 1980. The savory grazing method. *Rangelands* 2: 234-237.
- Schlecht, E., Susenbeth, A., 2006. Estimating the digestibility of Sahelian roughages from faecal crude protein concentration of cattle and small ruminants. *Journal of Animal Physiology and Animal Nutrition* 90: 369-379.
- Schmidt, L., 1993. Faecal nitrogen as an indicator for silage digestibility and energy content of silage. 6. *Mezinardni sympozim*. pp. 157-163.
- Schmidt, L., Jentsch, W., 1994. Die Schätzung der Verdaulichkeit von Konservatfütterationen für Rinder anhand des Stickstoffgehaltes im Rinderkot. *FBN Schriftenreihe, Dummerstorf* 7:179–184.
- Steingäß, H., Matusevicius, P., Drochner, W., 2000. Weidefutteraufnahme und Verdaulichkeit verschiedener Grünfütterleguminosen beim Schaf. *Verband Deutscher Landwirtschaftlicher Untersuchungs und Forschungsanstalten, Darmstadt*. pp. 204.
- Su, Y. Z., Li, Y. L., Cui, H. Y., Zhao, W. Z., 2005. Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, north China. *Catena* 46: 267-278.
- Thomas, S., Campling, R. C., 1976. Relationship between digestibility and faecal nitrogen in sheep and cows offered herbage *ad libitum*. *Journal of the British Grassland Society* 31: 69-72.
- Vallentine, J. F., 2001. *Grazing Management*. Academic Press. pp. 127-165, pp. 473-526.
- Van Soest, P. J., 1965. Symposium on factors influencing the voluntary intake of herbage by ruminant: voluntary intake in relation to chemical composition and digestibility. *Journal of Animal Science* 24: 834-843.
- Walton, P. D., Martinea, R., Bailey, A. W., 1981. A comparison of continuous and rotational grazing. *Journal of Range Management* 34: 19-21.
- Wang, S. P., 2000. Relationships between body gain and stocking rates of grazing sheep on typical Inner Mongolian grassland. *Acta Prataculturas Sinica* 9:10-16.
- Wang, S. P., 2000. The dietary composition of fine wool sheep and plant diversity in

- Inner Mongolia steppe. *Acta Ecologica Sinica* 20: 951-958.
- Wang, S. P., Li, Y. H., 1999. Degradation mechanism of typical grassland in Inner Mongolia. *Chinese Journal of Applied Ecology* 10: 437-441.
- Wang, S. P., Li, Y. H., Chen, Z. Z., 1999. The optimal stocking rates on grazing system in Inner Mongolia steppe. . Based on analysis of live weigh gain per animal and hectare and benefit. *Acta Agrestia Sinica* 7: 183-192
- Wang, S. P., Li, Y. H., Chen, Z. Z., 1999. The optimal stocking rates on grazing system in Inner Mongolia steppe. . Based on relationship between stocking rate and aboveground primary productivity. *Acta Agrestia Sinica* 7: 193-199.
- Wang, S. P., Li, Y. H., Wang, Y. F., Han, Y. H., 1998. The succession of *Artemisia frigida* rangeland and multivariation analysis different stocking rates in Inner Mongolia. *Acta Ecologica Sinica* 6: 299-306
- Wang, S. P., Wang, Y. F., Chen, Z. Z., 2001. The biological-economical principle on sustainable development of grassland livestock in Inner Mongolia steppe. *Acta Ecologica Sinica* 21: 617-623.
- Wang, S. P., Wang, Y. F., Chen, Z. Z., 2003. *Grazing Ecosystem and Management*. Science Press. Beijing.
- Wang, T., 2000. Land use and sandy desertification in the north China. *Journal of Desert Research* 20: 103-113.
- Wang, W., Liang, C. Z., Liu, Z. L., Hao, D. Y., 2000. Mechanism of degradation succession in *Leymus chinensis* and *Stipa grandis* steppe community. *Acta Phytocologica Sinica* 24: 468-472.
- Wu, J., Overton, C., 2002. Asian ecology: pressing problems and research challenges. *Bulletin of Ecological Society of America* 83: 189-194.
- Yao, Y. Q., Wang, S. P., Wang, Y. F., 1997. Influence of sulfur fertilizer on productivity of herbage and performance of Chinese merino fine sheep (wether) in Inner Mongolia seppe. *Acta Agrestia Sinica* 4: 236-243
- Zhang, Q., Zhao, X., Zhao, H. L., 1998. *Rangeland in sandy area*. China Ocean Press, Beijing, pp. 255.
- Zhang, Z. T., Xu, Z. X., Han, G. D., 1989. A comparison of rotational and continuous seasonal grazing systems. *Proceedings of XVI International Grassland Congress Nice, France*. pp. 1259-1260.
- Zhao, H. L., Zhao, X. Y., Zhou, R. L., Zhan, T. H., Drake, S., 2005. Desertification

processes due to heavy grazing in sandy rangeland, Inner Mongolia. *Journal of Arid Environments* 62: 309-319.

Zhao, X., Yao, Y., Yang, R., 1988. Ecological geographic characteristics and outlook of natural grasslands resource in Xinlin river basin. In: Inner Mongolia Grassland Ecosystem Research Station (ed.). *Research on Grassland Ecosystem*, Beijing Science Press. 3: 184-226.

Zheng, G. G., Tian, G. L., Xing, Y. L., Fu, J. N., 2006. A new approach to grassland management for the arid Aletai region in Northern China. *The Rangeland Journal* 28: 97-104.



## Chapter 2 Fecal Crude Protein Content as an Estimate for the Digestibility of Forage in Grazing Sheep

### Abstract

Regression equations were developed to predict the organic matter (OM) digestibility of forage-based diets from contents of crude protein (CP) and acid detergent soluble CP (ADSCP) in feces, with data (721 observations of nine types of diets) obtained from in vivo digestibility trials (n = 159) with sheep conducted at the Federal Research Centre of Agriculture, Braunschweig, Germany and in Inner Mongolia, China. Using the non-linear mixed model procedure, the developed regression equation is:  $OM \text{ digestibility} = 0.899 - 0.644 \times \exp(-0.5774 \times \text{fecal CP [g/kg OM]} / 100)$ . The estimated parameters of the equation were significant ( $P < 0.05$ ), and a random effect of diet was not observed ( $P > 0.05$ ). The mean prediction error (MPE) as percentage of observed mean was 7.7 %, indicating that the equation fits the data reasonably well. The equation slightly under-predicts the OM digestibility with a small mean bias of -0.014, representing 7.6 % of the total mean square prediction error (MSPE). The difference between estimated and measured OM digestibility is mainly caused by random variation (76.5 %). This indicates that the developed equation is accurate and can be used to predict the OM digestibility of forage ingested by sheep grazing on heterogeneous pasture. Although inclusion of ADSCP instead of CP in the prediction equation results in a slightly lower under-prediction (mean bias of -0.011, representing 5.1 % of MSPE), the prediction accuracy is not improved ( $P > 0.05$ ).

**Key words:** Sheep; Organic matter digestibility; Fecal crude protein

### 2.1 Introduction

The organic matter (OM) digestibility is the basal unit in evaluating the nutritive value of forage consumed by animals. The direct measurement of the amount of feed ingested and feces excreted is conducted in indoor digestibility trials. OM digestibility can also be determined with in vivo trials by using several internal and external markers, with in situ or in vitro procedures, and with near-infrared reflectance

spectroscopy (NIRS) (Menke et al., 1979; Ørskov and McDonald, 1979; Le Du and Penning, 1982; Holechek et al., 1986; Owens and Hanson, 1992; Givens et al., 2000; Hendricksen et al., 2002; Lewis et al., 2003; Ouellet et al., 2004). A major precondition for all of these methods is a representative sample of the ingested feed, which is difficult to receive in animals grazing heterogeneous pastures as forage species and their composition vary and diet selection occurs.

With the fecal crude protein ( $CP = N \times 6.25$ ) method, which is based on the positive relationship between CP concentration in feces and diet digestibility caused by the increase of non-dietary nitrogen (NDN) excretion in feces and the decrease of undigested fecal OM when OM digestibility increases, there is no need to collect representative samples of the ingested forage. Therefore, it can be used for estimating OM digestibility of diets selected by grazing animals. Considering the different digestive ability of animal species and the specific effects of the type of diet, some investigators recommended to establish individual regression equations for species and types of diets to estimate digestibility under grazing conditions (Le Du and Penning, 1982; Bartiaux-Thill and Oger, 1986). In contrast, others stated that establishing individual equations for specific diets would limited the general use of this method and demonstrated that a general equation can accurately predict OM digestibility for different forage-based diets (Leite and Stuth, 1990; Schmidt, 1993; Schmidt and Jentsch, 1994; Boval et al., 2003; Lukas et al., 2005). The inclusion of indigestible dietary CP in total fecal CP excretion might negatively affect the precision of the relationship between the CP concentration in fecal OM and OM digestibility, therefore, acid detergent soluble CP (ADSCP) was recommended as a more sensitive variable for estimation of OM digestibility (Guerin et al., 1989). However, Lukas et al. (2005) and Schlecht and Susenbeth (2006) found that replacing fecal CP by ADSCP did not improve the relationship to OM digestibility.

The objectives of this study which used data obtained at the Federal Research Centre of Agriculture, Braunschweig in Germany and at the Inner Mongolia Grassland Ecosystem Research Station in China were (1) to develop prediction equations for estimating OM digestibility based on fecal CP and ADSCP concentration; (2) to compare the accuracy of these equations using ADSCP or CP concentration; and (3) to evaluate the validity of the equations for estimating OM

digestibility of forages from the Inner Mongolia steppe, China.

## 2.2 Materials and methods

### 2.2.1 Data collection

Sheep data were collected from indoor digestibility experiments (153 diets, 676 observations) conducted at the Federal Research Centre for Agriculture, Braunschweig in Germany and at the Inner Mongolia Grassland Ecosystem Research Station, Xilinhot in China (6 diets, 45 observations). The OM digestibility was measured in digestibility trials with sheep for nine types of forages. Only to the hay diets in Braunschweig and to a hay diet in Inner Mongolia concentrate feed was added (Table 2.1). The experimental periods consisted of a preliminary 14 days adaptation period followed by 7-10 days to measure feed intake and excretion of feces. The range of dry matter (DM), OM, CP, crude fiber, crude fat and nitrogen free extract (NFE) concentrations in the diets were 139-939 g/kg fresh matter, 831-951 g/kg DM, 74-256 g/kg DM, 178-373 g/kg DM, 8-46 g/kg DM and 323-609 g/kg DM, respectively. Average daily intake of DM (IDM) and OM (IOM) ranged from 0.57 to 1.55 kg/d and from 0.52 to 1.36 kg/d, respectively. The proportion of concentrate supplemented in hay diets ranged from 18.1 to 39.3 % of DM, the CP content of fecal OM from 76 to 282 g/kg, the proportion of ADSCP in fecal CP from 59 to 89 %, and the OM digestibilities of the diets from 0.414 to 0.827. In the digestibility trials in Inner Mongolia, three hays were fed that were harvested from paddocks dominated by either *Leymus chinensis* (*L. chinensis* 59.3 %), *Stipa grandis* (*S. grandis* 21.9 %) or *Artemisia frigida* (*A. frigida* 62.5 %), representing extensive feed production. The mixed hay, mainly consisting of *L. chinensis*, *S. grandis* and *A. frigida*, was fed with a concentrate feed (30.5-33.7 % of the diet). The number of sheep in the trials ranged from 4 to 8.

### 2.2.2 Chemical analysis

In each digestibility trial, DM, ash, N ( $CP = 6.25 \times N$ ), crude fat, and crude fiber concentrations in the diet, feed residues, and fecal samples were determined using the methods as described by Bassler (1976). The NFE was calculated as  $NFE = 1000 - \text{ash} - CP - \text{crude fiber} - \text{crude fat}$  (all in g/kg of DM). In 161 fecal samples selected

**Table 2.1** Ingredients and chemical composition of the diets fed to sheep in digestibility trials conducted in Germany and China (values are ranges of the variables).

Data source	Diet		Concentrate, % of diet DM	IDM kg/d	IOM kg/d	Chemical composition, g/kg of DM						OM digestibility	CP g/kg of fecal OM	Proportion of ADSCP in fecal CP (%)	Sheep number
	Forage	Concentrate				DM (g/kg)	OM	CP	Crude fat	Crude fiber	NFE				
Braunschweig	FG	-	-	0.57-1.28	0.52-1.13	139-367	869-919	93-243	21-46	214-297	372-549	0.624-0.780	144-232	78-87	60
Germany	GS	-	-	0.71-1.47	0.62-1.31	164-554	831-942	80-197	11-40	221-361	357-526	0.590-0.827	114-273	73-88	178
	Hay	Soybean	18.1-39.3	0.80-1.10	0.74-1.05	824-893	891-951	130-256	8-23	211-347	420-513	0.511-0.826	96-282	74-89	232
	ReS	-	-	1.28-1.49	1.11-1.29	277-414	860-894	152-229	12-27	178-309	407-467	0.585-0.793	172-272	71-81	46
	LoS	-	-	1.28-1.38	1.15-1.35	281-356	875-905	160-248	17-34	213-329	374-438	0.572-0.742	158-259	59-65	58
	ALS	-	-	1.23-1.39	1.08-1.24	256-436	868-893	163-229	13-30	227-373	323-390	0.552-0.753	119-200	82-85	46
	GaS	-	-	1.25-1.55	1.13-1.36	206-400	880-908	186-252	15-21	234-335	342-390	0.536-0.735	146-252	81-87	56
IM China	MH	Concentrate	30.5-33.7	0.90-1.30	0.85-1.19	862-886	892-936	68-130	19-27	223-231	520-609	0.455-0.618	86-149	83-84	16
	Hay	-	-	0.82-1.45	0.77-1.34	866-939	921-949	74-95	17-29	300-332	501-523	0.414-0.631	76-152	78-83	29

<sup>a</sup> In Braunschweig data set: FG: fresh grass (intensive and extensive), GS: grass silage (early, late and very late cutting), Hay (intensive and extensive), ReS: red cover silage (early and late cutting), LoS: lotus silage (early and late cutting), ALS: alfalfa silage (early and late cutting), GaS: galega silage (early and late cutting), chemical composition of soybean (g/kg DM): OM, 922-935; CP, 462-505; Crude fiber, 70-126; Crude fat, 15-28; NFE, 307-346. In IM (Inner Mongolia) data set: MH: mixed hay, chemical composition of concentrate (g/kg DM): OM, 864-931; CP, 57-148; Crude fiber, 166-184; Crude fat, 22-32; NFE, 528-657.

<sup>b</sup> IDM: intake of dry matter.

<sup>c</sup> IOM: intake of organic matter.

<sup>d</sup> DM: dry matter, OM: organic matter, CP: crude protein, NFE: nitrogen free extract.

<sup>e</sup> ADSCP: acid detergent soluble CP.

from 1-2 animals with OM digestibilities close to the average of each trial, the ADSCP concentration was determined using the method as described by Van Soest et al. (1991) and Licitra et al. (1996). In this method, the acid detergent fiber (ADF) concentration in feces was measured using the ANKOM<sup>200/220</sup> Fiber Analyzer, then CP ( $N \times 6.25$ ) concentration in the residue was determined by the Kjeldahl method. The difference between total CP in feces and CP in the ADF fraction is defined as the ADSCP.

### 2.2.3 Calculation and statistical analysis

Inverse and quadratic functions were used to describe the relationship between OM digestibility of herbage and fecal nitrogen or CP concentration (Thomas and Campling, 1976; Schmidt and Jentsch, 1994; Boval et al., 2003). Lukas et al. (2005) using a wide range of data from cattle showed that a nonlinear regression equation more accurately predicts OM digestibility from fecal CP concentration than inverse and quadratic functions. In the present study, the non-linear mixed model procedure (NLMIXED) of SAS (2003) was used. The following model was used (Eq. 1):

$$y_{ij} = a - (b + u_i) \times \exp(-c \times x_{ij} / 100) + e_{ij} \quad (1)$$

where  $y_{ij}$  represents the  $j$ th OM digestibility on the  $i$ th diet ( $i = 1$  to  $9$ );  $x_{ij}$  is the corresponding concentration of CP or ADSCP in fecal OM (g/kg);  $a$ ,  $b$  and  $c$  are the fixed-effect parameters;  $u_i$  are random effects parameters of the type of diet, and  $e_{ij}$  is the residual error.

The prediction accuracy of relationship between the estimated and measured OM digestibility was examined using the mean-square prediction error (MSPE) as described by Rook et al. (1990) (Eq. 2):

$$\text{MSPE} = (\bar{E} - \bar{M})^2 + S_E^2(1 - b)^2 + S_M^2(1 - r^2) \quad (2)$$

where  $\bar{E}$  and  $\bar{M}$  are the mean of estimated (E) and measured (M) OM digestibility,  $S_E^2$  and  $S_M^2$  are the variance of E and M,  $b$  and  $r$  are the slope and correlation coefficient, respectively, of the linear regression of E on M. The three components

represent the mean bias ( $\bar{E} - \bar{M}$ ), the line bias (the deviation of the slope), and the random variation of the equation. Mean prediction error (MPE, %) was used to describe the relative prediction accuracy (Eq. 3):

$$\text{MPE} = \sqrt{\text{MSPE}} / \bar{M} \times 100 \quad (3)$$

The stepwise multiple regression technique was used to analyze effects of the proportion of concentrate in diets and the chemical composition (CP, crude fiber and ash) of diets on the difference between estimated and measured OM digestibility (Eq. 4):

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \dots + b_nx_n \quad (4)$$

where  $y$  is the difference between estimated and measured OM digestibility,  $x_i$  represent the respective variable of the analyzed factors,  $a$  is the constant and  $b_i$  are the partial regression coefficients of equation. The beta weight, i.e. standardized version of the regression coefficient, was calculated to describe the relative power of the analyzed dietary factors. Data analysis was carried out using SAS (2003).

## 2.3 Results

### 2.3.1 Relationship between OM digestibility and fecal CP

The following prediction equation (Eq. 5) to estimate OM digestibility from the content of CP in fecal OM was developed according to the model (Eq. 1) using all experimental data ( $n = 721$ ):

$$y = 0.899 - 0.644 \times \exp(-0.5774 \times \text{fecal CP [g/kg OM]} / 100) \quad (5)$$

where  $y$  is OM digestibility of diet. The p-values of the parameter estimates showed that the fixed-effect parameters ( $a$ ,  $b$ ,  $c$ ) and the residual error ( $e$ ) have a significant effect ( $P < 0.05$ ), whereas effect of the type of diets ( $u_i$ ) was not observed ( $P > 0.05$ ) (Table 2.2). This indicates that there is no significant effect of the type of diet on the estimation of OM digestibility, and that the developed equation can be generally applied to estimate the digestibility of OM of forage-based diets in sheep. The slopes

(b + u) for each type of diet are given in Table 2.3, and the data and the fitted regression equation (Eq. 5) are shown in Figure 2.1.

Table 2.2 The parameter estimates of non-linear regression equations, based on the model:  $y_{ij} = a - (b + u_i) \times \exp(-c \times x_{ij} / 100) + e_{ij}$ , where y is OM digestibility and x CP or ADSCP concentration in fecal OM (g/kg); a, b and c are the fixed-effects parameters;  $u_i$  are random effects parameters of the type of diet, and  $e_{ij}$  is the residual error.

Variable	Parameter Estimates						95% confidence interval	
	Parameter	Estimate	SE	DF	t value	P value	interval	
							Lower	Upper
CP (n = 721) (Eq. 5)	a	0.899	0.043	8	21.24	<0.0001	0.801	0.996
	b	0.644	0.034	8	18.71	<0.0001	0.565	0.724
	c	0.5774	0.110	8	5.28	0.0007	0.3251	0.8297
	ve	0.0012	0.006	8	18.87	<0.0001	0.0010	0.0013
	vu	0.0068	0.406	8	1.68	0.1313	-0.0025	0.0162
ADSCP (n=161) (Eq. 6)	a	0.849	0.057	7	14.87	<0.0001	0.714	0.984
	b	0.589	0.072	7	8.14	<0.0001	0.418	0.760
	c	0.8802	0.300	7	2.94	0.0216	0.1731	1.5872
	ve	0.0013	0.015	7	8.70	<0.0001	0.0010	0.0017
	vu	0.0068	0.571	7	1.19	0.2720	-0.0067	0.0203
CP (n = 161) (Eq. 7)	a	0.880	0.104	7	8.46	<0.0001	0.634	1.126
	b	0.583	0.062	7	9.45	<0.0001	0.437	0.729
	c	0.5885	0.310	7	1.92	0.0958	-0.1349	1.3120
	ve	0.0014	0.016	7	8.74	<0.0001	0.0010	0.0018
	vu	0.0091	1.064	7	0.85	0.4229	-0.0161	0.0342

<sup>a</sup> CP: crude protein, ADSCP: acid detergent soluble CP, n: number of observations.

<sup>b</sup> SE: standard error, DF: degrees of freedom, ve: variance of residual error, vu: variance of random effect parameter.

Table 2.3 The comparison of the estimated (Eq. 5:  $y = 0.899 - 0.644 \times \exp(-0.5774 \times \text{CP [g/kg OM] / 100})$ ) and measured OM digestibility using the mean square prediction error (MSPE) method.

Type of diet	No. of data	Slope value (b+u)	OM digestibility			SE	MPE (%)	Proportion of MSPE (%)		
			Estimated	Measured	Mean bias			Mean bias	Line bias	Random variation
FG	60	0.551	0.686	0.715	-0.029	0.0048	6.8	35.8	19.7	44.5
GS	178	0.548	0.681	0.712	-0.031	0.0030	7.5	34.1	14.9	51.0
HC	232	0.575	0.618	0.648	-0.030	0.0024	7.7	36.2	10.2	53.6
ReS	46	0.673	0.713	0.708	0.005	0.0030	4.5	2.4	26.4	71.1
LoS	58	0.761	0.702	0.665	0.037	0.0032	6.9	65.2	7.8	27.1
ALS	46	0.575	0.612	0.645	-0.033	0.0043	6.8	57.1	13.0	29.9
GaS	56	0.772	0.675	0.631	0.044	0.0033	7.8	79.9	8.2	11.9
IM <sub>1</sub>	16	0.638	0.538	0.540	-0.002	0.0089	7.2	0.3	20.9	78.8
IM <sub>2</sub>	29	0.709	0.554	0.518	0.036	0.0051	9.0	59.3	9.5	31.2
TIM	45	-	0.548	0.526	0.022	0.0052	8.5	24.1	14.9	61.0
TD	721	-	0.651	0.665	-0.014	0.0017	7.7	7.6	15.9	76.5

<sup>a</sup> FG: fresh grass, GS: grass silage, HC: hay + concentrate, ReS: red cover silage, LoS: lotus silage, ALS: alfalfa silage, GaS: galega silage, IM<sub>1</sub>: Inner Mongolia mixed hay + concentrate, IM<sub>2</sub>: Inner Mongolia hay, TIM: total Inner Mongolia data, TD: total data in this study.

<sup>b</sup> Mean bias: estimated value minus measured value.

<sup>c</sup> SE: standard error of mean bias.

<sup>d</sup> MPE: mean prediction error ( $=\sqrt{MSPE}/\bar{M} \times 100$ ;  $\bar{M}$  is measured mean value),

<sup>e</sup> MSPE: mean square prediction error.

The mean bias between estimated (Eq. 5) and measured OM digestibility of all diets was low ( $-0.014 \pm 0.0017$ ), and of the different type of diets ranged from  $-0.033 (\pm 0.0043)$  to  $0.044 (\pm 0.0033)$  (Table 2.3), For all diets, the residual variation of the mean bias differences between estimated and measured OM digestibility is mainly caused by random variation of the equation (76.5 % of MSPE), whereas the contribution of the mean bias (7.6 % of MSPE) and the deviation of the slope (15.9 % of MSPE) were relatively small. The MPE for all data is also relatively small (7.7 %) which indicates an acceptable accuracy for the OM digestibility estimate.



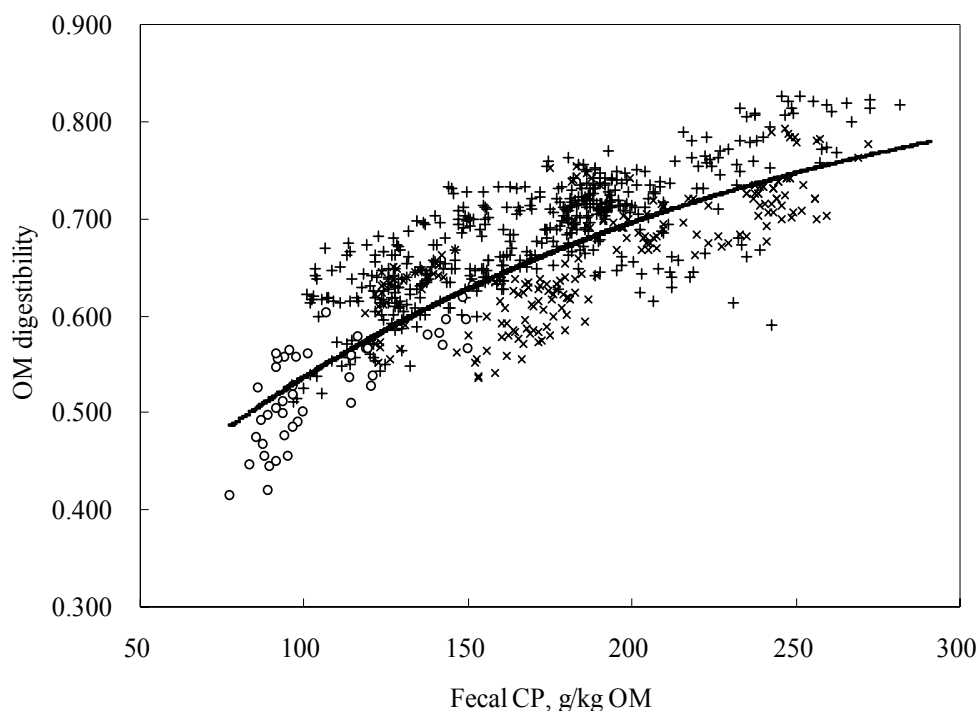


Fig. 2.1 The relationship between the concentration of CP in fecal OM and the OM digestibility as described by the regression equation  $y = 0.899 - 0.644 \times \exp(-0.5774 \times \text{CP [g/kg OM]} / 100)$  (Eq. 5) using data of grass (+) and legume (x) diets from Braunschweig and data of hay diets from Inner Mongolia (o).

### 2.3.2 Relationship between OM digestibility and fecal ADSCP

The prediction equation (Eq. 6) was developed to estimate OM digestibility (y) from ADSCP concentration of 161 fecal samples:

$$y = 0.849 - 0.589 \times \exp(-0.8802 \times \text{fecal ADSCP [g/kg OM]} / 100) \quad (6)$$

To enable a comparison of the prediction accuracy using fecal ADSCP instead of fecal CP concentration, an equation based on fecal CP of the same animals was developed as for Eq. (7) (n = 161).

$$y = 0.880 - 0.583 \times \exp(-0.5885 \times \text{fecal CP [g/kg OM]} / 100) \quad (7)$$

The parameter estimates show in accordance to Eq. 5 that the fixed-effect parameters (a, b, c) and residual error (e) have significant effects ( $P < 0.05$ ) in the

equations (Eq. 6 and 7), whereas random-effects of the type of diets ( $u_i$ ) are not observed for both equations ( $P > 0.05$ ) (Table 2.2).

Comparison of the prediction accuracy between Eq. 6 and Eq. 7 using the MSPE method is shown in Table 2.4. The mean bias, MPE and mean bias as proportion of MSPE are lower in Eq. 6 than in Eq. 7. However, the difference of the mean bias (-0.011 vs. -0.019) between both equations is very small and not significant ( $P > 0.05$ ), indicating that there is no significant improvement in accuracy when using ADSCP instead of CP in fecal OM to predict OM digestibility.

Table 2.4 Comparison of the predictive accuracy between equation Eq. 6 ( $y = 0.849 - 0.589 \times \exp(-0.8802 \times \text{fecal ADSCP [g/kg OM]} / 100)$ ) and Eq. 7 ( $y = 0.880 - 0.583 \times \exp(-0.5885 \times \text{fecal CP [g/kg OM]} / 100)$ ) for the subset of 161 observations using the mean square prediction error (MSPE) method.

Equation	No. of data	OM digestibility			SE	MPE (%)	Proportion of MSPE (%)		
		Estimated	Measured	Mean bias			Mean bias	Line bias	Random variation
Eq. 6	161	0.660	0.671	-0.011	0.0034	7.3	5.1	18.2	76.7
Eq. 7	161	0.652	0.671	-0.019	0.0037	8.2	11.8	17.2	71.0

<sup>a</sup> Mean bias: estimated value minus measured value.

<sup>b</sup> SE: standard error of mean bias.

<sup>c</sup> MPE: mean prediction error ( $= \sqrt{MSPE} / \bar{M} \times 100$ ;  $\bar{M}$  is measured mean value).

<sup>d</sup> MSPE: mean square prediction error.

## 2.4 Discussion

The developed regression equation (Eq. 5) describing the relationship between fecal CP concentration and OM digestibility is based on the biological relationship between non-dietary nitrogen (NDN) in feces and OM digestibility of diet. Fecal nitrogen excretion can be partitioned into NDN and undigested dietary nitrogen (UDN) using detergent extraction procedures (Mason and Frederiksen, 1979). Jarrige (1989) developed a linear regression model in which the fecal nitrogen excretion is divided into three main components (microbial, dietary and endogenous nitrogen) using data from sheep experiments. The equation indicates that fecal microbial nitrogen increases proportionally to the intake of fermentable OM and fecal endogenous

nitrogen proportionally to IDM. The concentration of fecal nitrogen (g N/kg fecal OM) was highly correlated with the concentration of fecal NDN ( $r = 0.97$ ) (Leite and Stuth, 1990), and the proportion of NDN in total fecal nitrogen accounts for more than 80 % (Mason and Frederiksen, 1979). Based on these findings, several prediction equations were developed using the fecal nitrogen or CP content for estimation of OM digestibility (Schmidt and Jentsch, 1994; Boval et al., 2003; Lukas et al., 2005).

The reliability of the fecal CP method depends on the range and number of observations of *in vivo* digestibility trials as well as on the regression model applied. Lukas et al. (2005) found that the one-factorial exponential model led to a more accurate prediction of OM digestibility than the inverse and quadratic ones. Schlecht and Susenbeth (2006) demonstrated that the non-linear regression equation developed by Lukas et al. (2005) in cattle for a wide range of different diets was also valid to estimate OM digestibilities of Sahelian roughages in cattle, sheep and goats. In contrast to the published equations the nonlinear mixed model was used in this study, which took into account the random effect of type of diet.

Since the biological basis for the relationship between the CP concentration in fecal OM and OM digestibility is the relationship between NDN in feces and OM digestibility, it can be assumed that the ADSCP fraction in feces, which mainly consists of microbial crude protein (Mason, 1969; Mason and Frederiksen, 1979), should be a more sensitive and precise estimate for OM digestibility because it is not confounded by variable proportions of undigested fecal CP. However, the comparison of Eq. 6 and Eq. 7 indicates that there is no substantial decrease in the bias between estimated and measured OM nor a higher precision of the prediction of OM digestibility when using ADSCP instead of CP in fecal OM. Lukas et al. (2005) assumed based on their data that ADSCP failed to improve the accuracy of prediction, because no diets with higher proportions of undigested CP were included, and that the greater analytical error in ADSCP than in CP determination may reduce the expected improvement to a certain extent. Schmidt (1993) suggested that the OM digestibility of strongly heated forages should not be estimated from the fecal nitrogen content.

The content of secondary compounds (e.g. tannins and saponins) in roughages also affect the amount of CP excreted in fecal OM by influencing rumen microbial

activity or apparent protein digestibility in the small intestine (Makkar, 2003). Schmidt (1993) stated that forage containing substances which bind protein and consequently reduce solubility (e.g. tannins) may result in higher fecal nitrogen excretion. In the present study, the proportion of ADSCP in fecal CP of *Lotus* silage, which contains considerable amounts of tannins (Reed et al., 2000), was lower (59-65 %) compared to those of the other types of diets (Table 2.1), leading to an overestimation of OM digestibility by  $0.037 \pm 0.003$ , representing 65.2 % of the total MSPE (Table 2.3). The OM digestibility of *alfalfa* silage was underestimated by  $0.033 \pm 0.004$ , representing 57.1 % of the total MSPE (Table 2.3). This could be caused by the negative effect of alfalfa saponins on microbial fermentation, which reduces microbial protein outflow (Lu and Jorgensen, 1987).

Lukas et al (2005) found that dietary CP and crude fat concentration as well as IDM did not affect the difference between estimated and measured OM digestibility, whereas the effects of dietary crude fiber content, proportion of concentrate in the diet, and forage type were significant. However, the magnitude of these effects was less than 2 percentage units in the OM digestibility. In the present study, the stepwise regression method revealed significant effects of the proportion of concentrate, and CP and crude fiber concentration in diet on the difference between estimated (Eq. 5) and measured OM digestibility (Table 2.5). The significantly negative correlation ( $r = -0.23$ ) between the proportion of concentrate in the diets and the difference between estimated and measured OM digestibility indicates that OM digestibility will be underestimated with higher proportions of concentrate. A significantly positive correlation ( $r = 0.226$ ) between CP concentration in diets and the difference between estimated and measured OM digestibility indicates that OM digestibility will be underestimated with lower CP concentration. However, the  $R^2 = 0.114$  of this regression equation is relatively small, showing that only 11.4% of the variation of the mean bias can be explained by the proportion of concentrate, CP and crude fiber concentration in diet.

Grazing is the dominant kind of use of the grasslands in Inner Mongolia, where *L. chinensis* and *S. grandis* are dominant species of the grassland community (Chen and Wang, 2000). Determination of OM digestibility of forage ingested by grazing sheep plays an important role in evaluating grassland management systems and animal

productivity. The method evaluated in this study can be seen as an efficient and easy applicable tool for grazing experiments. According to Eq. 5, the mean bias between estimated and measured OM digestibility was  $0.022 \pm 0.005$  (Table 2.3) in diets consisting mainly of forage from *L. chinensis*, *S. grandis* and *A. frigida*. However, the error of estimation of OM digestibility was mainly caused by random variation (61.0 %). The MPE as percentage of the observed mean value was relatively small (8.5 %), and the line bias (14.9 %) was similar to the line bias (15.9 %) of equation (Eq. 5) indicating that the predicted slope for Inner Mongolia data is close to the slope of the developed prediction equation in spite of less data were available and low OM digestibility were observed in Inner Mongolia diets used in the trials. This indicates that the developed equation based on a wide range of diets describes the specific diets from Inner Mongolia reasonably well. Therefore, this general equation presented here can be used to accurately estimate OM digestibility of forage ingested by sheep grazing in the Inner Mongolia steppe.

Table 2.5 Multiple linear relationship between the proportion of concentrate, crude protein (CP) and crude fiber concentration in the diet and the difference between estimated (Eq. 5:  $y = 0.899 - 0.644 \times \exp(-0.5774 \times \text{CP} [\text{g/kg OM}] / 100)$ ) and measured OM digestibility.

Item	Dietary factors			Constant	R <sup>2</sup>
	Proportion of concentrate in diets (% on DM basis)	CP (g/kg of DM)	Crude fiber (g/kg of DM)		
b	-0.00086	0.00032	0.00017	-0.109	0.114*
r	-0.230*	0.226*	0.040		
Beta weight	-0.201	0.209	0.147		

<sup>a</sup> b: regression coefficient; r: correlation coefficient of dietary factor; Beta weight = regression coefficient divided by its standard deviation.

<sup>b</sup> values are significant at  $\alpha = 0.05$ .

## 2.5 Conclusion

The concentration of CP or ADSCP in fecal OM is a reliable variable to estimate OM digestibility of forage consumed by sheep. Since laboratory analyses for ADSCP compared to CP are more laborious and expensive, predicting OM digestibility from

fecal CP concentration can be taken as the preferential method. Although the developed equation based on fecal CP slightly overestimates OM digestibility of hay from Inner Mongolia, the accuracy of this method is reasonable to predict the OM digestibility of sheep grazing on heterogeneous pastures such as the Inner Mongolia steppe of China.

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## References

- Bartiaux-Thill, N., Oger, R., 1986. The indirect estimation of the digestibility in cattle of forage from Belgian permanent pasture. *Grass and Forage Science* 41, 296-272.
- Bassler, R., 1976. Die chemische Untersuchung von Futtermitteln. Methodenbuch. Vol. inclusive of Suppl. 1 to 4. Verband Deutscher Landwirtschaftlicher Untersuchungs und Forschungsanstalten, Darmstadt, Germany.
- Boval, M., Archimede, H., Fleury, J., Xande, A., 2003. The ability of faecal nitrogen to predict digestibility for goats and sheep fed with tropical forage. *Journal of Agricultural Science* 140, 443-450.
- Chen, Z. Z., Wang, S. P., 2000. Typical steppe ecosystem of China. Science Press, Beijing, pp. 9-45.
- Givens, D. I., Owen, E., Axford, R. F. E., Omed, H. M., 2000. Forage evaluation in ruminant nutrition. CABI publishing. pp. 301-320.
- Guerin, H., Richard, D., Lefevre, P., Friot, D., Mbaye, N. D., 1989. Prevision de la valeur nutritive des fourrages ingeres sur parcours naturels par les ruminants domestiques sahariens et soudaniens. In : XVIth International Grassland Congress, Nice, France. INRA Editions, Paris, France, pp. 879-880.
- Hendricksen, R. E., Reich, M. M., Robertson, R. F., Reid, D. J., Gazzola, C., Rideout, J. A., Hill, R. A., 2002. Estimating the voluntary intake and digestibility of buffel-grass and Lucerne hays offered to Brahman-cross cattle using n-alkanes. *Animal Science* 74, 567-577.
- Holechek, J. L., Woffard, H., Arthun, D., Galyean, M. L., Wallace, J. D., 1986. Evaluation of total fecal collection for measuring cattle forage intake. *Journal of Range Management* 39, 2-8.
- Jarrige, R. (ed.). 1989. Ruminant Nutrition: recommended allowances and feed tables. John Libbey, Eurotext, London Paris. pp. 31-47.
- Le Du, Y. L. P., Penning, P. D., 1982. Animal based techniques for estimating forage intake. In: Leaver, J. D. (ed.). Forage Intake Handbook. The British Grassland Society, Hurley, Maidenhead, Berkshire, UK. pp. 37-75.
- Leite, E. R., Stuth, J. W., 1990. Value of multiple fecal indices for predicting diet quality and intake of steer. *Journal of Range Management* 43, 139-143.
- Lewis, R. M., Magadlela, A. M., Jessop, N. S., Emmans, G. C., 2003. The ability of

- the n-alkane technique to estimate intake and diet choice of sheep. *Animal Science* 77, 319-327.
- Licitra, G., Hernandez, T. M., Van Soest, P. J., 1996. Standardization of procedures for nitrogen fractions of ruminant feeds. *Animal Feed Science and Technology* 57, 347-358.
- Lu, C. D., Jorgensen, N. A., 1987. Alfalfa saponins affect site and extent of nutrient digestion in ruminants. *Journal of Nutrition* 117, 919-927.
- Lukas, M., Südekum, K. H., Rave, G., Friedel, K., Susenbeth, A., 2005. Relationship between fecal crude protein concentration and diet organic matter digestibility in cattle. *Journal of Animal Science* 83, 1332-1344.
- Makkar, H. P. S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds (Review). *Small Ruminant Research* 49, 241-256.
- Mason, V. C., 1969. Some observations on the distribution and origin of nitrogen in sheep feces. *Journal of Agricultural Science* 73, 99-111.
- Mason, V. C., Frederiksen, J. H., 1979. Partition of the nitrogen in sheep faeces with detergent solution, and its application to the estimation of the true digestibility of dietary nitrogen and the excretion of non dietary faecal nitrogen. *Z. Tierphysiol., Tierernährg. u. Futtermittelk.* 41, 121-131.
- Menke, H. K., Raab, L., Salewski, A., Steingass, H., Fritz, D., Schneider, W., 1979. The estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor in vitro. *Journal of Agricultural Science* 93, 217-222.
- Moore, J. E., Goetsch, A. L., Luo, J., Owens, F. N., Galyean, M. L., Johnson, Z. B., Sahlu, T., Ferrell, C. L., 2004. Prediction of fecal crude protein excretion of goats. *Small Ruminant Research* 53, 275-292.
- Ouellet, D. R., Petit, H. V., Veira, D. M., Charmley, E., 2004. Estimation of faecal output, digestibility, and intake using a controlled release capsule of alkanes in early and late lactation dairy cows fed two levels of concentrate. *Canadian Journal of Animal Science* 84, 277-289.
- Owens, F. N., Hanson, C. F., 1992. External and internal markers for appraising site and extent of digestion in ruminants. *Journal of Dairy Science* 75, 2605-2617.
- Ørskov, E. R., McDonald, I., 1979. The estimation of crude protein degradability in the rumen incubation measurements weighted according to rate of passage.



- Journal of Agricultural Science 92, 499-503.
- Reed, J. D., Krueger, C., Rodriguez, G., Hanson, J., 2000. Secondary plant compounds and forage evaluation. In: Givens, D. I., Owen, E., Axford, R. F. E., Omed, H. M. (eds). Forage evaluation in ruminant nutrition. CABI publishing, pp. 433-448.
- Rook, A. J., Dhanoa, M. S., Gill, M., 1990. Prediction of the voluntary intake of grass silages by beef cattle. 3. Precision of alternative prediction models. Animal Production 50, 455-466.
- SAS, 2003. Statistical Analysis Systems Institute. Version 9.5. SAS Institute Inc., Cary, NC.
- Schlecht, E., Susenbeth, A., 2006. Estimating the digestibility of Sahelian roughages from faecal crude protein concentration of cattle and small ruminants. Journal of Animal Physiology and Animal Nutrition 90, 369-379.
- Schmidt, L., 1993. Faecal nitrogen as an indicator for silage digestibility and energy content of silage. 6. Mezinardni sympozim. pp. 157-163.
- Schmidt, L., Jentsch, W., 1994. Die Schätzung der Verdaulichkeit von Konservatfütterationen für Rinder anhand des Stickstoffgehaltes im Rinderkot. FBN Schriftenreihe, Dummerstorf 7. pp. 179-184.
- Thomas, S., Campling, R. C., 1976. Relationship between digestibility and faecal nitrogen in sheep and cows offered herbage *ad libitum*. Journal of the British Grassland Society 31, 69-72.

## Chapter 3 Rotational and Continuous Grazing of Sheep in the Inner Mongolian Steppe of China

### Abstract

The aim of this study was to compare the effects of rotational and continuous grazing on the herbage mass (HM), feed intake, digestibility, and live weight gain (LWG) of sheep grazing at a stocking rate of 4.5 sheep/ha during two growing seasons in the Inner Mongolian steppe, China. Four 2-ha plots were used, which were equally distributed over a flat and a slope area (block). The two plots for rotational grazing were subdivided into four paddocks of equal size (0.5 ha), and sheep were moved to the next paddock each 10 days. Digestibility was estimated from fecal crude protein concentration and feed intake by oral administration of titanium dioxide (TiO<sub>2</sub>). The HM was similar in both grazing systems. The organic matter digestibility (dOM), and intakes of organic matter (IOM), digestible organic matter (IDOM) and metabolisable energy (IME) were lower ( $P < 0.05$ ) at rotational grazing than at continuous grazing, but LWG did not differ. Digestibility and intake decreased ( $P < 0.05$ ) with progress in the growing season, and differed between the two growing seasons. This was associated with differences in precipitation and herbage regrowth between seasons. In both seasons, precipitation was lower than the 30 years average. With similar intake and digestibility in the flat and slope area, LWG was higher ( $P < 0.05$ ) in the flat than in the slope area. This difference may be explained by increased energy costs for grazing and walking in the slope area. The higher feed intake and digestibility at continuous grazing did not result in higher LWG of sheep, probably caused by extra energy expenditure for grazing and walking in a larger area to select preferred plant species. In conclusion, further studies are required in years with average precipitations, and it seems necessary to quantify energy expenditure for physical activity before final evaluation of these grazing systems.

**Key words:** Sheep, rotational and continuous grazing, feed intake, herbage digestibility, live weight gain

### 3.1 Introduction

*Leymus chinensis* and *Stipa grandis* grassland, which represent the most widely distributed grassland types in the Eurasia steppe region, are mainly used as natural grazing lands providing herbage for animals (Zhao et al., 1988; Chen and Wang, 2000). However, due to the increasing grazing intensity the natural Inner Mongolia grasslands were degraded during the last three decades, which causes a high risk for wind and water erosion and sand storms (Lu et al., 2005). In addition, a number of studies reported that the animal performance, productivity of grassland and botanical composition of swards are negatively affected by high grazing intensity. Under heavy grazing, the grassland is dominated by the *Cleistogenes squarrosa* and *Artemisia frigida* community, leading to an increase in plant species with low nutritive value and to a decrease in herbage production (Li et al., 1999; Wang and Li, 1999; Chen et al., 2003). A sustainable utilization of grassland may improve the animal's performance on long term as well as protecting grassland from degradation and maintaining ecological stability (Li et al., 1999). However, only few studies have been performed to evaluate the effects of grazing management systems (e.g. rotational and continuous grazing, alternating grazing and hay production) on the grassland ecosystem in this region with respect to ecological and economical effects (Chen et al., 2003).

In rotational grazing the pasture is divided into paddocks, and each paddock is grazed for a short period at a high stocking rate. After grazing, paddocks in non-grazing periods are allowed to rest, can recover and undisturbed herbage regrowth can occur before being grazed again. Rotational grazing increases the number of grazing periods, decreases the time of grazing and increases grazing intensity within a short period. At the same grazing intensity, rotational versus continuous grazing improved herbage quality and live weight gain (LWG) of animal in the Inner Mongolia steppe (Zhang et al., 1989; Han et al., 1990). Recovery periods of the grassland after grazing is an important factor both on short term and on long term productivity of grasslands, realized either by increasing the number of grazing periods within the season or by preventing grazing in critical time periods (Li et al., 2001). On the contrary, Gammon (1987) and Derner and Hart (2004) reported that rotational grazing did not show greater LWG compared with continuous grazing. Mckown et al. (1991) compared the effects of grazing systems (rotational vs.

continuous) and grazing intensity on the nutrient intake, and concluded that the differences in nutrient intake between treatments were attributed primarily to difference in stocking rate rather than grazing system. The objective of this study was to investigate the effects of rotational and continuous grazing on herbage mass (HM), feed intake and digestibility, and LWG of sheep grazing at a moderate stocking rate of 4.5 sheep/ha throughout two grazing seasons on the Inner Mongolian steppe of China.

## **3.2 Materials and methods**

### **3.2.1 Site of study**

The study area belongs to the Inner Mongolia Grassland Ecosystem Research Station, which is administered by the Institute of Botany, the Chinese Academy of Sciences, located at 43°38'N, 116°42'E at an elevation of approximately 1,000 m above sea level. The regional climate is continental. The average annual precipitation of the last 30-year, observed by the local weather station in the region (approximately 7 kilometer to experimental site), was approximately 350 mm, with 60-70% of the total occurring from June to August. Annual mean temperature is -0.4°C, monthly mean temperature is -21.5°C in January and 19°C in July, with 150 to 180 plant-growing days per year. The monthly precipitation and monthly mean temperature in 2005 and 2006 are given in Figure 3.1. The soil is a chestnut soil in the Chinese classification and calcic-orthic aridisol in the Soil Taxonomy classification system (Xiong and Li, 1987). The grassland is dominated by two grass species: the perennial rhizome *L. chinensis* and the perennial bunchgrass *S. grandis*. Plant community cover is about 30-40% and may reach 60-70% in wet years (Jiang, 1985; Chen and Wang, 2000).

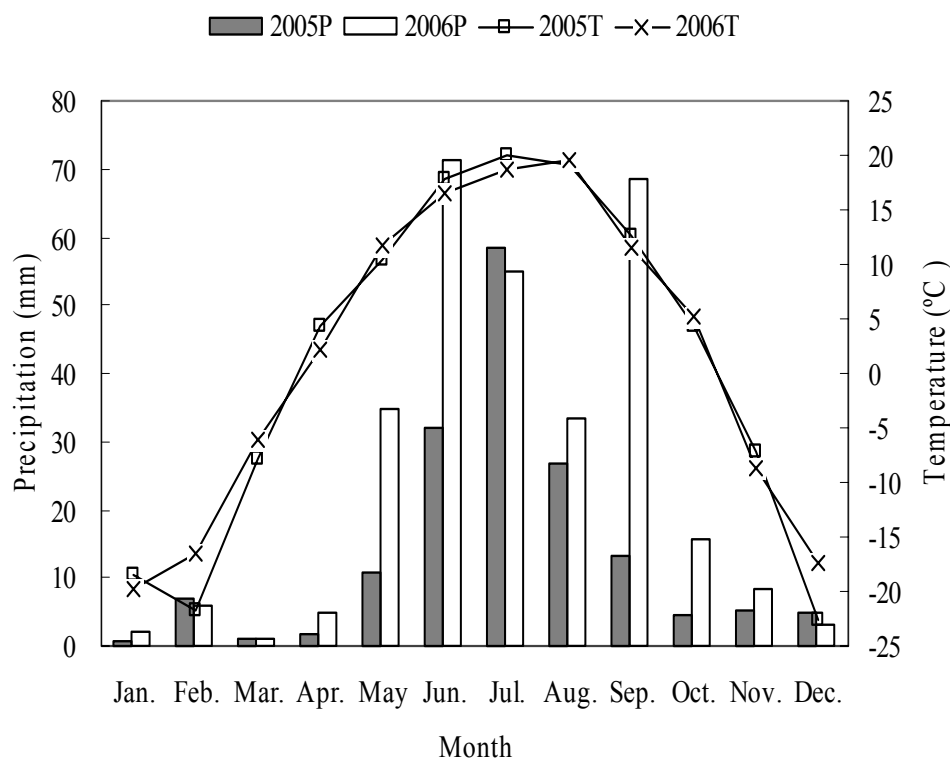


Figure 3.1 Monthly precipitation (P) and monthly mean temperature (T) in 2005 and 2006 in the study area.

### 3.2.2 Experimental design

Four 2-ha plots, equally distributed over a flat and a slope area (block) of the experimental site, were used for two grazing systems. Within each block, two plots were used for rotational and continuous grazing. The grassland was used for haymaking in the respective preceding years. The stocking rate was 4.5 yearling sheep per ha (nine sheep per plot of 2 ha, equivalent to approximately 145 kg of body weight per ha), which is considered as a moderate grazing intensity based on previous experiments in the Inner Mongolian steppe (Wang et al., 2001). Experiments started at mid of June and ended at mid of September corresponding with the growing season of herbage. Sheep grazed 24 h per day throughout the grazing season. The plots for rotational grazing were subdivided into four paddocks of 0.5 ha each. Sheep were moved to the next paddock after 10 days grazing. Thus, the paddocks were protected from grazing during 30 days. No grazing on the areas occurred outside the grazing season. The diversity of plant species of the two blocks at the beginning of July 2005 is given in Table 3.1.

Table 3.1 Diversity of plant species of the aboveground biomass in flat and slope block determined at the beginning of July 2005 in the study area (% DM basis).

Species	Flat		Slope	
	Mean	SD <sup>a</sup>	Mean	SD
<i>Leymus chinensis</i>	45.0	10.8	30.6	11.0
<i>Stipa grandis</i>	24.8	8.9	28.7	13.1
<i>Agropyron</i>	8.1	7.5	15.6	6.3
<i>Carex</i>	7.6	3.2	11.1	5.0
<i>Cleistogenes squarrosa</i>	7.6	1.7	5.9	2.9
<i>Achnatherum</i>	2.2	2.1	3.9	3.3
Others	4.7	2.3	4.2	2.7

<sup>a</sup> SD, standard deviation (n = 18).

### 3.2.3 Animals

In both years, 36 yearling Mongolian female sheep from the local breed (fat-tailed sheep) were used in the grazing experiments. Sheep were randomly assigned to the grazing plots after initial weighing. During the total grazing period sheep had free access to water and mineral lick stones. In the middle of July sheep were treated against internal and external parasites with disophenol. The live weights of sheep were measured at day 0 (initial weight after cutting wool, 32.3±5.2 kg), day 49 (36.2±5.7 kg) and day 98 (38.3±5.1 kg) in 2005, and at day 0 (initial weight after cutting wool, 31.4 ±4.6 kg), day 19 (33.5±4.7 kg), day 49 (36.8±4.8 kg) and day 79 (37.5±4.8 kg) in 2006.

### 3.2.4 Herbage mass and sward regrowth

The HM and sward regrowth in grazing plots were measured using enclosure cages. Three cages (2 × 3 m) were placed on representative areas in each plot, and two 0.25 × 1 m areas were clipped to ground level both inside the cages and in adjacent areas outside the cages. Samples were collected at the start of the grazing experiment in June and at the beginning of July, August and September.

### 3.2.5 Feed intake and digestibility

The intake of organic matter (IOM) per day was calculated by daily output of fecal OM estimated by the external marker titanium dioxide (TiO<sub>2</sub>) and by OM digestibility (dOM) of herbage ingested by sheep. TiO<sub>2</sub> was given orally to six sheep of each plot as a daily pulse dose of 2500 mg in a gelatin capsule during ten days at the beginning of July, August and September, respectively. On the last five days, fecal samples were collected once daily from the rectum and stored at -20 °C. Samples of each sheep collected within five days were pooled on equal fresh weight, homogenized, crushed, and two sub-samples were taken. One sub-sample was oven-dried at 65 °C for 48 h and milled through a 1-mm mesh sieve prior to TiO<sub>2</sub> concentration analysis, and the other sub-sample was stored at -20 °C pending dry matter (DM), N and crude ash analysis. For estimating fecal output, the recovery of TiO<sub>2</sub> was assumed to be 100% in the present experiment (Glindemann, 2007).

The dOM was estimated by the fecal crude protein (CP) method. The following nonlinear regression equation (Eq.1) describing the relationship between the CP concentration in fecal OM and dOM in sheep (Chapter 2) was used:

$$\text{dOM (\%)} = 89.9 - 64.4 \times \exp(-0.5774 \times \text{fecal CP [g/kg OM]} / 100) \quad (1)$$

Intake of digestible OM (IDOM) was calculated by IOM multiplying with dOM, and intake of metabolisable energy (IME, MJ/d) by multiplying IDOM (kg/d) with 16 (MJ/kg) as described by McDonald et al. (1988).

### 3.2.6 Chemical analysis

Herbage samples were oven-dried at 65 °C for 48 h to determine DM, crude ash, N (CP = N × 6.25), neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) concentration with Near Infrared Reflectance Spectroscopy. Frozen samples of feces were thawed, and analyzed for DM, N and crude ash concentration according to the methods of the Chinese Technical Committee for Feed Industry Standardization and the Chinese Association of Feed Industry (1996, 2000). In the oven-dried fecal sample, TiO<sub>2</sub> concentrations were determined by Kjeldahl extraction and subsequent photometric analysis as described by Glindemann (2007).

### 3.2.7 Statistical analysis

Factorial analysis of variance was carried out using General Linear Model procedure of SAS (2003) to determine the effects of grazing system ( $g_i$ : rotational and continuous), year ( $y_j$ : year 2005 and 2006), period ( $p_k$ : July, August, and September), block ( $b_l$ : flat and slope), and of interaction between grazing system and period ( $g_i \times p_k$ ) using the following model (Eq.2).

$$Y = \mu + g_i + y_j + p_k + b_l + (gp)_{jk} + e_{ijklm} \quad (2)$$

where  $\mu$  is the overall mean and  $e_{ijklm}$  is the random experimental error. When LWG of entire grazing period were analyzed, the factor  $p_k$  in the model was omitted.

## 3.3 Results

### 3.3.1 Effect of grazing system

The chemical composition of herbage in different periods of the growing season and at rotational and continuous grazing in 2005 and 2006 is given in Table 3.2. The LWG of sheep during different measurement periods are shown in Table 3.3. The effects of the experimental treatments on HM, IOM, dOM, IDOM and IME are shown in Table 3.4, and on LWG of sheep in Table 3.5. The grazing systems did not affect ( $P>0.05$ ) HM. The IOM, dOM, IDOM and IME at rotational grazing were lower ( $P<0.05$ ) with 1.09 kg/d, 54.9 %, 0.60 kg/d and 9.6 MJ/d, respectively, than at continuous grazing with 1.31 kg/d, 57.4 %, 0.75 kg/d and 12.0 MJ/d, respectively. The grazing systems did not affect LWG of animals ( $P>0.05$ ).

### 3.3.2 Effect of experimental year

The HM was higher ( $P<0.05$ ) with 569 kg/ha in 2005 than in 2006 with 402 kg/ha. The IOM, dOM, IDOM and IME were lower ( $P<0.05$ ) in 2005 with 1.12 kg/d, 54.8 %, 0.62 kg/d and 9.9 MJ/d, respectively, than in 2006 with 1.27 kg/d, 57.5 %, 0.73 kg/d and 11.7 MJ/d, respectively. The LWG per animal was lower ( $P<0.05$ ) with 65 g/d in 2005 than in 2006 with 83 g/d. Mean herbage regrowth was 257 kg/ha in 2005 and 994 kg/ha in 2006.



### 3.3.3 Effect of experimental period

The means of both years and grazing system for HM at the beginning of July, August and September were 623, 463 and 371 kg/ha, respectively, indicating a decrease ( $P<0.05$ ) with grazing periods. The IOM was higher ( $P<0.05$ ) in July (1.26 kg/d) and September (1.22 kg/d) than in August (1.12 kg/d). The dOM decreased ( $P<0.05$ ) from 58.1, 56.4 to 53.9 % in July, August to September. As a consequence, IDOM per animal was higher ( $P<0.05$ ) in July (0.73 kg/d) than in August (0.63 kg/d) and September (0.66 kg/d), and IME was higher ( $P<0.05$ ) in July (11.7 MJ/d) than in August (10.1 MJ/d) and September (10.5 MJ/d).

### 3.3.4 Effect of experimental block

The HM, IOM, dOM, IDOM and IME were not different ( $P>0.05$ ) between flat and slope areas. However, LWG was higher ( $P<0.05$ ) in flat (87 g/d) than in slope (61 g/d) areas.

**Table 3.2** Chemical composition of herbage offered in different periods of the growing season and at rotational and continuous grazing in 2005 and 2006 (%)

Year	Period	Rotational grazing					Continuous grazing				
		OM <sup>a</sup>	CP <sup>b</sup>	NDF <sup>c</sup>	ADF <sup>d</sup>	ADL <sup>e</sup>	OM	CP	NDF	ADF	ADL
2005											
	Jul.	94.2	9.3	72.4	34.4	4.3	94.7	10.2	71.2	32.7	3.9
	Aug.	94.4	8.5	74.1	35.3	5.4	95.0	9.5	72.1	34.0	5.1
	Sep.	94.4	6.6	73.3	37.0	5.7	95.0	8.4	72.7	34.5	5.5
2006											
	Jul.	93.2	12.7	69.3	32.3	3.9	92.6	15.3	65.6	31.0	3.8
	Aug.	92.6	12.4	70.0	31.9	4.5	93.1	14.4	69.0	32.0	5.3
	Sep.	93.6	10.6	68.0	33.0	5.6	92.5	12.4	68.8	33.1	5.1

<sup>a</sup> OM, organic matter; <sup>b</sup> CP, crude protein; <sup>c</sup> NDF, neutral detergent fiber; <sup>d</sup> ADF, acid detergent fiber; <sup>e</sup> ADL, acid detergent lignin.

**Table 3.3** The body weight (kg) and live weight gains (g per day) of sheep in the flat and slope area in the rotational and continuous grazing at the start, middle and end of the grazing season in 2005 and 2006.

Measured period		Rotational grazing				Continuous grazing			
		Flat		Slope		Flat		Slope	
		BW <sup>a</sup>	LWG <sup>b</sup>	BW	LWG	BW	LWG	BW	LWG
2005	day 0	31.3		32.9		31.2		33.7	
	day 45	34.6	73	37.3	99	35.1	88	37.9	94
	day 95	39.1	90	37.8	10	37.5	48	38.8	19
2006	day 0	30.3		31.9		30.1		33.1	
	day 19	32.8	122	33.8	99	32.3	119	34.9	109
	day 49	36.1	106	37.3	117	36.5	136	37.6	91
	day 79	38.0	64	37.1	-5	37.7	42	37.3	-8

<sup>a</sup> BW, body weight; <sup>b</sup> LWG, live weight gain in the respective period.

**Table 3.5** Live weight gain per sheep (g/day) grazing in the flat and slope) area at rotational and continuous grazing in 2005 and 2006.

year	Rotational grazing			Continuous grazing			Mean	SEM <sup>a</sup>	P value		
	Flat	Slope	Mean	Flat	Slope	Mean			GS <sup>b</sup>	Year	Block
2005	82	55	68	68	57	62	65	2.53	0.41	0.01	<0.001
2006	97	71	84	99	64	81	83				

<sup>a</sup> SEM, standard error of mean; <sup>b</sup> GS, grazing system.

**Table 3.4** Herbage mass (HM), intake of organic matter (IOM), organic matter digestibility (dOM), intake of digestible organic matter (IDOM) and intake of metabolisable energy (IME) in rotational and continuous grazing system in different periods of the grazing season in 2005 and 2006.

Item	year	Rotational grazing				Continuous grazing				Mean	SEM <sup>a</sup>	P value				
		Jul.	Aug.	Sep.	mean	Jul.	Aug.	Sep.	mean			GS <sup>b</sup>	Year	Period	Block	GS × Period
HM, kg/ha																
	2005	769	406	603	592	683	583	372	546	569	35.9	0.141	0.034	0.034	0.066	0.857
	2006	590	582	298	490	450	283	210	314	402						
IOM, kg/d/sheep																
	2005	1.02	0.95	1.12	1.03	1.26	1.23	1.15	1.21	1.12	0.02	<0.001	<0.001	0.010	0.182	0.094
	2006	1.24	0.99	1.21	1.14	1.51	1.30	1.39	1.40	1.27						
dOM, %																
	2005	53.8	54.2	51.8	53.3	58.0	56.2	54.8	56.3	54.8	0.14	<0.001	<0.001	<0.001	0.341	<0.001
	2006	58.4	57.4	53.6	56.5	62.2	57.8	55.4	58.4	57.5						
IDOM, kg/d/sheep																
	2005	0.55	0.52	0.58	0.55	0.73	0.69	0.63	0.68	0.62	0.01	<0.001	<0.001	<0.001	0.238	0.067
	2006	0.72	0.56	0.65	0.64	0.94	0.75	0.77	0.82	0.73						
IME, MJ/d/sheep																
	2005	8.8	8.3	9.3	8.8	11.7	11.1	10.1	10.9	9.9	0.17	<0.001	<0.001	<0.001	0.251	0.069
	2006	11.5	9.0	10.3	10.3	15.0	12.0	12.3	13.1	11.7						

<sup>a</sup> SEM, standard error of mean; <sup>b</sup> GS, grazing system.

### 3.4 Discussion

#### 3.4.1 Effect of climate

The herbage growth and regrowth after grazing are the main factors affecting grassland productivity and performance of grazing animals. In Inner Mongolia precipitation is the first-limiting factor determining magnitude and variability of primary production of *L. chinensis* and *S. grandis* dominated grassland (Xiao et al., 1995). Chen et al. (2003) reported that the lower precipitation in the region led to a decrease in the primary productivity and in the proportion of higher-quality herbage. There was no difference ( $P = 0.98$ ) in monthly mean temperature between experimental years. The annual precipitation was low with 166 mm in 2005 and 304 mm in 2006 compared with the average value of the last 30 years of 350 mm. During the growing period of herbage (May to August) the precipitation in 2005 and 2006 was 128 and 195 mm, respectively. Therefore, low herbage regrowth during experimental periods might be caused by the impact of the serious drought.

#### 3.4.2 Effect of grazing system

Although the effect of grazing system on HM was not significant, HM tended to be higher under rotational grazing, where a short period (10 days) with a high stocking rate (18 sheep/ha) was realised, compared to continuous grazing (592 vs. 546 kg/ha in 2005; 490 vs. 314 kg/ha in 2006). This indicates that non-grazing during 30 days with an undisturbed regrowth of the sward may lead to a higher herbage production in the growing season. Moreover, a high HM at the end of the grazing season may be beneficial to grazing in winter, and is also highly relevant for the protection of grassland against wind erosion during winter and spring.

It can be expected that sheep in the continuous grazing system might be given a greater opportunity for selective grazing than in the rotational grazing. Wang (2000) showed that the more palatable herbage (e.g. *L. chinensis* and *Cleistogenes squarrosa*) was overgrazed while less desirable plants (e.g. *S. grandis*, *Agropyron cristatum* and *Potentilla acaulis*) were less intensively grazed, especially at the beginning of the grazing period. In a rotational grazing system, grazing intensity during a short period

is higher leading to a less selective grazing behaviour and probably to a higher pressure to ingest less desirable plants as well (Stuth et al., 1987). Diet selection may affect the grazing animals' nutrient status leading to a higher digestibility of diet (Vallentine, 2001), which was also observed in the present study.

Simon et al. (1995) stated that continuous grazing maximised intake when herbage on offer did not limit feed intake. Animal herbage intake under rotational grazing was likely to be poor unless the rate of rotation was carefully synchronised to the pasture growth rate. Our present results also indicated that there was a higher IOM at continuous grazing than at rotational grazing. A higher dOM of herbage ingested by grazing cattle might result in an increase of IOM ( $r = 0.34$ ;  $P < 0.05$ ) (Boval et al., 2007). In this study, a positive correlation between dOM and IOM of herbage ingested by grazing sheep was also observed ( $r = 0.26$ ;  $P < 0.01$ ). With steers, *in vitro* DM digestibility of herbage on offer was significantly higher in continuously grazed than in rotationally grazed paddocks (Hafley, 1996). However, DeRouen and Ward (2005) reported that *in vitro* true digestibility was higher ( $P < 0.01$ ) at rotational grazing than at continuous grazing, but the difference did not result in improved animal performance. In our study, higher IDOM and IME were observed at continuous grazing which was caused by higher dOM and IOM of grazing sheep. Many grazing experiments have been unable to show higher animal gains at rotational than at continuous grazing (Gammon, 1987; Derner and Hart, 2004). The performance of animals did not reflect the effect of the grazing system, as it was more affected by the grazing intensity (Huston et al., 1993; Hacker and Richmond, 1994; Simon et al., 1995). The experiment of Hafley (1996) in yearling steers showed that individual animal weight gains were higher at continuous than at rotational grazing. On the contrary, Zhang et al. (1989), Han et al. (1990), and Allan (1997) reported higher LWG at rotational than at continuous grazing.

Walton et al. (1981) stated that the time spent grazing was greater at continuous than at rotational grazing. The energy cost of eating is directly associated with time spent grazing ( $r = 0.86$ ) and sheep need 2.23 kJ per hour of grazing and kilogram of body weight (Osuji, 1974). Therefore, it can be hypothesised that the increased grazing time at continuous grazing might be responsible for similar LWG in both grazing systems. In the present study, higher feed intake and digestibility at

continuous grazing did not result in improved daily LWG of sheep, probably caused by extra energy for walking in a larger area to select preferred plant species which reduced the amount of energy available for growth. The requirement for this activity can be estimated when the metabolisable energy (ME) requirement for maintenance of grazing sheep used in this study is assumed to be 5.3 MJ/d with 35 kg body weight and for 100 g/d body weight gain 2.1 MJ/d (NRC, 2007). The difference between IME and ME for maintenance and growth can be taken as an estimate for energy expenditure for activity of sheep which is 43% of IME at continuous grazing, and 31% at rotational grazing.

### 3.4.3 Effect of experimental year and period

The higher precipitation in 2006 than in 2005 was associated with a higher herbage regrowth. The higher regrowth in 2006 was related to a higher feed intake. The result of higher IOM in this year could be caused by a higher regrowth of herbage. The significant reduction of HM was due to the serious drought condition affecting herbage regrowth, which also affected IOM of grazing sheep. As a consequence, LWG of sheep decreased with grazing periods (Table 3.3). The dOM decreased and the ADL concentration increased with the progress in growing season of herbage. Wang and Li (1997) also demonstrated that herbage digestibility decreased with the advancing herbage maturity. In the present study, an interaction of the effect of grazing system and grazing period on dOM was observed. The dOM in July at continuous grazing system was 60.1%. It could be assumed that plant growth stages had a significant effect on the preference and selection of grazing animals (Ciavarella et al., 2000; Valentine, 2001). Grazing animals select young and green material above mature and dried herbage. The young and green herbage is high in nutrient content and digestibility (Valentine, 2001). In agreement, the dOM was higher, CP content higher, and NDF content lower in 2006 than in 2005.

### 3.4.4 Effect of experimental block

There was a higher proportion of *L. chinensis* in the flat (45.0 %) than in the slope area (30.6 %) (Table 3.1). The HM, IOM, dOM, IDOM and IME did not differ between blocks. However, higher LWG was observed in the flat areas. This could be caused partially by an assumption that *L. chinensis* had a higher digestibility

compared to the other species in plant community of grassland (Wang et al., 2007b), and it also has a high preference index (Wang, 2000), which is the ratio of the proportion of one species in diet of grazing animal to its proportion in the community. Moreover, grazing sheep need extra energy for walking in slope areas (Crocker and Watt, 2001; Lachica and Aguilera, 2005). The energy requirement for activity of sheep can be estimated by calculating the difference between IME and ME for maintenance and growth as mentioned above, which was 35% of IME in flat area and 40% in slope area. Therefore, the energy cost of locomotion might be higher in slope areas and responsible for a reduction in the amount of energy above maintenance that is available for growth.

### **3.5 Conclusion**

The LWG at a moderate grazing intensity did not respond to the grazing system probably due to the very low precipitation in both growing seasons, prohibiting a substantial regrowth of the sward which extent might be significantly affected by periods of non-grazing and, therefore, by the grazing system. Further studies are required in years with mean precipitations before final evaluation of the grazing systems can be made. Furthermore it seems to be necessary for grazing studies to quantify the energy expenditure for physical activity which affects besides the energy intake the amount of energy available for growth.

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## References

- Allan, B. E., 1997: Grazing management of oversown tussock country 3. Effect on liveweight and wool growth of Merino wethers. *New Zealand Journal of Agricultural Research* 40, 437-447.
- Boval, M.; Fanchone, A.; Archimede, H.; Gibb, M. J., 2007: Effect of structure of a tropical pasture on ingestive behaviour, digestibility of diet and daily intake by grazing cattle. *Grass and Forage Science* 62, 44-54.
- Chen, Z. Z.; Wang, S. P., 2000: *Typical steppe ecosystem of China*. Science Press, pp. 9-45.
- Chen, Z. Z.; Wang, S. P.; Wang, Y. F., 2003: Update progress on grassland ecosystem research in Inner Mongolia steppe. *Chinese Bulletin of Botany* 20, 423-429.
- Ciavarella, T. A.; Dova, H.; Leury, B. J.; Simpson, R. J., 2000: Diet selection by sheep grazing *Phalaris aquatica* L. pastures of differing water-soluble carbohydrate content. *Australia Journal of Agricultural Science* 51, 757-764.
- Chinese Technical Committee for Feed Industry Standardization and Chinese Association of Feed Industry, compilation of feed standard (1996, 2000), China Standard Press, Beijing.
- Crocker, K.; Watt, P., 2001: *The good food guide for sheep*. In: Milton, J.; Paterson, J.; Roberts, D. (eds). Principles of Ruminant nutrition. Department of Agriculture, South Perth, Australia, pp. 12-18.
- Derner, J. D.; Hart, R., 2004: Continuous and rotational grazing of shortgrass steppe: animal gains. *Society for Range Management Meeting Abstracts*. No. 75.
- DeRouen, S. M.; Ward, J. D., 2005: Evaluation of grazing methods with Bermudagrass pastures for stocker production. LSU Agricultural Center. Research and Extension.
- Gammon, D. M., 1987: A review of experiments comparing systems of grazing management on natural pastures. *Proceedings of the Grassland Society of South Africa* 13, 75-82.
- Glindemann, T.; Wang, C. J.; Tas, B.; Schiborra, A.; Gierus, M.; Taube, F.; Susenbeth, A., 2007: Impact of grazing intensity on herbage mass, live weight gain, forage quality and feed intake of sheep on the Inner Mongolia steppe (in preparation).



- Glindemann, T.; Wang, C. J.; Tas, B.; Susenbeth, A., 2007: Evaluation of titanium dioxide as a feces marker for estimation of fecal output in grazing experiments with sheep (in preparation).
- Hacker, R. B.; Richmond, G. S., 1994: Simulated evaluation of grazing management systems for arid chenopod rangeland in Western Australia. *Agricultural Systems* 44, 397-418.
- Hafley, J. L., 1996: Comparison of Marshall and Surrey ryegrass for continuous and rotational grazing. *Journal of Animal Science* 74, 2269-2275.
- Han, G. D.; Xu, Z. X.; Zhang, Z. T., 1990: Comparison of rotation and continuous-season grazing systems. *Chinese Journal of Arid Land Resources and Environment* 3, 355-362.
- Huston, J. E.; Thompson, P. V.; Taylor, J. C. A., 1993: Combined effects of stocking rate and supplemental feeding level on adult beef cow grazing native rangeland in Texas. *Journal of Animal Science* 71, 3458-3465.
- Jiang, S., 1985: An introduction to the Inner Mongolia Grassland Ecosystem Research Station, Academia Sinica. In: Inner Mongolia Grassland Ecosystem Research Station, *Research on Grassland Ecosystem* 1 Beijing, Science Press. pp. 1-11.
- Lachica, M.; Aguilera, J. F., 2005: Energy expenditure of walk in grassland for small ruminants. *Small Ruminant Research* 59, 105-121.
- Li, Y. H.; Chen, Z. Z.; Wang, S. P.; Huang, D. H., 1999: Grazing experiment for sustainable management of grassland ecosystem of Inner Mongolia steppe: Experimental design and the effect of stocking rates on grassland production and animal live weight. *Acta Agrestia Sinica* 3, 173-182.
- Lu, Z. J.; Lu, X. S.; Xin, X. P., 2005: Present situation and trend of grassland desertification of North China. *Acta Agrestia Sinica* 13, 24-27.
- McDonald, P.; Edwards, R. A.; Greenhalgh, J. F. D., 1988: *Animal Nutrition*. Copublished in United State with John Wiley and Sons, Inc., New York. pp. 245-259.
- Mckown, C. D.; Walker, J. W.; Stuth, J. W.; Heitschmidt, R. K., 1991: Nutrient intake of cattle on rotational and continuous grazing treatments. *Journal of Range Management* 44, 596-601.
- NRC (National Research Council). 2007. Nutrient requirements of small ruminants. The National Academy Press, Washington, D. C, pp. 54-73.
- Osuji, P. O., 1974: The physiology of eating and the energy expenditure of the

- ruminant at pasture. *Journal of Range Management* 27, 437-443.
- Simon, J. R. W.; Graeme, C. W.; David, G. M., 1995: Optimal grazing of a multi-paddock system using a discrete time model. *Agricultural Systems* 48, 119-139.
- SAS, 2003: Statistical Analysis Systems Institute. Version 9.5. SAS Institute Inc., Cary, NC.
- Stuth, J. W.; Grose, P. S.; Roath, L. R., 1987: Grazing dynamics of cattle stocked at heavy rates in a continuous and rotational grazed system. *Applied Animal Behaviour Science* 19, 1-9.
- Vallentine, J. F., 2001: Grazing Management. Academic Press. pp. 261-302
- Wang, C. J.; Glindemann, T.; Tas, B. M.; Rave, G.; Schmidt, L.; Weißbach, F.; Susenbeth, A., 2007: Fecal crude protein content as an estimate for the digestibility of organic forage in grazing sheep (in preparation).
- Wang, C. J.; Wang, S. P.; Zhou, H.; Glindemann, T., 2007: Effect of forage composition and growing season on methane emission from sheep in the Inner Mongolia steppe of China. *Ecological Research* 22, 41-48.
- Wang, S. P., 2000: The dietary composition of fine wool sheep and plant diversity in Inner Mongolia sheep. *Acta Ecologica Sinica* 20, 951-958.
- Walton, P. D.; Martinea, R.; Bailey, A. W., 1981: A comparison of continuous and rotational grazing. *Journal of Range Management* 34, 19-21.
- Wang, S. P.; Li, Y. H., 1997: The influence of different stocking rates and grazing periods on the amount of feces and its relationship to DM intake and digestibility of grazing sheep. *Acta Zoonutrimenta Sinica* 9, 47-54.
- Wang, S. P.; Li, Y. H., 1999: Degradation mechanism of typical grassland in Inner Mongolia. *Chinese Journal of Applied Ecology* 10, 437-441.
- Wang, S. P.; Wang, Y. F.; Chen, Z. Z., 2001: The biological-economical principle on sustainable development of grassland livestock in Inner Mongolia steppe. *Acta Ecologica Sinica* 21, 617-623.
- Xiang, Y.; Li, Q. K., 1987: Soil of China. Beijing, Science Press. pp. 746.
- Xiao, X. M.; Wang, Y. F.; Jiang, S.; Dennis, S.; Charles, D. B., 1995: Interannual variation in the climate and above-ground biomass of *Leymus chinensis* steppe and *Stipa grandis* steppe in the Xilin river basin, Inner Mongolia, China. *Journal of Arid Environments* 31, 283-299.
- Zhang, Z. T.; Xu, Z. X.; Han, G. D., 1989: A comparison of rotational and

continuous-seasonal grazing systems. *Proceedings of XVI International Grassland Congress* Nice, France. P. 1259-1260.

Zhao, X.; Yao, Y.; Yang, R., 1988: Ecological geographic characteristics and outlook of natural grasslands resources in Xilin river basin. In: Inner Mongolia Grassland Ecosystem Research Station, *Research on Grassland Ecosystem 3*. Beijing, Science Press. pp. 184-226.

## Chapter 4 General Discussion

Grazing animals are always selective in what they eat, especially in heterogeneous pastures as the Inner Mongolian grassland. Diet selection affects not only the accurate measurement of nutritive value of herbage ingested by animals, but also plant's growing and herbage availability of grasslands which, in turn, affect the successional processes in plant communities. Animals choose the preferred and palatable plant species or plant parts. Thus, the collection of a representative sample of herbage for evaluation of herbage quality becomes more difficult. A suitable and sensitive method for determination of the digestibility and intake of diet in grazing studies is needed. Grazing management can play a significant role in affecting grassland and animal productivity, nutrient fluxes within the system, and grassland deterioration (Vallentine, 2001; Freer and Dove, 2002). Therefore, different grazing systems have to be evaluated with regard to their ability to support sustainable and productive agriculture and to balance economical and ecological needs.

### **Fecal crude protein content as an estimate for the digestibility of forage in grazing sheep**

The relationship between CP concentration in fecal OM and OM digestibility of the diet, which is based on the increased microbial biomass and the decrease in fecal OM with an increase in OM digestibility of the diet, has been described and proven to be independent from effects of the type of diet, feed intake level, and animal species (Thomas and Campling, 1976; Schmidt and Jentsch, 1994; Lukas et al., 2005; Schlecht and Susenbeth, 2006). A new equation for sheep including data from hay of the Inner Mongolian grassland was established for estimating OM digestibility of diet (see Chapter 2). It could be shown that there is no significant effect of the type of diet on the estimation of OM digestibility allowing a general use for different roughage based diets and in grazing studies.

The fecal CP method for estimation of OM digestibility which represents the herbage consumed by grazing animals, overcomes constraints of other methods (e.g. in situ, in vitro, and NIRS) for which representative samples of diet are needed, because it is difficult to quantify the effect of selective grazing on the quality of the

consumed diet. Fecal CP method can be used when standard laboratory equipment for proximate feed analysis is available and can be easily applied. Special equipment or cannulated are not required. Fecal CP method could also be used for determination of the amount of herbage intake, when combined with application of an external marker for estimating the fecal output. Further studies seem to be necessary when feed with higher concentrations of secondary compounds are tested due to their potential to increase the amount of CP excreted in feces.

### **Rotational and continuous grazing of sheep in the Inner Mongolian steppe of China**

The knowledge of the complex interactions between management methods, environmental factors, plants, and grazing animals is vital for the understanding of how plants and grazing animals react to various grazing management schemes (Stuth et al., 1987). Continuous grazing in pasture allows unrestricted selective grazing of palatable species and parts of plant throughout growing season, often leading to a frequent and intensive defoliation which eventually reduces the vigour and productivity of the preferred species. This will affect potential growth and yield of herbage in pastures. Rotational grazing allows better and undisturbed herbage regrowth, since diet selection of grazing animals is reduced due to a higher grazing intensity during a short period, herbage is more uniformly grazed, and the grasslands regrow more uniformly (Valentine, 2001).

In the present study, higher intake and digestibility at continuous grazing did not result in higher animal weight gain, and animals grazing on flat areas had higher weight gain than in slope areas. A rough calculation indicates that the extra walking for diet selection at continuous grazing and locomotion on slope areas may increase the amount of energy requirements for activity of animals. Energy requirements for walking, grazing and ruminating are important proportions of the total energy above metabolisable energy for maintenance. Therefore, accurate estimates of grazing behavior and physical activity (e.g. walking, chewing, up and down locomotion on hill areas) as affected by grazing system, grazing intensity and biomass availability are required to investigate energy available for animal growth.

The climate is a dominating factor affecting biomass of grassland, the amount of

bare ground, and interacts with grazing treatments (Teague et al., 2004). In the present study, herbage regrowth, feed intake and digestibility varied considerably between years, which also reflect the strong influence of the different precipitation patterns. A relative high precipitation during time of vegetation resulted in a high herbage regrowth and HM at rotational grazing. The presented results also support the hypothesis that beneficial effect at rotational grazing may be observed in more humid climates (Holechek et al., 1999). Ongoing research will further investigate effects of different grazing systems on grazing behavior and physical activity, and to determine the long term effects of grazing system on grassland and animal productivity in the Inner Mongolia grassland.

### **Contributions to the DFG-Research Group “Matter fluxes in grassland of Inner Mongolia as influence by stocking rate” (MAGIM)**

The principal objective of MAGIM is to understand the interaction between grazing of steppe ecosystems and fluxes of water, nitrogen and carbon on site and regional scales. The effects of different grazing intensities on matter fluxes in grassland have been reported by other sub-projects of MAGIM group (DFG-Forschergruppe 536, 2006). Severe overgrazing by sheep leads to reduced grassland and animal productivity, affects soil conditions and availability of water and nutrients, and leads to deterioration of grassland.

In the present study, the developed equation for estimation of digestibility will give input to determine methane production by grazing sheep, and N recycling by the animal which is used for nutrient balances and herbage growth. Feed intake and digestibility of herbage and energy expenditure for activity of grazing sheep are also influenced by grazing system, and vary between and within years. These findings are important information for research on nitrogen and carbon fluxes, above and below ground productivity, and soil physical properties of grassland to develop concepts for improved rangeland management. Therefore, additional attention shall be paid to interaction of grazing intensity and system with respect to matter fluxes in grassland.

## References

- Freer, M., Dove, H., 2002. Sheep Nutrition. CABI publishing in association with CSIRO publishing, UK. pp. 1-70.
- Holechek, J. L., Gomea, H., Molinar, F., Galt, D., 1999. Grazing Studies: what we have learned. *Rangelands* 21: 12-16.
- Jones, R. M., Jones, R. J., McDonald, C. K., 1995. Some advantages of long-term grazing trials, with particular reference to changes in botanical composition. *Australian Journal of Experimental Agriculture* 35: 1029-1038.
- Lukas, M., Südekum, K. H., Rave, G., Friedel, K., Susenbeth, A., 2005. Relationship between fecal crude protein concentration and diet organic matter digestibility in cattle. *Journal of Animal Science* 83: 1332-1344.
- Schlecht, E., Susenbeth, A., 2006. Estimating the digestibility of Sahelian roughages from faecal crude protein concentration of cattle and small ruminants. *Journal of Animal Physiology and Animal Nutrition* 90: 369-379.
- Schmidt, L., Jentsch, W., 1994. Die Schätzung der Verdaulichkeit von Konservatfütterationen für Rinder anhand des Stickstoffgehaltes im Rinderkot. *FBN Schriftenreihe, Dummerstorf* 7:179–184.
- Teague, W. R., Dowhower, S. L., Waggoner, J. A., 2004. Drought and grazing patch dynamics under different grazing management. *Journal of Arid Environments* 58: 97-117.
- Thomas, S., Campling, R. C., 1976. Relationship between digestibility and faecal nitrogen in sheep and cows offered herbage *ad libitum*. *Journal of the British Grassland Society* 31: 69-72.
- Vallentine, J. F., 2001. *Grazing Management*. Academic Press. pp. 473-526.

## Chapter 5 Summary

The steppe of Inner Mongolia is overgrazed by sheep, which leads to reduced grassland and animal productivity, to deterioration of these grasslands and to desertification. Changing the grazing system from continuous grazing to rotational grazing may be beneficial for grassland and animal productivity, which is largely determined by intake and digestibility of feed. The objectives of this thesis were first to develop a method to estimate the organic matter (OM) digestibility in grazing sheep, and second to determine the effect of continuous and 10-day rotational grazing on herbage intake, OM digestibility and animal growth at a moderate grazing intensity during two grazing seasons.

With data from digestibility trials with sheep fed forages harvested in Germany and in Inner Mongolia, a regression equation was developed to predict OM digestibility of forage-based diets from contents of crude protein in fecal OM. The developed equation accurately fitted the data, as indicated by the relatively small mean prediction error and large proportion of the mean square prediction error due to the overall random variation. Although the regression equation slightly overestimated the OM digestibility of hay from Inner Mongolian grassland, the equation can be used to accurately estimate OM digestibility of herbage ingested by sheep grazing in the Inner Mongolia steppe.

The herbage mass was similar in both grazing systems, but herbage intake and digestibility were lower at rotational than continuous grazing in both grazing seasons. However, average daily live weight gain of sheep did not differ between rotational and continuous grazing. These findings may be affected by the very low annual precipitation. Therefore, the experiment should be continued under different weather conditions and to determine the long term effects of grazing system on plant and animal productivity.



## Zusammenfassung

Die Überbeweidung der Grassteppe durch Schafe in der Inneren Mongolei führt zu einer Reduktion der Produktivität der Grünlandbestände und der tierischen Leistung, zur Degradierung des natürlichen Pflanzenbestands und zur Desertifikation. Ein Wechsel des Beweidungssystems von einem permanenten zu einem rotierenden System könnte sich positiv auf das Grünland und die tierischen Leistungen, die weitestgehend durch Futteraufnahme und Verdaulichkeit des Futters bestimmt werden, auswirken. Die Zielsetzung dieser Arbeit war zum einen die Entwicklung einer Methode zur Schätzung der Verdaulichkeit der Organischen Substanz des Futters bei weidenden Schafen. Weiterhin sollte in dieser Arbeit der Effekt einer alle zehn Tage rotierenden gegenüber einer kontinuierlichen Beweidung auf die Höhe der Futteraufnahme, der Verdaulichkeit der Organischen Substanz und des Tiergewichtszuwachs bei einer moderaten Beweidungsintensität während zweier Jahre ermittelt werden.

Auf der Basis von Daten aus Verdauungsversuchen mit Schafen, die in Deutschland und der Inneren Mongolei durchgeführt worden sind, wurde eine Regressionsgleichung für grundfutterbasierte Rationen zur Berechnung der Verdaulichkeit des Futters aus dem Rohproteingehalt in der Organischen Substanz des Kots entwickelt. Obwohl die Regressionsgleichung die Verdaulichkeit der Organischen Substanz von Heu aus der Inneren Mongolei leicht überschätzt, kann die Gleichung zur genauen Bestimmung der Verdaulichkeit der Organischen Substanz von Grünfutter, welches Schafen in der Inneren Mongolei auf der Weide zur Verfügung steht, herangezogen werden, da nachgewiesen werden konnte, dass der Rationstyp abgesehen von dessen Verdaulichkeit keinen Einfluss auf den Rohproteingehalt des Kots ausübt.

Die beiden untersuchten Beweidungssysteme zeigten keinen Unterschied hinsichtlich der nach der Beweidung noch vorhandenen Biomasse, auch das Wachstum der Tiere war nicht verschieden. Die Futteraufnahme und die Verdaulichkeit waren hingegen im rotierenden System in beiden Jahren geringer. Dies könnte durch die sehr geringen Niederschlagsmengen in den beiden Untersuchungsjahren bedingt gewesen sein, die möglicherweise verhinderten, dass

sich positive Effekte eines ungestörten Wiederaufwuchses nach der Beweidung zeigen konnten. Mit den vorliegenden Ergebnissen wurden jedoch signifikante Effekte des Beweidungssystems nachgewiesen. Eine abschließende Beurteilung der Systeme ist aber erst möglich, wenn auch Ergebnisse aus Untersuchungen in Jahren mit mittleren Niederschlägen vorliegen, während die Schätzung der Verdaulichkeit des aufgenommenen Futters aus dem Rohproteingehalt des Kots bei weidenden Tieren als eine sehr robuste und gut abgesicherte Methode angesehen werden kann.

## 摘 要

内蒙古草原由于过渡放牧,导致严重的退化和沙化,从而降低了草地和家畜的生产力。草地放牧由连续放牧改变为轮牧制度可以有益于草地和放牧家畜生产力的改善。但确定适宜的放牧制度在很大程度上取决于放牧家畜本身的采食量及其对牧草养分的有效利用。本文研究的主要目的是:(一)建立一个适宜的预测放牧家畜所采食牧草的有机物质消化率的方法;(二)应用中度放牧,通过两年的研究去调查连续放牧和十天的轮牧制度对草地牧草的生长于再生、放牧家畜的牧草采食量、有机物质消化率和生长特性的影响。

建立预测牧草有机物质消化率的方法是基于家畜粪便有机物质中的粗蛋白质含量与家畜所采食牧草有机物质消化率的生物学关系。分析所用数据来源于德国和中国内蒙古绵羊以牧草为基础日粮的室内消化试验。通过分析误差的期望均方值对所采用非线性混合模型所建立的回归方程进行评估,结果表明具有较小的预测误差,其中误差的期望均方值很大一部分来源于总体的随机变异,说明回归方程与分析所用的试验数据具有较高的拟合度,所建立的回归方程能够用来对内蒙古放牧绵羊所采食牧草的有机物质消化率进行准确的预测。

虽然两种放牧制度对牧草的地上现存量没有显著影响,但在轮牧制度中放牧绵羊的采食量和牧草的消化率低于连续放牧。然而,这些差异并没有对绵羊的日增重产生显著影响。由于较低的年降雨量可以对这些试验研究结果产生较大的影响,所以试验将继续进行,比较不同年份,即在不同的气候条件下研究比较这两种放牧制度对草地植物和家畜生产力所产生的长期影响。

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May 2007

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## Appendix

Table 1 Chemical composition, proportion of concentration in diet, and intake, fecal CP concentration and OM digestibility of diets fed to sheep.

Type of diet	Trial	Sheep per diet	Chemical composition, g/kg of DM						Concentrate, % of diet DM	Intake, kg/d		CP g/kg of fecal OM	dOM, %
			DM g/kg	OM	CP	Crude fat	Crude fiber	NFE		DM	OM		
Braunschweig, Germany													
Red cover silage													
	1	4	312.4	866.1	228.6	26.6	204.1	406.8	-	1.28	1.11	245.4	72.5
	2	6	321.2	866.2	226.1	26.6	200.2	413.3	-	1.33	1.15	242.1	73.6
	3	6	414.0	884.8	151.5	12.2	308.8	412.3	-	1.28	1.14	180.7	60.5
	4	4	413.8	884.0	153.5	12.2	304.5	413.8	-	1.32	1.17	181.5	62.7
	5	8	277.4	889.9	221.4	25.7	178.1	464.7	-	1.28	1.14	249.9	78.5
	6	2	281.1	894.0	221.2	23.3	182.5	467.0	-	1.41	1.26	270.6	77.0
	7	6	295.2	860.4	162.4	15.1	243.3	439.6	-	1.41	1.26	270.6	77.0
	8	4	291.9	860.4	165.1	15.9	247.9	431.5	-	1.34	1.16	198.4	70.1
	9	6	370.1	893.6	196.4	14.0	240.4	442.8	-	1.44	1.29	214.1	71.7
Lotus silage													
	10	6	298.6	904.1	206.9	28.4	282.9	385.9	-	1.31	1.19	196.7	65.1
	11	4	300.9	902.7	204.0	28.4	278.7	391.6	-	1.36	1.23	202.6	65.7
	12	6	354.8	900.3	176.4	20.5	329.2	374.2	-	1.28	1.15	169.8	58.0

(continued)

	13	4	355.5	899.2	174.8	20.5	323.7	380.2	-	1.38	1.24	171.7	58.5
	14	6	298.2	885.5	194.9	33.9	252.8	403.9	-	1.33	1.18	202.8	67.5
	15	4	296.9	889.5	195.0	25.6	262.2	406.7	-	1.34	1.19	206.6	68.9
	16	8	280.9	905.1	161.8	18.5	304.7	420.1	-	1.38	1.25	164.1	62.8
	17	2	281.3	904.0	159.6	17.4	312.8	414.2	-	1.35	1.22	166.7	62.0
	18	6	312.8	875.2	247.7	24.0	219.1	384.4	-	1.35	1.18	251.9	70.3
	19	6	340.6	894.7	218.2	25.2	212.9	438.4	-	1.33	1.19	238.3	69.1
	20	6	343.4	881.5	219.3	23.1	236.2	402.9	-	1.34	1.18	224.2	67.5
Alfalfa silage													
	21	6	364.4	873.4	203.6	23.4	307.0	339.4	-	1.33	1.16	138.6	64.4
	22	4	369.0	872.7	204.3	23.5	306.8	338.1	-	1.34	1.17	142.0	65.4
	23	6	436.2	872.4	163.4	13.1	373.2	322.7	-	1.30	1.14	123.7	56.7
	24	4	436.1	868.5	165.8	13.1	364.3	325.3	-	1.34	1.17	124.3	57.9
	25	6	258.4	868.8	221.6	29.6	227.3	390.3	-	1.38	1.20	184.0	74.4
	26	4	258.4	868.8	221.6	29.6	227.3	390.3	-	1.38	1.20	189.4	73.7
	27	6	267.9	871.6	185.1	19.3	327.5	339.7	-	1.39	1.21	126.7	63.5
	28	4	267.4	870.9	185.1	19.1	326.6	340.1	-	1.34	1.16	129.5	64.2
	29	6	356.6	893.0	180.4	13.5	352.0	347.1	-	1.39	1.24	122.6	61.7
Galega silage													
	30	6	325.2	900.1	189.9	14.8	335.4	360.0	-	1.32	1.19	154.2	54.8
	31	4	332.9	902.5	186.2	14.6	334.4	367.3	-	1.38	1.24	154.9	57.5

(continued)

	32	6	357.0	907.8	191.5	19.7	312.8	383.8	-	1.27	1.16	161.8	57.9
	33	4	366.4	907.9	190.0	19.7	315.6	382.6	-	1.33	1.21	169.2	59.3
	34	6	207.8	879.6	248.5	20.9	234.5	375.7	-	1.48	1.30	243.8	72.3
	35	4	206.1	880.2	252.0	18.6	238.2	371.4	-	1.55	1.36	240.0	71.7
	36	6	333.3	885.5	206.1	18.7	299.3	361.4	-	1.35	1.20	177.7	63.3
	37	4	329.0	890.6	212.7	18.7	299.5	359.7	-	1.32	1.17	183.3	63.8
	38	6	332.6	905.4	244.3	18.5	252.6	390.0	-	1.36	1.23	206.5	68.1
	39	6	326.7	905.1	216.2	17.3	318.7	352.9	-	1.34	1.21	168.9	62.5
	40	4	399.7	901.1	222.9	15.8	319.9	342.5	-	1.31	1.18	177.0	62.6
Fresh grass													
	41	4	261.6	830.6	177.0	36.4	260.5	356.7	-	0.81	0.69	229.6	64.0
	42	4	273.6	871.0	171.7	39.8	274.8	384.7	-	0.91	0.80	216.5	65.1
	43	4	265.0	875.3	192.1	39.2	262.1	381.9	-	0.90	0.79	235.1	67.0
	44	4	171.9	876.9	206.6	33.4	254.8	382.1	-	1.20	1.05	222.9	74.4
	45	4	156.5	870.3	180.5	31.6	237.0	421.2	-	1.16	1.01	224.2	75.8
	46	4	198.0	880.4	140.9	31.1	220.4	488.0	-	0.94	0.83	195.4	70.9
	47	4	265.7	904.1	93.2	25.3	236.3	549.3	-	0.76	0.69	161.0	68.8
	48	4	554.2	905.4	142.9	31.9	306.2	424.4	-	0.99	0.89	191.3	74.3
	49	4	553.9	906.1	142.5	32.2	290.5	440.9	-	0.99	0.89	194.7	74.3
	50	4	139.2	869.2	144.0	21.4	282.0	421.8	-	0.93	0.81	188.6	75.6
	51	4	367.4	918.7	118.8	25.1	286.2	488.6	-	1.10	1.01	146.7	72.6



(continued)

52	4	208.8	901.5	204.2	33.4	249.9	414.0	-	1.03	0.93	205.6	73.6
53	4	176.2	898.1	218.7	27.7	242.2	409.5	-	1.09	0.98	205.5	71.9
54	4	172.9	901.1	129.1	33.8	284.3	453.9	-	1.03	0.93	189.0	74.0
55	4	180.4	896.7	136.4	30.6	282.1	447.6	-	1.08	0.96	201.3	74.0
56	4	249.2	889.9	211.3	39.6	256.1	382.9	-	1.09	0.97	184.6	71.4
57	4	276.0	898.0	208.3	45.9	257.5	386.3	-	1.09	0.98	186.2	67.3
58	4	209.6	878.6	169.2	39.8	297.1	372.5	-	1.10	0.97	179.6	69.5
59	4	269.0	900.6	234.9	43.6	248.5	373.6	-	1.02	0.92	196.2	64.4
60	4	221.6	896.2	243.1	34.0	214.4	404.7	-	1.09	0.97	208.1	68.9
61	4	377.4	935.2	147.2	24.5	324.8	438.7	-	1.20	1.12	149.1	69.3
62	4	375.0	930.7	140.0	26.3	335.7	428.7	-	1.01	0.94	148.5	69.3
63	4	486.3	908.8	183.4	36.6	275.5	413.3	-	1.02	0.93	198.4	71.3
64	4	503.9	909.0	174.3	37.8	284.1	412.8	-	1.06	0.96	192.8	71.3
65	4	197.0	871.2	134.9	39.9	300.9	395.5	-	1.01	0.88	202.7	65.2
66	4	360.7	916.5	124.3	27.0	309.4	455.8	-	1.08	0.99	170.6	72.1
67	4	163.7	869.1	98.0	25.0	345.5	400.6	-	1.20	1.04	177.9	71.6
68	4	395.4	892.7	136.5	31.3	310.2	414.7	-	1.03	0.92	187.3	72.6
69	4	415.2	892.7	127.5	39.3	322.5	408.6	-	0.96	0.86	182.5	71.6
70	4	164.3	879.1	85.3	25.5	360.7	407.6	-	1.21	1.07	163.8	71.3
71	4	517.1	914.5	128.6	19.1	328.5	438.3	-	1.03	0.95	175.6	70.8
72	4	519.6	912.3	134.5	20.9	332.9	424.0	-	1.04	0.95	179.6	67.5

(continued)

73	5	408.1	912.1	160.8	36.6	270.5	444.2	-	1.22	1.12	190.5	73.3
74	5	411.5	913.9	160.7	37.5	271.7	444.0	-	1.23	1.13	192.0	71.6
75	5	411.5	912.4	160.7	37.4	270.7	443.6	-	1.23	1.13	193.0	72.5
76	5	409.7	914.3	162.6	38.6	266.6	446.5	-	1.23	1.12	186.2	71.1
77	5	408.5	913.1	163.5	37.8	269.1	442.7	-	1.31	1.19	185.1	71.8
78	5	409.7	914.0	160.6	37.5	270.9	445.0	-	1.23	1.12	184.6	71.4
79	5	417.0	896.0	152.6	34.9	281.4	427.1	-	1.26	1.13	184.7	70.2
80	5	417.0	896.0	152.6	34.9	281.4	427.1	-	1.26	1.13	181.2	70.7
81	5	391.9	882.9	150.5	34.0	273.8	424.6	-	1.22	1.08	181.9	70.8
82	5	391.9	882.9	150.5	34.0	273.8	424.6	-	1.22	1.08	186.5	70.0
83	6	346.6	904.5	151.7	32.8	283.9	436.1	-	1.28	1.16	190.5	70.5
84	4	359.3	905.2	150.3	32.8	279.8	442.3	-	1.33	1.20	199.8	71.5
85	6	371.2	916.8	109.7	22.1	295.3	489.7	-	1.22	1.12	152.3	62.0
86	4	371.7	917.8	109.8	22.0	291.0	495.0	-	1.27	1.17	157.6	63.5
87	4	237.1	891.9	159.8	37.9	302.8	391.4	-	1.40	1.25	218.3	77.4
88	4	258.1	891.2	194.2	35.0	269.6	392.4	-	1.47	1.31	259.2	76.8
89	6	293.6	901.0	152.3	25.8	220.7	502.2	-	1.38	1.24	241.3	80.9
90	4	290.7	902.6	154.9	20.9	225.9	500.9	-	1.37	1.23	257.0	81.2
91	6	353.9	922.3	98.7	13.8	283.5	526.3	-	1.31	1.21	161.7	72.6
92	4	353.3	924.5	100.0	15.6	285.1	523.8	-	1.32	1.22	171.7	73.7
93	6	355.9	942.2	79.9	11.0	338.2	513.8	-	1.09	1.03	123.5	64.9

(continued)

94	6	360.3	906.6	196.9	30.6	252.6	426.5	-	1.30	1.18	232.6	77.6
Hay and concentrate												
95	4	852.9	909.0	189.2	20.0	260.0	439.9	19.1	0.97	0.88	186.5	66.6
96	4	848.1	908.1	188.0	18.2	253.1	448.7	19.2	0.96	0.87	186.0	67.3
97	3	862.4	924.1	150.1	11.8	290.0	472.3	18.9	0.91	0.85	134.9	61.3
98	3	858.2	924.0	170.3	14.5	269.7	469.6	18.9	0.98	0.91	171.7	67.5
99	4	839.7	927.1	166.6	14.8	309.7	436.0	18.4	1.00	0.93	178.4	68.3
100	4	856.7	944.1	144.3	12.5	296.3	491.0	19.0	0.97	0.91	128.5	60.8
101	4	846.8	915.1	169.0	14.6	290.5	441.0	18.9	0.98	0.89	167.5	66.3
102	3	850.7	939.1	160.5	15.0	296.4	467.2	18.2	1.01	0.95	126.4	60.9
103	4	864.4	945.6	143.1	15.3	302.0	485.2	18.2	1.01	0.96	125.2	61.6
104	4	854.0	926.5	129.7	15.1	317.6	464.2	18.1	0.97	0.90	120.7	62.4
105	4	862.5	920.3	256.5	18.7	213.4	431.6	39.3	1.02	0.94	263.2	81.8
106	4	862.6	920.7	256.3	18.8	211.2	434.3	39.3	1.02	0.94	258.5	81.4
107	4	831.9	913.8	167.6	10.6	299.1	436.6	19.5	1.02	0.94	136.4	64.8
108	4	842.2	947.1	160.0	11.9	265.0	510.2	18.1	1.08	1.02	124.4	55.6
109	4	841.1	942.9	171.3	11.1	263.3	497.2	20.4	1.00	0.94	141.4	65.0
110	4	842.2	911.8	151.9	11.1	265.7	483.1	20.4	1.00	0.91	150.0	69.6
111	4	832.4	922.7	153.5	10.7	298.1	460.4	19.9	1.02	0.95	138.7	61.9
112	4	845.5	940.4	175.8	11.8	252.8	500.0	20.3	1.00	0.94	114.4	57.3
113	4	825.5	935.1	180.5	11.8	248.5	494.3	21.2	0.95	0.89	166.5	63.8

(continued)

114	4	824.3	942.4	203.5	13.8	273.2	451.9	21.6	0.93	0.88	158.6	64.0
115	4	844.9	904.2	156.4	12.1	279.4	456.3	19.7	1.02	0.93	139.5	65.0
116	4	849.5	933.6	147.8	12.9	298.7	474.3	19.9	1.01	0.95	125.7	64.2
117	4	881.0	936.2	160.3	15.1	275.5	485.3	19.9	1.01	0.95	128.9	63.4
118	4	873.9	930.6	165.3	15.7	261.4	488.2	19.8	1.02	0.95	144.3	64.7
119	4	866.1	920.3	162.2	11.8	257.3	489.1	20.0	1.00	0.92	140.7	65.7
120	4	876.1	890.9	182.3	16.1	253.8	438.7	19.8	1.00	0.89	158.3	65.9
121	4	859.4	940.7	175.9	10.8	265.6	488.3	20.2	1.00	0.94	118.2	55.3
122	4	866.1	931.1	161.1	12.6	297.7	459.7	20.0	0.94	0.87	128.4	61.1
123	4	871.1	911.3	197.9	13.6	253.2	446.5	19.9	0.97	0.89	138.6	61.1
124	4	832.2	928.9	221.1	22.1	253.9	431.8	20.9	0.98	0.91	179.4	70.1
125	4	847.9	921.0	187.3	17.1	264.7	452.0	20.5	0.99	0.92	230.2	77.3
126	4	849.0	916.0	208.8	18.6	268.7	420.0	20.5	1.00	0.91	235.9	75.4
127	4	866.5	913.8	208.0	18.8	245.3	441.7	20.0	1.02	0.93	209.7	63.3
128	4	866.6	914.3	182.7	19.2	281.7	430.8	20.0	1.02	0.93	188.1	75.2
129	4	845.5	929.9	184.6	17.4	272.3	455.6	20.6	0.99	0.92	156.2	69.9
130	4	857.2	937.8	148.9	12.4	276.0	500.5	20.3	1.00	0.94	129.7	67.8
131	4	827.2	939.9	146.5	15.2	278.3	499.9	21.0	0.97	0.91	125.5	67.2
132	4	865.5	937.8	149.0	12.4	263.6	512.8	20.1	1.01	0.95	136.3	69.5
133	4	868.6	942.9	152.2	13.4	304.1	473.2	20.1	0.99	0.93	120.0	63.2
134	4	870.9	911.2	134.7	8.3	328.0	440.2	20.1	1.02	0.93	108.5	61.6

(continued)

135	4	879.1	924.7	186.7	17.4	264.1	456.4	19.9	1.03	0.95	168.5	66.4
136	4	890.9	933.3	166.4	14.1	286.9	465.9	19.6	1.04	0.97	146.0	69.5
137	4	857.7	919.1	180.5	15.0	245.3	478.4	20.4	0.97	0.89	155.6	64.8
138	4	876.4	918.0	205.7	17.3	248.5	446.5	20.8	1.03	0.94	163.3	65.8
139	4	888.4	935.3	147.8	14.9	261.3	511.2	20.5	1.04	0.97	115.5	66.1
140	4	888.9	927.6	171.5	21.8	270.5	463.8	20.5	1.04	0.97	150.4	64.3
141	4	873.5	948.6	203.8	15.4	264.7	464.8	20.9	1.02	0.97	131.0	57.7
142	4	876.3	934.1	163.4	13.4	321.9	435.4	20.8	1.03	0.96	126.8	62.4
143	3	881.8	932.1	139.9	13.7	347.3	431.2	20.7	1.03	0.96	97.0	51.8
144	4	886.9	945.4	144.8	15.1	346.8	438.7	20.5	1.03	0.98	102.6	53.0
145	4	881.7	951.0	156.1	15.4	312.9	466.5	20.6	1.03	0.98	124.0	63.0
146	4	868.2	926.7	166.5	15.8	310.0	434.3	21.0	1.02	0.94	113.6	55.7
147	4	875.7	905.6	157.1	15.0	282.4	451.0	20.8	1.03	0.93	131.9	61.6
148	4	878.5	942.9	141.1	14.3	302.9	484.6	20.7	1.03	0.97	108.0	66.0
149	4	878.5	920.5	156.1	16.8	292.1	455.6	20.7	1.03	0.95	122.2	64.1
150	4	880.9	920.5	186.6	23.0	242.5	468.3	20.7	1.03	0.95	157.2	63.7
151	4	874.5	919.2	169.1	16.9	287.4	445.9	20.8	1.02	0.94	133.7	62.5
152	4	893.4	933.3	136.0	13.6	302.8	480.9	20.4	1.05	0.98	102.9	62.4
153	4	876.8	934.9	140.3	14.5	331.4	448.7	20.8	1.03	0.96	103.2	61.8

Inner Mongolia, China

Mixed hay and concentrate 1

(continued)

154	8	861.9	935.7	68.1	27.0	231.1	609.4	31.0	1.07	1.10	96.3	53.6
Mixed hay and concentrate 2												
155	8	885.7	891.7	129.7	19.9	222.5	519.6	33.3	1.24	1.13	105.6	54.4
Stipa hay (in 2005)												
156	7	889.0	938.8	74.7	16.9	332.2	515.0	-	1.08	1.02	141.6	53.4
Leymus hay (in 2005)												
157	7	865.6	949.0	76.9	19.5	329.4	523.2	-	1.13	1.07	117.6	53.0
Stipa hay (in 2006)												
158	8	939.4	920.8	74.3	28.6	316.9	501.0	-	1.22	1.12	88.8	46.9
Leymus hay (in 2006)												
159	7	938.2	934.5	94.6	22.9	300.1	516.9	-	1.26	1.17	92.7	47.9

<sup>a</sup> In Braunschweig data set: red cover silage (early and late cutting), lotus silage (early and late cutting), alfalfa silage (early and late cutting), galega silage (early and late cutting), fresh grass (intensive and extensive), grass silage (early, late and very late cutting), hay (intensive and extensive), chemical composition of soybean (g/kg DM): OM, 922-935; CP, 462-505; Crude fiber, 70-126; Crude fat, 15-28; NFE, 307-346. In Inner Mongolia data set: chemical composition of concentrate 1 (g/kg DM): OM, 931; CP, 57; Crude fiber, 184; Crude fat, 32; NFE, 657; concentrate 2 (g/kg DM): OM, 864; CP, 148; Crude fiber, 166; Crude fat, 22; NFE, 528.