Changing livestock numbers and farm management to improve the livelihood of farmers and rehabilitate grasslands in desert steppe: a case study in Siziwang Banner, Inner Mongolia Autonomous Region

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Abstract

China's northern and western grasslands support the livelihoods of 40 million people, many from ethnic minorities. Income levels are among the lowest of any Chinese farmers. More than 90% of these grasslands are degraded, resulting in other environmental problems that include frequent dust storms and declining biodiversity. Numerous reasons for grassland degradation have been canvassed for many years. High stocking rates are recognised as one of the more powerful factors affecting grassland utilisation and livestock production. This paper analyses the current farm conditions and relevant environment parameters, and presents the results of a modelling study of a livestock production based on the farming system in Siziwang Banner, Inner Mongolia Autonomous Region, in western China. Siziwang is located on the desert steppe grassland ecosystem (300 mm average annual rainfall, 1,450 m altitude on the Mongolian Plateau, which extends into Mongolia). This study indicates that improving flock management and structure should lead to not only an increase in livestock productivity and whole-farm returns but also the rehabilitation of grasslands through significant and profitable reductions in stocking rates. Sustainable and profitable livestock production based on grasslands can be achieved in Siziwang and arguably across much of Inner Mongolia, complementing a range of Chinese Government policy initiatives.

Introduction

The consumption of livestock products in China (Garnaut and Ma 1992) is projected to increase considerably in the near future, yet how that will be achieved is uncertain (Verburg and van Keulen 1999). These projections have focused mainly on the ability of China to produce enough grain for human consumption and to feed the increasing livestock population, the latter assuming that feedlots will become the norm. However, the increasing scales of meat production will also affect the systems of livestock-keeping on grasslands and their interactions with the environment. Grasslands are the main natural resource used for livestock production (Verburg and van Keulen 1999). The extensive grasslands of the Inner Mongolia Autonomous Region have long been used for large herds of horses, sheep and goats (Wittwer et al. 1987). Of the total area of China, 35% is covered with grasslands (Wu

Pp. 80–95 in 'Development of sustainable livestock systems on grasslands in north-western China', ed. by D.R. Kemp and D.L Michalk. ACIAR Proceedings No. 134. Australian Centre for International Agricultural Research: Canberra, 2011.

and Guo 1994). Due to its low natural productivity and low management levels the carrying capacities per hectare are generally low. Carrying capacities have decreased due to grassland degradation.

Overgrazing of grasslands has often been identified as one of the major causes of degradation and desertification (Smil 1993). Overgrazing results in declining productivity over time, accompanied by a reduction in environmental values (Kemp and Michalk 2007). Strategies are needed to resolve how best to satisfy production and environmental goals. These dilemmas are complex because grasslands are productive natural resources and part of the environment that interacts with other environmental processes at regional (e.g. water production) and global (e.g. climate change) scales. The ultimate challenge is to devise management strategies that utilise grassland resources in a sustainable manner (Kemp and Michalk 2007).

The grasslands in Siziwang Banner[1] play a major role in providing people with the goods and services needed for survival. Yet, farmers now face a more harsh and unproductive environment than in the past with less land to sustain each household. With severe degradation of grasslands (Li 1997) farmers find it challenging to generate sufficient revenue for survival. The developing market economy and the desire of many farmers to obtain its goods and services are resulting in more farmers wanting to increase the livestock products they sell. Developing and implementing a practical strategy to improve farmers' incomes while rehabilitating grasslands in the desert steppe of Siziwang are examined in this case study.

Methods

The study reported here used farm surveys within the study village to describe the current farm conditions and livestock production system as a basis for then investigating a range of options. Those data were then analysed with a series of models (Takahashi et al. 2011) that incorporated the data available from local research, published information and expert opinion. Survey data were used to construct a 'typical' farm. This was based upon six farms but removing any anomalies; e.g. if only one household had cattle, not averaging that across all farms.

[1] A banner is an administrative region roughly equivalent to a county.

Site

Siziwang is located in the middle of Inner Mongolia, approximately 150 km (Li et al. 2008) north of Hohhot, the provincial capital. It lies in the northern piedmont of Yinshan Mountain on the Inner Mongolia Plateau, covers an area of 25,500 km^2 and has a human population of 209,000, many of them dependent upon agricultural activities for their livelihoods. The general area is classified as a typical zone of fragile ecology and an important ecosystem in northern China. The study area lies between 110.33° and 113.00°E, and 40.15° and 43.33°N. Altitude averages 1,450 m.

The desert steppe ecological region extends across large areas of the Mongolia Plateau in both China and Mongolia, mostly at 1,000–1,500 m elevation and including the Yin Shan, a mountain range that rises to 2,200 m. The desert steppe is situated in the transitional belt of monsoonal wind, which results in low rainfall of variable distribution. Water resources are consequently limited. The climate is best characterised as continental: windy in spring, low summer rainfall and mostly dry throughout autumn, winter and spring. The monthly average temperature varies from –15 °C in January to 20 °C in July (Figure 1). The annual average temperature in the region is in the range 1–6 °C. The winter period is long and cold, lasting for approximately 180–200 days from October through April. The summer is short and hot, extending for 70–120 frost-free days when plant growth can occur; some 60–70% of annual precipitation occurs through summer, particularly in the latter half. Annual average precipitation is 100–300 mm (Figure 1) and highest monthly averages are in July and August. The period of most variable rainfall May–June, at the start of summer, and this frequently determines the total grassland productivity for the year. The mean annual evaporation of 2,340 mm, is considerably greater than precipitation, leading to an annual mean net moisture deficit of more than 2,000 mm. The first snow falls around the end of September – early October and the last snowfall is usually in early May. Shallow snow often covers the ground for between 50 and 130 days. The soil is mainly composed of steppe soil, which is commonly calcified.

There is a high risk of wind erosion in Siziwang. Strong winds and poor vegetation cover result in significant amounts of wind erosion every spring from the fine unconsolidated surface soils typical of the region. Wind velocities peak in April (Figure 2).

The light chestnut soil has an organic carbon content of approximately 1.3%, with total nitrogen averaging 0.13% and calcification not far below the soil surface. Aerobic bacteria, actinomycetes and moulds constitute the main soil micro-organism populations.

The vegetation is that of the Inner Mongolian desert steppe, with the main species being:

- grasses—*Stipa breviflora, Stipa gobica, Stipa klemenzii, Cleistogenes songorica*, *Cleistogenes squarrosa*
- monocotyledons—*Allium mongolicum, Allium polyrhizum, Allium tenuissimum*
- forbs—*Convolvulus ammannii*, *Hetropappus altaicus*, *Lagochilus ilicifolius, Artemisia scoparia*, *Artemisia pectinata*
- legumes—*Caragana microphylla*, *Caragana stenophylla*, *Astragalus galactites*
- shrubs—*Ceratoides latens, Artemisia frigida, Kochia prostrata.*

The grass canopy is now typically short and uniform, averaging less than 10 cm in height at the peak of the growing season in summer. Annual herbage growth is low and unstable, large areas have net primary productivity levels less than 1 t dry matter (DM)/ha. Vegetation can be sparse (17–20% cover) with a very limited species composition and richness.

The low grassland productivity in Siziwang is a result of summer soil-moisture deficit and limited soil nutrients. Also, 25–35% of the limited precipitation falls as snow, adding little to soil moisture in spring. The low levels of annual biomass production result in the traditional land use of grazing. Previously grazing was nomadic, but individual households are now settled on allocated areas of land under the 'responsibility system' (Lin 1987). A long history of grazing by horses, sheep and goats has influenced the development of Siziwang landscapes. Stocking rates, and hence grazing pressure, have increased considerably over the past 50 years, to about 1–1.5 sheep equivalents/ha. Heavy grazing intensity perpetuates a grassland plant community dominated by secondary forage grasses with low growth forms. In addition, heavy grazing intensity prevents development of large species diversity. Our data indicate that the resulting grassland community is composed of 30% desirable perennial grass species and 70% undesirable perennial grass species.

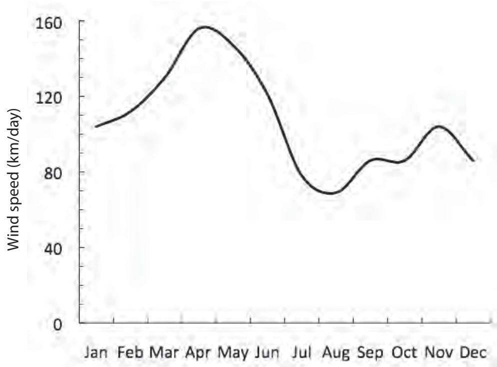

Figure 2. Wind speed per day during each month for Siziwang Banner, Inner Mongolia Autonomous Region

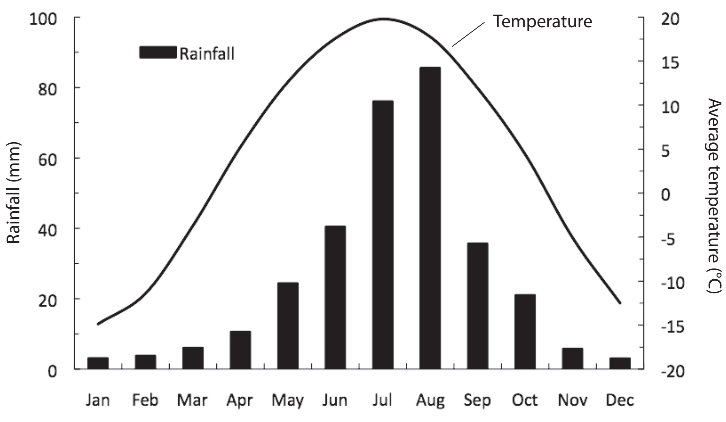

Figure 1. Mean monthly temperature and rainfall (1986–2006) for Siziwang Banner, Inner Mongolia Autonomous Region

Since 1950 there have been dramatic changes in livestock. Up until the mid 1980s, the total numbers of [sheep + goats] and cattle were similar (Figure 3). Cattle numbers then fell rapidly, accompanied by a rapid rise in sheep + goat numbers. (Cattle numbers rose recently, but mainly on dairy farms.) This was attributed to the degradation of grasslands which meant cattle had difficulty in satisfying their feed needs, even in summer. These changes in livestock groups did not cause any major changes in the average stocking rate for Siziwang, which remained around 1 sheep equivalent/ha through this change-over period (Figure 4). Stocking rates and hence grazing pressure have, however, increased fourfold over the past 50 years.

Field survey and expert opinions

The typical farm was characterised using information from the Bayin village in Chaganbulige township, Siziwang Banner. This village is 160 km north-east of Hohhot, Inner Mongolia, within the desert steppe region. In 2005, 15 farmers[2] were surveyed using semi-structured interviews to obtain data on the biological, economic and social components of the livestock farming system. More detailed data on livestock condition and seasonal changes in inputs and outputs were obtained from six of these farms, which then formed the core dataset for describing a typical farm. The objectives were to seek data and the opinions of these farmers on the resources they had, in terms of livestock productivity, grassland condition compared with 10 years ago, the costs and returns of livestock production and grassland management, and health of animals,

[2] The term 'farmer' is used in this paper to indicate herders/smallholders who depend primarily on livestock production from their farm for household income.

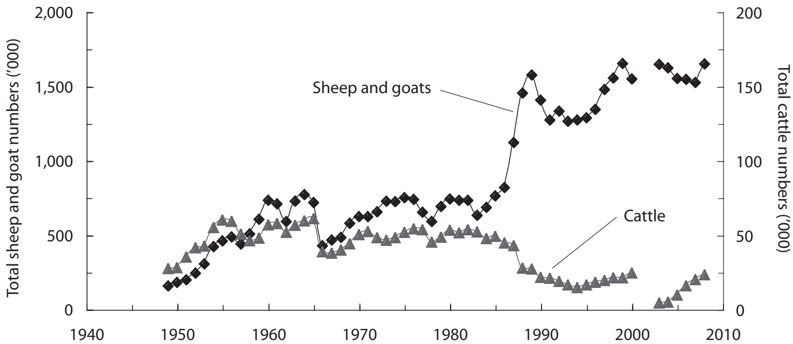

Figure 3. Total numbers of sheep and goats, and cattle, in Siziwang Banner, Inner Mongolia Autonomous region, 1949–2009

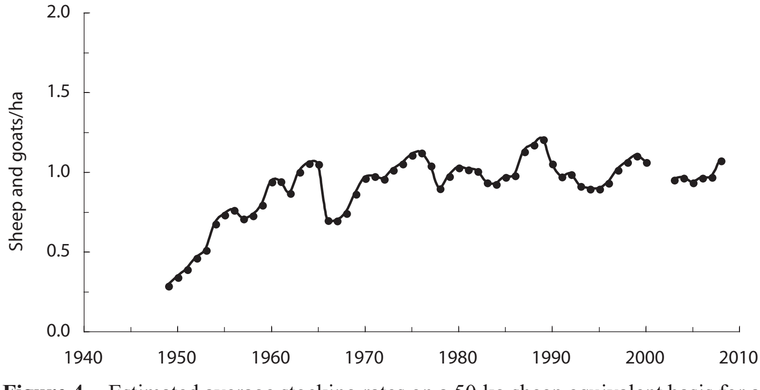

Figure 4. Estimated average stocking rates on a 50 kg sheep equivalent basis for all livestock in Siziwang Banner, Inner Mongolia Autonomous Region, 1949–2009

together with their ideas about improving livestock productivity and grassland condition. Officials and local experts of Siziwang and other departments were also consulted for information on the livestock production system. The research village was typical of the local area where the raising of sheep is the dominant rural activity. Over 90% of the sheep were local fat-tail sheep.

Model analysis

Two models were used to describe the current farm situation and to investigate options: a feed-balance (*StageONE*) model and a livestock production system optimising (*StageTWO*) model (Takahashi et al. 2011). The models were based upon simple biophysical (grassland and animal performance), cash flow, economic and social modules. They were constructed to evaluate technical options, including:

- farm structures that improve farm systems sustainability
- which grassland management tactics better reduce soil erosion, and their consequence (the Chinese Government is focused on the need to prevent dust storms)
- better alignment of livestock breeding cycles with feed supplies
- warm shed use and tactics to reduce animal numbers over winter (these factors could reduce the considerable loss of animals in some winters)
- the impact of developing market signals for quality, quantity and price, i.e. demand functions, of animal products and of policy changes, e.g. property rights. In the past the focus has often been simply on improving incomes, but the Chinese authorities are now very conscious of improving the landscape to maintain the resource base and reduce the cost of externalities.

Our modelling approach is based on the premise that there is no single solution to grassland problems. Rather, there is a wide range of strategic management options available for implementation by herder households that have the potential to both improve incomes and restore grasslands. Some options, particularly those related to changes in grassland grazing practices or livestock management systems, have a direct impact on household incomes, whereas others may have more direct impact on ecological issues or grassland policy development. Since it is too costly to evaluate the feasibility of these options with conventional field experiments, a modelling approach was justified from both technical and economic perspectives (Kemp and Michalk 2007).

The *StageONE* model was developed to evaluate the general nutrition of sheep and goats and their metabolisable energy (ME) balance throughout each month of the year. The *StageTWO* production system optimising model (Takahashi et al. 2011) was developed to evaluate alternative livestock management options on north-western China's grasslands. It uses the same core livestock production equations as the *StageONE* model. The *StageONE* model was used to examine the current conditions of, typically, dramatic weight loss in animals every year, and could also be used to manually investigate the detail of varying animal numbers, type, structure, reproductive performance etc. and variation in the feed supply. The *StageTWO* model imposed the constraint that animal live weight had to be maintained, i.e. a focus on production rather than survival. Other aspects of the typical farm, e.g. grassland area, crop area, manipulations possible and labour available, were considered and, within the constraints that were manually set, optimal solutions sought for stocking rates, enterprise mix, feeding and housing regimes etc. An important aspect of these models was to estimate the additional energy required for grazing and overcoming cold stress. This is significant in northern China because of the distance sheep are herded combined with low grassland biomass levels and the low winter temperatures experienced.

Results

Typical farm profile

Net farm income is derived from the return from sales of lambs and kids, wool, lamb wool and cashmere, old animals (all classes), animal hides and dung, minus the costs of crop production, various feed supplements, vaccines, medicines, fees for grassland rental, transportation of supplements, labour, artificial insemination, and repair and maintenance of farm facilities.

Some important constraints limit increasing the feed supply on the farm. The typical farming area is 520 ha, but increasing the available forage supply by sowing special-purpose crops is constrained by regulation in Siziwang: only 0.67 ha of fodder maize per household per year may be grown. Maize fields are sometimes irrigated. A widespread, 20-year period of low rainfall has reduced groundwater supplies and crop and grassland yields. While farms are managed as areas of individual responsibility, the livestock are herded daily when grazing. The productivity of grasslands is low, but it is considered uneconomic to sow more-productive plant species, or apply fertiliser.

There are, on average, 4–5 household members, including grandparents, parents and children. In addition to the family members, one labourer is commonly hired to assist the farm operation. The average cost of one labourer is ¥10,000 per annum. Family members often go to towns and cities for periods to earn extra income, and some family members now reside in towns to enable their children to obtain a better education. Farm families often have two children.

Livestock production system

Most of the 520 ha of grasslands on a typical farm in Siziwang is used for livestock production from an average of approximately 270 adult animals (Table 1). Raising sheep and goats for meat and fibre are the principal rural activities. Horses are no longer as common as they once were, or still are in Mongolia. Over 95% of the sheep are local Mongolian fat-tail sheep. Meat production is the main enterprise. The lambing time is mainly from December to March with lambs being sold in September. Male animals remain with the flock all year. The livestock population comprised 70% sheep and 30% goats. Comparison of the median data for the typical farm (derived from the 15 farms) with that for the 6 farms where more detailed data were obtained (Table 1) shows that farm size was 15% less in the subset and animal numbers were also lower. Those differences posed no difficulties for the modelling work done. Stocking rates were similar for each group.

Data from livestock inspections showed that the body condition of sheep was fair, with average fat scores around 1.5 in early summer (based on a 1–5 condition scoring criterion where condition class correlates to higher scores; Holst and White 2006). The general condition of the ewes was lower than desired. Body condition scores of 2 or more are considered to be optimal. The udder condition of the ewes was variable, although generally good for most after lambing. This suggests that they had used all their body reserves to produce the lamb or kid. Lambs were not normally weaned from their mother until the ewes stop producing milk, which typically occurred 3–6 months after lambing.

The estimates of actual ME intake and that required to maintain actual animal body weight (Figure 6) showed the large nutritional feed gap from November to May. This deficiency is very common in northern and western China and explains a large part of the significant live-weight loss that commonly occurs (Figure 5). The energy intake required to minimise any weight loss would be significantly higher than the maintenance curve (Figure 6) during this period. Ewes and does also produce lambs and kids during December–April, mainly in winter months, and the stress of lambing and lactation further exacerbates weight loss. Energy intake exceeds maintenance for only a few months during summer when grassland growth occurs and the quantity and quality of feed available are better than at any other time of the year. During summer live-weight gain occurs, commonly at a rate

Table 1. Animal numbers and grassland area for a 'typical' farm and six farms that were more intensively monitored in Siziwang Banner, Inner Mongolia Autonomous Region

Farm	Adult sheep and goats (no.)	Lambs and kids (no.)	Total animals (no.)	Grassland area (ha)	Adult stocking rate (head/ha)
Average (15 farms)	268	214	482	520	0.52
Buhechaolu	432	335	767	867	0.50
Siqingtu	199	143	342	349	0.57
Alatengbagen	152	121	273	320	0.48
Zhangjingui	454	261	715	1,312	0.35
Gendeng	254	176	430	545	0.47
Siqinbilige	165	104	269	213	0.77
Median (6 farms)	227	160	386	447	0.51

above that often predicted, as compensatory gain. The efficiency of weight gain over summer is high, but it occurs only because of the live-weight loss over winter. By September each year, adult animals are often back to no more than a live weight similar to that they had a year before. Young animals do make some net gain, but young sheep and goats can take 3–4 years to reach adult weights. Ewes of 2 years of age are nevertheless still able to produce a lamb, albeit small (2–3 kg at birth).

Grass starts to regrow from May to the end of September (Figure 7) when temperatures rise and moisture is available. Areas used for winter grazing by some farmers are ungrazed over summer, resulting in slightly more annual herbage growth. Forage supply is nevertheless severely reduced due to winter damage and severe grazing pressure. Animals have been traditionally taken out to graze every day of the year, irrespective of weather conditions.

The livestock production system optimising model (*StageTWO*) was used to estimate the optimal stocking rate on the typical farm, under conditions where animals were fed to at least maintain minimal weight loss. These estimates are based upon animals being fed, as needed, at a higher rate than currently, on prices remaining relatively the same as those found in the farm surveys and on sheds being used effectively to keep animals warm. Many farms have a 'warm' shed to trap heat and minimise the energy

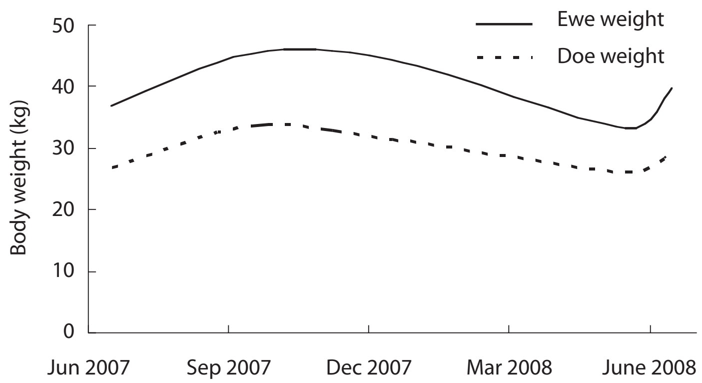

Figure 5. Changes in ewe and doe live weight from early winter to early summer (the main period of weight loss) in 2007–08 in Siziwang Banner, Inner Mongolia Autonomous Region

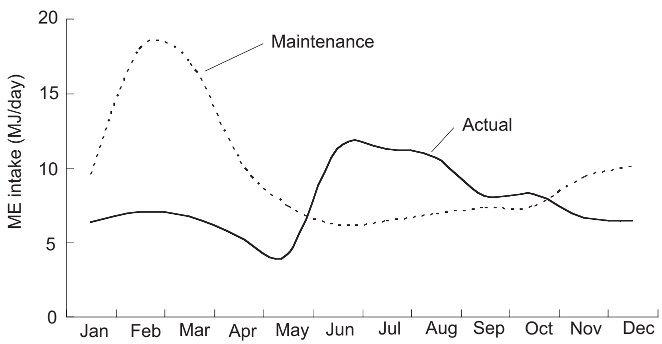

Figure 6. Estimated monthly trends in metabolic energy (ME) intake for ewes on the typical farms at Siziwang Banner, Inner Mongolia Autonomous Region, based on live-weight estimates, showing actual energy intakes and the intakes required to maintain live weights

loss of livestock in cold weather, although they are not always used effectively.

The current average stocking rate in Siziwang is considerably above the financial optimum (point on Figure 8 at ~0.8 breeding ewes/ha) and it is clear the current rate is only marginally profitable. Stocking at half the rate (~0.4 breeding ewes/ha) is significantly more profitable (4×) due to the reduced need for winter supplements and from keeping animals in a warm shed. Lower stocking rates significantly reduce the grazing pressure on the grasslands and that would provide opportunities for rehabilitation of this degraded resource.

Improved feeding of Mongolian fat-tail sheep during winter and spring

Improved feeding can enhance animal performance and, in some cases, grassland performance. Feeding livestock through the year at Siziwang commonly depends upon the grasslands available, which for much of the year are dead and scarce, and then whatever supplements the herder can obtain.

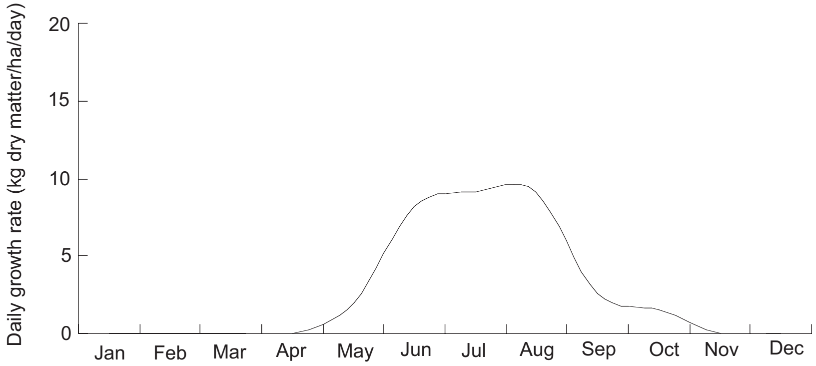

Figure 7. Estimated daily grassland growth rates for fields managed for summer or winter grazing in Siziwang Banner, Inner Mongolia Autonomous Region

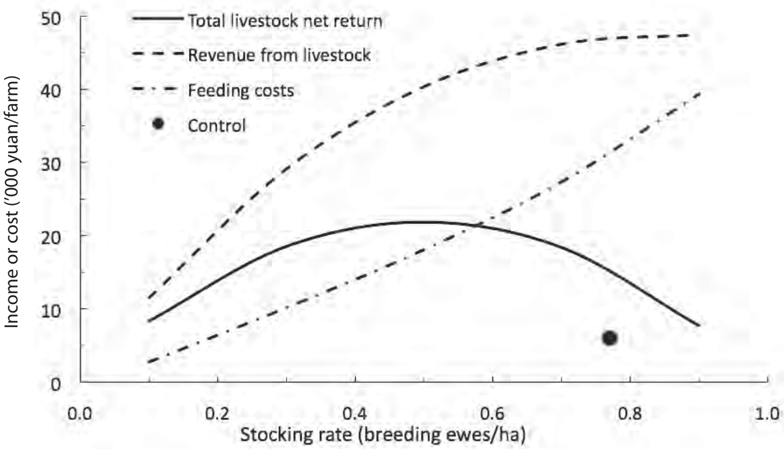

Figure 8. Livestock production revenue and feed costs for the current meat production system in Siziwang Banner, Inner Mongolia Autonomous Region, when animals are fed to maintenance requirements and kept through winter in a warm shed. The 'control' data point is an estimate of current net income from livestock on farms in same area, in which case animals graze outside all year, are not fed to maintenance requirements, and revenue and feed costs are less than apply in other calculations.

Supplementary feed in Siziwang commonly consists of mixtures of maize grain, stover and silage, grassland and opportunistic hay, millet stubble and concentrate (mixed and milled feed), usually purchased off-farm in the neighbouring cropland areas. Farmers often purchase whatever they can, e.g. stalks of potato plants after harvest, and they primarily consider the quantity, not quality, of feed when purchasing. There was little evidence that they were purchasing on an energy basis, whereas energy was clearly a major constraint that needed to be satisfied first. Some concentrates were sold on protein content, although it was highly likely that much of that protein would be used only as an energy source by starving livestock.

From the results of the field survey, it was evident that some farmers considered that concentrates cost too much, especially for adult animals. Consequently, they chose to feed concentrates to only pregnant ewes and lambs and for a short period. This was not always as strategic as it could have been: e.g. ewes were sometimes fed only from the time of lambing instead of a month before that, which would have beneficial effects on lamb development and lactation, or fed at low rates when that feed was available. No variation in rates of feeding commonly occurred (Table 2). To adequately feed ewes around lambing would require 1 kg/head/day, but often only 0.1 kg was actually fed. Maize stover, millet stubble and many of the hays stored had an estimated digestibility of less than 50%, which would at best cause only a slow rate of weight loss in a non-pregnant animal, but they too were fed at a low rate and thus would not stop much weight loss. More detailed analyses of the fodder stores on farms indicated that the actual amount stored was less than would be required to feed the animals for the periods specified. It further emerged that not all farmers could accurately estimate weights as they had limited training in that skill.

The models were used to analyse the costs and benefits of alternative feeding strategies (Figure 9). The ME balance comparisons between grazing grasslands versus maize hay, maize grain, millet hay and concentrate, in various combinations, suggest that feeding supplements of grass hay and millet hay or feeding supplements of maize grain and concentrate to grazing sheep were better than if the sheep only grazed. However, this was still not adequate to meet the ME demand. Results are improved when the sheep are fed hay, millet hay, maize grain and concentrate supplements, yet there is still a gap between modelled and actual ME demand from November to the following May. This may be attributable to lambing and lactation having greater ME costs. It may not matter, however, if animals are in a small negative energy balance for part of the year, utilising energy reserves in their body tissues, provided they can rear larger lambs and they have plenty of feed available to regain weight and restore body reserves after weaning.

The differences between feeding maize hay and millet hay versus maize grain and concentrates are largely due to the differences in the energy values of each feed source, but farmers are reluctant to purchase feed with higher energy contents as they see them as simply too expensive. Advisory services need to develop demonstrations and training material to properly test and explain how purchasing feed on a cost per unit of energy is the better strategy, as these results clearly show that small changes in feeding practice could significantly improve animal performance. Heavier ewes (and does) are likely to produce larger winter lambs and more milk, leading to larger and faster growing young livestock.

Changing lambing time

The field survey recorded that the lambing time of local Mongolian fat-tail sheep in Siziwang was from

Table 2. Supplements commonly fed if available, and rates of feeding (kg dry matter (DM)/head/day), to Mongolian adult fat-tail sheep through the autumn, winter and early spring in Siziwang Banner, Inner Mongolia Autonomous Region

Supplements	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Digestibility (%)
Maize hay	0.2	0.25	0.5	0.5	0.5	0.5	0.25	0.2	65
Maize grain	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	72
Millet hay	0.2	0.25	0.5	0.5	0.5	0.5	0.25	0.2	66
Concentrate					0.2	0.2	0.15	0.1	70

December through April, although most lamb in winter, around February. Those results suggest pregnancy starts in September, which would coincide with when ewes are in their best condition for the year and when rams would be at their most fertile. However, lambing in winter, when ewes are rapidly losing weight, leads to small lambs and poor lactation. Lambs have to be restricted in the milk they get from their mothers and fed concentrates from 10 days of age, or soon thereafter. Lambs are then struggling for some time before there is adequate green forage available from the grasslands, typically in July.

An alternative strategy would be to lamb in April, so that the ewes would be less stressed in the middle of the cold winter, and it would then be a shorter period before the lambs could graze green grass. The models were then used to evaluate the effects on ewes of April versus February lambing (Figure 10). In each case, the same types of supplements (maize hay, maize grain, millet hay and concentrates) were fed to the lambs and kids. The results show that an April lambing would result in improved nutrition of the ewe and an expectation that this would deliver benefits in the lambs.

By delaying lambing until April the ewes' energy requirements through winter are reduced, as is the gap between actual and maintenance energy intake requirements during the period of lambing (Figure 10). Lambing in April reduces the number of months where maintenance requirements are not satisfied. The warmer temperatures in April would further reduce stress on the ewes and lambs. This modelling did not estimate what effect lambing in April would have on lamb size, condition and growth rates, but the likely better ewe condition would be expected to carry through to the lambs. Additional analyses were done to estimate nutritional effects of lambing in summer. While more forage would be available at the time of lambing, extra feed would be required at other times to sustain the ewes, especially to attain a high level of pregnancies in mid-winter when animals are losing weight.

The economics of alternative lambing times were investigated with the *StageTWO* model in relation to

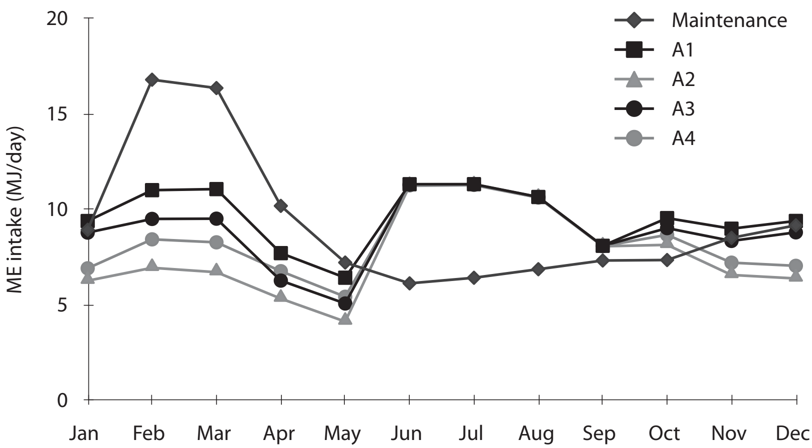

Figure 9. The effect of different possible supplements on estimated metabolisable energy (ME) intake by livestock in Siziwang Banner, Inner Mongolia Autonomous Region. Results derived from *StageONE* model. Maintenance: the energy required for maintenance at the same live weight; A1: actual energy intake of grazing all year with supplements (maize hay, maize grain, millet hay and concentrates) fed from October to the following May at the same live weight; A2: actual energy intake of grazing all year round on grasslands at the same live weight; A3: actual energy intake of grazing all year with supplements (maize hay and millet hay) fed from October to the following May at the same live weight; A4: the actual energy intake of grazing all year with supplements (maize grain and concentrate) fed from October to the following May at the same live weight.

optimising stocking rates and to feeding ewes to minimise any weight loss through the year. The modelling showed that, at low stocking rates (0.3–0.4 breeding ewes/ha, about two-thirds of current stocking rates, Figure 11), there were few differences between lambing times but, as stocking rates increased, lambing in July was more profitable and lambing in April uneconomic. These differences arose from rapidly increasing feed costs at higher stocking rates when lambing in April. At low stocking rates the costs of feed required for January and July lambing were similar, as the quantities required were similar, but as shown in Figure 11, the nutrition of ewes with July lambing was better. In these analyses no allowance was made for lambs born in July possibly being larger, or growing faster, as there are insufficient local data on those things. There were no differences assumed in gross income received for lamb sales or wool from the ewes. The only difference considered was the feed cost, which was determined by how much feed would be required (using a least-cost ration approach) to maintain ewe weights. Experiments would need to be done to investigate the effect of July lambing on flock and grassland performance, as it is likely that more benefits would accrue than these results suggest. Earlier it was shown that reducing stocking rates by half could lead to higher net farm incomes. That is obviously the first step in enterprise improvement. Once that had been done then changing lambing times could be worth further investigation.

Use of warm sheds during cold seasons

Siziwang is located on the Mongolian Plateau at an altitude of 1,450 m. The winters are cold. The mean monthly temperature around lambing time in January, the coldest month, is –15 °C. The effect of low temperature is compounded by high winds. The daily heat loss for sheep has been estimated at 9 –17 MJ /day during winter when the average temperature is below –5 °C, i.e. approaching twice the energy requirement of these animals in mild conditions. To further exacerbate intake problems, snow cover, combined with very little or no standing forage, prevents the animals from finding much to eat. At these times and under these conditions livestock mortality can be high. Consequently, there has been increasing interest in constructing 'warm' sheds, in which the half of the roof facing south is replaced by plastic or glass to trap the heat and the sheds are built or modified to minimise heat loss. Limited data on these sheds have shown that temperatures inside can be 10–11 °C higher than in a traditional shed. Traditionally livestock have been taken out to graze every day of the year, but the energy costs of walking and dealing with the cold are arguably greater than any benefits from grazing. Analysing the effect on energy intake of feeding and retaining animals in warm sheds from December to February (Figure 12) showed that actual intake used for maintaining animal function was then closer to maintenance requirements, although there was still a gap from January to May. The gap may due

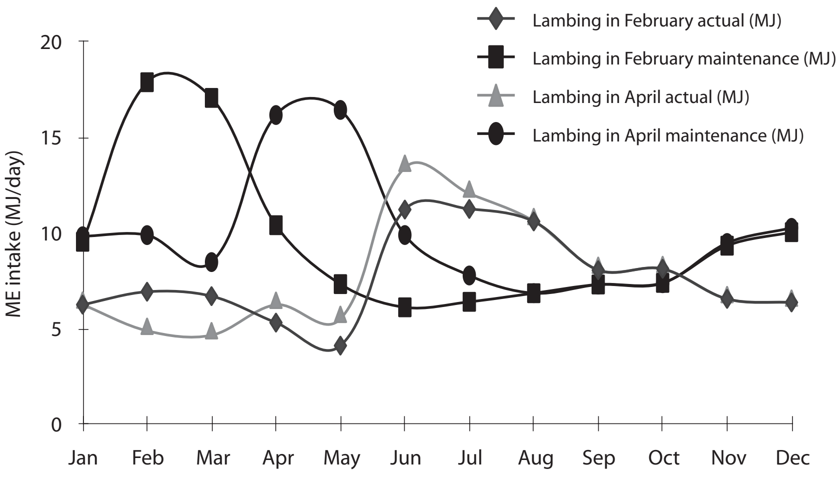

Figure 10. The effect of lambing time on energy balance (ME = metabolisable energy) of ewes at Siziwang Banner, Inner Mongolia Autonomous Region

to lambing and lactation having a greater ME cost. The results would be expected to reduce live-weight losses. The better performance would then lead to better lambs in winter.

The merit of pen feeding in a warm shed was then further evaluated against the traditional practice of grazing all year, using the *StageTWO* optimising model over a range of stocking rates. Preliminary analyses suggested that the period from December to February inclusive was the most critical for animal welfare and the time when the cost of supplementary feeding was within the likely resources of farmers. These analyses (Figure 13) assumed that animals would be fed close to maintenance requirements for actual body weights.

The results indicate that, while feeding costs were marginally higher (Figure 13b), the returns from weaners sold after pen feeding in warm sheds from December to February were also higher (Figure 13a) than for year-round grazing. When stocking rates were below 0.3 ewes/ha little difference was found in total herder net returns between year-round grazing and pen feeding from December to February. The optimal stocking rate for livestock kept in year-round grazing in the coldest part of winter increased to 0.5 ewes/ha, due to the higher returns from weaners, reflecting their better performance under these conditions. Pen feeding with summer grazing below 0.3 ewes/ha does, however, result in higher net returns compared with year-round grazing at 0.5 ewes/ha (Figure 13c).

The optimal strategy from these analyses was to feed ewes in the warm sheds for 90 days with a least-cost ration of 1 kg hay and 0.2 kg concentrate/day. Subsequent local experience is that ewes managed with this strategy have demonstrated the ability to maintain or improve body weight as gestation progresses. Pen feeding removes grazers from grasslands, reducing the impact of grazing on the grasslands and leading to small but perhaps useful increases in groundcover during spring.

Other analyses found that, if animals were pen fed from November–December through May, to reduce the damage to grasslands, that costs would exceed

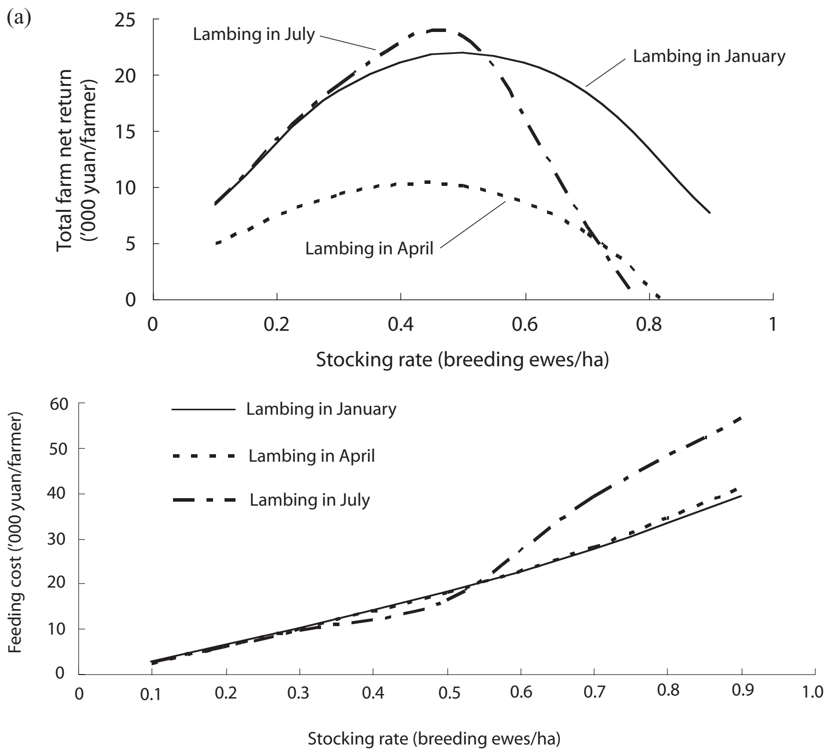

Figure 11. (a) Total farm net returns and (b) feeding costs under different lambing times in Siziwang Banner, Inner Mongolia Autonomous Region

any extra income from animals under current markets (Figure 14). Hence, farmers are unlikely to adopt this approach at present. Confining animals in warm sheds from December to April or March is, however, as profitable as current practices at low stocking rates and most profitable at a stocking rate about 0.3 ewes/ha. Ideally, grazing should aim to leave as much residue on the grasslands through winter into spring, to reduce erosion and grazing pressure on grasslands during initiation of new growth by forage plants in spring and early summer. This would promote increased root and above-ground plant tissue development and plant vigour, all of which would contribute to improved grassland condition and reduced risk of wind erosion.

Modelling predictions shown in Figure 14 suggest that pen feeding for several months provides more favourable total farm net returns and lower feeding costs than year-round grazing. Our expectation was that the optimal period for grazing would coincide with the highest predicted forage availability and greatest levels of inherent forage nutrition. Using this hypothesis we designed a typical farm based on the Siziwang Banner farms database.

The *StageTWO* model was used to test the typical farm under various farming strategies. The modelling results differed somewhat from our expectations. Farm strategies with pen feeding in excess of 6 months were unprofitable due to feeding costs. The best farm strategy was grazing April to November and pen feeding for the rest of the year. This strategy reflects that December is a critical time for animals. Further work is needed to find cost-effective practices for feeding animals through autumn, winter and spring to minimise damage to the grasslands and to limit dust storms.

Discussion

The current livestock production system is based upon a traditional survival management strategy. The challenge is to find pathways that will enable household incomes to improve and, at the same time, provide the conditions under which rehabilitation of the degraded grasslands can occur. In Siziwang, farmers often purchased simply whatever they could and they primarily considered the quantity of feed rather than its quality. Furthermore, there was little evidence that they purchased feed requirements on an energy basis. In our modelling, energy deficit was clearly the major constraint that needed to be overcome. Alternative feeding strategies based upon what is available can improve animal nutrition. Feeding maize hay, maize grain, millet hay and concentrates from October to the following May in a pattern that better reflected animal needs yielded much better outcomes.

Changing lambing times to July better aligns feed supply and demand and can reduce the need for supplements. Fewer supplements were required at this time for meeting the gestation and lactation demands of ewes and does. July lambing improved ewe nutrition and there is then an expectation that this would deliver benefits in the lambs. The financial benefits from lambing in July increased as stocking rates increased, although further work will

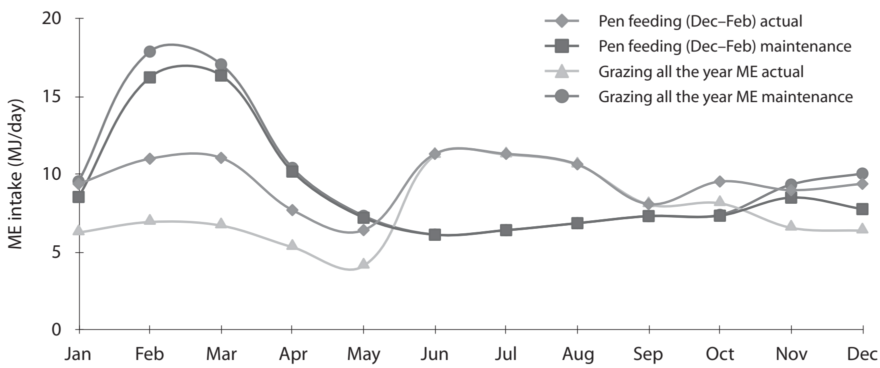

Figure 12. Energy balances for grazing ewes all year versus pen feeding in warm sheds in winter in Siziwang Banner, Inner Mongolia Autonomous Region (ME = metabolisable energy)

need to be done to review likely effects on grassland condition. The effect of feeding and retaining animals in warm sheds from December to March indicated that actual energy intake used for maintaining animal function was closer to maintenance requirements compared with grazing all the year. This would be expected to further reduce liveweight losses in ewes and does. The better performance would then lead to better lambs in winter.

Based on this modelling, the best financial strategy was grazing April to November and pen feeding for the rest of the year (for months). This requires pen feeding in a warm shed to get the greatest benefits. Temperatures in warm sheds are

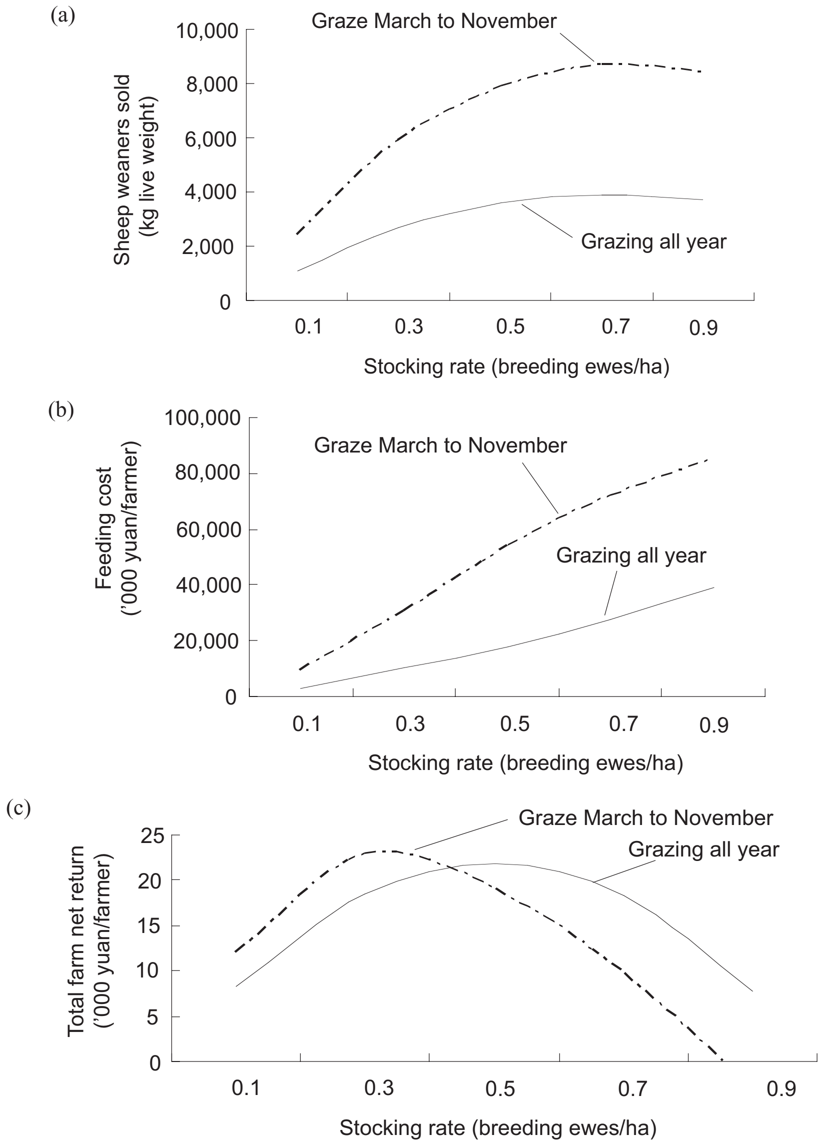

Figure 13. The estimated effects of stocking rate on sheep weaners sold (a), feeding cost (b) and the total farm net return (c) in Siziwang Banner, Inner Mongolia Autonomous Region for a typical farm, determined using the *StageTWO* model (see text for details)

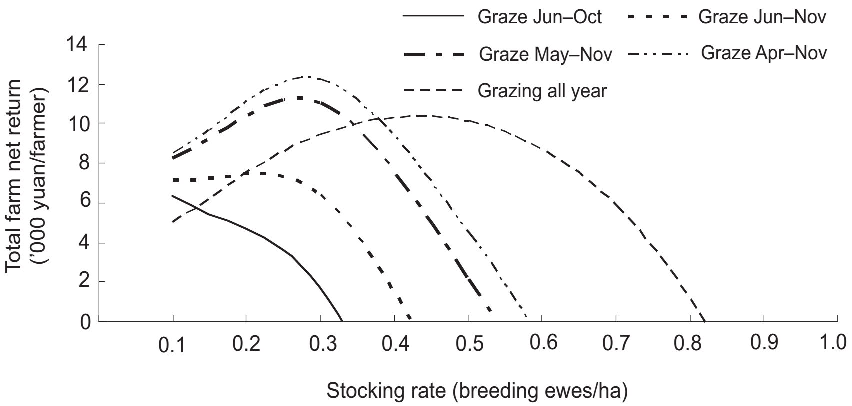

Figure 14. Total farm net return when animals graze all year and are fed supplements to maintenance requirements, or are grazed for part of the year and then pen fed for the remainder

typically more than 10 °C above outside temperatures. Animal nutrition was further improved by feeding a better designed ration using maize hay, maize grain, millet hay and concentrates from December to the following March. Lower stocking rates (0.3 ewes/ha) than year-round grazing (0.5 ewes/ha) could then be used to achieve as good or better net financial returns as apply on farms at present. Lower stocking rates then provide opportunities for grassland improvement.

Data collected from Siziwang showed that the prices of supplements are increasing, which will put more pressure on the grasslands and further reduce household incomes. To achieve the twin aims of improving household incomes and rehabilitating grasslands it may prove necessary to subsidise feed costs. Such subsidies may be needed to initiate a change in practices on farms, particularly to reduce stocking rates. Work will be needed to establish the rate of recovery of grasslands, then what stocking rates could be restored. Demonstration farms will probably be needed to show how these improvements could work in practice and to convince other farmers to adopt new livestock and grassland management practices with increased confidence.

There are limitations in our analyses to date that will require future attention. First, the sufficiency and accuracy of input data, as much is derived from farm surveys and a limited amount from experiments. These concerns range from the determination of grassland growth rates and of how they may change with different livestock management practices. If stocking rates are halved, this could result in higher grassland growth rates but not much is known about the likely scale of the effect and these potential benefits were therefore not built into the models; i.e. a conservative modelling approach was adopted. Second, the model simulates only average conditions. In future it would be useful to include estimates based on variability in climate and seasonal conditions. For example, analyses of rainfall variability at Siziwang have shown that the coefficient of variation in rainfall in May and June can approach 70%, whereas for the whole summer it is closer to 30%. Third, animals in Siziwang are at the limits of researcher experience in terms of their growth and development under very marginal conditions. Their annual cycles of starvation and then compensatory growth often only happen in other environments at less frequent intervals, as in exceptional droughts. These analyses have been done using current costs and returns and no account was taken of how better production from animals could attract better prices in markets.

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Grazing experiment on desert steppe in Siziwang Banner, Inner Mongolia Autonomous Region. This shows mid-summer vegetation under a moderate stocking rate. [Photo: D.R. Kemp]

Participants in an early winter meeting of the research team with herders, local officials and students, on the desert steppe at Siziwang Banner, Inner Mongolia Autonomous Region
[Photo: D.R. Kemp]

An example of a new warm shed (note the clear plastic roof) in the Inner Mongolia Autonomous Region. Holding animals at higher temperatures during winter reduces their weight loss.
[Photo: D.R. Kemp]

Policy environment for grassland and smallholder improvement

Although even goats are not interested in eating it, stover and 'hay' are used for winter fodder in Huanxian county, Gansu province. Herders need training on the benefits of using high-quality fodder rather than larger quantities of fodder. [Photo: D.R. Kemp]