Grassland rehabilitation through re-designing livestock management systems

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Abstract. Grasslands are one of the most important land types supplying critical ecosystem services including feed for livestock grazing. They occupy ~54% of the world's ice-free land surface. China contains the third largest area of grassland in the world, ~400 M ha, ~40% of China's land surface. Chinese grasslands are severely degraded primarily due to overgrazing, which contributes to local poverty because of poor livestock production. To both recover the degraded grassland and to enhance the local herders' income, a large farm-scale experiment was conducted in a desert steppe of Inner Mongolia, China from 2007 to 2012. We used a baseline survey, production models, and extension with government and private companies to test a redesigned grassland livestock management system. The new system employed summer grazing, winter greenhouse shed feeding, a reduction of overall stocking rate, lambing in summer (July), livestock infrastructure structure improvements, use of animal nutrient supplements, and incorporating crossbred Dorper and Mongolian sheep. This system showed positive advantages on animal production and household net income and transformed livestock production from a survival to a production enterprise. Of critical additional importance was that grassland rehabilitation occurred with the new management system, albeit slower than the more immediate positive changes to animal performance and herder net incomes. The integration of science, government and industry were key for this successful large-scale farm experiment.

Keywords: Stocking rate, farm-scale models, demonstration, extension, collaboration, desert steppe.

Introduction

Grassland includes natural grasslands, shrublands, woodlands, savannahs, tundra, deserts and alpine meadows, representing ~54% of the earth ice-free area (Estell *et al.* 2012). Grasslands provide not only food, fibre and other provisioning goods, but many additional ecosystem services (Havstad *et al.* 2007). Chinese grasslands are important parts of the Eurasian steppe. Many Chinese people have lived a transhumance existence on these grasslands for centuries. This use entails extensive grazing with few inputs. Livestock numbers have increased dramatically in recent decades. As a result, grassland degradation has become increasingly widespread and while livestock performance declined contributing to declining livestock based incomes and increasing levels of local poverty. Major features of degraded grassland are decreases in plant cover, net primary production, the capacity of soils to sequester carbon, increases in soil erosion and greenhouse gas emission from soil (Kemp *et al.* 2013). The key issue is the need to address both local poverty and grassland rehabilitation in concert at the same time. The Chinese Central government and local governments have made concerted efforts to restore degraded grasslands since 1985 (Han *et al.* 2008). More practical measures have been carried out since 2002, including people relocation, forage reseeding, grazing bans and fencing, which have promoted grassland recovery. However, implementations of these measures have been expensive and unsustainable.

Long-term overgrazing has been viewed as the key internal driver of grassland degradation with associated declines in animal performance resulting in herder impoverishment. Manipulation of grazing management, in particular reduction in stocking rates, has been employed as the least expensive and most useful tool to recover degraded grassland (Papanastasis 2009). However, other tools need to be employed to address herder incomes. In order to both restore degraded grassland and to enhance local herder incomes a large farm-scale experiment was conducted in Inner Mongolia, China from 2007 to 2012. The hypothesis that redesigning a farm-scale grassland livestock management system could both restore degraded grassland and improve household net income was tested in this experiment.

Methods

An experimental test of a redesigned farm-scale sheep grazing management system that emphasized both reduced stocking rates and technologies to improve individual animal performance was carried out in a desert steppe area of northern China from 2007 to 2012. A baseline survey on individual households was done to understand the existing, traditional sheep grazing management system in order to identify common problems. Survey results were used to develop a series of models to optimize both livestock production and household net income. Individual households were then selected as demonstration farms to test the models. We then solicited both local government and private company support to extend our demonstration households to additional farms in an expanded test of our hypothesis.

Experimental site description

The experimental site was in Siziwang Banner, Inner Mongolia, China. Siziwang Banner (county) is north of Hohhot, the capital city of Inner Mongolia Autonomous Region. Siziwang Banner is within an ecotone from cropland to grassland, which is north of Yin Mountain. The landscape is flat across the Mongolian Plateau (1500m altitude) (Fig. 1). The climate is characterized by cold winters, windy springs, and low annual precipitation that typically occur from July to September (Fig. 2). The vegetation is classified as desert steppe, a unique type of vegetation in China and Eurasia. Meadows are interspersed in lower lands within the large area of desert steppe. Soils are mostly light and brown chestnuts, which are of lower inherent fertility than soils from more mesic steppe. The main industry in this area is livestock agriculture though some areas are used for energy development. Grassland degradation is very serious due to overgrazing and drought (Han et al, 2011), and local households are impoverished.

Baseline Survey

Typical farms were grouped using information from Bayin Gacha (village in pastoral area), Chaganbulige Township, Siziwang Banner. Fifteen households were selected in 2005 as part of the survey to understand the current situation of management and economic levels. Semi-structured interviews were used to obtain data on economic, social and biological aspects of grassland management and livestock production. We selected six households for more detailed data, including livestock fat score, individual livestock teeth number, lamb birth weights, and different period economic inputs and outputs of households. Grassland production data were collected from long-term exclosures and a controlled stocking rate experiment within the study area (Wang *et al.* 2011). The typical farm had 520 hectares of grassland and 0.67 hectares of cultivated field for fodder production under limited rainfall, 270 adult sheep and goats with an average annual production of 214 lambs and kids. The flocks were 70% sheep and 30% goats (Han *et al*. 2011).

Australian Centre for International Agricultural Research (ACIAR)-Models and application

Three models (ACIAR Stage I, II, III) were used to test the balance between forage supply and livestock requirements, to predict the effect of changing the grassland livestock management system and to assess its sustainability (Takahashi *et al*. 2011; Han *et al*. 2011; Wang *et al*. 2011). The data used in the models were based on household surveys and results from the controlled grazing experiments (Wang *et al.* 2011).The Stage I model used calibrated farm data, analysed the metabolisable energy (ME) balance between feed supply and demand for all animal types and classes on the farm on a monthly basis under steady-state conditions, and was used to investigate scenarios for a range of potential livestock management options. Many management options were analysed in this model and the most promising were then tested further in other models.

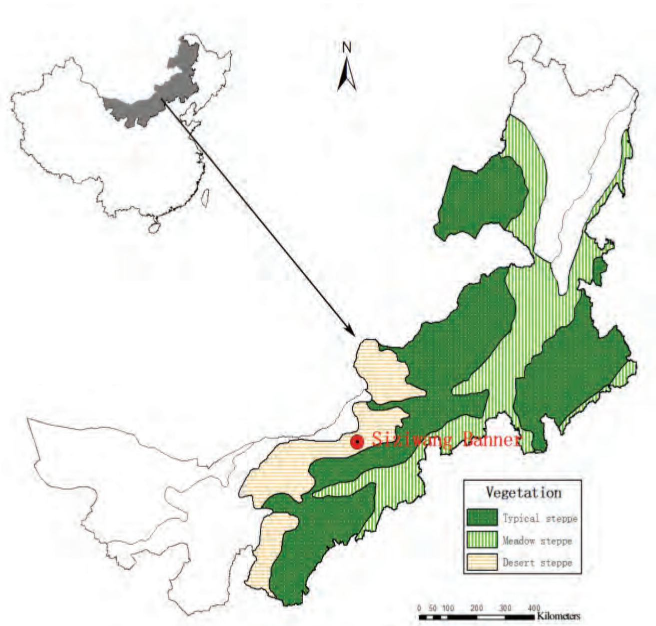

Figure 1. Experimental site.

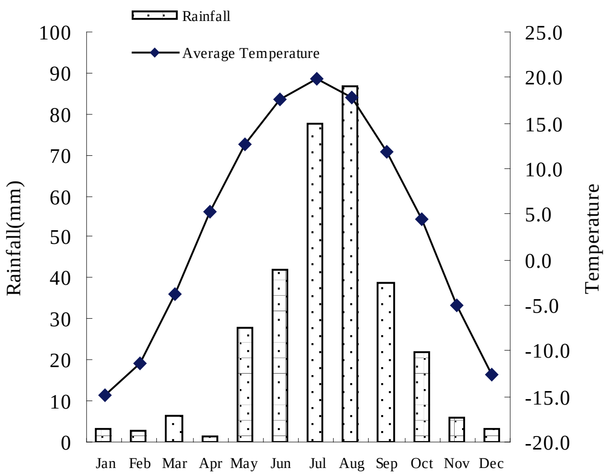

Figure 2. Mean monthly temperature and precipitation in Siziwang Banner (1986-2006), Inner Mongolia.

Stage II model is a steady-state linear program optimising model used to predict the optimal combination of factors that would enhance household income while changing stocking rate and other factors including lambing times, livestock infrastructure change (conventional or warm sheds) and livestock feeding strategies. Stage III model is a dynamic model, designed to take the better solutions from the previous two models and investigate long-term impacts on plant diversity and on wind-caused soil erosion. Plant diversity was analysed in terms of a simple model that grouped species functionally as desirable and less-desirable for livestock production. Scenarios explored included adjusting stocking rates in relation to the herbage mass on the grassland.

The results from the models were validated in a limited grazing experiment and on farms where herders had adopted the new management system.

On-farm Experiment

In 2007-2008, three experimental households using a redesigned livestock management system with reduced stocking rates and three control households utilising traditional management practices were selected to test the new management system. The main changes for the experimental farms were summer grazing for a 15% reduction in annual stocking rates and then animals were fed in a greenhouse shed through winter for about 3 months. The control farms used their traditional systems for grassland and livestock management. Livestock live weights, teeth conditions, fat scores (1-5 system), ewe udder scores, lambing times, lamb birth weights stocking rates, and forage and feed supplies were recorded every three months. The operational costs and income were recorded for the experimental and control farms. This farm experiment was used to demonstrate the model results.

Extension with government and private company

We worked with local government and a private company, Sainuo Sheep Company. The local government provided organisational support for the herder association to adopt new technology and subsidised cross-breeding of Dorper with local Mongolian fat-tail sheep. The private company promoted and marketed sheep products in 2009. Lambs of the crossbred sheep exhibited greater growth rates and higher quality carcasses. As a result, 560 households have now adopted the new management system during the first phase of the project and by 2012 (the second phase) 1200 households opted to utilise the new management system. Livestock responses, stocking rates, production costs, net income and grassland condition of 30 farms with the new grassland livestock management system and 61 traditional farms were summarized in order to evaluate the effects of the redesigned management system on livestock production, economic returns and grassland rehabilitation.

Results

Forage supply and livestock demand based on metabolisable energy

Modelling (Stage I) of the traditional farm management with year-long grazing and minimal nutrient supplementation led to low winter and spring forage and feed supply. These conditions result in low livestock production and excessive grassland degradation. Livestock managed under the traditional system always faced deficit ME balances during the winter-spring season, a critical period for livestock when most sheep begin lambing (Fig. 3a). When we changed the year-long grazing management to summer grazing and winter greenhouse shed feeding (half year using local feed type and rates) the ME deficit between forage supply and livestock requirement was greatly reduced due to the increase of forage and feed supplies in winter and spring (Fig. 3b).

Optimizing stocking rate and lambing time

The Stage II model identified the financially optimal stocking rate as 0.5 breeding ewes/ha, which is 65% of the traditional stocking rate of 0.76 breeding ewes/ha and net financial returns from livestock could double when animals were fed to maintain liveweight through winter and spring (Kemp *et al.* 2013). Reducing the stocking rate to 2/3 of the current situation then significantly improved the feed supply for each animal. Though production per unit area was reduced, the gain in production per unit animal over-compensated for this loss. The lower stocking rate provided the opportunity, through reduced grazing pressure, to rehabilitate grasslands. Modelling further showed that shifting the lambing time from February to April significantly reduced the ME deficit between forage supply and livestock requirement due to increased forage availability by early spring (Han *et al.* 2011). The net income per household was optimal when lambing occurred in July (Han *et al.* 2011). The local private company and herders then implemented a July lambing practice.

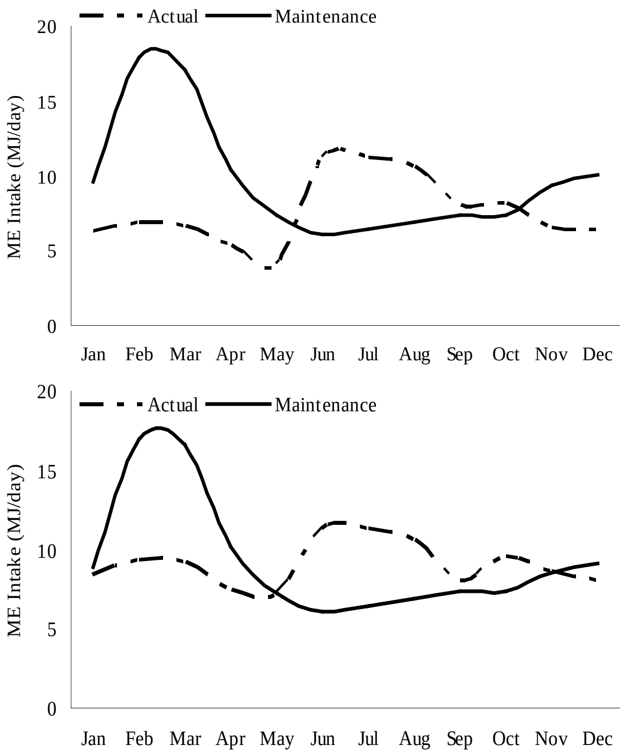

Figure 3. Stage I model of forage supply and livestock requirement (as ME) with (top) year-long grazing management and (bottom) summer grazing and winter greenhouse shed feeding for five months.

Demonstration of summer grazing and winter greenhouse shed feeding with destocking

Compared to year-long grazing, the demonstration experiment showed that the model predictions of only summer grazing and winter greenhouse shed feeding (3 months) with a 15% stocking rate reduction significantly reduced the liveweight loss of ewes in winter and spring (Fig. 4) with no additional net income reduction from livestock in the demonstration period (Fig. 5).

Extension and application

The 30 farms that initially adopted the new management system significantly reduced their stocking rate by 23%

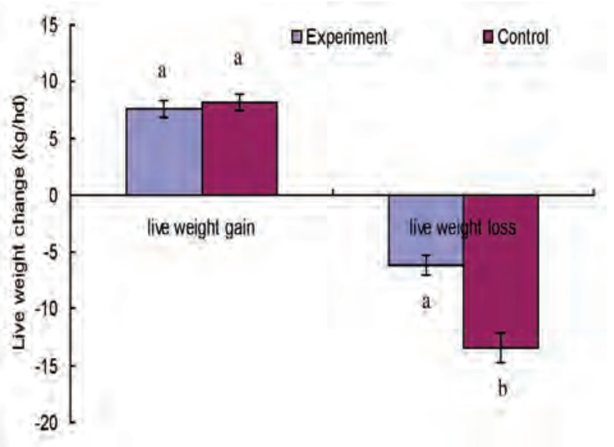

Figure 4. Liveweight gain in summer-autumn and loss in winter-spring of both experimental and control farms in Siziwang Banner, Inner Mongolia Autonomous Region from 2007 to 2008.

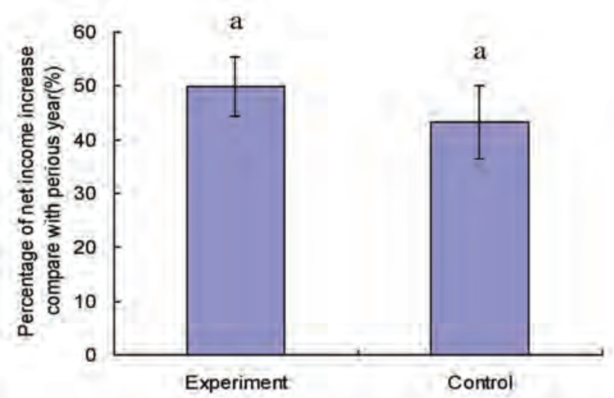

Figure 5. Net income increase of experimental and control households relative to previous year in Siziwang Banner, Inner Mongolia Autonomous Region from 2007 to 2008.

compared to the control farms and received 62% more net income per household than the control farms (P<0.05) (Table 1). However, the vegetation did not respond within the relatively short period the system was evaluated (Table 2), which is understandable in perennial grassland with a short growing season.

Discussion

Grassland degradation is a serious problem due to overgrazing throughout many pastoral areas of the world, including China, Mongolia and Africa. Traditionally, local herders will operate at high stocking rates in the belief that they can then extract higher livestock production from grassland resources. However, there are thresholds to stocking rate and livestock production that can be exceeded resulting in both production declines and land degradation. Can we design management systems that operate below these thresholds yet maintain land health while also increasing livestock production and herder incomes? Our experiences in Siziwang Banner in Inner Mongolia through six years of collaboration among herders, scientists, government officials and company managers would indicate that these desired results are achievable.

Re-designing grassland livestock management for production improvement and grassland recovery

In northern China, grassland production changes with season and livestock often starve during winter and spring. Liveweight losses during these cold seasons are common (Han *et al.* 2011; Yang *et al.* 2011; Zheng *et al.* 2011). When year-long grazing season was changed to a summer grazing with winter greenhouse shed feeding (3-5 months) liveweight loss was dramatically reduced (Fig. 4) due to improved nutritional levels from January to May (Fig. 3). This reduced grazing season has resulted in more litter remaining within the grassland and increased soil moisture for vegetation seedling establishment and survival in the subsequent year (Willms *et al.* 1993; Wang *et al*. 2011). The stocking rate reduction (34%) from 0.76 to 0.5 breeding ewes/ha resulted in increases in both gross income and feed costs, with maximum net income achieved at a stocking rate of 0.5 breeding ewes/ha (Kemp *et al.* 2013). Even with the reduction of stocking rate, the net incomes in experimental farms were same or higher than the control farms (Fig. 5 and Table 1), and also resulted in reduced grazing pressure on the grasslands. The new management system worked well given the multiple tactics of destocking, a shorter grazing season plus winter greenhouse shed feeding, proper nutrition for livestock in different seasons, and a lambing season more suited to spring forage growth. Therefore, the farms under the newly redesigned management had several positive advantages over the traditional year-long grazing system with low management inputs (Kemp *et al*. 2013). It was obvious that liveweight production and net income increased when new grassland livestock grazing management system was adopted in this area and other grasslands, such as the alpine meadow in

Table 1. Stocking rate and net income on control and on farms that had adopted the new grassland livestock management system after four years.

Farms	Area (ha)	Adult sheep number	Stocking rate (sheep unit/ha)	Cost of supplement (Chinese yuan/household)	Net income (Chinese yuan/household)
Control	406.4±54.2b	285±28b	0.61±0.05a	51,181±14,576a	94,715±15,543b
Experiment	785.1±145.0a	393±58a	0.47±0.06b	56,007±14,949a	278,442±57,348a

Table 2.Vegetation characteristics after four years extension in control and extension farms – there were no significant differences between the farms.

Farms	Coverage (%)	Plant density (No./m^2)	Plant species No. (No./m$^{2)}$	Percentage of annuals (%)	Plant community biomass (kg/ha)
Control	39.6±1.9	576.9±48.6	22.9±1.3	31.6±6.2	1,307.1±81.6
Experiment	41.6±3.5	684.5±30.6	26.7±1.7	20.7±4.4	1,146.5±109.4

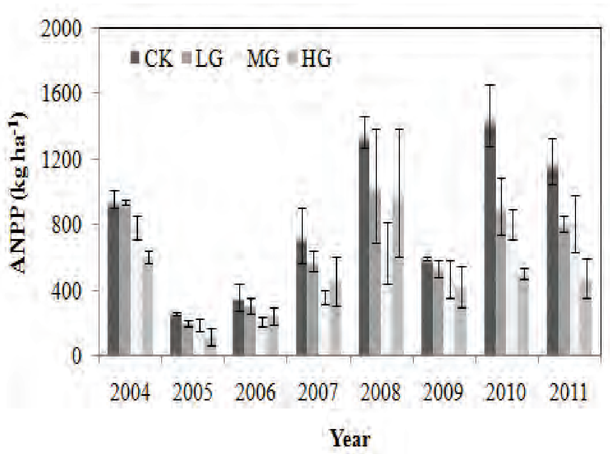

Figure 6. Aboveground net primary productivity at different stocking rates from 2004 to 2011 in a grazing experiment at Siziwang Banner.

Gansu and the typical steppe in Xilingole (Yang *et al.* 2011; Zheng *et al.* 2011). The new management system converted the traditional livestock management from a survival system to a production management system. This shift is a revolution within these pastoral areas (Kemp *et al.* 2013). In the new system, households explicitly alter their role to emphasize an animal production business with higher investment and higher net income.

Our results indicated that vegetation characteristics did not significantly change during the 4 years of this study. However, longer-term, controlled stocking rate experiments in the same area showed that aboveground net primary productivity under light and moderate stocking rates (66% and 33% reduction compared with heavy stocking) were much higher ($P<0.05$) than heavy stocking rates in the sixth and seventh grazing years (Fig. 6, Wang *et al.* in preparation), which illustrates the long time required for vegetation to respond to a reduced stocking rate. Attributes of vegetation recovery, including species, productivity, soil stability and ecosystem process and functions, are often uncoupled with improvements in livestock performance and increases in net income.

Science application

Sustainable grassland livestock management systems are highly complex because they incorporate plant, animal, soil, social and economic aspects. Interdisciplinary and multidisciplinary studies were required for the successful extension of our new management system applied at household scales. Scientists from China and Australia worked on the basic research, such as controlled stocking rate experiments and model development and then constructed productive tools for extension. Local government developed useful and practical policies to support households adopting these new technologies, helped to organize herders association and to support needed training in newer technologies for animal husbandry. A private company collaborated with herders, local government and scientists to promote the development of markets for higher quality animal products from these desert steppe grasslands. The use of Dorper-Mongolian fat-tail sheep crosses was an important element of the overall management system. The keys for the collaboration of herders, scientists, government officials and company managers were: (1) understanding the grassland livestock management system; (2) learning goals and objectives of each partner group; (3) emphasizing ecological limits and potentials in developing the management enterprise; and (4) and focusing on positive household livelihood outcomes as well as grassland improvement. Our achievements have been recognised by the Chinese and Australian Governments and other countries. Three subsequent projects have been funded by The Ministry of Agriculture of China, The Ministry of Science and Technology of China, and Australian Centre for International Agricultural Research to apply our useful grassland livestock management. These projects cover much of pastoral areas of China, including Inner Mongolia, Gansu Province, Hebei Province, Xinjiang Autonomous Region, Jilin Province, Sichuan Province, Qinghai Province, and Xizang Autonomous Region.

Conclusion

Degraded grassland can be recovered through re-designing the grassland livestock management system based on principles of proper stocking rate and improved individual animal performance. This new system includes summer grazing and winter greenhouse shed feeding, destocking, lambing time change, livestock infrastructure improvements, and improved animal nutrition. These factors resulted in improved livestock production efficiencies and enhanced net income of households. Science transfer needs herders, scientists, government officials and company manager working together to incorporate scientific findings into practices that can result in both grassland rehabilitation and local livelihood benefits. Recovery of degraded grassland with new grassland livestock management system will require time.

The key steps for implementing a successful new grassland livestock management system included: (1) understanding different aspects of grassland livestock systems including grasslands, livestock, herders, finances, social and religion factors; (2) using different models to evaluate different scenarios and predict possible changes; (3) demonstrating at farm-scales the management practices needed to adjust the management, and (4) evaluating the processes in order to apply principles of adaptive management.

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References

Estell RE, Havstad KM, Cibils AF, Fredrickson EL, Anderson, DM, Schrader TS, James DK (2012) Increasing shrub use by livestock in a world with less grass. *Rangeland Ecology and Management* **65**, 553-562.

Han GD, Li N, Zhao ML, Zhang M, Wang, ZW, Li ZG, Bai WJ, Jones R, David KR, Takahashi T, Michalk DL (2011) Changing livestock numbers and farm management to improve the livelihood of farmers and rehabilitate grassland in desert steppe: a case study in Siziwang Banner, Inner Mongolia Autonomous Region. In: Kemp D R, and Michalk D L (Eds.) Development of Sustainable Livestock Systems on Grasslands in North-Western China. *ACIAR Proceedings* 134, 80-95.

Han JG, Zhang YJ, Wang CJ, Bai WM, Wang YR, Han GD, Li LH (2008) Rangeland degradation and restoration management in China. *The Rangeland Journal* **30**, 233-239.

Havstad KM, Peters DP, Skaggs R, Brown J, Bestelmeyer B, Fredrickson E, Herrick J, Wright J (2007) Ecological services to and from rangelands of the United States. *Ecological Economics* **64**, 261-268.

Kemp DR, Michalk DL (Eds.) (2011) Development of Sustainable Livestock Systems on Grasslands in North-Western China. *ACIAR Proceedings*, 134, pp189.

Kemp DR, Han GD, Hou XY, Michalk DL, Hou FJ, Wu JP, Zhang YJ (2013) Innovative grassland management systems for environmental and livelihood benefits. *Proceedings of the National Academy of Sciences of the United States of America* **110**, 8369-8374.

Papanastasis VP (2009) Restoration of degraded grazing lands through grazing management: Can it work? *Restoration Ecology* **17**, 441-445.

Takahashi T, Jones R, Kemp DR (2011) Steady-state modelling – for better understanding of current livestock production systems and for exploration of optimal short-term strategies. In 'Development of Sustainable Livestock Systems on Grasslands in North-Western China'. ACIAR Proceedings, 134, 26-35. (Eds DR Kemp, DL Michalk)

Wang J, Zhao ML, Willms WD, Han GD, Wang ZW, Bai YF (2011) Can plant litter affect net primary production of a typical steppe in Inner Mongolia. *Journal of Vegetation Science* **22**, 367-376.

Wang ZW, Han GD, Jones R, Kemp DR., Li ZG., Takahashi T, Zhao ML (2011) What are the solutions for dust and biodiversity on China's grasslands? In 'Development of Sustainable Livestock Systems on Grasslands in North-Western China.' ACIAR Proceedings, 134, 128-138. (Eds DR Kemp, DL Michalk)

Wang ZW, Jiao SY, Han GD, Zhao ML, Willms WD , Hao XY, Wang J, Din HJ, Havstad KM (2011) Impact of stocking rate and rainfall on sheep performance in a desert steppe. *Rangeland Ecology and Management* **64**, 249-256.

Wang ZW, Jiao SY, Han GD, Zhao ML, Ding HJ, Zhang XJ, Wang XL, Ayers EL, Willms WD (in preparation) Effect of stocking rate on the variability of plant community productivity in a desert steppe.

Willms DW, McGinn SM, Dormaar JF (1993) Influence of litter on herbage production in the mixed prairie. *Journal of Range Management* **46**, 320-324.

Yang L, Wu JP, Jones R, Kemp DR, Ma ZF, Takahashi T (2011) Changing livestock and grassland management to improve the sustainability and profitability of alpine grasslands in Sunan county, Gansu province. In 'Development of Sustainable Livestock Systems on Grasslands in North-Western China'. *ACIAR Proceedings*, 134, 69-79. (Eds DR Kemp, DL Michalk)

Zheng Y, Xu Z, Kemp D , Shan G , Tian Q , and Xie J (2011) Public grazing systems on typical steppe grasslands in Taipusi Banner, Inner Mongolia Autonomous Region. In 'Development of Sustainable Livestock Systems on Grasslands in North-Western China'. *ACIAR Proceedings*, 134, 58-68. (Eds DR Kemp, DL Michalk)