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Development of sustainable livestock systems on grasslands in north-western China

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Development of sustainable livestock systems on grasslands in north-western China

Proceedings of a workshop held at the combined International Grassland Congress and International Rangeland Conference, Hohhot, Inner Mongolia Autonomous Region, China, 28 June 2008

Editors: D.R. Kemp and D.L. Michalk

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2011

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Kemp D.R. and Michalk D.L. (eds) 2011. Development of sustainable livestock systems on grasslands in north-western China. ACIAR Proceedings No. 134. Australian Centre for International Agricultural Research: Canberra. 189 pp.

ISBN 978 1 921615 45 6 (print)
ISBN 978 1 921615 46 3 (online)

Technical editing and design by Clarus Design Pty Ltd, Canberra, Australia
Printing by Elect Printing
Cover: Colin Langford, livestock advisory specialist, leads herder training in condition scoring of sheep at Siziwang Banner, Inner Mongolia Autonomous Region [Photo: D.R. Kemp]

Foreword

The Australian Centre for International Agricultural Research (ACIAR) has been engaged in collaborative research projects in China since the mid 1980s. These proceedings present the results of the first ACIAR project on livestock farming systems in north-western China. Livestock in that part of China rely on grasslands for much of their nutrition, but overstocking and restricted access to grazing lands have led to the twin problems of grassland degradation and low incomes for households dependent on livestock production. This project first sought to understand exactly how farmers (herders) managed their livestock in the vast grasslands across the region. Models were then developed to analyse the livestock farming system and investigate options for change. The project was characterised by regular workshops and discussions among researchers, herders, local officials and others in China involved in finding solutions to improving livelihoods and the degraded grasslands. On-farm implementation of project outcomes has now begun.

The results show that all-round benefits are possible. Net income from livestock can be achieved with fewer animals—in some cases livestock numbers can be halved—and this provides the opportunity to then reduce grazing pressure and rehabilitate the grasslands. Chinese grasslands appear to be more resilient than those in other countries, as evidenced by desirable grassland plant species regaining dominance after bans on grazing and a reduction in livestock numbers. Early results from demonstration farms are encouraging, but further work is needed to evaluate better pathways for improvement.

The project findings were first presented at a workshop held in association with the combined International Grassland Congress and International Rangeland Conference in China in 2008. The presentations were then written up and updated to give the papers presented here.

The methodologies and results used in the Chinese grasslands project demonstrate the strengths of a systems approach to identifying the scale of a problem and for evaluating a range of solutions. The solutions that have emerged would probably not have been yielded by an experimental approach. This has stimulated new areas of research in China, where systems approaches had not been recognised as a discipline, particularly in universities.

Nick Austin
Chief Executive Officer
ACIAR

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Acknowledgments

The work presented in these proceedings would not have happened without the support of, in China: the Gansu Agricultural University, the Gansu Grassland Ecological Research Institute, the Grassland Research Institute (Chinese Academy of Agricultural Sciences – CAAS, Inner Mongolia), the Inner Mongolia Agricultural University, and the ministries of Science and Technology and Agriculture; and, in Australia: the Australian Centre for International Agricultural Research (ACIAR), the Australian Greenhouse Office, the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF), Charles Sturt University, Industry & Investment NSW, and the University of Queensland.

We acknowledge particularly the enthusiastic participation in the project of the many groups and individuals associated with our partners in China. They were always willing providers of information, and discussions with them helped to formulate the proposals that have emerged.

We acknowledge too the assistance of the many farmers and herders in the case study villages and elsewhere who freely provided valuable information that enabled us to build sensible models and to test the ideas we developed. Some of those herders have now been to Australia to learn more about some of the alternative approaches to livestock raising proposed by the project. Also, many local officials from provincial to village levels have engaged in the surveys and discussions held and have been very supportive of the collective proposals put forward.

ACIAR has been the prime funding body, supplemented by funds from the Australian Greenhouse Office and various subprojects: 'Ecosystem service function and optimal distribution of ecological and productive function region' which is part of the development of basic research project of China (973 project): 'Basic research on sustainability and adaptability of northern grassland and farming grazing transitional zone ecosystem'; National Basic Research Development Program (973 Program, No. 2007CB106800), National Science and Technology Supporting Program during the 11th five-year plan period (2006BAD16B01, 2008BAD95B03, 2009A40020201, 20090306), and a grant (20071501, 20080706) from the Inner Mongolia Science and Technological Committee, China. Additional support has come from the International Cooperation Department of the Ministry of Agriculture, the International Cooperation Department of the Ministry of Science and Technology, the International Cooperation Department of CAAS and the CAAS Grassland Research Institute and, in Australia, Charles Sturt University and the New South Wales Department of Industry & Investment. This work led to further support from DAFF to do some preliminary testing of the ideas from this project on farms and to start developing appropriate training material for herders and officials.

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Introduction

Sheep being taken out to graze in spring on desert steppe in Siziwang Banner, Inner Mongolia Autonomous Region. Grazing at this stage causes considerable damage to the regenerating grasslands. [Photo: D.R. Kemp]

Chinese grasslands: problems, dilemmas and finding solutions

David Kemp, Colin Brown, Han Guodong, David Michalk, Nan Zhibiao, Wu Jianping and Xu Zhu[1]

Abstract

China's 400 million hectares of grasslands are its most extensive natural resource and have supported livestock production for millennia. During the past century, however, increasing pressures have resulted in a considerable rise in human and livestock populations that has limited household incomes and resulted in 90% of the grasslands being classified as degraded to some degree. Government policies have sought to reverse these adverse trends. This paper introduces projects designed to both improve household incomes and provide the opportunities for grassland rehabilitation. This work included analyses of policy development and its implementation from national to local levels, and of new environmental concerns to reduce greenhouse gas production from grazing livestock. The methodology employed was to survey the current farm structures and productivity, then use a systems approach and a series of computer models to analyse the current status of livestock production and investigate options for improvement. Officials at various levels of government and industry were surveyed to understand the policy and institutional settings that affect grassland utilisation. In developing strategies for farm and income improvement, emphasis was placed on the initial changes that could achieve real benefits, taking into account herder/farmer attitudes to livestock and land management. Initial work to test project ideas on farm has begun.

Introduction

The Eurasian grasslands form one of the world's largest sequence of ecosystems from eastern China[2] to eastern Europe. Across these grasslands many societies have evolved over millennia, dependent upon the resources provided and deriving their livelihood and culture from livestock. Increasing human populations have placed extreme pressures on these ecosystems, through alienation of ancient grazing lands as a result of land use for cropping, urbanisation, industrial development and related activities, as well as institutional changes that have greatly reduced traditional transhumance systems[3] (Humphreys and Sneath 1996). These pressures are acute in many regions and especially in western China.

China's 400 million hectares (ha) of grasslands, which account for 42% of the nation's land area (Hong 2006), are highly degraded as a result of overpopulation, overgrazing, improper land conversion to cropland and adverse effects of drought exacerbated by climate change (Li et al. 2008).

[1] For this publication, authorship has been attributed on a 'western' basis. The first-named author has been responsible for putting the paper together and other authors have then been listed alphabetically on family names. Each author is often representing a more extensive subgroup within the project. Many others have contributed to each paper. Their names appear throughout all the papers. This policy was adopted as a means of reflecting the wide-ranging contributions to the whole project.

[2] The People's Republic of China (PRC) is referred to as China in these proceedings.

[3] Pastoralism involving the seasonal movement of livestock to and from lowland and highland areas.

Pp. 12–23 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.

Statistics indicate that grassland degradation, which is thought to have begun in China by the late 1960s, has increased at an alarming rate and, in the past 10 years, the area degraded has risen from 55% to over 90% (UNDP 2002; Lu et al. 2006). The major evidence for grassland degradation is lower plant productivity and biodiversity, increased frequency of rodent and grasshopper infestations, and large-scale dust storms (Chen and Wang 2000; Lu et al. 2005).

Despite this widespread land degradation, China remains the largest producer and consumer of livestock products in Asia (FAO 2006), with grassland systems still producing 70% of China's wool, 33% of sheep meat, 14% of beef and 10% of national milk production (Li et al. 2008). Directly and indirectly, the grasslands of China support over 40 million people. This highlights the importance of grasslands to generate livelihoods for households in pastoral areas where livestock constitute up to 80% of the agricultural output value and remain central to the culture of minority peoples. Per-capita incomes in the Inner Mongolia Autonomous Region, Gansu, Xinjiang and across the Tibetan Plateau are consistently among the lowest in China (Brown et al. 2008). Minority groups, and particularly children and women, are more affected by reduced productivity from grasslands than those that find migration easier.

In response to growing demand for livestock products and to stabilise downward spiralling incomes, most pastoral households have simply increased stocking rates. This is reflected in the number of livestock grazing grasslands, which has increased from 12 million in the 1950s to more than 90 million (Chen et al. 2003). In Gansu and Xinjiang, which are among the most degraded of the western provinces (Lu et al. 2006), sheep numbers have doubled since 1994, providing further clear evidence that the degree of degradation is directly proportional to stocking rate (Wang et al. 1998).

Chinese grasslands are degraded to varying degrees as a result of significant overstocking and overgrazing during recent decades. This reflects the human and other pressures on these ecosystems beyond their productive potential, as well as government policies that failed to understand how limited the resources actually are in the grasslands (Ren et al. 2001), a common and often repeated problem around the world. Overgrazing occurs throughout the year, leading to major environmental problems including declining productivity, frequent dust storms, extensive siltation of the Yellow River and loss of biodiversity. Elderly herders have often commented along the lines that '50 years ago we had trouble finding the cattle in the grassland; today we can see the mice'. The frequent dust storms in spring across northern Asia are a significant reflection of this problem. In Beijing during April–May 2006, for example, there were 11 dust storms.

Grassland problems are exacerbated by the severe climate; a short 3–4-month growing season over summer (annual precipitation of 150–450 mm, excluding deserts; 25% as snow) and then dry, cold periods from autumn through to spring (temperatures often below –20 °C). That means there are only a few months each year when green forage is available and when fodder can be stored for winter. Animal losses in winter are considerable in some years.

China, like the rest of the world, is increasingly focused on the problems arising from human-induced climate change. Livestock are a significant contributor to greenhouse gases through enteric methane emissions. Non-dairy cattle produce around 60% of the enteric methane emissions and 18% of China's national methane emissions. Reducing methane output would require significant reductions in livestock numbers and/or systems for more efficient production of livestock.

The problems arising from the current state of grasslands in China, the desire to rehabilitate the grasslands and improve household incomes, and related issues across the landscape, have resulted in national policies for China to 'implement the strategy of rejuvenation of the nation through science and education and that of sustainable development' (a 2002 amendment to the Communist Party of China Constitution).

The seriousness of this problem has been recognised by the Chinese Government with the passing of a substantially revised and upgraded National Grassland Law in 2002 and the allocation of 60 billion RMB[4] over 10 years through a multitude of associated programs and projects for the sustainable development of grasslands in western China. The approach adopted for this national program—of integrating economic development with sustainable solutions (long advocated by authors such as

[4] The official unit of currency in China is the yuan (¥), also known by an older term, renminbi ('people's money'). Exchange rates in 2009 were ¥5 = A$1.

Longworth and Williamson (1993))—broadly has the twin objectives of:

1. promoting ecologically sustainable use of grasslands (with benefits including rehabilitating degraded grasslands, improving biodiversity, and reducing dust storms, river siltation and desertification)
2. improving the income and wellbeing of herders, many of whom are from ethnic minority groups.

Implementation of a grassland strategy in China has occurred through the enactment of policies and regulations at the national, provincial, prefectural and county level and has been reinforced or made operational through a variety of funded programs and projects. The Chinese initiative is being supported by other funding sources, such as the World Bank (WB) program[5] (approximately US$100m, including loan funds of US$68m plus US$10m from the United Nations Development Programme Global Environment Facility (UNDP–GEF)) targeted at counties in Gansu and Xinjiang, two of the poorest provinces in China. Discussions with officials at all levels from the national to county have strongly advocated the development of new policies and technologies to support the program, but the information and tools to identify the most effective solutions are lacking.

Cultural perspective

The farmers, herders and smallholders whose livelihoods depend upon livestock live on part of the world's most extensive grasslands, as some of their forebears have done for centuries and, in some cases, millennia. This background has resulted in attitudes to livestock and land management that greatly influence current practices and need to be considered when developing proposals for changes in farm practice.

Traditional livestock management practices are often based upon survival through the year rather than producing goods for a market and running the farm as a business. Wealth was often traditionally encapsulated in the number of livestock a herder had—a livestock 'bank', rather than their productivity. During the past 50 years, herders have been in transition, especially since 1979 when the 'household production responsibility system' and a rapidly developing market economy were initiated in China. Many herders now receive prices for livestock products that reflect the quantity and quality of those products. They have become more interested in improving productivity from every animal in their flocks and herds.

These transitions in livestock producer attitudes are similar to those observed in Africa. The spectrum of 'user/keeper/producer/breeder' defined by Luke (1989) and discussed for East Africa by Neidhardt et al. (1996) is now being seen on the grasslands in China. The 'users' are traditional gatherers and hunters who moved onto confining and owning livestock, becoming 'keepers', whose main interest was survival of the maximum number of animals. Many of them are now more 'producers' than keepers and a few have become 'breeders' who use introduced breeds, select the better animals to keep and feed them at a higher rate than in the past. However, while many are now thinking more about production, they still have a strong 'keeper' philosophy, believing that if an animal survives through the year then they have been successful, even if the animal lost 30% of its body weight through winter. These aims and attitudes vary greatly between groups and need to be considered in developing recommendations for changes in farm practices. For instance, feeding for enhanced production through winter is a concept that would be incomprehensible to many. Initial changes therefore need to focus more on minimising weight loss and at feeding to no more than maintenance standards.

Land has traditionally been used in common by local groups, rather than being accessible to all. There were no single landowners, apart from a feudal landlord or 'the state', or land was held by groups that had historical rights. Under such arrangements, the land was of no saleable value to individual herders. Herders then seek out any available forage and aim to exploit it before others in their group. In this system there is no incentive to preserve forage that would then likely be used by others. When the density of people and animals was low, then some areas were not grazed or cut for hay every year. In consequence, per animal productivity was probably good over summer, and even winter grazing may have provided quantities of low-quality

[5] Unless otherwise stated, references to the World Bank program in these proceedings refer to the Gansu Xinjiang Pastoral Development Project, launched in 2003. Drs D. Michalk, D. Baker and J.P. Wu, all ACIAR team members, have been closely involved in developing and monitoring the technical aspects of this World Bank project.

fodder. There was often a seasonal migration to summer grazing lands. Winter grazing lands were therefore more likely to be the heavily used, although this was dependent upon local populations. In Taipusi, one study village that had three families 50 years ago now has 66, and all grazing is close to the permanent houses. This has resulted in a considerable reduction in grassland productivity. Under the household production responsibility system, herders are being allocated individual, heritable rights to areas of land for up to 30 years. Such land cannot be sold neither can it be treated as an asset. It can be rented to others, but typically for no more than a year. There is thus no incentive to improve the grasslands.

Despite the closer settlement that is now very common, herders still seem to treat the grasslands as common land and aim to utilise them as heavily and quickly as possible. This applies even when fencing is in place to mark the boundaries of individual farms. Most commonly there are no subdividing fences on farms and the whole farm is used all year. Access to land is something that herders will argue for, in the past have fought for and, in traditional societies, has religious significance, but its 'value' cannot be considered in the same sense as an owned asset. Land is to be used and herders may believe they have traditional rights to do so, but they do not believe they should have to pay for that grazing land or its maintenance.

The number of animals on a 'farm' at any one time often seems to be highly variable. Relatives, friends and village officials often ask a herder to 'look after' their livestock for a while for various reasons. This creates a 'quasi-common' grazing system that complicates improvement of management practices and limits opportunities for grassland rehabilitation. Farm survey data do not always capture these variable numbers of animals. There is poor acknowledgment of the amount of grass actually eaten by livestock.

The task in these proceedings has not been to investigate how recent historical trends could be reversed to better accommodate traditional attitudes and practices in the expectation that that would provide sustainable solutions, but rather to explore solutions that should result in improvements in incomes and grasslands under the current circumstances. There is no evidence that Chinese policies would want to dramatically change current arrangements; although considerable flexibility is possible within the broad parameters of a market economy. The overriding issue is that there are now more people and animals eking out an existence on the grasslands than there were in 1950, as discussed in the case study papers to follow. In 1947 there were 7 ha per animal in Inner Mongolia but, by 1965, this had fallen to only 2 ha. This reduction, coupled with a decline in grassland productivity in the order of 50% or more, with fewer nutritious plants, resulted in a continual decline in the forage resources available per animal and declining carcass weights (Erdenijab 1996). It also needs to be acknowledged that the livestock management practices that evolved in past centuries are unlikely to suit current conditions, as the resources available per capita have been seriously depleted. Herder knowledge about animal management on the grasslands, while very important, would not encompass all the experiences needed to improve sustainable livestock production in market economies in northern China. In consequence, these proceedings assume that farmers and herders wish to improve incomes and their grasslands through enhancing the sustainability of their livestock production systems within the constraints of land area, climate and soil conditions that typically apply today.

Overgrazing

It is widely agreed that the major cause of grassland degradation is overgrazing, which leads, in time, to a decline in incomes. There is growing recognition that this outcome has been driven by initiatives taken at a range of levels, from national policy to the individual herder. For example, several initiatives resulted in stocking rates increasing manyfold since 1950 as part of a policy to increase wool and red-meat production and cropping of grassland areas. Increased cropping led in turn to higher stocking rates on the remaining grasslands. Population pressures have been exacerbated by considerable (encouraged) migration of peoples from southern China since 1950 as a result of policies that did not appreciate what might be all the impacts on natural resources. The apparent productivity of grasslands was probably a result of the relatively low levels of utilisation and some accumulation of herbage through the years of conflict up to 1949. Herders in turn considered that their income was primarily dependent upon the number of animals they had. Local policies sought to increase animal numbers as a means of improving incomes. However, the developing markets in China now mean that herders receive payments based more on the value of specific products from animals rather than a price per head, irrespective of what is produced.

Grassland degradation problems are most apparent in areas of common grazing and are further exacerbated by continuous grazing throughout the dry autumn–spring period when there is no pasture growth. This then has effects on the subsequent short summer pasture production period. These feed-forward influences continue to degrade grasslands and reduce their productivity. Much of the feed supply is used for survival. Animal growth rates and productivity per head are very low and mortality through many winters is high, with losses up to 20% in years with heavier snow falls. As relative prices fall, many herders have seen their salvation coming simply from having more animals, rather than obtaining greater net incomes from more efficient production and marketing systems.

It is generally considered that many of the solutions to the Chinese problem of grassland degradation and associated greenhouse gas emissions lie in improving the livestock farming systems and shifting the emphasis to production efficiency, as distinct from survival of livestock. While it is recognised that such a change would involve significant community and social issues, they are outside the bounds of this work to consider in any detail. However, the broader debate about grassland sustainability and greenhouse gas abatement needs to be well informed by science-based information that covers the whole system from policy to markets, to livestock performance, to grassland biology. Fortunately, much can be done by integrating existing knowledge of livestock production components within a systems framework to explore various management options.

In this context:

- reducing livestock numbers does not mean less animal product and income, as fewer, better fed animals will produce more meat, milk and wool per unit area of land
- improved feed conversion efficiency in the production of animal products will directly reduce the amount of methane emitted per kg of animal product over an animal's life
- preliminary estimates presented in these proceedings suggest that if the animal numbers per ha in China were halved the product per ha could be doubled—the animals on grasslands are typically grossly underfed and average production rates very low
- methane production can be reasonably estimated using animal and feed information and published relationships
- reducing the stock density on grasslands can lead to a restoration of ecosystem function and provide opportunities to sequester more carbon, and reduce dust storms and desertification—in many parts of China the carbon stored in grassland soils could be doubled
- market incentives could contribute to better grassland management through higher prices per unit of animal product, providing an incentive to increase yield of animal product per head through reduced stocking rates
- farm productivity may or may not satisfy household needs—if a farm is too small and/or too degraded to satisfy the required household income, the solution is not to increase the number of grazing animals, but to find other sources of income, which might include grazing compensation schemes.

Understanding animal production

Finding solutions to overgrazing will take several lines of investigation, to take account of different farm systems. As a starting point it is useful to consider the basic relationships between animal production and stocking rate for grazing livestock (Figure 1) as a guide to setting appropriate stocking rates.

Considerable research and herder experience has shown that as stocking rates increase, a decrease in per head production (e.g. meat, milk, wool and growth of lambs, calves and kids produced) will eventually occur, driven by a decline in the quantity and quality of forage available per head. The productivity per ha will, however, increase until around the point where production per head is half that of the maximum possible. For this discussion, a linear rate of decline between per head production and stocking rate is assumed. Curvilinear relationships between stocking rates and per head production are possible (Kemp and Michalk 2007) but the general points remain the same. Where productivity per head and per ha is negative, as applies in winter in northern and western China, these curves can extend to higher stocking rates than shown.

Within animal production systems it is very difficult on a farm scale to achieve the biological maximum (a relative stocking rate of 1 in Figure 1).

Note too that the biological maximum would not coincide with maximising net profit. It is more realistic to attain, say, 75% of that biological maximum. The shapes of these curves mean that 75% of the animal production per ha can be achieved at two points (A or B in Figure 1). Stocking rates on Chinese grasslands indicate that they are often to the right of point B on these curves, as productivity per head is often low, particularly when annual production is considered. Over a year, the net change in animal weight is often very low. At point A the production per ha is the same as at B, but the rate of animal production per head is three times that at point B, meaning that growing animals e.g. calves or lambs, reach marketable weights in about one-third of the time. Overall, at point A, as compared with point B, the same production per ha can be achieved with less than half the animals in half the time. Economic optima would normally be much closer to the stocking rates at point A than at point B, because of the reduced costs. As marginal costs per animal increase, then the optimal stocking rate will decrease. This is particularly important when more account is taken of longer term sustainability criteria in analyses, such as declining productivity over time due to overgrazing. Land area is now a major constraint on productivity across China, hence analyses need to include per ha production.

These relationships suggest that if animals are managed at point A rather than point B, the methane production from young animals being sold for meat would be considerably lower. Their per head per day productivity at point A would be 2–3 times that at B, while their methane output would be only marginally greater, based upon the general relationships for methane output discussed in Dong Hongmin et al. (2011). However, because such animals would reach market specifications much earlier, their total methane output (per head or per kg of product) could easily be half or less.

The general implication from these curves is that a conservative stocking rate policy would not reduce animal product per ha, would improve net profit per ha and would significantly reduce methane reduction. Modelling these data and deriving realistic farm optima are discussed elsewhere these proceedings.

A new, systems approach to grassland problems

Chinese policies and international collaborative programs with Australia have specifically recognised grazing management and protection of the grasslands as a priority for research in north-western China. Allied to this are the identified needs to improve livestock feed production, conservation

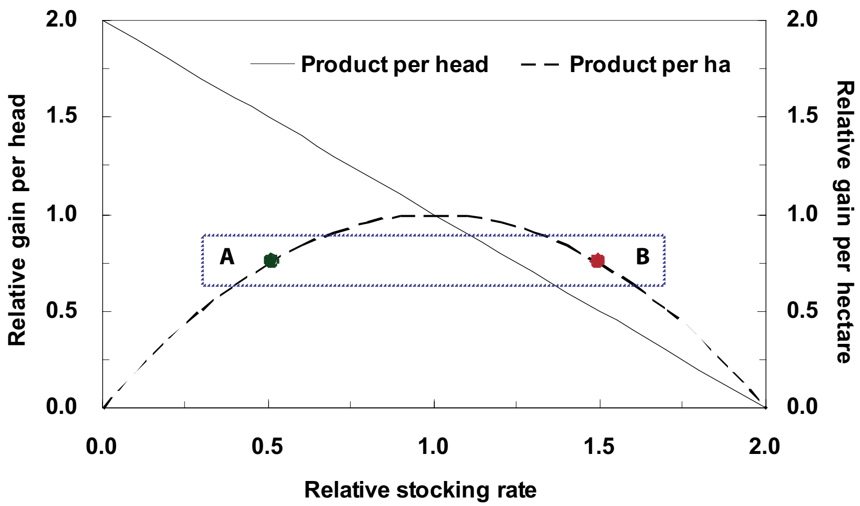

Figure 1. Basic relationships between animal production per head and per hectare for grazing livestock (based upon Jones and Sandland (1974)). Points A and B are explained in the text.

and utilisation; research on how to involve resource users and stakeholders in designing and implementing resource management studies; and the development of an understanding of socioeconomic and policy issues that affect grassland use. These issues, at a range of scales from national to provincial to farm level, are discussed in other papers in these proceedings.

To date, most research has investigated components of the grassland systems, often in isolation from others. This has been the case both within and between the biophysical, economic and policy elements of the system. Consequently, previous programs targeting sustainable use of the Chinese grasslands have had limited success, which can be attributed in part to this poorly integrated approach. Some have tried to deal with the possible ways to balance the apparently conflicting objectives of grassland protection and income generation (e.g. Niu and Chen 1994; Xin et al. 2000; MOA 2002) but few have come up with sound proposals that can help the smallholders in the north-west to increase their incomes and to protect the environment.

Analysis of farming systems in China is relatively new. The compartmentalised approach to agriculture has meant that few people have attempted to analyse the whole system and to seek more sustainable solutions from that broader analysis. With a developing market economy, the drivers for production systems are changing from past practices and yet many researchers have not incorporated those changes into their thinking. The systems approach calls for an understanding of how policy and institutional settings bearing on grasslands and livestock and, indeed, in other areas such as regional growth, settlement and market development influence household decisions. The integration of policy development and implementation and the developing market economy, which aims to improve incomes and rehabilitate grasslands, provides the context for the work discussed here.

The development of a grassland livestock farming system framework serves many purposes. First, it will become a focus for a change in the way scientists and government agents think about grassland systems and will provide a structure for the assemblage of economic, scientific and on-farm data within western China. This capacity building will be supported by targeted training in a range of topics from systems analysis through to grassland assessment. Second, models based upon simple biophysical (grassland and animal performance), cash flow, economic and social modules will be used to evaluate technical options including: farm structures that improve farm systems sustainability; which grassland management tactics better reduce soil erosion and its consequences; better alignment of livestock breeding cycles with feed supplies; tactics to reduce animal numbers over winter; animal housing; and the impact of policy changes and developing market signals for quality, quantity and price, i.e. demand functions, of animal products. The information obtained will be used to identify areas for future research and/or demonstration and will provide substance to the training initiatives funded by the WB. 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. Additional components of the projects reported here investigated the national, provincial and local policies that affect grassland rehabilitation and smallholder incomes.

Aims

Rehabilitation of the vast area of grasslands and improvement of smallholder incomes are the broad aims of the work to be reported. Also considered are Chinese Government policies for these grasslands and the focus of international programs such as those of the WB and the UNDP–GEF.

This project aims to change the approach to grassland management by concentrating on the livestock farming system rather than its individual components. This approach helped to identify better strategies, including research and development and policy options, to improve smallholder incomes and overcome grassland degradation. National and local policies have been developed to combat these problems and Chinese scientists have researched many components of livestock production and proposed better integrated livestock system concepts. To date, however, they have been unable to integrate such strategies into a whole farm, market and policy framework. In the absence of such a framework, it has been difficult to articulate the potential benefits of alternative farm development strategies when considering research activities, delivering extension messages or developing effective policy.

Objectives

The work reported in these proceedings is based upon projects funded primarily by the Australian Centre for International Agriculture Research (ACIAR) through its project number LPS/2001/094, which ended in March 2010, supported with additional funds from the Australian Greenhouse Office (AGO) and the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF). Various components were also funded by a range of Chinese agencies and programs. The main objectives were:

1. To develop a framework for grassland farming systems that integrates the major components that influence grassland use.
   Activity 1.1: Describe the livestock production systems in the target regions, and develop realistic production functions for biophysical elements on farm.
   Activity 1.2: Analyse the current policy/regulatory and market settings, their implementation and impacts on herders and the grasslands.
2. To develop a suite of policy/regulatory approaches and on-farm strategies that impact positively on herder incomes and grassland rehabilitation (using the farming systems framework).
3. To build the capacity of research and extension personnel to analyse and determine key intervention strategies into grassland farming systems.
4. To estimate the impacts on methane emissions of alternative livestock management systems for sustainable, profitable grasslands.
   Activity 4.1: Incorporate methane output estimates into the desktop models of the livestock farming systems in the grasslands of western China.
   Activity 4.2: Develop the three-stage modelling approach to provide a generic framework for analysing grazing systems elsewhere in China and in Australia.
5. To assess the impact on greenhouse gas emissions of grassland policies affecting methane from livestock.
   Activity 5.1: Broaden the policy studies to analyse the potential impact of current Chinese Government grassland policies from a greenhouse gas perspective.
6. To calibrate the models using survey data from farms/smallholders in Inner Mongolia and Gansu.
   Activity 6.1: Conduct field surveys at study villages in Inner Mongolia and Gansu to obtain basic data on plant and animal status to check model estimates.
7. Promote project results to government agencies and the international community, aiming to influence national and local policies, extension and research programs.
   Activity 7.1: Hold a satellite meeting at the combined International Grassland/Rangeland Congress in China in July 2008.
   Activity 7.2: Prepare an ACIAR publication outlining the modelling and policy approaches adopted by the project.

These objectives are dealt with in the papers to follow in these proceedings. This publication is based on the workshop held in 2008 at the International Grassland/Rangeland Congress held in China and updated during the following year (Objective 7). The work reported here is on the Chinese components of these projects. The Australian component is discussed in the final project report to ACIAR.

Project methodology

The core methodologies employed in these projects were to survey farms in case study villages, to use the data collected to parameterise a series of farm-level models developed for these projects, and to investigate policies and their application from a national to local level through the six layers of government common in China.

While the models were being parameterised a series of regular workshops and related meetings were held to identify how these models were to be used and the general questions that the models should be able to answer. The questions formulated were important for structuring the models developed. It was decided after some early work that it was more relevant to concentrate upon the initial changes that could occur on farms that would contribute to the general project goals of improving herder incomes and providing opportunities for rehabilitating the grasslands. Investigation of practices that were several steps beyond where the typical herders might operate in the foreseeable future were not considered. The animals on the farm became the prime focus, as stocking rates have a great influence on grassland condition and they produce the income upon which each household depends. Resolving ways of maintaining or increasing income with fewer animals was investigated with the tools developed. The following are examples of the key questions that arose from early discussions:

- Could regulatory changes, such as periods of zero grazing or 'forbidding grazing' achieve the goals set, what would be the costs and would other strategies be better?
- What policies and institutional settings affect grassland utilisation; how can coordination across the different policies, programs and administrative levels be improved; and how can policy objectives be more effectively achieved?
- Does reducing grazing from mid autumn through spring increase grassland productivity?
- Can supplementary feeding in spring reduce grazing pressures? Which farming systems have the capability to change to such a system?
- What is the effect on subsequent productivity and wind erosion of setting minimum levels of herbage mass below which grasslands should not be grazed[6] over summer?
- Can livestock breeding cycles be reorganised to better align with forage availability?
- What are the options for the provision of higher quality forage to enable better animal performance and earlier sales?
- Can animals be fed in warm sheds over autumn to spring to protect livestock from the cold, to manage intake better and to improve profitability?
- Which fodder sources are the more profitable?

In addition, there were some second-phase questions commented on in these proceedings:

- Are current price premiums an accurate reflection of the value Chinese consumers place on quality attributes of ruminant livestock products, or do market imperfections and current price discovery mechanisms distort household decisions and farming systems and hinder the development of high-quality products based on reduced stocking rates?
- Is resource security (some form of land tenure) always a prerequisite for better land management? What other initiatives are required to support such changes?
- Will genetic improvement of livestock enhance the quality of livestock products?

Marketing questions were a particular difficulty as the market structures have been changing rapidly in China and herders are now presented with a range of choices. There is often a lack of transparency in markets and it is then difficult to get accurate price information. The analyses presented reflect the available data that were used to construct the models.

To date, some of the above questions have been, to varying degrees, investigated separately in China without considering the interactions within an integrated farming systems framework. For new practices to work, it is necessary to establish the likely interactions and the economic incentives required, including the market development that may be needed to justify alternative strategies and policy changes. Improvements may need to be combined with downstream value-adding and marketing strategies in ways whereby herders obtain additional benefits, thus reinforcing incentives to change. Wider policy implications need to be investigated, such as downstream effects of changing livestock production practices, the likely demand functions and property rights. Also requiring analysis are the interrelationships between centrally determined policy and their implementation at a local level.

Development of general grassland–livestock farming systems models (concentrating upon the main interactions) was considered the logical way to work through the options that will cover policy, biology, economics and sociology, as well as the impacts of developing markets. The broad parameters of this system are known, but little work has been done to quantify the dynamic interactions between components of the farming system. The need to think in this integrative fashion has been promoted by leading Chinese scientists (Ren et al. 2001) but their 'model' needs to be activated, quantified and expanded to give greater weight to the market and policy impacts on grasslands. Developing this approach into a working model will be part of this project, with various institutional alliances responsible for development of major model components, e.g. production response functions for animals.

The focus in this work was on achieving broad-sense sustainability, i.e. environmentally, economically and socially integrated solutions that can be implemented and which should have a high chance of success. A broad-sense approach looks for trade-offs, although in some areas trade-offs will not be

[6] Work done at Orange, New South Wales, Australia, by ACIAR team members has shown the benefits of using this strategy.

possible and ecological limits will apply, as in the case of degrading grasslands beyond the point where they can recover in a reasonable time.

Given the short-term nature of this project and that no equivalent system analysis has been done in China, the plan was to develop a general framework that incorporates the main relationships for which data could be obtained, plus other relationships for which a reasonable interpretation can be made.

A three-stage modelling approach was used to first create, in stage 1, the base 'typical' farm for two villages in Gansu and two in Inner Mongolia. These villages contained a wide range of farm sizes and enterprise mixes. A stage 2 model used enterprise budgets and linear programming to investigate alternative farm strategies based on the typical farm. Stage 1 and 2 models analyse livestock systems within a typical year. A third-stage model, which is in an early phase of development, is being used to investigate the overall sustainability of alternative strategies over the long term, focusing on soil erosion. In each stage, methane emissions are estimated. In addition, a fourth model (*StageONE*) was developed to rank the performance of individual animals on a farm and to determine which animals to keep or cull. The 'typical' farm created in these models is based on a village average and does not represent any actual farm.

Through the project a relative ranking of initial changes advisable on farms was developed. The changes were grouped into six main areas that were used as a checklist against which any proposed changes in practice could be evaluated:

- **Enterprise**—what is the better livestock production system for the farm?
- **Animal management**—what changes are needed in the type, numbers and management of animals? **Animal nutrition**—what changes are needed in animal feeding through the year?
- **Grassland management**—how will a better livestock production system improve the sustainability of the grasslands?
- **Infrastructure changes**—what else needs to change on the farm for a better livestock system?
- **Finance and social implications**—will there be other costs for the herder when changing to a better livestock system?

The projects developed recommendations for initial on-farm changes that would improve incomes and provide opportunities for grassland rehabilitation. In the later stages of this work, demonstration farms were established at three of the case study villages (in Sunan, Siziwang and Taipusi) to investigate the application of reducing animal numbers, restricting grazing and feeding animals better in warm sheds through winter. Preliminary results are reported in the papers that follow.

Training

Implementing change on farms depends not only upon developing appropriate technology, but also must consider the cultural background of the herder. As discussed earlier, many herders are currently at or only starting to move from subsistence farming thinking. The spectrum of 'user–keeper–producer–breeder' defined first by Luke (1989) and discussed for East Africa by Neidhardt et al. (1996) identified that motivations vary greatly between groups. Many of the technologies discussed in these papers are more appropriate when herders have reached the 'producer–breeder' stage. Training needs are therefore seen as vital to the proper development of technology and its implementation.

Capacity building was an important part of this project in two quite different ways. The first was conventional, through training of government officials and scientists from national, provincial and county agencies. This component was linked with funded development activities in order to maximise impact and so reduce the cost to ACIAR. The second approach to capacity building was less conventional. Here the intention was not to train people to become 'experts' outside their current expertise, but to increase their awareness of how their own expertise can better link with other disciplines, and how a farming systems approach can be used to unravel and solve problems.

A vital part of this work has been to enhance understanding of the policy and institutional framework currently in place for grassland and smallholder improvement and to include the greenhouse implications of those policies. An analysis was made of existing grassland policies and how they are being implemented at all levels.

Project participants

The projects reported in these proceedings engaged many of the key grassland researchers and agencies in China: Gansu Agricultural University (GAU); Gansu Grassland Ecological Research Institute of Lanzhou University (GGERI, LU); the Grassland

Research Institute (GRI, Chinese Academy of Agricultural Science—CAAS); Inner Mongolia Agricultural University (IMAU); the Research Centre for Rural Economy (RCRE, Ministry of Agriculture—MOA); and the Institute for Environment and Sustainable Development of Agriculture (IESDA, CAAS). In addition, close relationships were developed between project participants and various local (provincial, county, village etc.) government agencies, especially those in Gansu (Huanxian and Sunan) and Inner Mongolia (Siziwang and Taipusi). This project formed a close association with WB and UNDP–GEF grassland programs, with three WB technical consultants involved in this project as well as key individuals within national Chinese institutions. Through these linkages, the project influenced a range of levels, from policy to local government, through participation, training and workshops.

These projects were developed after extensive consultation with Chinese scientists, local authorities, smallholders and other Chinese and Australian people familiar with the regions under study. It drew upon information from previous ACIAR projects that have investigated various policy, economic and biophysical components of the farming systems. Information from previous Australian Agency for International Development funded grassland improvement work in Inner Mongolia was also relevant.

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Locations of study villages across Gansu province and the Inner Mongolia Autonomous Region [Google™ Earth image]

Workshops to discuss progress were held once or twice a year during ACIAR project number LPS/2001/094. This meeting was held in Hohhot at the Inner Mongolia Agricultural University. Professors Zhao Mengli, Yun Jinfeng, Wu Jianping and Dr David Michalk from left. Dr Randall Jones at end of table is preparing the next paper for discussion. From right, Professor David Kemp, Academician Nan Zhibiao, Professor Xu Zhu and Dr Tian Qingsong at end of table. [Photo: Han Guodong]

Understanding livestock systems and developing solutions

Team members interview a herder during collection of data on the livestock farming system on the desert steppe, Inner Mongolia Autonomous Region. Dr Taro Takahashi (on right) was involved in developing the models used. Dr Wang Zhongwu (left) did his PhD on grazing effects on biodiversity on the desert steppe. Postgraduate students helped to collect the data and, if necessary, revisited farms to check or clarify the information. [Photo: D.R. Kemp]

Steady-state modelling for better understanding of current livestock production systems and for exploring optimal short-term strategies

Taro Takahashi, Randall Jones and David Kemp

Abstract

In developing countries there are often few data available to analyse livestock production systems. This chapter outlines two steady-state models that were developed for the investigation of current and alternative grassland livestock production systems. The *StageONE* model was designed to primarily analyse feed supply and demand using data collected in farm surveys. The basic functions in this spreadsheet model are the same as used in other more advanced decision-support systems. This model is designed for manual data entry with access to all calculation stages so that it can also be used for training. The time step is monthly and the model is normally used to estimate the energy balance through a year. The *StageTWO* model uses the same basic functions but is a linear programming model designed to find optimal solutions for livestock systems within the constraints that apply on typical farms. Both models are parameterised with data, collected or estimated, for grasslands, feed sources, livestock, weather and economics.

Introduction

The analysis of the biophysical performance of a grazing enterprise requires thinking about livestock, grasslands and feeding in a systems framework, whether one is trying to maximise the farm's profit, preserve pasture condition or reduce greenhouse gas emissions. Once those relationships are understood, financial analyses can then be done within the realistic limits that apply. The core issue is the interaction between feed supply and animal demand. Decision-support systems such as GrassGro (Donnelly and Moore 1997) and the SGS Pasture Model (Johnson et al. 2003) are valuable tools for the analysis of current practice and future strategies for a specified grazing system. They provide a reasonably accurate estimation of what happens on the farm, assisting the understanding of its farming system. They are valuable for scenario analyses in which the outcomes of alternative operational strategies are considered. Decision-support systems such as GrassGro and the SGS Pasture Model do, however, require a large set of input data to meticulously describe the climate, soils, pastures and animals before the livestock grazing system can be simulated. Parameterising such models is a challenging and time-consuming task in many regions, especially in developing countries where detailed data are not available. Estimates can be made to fill in data gaps, but this can result in much of the input data being guesstimates, which reduces the quality of the predictions made. The complicated interface of decision-support software can also be a deterrent for herders and advisory officers, whose experience with computer modelling is, in general, limited. A simpler strategy is needed for developing countries and for initial analyses of medium-scale alternative livestock management practices. These needs also often apply in developed countries.

Bioeconomic farm models are a useful tool to assess the impacts of policy changes and technological innovations on the production and economics of farming systems. These mechanistic models use mathematical and optimisation procedures, often

Pp. 26–35 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.

within a linear programming framework in which the farm is represented as a linear combination of 'activities' to match the reality of many small herders who are striving with limited resources to improve their situation. An activity is a coherent set of operations with corresponding inputs and outputs that results in an outcome such as the delivery of a marketable product. Constraints to activities are specified as the minimal or maximal amount of inputs or resources that can be used. The matrix of activities and constraints is optimised for an objective function such as profit.

This paper first introduces a computer-model decision-support system that is easy to parameterise and designed to enable users to better understand the interaction between feed supply and animal demand for a typical farm. The *StageONE* model is written within Microsoft® Excel to achieve portability (it also runs under OpenOffice) and requires only minimal data input, some of which can be estimated in workshops with local experts if no measurements are available. While its predictions of pasture and animal productivity will not be as accurate as those estimated by research models, it does use algorithms related to those in research models to estimate forage animals' intake, and can replicate a grazing system to an extent where one can plausibly evaluate the current farming practice and analyse the outcomes of alternative strategies. The model is designed to simulate a single year, with options to achieve steady-state solutions or replicate a specified set of conditions. The key design feature is that many parameters need to be manually entered, so that the user develops a clear understanding of how changing values will influence predictions of energy demand and consumption. *StageONE* can be used as an efficient training tool in both developing and developed countries to help officials, herders and students to better understand animal production. There are many cases, particularly in developing countries, where the benefit of *StageONE*'s simple approach outweighs the limited accuracy in the model, as the main interest is often to investigate larger system changes rather than subtle manipulation of a well-managed system. Often the model is used to simulate current and alternative livestock management practices for an average year and has the limitations that follow from that practice. Simulations can of course be run for a range of different conditions to then estimate variability.

To complement the *StageONE* model, a second, linear programming *StageTWO* model was developed to find optimal livestock management solutions under average conditions for a typical farm.

StageONE data requirements

The entire model runs in Microsoft Excel (or OpenOffice) with no additional software required. Before a model run, users need to fill in a pre-formatted work sheet ('the data work sheet') within the model, describing the farm's current operation. The time step of the model is monthly, hence data values are required for each month. In practice, a few key values need to be known and intermediate values are then interpolated. The individual data requirements are given below. The model was initially developed for the relatively simple grazing systems used on temperate grasslands in northern and western China, but it is relatively easy to adapt it to more- or less-complicated systems. The information presented here focuses on the principles involved in model requirements and use. Data are processed mainly on a per-farm basis, then also expressed per livestock unit and per hectare (ha) to enable comparisons between farms. Examples of its use are given in the case study chapters to follow.

Pastures

The basic version of the model allows for a maximum of four pasture types, but uses data for only those pastures where the specified area is greater than zero. For example, if the farm grazes both summer and winter pastures, two separate entries are necessary. The data required for each pasture type are:

Area: single (annual value) parameter in hectares for each pasture type used on the farm.

Pasture composition: single (annual value) parameter representing the typical ratio of desirable species to less-desirable species on the pasture. Desirable species are those of higher nutritive value to livestock.

Daily pasture growth rate: for each month of the year as kilograms of dry matter (DM) per ha per day.

Digestibility: two aggregated values for each month, for desirable species and for less-desirable species as percentage digestible material.

Grazing pattern: binary values to specify whether (1) or not (0) the pasture is grazed each month.

Livestock

For each animal class several basic parameters are needed. In *StageONE*, one breed of animals would normally consist of three animal classes: adult females, castrated adult males and growing animals. For example, if the farm runs a single breed of meat sheep and a single breed of goats, six separate entries—ewes, wether sheep and lambs; does, wether goats and kids—would be necessary. Uncastrated adult males are not considered in the model as these rams, bucks and bulls are a small proportion of the flock or herd and can be included with castrated males.

Livestock calendar: specifies the months for lambing, weaning, shearing and lamb sales for each breed.

Number: for each month, the number of animals in each class is specified to reflect births, deaths, purchases and sales.

Body weight: typical values for each month, gross of conceptus. Often only a few values are known and the rest interpolated.

Supplements: amount and type of supplements fed and their digestibility, for each month.

Standard reference weight (SRW): live weight of an animal of that breed when skeletal development is complete and the condition score is in the middle of the range (Freer et al. 2007). This parameter is critical for improving estimates of animal intake and growth rates as body weights fluctuate considerably through the year.

Weather

Historical data from a local meteorological site are used to characterise climatic stress on livestock. These values are used solely for the estimation of the cold allowance factor (see below), which is of major importance in northern and western China. While this factor can in some cases have an overwhelming effect on the model output, users can run the model without climate data or use general estimates if no direct measurements are available.

Average temperature: in degrees Celsius.

Average precipitation: in millimetres per day.

Average wind velocity: in kilometres per hour.

Finance

Data are used to estimate the net financial returns from the livestock enterprise on the farm.

Input prices: for each type of supplement fed and annual animal husbandry cost per head.

Annual fixed cost: mainly for machinery and other infrastructures, but can also include the cost to maintain pasture quality. This is an average for the whole farm, expressed on a per-head basis.

Fibre yield: wool, cashmere and hair yields from shearing. Meat yield is calculated internally from the body weight at the time of sales.

Output prices: for meat and fibre. Required for each month if price fluctuations are large; otherwise the same value is used for all months.

StageONE model algorithm

The principal objective of *StageONE* is to estimate the seasonal feed balance between supply and demand for grazing animals. Data are estimated in terms of actual DM and metabolisable energy (ME) intake per head for each month. Analyses focus on energy. Separately, the model calculates the animal's daily ME requirement in megajoules (MJ) for maintenance (MJ ME/day) under the user-specified livestock body weights and conditions for comparison with estimates of actual ME intake, to highlight periods of deficit and surplus. Estimates of the ME requirement for an animal are based on live weight, biophysical conditions such as pregnancy, lactation and fleece length, and on external grazing conditions such as temperature, wind speed and distance walked daily.

The animal's feed balance (MJ ME/day) i.e. feed surplus or deficit) is calculated as the difference between the daily ME intake and daily ME requirement for maintenance. This balance is then used to predict daily body-weight gain (g/day), or loss, which has strong and direct implications on the farm's profitability. The model has a capability to use this daily weight change for the current month to estimate the animal's body weight in the next month. By default, however, it uses exogenously specified body weight for each month, independently of the predicted weight gain/loss in the previous month, so that a bad estimation of feed budget in one month does not impose any carryover effect on others. Comparisons of predicted and input body weights often highlight where there are problems in parameterising the model that then require a careful consideration of all the input data to resolve.

The remainder of this section outlines the equations used to derive the animal's feed balance. The basic concepts follow that of SCA (1990) and Freer et al. (2007), although modifications have been made in some instances to satisfy the need to keep *StageONE* as a relatively easy-to-use and intuitive model. Throughout this paper, superscript t specifies the month in question, subscript j the pasture, and subscript i the animal class. They are suppressed for notational simplicity whenever their omission does not cause any ambiguity.

Step 1: Availability of grass

At the beginning of each month, the grass in each month grows at the user-specified rate. After growth, a portion of the total grass is lost to wind and by decomposition, but the reminder is available to livestock:

$$G_j^t = G_j^{t-1} - I_j^{t-1} - GW(G_j^t) \qquad (1)$$

where G is the DM available to animals, I the total DM intake by animals, and GW the wastage of DM due to natural causes. By default, GW is 10% of G; this can be easily changed on user request to reflect the local situation.

Step 2: Supplementary feeding

Average feed intake is estimated for each animal class. Every day of the month before they are put on the pasture, animals can be fed with supplements of the type and amount specified by users; i.e. the basic assumption is that animals are fed before they graze each day, which could limit intake from grasslands in some instances. This assumption was derived from farm surveys that found some supplements were often fed before animals grazed in winter. Users have an option to feed no supplement to one or more animal classes for the entire year or for selected months. Animals eat all supplements fed unless they, collectively, exceed their gut capacity, derived by:

$$PI = \frac{104.7(0.0795DMD_0 - 0.0014) + 0.307LW - 15}{104.7(0.0795 \times 80 - 0.0014) + 0.307LW - 15} \qquad (2)$$

where DMD_0 is the average digestibility of the supplements (subscript 0 is for 'pasture$_0$'), LW the animal's live weight net of conceptus and, strictly speaking, of fleece. PI is the potential DM intake of the animal when digestibility of feed is at least 80% hence is not limiting the animal's intake. For adult, non-lactating animals,

$$PI = 0.028SRW \qquad (3)$$

Lactating animals and growing animals have other terms added to the right-hand-side of equation (3), in order to take into consideration their increased appetite and skeletal size, respectively (Freer et al. 2007).

Step 3: Grazing

Following the feeding of supplements in the morning, animals are put on the specified pasture, j, for grazing. Dry matter on each pasture is divided into two groups: desirable species and less-desirable species. All animals that have not reached their gut capacity with supplements will eat desirable species first, then less-desirable species only if space remains in the gut after eating desirable species. The intakes of desirable species and less-desirable species are derived separately from the common equation:

$$I = PI \bullet RI_{GC} \bullet RI_{DMA} \bullet RI_{DMD} \qquad (4)$$

where three relative intake penalties, RIs, represent external factors that prevent animals from realising their biological potential—insufficient gut space due to earlier grassland consumption (GC), insufficient DM in the pasture that physically slows down the process of eating, and low digestibility that slows down the process of digestion. The first two are derived by:

$$RI_{GC,p} = RI_{GC,p-1}(1 - RI_{DMA,p}) \qquad (5)$$

$$RI_{DMA,p} = 1 - e^{-2G_{j,p}^t} \qquad (6)$$

and the third by the second term on the right-hand side of equation (2)—replacing the subscript 0 with subscript j. The second subscript, p, refers to the stage of the monthly eating points; that is, 1 for supplements, 2 for desirable species, and 3 for less-desirable species.

Once the DM intakes (DMI) of supplements, desirable grass and less-desirable grass have been derived, they are converted, separately, into the metabolisable energy content using the following equation:

$$energy = DM(-1.7 + 0.17DMD) \qquad (7)$$

Aggregating this value for all three eating points yields total daily ME intake by this animal class for this month.

Total intakes from pasture *j* over all animal classes, multiplied by 30 days, are then used to calculate the next month's availability of grass, according to equation (1).

Step 4: Energy requirement

In order to estimate the feed balance, the daily ME intake derived above is matched against the ME requirement for each class of animals. The ME requirement, defined here as the level of metabolisable energy required for the animal to maintain its live weight, is derived largely independently of the above three steps, using the following equation:

$$ME = ME_{base} + ME_{graze} + ME_{cold} + ME_{preg} + ME_{lact} \qquad (8)$$

That is, the total ME requirement comprises the basic metabolism requirement as well as additional requirements for exercise, insulation to overcome cold weather, pregnancy and lactation. The last four terms of the right-hand side of equation (8) are added only when a circumstance is relevant.

ME_{base} is the energy requirement for an uneventful life—no excessive walking, cold weather, pregnancy or lactation—and is given by equation (9) in which *MEI* is the ME intake estimated in Step 3 above.

ME_{graze} is the additional energy requirement for excessive exercise. Such exercise includes walking to the paddock, walking to a water source, and walking within the paddock looking for palatable species. It is given by equation (10) in which *D* is the horizontal-equivalent distance walked in kilometres. The subscript *graze* in the two terms excludes supplements from the calculation of the respective value.

ME_{cold} is the additional energy requirement for cold weather which makes animals insulate, in order to self-generate heat, their own tissues, coat and a layer of air immediately outside of the coat. It is given by equation (11) in which W_{preg} is the weight of conceptus and *T* the average temperature. I_e is an external insulation coefficient with the dimension °C•m^2/MJ and is a rather convoluted function of the live weight, average daily precipitation and average wind velocity.

ME_{preg} is the additional energy requirement for pregnancy, to be used for the development of conceptus. It is given by equation (12) in which W_{birth} is the typical birth weight of young animals and t_{preg} time from conception in months.

ME_{lact} is the additional energy requirement for lactation and is the smaller of two values—one associated with the biologically maximum milk production by the mother (ME_{lact1}) and another associated with the young's ability to consume milk (ME_{lact2}).

They are given by equations (13) and (14) in which BC_{birth} is the mother's body condition relative to animals with the standard reference weight, t_{lact} the time of lactation in months and BW_{young} the body weight of the young.

With equations (8)–(14) the total ME requirement is estimated.

Step 5: Energy balance

The energy balance, either in surplus or in deficit, is given by subtracting the ME requirement from the

$$ME_{base} = \frac{0.26LW^{0.75}e^{-0.12}}{0.02(-1.7+0.17DMD)+0.5} + 0.09MEI \qquad (9)$$

$$ME_{graze} = \left(0.02DMI_{graze}\left(0.9 - \frac{DMD_{graze}}{100}\right) + 0.0026D\right) \bullet \frac{LW}{0.02(-1.7+0.17DMD)+0.5} \qquad (10)$$

$$ME_{cold} = 0.09LW^{0.66} \bullet \frac{39 - 1.3\left(\frac{ME_{base}+ME_{graze}+0.38W_{preg}}{0.09LW^{0.66}}\right) - I_e\left(\frac{ME_{base}+ME_{graze}+0.38W_{preg}}{0.09LW^{0.66}} - 1.3\right) - T}{1.3 + I_e} \qquad (11)$$

$$ME_{preg} = \frac{0.0491e^{(-0.00643\frac{t_{preg}}{30})}\ \frac{W_{birth}}{4}e^{\left(7.64-11.46e^{-0.00643\frac{t_{preg}}{30}}\right)}}{0.133} \qquad (12)$$

ME intake. In addition, *StageONE* plots monthly values of both the ME intake and the ME requirement, the resulting graph showing the seasonal change in energy balance in an intuitive manner, helping herders', local officials' and researchers' understanding of the current farming system.

The model predicts the daily body-weight gain (BWG) for each month. For adult animals and growing animals, this is given by, respectively, equations (15) and (16) in which Z is the standard weight for the animals of the relevant age relative to the standard reference weight. By default, this ratio is given by equation (17).

StageONE model interface

While the modelling approach described above is reasonably applicable to most types of ruminants, the actual functional forms and parameters can be significantly different for non-standard breeds. It cannot be over-emphasised that users should refer to local publications and their own experiments to make sure that foregoing equations represent the local circumstances reasonably well. Using inappropriate assumptions will results in misleading output. A particular difficulty is the uncertainty of parameters for fat-tail sheep in comparison with short-tails as there is very little published information about how these animal types differ. It is suspected that patterns in fat metabolism in winter will vary between them, confounding estimates of energy use.

Once users are convinced that formulisation and parameterisation are adequately representative, and have entered all necessary information on the data work sheet, the model is ready to run. The model can be run in two modes: classic and advanced. Most users will need to use only the classic mode.

Classic mode

In this mode, body weights of animals for each month are specified by the user, regardless of the model's internal predictions about live-weight gain or loss. The model tries to find a steady state in terms of DM in each pasture; that is, a situation where the carryover of grass from December, Year y to January, Year y+1 coincides with that from December, Year y+1 to January, Year y+2.

The classic mode has at least two advantages. First, it eliminates the effect of bad estimation of any month's live-weight change from estimations in the subsequent months as, at the beginning of each month, the weight data are reset to the user-specified value. Second, users do not have to measure the current level of DM standing on each pasture, as it is automatically estimated by the model to match the animals' weight

$$ME_{lact1} = \frac{0.389 SRW^{0.75} BC_{birth} \dfrac{\frac{t_{lact}}{30}+2}{22} e^{1-\frac{\frac{t_{lact}}{30}+2}{22}}}{0.94\left(0.4+0.02(-1.7+0.17DMD)\right)} \tag{13}$$

$$ME_{lact2} = \frac{4.7 BW_{young}^{0.75}\left(0.3+0.41e^{-0.071\frac{t_{lact}}{30}}\right)}{0.94\,[0.4+0.02(-1.7+0.17DMD)]} \tag{14}$$

$$BWG_{adult} = \frac{0.043(-1.7+0.17 \bullet DMD)ME_{balance}}{0.92^2(13.2+13.8BC)} \tag{15}$$

$$BWG_{growing} = \frac{0.043(-1.7+0.17DMD)ME_{balance}}{0.92\left(4.7+\dfrac{MEI}{ME_{base}+ME_{graze}+ME_{cold}}+\dfrac{18.3-\dfrac{MEI}{ME_{base}+ME_{graze}+ME_{cold}}}{1+e^{-6*(Z-0.4)}}\right)} \tag{16}$$

$$Z = 1-\frac{(SRW - W_{birth})e^{-\frac{0.0157\cdot\frac{t_{age}}{30}}{SRW^{0.27}}}}{SRW} \tag{17}$$

change. For these reasons, the classic mode is the preferred option for inexperienced users.

Advanced mode

In advanced mode, users can specify an initial value for DM on one or more pastures, the body weights for one or more animal classes, or both. When an initial value is given to a pasture, the model no longer tries to find a steady state, instead taking that value, for that month, as granted. For example, if a user gives the initial value of 1,000 kg DM/ha as of April, the model starts its estimation of DM from that month, carries over the reminder to May and so on, up until March. Although the carryover value from March to April will not be exactly 1,000 kg DM/ha, the model stops its estimation here and produces the report. This method is useful when the effect on DM conservation of a single year of grazing is of particular interest. Initial values can also be given to more than one month; in such cases there will be more than one 'gap month' when the end-of-month DM level does not coincide with that at the beginning of the next month.

When an initial value is given to the body weight for an animal class, the model no longer reads user-supplied weight values for this animal class for other months, and instead estimates them internally according to its prediction on body-weight change. For example, if a user gives the initial value of 40 kg for ewes in April, the model uses this value to calculate the feed balance in this month and then, according to its own estimate, determines the body weight for May, June and so on up until March. This method is useful when a single-year effect of stocking rate on the stock's body weight is of particular interest, or when the body-weight data from the farm are unreliable. Initial values can also be given to more than one month; in such cases all these values are taken exogenously but body weights for all in-between months are filled by internal estimates. These initial values are to be specified on the cells immediately below body weight for each animal class. The cells are unlabelled in order not to confuse the classic-mode users.

StageONE model outputs and use

At the end of each run, the model produces two sheets of output: a work sheet that reports the crucial values and performance indices to understand the farm's operation, and a series of graphs showing trends in key parameters over time. The results work sheet consists of two reports of farming systems: the biophysical report and the financial report. The financial report is meaningful only if users had input values before the model run. When those values, particularly market prices of production inputs and production outputs, are unavailable or unreliable, users should concentrate on the biophysical report.

Once users are convinced from the reports and graph that the model is a reasonably good representation of the farm's current operation, they can proceed to conduct scenario analyses to see the effect of various alternative operations. For example, users can see the effect of additional supplementation during winter months in terms of the live-weight difference at the time of sales, and compare the benefit the farm enjoys (additional revenue due to heavier animals) against the cost it incurs (additional expense on supplements). They can also see the return to the farm's investment in a warm shed by comparing the increased revenue for heavier animals (produced because of a lower energy requirement at a higher temperature and in the absence of wind) and the annualised cost of the housing. It is possible to change the lambing time from, say, spring to autumn, to seek a better usage of pasture while animals are pregnant. Such a strategy, however, requires more supplementation for lambs in their first 6 months. The costs and benefits of alternative strategies must always be evaluated.

The *StageONE* model is designed for manual data entry and investigation of tactics and strategies. This requires users to have a reasonable understanding of the biophysical aspects of livestock production. All intermediate calculation steps are available to users, if they need them to understand the results obtained. This training role is critical in building the skills of those who have not previously analysed livestock farming systems.

StageONE versus *StageTWO*

The *StageONE* grazing farm model proved to be a powerful tool with which to understand grazing systems (see later case study chapters). The model requires a much smaller set of data than does most decision-supporting software, making it an attractive alternative to them—particularly so in areas where few pasture and livestock data are available. *StageONE* is also a good training tool for herders, extension officers and researchers with a less-than-strong scientific background and computer literacy, as the model runs entirely on Microsoft Excel and its output is visually intuitive.

One limitation of *StageONE*, however, is that the model does not give answers to whole-farm resource allocation problems. All supplements on the farm are assumed to be 'purchased', with no distinction made between external transactions and domestic production. Effects of in-house crop, hay and silage production on the farm's overall income are not considered, and neither are the farm's land and labour constraints.

While such simplicity makes *StageONE* a good starter's kit for the analyses of grazing enterprises, there are times when efficient whole-farm resource allocation is the key to poverty alleviation and environmental conservation. To help solve such problems, the *StageTWO* model was developed. It allocates a grazing enterprise's resources to maximise the farm's overall profit. *StageTWO* was designed using Microsoft Excel with users with little modelling experience in mind. While it requires the What's Best® optimisation add-in, users do not have to learn the intricacies of linear programming: they operate the model through an interface on the main spreadsheet.

Like *StageONE*, the model requires a minimal amount of input data, which are converted into a reasonable replica of the pasture–animal interactions on farm. Many programming concepts and scientific functions are shared between the two models, making it easy to compare the outputs from both. In this section, only those aspects that add to the outline previously given for the *StageONE* model will be presented, but readers need to remember that many of the basic functions are shared.

StageTWO model algorithm

The principal objective of *StageTWO* is to evaluate alternative livestock production systems, within the constraints of a typical farm, utilising the energy available from grasslands and crops most efficiently, across space and over time, to maximise net financial returns. A least-cost ration approach is used to model the use of alternative feed supplies.

Step 1: Derivation of energy requirements and intake for individual animals

An animal's demand for energy depends on its biophysical characteristics, the environment it lives in and what herders are managing the animals for. An important requirement is to clearly identify the livestock management calendar to then enable a better estimate of animal feed requirements. Ideally, a table of target weights, month by month, needs to be estimated to do the calculations required. As few farms have accurate scales, some estimates are inevitably required, based on likely annual patterns in live-weight change. Herders and local officials provided reasonable live-weight estimates for cardinal points during the year; e.g. for adult ewes at joining, pre-lambing and post-weaning; for lambs at weaning, sales and maiden joining; and for rams, a single representative weight. Gaps in the data are then estimated by interpolation. Animal demand is then estimated, using the equations given earlier, for each class of animal, taking into account its live weight, body condition, such as fleece length and condition score, pregnancy and lactation state and by external conditions such as temperature, wind speed and distance walked daily. Where noted, the equations used were from the estimation methods recommended by MAFF (1984), SCA (1990) and Freer et al. (2007). Some modifications have been made to simplify equations to minimise data requirements.

The estimation of energy intake in *StageTWO* differs significantly from that in *StageONE*. In *StageONE*, intake is governed by what is available at the time as described by herders and others. That means intake rates can be significantly below maintenance requirements, resulting in significant weight loss. In contrast, *StageTWO* was constrained to feed animals to at least a maintenance level, as preliminary work showed that unless that occurred net financial returns from livestock were severely constrained. It was also difficult to use a linear programming model where the constraints could end up in conflict, i.e. where livestock are fed at either sub-maintenance levels or to maintenance. The results from typical sub-maintenance feeding can be evaluated using the *StageONE* model.

Step 2: Determination of steady-state flock structure

StageTWO, like *StageONE*, aims to estimate farm livestock performance for a typical farm for any given year. Neither model looks at productivity over the longer term. An important aspect of this approach is to then derive a flock/herd structure that can then be optimised. Most farms investigated bred their own replacements. In general these farms are to some degree approaching a steady state as, over time, animal numbers are similar. A *Flock Calculator* was incorporated into *StageTWO* to estimate flock/herd structures so that the energy demand and utilisation could be more accurately estimated. This was estimated using equation (18), in which i is the age of ewes, Y the years in production life, and m the mortality coefficient (unity minus the annual mortality rate). One can show that the equality

$$\sum_{k=1}^{Y} N_k^{ewes} = 1$$

holds for all m and Y; hence N_i^{ewes} is the proportion of the ewe population that is i years old. When $Y = 5$, for example, each N_i^{ewes} takes a value slightly larger than smaller than 0.2 depending on the value of m. It is always that $N_i^{ewes} \geq N_{i+1}^{ewes}$. Users specify their overall flock size by the number of adult ewes, defined here as ewes more than 1 year old. A farm whose flock size is α needs to keep αN_i^{ewes} lambs for self-replacement and sell all others at the market, in order to maintain its steady state. The farm needs also to sell $m\alpha N_i^{ewes}$ old ewes that have completed their production life at the end of the production year. The numbers of rams and wethers, if any, are specified independently of this process as they do not affect the steady-state of the flock structure.

Step 3: Optimisation of farm profit

Given the energy demand to satisfy the target weight set by users, the optimisation problem the farm faces can be expressed as equation (19) subject to $EC \geq 0$, $AC \geq 0$, $CC \geq 0$, $LC \geq 0$, $x > 0$, $y \geq 0$, where p and q are row vectors of net output prices (positive sign for outputs and negative sign for inputs) for livestock production and crop production, respectively, and x and y are column vectors of the absolute values of outputs and inputs for livestock production and crop production, respectively. EC, AC, CC and LC represent sets of constraints on (i) energy consumption by animals, (ii) areas for grazing and cropping, (iii) working capital and (iv) labour requirement for farming activities, respectively, all of which, as well as function $f(\bullet)$, are restricted to being concave. Applying the Kuhn–Tucker theorem, the existence of solutions for this problem is guaranteed.

StageTWO consists of some 400 constraints and 400 factors of x and y. Among them, the most important is a subset of *EC*, which has a direct, and probably the largest, effect on the farm's profitability, as expressed in equations (20) and (21), in which terms beginning with c are components of the model's constant vector c supplied by users, with $c^j_{p,growth}$ being monthly growth rate of DM and $c^j_{p,carryover}$ the carryover coefficient that represents water and wind erosions. Inequality (20) says that, for each month from January to December, the energy demand ED^j has to be met by energy supply from pastures (x^j_p) kg DM from pasture p) and supplements (x^j_s kg DM for supplement s), whose energy values are v^j_p MJ/kg DM and v^j_s MJ/kg DM, respectively. The supply of forage from pastures, in turn, is limited by inequality (21), in which the month's DM usage ($x^j_p + b_p^{j+1}$) has to be met by the DM supply ($c^j_{p,growth} + c^j_{p,carryover} b_p^{j-1}$).

The set of 12 inequalities (equation (21)) makes *StageTWO* a complete, steady-state model; that is, not only does it hold the monthly flock structure and associated body weights constant every year, it also utilises its pastures in exactly the same way every year. In other words, the number of lambs, their body weight, their feeding pattern, the DM standing on pastures—to name a few factors—in, say, May this year will always coincide with those from May last year. This characteristic of *StageTWO* prevents the occurrence of 'Pondi game'—where all renewable and non-renewable resources are exploited and exhausted at the final month of the model.

$$N_i^{ewes} = \frac{m^{i-1}}{\sum_{k=0}^{Y} m^k} \text{ for } i = 1, 2, \dots, Y \tag{18}$$

$$\max_{\mathbf{x},\mathbf{y}} f(px + qy) \tag{19}$$

$$\sum_p \left(v_p^j x_p^j\right) + \sum_s \left(v_s^j x_s^j\right) - ED^j \geq 0 \text{ for } j = 1, 2, \dots, 12 \tag{20}$$

$$b_p^j \equiv c^j_{p,growth} + c^j_{p,carryover} b_p^{j-1} - x_p^j - b_p^{j+1} \geq 0 \text{ for } j = 1, 2, \dots, 12 \tag{21}$$

StageTWO model interface

While the optimisation problem (equation (19)) is a self-contained problem that can be solved independently for any given energy demand (*ED*), there are many cases when it is convenient to compare the results from multiple sets of them. In *StageTWO*, up to 12 sets of *ED* can be pre-filled into the user interface work sheet on Excel. According to their research need, users can compare, for instance, the optimised profits from different enterprises (mutton sheep, fine-wool sheep and cashmere goats), different lambing months, different grazing patterns (e.g. when to house them to save ME_{graze} and ME_{cold}) or different stocking rates (for different α). Being a concave programming model, *StageTWO* may choose a combination of more than one *ED* set as an optimal solution—such as 'March-lambing mutton sheep with $\alpha = 100$ and September-lambing cashmere goats with $\alpha = 50$'—if it is more energy-efficient to do so.

Users have access to all exogenous values including p, q, v_p, v_s and c so that they can modify them according to their local situation. Once the model has been set up for a single locale with multiple sets of *ED*, however, it is rare that users need to change many values to conduct their analyses. For this reason, only major parameters are accessible from the user interface work sheet; this way, common, virtual experiments can be run in an intuitive environment. Parameters accessible from the user interface work sheet include areas of pastures and crop fields, pasture compositions, upper and lower limits on supplementary feeding, and working capital and labour force available. In addition to these parameters, users can also specify whether animals are housed in each month (this changes ED^j), as well as which sets of *ED* the model is allowed to choose for the current run. When the model run is restricted to a single *ED*, it is a simple optimisation problem represented by equation (19).

At the completion of each model run, *StageTWO* produces a report work sheet that summarises critical figures of the optimised operation. All other values, including Lagrangean multipliers, can be found in the main matrix.

The advantage of the steady-state approach is its relatively small data requirement. Compared with most decision-support systems or sustainability models that require chronological data on weather, soil and pastures, *StageTWO* requires a significantly smaller number of user-specified parameters. This is particularly attractive in developing countries where it is difficult to find scientific data; in those areas, *StageTWO* can be a quick solution for both scientific analyses and farming training programs.

Needless to say, the moderate data requirement comes at a cost. The model has limited capability to analyse long-term effects of grazing or lack thereof, as such effects cannot be measured under *StageTWO*'s assumptions that neither pasture composition, pasture growth rate nor soil fertility change over time. It is crucial for users to be aware of this characteristic of the model and combine their analyses with those from long-term sustainability models if necessary.

Subsequent chapters show how these models have been used to analyse the typical farms in four counties across northern China. Those analyses have identified the main issues confronting livestock producers, and strategies that can result in improved net financial returns.

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Dynamic modelling of sustainable livestock production systems

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Abstract

Finding solutions to the complex problems of grassland rehabilitation and improvement in household incomes for the herders dependent upon livestock production from grasslands requires the development of integrated modelling tools to identify the more likely solutions that can then be tested over time on farms. This paper outlines a dynamic bioeconomic model designed to analyse the main options available to improve grasslands and income from livestock on low-productivity grasslands in northern China. The model requires basic information obtained from farm surveys to structure the livestock production system and uses general relationships between livestock consumption of grasslands and grassland productivity, plus functions that simulate erosion and soil fertility loss due to wind, to estimate longer term productivity and financial returns. Initial simulations show the benefits of managing grazing pressures to higher levels of herbage mass than would be current practice on farms.

Introduction

Chinese grasslands are commonly regarded as being in a highly degraded state. Overgrazing by livestock is the most common form of degradation, resulting in low levels of herbage mass and consequent soil erosion due to the forces of wind and water.

Soil erosion is of major concern across many landscapes and especially on the Loess Plateau, not just because of a loss in agricultural productivity but also due to the effects of sedimentation in the Yellow River. Soil loss due to wind erosion reduces agricultural productivity, and there are serious off-site consequences from dust storms in large cities such as Beijing. These include costs to infrastructure maintenance, increased incidence of accidents due to loss of visibility and increased human health costs arising especially from respiratory ailments. Consequently, the current management of Chinese grasslands is considered unsustainable.

There are numerous definitions of the concept of 'sustainability'. The most widely used definition of 'sustainable development' is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987, p. 43). There are two potential versions of sustainability: strong and weak sustainability (Turner et al. 1994, p. 55). The main difference between these two versions is the ability to make trade-offs between the various forms of capital (natural, human, social) in the case of weak sustainability. Cases of strong sustainability require that the stocks of natural resources must not be reduced over time—the same stock of resources available to current generations will be available to future generations. This typically applies to endangered species that could not be replaced or to a finite water or other resource whose use would severely compromise future generations. The concept of weak sustainability allows for substitution between the different forms of capital stock, thereby allowing an overall economic system to be sustainable by trading-in some forms of capital for others. It applies to many agricultural systems.

Rather than being overly concerned with exact definitions or types of sustainability, a better

Pp. 36–43 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.

approach may be to accept that the goal of sustainability in a general sense is to improve the productive performance of a system without depleting the natural resource base upon which its future performance depends (Pearce and Turner 1990, p. 24). Heal (1998, p. 48) suggests three axioms of sustainability:

1. a treatment of the present and the future that places a positive value on the very long run
2. recognition of all the ways in which environmental assets contribute to economic wellbeing
3. recognition of the constraints implied by the dynamics of environmental assets.

These have implications for the types of models to be used for studying the sustainability of Chinese grasslands and the resulting data needs. Dynamic models that consider the long run (e.g. 20–30 years) are more appropriate than single-period, steady-state models (axiom 1). Such models allow identification of the value of preserving natural resources for future use. Grassland systems provide a range of environmental services other than just livestock production, and these environmental values should be accounted for where possible (axiom 2). For example, soil loss due to wind erosion leads to dust storms across China and neighbouring countries, resulting in a number of off-site costs. Including the impact of externalities from the management of natural resources is an important component of economic welfare analysis. Bioeconomic models are commonly used where there are important interactions between biological stocks, the decisions to use or preserve those stocks and the economic consequences of those decisions (axiom 3). Such models are important for accounting for any constraints to either the level of biological stocks or the dynamic interactions between them and the economic system.

This paper outlines a bioeconomic model used to investigate key management options to limit wind erosion and soil loss from semi-arid grasslands in northern China and to optimise long-run financial returns. Examples are presented for model output for the desert steppe grasslands in Siziwang in the Inner Mongolia Autonomous Region. Further details of this region are presented in Han Guodong et al. (2011) and Wang Zhongwu et al. (2011). In addition some basic data on grassland growth are used for the typical steppe at Xilinghote as no equivalent data are available for Siziwang. This was done to illustrate how the model works. However, the conclusions about stocking rates then need to be interpreted with some care as they could overestimate actual values. The model presented here will be further developed with relevant datasets for a range of conditions across northern China.

A bioeconomic model of sustainable grazing

A bioeconomic modelling system (Clarke 1990) was developed to evaluate alternative livestock management options in northern China's grasslands. This follows the framework presented by Pandey and Hardaker (1995) for including the inter-temporal trade-offs for a sustainability problem.

$$\max \quad J = \sum_{t=0}^{T} \pi(x_t, u_t)\delta^t \qquad (1)$$

subject to

$$x_{t+1} - x_t = g(x_t, u_t) \qquad (2)$$

$$x_0 = x(0) \qquad (3)$$

where J is the discounted sum of the performance measure over the planning horizon T, t is an index for year, p is a measure of farm performance, x is the stock of natural resources (state variables), u is the set of management decisions (control variables), δ is the discount factor, and g is the measure of the change in the stock of the natural resources over time, which depends on the stock size and the management decisions.

For the sustainable grassland problem, three inter-temporal states of nature are identified: the maximum annual biomass of grassland production, the carryover of grassland herbage mass and the soil depth. The measure of maximum biomass achievable represents the grassland condition and is used as the carrying capacity, or asymptote, in a pasture growth equation. The level of herbage mass of the grasslands is an important determinant of livestock production and the degree of soil erosion. The growth of new herbage mass (daily or monthly) is a function of the grassland biomass carrying capacity, soil fertility and the existing biomass. Hence, the carryover of herbage mass is important to derive the starting value for monthly growth rate. The soil depth variable is used to account for the cumulative effects of soil erosion upon soil fertility and consequently on pasture growth. This is a dynamic relationship as soil erosion is directly influenced by herbage mass along with weather conditions and the soil properties.

The main decisions governing sustainable grassland resource use involve the choice of livestock enterprise, the stocking rate and the supplementary feeding strategy. The two key decisions are stocking rate (defined in terms of breeding ewes per hectare (ha)) and the level of supplementary feeding (defined in terms of kilograms (kg) of supplement fed per animal per day). Pen feeding in warm sheds is another management strategy to reduce stress on the grasslands, whereby livestock are kept indoors and fed solely on supplements during winter and early spring. This allows greater herbage mass to be maintained on the grasslands thereby reducing the potential for soil erosion and resulting in higher pasture growth rates in spring. The potential effect of pen feeding can be simulated by increasing the supplementary feed ration over these months, thereby satisfying livestock energy needs so that no grassland resource is utilised.

A monthly time step is used to calculate pasture growth, livestock energy demands, pasture intakes, and changes in animal body weights. Livestock productivity in terms of adult sheep body weights and lamb weight gain is a function of the quantity and quality of the grassland resource.

States

Grassland condition

A grassland condition (*GC*) state variable is defined to represent the change in grassland quality over time. This variable is the maximum herbage mass that can be produced within a growing season and is used as the asymptote in a pasture growth equation. It thus directly determines the rate of growth and herbage mass that can be achieved from the grasslands. The change in grassland condition (*GC*) is a function of its intrinsic growth and the harvest of the grassland condition (*H*) through the intensity of grazing by livestock. Consequently, this state can be represented by a resource-harvest model (Clarke 1990):

$$GC_{t+1} = GC_t + \Delta GC_t - H_t \quad (4)$$

Soil depth

The level of soil fertility is likely to influence the rate of change in the condition of the grasslands as well as the growth of herbage mass. Soil fertility is a function of soil depth, which itself is a function of soil loss as a result of wind erosion. Soil nutrients tend to decline exponentially at a rapid rate with depth from the soil surface, hence even small amounts of soil erosion remove considerable amounts of nutrients. The soil depth state variable (*SD*) is derived from equation (5). We do not account for any increase in soil stock in this model, although in practice some soil will be deposited in some areas during episodes of soil erosion. There is, however, a net soil loss across much of north Asia each year.

$$SD_{t+1} = SD_t - \Delta SD_t \quad (5)$$

Grassland herbage mass carryover

The grassland herbage mass carryover (*HC*) variable is simply the final grassland biomass mass (*B*) derived for the final month of the previous year. It is given by:

$$HC_t = B_{t-1(i=12)} \quad (6)$$

This variable is used in the calculation of the initial pasture growth rate and as part of a vegetative cover variable in the wind erosion equation. The assumption in the model at this stage is that losses through winter will be minimal in the absence of grazing, although that is obviously an overestimate. Future developments of the model will incorporate a loss function driven by climatic conditions and general plant breakdown. The data to develop such a loss function are not readily available at present.

Decisions

There are two key decisions that will drive much of the system performance in the example presented in this paper: the stocking rate (*SR*) of sheep on the grasslands over the summer months (breeding ewes/ha), and the level of supplementary feeding (*SF*) to adult sheep and lambs in each month (kg/head/day—typically through winter). Stocking rate is varied from 0 to 1 ewe/ha, while supplementary feeding in a grazing system is restricted to standard district practices of around 1 kg/day in the winter months.

Two grazing management strategies are evaluated: continuous stocking and tactical grazing. For the first strategy the stocking rate is fixed regardless of grassland condition for the simulation period at rates of 0, 0.25, 0.50, 0.75 and 1.00 ewes/ha. These stocking rates are then applied to a long-term simulation when the initial grazing threshold is reached (GC_0). This is similar to applying a grazing ban until a discernible improvement in grassland condition is obtained. GC_0 is pre-defined at values of 500, 1,000, 1,500, 2,000 and 2,500 kg dry matter (DM)/ha. The assumption in the model is that GC_0 values reflect the likely range in herbage mass of forage that would be encountered in the region, from the worst to an optimistic best. The change in the grassland condition over time from this initial value, following application of the strategy, can then be estimated.

Under tactical grazing (*TG*) management the stocking rate is varied according to grassland condition around a defined grassland threshold (*GT* as herbage mass, kg DM/ha). Below this threshold a conservative stocking rate is adopted; above it, more intensive utilisation of the grasslands by livestock can occur. In this study a threshold of 1,500 kg DM/ha is used for all simulations, i.e. the midpoint in GC_0 examined above and a level where forage intake by sheep and goats is near optimal. The following tactical grazing options were evaluated by the model, where the first parameter is the stocking rate (ewes/ha) below *GT* and the second parameter is the stocking rate (ewes/ha) above *GT*: TG_1 (0.00:0.25), TG_2 (0.00:0.50), TG_3 (0.25:0.50), TG_4 (0.25:0.75) and TG_5 (0.50:0.75). These stocking rate values were chosen to cover the likely range to be encountered in the district modelled (Han Guodong et al. 2011). In this way the interaction between stocking rates and *GT* values could be explored. The options TG_1 and TG_2 are similar to applying a grazing ban until a discernible improvement in grassland condition is obtained.

An option to reduce grazing pressure on the grasslands in winter months is to pen feed animals on supplements only, with no access to the grasslands. This can have two potential outcomes: first, by maintaining greater herbage mass through winter the propensity for wind erosion in spring is reduced and, second, the combination of a higher quality ration and the reduction in cold stress from winter grazing can improve animal productivity. This productivity gain can be expressed as higher ewe body weights and accompanying fecundity.

Profit function

The profit function in the model represents the net farm income (π) from the livestock activities, being the difference between livestock income (Y_L) and livestock costs (C_L).

$$Y_L = L_{PRICE}L_{SOLD}L_{WEIGHT} + E_{PRICE}E_{SOLD} + W_{PRICE}W_{SOLD} \quad (7)$$

$$C_L = E_{VC}TEWES + L_{VC}TLAMBS + S_{COST}TSUPP \quad (8)$$

$$\pi = Y_L - C_L \quad (9)$$

where L_{PRICE} is the price of lambs (¥/kg), L_{SOLD} is the number of lambs sold, L_{WEIGHT} is the live weight of lambs (kg/head), E_{PRICE} is the ewe sale price (¥/head), E_{SOLD} is the number of ewes sold, W_{PRICE} is wool price (¥/kg), W_{SOLD} is amount of wool sold (kg), E_{VC} is the variable cost per ewe (¥/head), *TEWES* is the total number of ewes on hand, L_{VC} is the variable cost of lambs (¥/head), *TLAMBS* is the total number of lambs, S_{COST} is the cost of supplementary feed (¥/kg), and *TSUPP* is the total amount of supplement fed for the year (kg). The model assumes that a herder aims to maximise the net present value (NPV) of net farm income over the planning horizon (*T*).

$$NPV = \sum_{t=0}^{T} \frac{\pi}{(1+\beta)^t} \quad (10)$$

where β is the discount rate.

Data requirements

Bioeconomic models require detailed biological data of the systems being investigated. In the case of sustainable Chinese grasslands, these include historical weather data (daily, weekly or monthly), parameters to estimate the growth and quality of pasture, parameters for modelling livestock production, and parameters for estimating the change in grassland condition and the amount of soil erosion (soil depth). Financial data are required to value the economic performance of the system and the effects of alternative decisions upon long-run farm income. Data for parameterising this model were obtained from a number of sources including published information, farm survey data, experimental results, and expert opinion as outlined elsewhere in these proceedings.

The change in grassland condition could be represented by a logistic function. Historical grassland data were used to estimate the logistic parameters. An example is given in Figure 1a for data from Inner Mongolia for a logistic curve fitted to a long-run livestock exclosure experiment. This showed that, in a higher rainfall region to that used for the rest of this study, it took 15–20 years for the potential ceiling yield of grasslands to be restored and that, over that time, yields effectively trebled.

Figure 2 shows functions derived from the model.

Economic simulation results and discussion

The model was simulated for the five different GC_0 states, ranging from extremely degraded (500 kg DM/ha) to good (2,500 kg DM/ha), for each of the continuous and tactical stocking decisions.

For each of the tactical grazing options the grassland threshold was set at 1,500 kg DM/ha. The NPV for each GC_0 and grazing decision is reported in Table 1. For the continuous grazing options the stocking rates that resulted in the highest NPV were 0.25 ewes/ha for GC_0 500, 0.50 ewes/ha for GC_0 1,000 and 1,500, and 0.75 ewes/ha for GC_0 2,000 and 2,500, Clearly then, the long-run economic returns are influenced by the state of the grasslands, with a higher initial quality grassland able to support higher stocking rates.

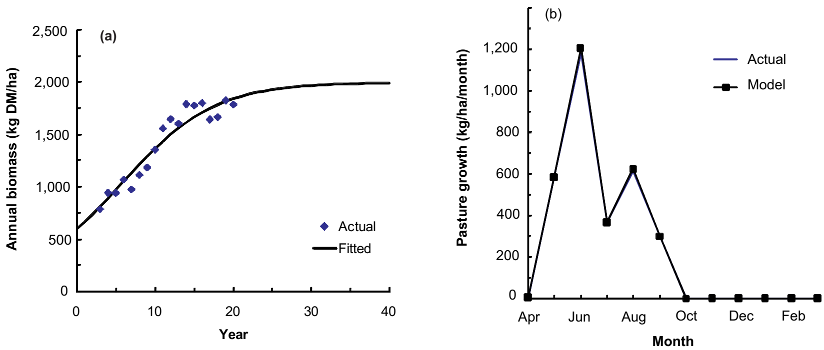

Figure 1. (a) Fitted logistic growth curve (—) to actual data (◆) on grassland condition response to livestock exclosure for Xilinghote, Inner Mongolia Autonomous Region, typical steppe (Source: Professor Liu, Inner Mongolia University); (b) fitted sigmoid growth curve to Inner Mongolia pasture growth data

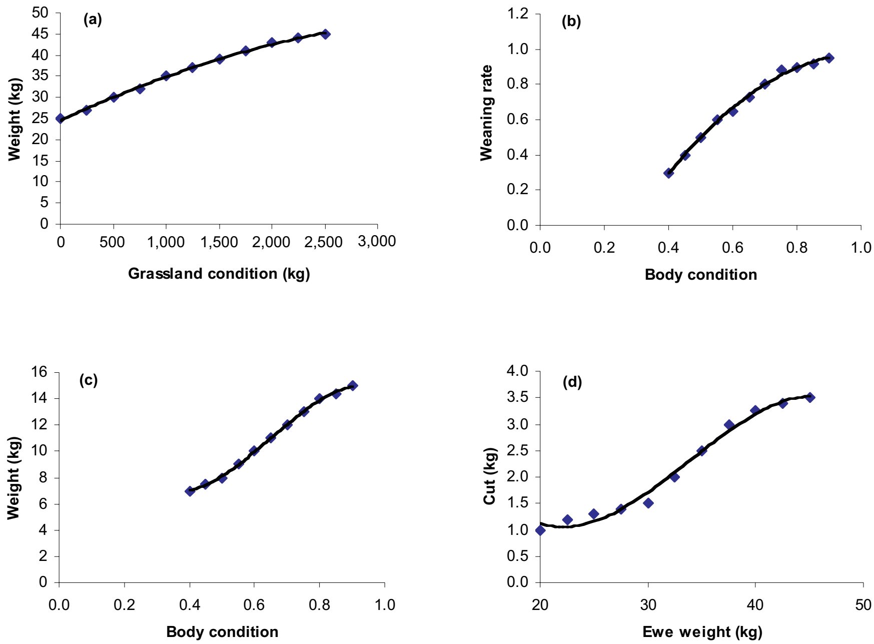

Figure 2. Functions derived from the model: (a) initial ewe weight, (b) weaning rate, (c) weaning weight and (d) wool cut

Table 1. Net present value (¥) modelled estimates for continuous grazing (ewes/ha) and tactical grazing options from 52-year simulations for different initial grassland condition (GC_0) states (kg DM/ha) in Siziwang Banner, Inner Mongolia Autonomous Region

Ewes/ha	GC_0 500	GC_0 1,000	GC_0 1,500	GC_0 2,000	GC_0 2,500
Continuous grazing					
0.25	**56,079**	87,571	100,891	106,958	109,001
0.50	11,898	**127,628**	**169,734**	190,079	199,245
0.75	–83,252	41,443	138,270	**192,001**	**219,853**
1.00	–137,702	–43,477	51,763	120,219	162,960
Tactical grazing					
TG_1 (0.00 : 0.25)	55,882	79,126	100,891	106,958	109,001
TG_2 (0.00 : 0.50)	**90,697**	**132,273**	168,318	189,661	198,367
TG_3 (0.25 : 0.50)	73,649	129,861	169,062	189,422	198,808
TG_4 (0.25 : 0.75)	74,510	127,806	**175,892**	**211,517**	227,287
TG_5 (0.50 : 0.75)	11,898	127,628	174,078	210,247	**231,610**

The NPV for the tactical decision options generally show an improvement on what can be obtained under continuous stocking. Not only are the returns from tactical grazing higher but, for each GC_0, a tactical grazing option resulted in the maximum NPV: TG_2 for GC_0 500 and 1,000, TG_4 for GC_0 1,500 and 2,000, and TG_5 for GC_0 2,500. This result supports the view that extended 'grazing rests' until better grassland condition states are reached will result in higher subsequent stocking rates and financial returns over the long term. This can mean an extended grazing rest is required for more than a few years to achieve the desired grassland condition.

The model cannot resolve what effect these treatments would have on the floristic composition of the grasslands. Degraded grasslands typically have a higher proportion of lower quality grassland plants, but experiments would be needed to resolve which approach resulted in the better grassland condition. It may be that, if the grassland is significantly degraded at the start, then lower stocking rates than these simulations suggest would be required to enable a shift in botanical composition to more desirable species.

Relative to each initial grassland condition state, the model derives a range of biological outcomes from following these different grazing management decision rules over the simulation period. Table 2 presents the average annual soil loss from wind erosion over the simulation period for each of the continuous grazing options and the best of the tactical grazing decisions for that condition state. This clearly shows that as the initial grassland condition increases there is a concomitant reduction in soil loss. More significant, however, is the effect of increasing stocking rate regardless of the initial grassland condition. For example, in the case of GC_0 1,000, soil loss rises from 9.7 t/ha/year at 0.25 ewes/ha to 47.4 t/ha/year at 1.00 ewe/ha. Even in the case of GC_0 2,500, large rates of annual soil loss (36.0 t/ha/year) can occur at the highest stocking rate.

Table 2. Average soil loss (t/ha/year) for continuous grazing (ewes/ha) and the best tactical grazing option over from 52-year simulation for different initial grassland condition (GC_0) states (kgDM/ha) in Siziwang Banner, Inner Mongolia Autonomous Region

Ewes/ha	GC_0 500	GC_0 1,000	GC_0 1,500	GC_0 2,000	GC_0 2,500
Continuous grazing					
0.25	11.4	9.7	9.4	9.3	9.3
0.50	28.2	11.5	10.4	10.1	10.0
0.75	51.0	36.5	26.0	21.1	18.9
1.00	53.6	47.4	41.7	38.2	36.0
Tactical[a]	11.2	10.4	10.6	10.5	10.6

[a] Tactical is the economic optimal tactical grazing option for each individual GC_0 state defined in Table 1.

The adoption of tactical grazing has the potential to reduce soil loss (Table 2) as higher biomass values are achieved by this strategy. This is indicated by the temporal change in grassland condition for a number of grazing strategies (Figure 3a). If livestock were to be completely excluded then grassland condition would increase (from an initial state of 1,000 kg/ha) to an asymptote of almost 2,800 kg/ha within 20 years. Utilisation of grassland, on the other hand, reduces any improvement in its condition (even at moderate stocking rates of 0.25 and 0.50 ewes/ha) and, for stocking rates greater than 0.50 ewes/ha, the grassland degrades further. The tactical grazing strategy TG_2 results in an increase in grassland condition through the adoption of grazing rest, and condition is then maintained at around 1,500 kg/ha.

The effects upon soil depth and the soil fertility index over the simulation period are illustrated in Figures 3b and 3c, which show that, at the highest stocking rates, substantial degradation of the soil resource is likely to occur. In this case study, there is still some level of soil degradation at the most conservative stocking decisions, regardless of the initial grassland condition. This outcome is due to the high erodability index of Siziwang soils and the low herbage mass values during periods of peak wind erosion in April and May. In addition to the modelling of pasture growth, the representation of soil erosion from the model requires further investigation and validation.

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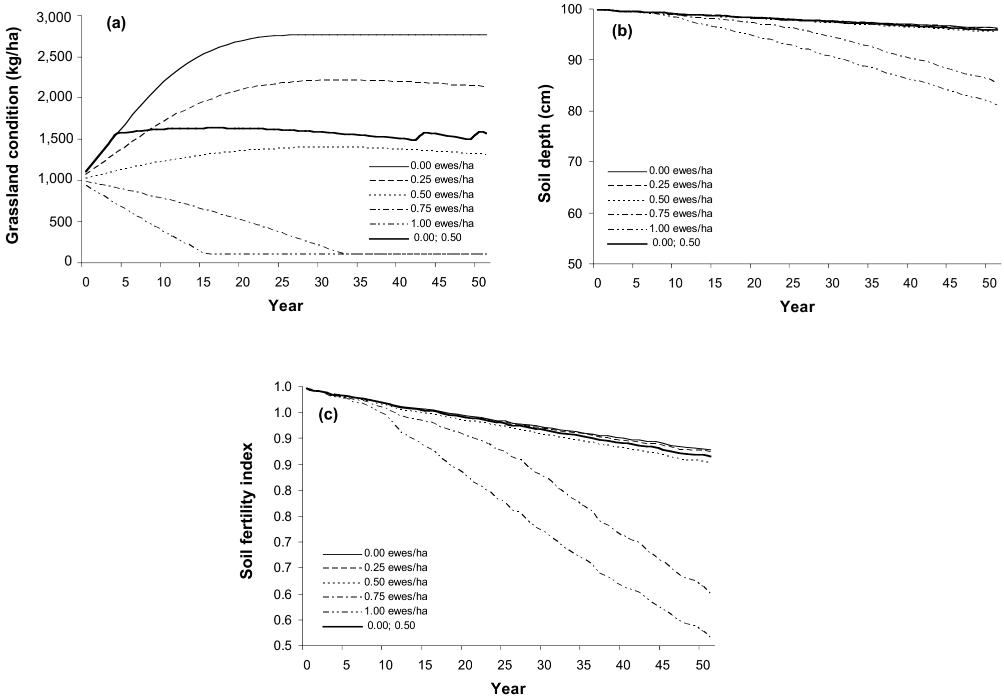

Figure 3. The temporal impact of alternative continuous and tactical grazing decisions on (a) grassland condition, (b) soil depth and (c) soil fertility index for the case of GC_0 of 1,000 kg/ha

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Intense dust storms in Beijing in April 2001 were a serious off-site effect of grassland degradation in north-western China. [Photo: R. Jones]

Farms and housing on loess soils in Huanxian county, Gansu province. A new warm shed for livestock can be seen on the left of the path that runs down the hill. [Photo: D.R. Kemp]

Sheep tracks on loess soils at the end of winter in Gansu province [Photo: Hou Fujiang]

Case studies of typical farms in Gansu province and the Inner Mongolia Autonomous Region

Peak summer grassland growth under common, continuous grazing at Taipusi Banner, Inner Mongolia Autonomous Region. [Photo: Xu Zhu]

Grazing systems on loess soils: options in Huanxian county, Gansu province

Wang Xiaoyan, Hou Fujiang and Nan Zhibiao

Abstract

Huanxian county is in the northern part of eastern Gansu province on the Loess Plateau where there is a traditional integrated crop–livestock grassland farming system. In past decades, the grasslands have degraded seriously and herder incomes are below the national average. Livestock production needs to be improved to help rehabilitate the degraded grasslands and improve household net incomes. Farm conditions were surveyed over 3 years to define the typical livestock farm in the area. Data were then analysed using models to describe current conditions and then to investigate options for improving farm performance. The models used results from a grazing experiment to define production functions. Livestock currently face major feed deficiencies through much of the year. Analyses showed that, under optimal stocking rates, net financial returns for mutton or wool production were lower from seasonal grazing plus pen feeding than from grazing all year, because of the higher feeding cost. Optimal stocking rates are significantly lower than current rates. The estimated optimal stocking rate for net farm income from wool production was higher than for mutton production. Subdivision of grazing into one field grazing all year versus three fields did not change net farm income, but did provide opportunities to rehabilitate grasslands. For the current practice of January lambing, the more profitable returns come from selling lambs at 18 months of age, rather than at 3–12 months, but this increases the grazing pressure on grasslands and hence alternatives need to be found. Significant opportunities exist for herders to improve incomes and rehabilitate grasslands within their existing farms.

Introduction

The Loess Plateau in central China is a major area of agricultural production and has been so for at least 5,000 years (Cao 2006). The loess soils are of moderate fertility and support both grazing and cropping. The region is characterised by high levels of soil erosion and major environmental problems (Xin et al. 2009). About 97% of grasslands are considered to be degraded, 47% of them severely so (Hou and Nan 2006). Herders in these areas are among the poorest in China, with small farms and limited resources.

Most of the rainfed farming systems on the Loess Plateau integrate livestock and crop production (Ren 2003; Hou et al. 2008). The short growing season over summer provides some grazing when animals can recover from the stressful cooler seasons. Generally, crop residues, by-products and some surplus grains are used to feed livestock through the autumn, winter and spring. Large livestock are used for draft for crop production and livestock manure is used on crop land (Hou et al. 2008). The farming system is characterised as self-sustaining, with a strong emphasis on subsistence and survival strategies rather than on optimising the output of crop and livestock products (Hou and Nan 2006). Farmers harvest food from both crops and livestock and sell surpluses in local markets. Market systems are not well developed, but are changing in response to the changing economic conditions in China.

This paper first describes the typical farm production system (a case study of Daliangwa village) on the Loess Plateau in eastern Gansu, based on 3 years

Pp. 46–57 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.

of survey data, then analyses that system using models designed to investigate current practices and alternative tactics and strategies for livestock enterprises. The overall aim is to identify practices that are more likely to lead to improved household incomes and opportunities to rehabilitate the degraded grasslands.

Huanxian county

Huanxian county (36.02°–37.15°N, 106.35°–107.75°E, altitude 1,100–2,080 m) is in the northern part of eastern Gansu, on the Loess Plateau, adjacent to the south-eastern edge of the arid desert area in north-western China and has been used for traditional farming–pastoral activities for millennia (Jing and Chang 2002). The environment and social structures of Huanxian county are typical of much of the Loess Plateau. Weather records collected during the past 50 years show that annual mean precipitation is 425 mm, over 60% of which falls from July to September; annual mean air temperature ranges from 6.7 to 9.2 °C (Hou et al. 2002) (Figure 1).

There are 330,000 people in the county, 94% of whom are involved in crop and livestock production. Total land area is 9.25 million hectares (ha). The population density of 357 people/km^2 considerably exceeds the recommended international standard of 33 people/km^2 for similar arid and semi-arid regions identified by the United Nations. Huanxian is one of the typical poverty counties in Gansu province (Hao et al. 2004) because of the pressures from human and animal populations and the degraded natural environment. In Huanxian there are 62,000 people (19% of the population) who are classified as being in severe poverty. In Daliangwa village, Huanxian county, the average net per-capita income of herders was approximately ¥2,240 (A$450) in 2006 and ¥1,750 (A$350) in 2007 (see Table 1), marginally above the average for the whole county, but below the national average and below the poverty level of around US$2/head/day. There is an average of 5.9 people per farm. Livestock production contributed on average 32% and 40% of total net income on farms in 2006 and 2007, respectively. Gansu is among the poorest provinces in China.

Table 1. Net income of mixed livestock–cropping farms in Daliangwa village, Huanxian county, Gansu province

	Area (ha)	2006 (¥/farm)	2007 (¥/farm)
Livestock	8.4	4,220	4,140
Crop	2.8	9,025	6,180
Total	11.2	13,230	10,320

The current ratio of crop:grazing:woodland in the region is 8:24:1. Some 92% of farms have both crop and grazing lands managed in an integrated system (Table 2) (Wang 2008). Small grain crops include buckwheat, winter wheat and millet, the main cash crop is potato and lucerne is the most important forage crop (Table 3). The main livestock are goats,

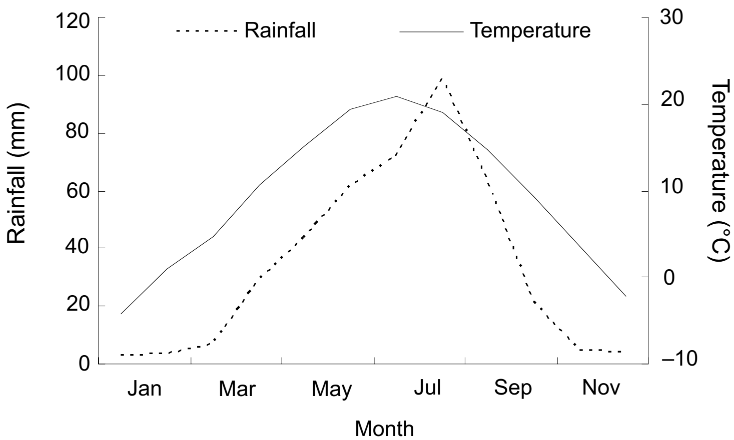

Figure 1. Average air temperatures and rainfall in Huanxian county, Gansu province

Table 2. Average livestock numbers in 2007 for farms in Daliangwa village, Huanxian county, Gansu province

	Mean number of livestock (head/farm)	Farms with this livestock type (%)
Donkeys	1.2	92
Goats	10.0	38
Sheep	2.4	21
Cattle	0.1	4
Farms with livestock production		92
Average livestock number per farm	13.7	

sheep, donkeys and cattle (Table 2). Cattle and donkeys are used mainly as draft animals in crop production. Livestock traditionally graze throughout the year. Sheep and goats are the more profitable livestock types. The data used for modelling were from farms that had 19 or more sheep plus goats. Those with fewer than that had animals that were primarily kept for home consumption. Some supplementary feeds, mainly lucerne hay, potato and other by-products of wheat, buckwheat and other crops, are fed at a subsistence level in the colder seasons. Of interest is the increase in area of lucerne relative to other crops between 2006 and 2007 (Table 3). This may become a stronger trend to provide supplementary fodder for livestock through winter.

Table 3. Percentage of crop land used for different species on farms in Daliangwa village, Huanxian county, Gansu province. Total crop area averaged 2.9 ha. Note that land area in China is measured in mu (1 mu = 0.0667 ha) which results in small fields being devoted to different crops.

Crop	2006	2007
Lucerne	25	36
Winter wheat	1	8
Buckwheat	31	21
Potato	29	15
Broom-millet	6	3
Millet	6	1
Canola	2	1
Other	1	15

About 97% of the grazing lands on the Loess Plateau are degraded to varying degrees, and more than 33% are considered to be seriously so (Ren et al. 2000). The Loess Plateau has some of the most severe soil and water erosion in the world, with erosion gullies up to 300 m deep. Soil and water loss occurs on 71% of the land and 1.6 billion tonnes of soil flow annually into the Yellow River, resulting in a large loss of soil fertility (Fu 1997). Average annual losses of nutrients are: nitrogen, 60–150 kg/ha; phosphorus, 90–225 kg/ha; and potassium 1,200–3,000 kg/ha. Programs to stabilise erosion and reclaim grazing lands have been in place in Huanxian since 1981. In the 20 years to 2001, 127,000 ha were reclaimed. Assuming that this land can carry one sheep equivalent per ha, then this would equate to a net benefit of ¥20m (A$4m)/year. Soil erosion and water loss, grassland degradation and population pressures from humans and animals are the main factors limiting agricultural production. The region is prone to droughts. From 2004 to 2007, for example, due to low rainfall, little wheat was produced.

Methods

Data

To characterise the typical farms in the area and to provide basic information for the farming system models used (see below), data were obtained from farm surveys and from field experiments done in the area. These data were then used to obtain basic production functions for the models. During 2005–07, over 150 farms were surveyed to record details of the components and all inputs and outputs for the production system. This information included all cash income and expenditure; livestock inputs and outputs—numbers, grazing periods, pen-fed time, lambing, kidding and calving times and yield of products for all livestock; and crop inputs and outputs—which crops were planted, areas, yields, and planting and harvest times. Inputs for livestock production included supplemental feed, pesticides and labour, and outputs were meat from young and old animals, and wool and cashmere yields. The inputs for crop production included fertilisers, chemicals, labour, animal draft, machinery, diesel fuel, plastic film (now widely used across semi-arid China to conserve water use and warm soils to stimulate earlier growth of crops) and irrigation, and the main outputs were yield and price of every crop and product by-product. Estimates were made of animal live weights for each month of the year. Where farm data were not available, some estimates derive from discussions with local officials.

Two groups of field experiments using local Tan sheep rotationally grazing natural and sown grasslands have been underway since 2001 at the field experiment station at Daliangwa village, Tianshui township, Huanxian County, done by the College of Pastoral Agriculture Science and Technology, Lanzhou University. In the grazing experiment the effects of different stocking rates on grasslands and livestock production were studied on an area grazed only in summer and on an adjacent area that was grazed only through autumn. Both sites were on typical steppe. Rotational grazing of sheep started in mid June and ended in mid September, while cool-season grazing was implemented from early November through late December. The stocking rates applied were 2.7 sheep/ha (8 sheep unit months (SUM)/ha), 5.3 sheep/ha (16 SUM/ha) and 8.7 sheep/ha (26 SUM/ha), with free grazing and exclosures as controls. Livestock were weighed monthly during grazing, and wool yields were measured every year. Herbage mass of desirable and undesirable species was measured every month (Tian et al. 2004; Chen et al. 2008). The sown grasslands were established to lucerne in 1998, 2000, 2002, 2003 and 2005 and yields of two-cut hay were determined each year (Chang et al. 2004; Chen and Hou 2009).

Models

The data collected from farm surveys and from the field experiments were used to construct a 'typical'[1] farm for Daliangwa village. The parameters that made up the typical farm were the input data to two models used to analyse the current conditions and options for farm improvement. These models were the *StageONE* feed-balance analyser and the *StageTWO* optimising model (Takahashi et al. 2011). The *StageONE* model is designed for manual manipulation of input data to investigate current and alternative conditions. The *StageTWO* model uses the same starting values as *StageONE*, but then investigates optimal solutions for parts of the livestock production system such as least-cost rations and the farm balance in grazing and crop areas at a range of specified stocking rates. The *StageTWO* model is typically used in a mode that constrains feeding rates of livestock to conditions where live-weight losses are minimised, i.e. a production rather than survival focus. Both models derive net farm livestock financial returns for the starting conditions using biophysical and financial data. The general aim is to investigate tactics and strategies that herders could use to initiate a program of farm improvement. The aim was not to find an ultimate solution that would apply for the next century, as that is impossible unless future conditions can be predicted. As the typical farm investigated is based upon data with obvious uncertainties, only substantial improvements in farm performance are considered as being likely to translate into real benefits to herders.

[1] The 'typical' farm was based on averages, using data for farms that had a higher proportion of farm income from sheep and goats, and excluding data for other species (e.g. cattle) that were not on all the subset of farms used to define the 'typical' farm.

Simulation of the livestock farm system in Daliangwa village

Current system

In the northern part of the Loess Plateau, Tan sheep are the dominant livestock type. Lambs are born from November through February and sold at about 18 months of age, according to the herder's need. Grasslands are continuously grazed at a stocking rate of about 1.9 sheep/ha (22.8 SUM/ha) throughout the whole year. This grazing system is consistent from year to year (Hou et al. 2002). There is always an energy deficiency from late September to April (Figure 2). Besides grazing, lucerne hay, by-products of wheat, buckwheat, broom-millet and maize and potato were supplied to livestock in the cool season and around lambing/kidding time.

Wool versus mutton

The traditional sheep in Daliangwa village are small Tan sheep that produce low quantities of low-quality wool, but whose meat is favoured by locals. They are preferred because they can survive under the typically harsh conditions that prevail. Given the poor nutrition of animals through the year and the expense of purchased fodder, one alternative strategy is to change flocks to better wool-producing animals than have been traditionally bred in Gansu. Australian Merinos have been introduced successfully in other parts of Gansu. Meat versus wool options were evaluated in the *StageTWO* model at a range of possible stocking rates.

Estimated net livestock enterprise returns from mutton production increased up to the optimum and current stocking rate of 1.9 sheep units (SU)/ha (Figure 3). There was no requirement for supplementary feed if the stocking rate was below 1 SU/ha, although after this point, feeding costs rose sharply as the stocking rate increased (Figure 3). In comparison, a wool-production system increased net livestock enterprise returns up to a stocking rate of 3.3 SU/ha (Figure 3) due to generally lower requirements for supplementary feeding and because longer periods of maintenance feeding were then possible. There was no requirement for supplementary feed if the stocking rate was below 1.8 SU/ha. The net return from wool production was more than that from mutton production because of the lower feeding cost. The higher returns from wool production were, however, at higher stocking rates than for mutton production, which could be disadvantageous for grassland rehabilitation. Insufficient information is available to adequately model the long-term impact of different stocking rates on grassland condition, except that it is considered that current stocking rates are probably too high and will lead to further deterioration of grasslands. The analysis of this strategy suggests that current practices used for mutton production are close to optimal for the way they are currently managed. It is evident, however, that by switching to wool production herders could obtain the same income as at present with lower stocking rates. That could prove a valuable strategy opening opportunities for grassland rehabilitation without reducing household income. Such a change would require some government intervention to provide appropriate incentives.

Seasonal grazing

Continuous grazing at current stocking rates has resulted in serious degeneration of grasslands and in poor livestock production. An alternative strategy that can provide opportunities for grassland improvements would be to graze different areas in different seasons, thus providing rests that could assist in rehabilitation. The system that was investigated, based in part on the general layout of land available on farms, was to compare a three-field rotational grazing system (summer grazing of land from June through August; autumn and spring grazing of land from September through November and from April through May; and winter grazing land from December through March) with a one-field grazing plus pen-feed system (livestock graze

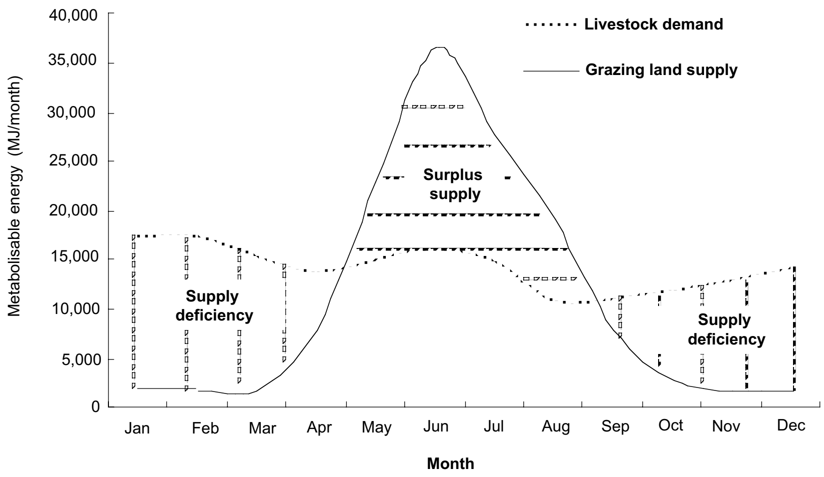

Figure 2. Energy supply from grasslands and supplementary fodder, and demand from livestock, in Daliangwa village, Gansu province (adapted from Hou et al. 2008)

grasslands in summer and autumn, from June through October, then fed in a warm shed from November through May, to minimise weight loss from cold conditions).

Net financial returns for mutton production from grazing all the land all year versus grazing land seasonally increased up to an optimal stocking rate of 2 SU/ha (Figure 4), but with no financial differences between those systems. Due to higher feed costs, net returns to mutton production from grazing one field for summer and another in autumn, then pen feeding in a warm shed, were lower than the other strategies around the optimal stocking rate (Figure 4).

Net financial returns for wool production from the three grazing strategies increased as the stocking rate increased, but that for one-field seasonal grazing was substantially lower than the others when the stocking rate was more than 1 SU/ha (Figure 5). The difference between three-field seasonal grazing and one-field grazing all year were not significant. These results were driven by the differences in feed cost required to minimise any weight loss in livestock. The feed costs for one-field seasonal grazing plus pen feeding in a warm shed were much higher than that for the other strategies. There was no requirement for supplementary feed for one-field grazing all year and three-field seasonal grazing if the stocking rate was below 2 SU/ha (Figure 5). Thus, while net returns were similar for one- versus three-field grazing, the latter provided good opportunities for resting and rehabilitating areas of grassland.

Changing lambing time and sale dates

In the current livestock production system lambs are born in January (mid winter) when temperatures are low and the ewes are losing weight. The new lambs are then under a poor level of nutrition until June, when grass growth becomes adequate for grazing. As lamb growth rates are low, they are often not sold until early autumn, 18 months later. By lambing in spring or summer the lambs would have better opportunities to access higher quality forage and less need for supplementary feed. However, lambing at that time might mean that lambs are small and prices low during traditional sale times. Comparisons were made of the effects on net income of changing lambing times and of varying the age at sale to 3, 6, 9 or 12 months, relative to the current practice of selling at 18 months of age.

Net livestock financial returns increased as the stocking rate increased for all lambing times investigated (Figure 6). Although the net livestock return was highest for the control (18 months) (Figure 6), the other lambing and selling times could produce

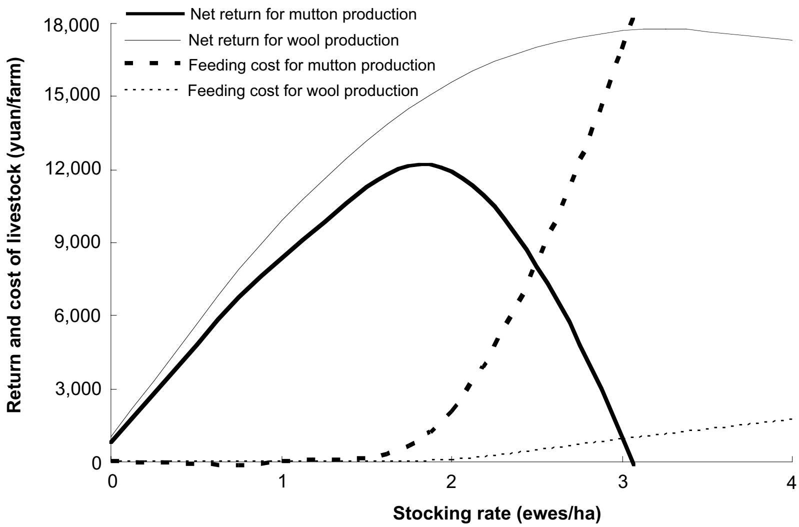

Figure 3. Net livestock returns and feeding costs for mutton and wool production at different stocking rates for current systems. Data from the *StageTWO* model (Takahashi et al. 2011).

more economic profitability by shortening feeding times and increasing the turn-off rate for the same period.

The results show that, irrespective of lambing time, there was no requirement for supplementary feed if the stocking rate was less than 2 SU/ha (Figure 7). Feed costs were highest for the control. January lambing had higher costs than April and July lambing if lambs were sold at 3 or 6 months of age. The differences among the three lambing times were not significant when selling lambs at 9 or 12 months of age (Figure 7). These analyses support the local practices of lambing in winter and retaining the lambs for 18 months before sale. However, other options reduce the need to purchase feed, which could then free more land for growing crops and potentially reduce stocking rates with only small consequent changes in net farm income that are probably acceptable as part of local government policies to rehabilitate the grasslands.

Discussion

Herders have developed local livestock management practices for Tan sheep over many years. Those practices have evolved in response to seasonal feed availability and other factors, and were developed with a subsistence and survival perspective. However, farming is becoming more of a business, integrated within the wider Chinese market economy. Incentives are increasing for more and better quality livestock products, although those incentives are not yet fully developed at a farm level. These trends mean that a more production-oriented approach is becoming more relevant to herders. The practices investigated in this chapter have identified some directions that can be investigated on farms and in research to find solutions to the twin problems of improving incomes and rehabilitating degraded grasslands.

Seasonal rotation of grazing can reduce the pressure on grasslands, especially in spring, and

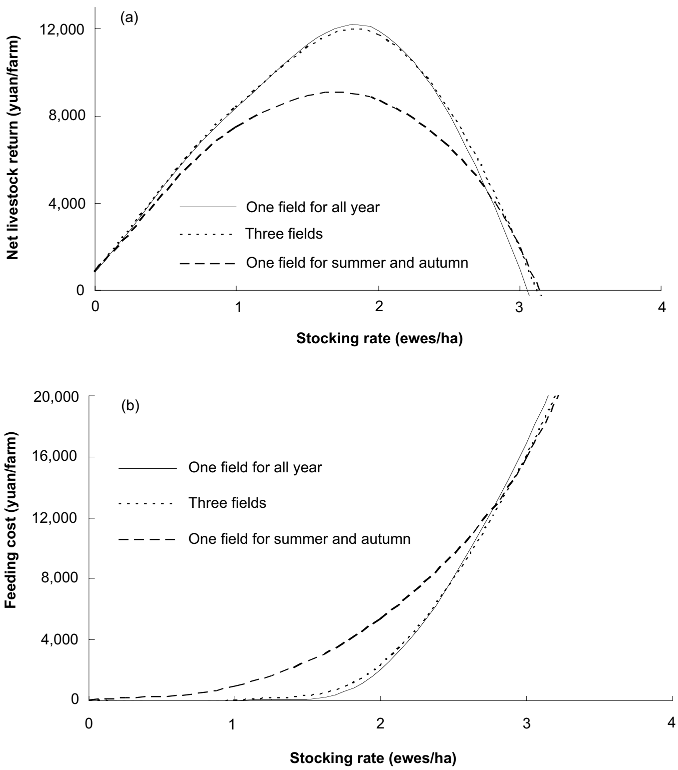

Figure 4. Net livestock return (a) and feeding cost (b) of different grazing strategies for mutton production

allow more time for grass regrowth and re-seeding. Moreover, livestock would graze the grasslands more uniformly, lessening the opportunities for less-desirable species to become dominant. The results (Figure 4) nevertheless showed no significant difference between continuous grazing the whole farm as one field versus seasonal grazing on three fields as regards net livestock financial returns and feed costs. It must be remembered, however, that the simulation of continuous grazing used for this comparison incorporates feeding animals through the year to minimise live-weight loss, whereas current practices typically result in significant live-weight loss through the cooler months of the year. Continuous grazing with considerable winter live-weight loss is the dominant grazing pattern, and herders view grazing on these grasslands as free. In such circumstances, degradation is unavoidable. Seasonal grazing, on the other hand, would help in managing grasslands and it would not add to costs, as herders can manage their livestock within defined areas. Alternative patterns in seasonal grazing are then possible, varying which field is grazed in which season and targeting fields to get a better response in floristic composition.

Recently, the local government has published a policy for feeding livestock in a feedlot instead of grazing on grasslands for the whole year. Grazing in cold weather can result in a more than 30% loss of livestock production, including a 20–30% decrease in live body weight and sometimes death of livestock (Ren et al. 2000). While rotational grazing in the warm season could be integrated with pen feeding in the cold season, herders consider it bad for Tan sheep to be kept and fed in a shed. This suggests that research is needed on the best way to manage sheep in sheds through the winter months. Chen (2006) reported that the proportion of mutton production from Tan sheep to total meat production in Ningxia Hui Autonomous Region (adjacent and to the north of Huanxian) was only slightly higher (11%) than the average (10%) for China as a whole. This suggests that, while herders often prefer Tan sheep, other breeds (some crossed with Tan) have

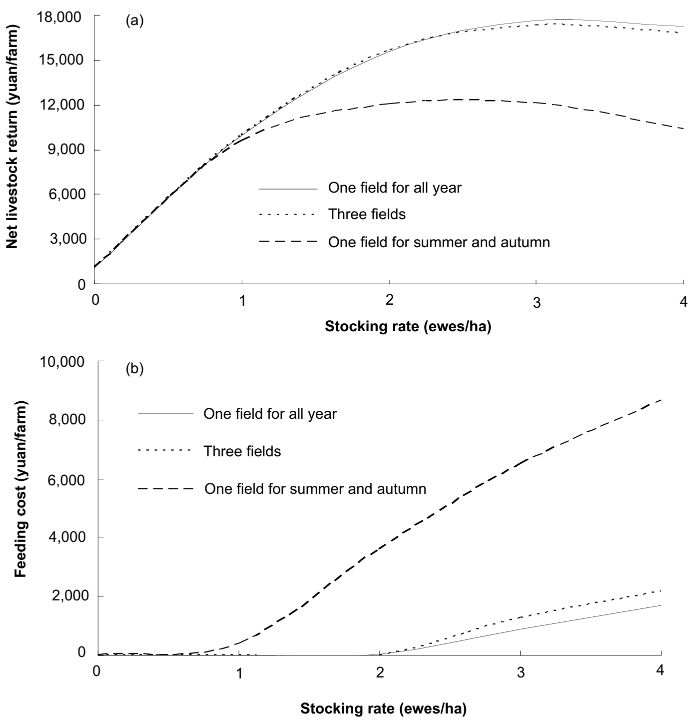

Figure 5. Net livestock return (a) and feeding cost (b) of different grazing strategies for wool production

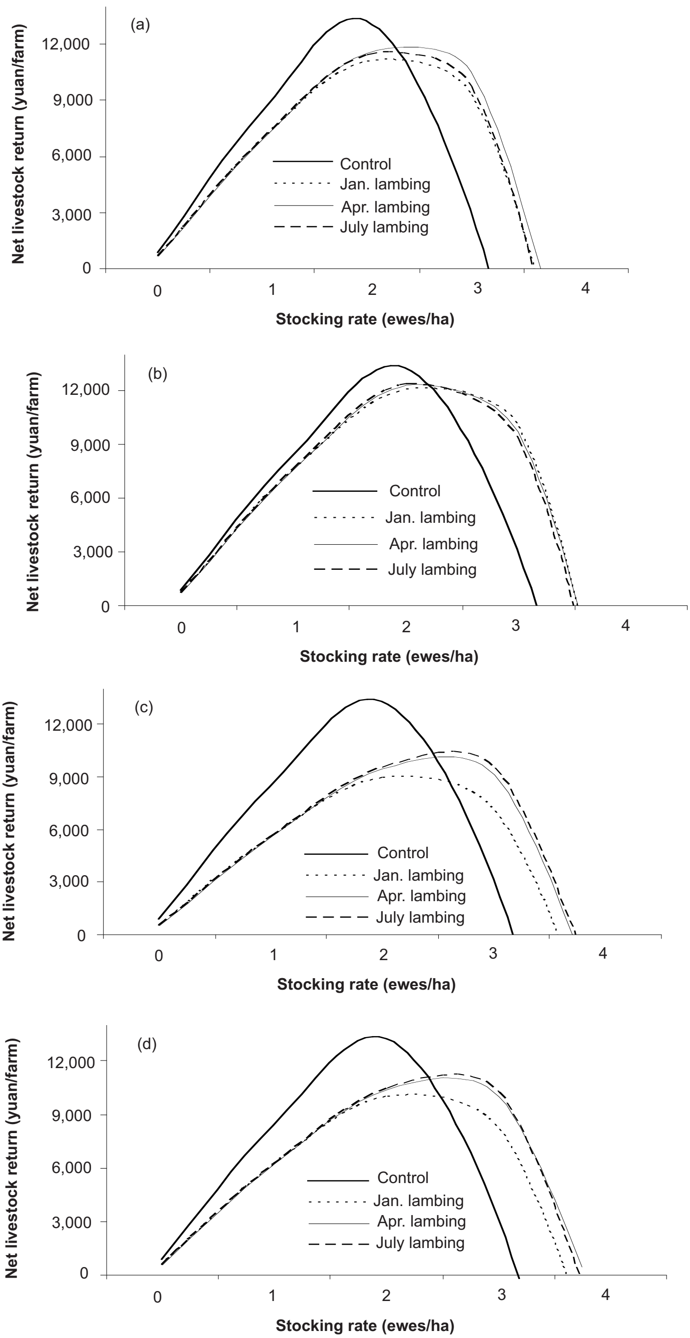

Figure 6. Net livestock returns for different lambing times and for selling lambs at different ages: (a) 3 months, (b) 6 months, (c) 9 months, (d) 12 months

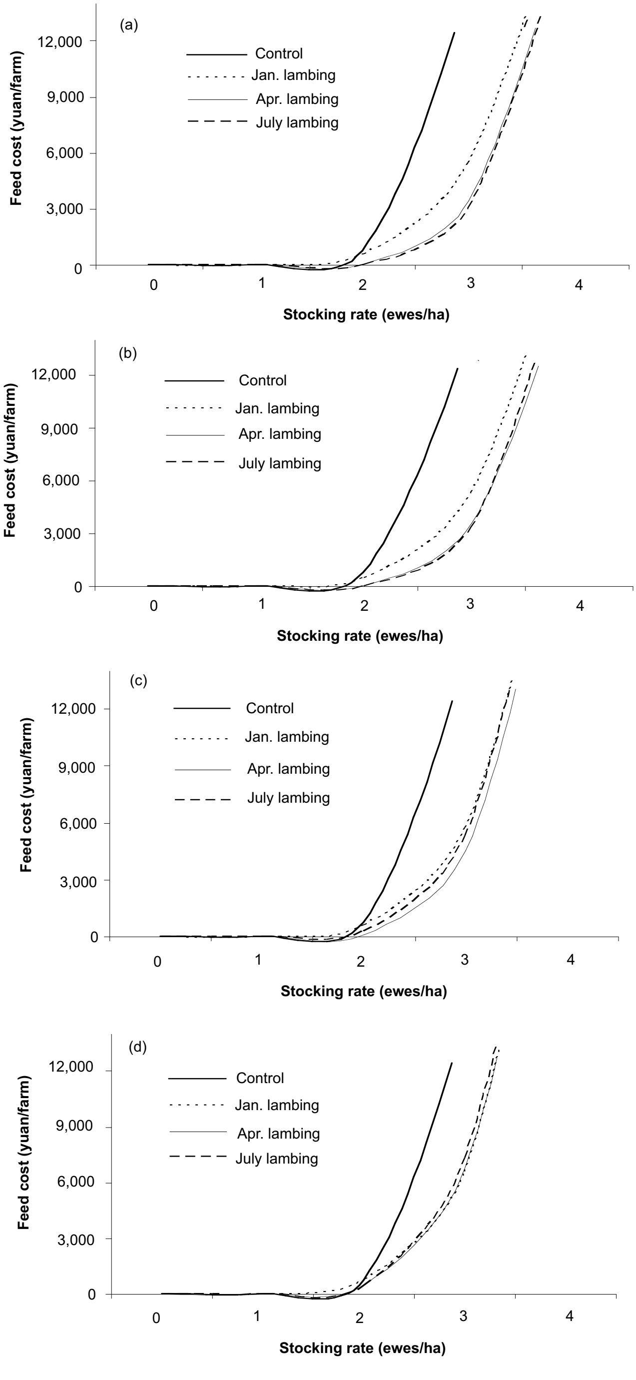

Figure 7. Livestock feed costs for different lambing times and for selling lambs at different ages: (a) 3 months, (b) 6 months, (c) 9 months, (d) 12 months

been found to be more useful and that change is possible. With deteriorating grasslands, more shed feeding of sheep is probably occurring. The potential for shifting to a multi-field farm system and more pen feeding should be the subject of further research.

Wool can produce higher net financial returns than mutton production, or maintain the same returns as at present at a lower stocking rate (Figure 3). There is a risk, however, that herders will aim to maximise net financial returns, which would mean higher stocking rates (Figure 3) and consequent increased risk of deterioration in the grasslands. Lower stocking rates could be maintained by regulation in these closer-settled regions. Further work is needed to investigate the long-term impacts of wool versus mutton production on grasslands. A further issue with wool production is that prices for better quality wool in the local markets are poor as it is not a traditional activity. Gansu is, on the other hand, a fine-wool-producing area within China and, if subsequent studies clearly showed that wool production in these grazing areas was more profitable than mutton, local government could assist in the development of a viable fine-wool market.

Lambing times can be changed to align better with grassland growth and to minimise feed costs and stalled development of young animals. Currently, the time to lamb and to sell depends mainly on when the herder needs money and when traders call, and is often in autumn, so as to reduce the numbers of animals that need to be fed through winter. It is evident (Figures 4 and 5) that selling lambs at 18 months yields the better return. To herders, immediate net return is the most important factor influencing how they operate their agriculture system, despite the knowledge that grassland are degrading seriously year by year and that longer term incomes will fall in consequence. Feed cost is perceived by herders as a major issue and that provides an opportunity to suggest to herders that they change practices, e.g. to fine-wool sheep.

Among the herders surveyed some had commented that they consider livestock production more profitable than crops, but marketing issues were a limitation to them doing more. However, they were often expressing a view that income is directly related to animal numbers rather than to animal products. To improve meat production systems, the forage supply needs to be improved. At present much of the supplementary feed is derived from crop by-products. The expanded use of lucerne could be a better solution and further work is needed to resolve some agronomic and usage issues concerning lucerne. Planting more artificial grasslands would also help, although the price of grass seed has made that uneconomic at present. Developing practices that enable the natural grasslands to be rehabilitated would play a key role both in sustaining farming production and protecting soil by covering the land surface in winter and spring when strong winds are driving serious soil erosion. Since the work reported here was done, the local government has imposed total grazing bans on the grasslands to enable rehabilitation. Policies need to be developed to ensure that, when grazing resumes, sustainable stocking rates are used and optimal farm strategies implemented. This could mean that wool production becomes preferred over meat production, reducing the need for growing or purchasing fodder. This in turn could allow a greater proportion of crop land to be devoted to more profitable crops such as potatoes.

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A summer grazing experiment on loess soils in Huanxian county, Gansu province. Poor grassland growth means that animal growth rates are also low and total lifetime methane production and output per unit of saleable product is greater than if the animals were better fed. [Photo: D.R. Kemp]

Public grazing systems on typical steppe grasslands in Taipusi Banner, Inner Mongolia Autonomous Region

Zheng Yang, Xu Zhu, David Kemp, Shan Guilian, Tian Qingsong and Xie Jihong

Abstract

Chinese grasslands are suffering considerable pressures from human and livestock populations. It has been estimated that 90% of Chinese grasslands are suffering from light to heavy levels of degradation. Livestock numbers on northern China's grasslands have increased dramatically as households seek to improve incomes. In Taipusi Banner in the Inner Mongolia Autonomous Region in northern China this has resulted in severe overgrazing and degradation to 90% of the 160,000 ha of typical steppe grassland. Current stocking rates are above those recommended. Sustainable grassland and livestock production requires a systems analysis of current farm practices and options. This paper examines current conditions and the results of a modelling study of a grassland system in Taipusi Banner. This shows that reducing stocking rates leads to not only opportunities to rehabilitate grasslands, but also to increases in whole-farm returns and livestock productivity. Additional benefits would accrue from changing lambing times from mid winter to late spring, and changing enterprises to fine-wool production, rather than mutton or cashmere. Cattle are kept but are considered a severe drain on resources and household incomes.

Introduction

Grassland degradation is a serious problem across northern and western China. It has been estimated that 90% of Chinese grasslands are suffering from different degrees of degradation, and the area of degraded grasslands has been increasing by about 2 million ha every year (Li 1997) until most of it is now in a poor state. This is part of a global problem in which grasslands are generally under increasing pressure from increasing human populations, reduced areas with increasing livestock numbers, declining terms of trade for livestock production, and poor management (Kemp and Michalk 2007). The grasslands of the typical steppe ecosystem, part of the vast Eurasian grasslands, are no exception.

Taipusi Banner[1] is in the east of the Inner Mongolia Autonomous Region (41°35'–42°10'N, 114°51'–115°49'E), south of Xilingol league and about 400 km due north of Beijing, within the vast semi-arid grassland region of Eurasia (Wang 2000). The total area of the banner is 341,500 ha. The main vegetation type is grassland, occupying an area of over 160,000 ha. Grasslands are not only the most important productive resource for animal husbandry and for development of the regional economy, but also the means for controlling dust storms in and around Beijing and northern China. Grasslands have important functions in maintaining the ecological balance, moderating climate, conserving and protecting water and soil, preventing wind erosion and reducing dust storms. These functions have been impaired by considerable degradation of the

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

Pp. 58–68 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.

steppe typical of Taipusi. Approximately 90% of the grasslands are rated as being in poor condition, a matter of serious concern. The current level of degradation has resulted in increasing rates of desertification and in the frequency and severity of dust storms. Statistics recorded by the local authorities show that stocking rates have increased sixfold since 1949 (Figure 1), which is arguably a major cause of the degradation seen. Much of the land is commonly grazed, which means, in effect, that it is impossible to improve management of the grasslands under current conditions.

Many households are dependent upon livestock for income. They are among the poorer groups in the region because of the increasing human population and livestock overgrazing, and inappropriate reclamation and management of grasslands in recent years. According to incomplete statistics, average household incomes were about ¥1,500 (Chinese yuan/RMB) in 1998 and increased to only ¥4,300 in 2007. These farmers are among the poorest in China.

Livestock management practices that evolved over centuries are no longer appropriate at the high human and livestock population densities that now exist on the more settled landscapes. Resolving the conflict between grassland degradation and sustaining household economies is the major task set for grassland researchers by government policies. This paper outlines the current environment and conditions for livestock production on the typical steppe and investigates some of the more immediate options that could be employed to improve, or at least stabilise, household incomes and assist in rehabilitating the degraded grasslands. Thirty farms across three villages were surveyed to collect information enabling description of average farm conditions. A typical farm for the area was then 'constructed'. It provided the basic data for modelling current conditions and as the base from which to investigate alternative practices that could be employed to improve incomes and/or rehabilitate grasslands. The models used have been described earlier in these proceedings (Jones et al. 2011; Takahashi et al. 2011).

Climate, soil and grassland condition

Climate

Taipusi Banner is in middle latitudes with a temperate semi-arid continental climate: cold and dry in winter, warm and wetter in summer. The average daily temperature is 2 °C (Figure 2). The effective annual accumulative temperature is 1,790–2,198 °C (T>10 °C). The average annual precipitation is 400 mm. A higher level of variability in precipitation at the start of summer often determines subsequent grass growth for the year. Late summer rainfall is more reliable but less important for plant growth. Solar radiation is high: total radiation intensity averages 156–160 W/cm^2; photosynthetically active radiation averages 77–85 W/cm^2; annual average sunshine hours are 2,900, with 1,000 hours from May to August. The frost-free period is 115 days from the middle of May until the middle of September. Wind run is high: the average speed is 4 m/second, reaching 5 m/second in spring. Annual average humidity is under 60%, leading to a high annual average evaporation of 1,700 mm, five times that of precipitation (Figure 2). Seasonal droughts occur in most springs and autumns and less frequently in summer.

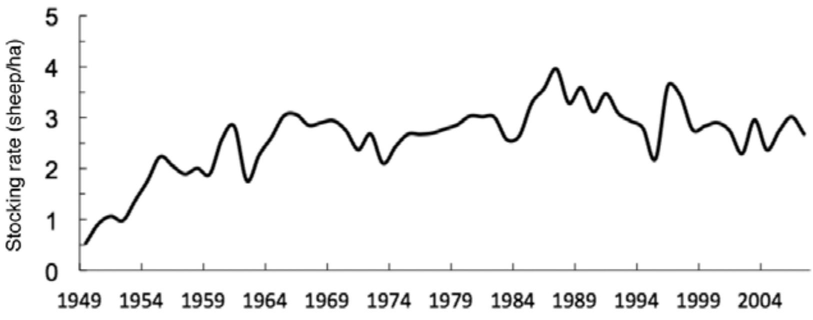

Figure 1. Stocking rate in Taipusi Banner, Inner Mongolia Autonomous Region, 1949–2007, based on total livestock numbers unadjusted for any variation in live weight over this period.

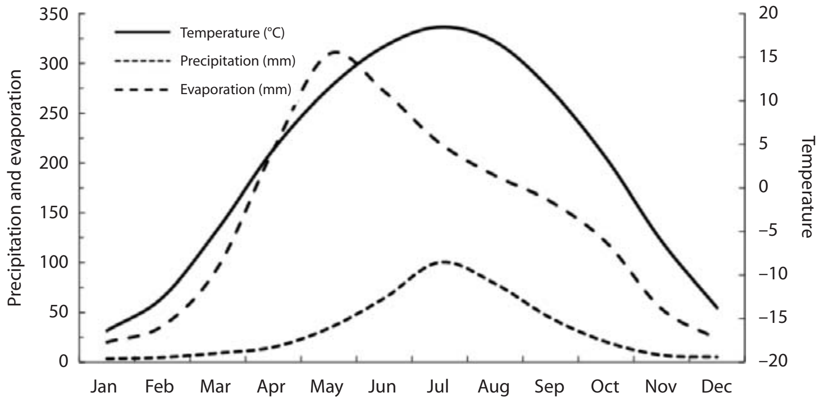

Figure 2. Monthly temperatures, precipitation and evaporation at Taipusi Banner, Inner Mongolia Autonomous Region, 1971–2008

Soil

The soils in Taipusi are of three main types: chestnut, chernozem and meadow soil. Chestnut soils occupy 80% of the region. Chestnut soils are in hilly areas, chernozem in the low mountains and hills, and the meadow soil is in the valley and basin plain areas. The physical and chemical properties of chestnut soil under different intensities of livestock utilisation or clipping are summarised in Table 1.

These soils degrade with increased intensity of utilisation; bulk density, hardness and pH all generally increase, while the organic matter, total nitrogen and total phosphorus generally decrease. While the decline in soil conditions with increasing utilisation is apparent, the mechanisms and rates whereby soils can be restored to a better state need to be the subject of future research.

Grassland condition

Investigations of grassland conditions over the past 20 years identified that some 153,000 ha (93%) of the 164,000 ha of the grasslands in Taipusi are degraded to some degree: 68,000 ha (44%) display light degradation, 83,000 ha (54%) medium degradation and 2,500 ha (2%) severe degradation, according to the Chinese grassland evaluation standard (Grassland Survey and Design Institute, Inner Mongolia, 2005).

A survey of the grasslands in August 2006 found that there are 40 plant families, 120 genera and 200 species distributed on the Taipusi steppe. Species of Gramineae, Leguminosae and Compositae were the dominant groups (Table 2). Classification is as given by Chinese Academy of Science (2005). The main grassland types were: *Leymus chinensis* + *Stipa krylovii* + forbs; *Leymus chinensis* + *Cleistogenes squarrosa* + *Artemisia frigida*; and *Serratula centauroides* + *Stipa krylovii* + forbs. *Leymus chinensis*, *S. krylovii* and *S. centauroides* were the dominant species in the upper layer of the communities. *Cleistogenes squarrosa*, *A. frigida* and *Potentilla acaulis* were located in the lower layer of the communities. The accompanying species included *Agropyron cristatum*, *Elymus dahuricus*, *Carex duriuscula*, *Melilotoides ruthenica*, *Artemisia capillaris, Phlomis tuberosa*, *Iris dichotoma, Haplophyllum dauricum*, *Saposh-*

Table 1. Physico-chemical properties of chestnut soils with different utilisation modes and intensities (0–10 cm layer)

Utilisation mode and intensity	Bulk density (g/cm^3)	Hardness (kPa)	pH	Organic matter (%)	Total nitrogen (%)	Total phosphorus (g/kg)
Severe	1.3	1,135	7.6	3.6	0.21	0.28
Medium	1.2	1,010	7.5	3.7	0.25	0.33
Light	1.1	960	7.5	6.2	0.23	0.34
Clipping	1.3	500	7.3	6.3	0.25	0.30

nikovia divaricata, Heteropappus altaicus, Allium tenuissimum, Allium condensatum, Salsola collina, Astragalus adsurgens, *Lespedeza davurica*, *Hedysarum gmelinii* and *Caragana microphylla.* Toxic species included *Clematis aethusifolla*, *Stellera chamaejasme*, *Delphinium grandiflorum*, *Thermopsis lanceolata* and *Oxytropis glabra.* On overgrazed segments, the grasslands become dominated by *A. frigida,* while *P. acaulis* increases and *L. chinensis* and *S. krylovii* decrease. The presence of the other species does not change noticeably. Exclosures have demonstrated that species composition can be improved (Shan Guilian et al. 2008).

The yield of natural grasslands is low and the forage quality is poor on Taipusi steppe because of the large areas of degraded grasslands (Table 3).

Farm survey

Since 2005, 30 farms have been surveyed at Benbenshan, Geritu and Jilinwusu villages. Semi-structured interviews were used to obtain data on farms and their enterprises. Data were collected on livestock breed and number, the income of herders, the cost of livestock supplements and management, the grasslands, other crop-land harvest and condition, the infrastructure for livestock and the household labour (Zheng et al. 2008). Local govern-

Table 2. Grassland composition of the steppe at Taipusi Banner, Inner Mongolia Autonomous Region

Species group	Plant species
Grass (Graminae)	*Stipa krylovii* *Leymus chinensis* *Cleistogenes squarrosa* *Agropyron michnoi* *Koeleria cristata*
Legume	*Melissitus ruthenica* *Oxytropis myriophylla* *Astragalus adsurgens*
Compositae	*Heteropappus altaicus* *Serratula centauroides*
Shrub	*Artemisia frigida* *Artemisia capillaris*
Forb	*Allium anisopodium* *Allium condensatum* *Allium tenuissimum* *Salsola collina* *Iris dichotoma* *Haplophyllum dauricum* *Phlomis tuberosa* *Potentilla acaulis* *Potentilla bifurca* *Potentilla tanacetifolia* *Thalictrum petaloideum* *Carex duriuscula*

Table 3. Yield (dry matter, DM) and crude protein of different ranks of grassland of the steppe at Taipusi Banner, Inner Mongolia Autonomous Region, based on a mixed sample taken in August 2007

	Severe degradation	Medium degradation	Light degradation	Light clipping	Medium clipping
Yield (kg DM/ha)	410–620	1,120–1,270	1,570–1,735	2,650–2,840	1,960–2,250
Crude protein (%)	10.0	10.5	11.1	11.7	8.7

ment leaders, animal husbandry bureau and grassland station officers contributed to the data collected. Six farms in Geritu and Jilinwusu villages were then monitored in more detail from 2007, collecting data every 3 months on live weights, fat scores, teeth, udder and body condition of all animals on each farm. These data were used to construct a 'typical' farm for the area. The typical farm is based upon averages, but avoiding anomalies such as attributing cattle to all farms if only a few had them.

The estimated stocking rate on these Taipusi steppe farms was 3 sheep equivalents (SE)/ha. Sheep were 70% of the total biomass of small animals. The selling rate of all the animals was 55%, and the survival rate of young animals 99%. The average weight of adult sheep and goats was 35–50 kg/head, of lambs/kids 15–20 kg/head and of young cattle 120–150 kg/head when sold. Weights are at a minimum in early summer and maximal in late summer. The sheep breed is mainly a short-tail Mongolian mutton cross (some generations ago fine-wool sheep had been introduced but there is little evidence of them in the present flocks). Goats are only a small part of the livestock because government policy is to reduce their number since they are considered harmful to the grasslands. They may in fact help to control some of the less-desirable forbs, grasses and shrubs and the degradation widely acknowledged may simply be a result of the high grazing pressure (Figure 1). Cattle were present on many farms and they roamed freely throughout the village. The cattle were in poor condition, their productivity very low and, as discussed later, there seemed little merit in retaining most of them.

Grazing practices remain traditional. Livestock are taken out to graze in the morning and again in the afternoon for most days of the year, but grassland production can meet the demands of livestock from mid to late summer (late June–September) only. No supplements are fed to livestock in summer, except some minerals such as salt. In winter, supplements are normally fed from December to May, but at sub-maintenance rates. There is now a grazing ban imposed from early April until late May each year to try to reduce dust storms and to enable unimpeded early growth on the grasslands and improve total annual yields. This ban is through the period when herders may not have much useful fodder left. Livestock are given some fodder in the morning and afternoon every day through winter.

Sampling of the grasslands in a commonly grazed area during 2007 shows the low levels of production achieved (Figure 3). The grasslands contained *Aneurolepidium chinense, C. squarrosa, A. frigida, S. krylovii*, and *Pocockia ruthenica*.

Hay, maize silage and maize straw are collected by each herder from their own hay and maize land. They harvest about 20 t of meadow hay and maize silage. Herders buy some fodder from the market each year: 1–2 t maize grain, 0.5–1 t flaxseed, 5–10 t lees (a by-product of brewing) and about 0.5 t sugar beet, naked oats and concentrates (mixed and milled feed). Details of the crude protein content and dry matter (DM) digestibility of the feeds available on farms in 2007 are given in Table 4. As energy deficits are of much greater importance than protein (see later) it is evident that some of these winter feed sources are sub-maintenance, i.e. animals will, at best, lose weight slowly if fed unlimited quantities of them, while others may sustain animals under mild conditions. In the case of Taipusi, where winter temperatures and wind-chill factors result in high demands for energy, the animals are likely to lose weight.

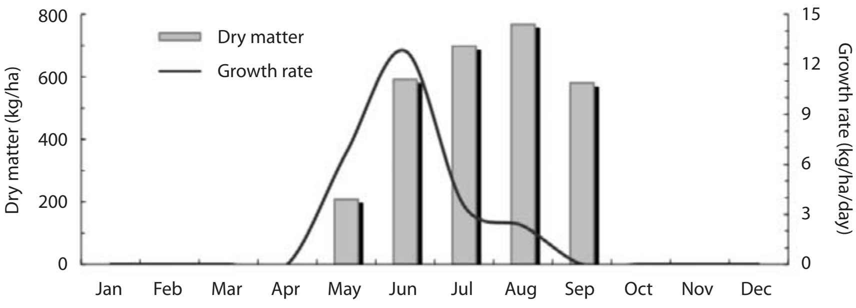

Figure 3. Herbage mass of commonly grazed grasslands at Geritu village in Taipusi Banner, Inner Mongolia Autonomous Region, in 2007

Table 4. Analyses of the crude protein (CP) and dry matter digestibility (DMD) content of a range of fodders available on farms in Taipusi Banner in 2007

	Hay	Maize seed	Maize straw	Flaxseed	Lees	Sugar beet	Naked oats
CP (%)	7.7	8.1	5.7	17.7	10.2	7.5	6.0
DMD (%)	71	92	66	42	32	92	61

Modelling current conditions and options

Current situation of typical farms

The typical farm averaged 42 ha of grasslands for grazing and 1 ha of land for fodder (typically maize silage and maize straw). Livestock production is mainly for meat from Mongolian mutton cross sheep, a few remnant fine-wool sheep and cashmere goats. Lambing and kidding time is from January to March and the young animals are sold in September and older sheep by December. Farms also have cattle and, as their biomass is equivalent to 80% of the sheep plus goats, the available area of grasslands for sheep plus goats was then considered to be 21 ha. However, as common grazing all year is the current situation on Taipusi farms these are only notional allocations of the available farmland. This was considered reasonable, as the whole area was uniformly grazed, with flocks and herds being taken across the total land available.

Livestock graze throughout the year on the same grasslands, resulting in very high grazing pressures. Estimates of the energy intake by ewes in comparison with their requirements for maintenance at the same body weights (Figure 4) demonstrated that there is a major deficit from September to early May. These animals lose weight through that whole period, as confirmed by measurements of live-weight loss and declining fat scores in 2007. There is no grass growth from October to late May in Taipusi because of the very low temperatures (Figure 2).

At present in Taipusi, the current stocking rate is about 3 sheep (breeding ewes)/ha. With minimal change in farm practices, i.e. feeding of animals in winter to at least maintain live weights, the *StageTWO* livestock production optimising model predicts that a lower stocking rate of around 2 sheep/ha would lead to substantial increases in net income (Figure 5). This model estimate is derived by optimising a least-cost ration based upon the fodder that farms have readily available. At current stocking rates, herders are still making a positive net income and, as more animals are typically perceived as enabling higher incomes (total revenue is higher), the herders at Taipusi probably think they are doing the best possible. At current stocking rates total feed cost is about half the total revenue, which may act as a limit on animal numbers.

The aforementioned results from using these models to analyse the current situation show that the amounts of supplements typically fed are often

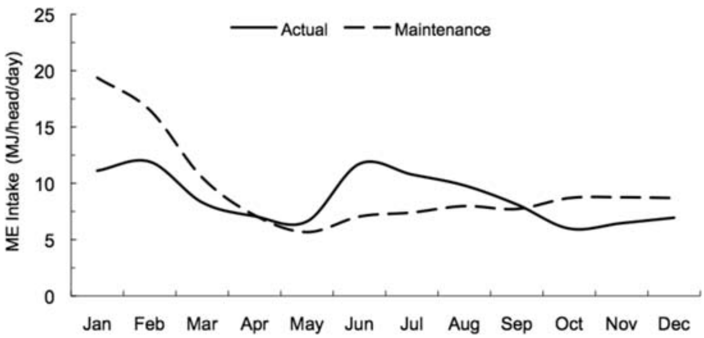

Figure 4. Estimates using the *StageONE* feed balance model, showing actual metabolisable energy (ME) intake for ewes throughout the year in relation to the maintenance requirements at the same live weights (lambing in January)

below requirements, which then leads to considerable live-weight loss and very marginal animal performance. If the animals are fed to minimise live-weight loss the net financial returns at current stocking rates would be about half that at a 30% lower stocking rate. The quantity, quality and cost of available supplements place severe limitations upon the number of animals that can be sustainably carried on these farms.

Grazing ban

In view of the heavy pressure on grasslands, there is now a seasonal grazing ban imposed from early April until late May each year, to enable unimpeded early growth on the grasslands. Compared with continuous grazing, a grazing ban can improve the growth rate of grass and total annual yields of grassland (Figure 6, see modelling in Takahashi et al. 2011).

Options for farm improvement

Changing the lambing time

The survey of farms found that the livestock lambing time ranged from January to March. The *StageONE* model result shows, however, that lambing in January results in a sub-maintenance

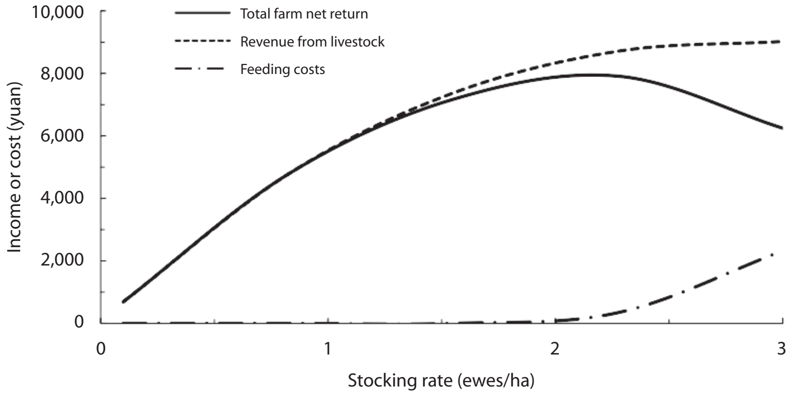

Figure 5. Estimates of optimal financial returns in relation to stocking rates with minimal changes in farm management

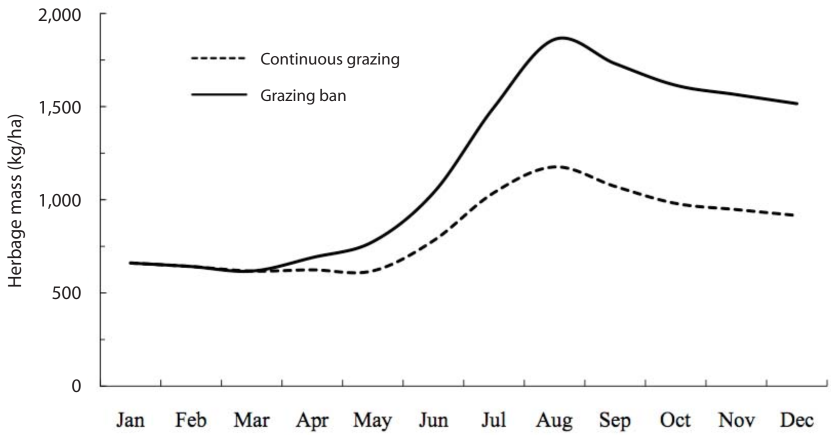

Figure 6. Estimates using the *StageONE* feed-balance model, showing actual herbage mass throughout continuous grazing and grazing ban years.

level of energy intake for ewes for most of the year (Figure 4). This model was then used to examine the benefits of lambing in April or July.

April lambing (Figure 7a) maintained the energy intake better through winter, although the rapid increase in energy requirements around lambing were not adequately met. This was nevertheless better overall than January lambing. Lambs born in April would have reduced energy demands as the weather is considerably warmer and they would be able to take full advantage of grass growth through summer. The better ewe nutrition through winter could result in larger lambs and a higher level of milk production, but it would be better if the ewes received some extra good-quality fodder around lambing.

A July lambing (Figure 7b) was the better fit between actual energy intake and maintenance requirements at actual live weights, but that tactic would have adverse effects on the lambs as they would be weaned into colder weather, and extra supplements would need to be purchased to support them. Many lambs are traditionally sold at the end of summer (often in September) which minimises the amount of supplementary feed they would require.

The effects of different lambing times were then examined further using the *StageTWO* optimising model where animals are fed to at least maintenance levels. This was examined in relation to stocking rates (Figure 8) as the optimal solutions are often influenced by animal densities. These results shown in Figure 8 suggest that, due to the lower feed cost, lambing in July would achieve higher net financial returns for farms than lambing in January or April. These analyses made no assumptions about different lamb prices that might apply from different lambing times, or about being able to get ewes pregnant in the middle of a very cold winter. They assume that livestock will walk long distances to graze in this time and that the grassland herbage available is dead and minimal in winter. Cold weather often causes a high mortality

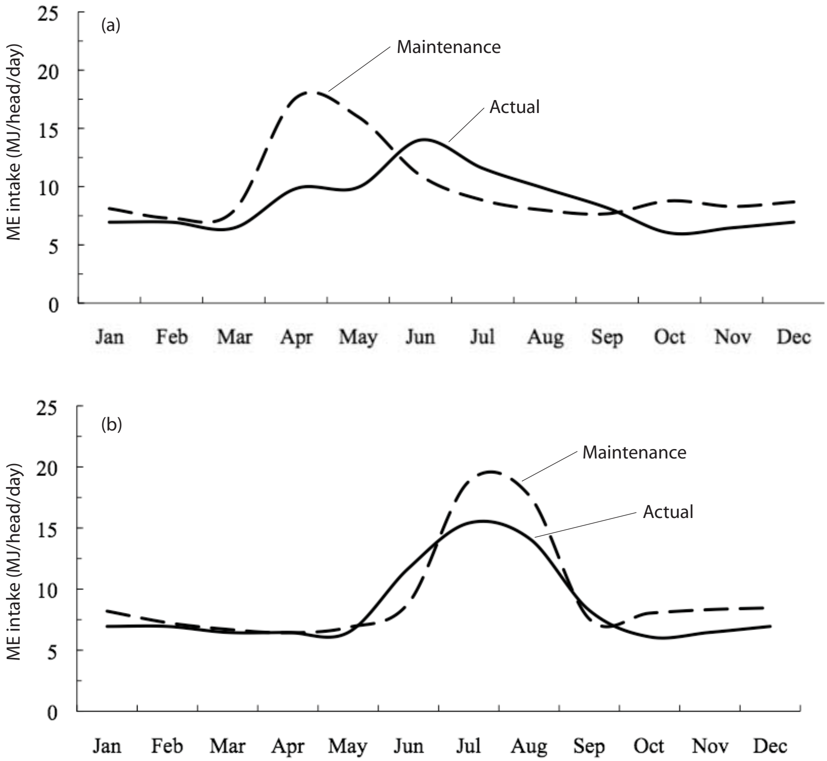

Figure 7. The effect on the energy balance (metabolisable energy (ME) intake) of ewes of changing the lambing time to (a) April or (b) July, determined using the *StageONE* feed-balance model

rate, low weaner weight and low joining weight of ewes. Further work will be needed to resolve if a July lambing would result in the gains that these analyses suggest. An April lambing was an improvement over January, yielding income not much less than July lambing, and there are fewer uncertainties underlying the estimates. An April lambing could be more readily adopted by herders, although to attain these benefits higher feed costs are required.

Selecting different livestock types

Farms at Taipusi have sheep, goats and cattle. Sheep are predominately meat types but, in the past, fine-wool sheep have been successfully managed in the area. Cattle were not considered viable, as preliminary analyses suggested they were struggling under current grassland conditions. Many cows did not produce calves until 4 years of age and milk yields were very low—often 3–4 cows were being milked to simply satisfy household needs. In general, it was concluded that all the cattle should be sold and replaced with sheep or goats, or only 1–2 kept for household use.

A comparison was made between using sheep for meat (mostly mutton) or fine wool, or using goats for cashmere and some meat. This was done with the *StageTWO* optimising model. The results of this comparison showed (Figure 9) that both fine-wool and mutton production achieved similar levels of net farm financial returns and that both were better than the current enterprise of goat production when the stocking rate was less than 3 ewes/ha. The current local policy in Taipusi is to replace goats with sheep, but this is dependent upon the relative prices of wool and cashmere, and it is probable many households have kept both sheep and goats to minimise risk.

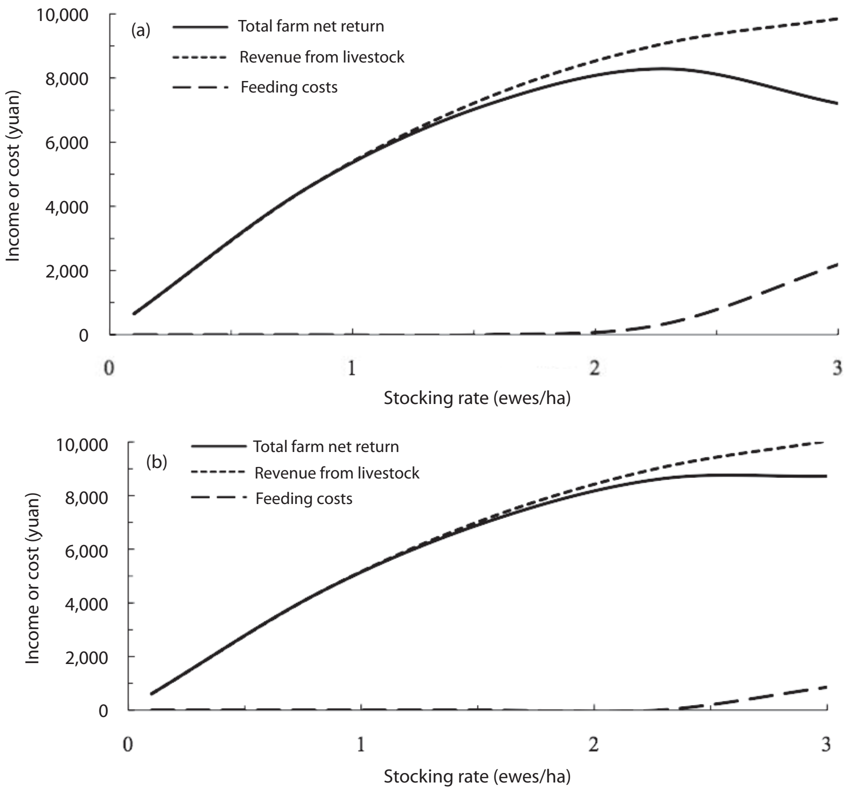

Figure 8. The effects of different lambing times (April (a) and July (b)) in relation to stocking rates: total farm net income and total feeding costs determined using the *StageTWO* optimising model, where animals are fed to at least maintain live weights

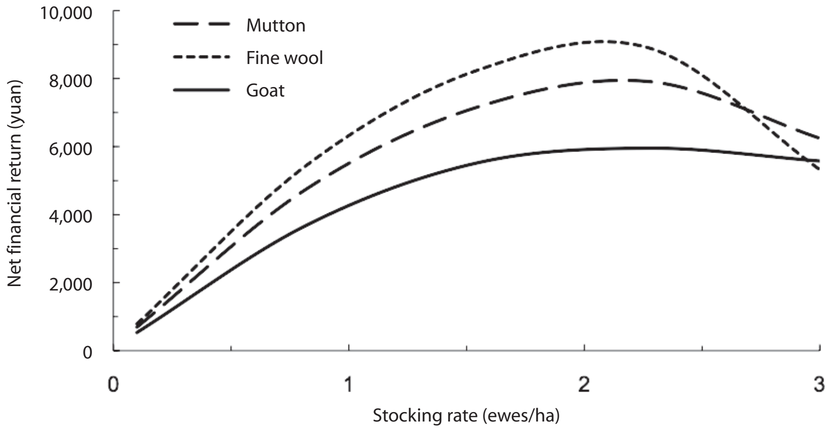

Figure 9. Net farm financial returns from changing enterprise in relation to stocking rates, determined using the *StageTWO* optimising model. Results are for a 'typical' farm, based on surveys at Taipusi Banner, Inner Mongolia Autonomous Region.

Discussion

The farm surveys done show that herders at Taipusi in Inner Mongolia are poor, with limited resources, little available forage and few options for farm improvement within a communal grazing system. The analyses presented here do show, however, that improvements in farm productivity and net farm financial returns can be achieved by reducing stocking rates, modifying lambing times and changing enterprise types. These analyses were made using two farm models: the *STAGEOne* model enables a manual analysis of the livestock production system; *StageTWO* builds upon the first model by enabling optimised solutions (for net financial returns) within specified constraints. The aim has been to find solutions that improve farm incomes and provide opportunities to rehabilitate the grasslands.

Current stocking rates are around 3 adult sheep/ha. For the current, predominately mutton sheep system, by reducing stocking rates to closer to 2 sheep/ha, net financial returns could be improved by 27% (Figure 5). Further gains could result from changing to fine-wool sheep at the same lower stocking rate. Fine-wool sheep could improve incomes by 12% compared to mutton (Figure 9). At the same time, reducing goat numbers could produce useful benefits for the grasslands, especially when combined with an early summer grazing ban that enables the grasslands to re-establish after the winter. Reducing stocking rates is generally acknowledged as necessary in Inner Mongolia (Houston et al. 2004).

If herders want to increase their net incomes under the current high stocking rate, changing lambing time would seem to be a viable option. Further improvements in net financial returns would be gained by lambing in late spring (15%) or summer (40%) (Figure 8). However, further research will be needed to resolve if July lambing would result in the gains that these analyses suggest, as many other system changes would apply and finishing lambs for traditional autumn markets could prove difficult. Better ewe nutrition through winter should result in larger lambs and a higher level of milk production, although it would be better if the ewes received some extra high-quality fodder and protection from the cold (such as can be achieved in warm sheds) around lambing time.

These initial studies based on a typical farm at Taipusi, Inner Mongolia, show that there are realistic options that herders can try. Those options are compatible with current systems and hence potentially adoptable. The directions of change, by reducing stocking rates and pressure on grasslands, will aid grassland improvement, but further research will be needed to establish if the rate of change would be sustainable.

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Peak summer growth on typical steppe at Taipusi Banner, Inner Mongolia Autonomous Region [Photo: D.R. Kemp]

Changing livestock and grassland management to improve the sustainability and profitability of alpine grasslands in Sunan county, Gansu province

Yang Lian, Wu Jianping, Randall Jones, David Kemp, Ma Zhifeng and Taro Takahashi

Abstract

Grassland degeneration is a serious ecological and social problem in north-western China, and overgrazing is one of the most important reasons for degeneration. Overgrazing issues were assessed by first investigating the feed balance between forage and supplement supply versus animal demand. The effects on the feed balance of alternative management practices were investigated using *StageONE* and *StageTWO* models to assess ways of improving animal performance and identify opportunities to rehabilitate grasslands. This study was done for a typical farm in the town of Kangle in Sunan county, north-western Gansu. Analysis of the feed balance showed the metabolisable energy feed supply is typically grossly deficient from October to May because the quantity and energy content of the frosted forage is then very low. The peak of herbage production is in June, the highest maintenance requirement is from March to May and there is an excess of herbage above maintenance in summer grasslands, which enables animals to grow. Grazing in the cold season requires a great deal of energy to maintain body temperatures and for walking, and contributes to the –30% of live-weight loss that occurs through that period. Results were discussed with local herders and technicians, who considered that the modelling accurately reflected the local situation. The amounts of supplements fed through autumn, winter and spring are inadequate to maintain animal condition. A better alignment of feed supply and demand could be achieved by changing the lambing time from April to June. Most households in Sunan have built warm sheds, but they are not well used. Modelling suggested that herders should pen feed ewes in warm sheds through the cold season, as that would lower maintenance requirements and aid better survival and growth of lambs. These practices are now being tested on five farms and the initial results support the model results. Better feeding through the cold weather increased costs and net income from livestock. Future on-farm work will investigate decreasing animal numbers by improving animal production efficiency using a new precision livestock management model.

Introduction

Grassland degeneration is a serious ecological and social problem in north-western China (Long Ruijun et al. 2005). It is estimated that over 90% of Chinese grasslands are facing substantial degradation problems from overgrazing by livestock, as evidenced by a reduction in grassland herbage mass, increased soil erosion and declining agricultural productivity. There are two aspects to grassland degradation: conversion of grasslands to agricultural land and over-exploitation of existing grasslands (Nan Zhibiao 2005). There has been, on the one hand, a reduction in the area of grasslands and, on the other, an increased need for them to support more livestock to meet various policy initiatives

Pp. 69–79 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.

(Wang Renzhong and Ripley 1997). As the grassland environment has deteriorated, the quantity of high-quality grasses and legumes available has declined, leading to a fall in the economic viability of grassland areas. Combined with a reduction in herbage mass and increased wind erosion of the topsoil, the future ecological and economic viability of many grassland areas is questionable. About 70% of China's population lives in rural areas, and many of these people depend upon grasslands for livestock production. Consequently, the management and state of Chinese grasslands has important implications for China's welfare and productivity.

Sunan is a Yugu minority autonomous county in Zhangye prefecture of Gansu province, China. The county consists of four separate geographical areas all of which have a significant population of the Yugu nationality and of Tibetan and Han groups. Sunan is officially recognised at central and provincial government level as being a pastoral county. Most of Sunan is extremely mountainous with very little land available for cropping or for sown grasslands. Altitudes range from 1,300 to over 5,500 m. The relatively high altitude of the most of the county results in low temperatures: the average annual temperature is only 0.5 °C (Figure 1). The low winter temperatures have severe effects on the energy requirements of livestock. For sheep with a reasonable covering of wool (average length is 65 mm in Sunan) the lower critical temperature for adult sheep is –3°C (Freer et al. 2007) below which energy requirements significantly increase. The average temperature is below this for 5 months of the year—in the coldest months it is <–10 °C. Summer is the wettest season, and the average annual precipitation is 360 mm.

Almost all rural activities in Sunan are based on the alpine and adjacent grasslands. The raising of sheep and, to a lesser extent, goats is the dominant rural activity. Over 90% of the sheep are Gansu alpine fine-wool sheep, derived from Merino sheep brought into the area decades ago. The predominant soil type in Sunan county is a dark-brown soil with significant quantities of calcium. Soils are mainly deficient in nitrogen and phosphorus. The grassland types in Sunan county are extensive across large areas of the Tibetan Plateau and other regions of similar altitude in western China.

This paper investigates the agricultural ecosystem, and specifically livestock production, on alpine grasslands in Sunan county, Gansu province. Analyses of the current conditions and options for livestock management are then made using two bioeconomic modelling frameworks developed to evaluate the effects of finance, grassland management, animal management, animal nutrition and infrastructure changes on farms. The analyses presented here were selected from a wide range of ideas considered. These are the approaches more likely to deliver improvement in incomes, enable options for grassland rehabilitation and be adoptable in whole or part by herders.

Methods

Data for modelling

Data to parameterise the models were obtained from a range of sources including trials, farm

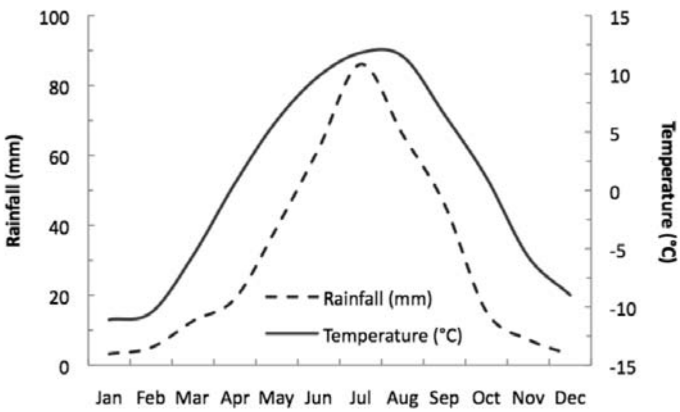

Figure 1. Mean monthly temperature and rainfall for Sunan county–2007 (Data source: Sunan Meteorology Bureau)

surveys, published information, other field data and expert opinion. A number of functional relationships between various biological parameters and either grassland condition or livestock condition were derived using an expert consensus approach.

Field survey and expert opinions

Since 2005, 52 herders within the areas of Kangle and Dahe towns have been surveyed using semi-structured interviews. Towns are administrative units rather than contiguous urban units. The interviews sought information on farm resources, livestock productivity, grassland condition now and 10 years ago, the costs and returns of livestock production and grassland management, the health of animals and herder ideas about improving livestock productivity and grassland condition. The officials and local experts of the Sunan Animal Husbandry Bureau and other agencies were consulted. From these surveys, Kangle town was chosen as the main research site for investigating a typical grassland livestock-farming system based on Gansu alpine fine wool sheep. These data were used to construct a *typical* farm for Kangle town, based on the averages from the survey data, but removing anomalies that did not make sense; e.g. averaging that was not useful if, say, only one farm had a different activity to the others. Other data sources were then used to gain information that the herders could not provide, such as estimates of grassland growth.

Grassland herbage mass and composition

In cooperation with the Grassland Management Station of Sunan Animal Husbandry Bureau, the grasslands have been monitored since 2004. Monthly data on herbage mass, groundcover and species composition were collected for the period of grass growth from May to October.

The grassland types were natural grassland and mountain meadow. The main grasses in these ecosystems are *Agropyron cristatum*, *Stipa krylovii*, *Koeleria cristata*, *Poa pratensis* and *Leymus secalinus*, and the main forbs *Stellera chamaejasme*, *Thermopsis lanceolata*, *Artemisia frigida*, *Heteropappus altaicus*, *Gentiana scabra* and *Iris loczyi* (Zhao Chenzhang et al. 2005). Legumes are rare.

Livestock management in winter experiment

Animals in Sunan county have around 3 months grazing of grasslands during the growing season in summer, then graze very limited dead herbage through the rest of the year when temperatures are often well below 0 °C and animals are housed in sheds in the evenings. Recently there has been increasing interest in the use of warm sheds (greenhouses) in which the half of the roof facing south is replaced with plastic (or glass) to help trap heat and maintain animals in conditions where weight loss is lower. Other modifications are made to the sheds to minimise heat loss. However, there have been no studies on whether use of these sheds and improved feeding strategies (as is shown later, animals typically starve through winter) improve the performance of Gansu alpine fine-wool ewes and lambs.

One hundred and eighty adult Gansu alpine fine-wool ewes (24–36 months of age), 38 maiden Gansu alpine fine wool ewes (19 months of age) and 40 Gansu alpine fine-wool lambs (7 months of age) were used in a 151-day grazing and greenhouse pen-feeding experiment from December 2005 to May 2006. The sheep were divided randomly into two groups, comprising in each case animals from the three groups described above. Sheep in the control group were conventionally grazed during the day and housed at night in a typical open shed. Sheep in the experimental group were pen fed in a greenhouse shed with improved feeding all day. Animals were weighed and their body condition checked monthly. These data were used to help parameterise the bioeconomic models.

Model analyses

The data collected from farm surveys, expert opinion, grassland measurements and the experiment to investigate pen feeding in warm sheds were used to construct a *typical* farm for Kangle town, Sunan county, Gansu. The parameters that made up the typical farm were the input data to two models used to analyse the current conditions and options for farm improvement. These models were the *StageONE* feed-balance analyser and the *StageTWO* optimising models (Takahashi et al. 2011). The *StageONE* model is designed for manual manipulation of input data to investigate current and alternative conditions. The *StageTWO* model uses the same starting values as *StageONE*, but then investigates optimal solutions for parts of the livestock production system, such as least-cost rations and the farm balance in grazing and crop areas at a range of specified stocking rates. The *StageTWO* model is typically used in a mode that constrains feeding rates of livestock to conditions where live-weight losses are minimised. Both models derive net farm livestock financial returns for the starting conditions using biophysical and financial data. The general aim is to investigate tactics and strategies that herders could use to initiate a program of farm improvement. The aim was not to find an ultimate solution that would apply for the next century, as that is impossible unless future conditions can be predicted. As the typical farm investigated is based upon current data containing obvious uncertainties, only substantial improvements in farm performance are considered as being likely to translate into real benefits to herders.

Results

Current Sunan livestock production system

The typical farm in Kangle town of Sunan county has around 93 ha of grasslands, which are primarily used for production of wool and meat from Gansu alpine fine-wool sheep (Table 1). Lambing time is mainly from March to May and the sheep are sold around the end of September. There are no crops and very little sown forage production. The most common forage was oats, sown on less than 0.2 ha. There are three types of grasslands, classified by the time they are grazed. Summer grasslands, grazed from July to August, are at the highest altitude and have a short growing season. They are grazed in common with other flocks from the village. Autumn/spring grasslands are at middle altitudes and are grazed in June and September–October by livestock as they move between winter and summer grazing lands. Winter grasslands (grazed from November to May) are at the lowest altitude. Winter grasslands are divided between lambing grasslands and non-lambing grasslands. From November all animals graze on non-lambing grassland and, at lambing time, lactating ewes graze in lambing grassland. There is no grass growth in Sunan from October until late May, because of the extremely low temperatures (see Figures 1 and 2).

The sheep are grazed on winter grasslands from November to the following May, to utilise the limited, low-quality forage available. In terms of the ewe's maintenance energy requirements, the actual energy intake is deficient from the middle of October to late May (Figure 3). The only supplement typically fed is oat hay at 0.5 kg/head/day from the middle of March to May. The deficiency in energy intake leads to a significant weight loss. In years with a dry spring many ewes die. The need to change from the survivor strategies of the past to a production focus is clear in order to minimise weight loss and mortality.

Table 1. Typical farm in Kangle town of Sunan county, Gansu province

Herd structure			
Number of animals (head)	180–220	Breed	Gansu alpine fine-wool sheep
Ewes (head)	90–110	Wethers (head)	10–20
Rams (head)	3–4	Lambs (head)	30–40
Replacements (head/year)	45–55	Mortality rate of lambs (%)	8
Production system main characteristics			
Mating	Nov–Dec	Mating type	Mostly artificial insemination
Lambing	Mar–May	Weaning age (month)	4–7
Sheep sales	Sep–Oct	Age of lamb sale (month)	4–7
Lamb live weight at sale (kg)	17–35	Shearing method	Half by machine, half by hand
Wool yield (kg/head)	2.6–3.3	Shearing date	July
Wool price (¥/kg)	13–25	Shearing cost (¥/head)	3
Health costs (¥/head)	4–6		
Grassland use calendar			
Grassland category	Time when grazed		Area (ha)
Summer	20 Jun – 20 Aug		23 (common grazing)
Spring and Autumn	20 May – 20 Jun; 20 Aug – 20 Oct		23
Winter	20 Oct – 20 May		30 + 17 (lambing)
Farm income (annual)			
Gross income (¥)	18,820	Average income (¥/person)	5,086
Livestock income	17,778	Percentage from livestock	94

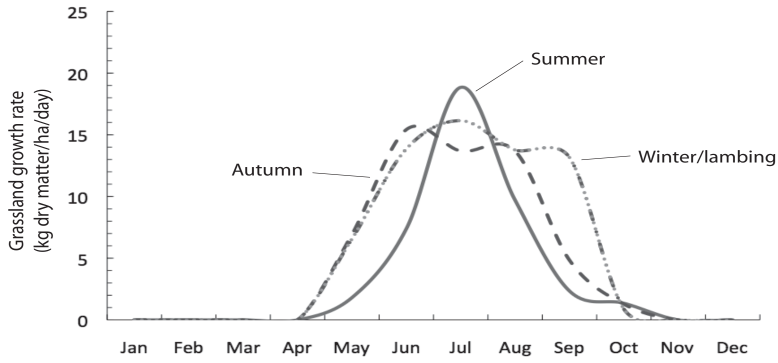

Figure 2. Estimates of grassland growth rates for each grassland type on a typical farm at Sunan county, Gansu province, based upon limited data on grassland annual growth and known seasonal patterns

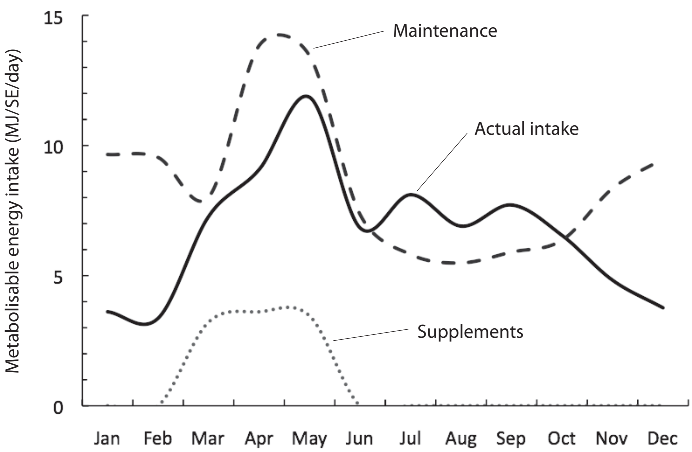

Figure 3. Livestock total (actual) and supplement (oaten hay) metabolisable energy intake versus maintenance energy requirement at same live weight per sheep equivalent (SE) for all animals on the typical farm in Sunan county, Gansu province. Grassland intake is the difference between total and supplements. Ewes lamb in April.

Analysis of ewe live weight at standardised stocking rates (adjusted to a 50 kg equivalent) and herbage mass per grazed hectare for an average year in Sunan county (Figure 4) shows that ewe live weight falls sharply from April to May (see Figure 5) and then increases slowly from June to October when increasing quantities of green grass are available. The standardised stocking rate varies between months, in part due to the changing live weights reaching a minimum in May after lambing on winter grasslands. These animals have a high capacity for intake because their standard reference weight is their previous peak body size (Freer et al. 2007), which results in high rates of compensatory gain on the sparse pastures through summer. The highest stocking rate is from June to September when lambs are growing and sheep's body weight increases. Most of the lambs and culled ewes are sold at the end of September, resulting in a substantial reduction in stocking rate. There are further reductions from November when the animals start to graze the larger area of winter grasslands. The herbage mass is nevertheless very low at all times, severely limiting animal productivity. This system has a high level of risk. If there is a dry spring, poor summer growth and/or winter storms, then mortality rates increase. Even if the *quantity* of autumn, winter and spring grass were greater, the *quality* would not be sufficient to satisfy maintenance requirements. This deficiency in energy intake through the cooler months always leads to significant weight loss. Animals typically lose weight from the first frost in October until the start of summer in late May. The loss in ewe live weights from April to May is associated with lambing and lactation.

Improved feeding of sheep during winter and spring

The extensive period of low livestock nutrition during winter and spring that results in significant weight loss in average years is a major constraint on animal production (Figures 3 and 4). In Sunan there are limited opportunities to conserve fodder, but it is possible on some of the grassland areas. The alternative of purchasing meadow hay is often rejected by herders as being too expensive because of transport costs. The feed balance, *StageONE* model was then used to investigate the benefits of making hay and growing maize on the available area on a typical farm (Figure 6). Grain can be purchased and is more cost effective as an energy source. Herders often limit the amount fed to what they think is a minimal affordable level as they are focused on survival strategies. However, it was known that this would still be below maintenance requirements. Analyses were then done to investigate the effects of feeding closer to what herders might consider to be an upper economic limit of feeding ewes 0.5 kg/day/head hay from March to May and 0.3 kg/day/head maize from April to May. These levels of feeding were suggested by the results of farm experiments that showed increased supplements at this time could improve lamb birth rates and survival. While the benefits to ewe nutrition of feeding both a typical amount of hay plus some maize could be demonstrated (Figure 6), they were not sufficient to limit actual live-weight loss during the winter, but closer to maintenance requirements from March to May. There are nevertheless still large deficiencies from November to March with this system. Feeding these higher rates of supplements (0.5 kg/day/head hay and 0.3 kg/day/head maize) to ewes from November to May does bring energy intake closer to maintenance energy requirements except around lambing, but the increased costs cause a decrease in net income from livestock (Figure 6).

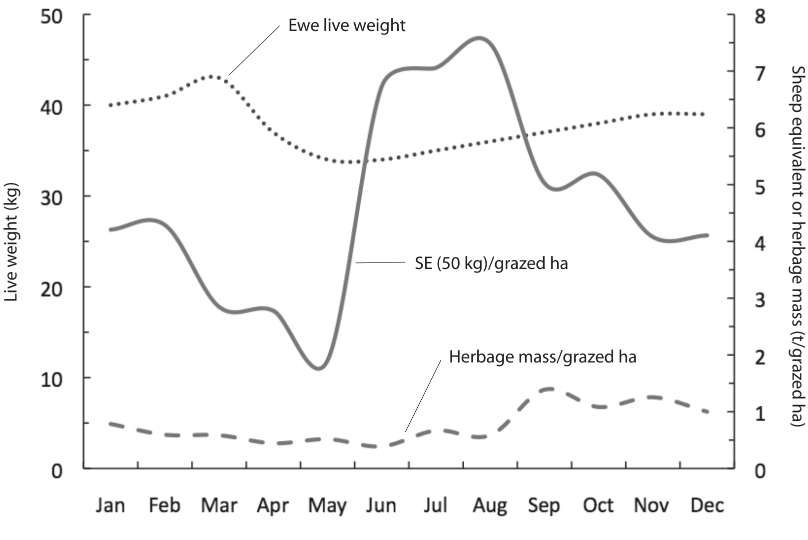

Figure 4. Ewe live weight, standardised stocking rates (all livestock at 50 kg equivalent) and herbage mass per grazed hectare for an average year in Sunan county, Gansu province. Note the sheep equivalent (SE) does not consider the physiological state of animals, only their live weights.

Farmers often feed other supplements such as mixtures of maize bran, oats and alfalfa hay and grain, usually purchased off-farm, but estimates (not presented here) of their impact showed the general result that, at the rates fed, energy intake was likely to be significantly below maintenance requirements.

Further analyses of these alternative feeding strategies (Figure 5) showed the net profit from livestock decreased slightly with the shorter period of feeding in spring, and more so with feeding from November to May. Costs greatly increased from feeding these additional supplements. These analyses assumed the same gross income per kg of animal sold, whereas better feeding is likely to result in more meat or wool on animals and a higher price per unit of animal product. Feeding higher levels of supplements needs to be tested on farms to determine the actual costs and benefits.

Pen feeding in warm shed during cold seasons

While improvements in livestock productivity through winter can be achieved by providing more supplements, the low temperatures mean that considerable amounts would be needed to prevent any weight loss and improve the productivity of ewes during pregnancy and lambing. Significant weight loss is directly due to the energy demands of maintaining body temperature. This can be offset by keeping animals in a warm shed, particularly during the coldest parts of the year.

An analysis of improved feeding (the same regimes as outlined in the previous section) plus keeping animals in a warm shed showed that the maintenance requirements of livestock could then be satisfied. The annual metabolisable energy required for maintenance of sheep grazed all year was 12% and 9% higher, respectively, than those kept in a warm shed or in a traditional shed during winter (Figure 7). During winter the energy requirements of animals kept in a warm shed are considerably lower than those grazing outside.

Changing the lambing time

The farm survey found that the traditional lambing time in Sunan county had been in January. In response to the results of the work presented here, this has now shifted to lambing in March–April, with a few flocks lambing in May.

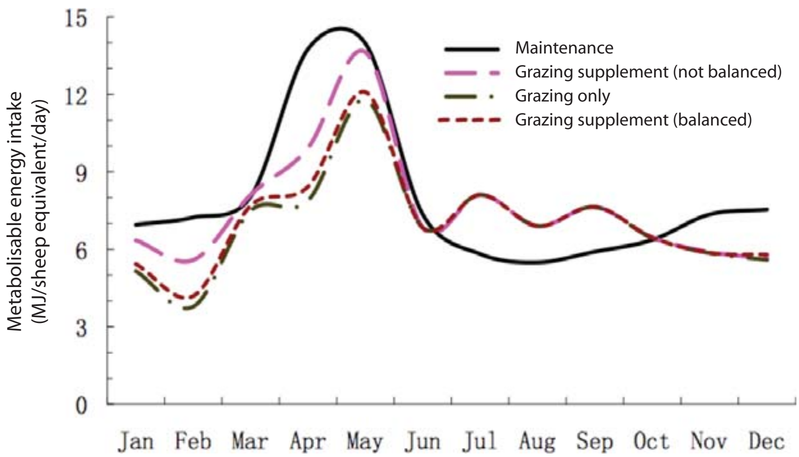

Figure 5. The metabolisable energy (ME) balance of ewes grazed all year versus grazed plus hay and grain supplements in April lambing. Estimates are from the *StageONE* feed balance analysis model. 'Maintenance' is based on supplements for ewes of 0.5 kg/day/head hay and 0.3 kg/day/head maize. 'Grazing + supplement (not balanced)' means, for ewes, grazing plus a supplement of 0.5 kg/day/head hay from Mar to May and 0.3 kg/day/head maize in April and May. 'Grazing + supplement (balanced)' means, for ewes, a supplement of 0.5 kg/day/head hay and 0.3 kg/day/head from November to May plus grazing.

We analysed the energy balance with the *StageONE* model for different lambing times (Figure 8). January lambing results in major feed deficits (only 50% of maintenance) from December through February (Figure 8a). April lambing is closer to satisfying maintenance requirements around lambing, although during pregnancy there are significant energy deficits (Figure 8b). May lambing does enable further small improvements over lambing in April, and the closer alignment with maintenance requirements would be expected to produce higher weight gains for the same input of supplements (Figure 8c). June lambing continues to make further improvements over the other tactics, with estimates of actual intake being above maintenance, which should, in turn, lead to higher live-weight gains (Figure 8d). Lambing in June means that ewes and lambs gain more benefit from green grasslands than at other times. These simulations assume that all lambs are sold at the same time in autumn. The benefits of the system could be further refined by optimising the times at which lambs and cull animals are sold. It may be that the better returns could be achieved by selling young animals at 3 months of

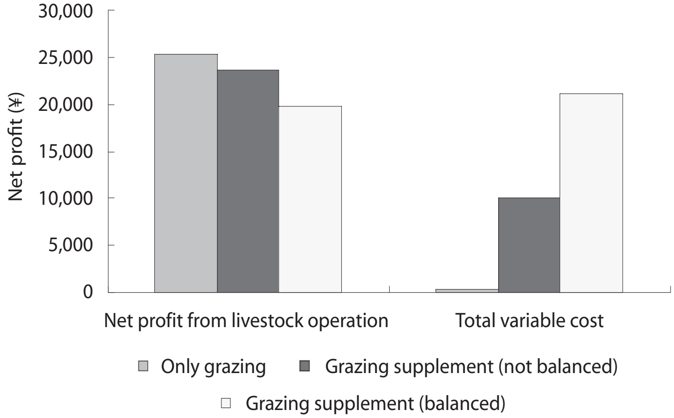

Figure 6. Net profit from livestock and total variable costs for grazing only versus additional supplementary feeding plus grazing in Sunan county, Gansu province. The number of animals was the same for each system modelled. Animals housed in conventional sheds.

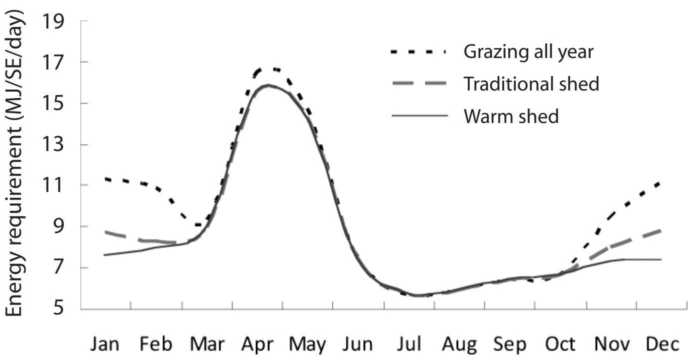

Figure 7. The difference in energy requirements (MJ/sheep equivalent (SE)/day) for Gansu alpine fine-wool sheep: grazing all year versus pen fed in a traditional or warm shed during cold seasons. Animals have the same live weight and lambing in April. A supplement composed of 0.5 kg/day/head hay and 0.3 kg/day/head maize was fed from November to May in each case.

age. At this stage the markets are not sufficiently developed to indicate what would be reasonable prices for young animals.

Combining tactics

The above analyses show that changing lambing times, improving feeding in winter and using warm sheds would all lead to significant gains in animal nutrition. The combination of tactics from these separate analyses was then investigated. This showed that the net farm financial returns from livestock reached a maximum when the stocking rate was about 1.5 ewes/ha, this point being where feed costs started to rise steeply (Figure 9). This optimal stocking rate is similar to the overall stocking rate on a typical farm (Table 1) and may be a little higher. While this prediction would align with what herders currently want to do, it may not be the best for grassland improvement. Future modelling needs to examine the longer term consequences of these different strategies.

Discussion

Grassland degeneration is a serious problem for vast areas of northern and western China, and well recognised in the region of this study. Overgrazing is one of the major reasons for degeneration. A core issue for improving livestock production on the grasslands of northern and western China is the need to improve livestock productivity. The modelling presented in this paper shows how an analysis of the energy feed balance highlights major deficits and enables an investigation into more efficient systems. Once the better options for managing feed supply and demand are identified, more comprehensive financial analyses can be made to develop overall farm system strategies.

For Kangle town in Sunan county, continued wool production offers better prospects than meat production, as the sheep can be fed closer to maintenance requirements than the higher requirements for meat production. Other modelling (not presented here) showed that feeding for meat production was

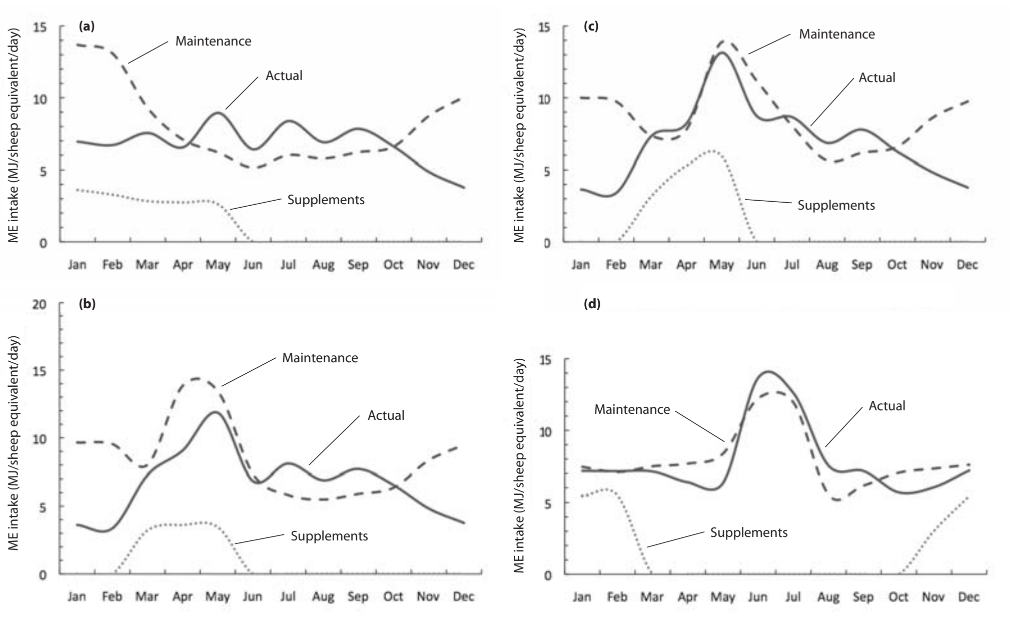

Figure 8. The effect of lambing time on the feed energy balance for ewes in Sunan county, Gansu province: (a) lambing in January (previous practice) and oaten hay fed January–April; (b) lambing in April and fed oaten hay and maize grain March–May; (c) lambing in May and oaten hay fed March–May and maize grain fed in April–May; (d) lambing in June and oaten hay fed in December, April and May, and maize grain fed in December. In each case, oaten hay was fed at 0.5 kg/day/head and maize grain at 0.3 kg/day/head (ME = metabolisable energy).

too expensive to be viable, as little supplementary fodder can be grown locally and transport costs are considerable. Feeding closer to maintenance requirements would enable breeding to continue, although viable systems will then require lambs and culled sheep to be sold earlier to reduce feed costs through autumn to early summer. The optimal time for sales was not modelled, as markets are rapidly developing and it is difficult to identify consistent prices per unit of animal product that would enable these refinements in farm strategies.

Within the flocks in Kangle it is known that some animals arguably cost more to keep than the revenue earned from them. These animals are in poor condition, have poor teeth and udders, and should be culled. Other tools are being developed to help herders cull such animals (Kemp et al. 2011). A 'precision livestock management tool' (PLMT) enables the value of individual animals to be estimated so that flocks can be rated from best to worst and the least productive animals culled. Analyses done with this tool show that net farm incomes can be increased with fewer, but more efficient, animals.

The results from modelling presented here show that feeding animals better and closer in tune with reproductive requirements, changing lambing times to better accord with seasonal feed supplies and using warm sheds to reduce energy requirements in winter all enable improvements in animal production efficiency and thence in net farm incomes from livestock. The PLMT further enables refinement by culling the least efficient animals such that net farm income can then be maximised at lower stocking rates. The modelling presented in this paper is based on average values for animals in the flocks surveyed. More efficient animals provide a way of sustaining incomes with fewer animals such that overall stocking rates could then be reduced, providing opportunities for regeneration of the grasslands. All these steps can be considered as the first phase in farm improvement. They aim to move towards a production focus from traditional survival attitudes. They represent only the first steps but ones that start to improve farm financial viability and provide a means of rehabilitating grasslands. Future work needs to test these ideas and to resolve many of the details that undoubtedly apply.

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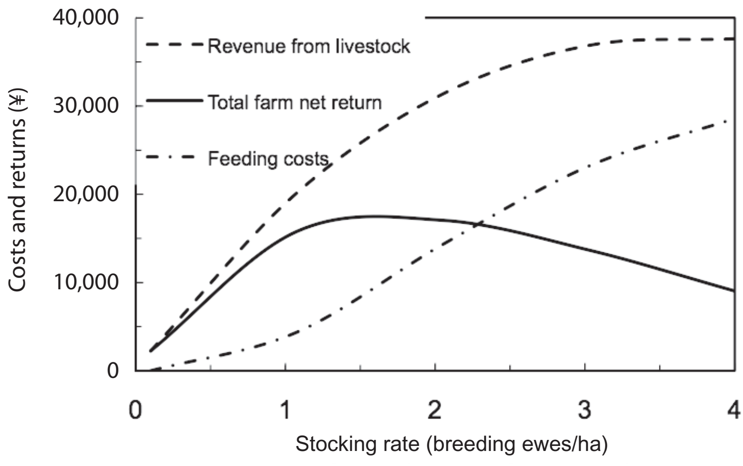

Figure 9. Optimal results of local production system by bioeconomic model II. The revenue from livestock increases steadily when the stocking rate is below 3; the net return is highest when the stocking rate is about 1.5; and the feeding cost increases sharply when the stocking rate is above 1.

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A new town in Sunan county, Gansu province. It has feedlots, overcoming the need to graze the hills. Photograph taken in early winter. [Photo: D.R. Kemp]

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

Han Guodong, Li Na, Zhao Mengli, Zhang Min, Wang Zhongwu, Li Zhiguo, Bai Weijie, Randall Jones, David Kemp, Taro Takahashi and David Michalk

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.

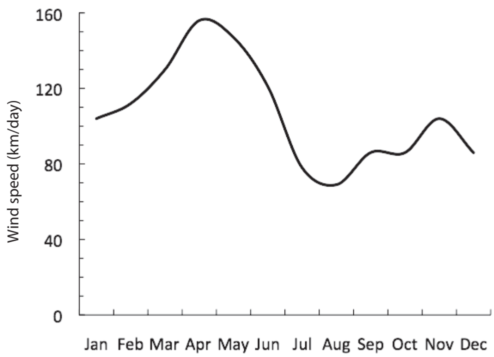

Figure 2. Wind speed per day during each month for Siziwang Banner, Inner Mongolia Autonomous Region

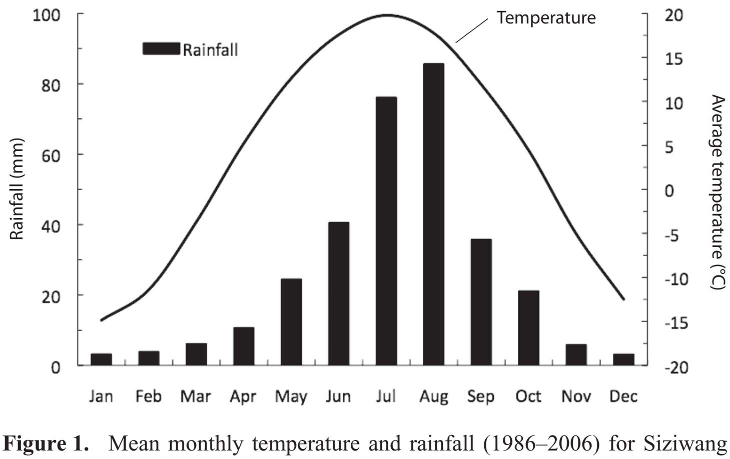

Figure 1. Mean monthly temperature and rainfall (1986–2006) for Siziwang Banner, Inner Mongolia Autonomous Region

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.

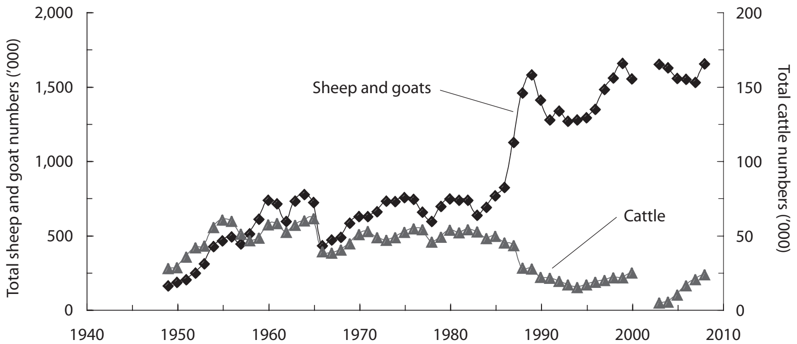

Figure 3. Total numbers of sheep and goats, and cattle, in Siziwang Banner, Inner Mongolia Autonomous region, 1949–2009

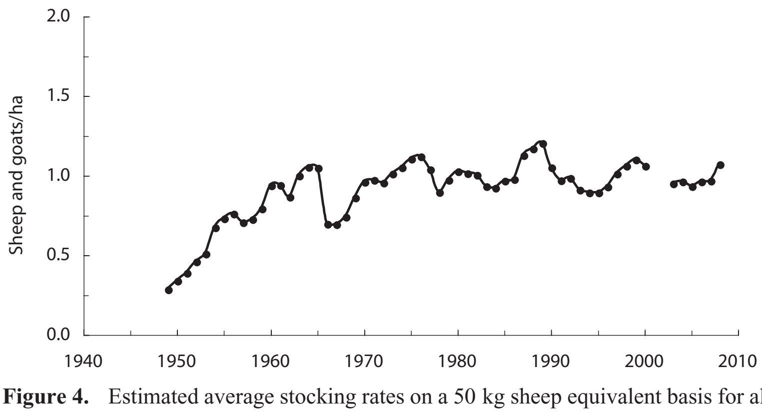

Figure 4. Estimated average stocking rates on a 50 kg sheep equivalent basis for all livestock in Siziwang Banner, Inner Mongolia Autonomous Region, 1949–2009

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

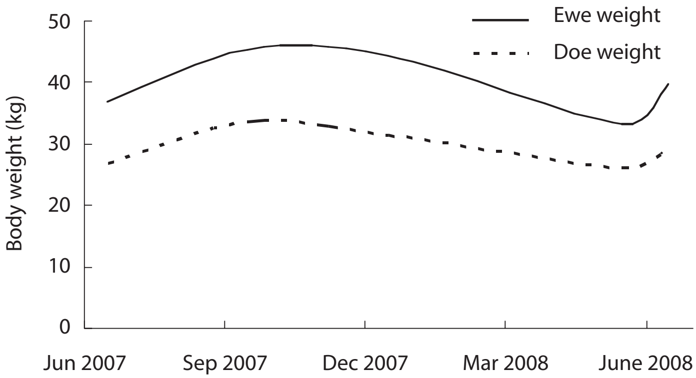

Figure 5. Changes in ewe and doe live weight from early winter to early summer (the main period of weight loss) in 2007–08 in Siziwang Banner, Inner Mongolia Autonomous Region

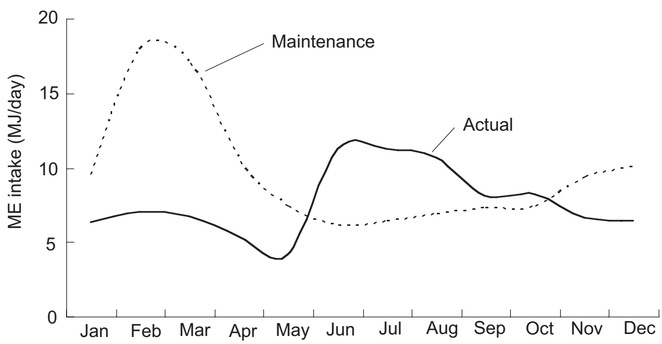

Figure 6. Estimated monthly trends in metabolic energy (ME) intake for ewes on the typical farms at Siziwang Banner, Inner Mongolia Autonomous Region, based on live-weight estimates, showing actual energy intakes and the intakes required to maintain live weights

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.

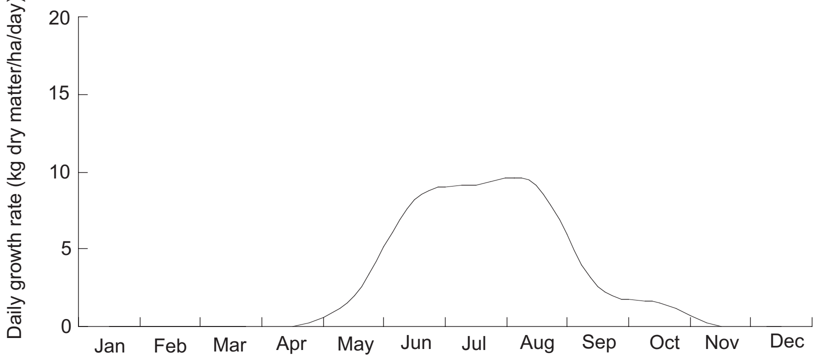

Figure 7. Estimated daily grassland growth rates for fields managed for summer or winter grazing in Siziwang Banner, Inner Mongolia Autonomous Region

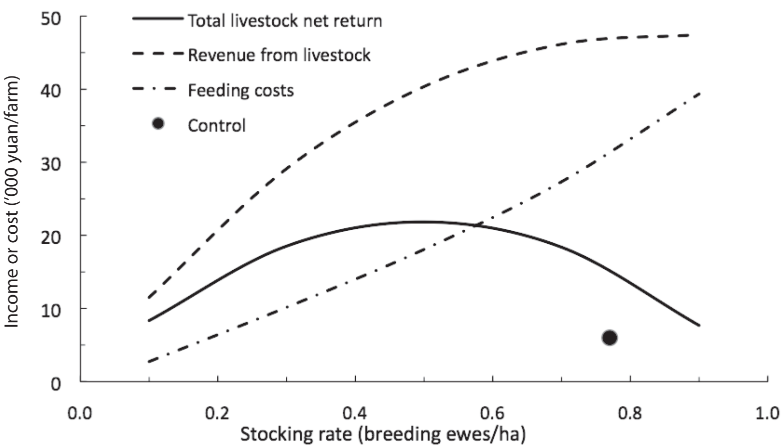

Figure 8. Livestock production revenue and feed costs for the current meat production system in Siziwang Banner, Inner Mongolia Autonomous Region, when animals are fed to maintenance requirements and kept through winter in a warm shed. The 'control' data point is an estimate of current net income from 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

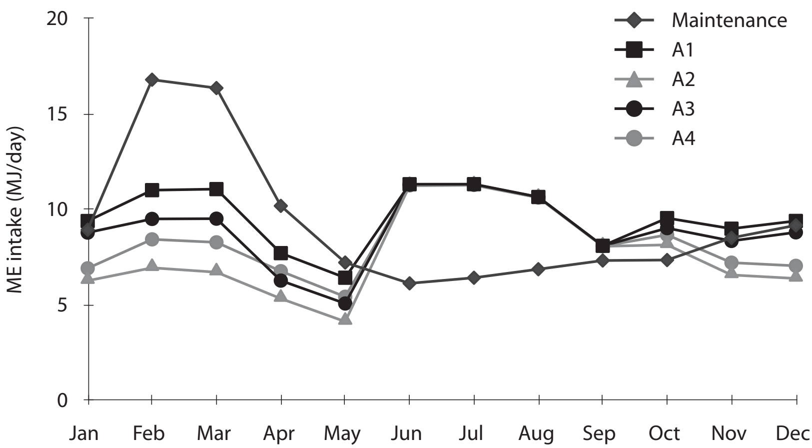

Figure 9. The effect of different possible supplements on estimated metabolisable energy (ME) intake by livestock in Siziwang Banner, Inner Mongolia Autonomous Region. Results derived from *StageONE* model. Maintenance: the energy required for maintenance at the same live weight; A1: actual energy intake 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

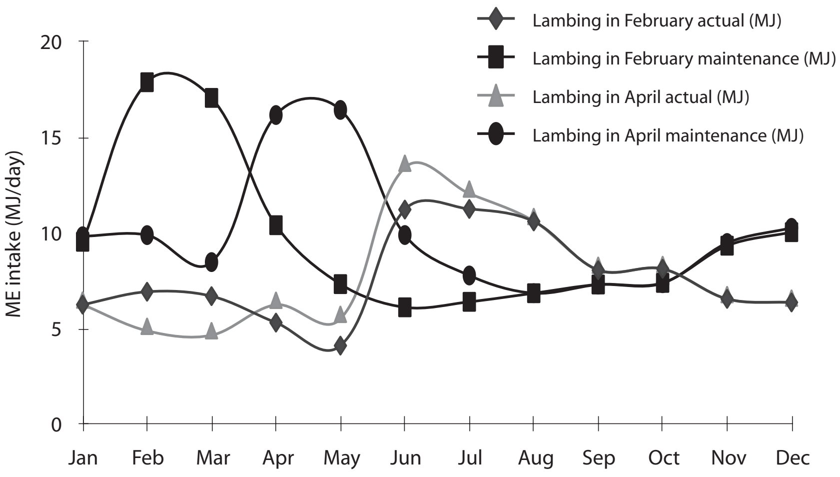

Figure 10. The effect of lambing time on energy balance (ME = metabolisable energy) of ewes at Siziwang Banner, Inner Mongolia Autonomous Region

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

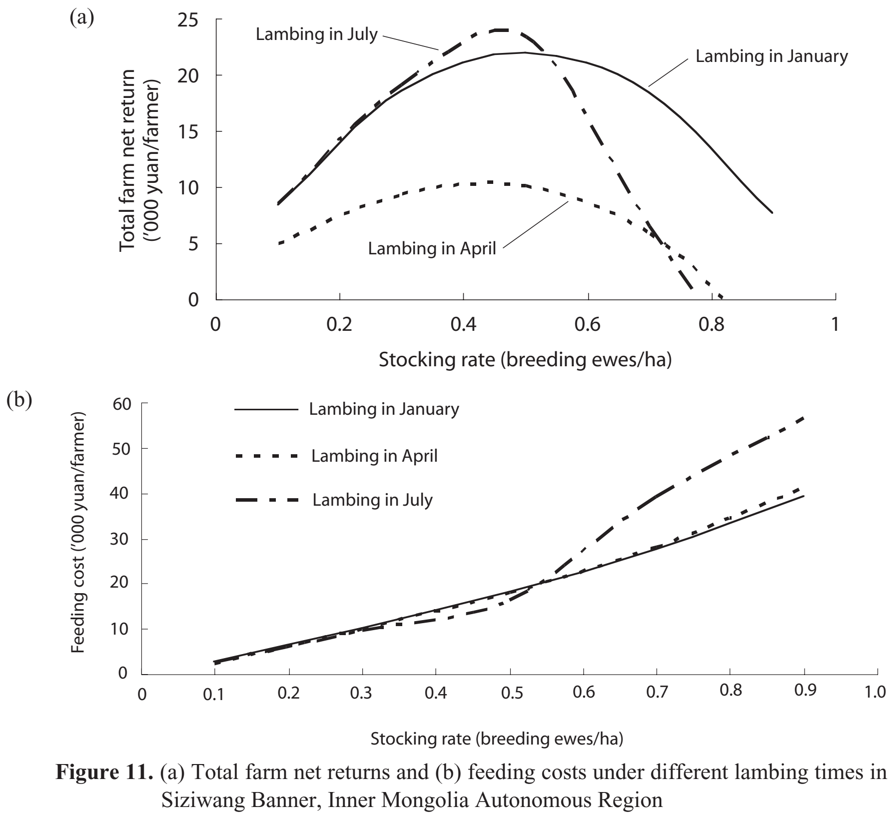

Figure 11. (a) Total farm net returns and (b) feeding costs under different lambing times in Siziwang Banner, Inner Mongolia Autonomous Region

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

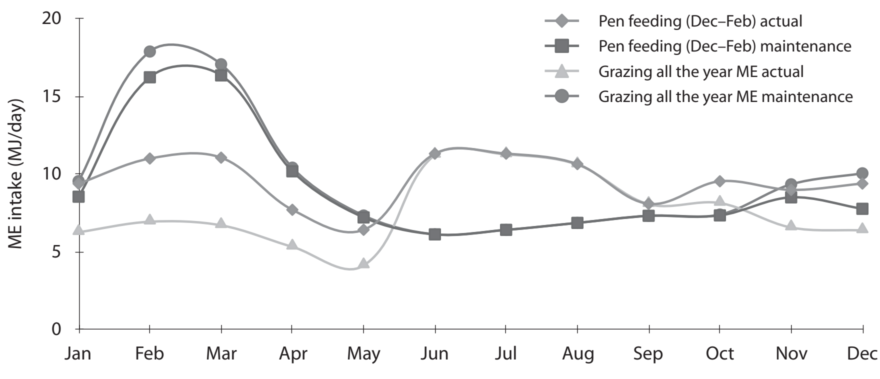

Figure 12. Energy balances for grazing ewes all year versus pen feeding in warm sheds in winter in Siziwang Banner, Inner Mongolia Autonomous Region (ME = metabolisable energy)

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 live-weight 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

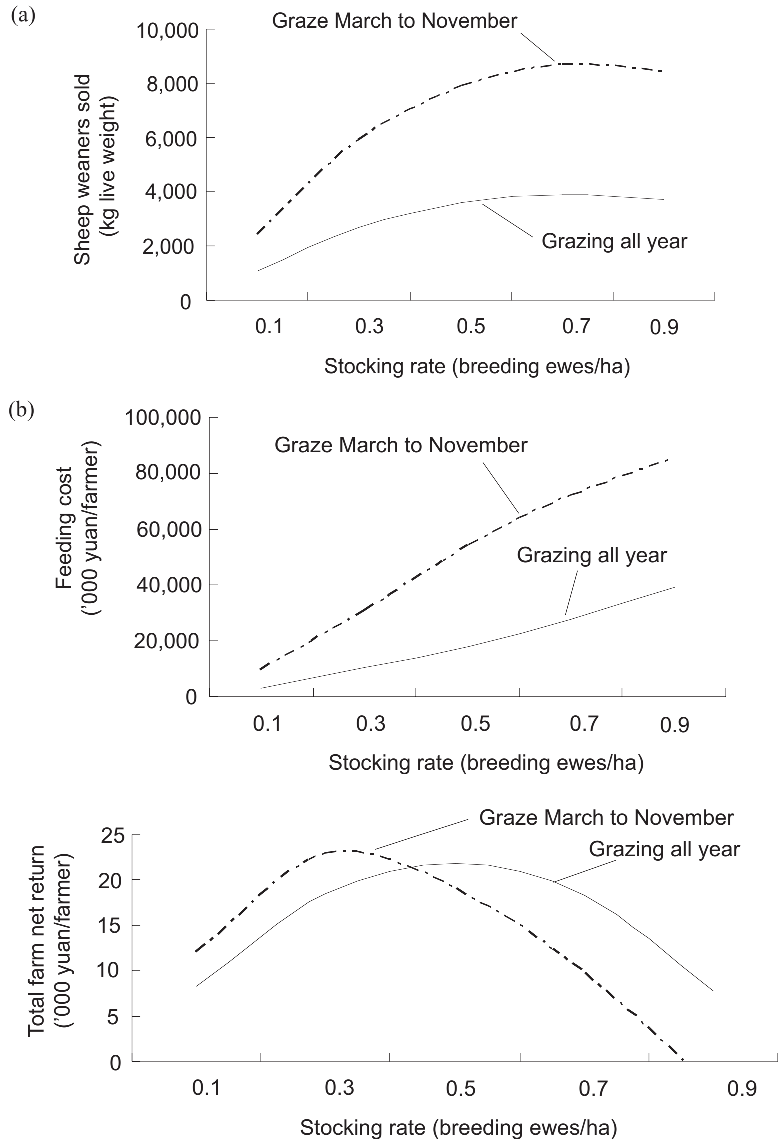

Figure 13. The estimated effects of stocking rate on sheep weaners sold (a), feeding cost (b) and the total farm net return (c) in Siziwang Banner, Inner Mongolia Autonomous Region for a typical farm, determined using the *StageTWO* model (see text for details)

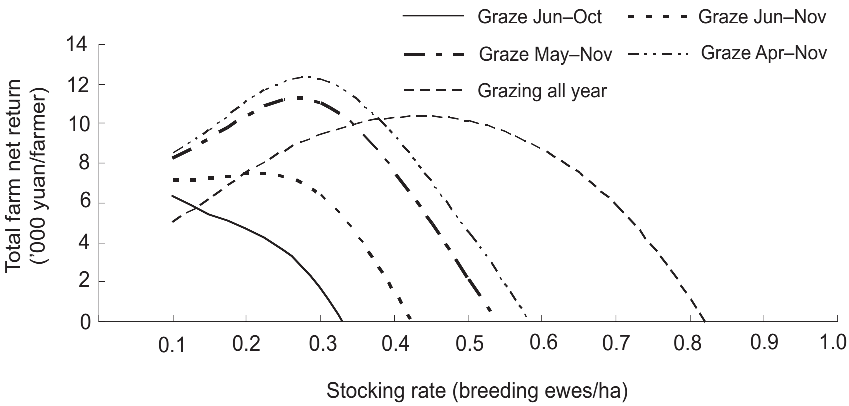

Figure 14. Total farm net return when animals graze all year and are fed supplements to maintenance requirements, or are grazed for part of the year and then pen fed for the remainder

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]

Developing the right institutional environment to deal with grassland degradation in China

Scott Waldron, Colin Brown and Zhao Yutian

Abstract

Restoring China's grasslands and improving herder livelihoods requires solutions that encompass ecological, technical, economic and social dimensions. Vertical line bureaus of the state do not always integrate these dimensions through institutional design, but measures to increase inter-agency coordination could be applied to the grassland setting. Another overriding issue of coordination is the relationship between state and other agencies that govern the grasslands, including collectives and individual herders. Measures to increase the capacity of, and the interaction between, each of these sectors in a balanced way are key components of strategies to create a better institutional environment to achieve grassland rehabilitation and sustainable development.

Introduction

Getting the institutional framework right is crucial in dealing with the problem of grassland degradation in China. Most studies on institutional aspects on grassland management focus on property rights. However, the attention of this paper is mainly on organisational structures and the governance of China's grasslands, especially on the role of the state[1] as this better reflects the way policies are developed and implemented in China.

The Chinese Government has in recent years significantly reformed the institutional structures that govern the use and management of grasslands. In addition to a critical analysis of these reforms, this paper outlines some of the debates occurring in China about grassland institutions which may be implemented into the future. Analysis is based on fieldwork for Australian Centre for International Agricultural Research (ACIAR) Project LPS/2001/094, 'Sustainable development of grasslands in western China', between 2005 and 2007, and other research projects that the authors have been involved with concerning grassland degradation and China's pastoral region.

The plethora of institutional issues is discussed at length by Brown et al. (2008, Chapter 3). This paper draws out and reports on some prescriptive findings arising from that more detailed analysis. Figure 1 outlines four forms of institutional structures relevant to grassland management in China, namely governance structures, vertical state structures, horizontal state structures and industry structures, each of which is discussed in sequence. As Figure 1 highlights, there are strong relationships and interactions between these structures.

Governance systems

Decisions about grassland, livestock and ecological management are made by three different governance systems, namely the state (at national to township level), the collective (at village and social group level) and individuals (herders and households). An ongoing debate about the appropriate balance or

[1] State in this context means the national body responsible for managing the country.

Pp. 98–104 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.

distribution of roles between these systems continues in China. The premise of this paper is that all three governance systems should play a role in improving grassland management, rather than any one of the levels dominating.

The implementation of the Household Production Responsibility System to pastoral areas in the 1980s decentralised decisions about grassland–livestock management to individual households. Further allocations of use rights over most grasslands since then and revisions to the Grassland Law and other measures have re-emphasised the role of individual households in grassland management. A range of training and research programs, including ACIAR Project LPS/2001/094, aim to increase the decision-making capacity of individual households to sustainably manage their livestock and grasslands.

However, many parts of the pastoral region have yet to create the institutional framework and economic incentives that would encourage households to put into practice sustainable management systems. Household use rights over spring and summer grasslands have only recently been allocated in many parts of the pastoral region and remain generally insecure, as evidenced by grazing restrictions in recent years. Furthermore, the realities of land and livestock systems in pastoral areas mean that it is impractical to build perimeter fences around individual household lots in large areas of spring and summer grasslands.

Many herding and livestock management decisions are consequently still made collectively at the village level or by groups of households, while disputes are resolved through village leaders. For some activities, group management provides more equitable access to resources and can be aligned with local social settings and spatial complexity. As a result, village leaders and community groups undoubtedly will continue to play a role in collective decisions and in mediating disputes either formally or informally. Various studies such as that of Banks et al. (2003) have argued that government should support these community-based governance and institutional structures much more than it has in the past. Indeed, much of the challenge in improving management of the grasslands is in protecting individual rights while also building the capacity of group management structures.

Groups and village collectives cannot be expected however, to deliver all the solutions. Many younger

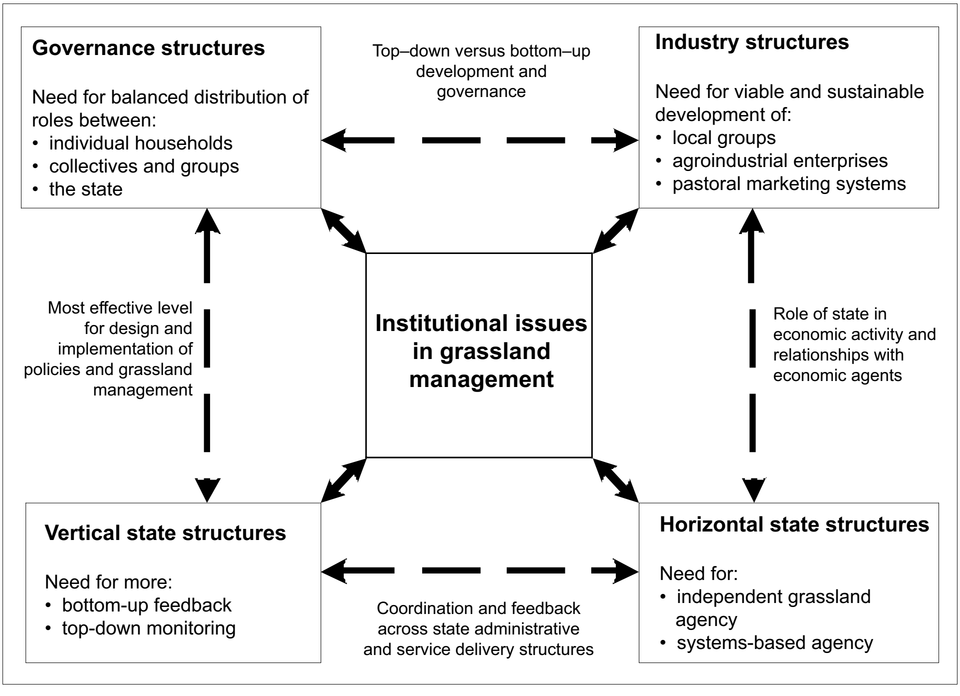

Figure 1. Key institutional issues in grassland management

members of pastoral households are working off-farm, agistment and contract grazing is increasing, and traditions are breaking down. Grazing production and marketing systems and regulations are become increasingly complex and households may want to pursue farm management systems different to those of their neighbours. The varied incentives and farm management methods of households could be expected to make it increasingly difficult for local collectives and groups to apply uniform rules across the households. If these developments increase disputes between households or within the groups, traditional community mechanisms through consensus style processes will be put under extreme pressure.

Group management is based on maximising collective benefits. However, many instances of inappropriate or illegal grazing in the pastoral region are committed by large herders, many of whom are leaders in their communities. If the government is to provide additional powers to these community bodies or leaders, it needs to monitor their accountability to their communities. Thus, irrespective of whether community leaders or local state officials oversee grassland management, appropriate checks and balances on their operations need to be in place.

At a level up, the state has always played a significant role in grassland and livestock management, especially through extension and grassland improvement activities. However, the severity of grassland degradation and the shortcomings of individual household and collective management systems have led the state to exert more influence over grassland planning, management, utilisation and protection in recent years. This has taken the form of various edicts, laws and regulations, as outlined in Brown et al. (2008, Chapter 4). These measures are usually backed by increased funding and projects to generate compliance of households and local groups. Some of these measures, such as grazing bans, increased pen feeding in warm sheds, intensification and resettlement dramatically alter how households and groups operate. Just how sustainable these top-down state measures will be once the substantial external inputs (both in the form of subsidies and political pressure) are withdrawn remains to be seen.

Although the role of the state in grassland management is increasing, there are major constraints on its capacity to deal with grassland degradation. What appear to be strong policies, regulations and funding at macro levels can have a much more subdued impact when spread among millions of households across vast distances. Even with a major increase in capacity as part of the new grassland programs, grasslands inspectors cannot cover the vast areas involved on any close, regular or ongoing basis. Despite having the mandate and, indeed, the responsibility to enforce regulations such as stocking rates and grassland regulations, in general the state rarely does so. In addition to the logistics and costs involved, local state officials are unable or unwilling to impose burdens on or interfere in the immediate interests of local minority households. As a result of these constraints, and to restate the premise of this section, this strengthening of state powers must therefore occur in parallel with an increase in the capacity of individual households and collectives to manage their own affairs.

Vertical state structures

Given that the state is re-asserting control over grassland management, major issues arise in coordination between components of the sprawling state system in both vertical and horizontal directions.

With regard to vertical coordination, the main premise in this section is that there is too little local input into the design and formulation of grassland policies in China, while there is too little higher administrative level input into the monitoring and inspection of grassland activities. The premise does not imply that central and provincial governments should not be the major driver of grassland policies or that local officials should not form a key part of monitoring and enforcement, but that the current distribution of roles in both these areas is unbalanced. The result is an enormous gap between the design and the implementation of grassland policies in China.

Grassland laws and policies in China have traditionally been made in a top-down manner. This approach has advantages in so far as higher level government will pursue societal interests broader than the more narrow and parochial interests of local governments. However, high-level laws and policies will be irrelevant or ineffective if they do not reflect the reality of conditions ‘on the ground‘, as is the case, for example, for stocking rate standards and enforcement.

In order to narrow the gap between policy formulation and enforcement, China has sought to update large numbers of grassland policies and laws in recent years. Broadly framed national-level laws enable significant flexibility in interpretation and implementation at local levels, including in provincial and autonomous region regulations which, in turn, enable significant flexibility to prefecture levels and below. In addition, higher level officials routinely collect information from local areas through, for example, reports and visits. In practice, however, major programs such as grazing bans, increased pen feeding and herder relocation are developed from the top down.

Another major problem with policymaking for the grasslands is that there is a lack of institutional capacity to implement and enforce even the well-designed policies. This is largely due to an over-reliance on local-level monitoring and inspection of grassland activities and programs. Local-level monitoring and inspection of higher level policies is particularly ineffective if the measures are seen as adversely affecting local herders and conflicts of interest arise amongst local-level agencies. Thus, the inspection process needs to be more independent, with more power and responsibilities given to higher level authorities.

This does not necessarily mean that higher level authorities will conduct more on-ground inspection themselves. Indeed, the costs and logistics of on-ground inspections mean that inspection will be done predominantly by local-level agencies. However, central-level agencies need to exert more influence in overseeing the inspection activities of local-level agents by auditing, random checks and by tying project funds to inspection performance. Recent institutional changes such as the creation of the Grasslands Monitoring Centre represent a significant step in this regard. However, the system is still constrained by human and financial resources, which the State Council should consider increasing.

Horizontal state structures

With respect to horizontal coordination, the main premise in this paper is that systems-based organisations should play a greater role relative to specific line agencies in the management of the grasslands.

By far the most important institution in grassland management is the Ministry of Agriculture, especially the Animal Husbandry Bureau hierarchy and the subordinate grassland division and grassland station system, which provide extension services and perform inspections down to township level. The Animal Husbandry Bureau is predominantly a production-oriented agency with a lesser role and interest in environmental management of the grasslands. Nevertheless, the Animal Husbandry Bureau is charged with monitoring and inspecting grassland use, thus creating an institutional conflict of interest. In addition to this conflict of interest, the effective management of grasslands, livestock, crops, water, people, markets and the environment requires a systems-based institution rather than a series of institutions with a separate focus on each of the subsystems. In this institutional environment, jurisdiction is established through damaging turf wars and institutional 'muddling through'.

As a result of these types of problems, the state has in recent years replaced 'specialised' (or production and industry oriented) departments with 'macro control' departments in nearly all sectors in China, although less so in the agricultural sector (see Waldron and Brown 2006). In grassland management, the 'macro control' department is the Ministry of Environmental Protection, which has been granted increased jurisdiction over some aspects of grassland management, along with the Grassland Police in some areas. However, these institutions will not replace the functions of the grassland stations of the Animal Husbandry Bureau, because they cannot develop a network of comparable size and reach down to township level.

Thus, as part of the 'muddling through' institutional reform process, a more constrained institutional development has been the creation of the Grasslands Monitoring Centre as a service unit within the Ministry of Agriculture. The centre lies outside of the Animal Husbandry Bureau and so may provide a check on the over-emphasis on production. There have been calls to elevate the position and increase resourcing to the Grasslands Monitoring Centre, even to a position outside the Ministry of Agriculture hierarchy. Acceptance of the proposition is not straightforward as there are both merits and potential practical shortcomings in such a move, yet it is a proposition worthy of further serious consideration.

Another institutional structure widely used in China that appears applicable to the grasslands is the 'leading group' structure. Leading groups facilitate inter-agency cooperation and coordination, reduce institutional overlaps and mixed signals to individual grassland users, and help to develop a more consistent set of objectives. Leading groups have been established in China to address many complex inter-agency problems including the State Council Office of the Leading Group for Western Region Development and the State Council Development-Oriented Poverty Alleviation Leading Group. Leading groups include representation from a large number of relevant line bureaus, which allocate staff and other resources to participate in the structure. At the central level, leading groups can report directly to a state councillor (in charge of agriculture). The group hierarchy can extend down to county level and report to county vice-governors (in charge of agriculture).

Alternatively, the leading groups may have no central-level representative but instead are established in areas where, for example, grassland degradation is severe and remediation is a priority of the local government. The need for and feasibility of a leading group or other independent type of agency is strongest at the local level. County-level governments have a high capacity to coordinate between different administrative agencies because they control and allocate funding and personnel for service (extension and inspection) agencies. The role of administrative agencies such as the Animal Husbandry Bureau and grassland stations is crucial at the local level given that they will be implementing programs and providing support and extension services.

A deeper and more permanent institutional reform that has been discussed in China includes the establishment of a fixed administrative agency that reports directly to the State Council. Administrative agencies with jurisdiction over resources similar to grasslands and that report directly to the State Council include the Ministry of Water Resources and the State Forestry Administration. It is unrealistic to expect that a parallel independent grassland agency would be created at this level. However, there is a stronger case for the establishment of a systems-based natural resource management agency that reports directly to the State Council and which formulates strategies to deal with grassland degradation and other natural resource management problems such as water and forestry. The importance and duties of the agency would be reflected in its designation as an administration, ministry, commission or other designation. Moving jurisdiction over grasslands to an all-encompassing body would be a major institutional reform, but warrants consideration if grassland degradation as well as other natural resource management problems are to be dealt with effectively and in an integrated way.

Industry structures

Liberalisation measures in the 1980s have led to what are known in China as fragmented and 'chaotic' production, marketing and processing structures. To overcome this problem, China has in recent years attempted to re-centralise some of these structures, especially through the development of local group structures and agroindustrial enterprises. While these structures are an important aspect of better managing livestock and grasslands, they are by no means a panacea and in some cases can be counterproductive. Thus, several issues in the development of local groups and agroindustrial structures require critical examination.

There are many forms of local groups in China including cooperatives, associations, 'small livestock-raising areas' and specialised villages. The state is interested in developing local groups, especially because they are indispensable in the delivery of extension (breeding, feeding, veterinary and disease control) services. Small livestock-raising areas, particularly those in agricultural, semi-pastoral and settlement areas, usually have some form of effluent drainage and treatment infrastructure that includes methane converters. If local government can attract an agricultural processing company to establish locally (and thereby provide local employment, taxes and fees), the company will inevitably organise the establishment of local groups capable of producing and supplying homogeneous pastoral products to the enterprise. As mentioned earlier, herder groups are important in grassland management, especially where grazing is undertaken collectively in spring and summer in mountainous areas. The intensification of livestock systems in pastoral areas, including the use of collective penning facilities in settlement schemes, may further facilitate the growth of groups in pastoral areas. In these cases, the advantages of group purchasing, feed storage and treatment, effluent treatment and water use might become more obvious to households.

China has taken significant measures in recent years to facilitate the development of local groups. The long awaited Cooperative Law enacted in 2007 notionally increases the independence and resourcing opportunities for cooperatives. The law allows for the establishment of legal person status of local groups (as cooperatives) that can take out loans independently of other bodies (companies, state), enter into contracts independently and contest disputes in courts. Government at all levels encourages the development of local groups through more direct inducements and resources such as infrastructure and access to cheap credit.

Although the benefits of local group structures are widely acknowledged and China has attempted to develop local groups, several problems need to be overcome. After local groups are established with support from local government they very often become, in Chinese terms, 'unstandardised'. That is, infrastructure is unused or falls into disrepair, households operate autonomously and the local group is unable to produce homogeneous product that meets the (quality and quantity) specifications of the companies or markets they were set up to supply. While such problems are ubiquitous in China, they are magnified in pastoral areas. The distance between households makes coordination and logistics difficult and increases transaction costs. Pastoral households use diversified systems as a risk mitigation strategy that can conflict with the homogeneous product specifications implied in group marketing structures.

As such, institutional measures (such as the Cooperative Law) and initial resourcing and inducements (from local government) are necessary but not sufficient steps in the development of local groups. An enormous and ongoing investment in building the management and technical capacity of local groups is required through training and extension activities. Furthermore, the development of local groups will be constrained by the marketing channels and processing systems that they sell into. The predominance of speculative dealers in pastoral areas means that it can be difficult for groups to secure premiums and sales channels for better quality pastoral products. As a result, considerable attention has turned toward the development of vertically integrated and agroindustrialised marketing and processing systems. These systems are developing from a low base in western China.

Various types of 'dragon-head' agricultural enterprises have developed tightly defined contractual relationships with producers. For example, contracts are established between dairy companies, milking stations, dairy groups and households; between abattoirs and beef cattle producers; between breeding companies and meat sheep households; and even between marketing companies and fine-wool groups and producers. These forms of contractual relationships are most prevalent in semi-pastoral areas for higher value products supplied to modern enterprises. Relationships between enterprises and producers tend to be less formalised in pastoral areas but still influence production structures. For example, large abattoirs or textile mills meet with county animal husbandry bureaus to communicate the types of animals or animal products that they require or to get help to build a 'production base' for raw material inputs. This is very often reflected in the policies and extension (especially breeding) services delivered to household producers in the county. There are many examples, especially in semi-pastoral areas, where local government has established local groups for the specific purpose of supplying specific enterprises.

The benefits that accrue to the groups and households supplying these enterprises are dependent on the ongoing viability, the purchasing practices and the conduct of the enterprises. There are numerous cases of poor performance in corporate governance in the slaughter and dairy-processing sectors in western China. Abattoirs and dairy companies regularly discount grades of animals and milk as a means of reducing raw material input costs. There are growing concerns about the establishment of local monopolies and anti-competitive behaviour for cattle and sheep abattoirs in western China. Local (county and city) government is centralising the slaughter sector to enable more routine inspection and the delivery of safer beef and sheep meat (which is classed by the state as a 'staple food' for ethnic minority populations in western China).

While marketing issues were not included in the scope of activities for ACIAR Project LPS/2001/094, several major issues have emerged from this and other research by the authors. The most fundamental issue is that preferential policies toward dragon-head enterprises can distort markets and even damage the interests of producers that supply them, which is precisely the opposite of the intention of the agroindustrialisation program. Rigorous scrutiny of the resources provided to these enterprises is therefore needed as these relatively scarce resources may be better diverted toward the development of marketing systems, especially to the elaboration, adoption and enforcement of quality and food safety standards and the creation of information systems. To that end, there are many institutional and local-level initiatives beyond the scope of this overview paper that need to be considered. The development and improved governance of the marketing system in pastoral areas is a critical but largely neglected institutional aspect of the sustainable development of grasslands in western China.

Concluding remarks

In order to meet immediate social and policy objectives, China has reformed the institutional structures that govern its grasslands. Some of these measures, such as changes to property/use rights, grazing bans, resettlement and intensification are quite radical, while others, such as the establishment of the Grasslands Monitoring Centre, are more constrained. These reforms are initial steps and precursors to sustainable, longer term institutional change. Key areas in this regard should include:

- increased capacity of extension, training and information systems so that individual households and local groups are more able to make their own sound decisions
- the development of pastoral marketing systems so that prices reflect the true value of pastoral products
- the evolution toward a systems-based state grassland agency able to make policies that incorporate the multiple production, environmental and livelihood values of the grasslands.

In the usual Chinese fashion, further institutional change will be introduced incrementally over many rounds of reforms and will require careful and considered input from the full range of policy-makers, development agencies and researchers.

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A map in a county Animal Husbandry Bureau office showing which areas are, under the 'Reduce livestock, return the grasslands' program, to be subject to grazing bans, seasonal grazing restrictions or rotational grazing in different time periods. [Photo: S. Waldron and C. Brown]

Policy settings to combat grassland degradation and promote sustainable development in western China

Colin Brown, Scott Waldron and Zhao Yutian

Abstract

Addressing complex, multi-dimensional and substantive challenges posed by grassland degradation and the goal of sustainable development in China's pastoral region involves not only the management of grasslands but also the management of livestock, people and industry structures. China has embarked on major policy reforms in areas such as market liberalisation, structural adjustment and industry modernisation, but these reforms need to be tailored to the pastoral region if they are to meet the particular challenges of the region. Similarly, specific technical innovations to restore the balance between livestock and grassland systems need to be aligned with household resources, knowledge systems and management practices if they are to be effective and if unforeseen, perverse effects are to be avoided.

Introduction

In discussing policies that impact on grassland degradation and management in China, most attention focuses on the national Grassland Law. Yet despite being the 'flagship' for grassland policies, the Grassland Law forms only part of the policy response in dealing with grassland degradation. Addressing grassland degradation involves not only the specific management of grasslands but also the management of livestock, people and industry structures. Furthermore, grassland degradation is affected by broad policy and society developments in areas such as environmental protection, industry modernisation and poverty alleviation.

Apart from the diverse range of areas legislated for the impact on grassland degradation, national legislation such as the Grassland Law represents only part of the policy response that includes edicts, legislation, regulations, standards, programs and specific measures as highlighted in this paper. The intricacies of this policy web are compounded by the complexity and multiple dimensions of the grassland degradation problem. Issues of coordination and consistency that arise in such a policy environment are highlighted in the next section.

Brown et al.[1] (2008) describe and analyse the plethora of policies in China that directly or indirectly impact on grassland degradation and sustainable development in China's pastoral areas. This paper does not seek to repeat the discussion of, or reproduce the categorisation of, policies presented in Brown et al. (2008). Instead it reflects on how a suite of policies has sought to achieve various balances, namely a balance between livestock and feed, between livestock and people, and between livestock value and grazing pressure, and what needs to be done from a policy perspective to achieve more effective grassland management in the future. A more complete analysis is presented in Brown et al. (2008) beyond the overview that appears in the sections below.

[1] This book has been translated into Chinese and was published by China Agricultural Publishing House in 2009.

Pp. 105–114 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.

The analysis underpinning Brown et al. (2008) and this paper is based on fieldwork carried out as part of Australian Centre for International Agricultural Research (ACIAR) project LPS/2001/094, 'Sustainable development of grasslands in western China', and also draws heavily on the authors' research into China's grassland policies, pastoral region and ruminant livestock industries over a much longer period. Repeat visits over extended periods enable lessons to be drawn on previous policy settings as well as the impact of these measures through time.

The foremost challenge confronting Chinese policymakers with respect to grassland degradation is that, under current and likely future technologies and economic conditions, there are simply too many ruminant livestock in pastoral areas. For the most part, Chinese policymakers have been unable to come to terms with these technical, economic and ecological realities. Rehabilitating grasslands or intensifying livestock systems is unlikely to achieve long-term goals unless this underlying core problem is solved. Structural adjustment, another broad focus of the Chinese Government efforts in western China, may offer the long-term solution, but the transition path, both for poor pastoral households and for the ecology of the grasslands, is unlikely to be smooth and will require more refined interventions or measures than are currently in place.

Policy consistency

Figure 1 provides a simplified representation of the plethora of policy instruments in China that affect

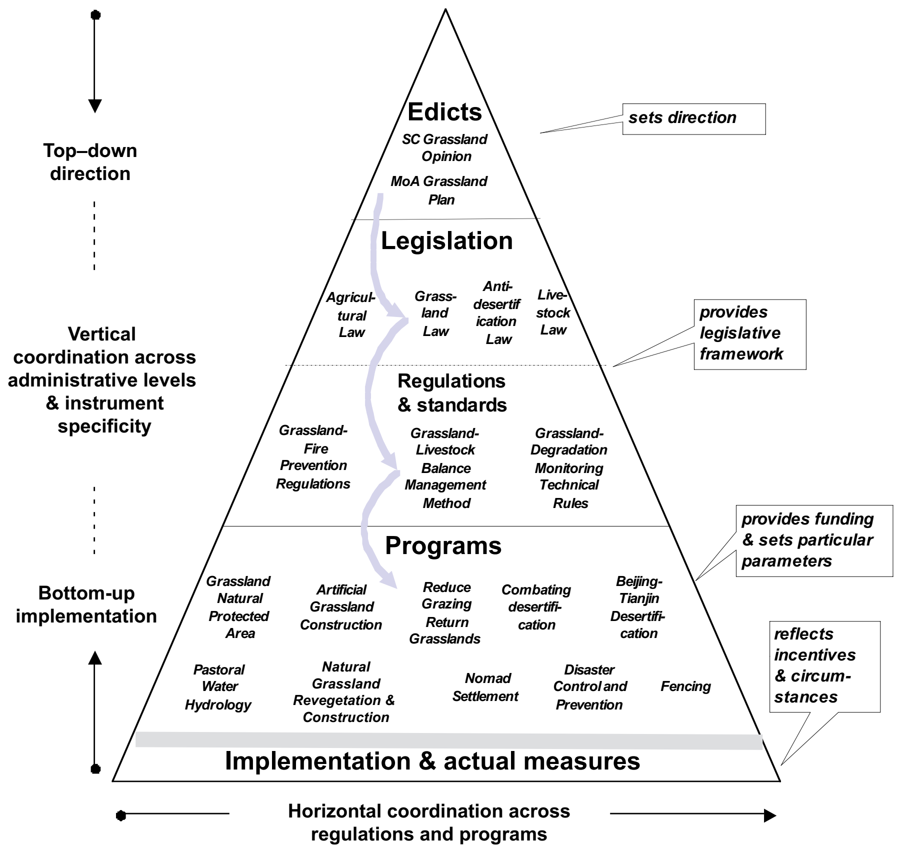

Figure 1. Overview of the network of policies affecting use and management of grasslands in China (Source: based on Figure 4.1 in Brown et al. 2008)

grassland utilisation. The many policy areas that impact on grasslands raise issues of consistency across those policies. One example of the inconsistencies evident is that, while grazing restrictions are now being enacted to scale back livestock as part of the specific suite of grassland measures, livestock targets in pastoral areas have, in general, continued to grow under various livestock plans as such has been seen, simplistically, as a way of improving incomes. The myriad of policy instruments and their intricate web mean that unintended or unforeseen impacts are common, and efforts to resolve or minimise these adverse impacts are not straightforward. Nonetheless it does highlight the need for institutional measures as suggested in Brown et al. (2008; Waldron et al. 2011), such as involving a natural resource management-based agency in the policy design process where some of the key inconsistencies within and across the legislation may become more apparent and then be solved. It also raises the challenge of a more thorough assessment of policies for inconsistencies before their enactment in an era where most policy formulation and administrative groups are being downsized.

The other aspect of consistency is whether policy edicts are consistent with legislation, regulations, and programs. Figure 1 highlights that, for some of the major policy instruments, a direct path from edicts to programs can be followed (such as the path from the Ministry of Agriculture (MOA) Grasslands Plan to the Reduce Grazing Return Grasslands program). These notional paths do not, however, necessarily mean that the implementation of specific programs aligns with the spirit of the relevant edict at the central level. Policy edicts in general do set the policy agenda and provide the framework for the design of legislation and programs as there is still sufficient influence to ensure conformation with these high-level directives. The main disjuncture arises in how the programs are implemented, with the consistency dependent on whether the local incentives or objectives align with those of the central policymakers.

The portrayal of this policy web and related edicts, legislation, programs and specific activities in Figure 1 reveals several aspects of how scientists should engage in the policy process. To have most impact, research needs to anticipate emerging issues and be undertaken in a timely manner before overarching plans and edicts are decided by high-level decision-makers. Plans and edicts are crucial in setting the policy agenda, in framing legislation and, especially, in influencing local-level programs and the funding of those programs. Key grassland scientists in China have an important role in influencing this agenda and moulding these plans. Once the plans and edicts are in place, it is difficult for policymakers to reverse their positions. In these circumstances, innovative, relevant and useful research ideas should be aimed at contributing to the design of local-level programs rather than the overarching plans, edicts or legislation. In general, researchers will find these local-level programs and projects easier to influence than the higher level regulations and opinions, as they are more flexible, especially in their implementation phase.

Livestock feed balance

A key element of managing the grasslands is to maintain a balance between livestock feed required and livestock feed available. Efforts to achieve this balance feature across the policy web highlighted in Figure 1, including the MOA Grassland Plan, Article 33 of the 2002 Grassland Law, the Grassland – Livestock Balance Management Methods, and the key Reduce Grazing Return Grasslands program. Where there is an imbalance in terms of feed requirements exceeding feed supply, in general this has not been dealt with by reducing livestock numbers but either by intensifying livestock systems (using more non-grassland feed resources) or by increasing grassland feed through pasture and forage improvement. Thus, in most parts of the pastoral region, livestock numbers have continued to increase even after various forms of grazing restrictions have been implemented.

The premise in this paper and these proceedings is that the notion of seeking a balance between livestock feed required and feed available is crucial if ruminant livestock systems are to be sustained in pastoral areas. However, the diverse characteristics of China's pastoral region and ruminant livestock systems means that this balance can only be approximated and used as an indicator to guide policies and management rather than as a specific instrument. Where it is used in a particular role, efforts need to be made to update and refine livestock and feed standards to ensure their relevance.

In essence, there are several aspects to consider when applying the livestock feed balance strategy in practice. In particular, it is impossible to view the balance with any degree of specificity. The grasslands are extremely heterogeneous and, even with a fine classification of grassland types, estimates of productivity for particular grasslands will be only a broad guesstimate of actual productivity for any specific pasture. Similarly, there are many different parameters that affect livestock feed requirements and so the use of generic estimates of livestock feed requirements by broad livestock type will only partly reflect actual feed requirements.

Compounding the inaccuracy associated with the use of general feed and livestock parameters is the stochasticity of the system: the feed available, in particular, can vary dramatically depending on prevailing conditions. Indeed, various studies have argued that grazing strategies in these stochastic systems are largely irrelevant and that opportunistic grazing should be practised based on grazing when forage is available and to maintain herbage above minimum values. However, while this may be the case for some systems, grazing pressure can be expected to affect the resilience of the system.

Setting productivity levels both for different types of grasslands and for different livestock is a massive task in China because of the inherent heterogeneity, and there have been significant lags in updating stocking rates and carrying capacities. Relevant clauses in the 2002 Grassland Law and the Reduce Grazing Return Grasslands program have led to efforts directed at a new grassland census. However, there are serious human resource constraints to undertaking an accurate census within the pressures and time frames existing, let alone any incentives to under- or overestimate these figures. Brown et al. (2008, Table 2.7) use updated livestock numbers and pasture productivity that account for degradation to show how existing estimates grossly overstate the difference between actual stock numbers and theoretical stocking capacity.

The implications that follow from the problems in accurately determining feed–livestock balances are that the accounting of feed requirements and feed available should be viewed as a rough indication only. If the consequences of grassland degradation and excess grazing pressure are anticipated to be higher than the opportunity cost of lost production from conservative stocking rates, a more cautious approach should be adopted when linking household contracts with stock numbers. Where feed–livestock balances are used in a specific role, the feed and livestock standards need to be refined and updated more frequently than has occurred in the past (roughly every 20 years) as technologies and circumstances change, in this case accentuated by pasture degradation over those periods. The resource constraints preclude a rigorous or widespread updating but more modest, cost-effective, although not entirely accurate, updates may be better than relying on the status quo or current estimates.

A more important implication from a policy perspective lies in how the balance is being addressed. As mentioned, for the most part this has involved imposing various forms of temporary grazing bans or restrictions and by trying to intensify ruminant livestock systems. Although these may provide short-term relief for the grasslands, how sustainable these measures are is more debatable. Ultimately, to be sustainable the intensive livestock systems need to be profitable for individual households, otherwise there will be pressure on them to reduce feed costs by increasing grazing. Previously degraded pastures rehabilitated under the grazing restrictions cannot return to their former stocking rates in the near future. Thus, ruminant livestock numbers will have had to decline or the intensive systems become sufficiently profitable to ensure a switch to them, thereby enabling reduced grazing pressure.

Similarly, the moves from extensive toward more intensive production of ruminant livestock in the pastoral region involve technical innovations to increase livestock productivity (through genetic and veterinary systems improvement) and increased feed supplies (from crops, forages and crop residues). These measures can be counterproductive to sustainable grassland use if they allow households to carry more livestock over winter and into grazing periods. Artificially high numbers of livestock in spring and summer exert grazing pressures that cannot be met solely through grassland improvement technologies such as fencing and pasture sowing.

Technology can play a big role in adapting to changing feed–livestock balances and improving the competitiveness and sustainability of livestock systems. Indeed, practice changes and innovations in grazing, feed and livestock systems identified in this ACIAR project can be effective both in reducing grazing pressure and in raising incomes. It is important to appreciate, however, that technology is only part of the solution and not, as is seen in some quarters, the panacea. Conditions and circumstances make it infeasible to maintain these technologies in all but some regions. In some semi-pastoral areas it may be technically feasible and economic—and therefore sustainable—to raise ruminant livestock intensively, provided the livestock products are of relatively high value. However, in genuinely pastoral areas, intensively raising ruminant livestock for long periods is unlikely to ever be sustainable. In these areas there is no overarching technical solution and the real question is how to implement policies to reduce the number of people and livestock on the grasslands to a sustainable level in a socially and politically acceptable manner.

Although technology alone cannot provide the solution to grassland degradation in China, it can form an important part of the solution. Technical improvements, provided they are economically viable, do offer scope to overcome selective feed deficits and increase livestock productivity. However, to be effective and efficient, the technical innovations must be complemented with the necessary management practices, such as selective culling, higher turn-off rates and pasture spelling. Indeed, there is a close synergy between the technical innovations and management practices: the innovations enable efficient management practices to be employed, while without the management practices the innovations may simply waste resources or be counterproductive.

There are various dimensions to sustaining the technical innovations. The innovations must fall within the household's frame of reference. Herders live in an environment where they constantly need to adapt and innovate in order to survive, let alone prosper. However, some of the more grandiose innovations may require herders to take on substantial new risks, to be able to finance the innovations, and to radically change their household systems. For these households, only significant coercion will force them to take up the innovations and then only while the source of coercion applies. Technologies that sit within frames of reference of households, and innovations that are more in line with household resources, capabilities and decision-making processes are likely to be much more effective. Too many livestock systems or technological improvements rely on a level of precision and skills that many pastoral households simply do not have or that are not underpinned by systematic extension or training support in these remote, geographically dispersed and fiscally challenged pastoral areas. Furthermore, many livestock genetic improvement and intensive feeding systems are developed in trial or demonstration environments that do not align with the constrained feed regimes of pastoral households. Consequently, actual productivity and returns fall well short of the potential productivity and returns achieved under the unconstrained and feed-rich situations on which many of the technologies are premised. Selecting and tailoring technologies to a realistic assessment of household resources, skills and knowledge is crucial not only to the livelihoods of herders using the technologies but also to promoting their use through time. Technical programs and funding must be an integrated package that includes extension programs if they are to be effective.

Furthermore, and especially with the additional risks, effort and inconvenience, it must be possible to clearly demonstrate a substantial economic return to households if they are to take them up permanently. Currently, there is virtually no capacity at household level and little capacity at below-county state level to determine these economic returns. This is despite the high opportunity costs of inappropriate decisions at the household and regional level. There is a lack of economic analysis in the assessment of various technologies and livestock systems. Economic analyses would enable better targeting of extension programs, more rigorous analysis of investment options, more efficient support measures by local governments and a clearer understanding of the incentives needed by local agents to adopt particular livestock, pasture or fencing practices. Thus, the economic analyses would facilitate households making more informed choices on the uptake of new practices, and provide officials with an idea of what levels of support or compensation may be needed to effect particular changes. Economic analyses that would be useful in this regard include cost–benefit analysis of various grassland investments, comparative profit analysis of alternative livestock and feed systems, and household modelling, budgeting and livelihood analysis to examine the impact of various measures and systems on individual households or groups of households.

The case for widespread rigorous economic analysis at all levels is unrealistic given the constrained funds and human resources in these pastoral areas and the lack of financial capacity of households to pay for such advice from a non-state provider. Yet there is a case for building economic analytic skills and capacity among existing extension officers and policymakers. There exists considerable statistical and household information on which to conduct the analysis, and even the capacity to understand opportunity costs and the benefits and costs of innovations may improve decision-making at household and policy level.

Technology has been used to aid various aspects of the 'macro' management of the grasslands. In particular, remote-sensing technologies have in recent years begun to be used to monitor the grasslands, with moves to integrate this information with crop and pasture modelling. However, a large gap exists between grassland scientists and officials in the use and interpretation of this information, while substantial divergences occur in how the research and advice are used by officials at different administrative levels. The full potential of more sophisticated grassland monitoring and management systems will not be realised unless county-level policy and extension officials are involved, and the technologies and systems can be directly applied by these local managers and officials.

Livestock–people balance

As mentioned, technology is unlikely to resolve the livestock–feed imbalance on its own as there are simply too many ruminant livestock on the grasslands. Reducing livestock numbers in pastoral areas involves either fewer pastoral households or diversifying the source of incomes for these households so they are less reliant on livestock.

The uppermost echelons of Chinese policymakers are well aware of the need for this broader structural adjustment in the pastoral region, and it features prominently in programs such as 'Develop the West' aimed at building infrastructure, education facilities, communication and a more vibrant industry base. Much of the interest has been prompted by the radical transformation that has occurred elsewhere in the rural sector and especially in the more intensive agricultural areas of eastern China.

A more active intervention in managing people has occurred through settlement or resettlement programs. Such programs have sought to provide a cost-effective way of delivering different services such as education and health to the remote and dispersed pastoral peoples. An element of the program has been to resettle people away from severely degraded grassland areas.

The premise in this paper is that awareness of the need to 'manage' people in dealing with the issue of grassland degradation is commendable. However, the generic measures used to facilitate structural adjustment may overlook the poorer and/or disadvantaged households and that more effective measures and targeted programs may be needed to aid this group of households to take advantages of the opportunities afforded by economic growth and transition. In other words, the generic policies used effectively to facilitate structural adjustment in rural areas of eastern China may not necessarily achieve their goals in some parts of the pastoral region, especially among the poorer households that do not have the skills needed to access the opportunities that may arise as part of the process of structural adjustment, and that have less access to settlement and other programs. If the ultimate goal is to aid the poorest and most disadvantaged households, far more specific measures tailored to the needs and characteristics of these households are required.

In essence, in addition to the high-level policy challenges of sustaining broad-based economic growth, there are more specific policy challenges in helping pastoral households participate and benefit from growth. In particular, many pastoral household members do not have the basic literacy, numeracy or Chinese language skills to work even in prefecture-level cities. Improving these skills is a stated policy objective for government at all levels but delivering the education and training needed is more difficult. In an era of fiscal decentralisation, cash-strapped local governments in many pastoral areas do not have funding to sufficiently invest in schools that are accessible to the scattered pastoral population. There are examples of small schools that do not meet national teaching standards and attendance records being closed down or cut off from higher level funding. Access to education will increase over time through resettlement schemes and as relatives move to urban areas and are able to look after second-generation relatives while they go to school. However, this is most likely to apply to the relatively wealthy, entrepreneurial, well-connected pastoral households or cadre families.

A major aspect of the transition is to provide educational opportunities to pastoral households disadvantaged by income, location or ethnicity. Education is required to help the first generation of children access off-farm work. Improving the capacity of households staying in pastoral areas to adopt practices to improve their livelihoods on-farm is also an important part of the overall structural adjustment process. Higher skill levels will be required of the next generation of pastoral residents if they are to achieve a balance between multiple income, environmental and social objectives. Given the inherent difficulties that will continue to face pastoral households, local government officials will still need to play a proactive role in guiding household activities on-farm.

A similar situation applies to settlement programs. Most schemes involve the larger, richer households, as often there is a significant financial co-contribution required or because they have the skills or connections to move. Small households, perhaps more in need of resettlement and access to basic services, are often the least able to do so. Another issue with settlement programs in dealing with the grassland degradation problem is that, while they involve settlement or resettlement of herders, this does not include their grazing practices or livestock: that is, the settled households often still use migratory stock routes or summer pastures, and the schemes are settlement schemes rather than migration schemes. The settlement schemes with suitable water have areas of forage production and so facilitate some intensification of livestock systems especially over winter. However, as mentioned above, the extent to which they will reduce grazing pressures in general depends on the extent to which the intensive winter pen-feeding systems may overcome some of the natural checks and balances on livestock numbers. The paucity of land to resettle people in some parts of the pastoral region means that they are often resettled in reclaimed desert areas where some access to water can be found. Salinity and other ecological problems have arisen in some cases and pose questions about the long-term viability of these schemes.

Livestock value–grazing pressure balance

One aspect of the general goal of retaining livestock's contribution to rural development for pastoral households under conditions of limited pasture resources is to increase the unit value of livestock. A premise in this paper is that opportunities do exist to increase unit value but that they warrant close scrutiny as some market segments and livestock systems are more suited to some households than others. Furthermore, more liberal markets have not necessarily led to accurate and fair prices for pastoral households and various measures are needed to improve the price discovery process.

Livestock numbers may be a crude indicator on which to base optimal grazing strategies, and so it may be more relevant in deciding what activities to pursue to consider livestock value per unit grazing pressure. There are a number of ways to increase this indicator: that is, some livestock may attract higher returns, lower costs, or higher net returns relative to other livestock types and relative to their use of grassland feed resources. This involves different types of livestock (beef cattle versus dairy cattle versus cashmere goats versus meat goats versus wool sheep versus meat sheep) as well as different breeds of the same livestock (improved versus local cattle). In general, breeding and improvement programs and decisions have not been well aligned with production and market conditions and development goals. Similarly, herd structure, culling strategies and livestock systems have considerable scope for improvement but have often received less attention.

The other main area of attention on livestock value focuses on marketing. Low product prices are widely blamed for the problems besetting the pastoral region. The argument claims that herders do not receive fair remuneration for their products and that the flow-on adverse effects on their incomes create pressures to expand production and over-utilise grasslands. Claims of this type warrant close investigation both to avoid the potential for perverse policy responses and to prevent attention being diverted to areas where the benefits may be modest. Nonetheless it is clear that markets for livestock products in the pastoral region do not operate perfectly. Information asymmetries, e.g. poor transparency in prices, a lack of core marketing services and infrastructure, and high transaction costs, all create the potential for market failure and the need for some form of remedial intervention. Furthermore, as discussed below, other government policies impact on the markets for ruminant livestock products from the pastoral areas. Thus, an investigation of the instruments used to influence markets in pastoral areas is warranted, along with an assessment of what changes to that intervention may be needed.

Market issues arise at a macro or price determination level and at a micro or price discovery level (Brown et al. 2008: Han Guodong et al. 2011). Crucial at the macro or price determination level are supply-driven industry policies where particular industries are actively encouraged and support is given to build the production base and capacity within the region. This is especially prevalent but not confined to the pastoral region where waves of fashionable or 'pillar' industries from fine wool to beef cattle to meat sheep to dairy cattle have occurred. Although there is a level of market integration in ruminant livestock products between agricultural and pastoral areas, and while much of China's ruminant livestock products are produced outside of the pastoral region, these industry pushes have adversely affected local prices. This has been evident especially in areas such as Xinjiang and in industries such as sheepmeat and dairy. Thus, policymakers need to be aware of the potential impact on local markets and prices of strong industry pushes. While the industry policy instruments employed focus almost exclusively on building production capacity, such efforts must be accompanied by and, indeed, premised on identification of market segments and channels.

To some extent the government has presumed that opening of markets will have created various opportunities not available in the regulated, sole procurement channels that existed previously, and that herders would receive more accurate and remunerative prices. But the opening of markets and the transition from centrally planned, sole procurement channels has not been accompanied by market support or infrastructure. Markets for many products in pastoral areas are chaotic, fragmented and small scale.

An understanding of these broad forces of supply and demand, and of the extent of market integration, reveals something about the general level of prices. Conceptually these forces interact to generate a market clearing price and quantity. In practice, however, it is not a single equilibrium but a grouping of points in price–quantity space that characterises the market in question. The interaction between buyers and sellers (and market intermediaries) determines the specific price and quantity of any particular exchange. This process of price formation or price discovery is crucial in the debate about the reasonableness of the returns to pastoral households. It is often argued that, while a general level of prices for a particular product may be sufficient to generate reasonable returns, the absence of various marketing channels or market services and the practices of various market intermediaries mean that some pastoral households do not receive fair value for their outputs, given the general level of prices in the market. Oft-cited in the debate about how to improve the incomes of pastoral households is the suggestion that they engage in producing for the higher value segments of the market. Producing for the higher value segments usually involves raising improved breeds and adopting new and specific management practices, and the viability and suitability of these new systems and practices to the pastoral households are crucial issues. However, the strategy also requires that the pastoral households have access to a price discovery process that rewards higher value or quality products with higher premiums. The higher value segments normally have differing market channels to that for the sale of traditional generic products and so understanding the process of price formation in these different channels is vital.

There are various measures that could be implemented to improve price formation and facilitate the transmission of fair and accurate prices to pastoral households. These are canvassed in detail in Brown et al. (2008, Section 7.2). Some of these, such as the practices of agroindustrial enterprises and groups, concern industry structures. They are discussed by Waldron et al. (2011) in these proceedings. The following are some key aspects:

- Inspection roles need to be extended to oversee not only health inspection but also independently monitor product specifications that form the basis of product payment. Quality discounts for product attributes can often discount 'premium' product prices to below mass-market generic product prices, with households unable to verify measurements or with no feedback on how to achieve the attributes.
- As a check on rogue practices, traders and dealers and other market intermediaries should be registered. In general, most problems with inappropriate trading behaviour arise from itinerant or irregular or non-local traders who do not have the same peer pressure to operate in an ethical manner. This presents a problem for many remote pastoral areas that are seeking to attract traders so as to create a vibrant and competitive trading sector to service local producers. Traders

generally resist registration because of the extra costs and constraints it may impose on their operations, although registration can bring them legal benefits. Enforcing registration is extremely problematic, and widespread registration therefore may require a set of incentives to encourage traders to seek it. These might include low-cost and convenient registration as well as an expansion and promotion of the benefits of registration. Furthermore, if the registration system were national, or at least regional, and could guarantee traceback to registered dealers, then this might provide a competitive edge to registered over non-registered traders in attracting sellers.

- Another check on the activities of traders may be in producer groups establishing alternative selling channels. For premium markets, or where product attributes are important, many traders will seek to purchase on a mixed average grade basis and generate profits through sorting the product and on-selling differentiated grades. If groups seeking to produce differentiated premium products cannot entice traders to buy on a more differentiated basis, the groups may need to consider establishing their own market channels. This is not to suggest that producer-oriented groups should move into full-scale trading activities or that this would be suited to all groups, as it would require, among other things, sufficient awareness of market segments, finance capabilities and other market infrastructure. Instead, in some circumstances the presence of an alternative marketing channel may influence the buying behaviour of traders to offer exchanges on other than a mixed average grade basis. The policy dimensions are that the groups may need support in various areas (marketing skills, market infrastructure and initial working capital) to facilitate such moves.
- Another factor bearing on improved selling decisions and price discovery is better market information. This can take on numerous forms depending on the product and industry participants, and can involve other dimensions such as standards and classification systems. Indeed, some information systems and grading systems will be inappropriate as their costs will be greater than the potential benefits. Nonetheless, given the general paucity and asymmetry of information, some form of market information through relatively low-cost communication means and suitably crafted classifications is appropriate.

If prices or unit values for their outputs increase, the household may be under less pressure to overstock. However, higher prices can be a signal to increase livestock numbers, depending on the capacity of the households to increase their numbers and on the relative prices and returns of other household activities. Thus, from the perspective of reducing grazing pressures, higher prices and unit values need to be accompanied by other measures and incentives that encourage the herders to limit livestock numbers.

Concluding remarks

The multidimensional nature of resolving the twin objectives of reversing grassland degradation and promoting the sustainable development of China's pastoral region poses major challenges for Chinese policymakers, not only in formulating and evaluating specific grassland policies, but also in being aware of how policies in other areas can affect grasslands and herders. Within this complex policy environment, dealing with unintended or unforeseen adverse impacts and ensuring consistency among the various policies is an ongoing and demanding task. Broad policy directions within China, such as market reforms, the facilitation of economic growth and structural adjustment, and industry modernisation are all apparent within the pastoral region and impinge on grassland utilisation. But their manifestation in pastoral areas can differ from experience in other sectors and other parts of Chinese society, and proactive efforts to tailor these measures to the characteristics and needs of pastoral areas are needed if their full potential is to be realised.

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A major national food-processing and restaurant chain based in the Inner Mongolia Autonomous Region advertises its hot-pot product based on 180-day-old lamb. The company coordinated with local government agencies to educate households on the advantages of changing traditional production regimes to produce and sell fat lambs out-of-season. This program is now developing in Siziwang Banner. [Photo: S. Waldron and C. Brown]

Reducing methane production from livestock: can more efficient livestock systems help?

Dong Hongmin, Li Yue, David Kemp, David Michalk, Na Renhua, Taro Takahashi and You Yubo

Abstract

Ruminants are an important source of greenhouse gas (GHG) emissions. In China, methane (CH_4) emissions released from ruminant enteric fermentation have reached 11 Mt, 59% of the total CH_4 emissions from agricultural sources and 35% of the total GHG emissions from the same sources. CH_4 emissions from individual ruminants can be reduced by improving the rumen environment, changing the feed mix and refining coarse feeds. Optimised animal-breeding techniques and improved animal management can also reduce per-animal CH_4 emissions. In this paper, experiments and associated economic assessments of mitigation techniques are considered.

Introduction

Livestock production activities provide proteins and energy to improve the diet of humans, but they also generate a large quantity of greenhouse gases (GHGs). GHGs released from ruminant livestock production are mainly in the form of methane (CH_4) derived as a by-product of digestion (Moss et al. 2000). CH_4 and nitrous oxide (N_2O) are also released from animal manure (Eckard et al. 2010). The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007) estimated that CH_4 released globally from enteric fermentation accounted for 32% of the total non–carbon dioxide (CO_2) emissions from agriculture in 2005, or 38% of the total GHGs emitted from all agricultural activities (US-EPA 2006). GHGs released from animal manure account for another 7% of the total non-CO_2 emissions from agriculture (IPCC 2007). This ranks CH_4 from the world's livestock production sector second in importance to N_2O emissions from soil as a source of GHG emissions in the agricultural sector.

Ruminants dominate CH_4 production, and the world's population of cattle, buffalo, sheep and goats produce 76–92 million t of CH_4/year (Denman et al. 2007), accounting for about 28% of the global anthropomorphic emissions (Beauchemin et al. 2008). With an energy content of 55 MJ/kg (Brouwer 1965), CH_4, which is formed in the forestomachs of ruminants during fermentation of ingested feed, can represent an energy loss of 5–15% of an animal's gross energy intake, depending upon feed quality and ruminant species (Czerkawski 1969). Sheep and cattle typically lose 6–7% of their ingested energy as eructated CH_4 (Johnson and Johnson 1995; Pelchen and Peters 1998) but animals with low levels of production efficiency have much higher CH_4 emissions per unit of energy intake (Leng 1993). For grazing livestock digesting typically 60–80% of their forage diet, enteric CH_4 represents a diversion of at least 8% of digested energy (Lassey 2008), while 6–10% of the total gross energy consumed by dairy cattle is converted to CH_4 and released via eructation (Eckard et al. 2010). Lassey (2008) calculated that if this energy lost through enteric CH_4 production could be redirected into animal productivity, the avoided GHG emissions would be equivalent to reducing

Pp. 115–127 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.

annual CO_2 emissions by 1.7 Gt. This is equivalent to 6% of current CO_2 emissions from combusted fossil fuels. Reducing enteric CH_4 production would significantly improve on-farm profitability as well as benefiting the environment (Eckard et al. 2010).

Annual increases in CH_4 emissions correlate directly with increasing populations of domestic animals. It is predicted that, if no effective emission mitigation measures are taken, enteric CH_4 emissions could increase by as much as 60% by 2030. This reflects the growing global consumption of livestock products, which is fuelled by a combination of population growth and an increase in per-capita consumption of these products. Predictions are that demand for meat and milk will double by 2050 (FAO 2006) as living standards improve in developing economies. With livestock-related emissions already significant and predicted upward global trends in production, can GHG emissions from livestock be reduced by adopting new ways of feeding, breeding or managing animals?

GHG emission mitigation in China has become an increasing concern for policymakers and researchers (Zhang 2010; Zhang and Chen 2010). China now ranks close to the USA as the world's largest emitter of CO_2-equivalent (IEA 2009; Schmidt and Marschinski 2010) although on a per capita basis it is much lower. Scientists in China and other countries studying CH_4 emissions from a range of livestock production systems have identified some management options with potential to reduce CH_4 emissions (e.g. Peng 2002; Boadi et al. 2004; Fan 2004; Lovett et al. 2006; Monteny et al. 2006; Dong et al. 2008). Broadly speaking, four main approaches to reducing CH_4 emissions in livestock production have emerged: (1) improving livestock productivity; (2) changing the management system; (3) managing the outputs more efficiently; and (4) reducing livestock numbers (Garnett 2009).

In this paper some of the CH_4 mitigation options that are applicable in China are reviewed. They include increasing production per animal, modifying diet and decreasing methanogen activity. Practical farm-based management practices that reduce livestock numbers are the focus of detailed analyses in other chapters in these proceedings. Only the implications of those practices for CH_4 reduction are discussed here.

GHG emissions from animal-raising activities in China

Livestock production has flourished in China since 1980 due to a threefold increase in meat consumption as a result of the improving economy and the continuous change in dietary preferences, particularly in urban areas in eastern China (Chen et al. 2006). China's current annual per-capita consumption of meat, egg and dairy products respectively has reached 32, 18 and 32 kg. This means livestock production now constitutes a mainstay industry in China's rural economy, and is an important source for increasing farmers' incomes (Li et al. 2008). Since 1992, increasing demand for beef, mutton and milk has caused the rapid growth of cattle, sheep and goat populations. While the demands for food of animal origin, especially among China's urban population, may have been largely satisfied, it has come at significant costs in terms of grassland degradation and CH_4 emissions. The supply of animal products has been achieved primarily through increasing stocking rates well beyond the sustainable carrying capacity (Chen et al. 2003).

Agricultural CH_4 emissions have been investigated in China including those from rice cultivation, livestock production, manure management and biomass burning (Zhang and Chen 2010). According to the National Climate Change Programme (National Development and Reform Commission 2007), China's net GHG emissions reached 5,600 Mt CO_2 equivalent (CO_2-e) in 2004, with some 10% generated from agriculture and 7% from livestock production. Based on 2003 livestock statistics, Zhou et al. (2007) estimated CH_4 emissions from enteric fermentation from all livestock to be 8,366 Gg (15.9 Mt CO_2-e), with an additional 1,013 Gg (1.9 Mt CO_2-e) from manure management, equivalent to about 32% of the total CH_4 output from China's agricultural sector, making the livestock sector a major source of GHGs emission. Ruminants are the largest source of enteric CH_4, accounting for 90% (Johnson and Ward 1996; Zhou et al. 2007) of the total. In China, non-dairy cattle contribute 51% of CH_4 emissions from enteric fermentation, followed in decreasing importance by buffalo, dairy cattle, sheep and goats (Zhang and Chen 2010). Emissions from dairy cattle are expected to increase significantly from the current level of 1.5 Mt CO_2-e, as the industry is expanding more rapidly than other livestock sectors (Fuller et al. 2006). The problem is further compounded as the potential annual production of forages declines due to changes in plant species and loss of soil fertility as a result of grassland degradation. There is a consequent spiralling decline in sustainability of the system, including the depletion of soil organic matter and a rising contribution of CO_2 to the atmosphere.

With continued human population growth and increasing numbers of livestock and poultry in China, ascending trends for GHG emissions, and for CH_4 emissions in particular, are expected to continue for some time, even if emission reduction measures are implemented. According to the US Environmental Protection Agency (US-EPA 2006) predictions, China's GHG emission footprint for the livestock sector in 2006 was more than double that compared with 1994 data. Since livestock activities will remain an important CH_4 emission source in China, carbon-reduction strategies such as diet manipulation, enterprise selection and breed improvement to reduce emissions from enteric fermentation deserve more attention (Zeng et al. 2009). A number of CH_4 abatement options have already been identified by targeted research that can be immediately implemented in China's livestock production systems (Eckard et al. 2010). Some of these are discussed in the following sections. They hold promise of not only CH_4 mitigation but also economic benefit to farmers through improved feed efficiency.

Reducing CH_4 emissions from enteric fermentation

Ruminants release CH_4 as a by-product of enteric fermentation, a process by which ingested feed is digested by microbial metabolism in the rumen (McAllister and Newbold 2008). CH_4 is a colourless, odourless gas produced predominantly in the rumen. Eructation is the main route of its emission from ruminants (Boadi et al. 2004). The conversion of feed material to CH_4 in the rumen involves the integrated activities of different microbial species, with the final step carried out by methanogenic bacteria (McAllister et al. 1996; Moss et al. 2000). These microbes use H_2 produced by other rumen organisms in primary fermentation processes. They prevent it accumulating, which would inhibit hydrogenase and limit oxidation activities when there are no alternative pathways for H_2 disposal (McAllister and Newbold 2008). This means that microbes that use H_2 for growth are essential to keeping the partial pressure of H_2 in the rumen low, so that digestion can proceed normally and produce acetate and propionate. It follows then that managing H_2 production in the rumen is an important factor to consider when developing strategies to control ruminant CH_4 emissions (Boadi et al. 2004). McAllister and Newbold (2008) have identified three strategies to reduce methanogenesis in the rumen: (1) direct inhibition of methanogensis with the need to redirect H_2 into alternative products; (2) reduction of H_2 production in the rumen; and (3) provision of alternative sinks for H_2 disposal in the rumen.

The major management factors that can be used to manipulate H_2 production and CH_4 emissions from enteric fermentation include: animal type/weight and feed type/quality and intake level. In practice, nutrition, management, reproduction or genetics are key areas where animal productivity can be improved significantly. As productivity increases, CH_4 production per unit of meat, milk or fibre is reduced (Boadi et al. 2004) due to an increase in the ratio of livestock 'production' to 'maintenance' (Monteny et al. 2006). Blaxter (1967) calculated that when intake is increased from maintenance to twice maintenance, the total production of CH_4 increases but the amount of energy lost as CH_4 per unit of feed consumed falls by 30%. The prospect of capturing extra energy from digestion of forage and converting it into saleable product provides farmers with an incentive to adopt CH_4 reduction strategies (Joblin 1999).

Reducing CH_4 by dietary manipulation

Several comprehensive reviews of the nutritional effects of enteric CH_4 production (Johnston and Johnson 1995; Boadi et al. 2004; Beauchemin et al. 2008; McAllister and Newbold 2008) clearly show that changes in diet composition and feeding strategy strongly affect rumen function and performance of ruminants, and their total GHG production. The nature and rate of fermentation of carbohydrates determine the proportion of individual volatile fatty acids (VFA) formed and, in turn, the amount of CH_4 produced (Boadi et al. 2004).

According to Monteny et al. (2006), the most effective measures to reduce CH_4 through dietary manipulation include: (1) increasing the level of starch or rapidly fermentable carbohydrates to enhance propionate production and reduce excess H_2 and subsequent CH_4 formation; (2) changing feed composition, processing and/or intake to allow for higher animal productivity; (3) reducing H_2 production by addition of (unsaturated) fat or stimulation of acetogenic bacteria; and (4) reducing methanogens or removing protozoans through additives or probiotics. Monteny et al. (2006) concluded that only (1) and (2) have immediate application to livestock production whereas options (3) and (4) are still under study or may encounter resistance from consumers.

Feed quality

Improving forage quality through feeding forage with lower fibre and higher soluble carbohydrates, changing from C4 to C3 grasses, or grazing less-mature forage can significantly reduce CH4 production (Beauchemin et al. 2008). Improving forage quality also tends to increase the voluntary intake and reduces the retention time in the rumen, thereby promoting energetically more efficient post-ruminal digestion and reducing the proportion of dietary energy converted to CH_4 (Blaxter and Clapperton 1965). Lower emissions from animals fed legumes are explained by the presence of condensed tannins (CT), lower fibre content, higher dry matter intake (DMI) and more rapid passage from the rumen (Beauchemin et al. 2008). Improving dietary quality can both improve animal performance and reduce CH_4 production. It can also improve efficiency by reducing CH_4 emissions per unit of animal product. In contrast, CH_4 production in ruminants tends to increase with the age of the forage fed.

The composition of both structural (i.e. fibre) and soluble carbohydrates is important in developing low CH_4 emission rations. For example, CH_4 production per unit of cellulose digested is reportedly three times that of hemicellulose (Moe and Tyrrell 1979). The proportions of cellulose, hemicellulose and lignin in cell walls change as plants mature, leading to declines in both digestibility and CH_4 emission per unit fed. Since structural carbohydrates produce more CH_4 per unit of substrate digested than non-structural carbohydrates, adding grain to a forage diet increases starch intake and reduces fibre intake which, in turn, reduces rumen pH and favours the production of propionate rather than acetate in the rumen (McAllister and Newbold 2008).

When grain accounts for more than 90% of the total energy intake (typical of the feeds used in cattle feedlots) CH_4 is reduced to 2–3% (Johnson and Johnson 1995). However, when the feed ration is made up entirely of fibre, then more than 10% of the total energy intake is released as CH_4. Grain type also produces significant variation in CH_4 emissions. For example, barley-based feed rations may produce a CH_4 emission accounting for 6.5–12% of the total energy intake, whereas for maize-based rations it is 5% or less (Yang Zaibin 2006). In another Chinese study, Yan et al. (2000) reported that the addition of 5.5 kg of sweetpotato to a feed ration fed to dairy cattle with a daily milk output of 15 kg reduced CH_4 emissions by 44% compared with a hay-only feed ration. Fan et al. (2006) examined the effects of feed type on daily CH_4 emissions from rumen fermentation of bullocks. They used a sulfur hexafluoride (SF_6) tracer method described by Johnson et al. (1994). Their results showed that different types of coarse feeds produced CH_4 emissions in the following order: maize stalks > rice straw > lucerne. The same study calculated the impacts of coarse feeds type, concentrate/roughage ratio and energy intake level on CH_4 emissions from beef cattle as follows: coarse feeds type > concentrate/roughage ratio > energy intake level. The results of these Chinese studies are summarised in Table 1.

Concentrate/roughage ratio

It is a well-established nutrition principle that increasing the level of concentrate in the diet reduces the dietary energy converted to CH_4

Table 1. Effect of feed type on daily cattle methane (CH_4) emissions

Animal	Feed type	CH_4 emission (L/head/day)	Data source
Beef	Dry maize stalks Straw Lucerne	238 232 229	Fan (2004)
Dairy cow	Hay Hay + sweetpotato	260 146	Yan et al. (2000)

(Blaxter and Clapperton 1965). This occurs because feed rations rich in starch favour propionate production thereby reducing CH_4 production per unit of fermentable organic matter in the rumen. Conversely, a roughage-based diet will favour acetate production and increase CH_4 production per unit of fermentable organic matter in ruminants (Johnson and Johnson 1995). The reduction in CH_4 output by shifting H_2 flow towards alternative electron acceptors such as propionate significantly enhances the utilisation of feeds and animal performance.

In China, Han and Feng (1997) investigated the differences in CH_4 and propionic acid output from the gastrointestinal tracts of bullocks fed rations with concentrate:roughage ratios of 0:100, 25:75, 50:50, and 75:25. Their results indicated significant differences in CH_4 output from the rumen, with respective per animal emissions of 64, 44, 29 and 19 L CH_4. As reported by others (Johnson and Johnson 1995), the addition of concentrates was desirable for the fermentation of propionic acid which, in turn, reduced the CH_4 output. Propionic acid output in the research of Han and Feng (1997) was strongly negatively correlated with CH_4 emissions. In a similar experiment using rice straw as the coarse feed, Fan et al. (2006) detected a highly significant difference ($P < 0.001$) in CH_4 emissions from beef cattle fed rations containing a straw content of 25%, 60% or 100%. Wang et al. (2007) confirmed an increase in propionic acid output in lactating cows fed rations with different concentrate:roughage ratios (30:70 for silage mix, 50:50 for equal proportions of coarse mix concentrates and 65:35 for a high-concentrates mix). These feed mixes produced respective daily milk outputs of 15.2, 17.1 and 18.5 kg. This clearly demonstrates that feeding a high proportion of concentrate effectively diverts the rumen H_2 from CH_4 and significantly increases ($P < 0.01$) propionic acid and milk production, irrespective of the type of roughage used. Table 2 summarises some of these results of reducing animal CH_4 emissions by varying the concentrate:roughage ratio in the feed supplied to various classes of cattle.

In practice, the use of concentrates to lower CH_4 emissions from dairy production has its physiological and economic limits. Milk quality, for example, is negatively affected once concentrates in feed rations exceed around 50% of the feed ration, while implementing high-concentrate feeding programs is profitable only with high productivity (8,000 kg milk/305 day lactation) dairy cows (Beauchemin et al. 2008). The increased use of grain to improve feed efficiencies and reduce CH_4 output per unit of product will entail the increased use of fossil fuel for nitrogen fertiliser and machinery, contributing negatively to the overall GHG budget through additional emissions of N_2O and fossil carbon (Boadi et al. 2004). This implies that there will be some circumstances for which increased concentrate feeding will both reduce GHG emissions and increase farm profitability, and others that achieve neither emission reduction nor increased profits. Since other situations may not produce either a CH_4 reduction or production efficiency gain, careful assessments of individual systems are needed to

Table 2. Effect of different concentrate:roughage ratios on methane (CH_4) emissions from, and the output of rumen propionic acid in, the gastrointestinal tracts of various animal types

Animal type	Feed type	Concentrate: roughage ratio	CH_4 (L/day)	Propionic acid (mol/day)	Data source
Bullock	Chinese wild rye	0:100	208	3.3	Han and Feng (1997)
		25:75	201	4.6	
		50:50	194	6.6	
		75:25	171	8.8	
Lactating cow	Silage corn	30:70		23.8	Wang et al. (2007)
		50:50		26.4	
		65:35		27.3	
Beef	Rice straw	75:25	174		Fan (2004)
		40:60	190		
		0:100	239		

confirm that increasing the proportion of dietary concentrate will result in a net reduction in GHGs (Beauchemin et al. 2008).

Feed processing and preservation

Numerous studies have shown the importance of an optimal forage to concentrate ratio. Roughage is an indispensable daily feed component needed to maintain rumen function in ruminants. When high levels of concentrates are fed, various metabolic and health problems occur. They include loss of appetite, acidosis, tissue damage, decreased performance and, in some instances, death (Miller and O'Dell 1969). Some of the metabolic changes affect milk fat composition and efficiency of energy utilisation (Beauchemin et al. 2008). Since the high fibre content of roughage is the prime contributor to the large CH_4 emissions from ruminants, it is important to use all available management tools to minimise those emissions. It is known that stage of plant maturity, method of preparation, chemical treatment and physical processing all affect CH_4 output per unit of forage digested. This means that common management practices such as ensilaging forage, treating forage with ammonia and chopping may be effective in improving both the palatability and digestibility of coarse feed, significantly reducing CH_4 emissions.

Chopping, grinding or pelleting forage to improve utilisation by ruminants potentially decreases CH_4 emissions by 40% when fed at high intake rates (Johnson et al. 1996). In a study of New Zealand grazing systems, Lassey et al. (1997) showed that CH_4 emissions increased with the maturity of the grass grazed. They showed that the effects of feed processing were significant, with roughly cut grass producing more CH_4 than finely cut grass. In China, You (2007) showed the effects of feed processing using silage and ammonia-treated and air-dried maize stover with reductions ($P < 0.05$) in CH_4 emissions of up to 10% when beef cattle were fed silage compared with air-dried hay (Table 3). Processing methods affect production, with respective daily weight gains of 0.97, 0.90 and 0.71 kg measured for beef cattle fed with a 50:50 concentrate:roughage ration using ammoniated, ensilaged and air-dried maize stalks. Fan (2004) confirmed that beef cattle fed with ensilaged maize stalks had a significantly lower ($P < 0.05$) CH_4 emission than those fed air-dried maize stalks (Table 3).

These differences between CH_4 outputs from animals fed air-dried and ensilaged forage reflect changes in fermentation patterns in the rumen that shift the proportion of acetic to propionic acid produced and consequent change in CH_4 production (Yan et al. 2000). Li et al. (2007) confirmed this shift in an experiment with young dairy cows fed with sun-dried maize stover and maize silage feeds. Their results showed a rumen propionic acid concentration of 17.3 mmol/L for sun-dried maize stover and 18.6 mmol/L for cows fed with silage, indicating that silage feeds led to lower CH_4 emissions than did stalk feeds. From these studies, it can be concluded that properties of the forage that reduce the rate of digestion or prolong the residency of feed particles within the rumen generally increase the amount of CH_4 produced per unit of forage digested.

Reducing CH_4 emissions by adding fatty acids to daily feeds

Fats are added to feed rations of dairy cattle to increase energy intake, thereby enhancing milk yield and modifying the fatty acid composition of milk fat (Ashes et al. 1997). Several studies (Machmüller and Kreuzer 1999; Jordan et al. 2006a, b, c) clearly show that supplementation of diets with lipids that are not protected from ruminal digestion reduces enteric CH_4 emissions (Beauchemin et al. 2008), with medium chain fatty acids (C_8–C_{16}) causing the greatest reduction in CH_4 production (Dohme et al. 2000). Research results indicate that reductions in CH_4 production of more than 40% are possible with high levels of lipid supplementation (Machmüller

Table 3. Effect of processed maize stalks in animal feed on methane (CH_4) emissions

Animal type	Treatment	CH_4 emission (L/day)	Data source
Beef	Ammoniated maize stover Ensilaged maize stover Air-dried maize stover	248.4 234.3 261.7	You (2007)
Beef	Ensilaged maize stover Air-dried maize stover	196.4 229.1	Fan (2004)

and Kreuzer 1999; Jordan et al. 2006c), although reductions of 10-–25% are more likely in commercial practice (Beauchemin et al. 2008).

Fat additions to ruminant diets reduce CH_4 energy losses by several mechanisms, including biohydrogenation of unsaturated fatty acids, enhanced propionic acid production and inhibition of protozoans (Johnson and Johnson 1995). However, the effectiveness of adding lipids to rations specifically to reduce CH_4 emissions depends on a range of factors including the level of supplementation, the fat source, the fatty acid profile, the form in which the fat is administered and the type of diet prepared (Beauchemin et al. 2008). In practice, it is recommended that total fat should not exceed 6–7% of dietary dry matter, as higher rates depress DMI, negating the advantages of increased energy density in the diet due to the addition of fat (Beauchemin et al. 2008).

Machmüller and Kreuzer (1999) showed from in-vitro experiments that coconut oil (rich in saturated medium-chain fatty acids), sunflower oil (rich in linoleic acid) and flax oil (rich in linoleic and linolenic acids) could significantly reduce the number of protozoans present in the rumen and reduce CH_4 output. Very high CH_4 reductions of 40–60% occurred particularly when coconut oil or myristic acid was added as 3–6% of the dietary dry matter (Machmüller and Kreuzer 1999; Machmüller et al. 2003). Similarly, Odongo et al. (2007) reported that daily rations with 5% tetradecanoic acid added reduced CH_4 output by 36% and milk fat by 2.4%, compared with controls that did not include fatty acid supplement. A Japanese study (AF&F JTS 2002) reported that, over a 9-month test period, the addition of 4% of calcium-conjugated linoleic acid (fatty acid content 83.8%) produced a CH_4 emission of 187 L, compared with 215 L from fatty acid–free controls (Table 4). Zhang et al. (2008) examined the impacts of linoleic and linolenic acids fed in different proportions (0:0; 10:0; 8:2; 6:4; 5:5; 4:6; 2:8 and 0:10) on rumen fermentation and formation of CH_4, with the total amount of linoleic and linolenic acids added equal to 5% of the dry matter substrate. CH_4 output was significantly reduced by variable amounts in all groups treated with either linoleic or linolenic acids compared with the fatty–acid free control treatments. The treatment with linolenic acid showed the largest CH_4 reduction compared with the control: 54% in 24 hours.

Collectively, these results demonstrate the potential value of lipid additives as a means to mitigate CH_4 output from ruminant livestock and, at the same time, improve performance (Jordan et al. 2006a). However, while the addition of fats reduces CH_4 production, due to depressed fibre digestion, excessive addition would not result in increased energy availability to the animal for growth and milk production (Dong et al. 1997; Boadi et al. 2004). The negative effects of feeding lipids, such as those reported by Lovett et al. (2003) and Jordan et al. (2006b), are not as severe when low-fibre diets are fed (Beauchemin et al. 2008). More importantly from a practical perspective, most of the studies that evaluate the effects of lipid supplementation on CH_4 have not yet tested whether the reductions in CH_4 are sustained over long periods, such as entire lactations in dairy cattle or finishing periods for beef cattle (Beauchemin et al. 2008).

Reducing per-animal CH_4 emissions by animal manipulation

Identifying for selection animals that produce lower amounts of CH_4 may be a cost-effective strategy for reducing emissions. In general, faster growth, higher milk and meat yields, and shorter dry periods in lactating females will lower enteric CH_4 emission. It is reasonable to assume that high-yield species, high-yield breeding techniques and enhanced rumen fermentation would result in reduced CH_4 emissions. There are several experiments whose

Table 4. Impacts of fatty acids and fatty acid calcium on methane (CH_4) emissions from cattle

Animal	Fat type	CH_4 emissions (L/day)	Data source
Dairy cow	Daily feeds with 5% of myristic acids Fatty acid free daily feeds	391 608	Odongo et al. (2007)
Beef	Daily feeds with 4 calcium-conjugated linoleic acid Fatty acid calcium free	187 215	AF&F JTS (2002)

results indicate variations between animals in CH_4 emission per unit of feed intake (Eckard et al. 2010). Pinares-Patiño et al. (2003), Clark et al. (2005) and Hegarty et al. (2007) report substantial variation in CH_4 emissions among dairy cows, sheep and steers, suggesting that animal breeding could achieve a 10–20% reduction in emissions. A study initiated by the New Zealand Ministry of Agriculture (NZ-MAF 2001) reported that increasing annual milk output from 3,000 L to 4,000 L resulted in a reduction in CH_4 emission per unit of diary product of 18% with further reductions at 5,000 L/year (Table 5). Robertson and Waghorn (2002) observed 8–11% lower CH_4 emissions in Dutch–US-cross Holsteins compared with New Zealand animals.

Hegarty (2001) concluded that this natural variation can be exploited to breed animals that consume less feed than unselected populations while achieving desired rates of growth and CH_4 reduction. Results reported by Okine et al. (2002) that Canadian high net feed efficiency (NFE) steers produced 21% lower CH_4 emissions than low NFE steers suggests that selecting animals with high NFE offers an opportunity to reduce daily CH_4 emissions. An important and heritable trait contributing to increased feed efficiency is a faster rate of passage of feed from the rumen (Boadi et al. 2004). In practical terms, high NFE animals reach slaughter weight at a younger age with reduced lifetime CH_4 emissions per animal. As Eckard et al. (2010) pointed out, and confirmed by this review, there are several options for breeding ruminants with lower CH_4 production that, when combined with changes to feeding systems, can potentially reduce total CH_4 emissions and improve on-farm profitability.

Case study: CH_4 emission reduction in ruminants

The *StageONE* model (Takahashi et al. 2011) was used to estimate the effect of the age at which lambs were sold on lifetime CH_4 emissions in the four focus counties selected to provide a range of contrasting household circumstances representative of grasslands in western China. CH_4 emissions clearly increase the longer it takes animals to reach the production targets set by farmers and local markets. At Huanxian, keeping lambs for 18 months before selling them was a more profitable strategy (Wang Xiaoyan et al. 2011), but the estimated total CH_4 output was considerably more than that at other villages (Table 6).

CH_4 emissions per sheep equivalent are relatively similar, although lower than the CH_4 estimates of 7.1–8.9 kg/head/year for 3–7-month-old sheep (27 kg) reported by Sun (pers. comm.). When considered on a unit-area basis the slow-growing lambs at Huanxian produced 5.5 times the CH_4 of lambs per unit area over their lifetime than was the case at Siziwang and 5.25 times that of Siziwang per unit of meat sold. The fine-wool lambs at Sunan county are slower growing than the meat animals at other villages and as a result have greater CH_4 emissions per unit of product. The benefits of improving the animal growth rates by reducing animal numbers and providing better feed, as shown in the case studies in these proceedings (Han Guodong et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng Yang et al. 2011), extend to significant reductions in CH_4 output when considered over the lifetime of an animal and when expressed on a unit-product basis.

Conclusions and recommendations

Reducing the rate of CH_4 emissions from ruminants is possible through a focus on improving the efficiencies in livestock production. This would involve changing a range of practices:

- Reducing the number of animals reliant on grasslands increases the feed supply available per animal and thereby also their growth rates and productivity in terms of meat, milk and fibre. As shown by Kemp et al. (2011), halving animal numbers could double per-head growth rates and, while the instantaneous rate of CH_4 production per

Table 5. Methane (CH_4) emissions from a 450 kg New Zealand cow at different milk production levels (Source: NZ-MAF 2001)

Milk output (L/year)	3,000	4,000	5,000
CH_4 emission (kg/head/year)	86.5	90.4	94.2
CH_4 energy as a proportion of total energy intake (%)	7.11	6.98	6.85
CH_4 emissions per milk product (kg/1000 L of milk)	28.8	25.8	23.5

Table 6. Modelled methane (CH_4) output of Chinese sheep in different regions of the Inner Mongolia Autonomous Region and Gansu province

	Siziwang	Taipusi	Sunan	Huanxian
Grassland type	Desert steppe	Typical steppe	Desert steppe to alpine meadow	Typical steppe
Farm size (ha)	800	33	134	74
Livestock type	Mongolian mutton sheep	Mutton sheep	Fine-wool Gansu alpine	Tan mutton sheep
Breeding ewes (no.)	180	50	88	60
Stocking rate (ewes/ha)	0.23	1.5	0.7	1.9
Lambing month	February	January	May	January
Lamb sales after	7 months	8 months	4 months	18 months
Emission per sheep equivalent (kg CH_4/50 kg animal/year)	6.1	5.8	5.3	5.9
Per area emission (kg CH_4/ha pasture/year)	3.0	14.7	5.2	16.4
Per production emission (kg CH_4/kg lamb meat/year)	0.4	0.6	1.4	2.1

kg of live weight may rise a little, the average rate over the lifetime of young animals produced for sale is considerably reduced. The more rapidly that meat animals grow, the less is their rate of CH_4 output over their lifetime. An overall reduction in stocking rates on farms, while enabling higher productivity, would undoubtedly result also in lower rates of CH_4 emission per farm.

- Mature animals have a finite life and opportunities to reduce their CH_4 output rates depend upon how they are managed. For fibre-producing animals, increasing wool yield and fibre quality through introducing better genetics would yield substantial benefits. For breeds used for meat production, increasing their fecundity (as discussed by Michalk et al. 2011) would see significant overall reductions in rates of CH_4 emission per farm.
- Improved animal genetics is a medium-term goal for the reduction in rates of CH_4 emission. It is suggested that any work to improve genetics needs to focus initially on breeds that can increase the output of animal products per unit of feed consumed, in a shorter time. These efficiency gains can produce early benefits. A long-term goal could be to modify rumen flora and, perhaps, aspects of animal genetics that minimise CH_4 output but, because that may mean replacing 400 million animals in China, it is a pathway less likely to be viable unless there was a clear long-term financial incentive to farmers.
- Improving feed quality and paying attention to ration formulation offers real potential to immediately improve the efficiency of feed conversion and reduce rates of CH_4 emission per unit of product. In northern and western China, the main benefits will come from improving the quality of the feed supply through the long, cold months of autumn to the following summer. This includes improving the quality of hay and silage made from grasslands and forage crops.
- In the medium term, reducing stocking rates to achieve the gains discussed here would produce additional benefits if the grasslands were better managed to increase the average herbage mass. This would lead to higher rates of carbon sequestration which, while perhaps not directly lowering CH_4 emissions to the atmosphere, could fix more CO_2.

The strategies that reduce CH_4 emissions per unit of animal product need to be acknowledged and incorporated in China's national GHG accounting. The IPCC Guidelines (Dong et al. 2006) allow for this, but the simpler IPCC Tier 1 strategies are often used. The market incentives from improving the efficiencies of production through reducing the number of animals, while improving net household incomes and assisting in grassland rehabilitation could produce larger benefits in the short to medium term. Application of many of the options identified and discussed in this paper should lead to actual overall reductions in CH_4 emissions from ruminant livestock in China. These management strategies would apply equally in other developing countries, but would have less impact in developed countries where efficiencies in livestock production are already much higher.

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What are the solutions to the problems of loss of soil and plant biodiversity on China's grasslands?

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Abstract

Grassland degradation in the Inner Mongolia Autonomous Region is a consequence of over-utilisation due to relatively high stocking rates, resulting in environmental problems including declining forage productivity, reduced herbage mass, frequent dust storms and the loss of biodiversity which reduces grassland ecosystem function. The factors affecting wind erosion rates and grassland condition were evaluated using data from a grazing experiment and a model of a livestock farming system on desert steppe in Siziwang Banner, Inner Mongolia. The frequency and intensity of dust storms are related to the wind speed but can be ameliorated by the herbage mass of grasslands. Model predictions agreed with recorded incidences of dust storms. Results from a grazing experiment between 2004 and 2008 that assessed the impact of stocking rates on grassland herbage and plant species biodiversity showed that herbage mass declined as stocking rates increased and rainfall decreased, which raised the risk of wind erosion. Plant species biodiversity was higher in lightly grazed plots, although effects were small. Species biodiversity within each year increased significantly with the increase in above-ground net primary plant production and herbage mass related to increased precipitation. Precipitation above the average rainfall (190 mm) maximised herbage mass, and species diversity tended to be constant below that average. Managing to limit wind erosion by reducing stocking rates is, however, more important than managing for biodiversity in this system. Reducing stocking rates to more sustainable levels needs to be widely applied as a Chinese policy initiative across Inner Mongolia to achieve sustainable grassland ecosystems.

Introduction

Human activities have had significant impacts on natural ecosystems throughout the world. Over-utilisation of natural resources results in environmental problems which, on the grasslands of northern Asia, include forage productivity decline, frequent dust storms and the loss of biodiversity. High stocking rates are widely recognised as one of the major factors that have greatly increased grassland utilisation, resulting in severe environmental problems on the grasslands of China. Serious grassland degradation was evident by the late 1960s and, since then, the area of degraded grasslands has increased by around 15% each decade (Ye et al. 2000).

Grassland degradation across much of northern China results in a loss of topsoil due to higher rates of wind erosion and a consequent loss in the productivity and range of the better plant species. Soil erosion resulting in dust storms has serious off-site consequences in urban areas such as Beijing. The on-site effects of grassland degradation include, primarily, a decline in incomes as the quality of resources is reduced, leading to lower living standards and poverty. Substantial increases in population and livestock have resulted in an exacerbation of soil erosion by wind action in arid and semi-arid China, especially in Siziwang Banner[1] of the Inner

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

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Mongolia Autonomous Region (Dong et al. 2000) where the work reported in this paper was done. This is a problem in many parts of the world with the estimated global area affected by wind erosion being 550 million ha, of which approximately 300 million ha is described as severely affected (Lal 2003).

The rates of soil erosion due to wind are related to the grassland condition which, in turn, is influenced by stocking rates. With an increasing population in grassland areas and associated high grazing pressure from livestock, there has been a rapid increase in the frequency and intensity of dust storms in arid and semi-arid areas (Dong et al. 2000). Dust storms have long been a problem in Siziwang: between 1981 and 2000 there was an average of 1.7 major events per annum as recorded by the Siziwang Banner Weather Station, whereas previously it had been considerably less than 1 per annum. In addition there are many minor dust storms. Overgrazing due to increases in stocking rate typically leads to a substitution of tall grasses for shorter grassland species (Briske 1996). In a review of North American grassland research, Holechek et al. (1999) identified that grassland production was respectively, 36% and 23% higher for light and moderate grazing treatments than under heavy grazing. This results from the close relationship between herbage mass and grassland productivity. The optimal combination of stocking rate and herbage mass that results in minimal wind erosion rates and maintains the grassland biodiversity will depend upon local conditions.

Darwin (1859) identified the relationship between biodiversity and the above-ground net primary production (ANPP) of an ecosystem. However, the form of this relationship can vary. First, there can be an increase or decrease of biodiversity that has no effect on the ecosystem function, as reported by Hooper and Vitousek (1997). Second, ANPP may fall with an increase in ecosystem biodiversity, as found by McNaughton (1993), Silvertown et al. (1994) and Kemp et al. (2003). Third, ANPP may increase as biodiversity increases, as described by Tilman et al. (1996). Grasslands can provide greater protection from soil erosion and dust storms in situations where there is high vegetation cover and species diversity (Li Ning et al. 2005; Yang et al. 2006) but, for many ecosystems, it is not clear if the optimal levels of herbage mass for ANPP are associated with an increase or decrease in biodiversity.

Most of the previous Chinese studies have focused on the frequency, intensity and effects of soil erosion on the vegetation and soil. Although a few studies have considered variable stocking rates, they have not examined the relationship between livestock management, grassland condition, species biodiversity and wind erosion of soil. This paper examines the relationships between stocking rates, herbage mass, biodiversity and wind erosion of soil in the desert steppe region of north-western China. Data from an experiment in Siziwang that investigated the effects of stocking rates on herbage mass and plant species biodiversity are used to illustrate relationships. Analyses were extended using a model to investigate the likely interactions between climate, stocking rate and herbage mass. The model was parameterised using the results of the experiment and the information from the literature.

Study area and methods

Site description

The grazing experiment and parameterisation of the model were done in Siziwang, Inner Mongolia, China (41.77°N, 111.88°E; elevation 1,460 m) on the desert steppe. The dominant species are *Stipa breviflora* (C3 grass), *Cleistogenes songorica* (C4 grass) and *Artemisia frigida* (small C3 shrub). The mean vegetation canopy cover was in a 17–20% range. Sheep had long been grazed all year on the experimental site at a stocking rate of less than 1 sheep/ha/year before 1988. In more recent times the stocking rate in this region has increased to around 1.5 sheep/ha/year. As a result of this increased grazing intensity there has been a decline in the condition of the grassland, with the average height of vegetation now being about 8 cm.

The typical soil in the area is a Kastanozem (Food and Agriculture Organization of the United Nations (FAO) soil classification; Table 1). The climate is continental with a mean annual precipitation of 190 mm, most of which occurs from June through August. The mean annual temperature is 3.4°C. The annual frost-free period is about 120 days.

Grazing experiment

The effect of grazing on the plant community of the *S. breviflora* desert steppe site was examined in a 4 (grazing treatments) × 3 (replicates) randomised complete block experiment. In June 2004, 12 paddocks, each about 4.4 ha, were fenced and stocked with sheep at rates (and range over 2004–2008) of 0, 0.8 (0.6–1.1), 1.6 (1.2–2.1) and 2.8 (1.8–5.8) sheep/ha, respectively, for the control (non-grazed enclosure), lightly grazed (LG), moderately grazed (MG) and heavily grazed (HG) treatments. The stocking rates quoted are calculated on the equivalent biomass of a 50 kg sheep (based on live weights over the grazing period) and, in the case of the HG treatment, one replicate had double the planned stocking rate for the first 3 years—hence the large variation noted. Plots were grazed with local adult Mongolian fat-tail sheep (wethers), from 1 June to 30 November every year from 2004 to 2008. The grazing time was from 0600h to 1800h every day. The sheep were penned in a shed from 1800h to 0600h next morning. The same group of sheep grazed in the same paddock each day for the duration of the experimental period. The sheep were offered water twice each day (at early morning and evening) in their pen. Salt was offered ad libitum during the entire grazing period. During the winter, all experimental sheep were kept in shed pens and supplied with hay, maize stover and some grain, fed at the survival rate that typically applies in the district. Plant community data were collected once every month during summer, and plant biomass, density and coverage by species were also recorded (Wang Zhongwu 2009). Emphasis was on measuring the effect of grazing on the grasslands rather than on animal production.

Modelling

A dynamic model was developed to incorporate relationships from the grazing experiment and the literature to enable the interactions between climate, weather, grassland herbage mass, stocking rate, wind erosion rates and biodiversity to be examined over periods of up to 50 years. The model (Jones et al. 2008, 2011) enabled analysis of different grazing management practices.

Data analyses

Species biodiversity was analysed using the following indexes:

Shannon-Wiener index (H)

$$H' = -\sum P_i \log P_i$$

Simpson index (D)

$$D = 1 - \sum (P_i)^2$$

where P_i defines the relative frequency of each different species, $P_i = n_i/N$ and n_i is the density of each species in a surveyed quadrat; N represents the total density of all species in the same quadrat.

All data from the grazing experiment were analysed using the MIXED Procedure in SAS (SAS Institute 2008). The effects of stocking rate on species biodiversity were tested with stocking rate, year and their interaction as fixed effects and replications, and replication × stocking rate as random effects. The least significant difference (LSD) test was used to determine when treatment differences were significant ($P < 0.05$). Other analyses were done using Systat V13.

Results and discussion

Wind speeds and soil erosion

Rates of soil erosion due to wind depend upon wind speed, vegetation cover and soil type. The model was used to simulate how these rates would vary. In Siziwang, the strong winds characteristic of spring and the poor vegetation cover on the fine sandy loam soils combine to produce regular dust storms. Average monthly wind speeds for Siziwang are presented in Figure 1, which shows increasing wind speed in spring, peaking in April. Wind speeds nearly double from January to April, then fall to a minimum in August before a small rise to November. In summary, peak wind speeds occur in spring when plant cover is minimal.

Rates of soil erosion were estimated using the wind erosion equation (Jones et al. 2008, 2011) with climate values for Siziwang and estimates of

Table 1. Soil properties in 2004 at start of the grazing experiment on the desert steppe at Siziwang Banner, Inner Mongolia Autonomous Region

Depth (cm)	Soil organic matter (g/kg)	Total nitrogen (g/kg)	pH	Sand (%)	Soil texture	Bulk density (g/cm^3)
0–10	24.7 ± 1.8	1.82 ± 0.05	7.7 ± 0.05	60.0 ± 4.2	Sandy loam	1.44
10–20	20.9 ± 1.1	1.58 ± 0.04	8.0 ± 0.05	59.9 ± 4.3	Sandy loam	nm[a]

[a] nm – not measured.

average herbage mass. The greatest soil loss occurs in May as a result of low herbage mass and high wind speeds (Figure 2). This is when the incidence of dust storms in this region reaches a maximum. China has imposed a regulation that prohibits grazing in May in many regions. Generally, the model predicts that most soil loss occurs from November to April, which corresponds to the period of no growth on grasslands. There is the potential for herders to improve the quantity and quality of the diet for their animals through this period by restricting grazing and feeding supplements. This can also improve the ecological condition of the grasslands as well as the benefits discussed in the analysis of the farm system by Han Guodong et al. (2011) elsewhere in these proceedings. Research is needed to investigate the relationship between the amounts of grass left in fields over winter, spring and summer, and subsequent growth and development of the grasslands.

Plant productivity and soil erosion

The relationship between wind erosion of soil and vegetation herbage mass is illustrated in Figure 3. In this case, simulations of the model were done for three different types of vegetation: poorly productive (V1), reasonably productive (V2) and highly productive (V3) species. Differences in productivity reflect that some plants are more tolerant to wind erosion due to the positioning and anchoring of residue, and windbreak effects. In general, the finer and more upright the plant residue the more effective it will be in reducing wind erosion. This differentiation in terms of species productivity is made to reflect the fact that, for the same herbage mass, different plants, due to their type and structure, will have differing effects on the rate of wind erosion.

The results of the model simulations show that, for any given standing biomass value, substantially different rates of soil erosion can result, depending upon the species type present in the grasslands. For example, at an average standing biomass of 150 kg dry matter (DM)/ha, typical of desert steppe in early summer, the annual soil loss can range from 85 t/ha (V1, species that have low growth potential) to 15 t/ha (V3, species that are more productive and achieve greater groundcover). Further research is required in Siziwang to classify the grassland species according

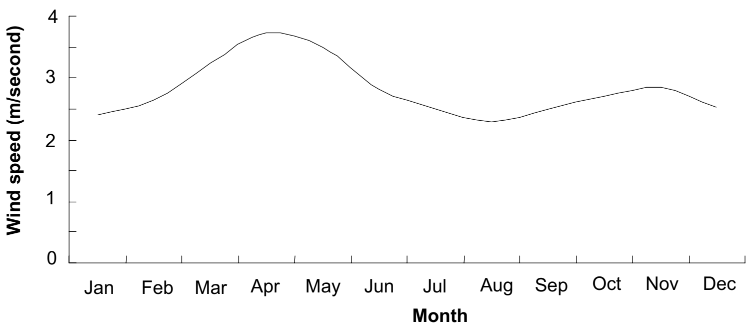

Figure 1. Mean monthly wind speeds (1961–2008) in Siziwang Banner, Inner Mongolia Autonomous Region

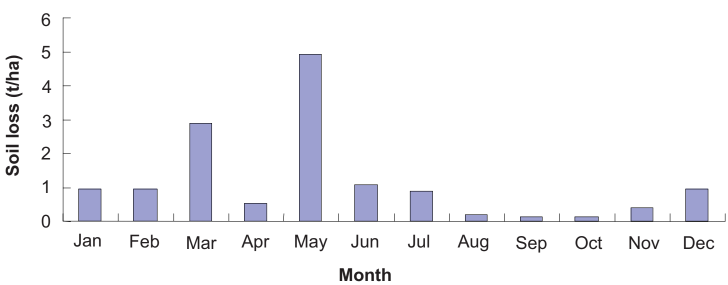

Figure 2. Modelled estimates of average monthly soil loss in Siziwang Banner, Inner Mongolia Autonomous Region

to their influence on wind erosion rates. However, there is a strong likelihood that, as the grasslands degrade, there is a change to shorter species that are likely to be less effective against wind erosion, except in those instances where the species that replace desirable grasses are semi-shrubs. The model simulations suggest that substantial rates of soil loss can occur at biomass values less than 200–300 kg DM/ha, which are common in Siziwang. This finding aligns with local experience.

Vegetation cover is a function of grassland growth, consumption by livestock and natural senescence of pasture. Potential green herbage mass in ungrazed situations for Siziwang is given in Figure 4 for three different grassland conditions: highly degraded (30% desirable species), moderately degraded (50% desirable species) and good condition (70% desirable species). Desirability relates to potential productivity of higher nutritive value herbage. Pasture growth begins in May and peaks through July–August. From December to April the herbage mass can be quite low due to continual grazing and high natural senescence rates because of the harsh winter conditions. Observations and measurements in the region suggest that, as grasslands degrade, plant density decreases, as

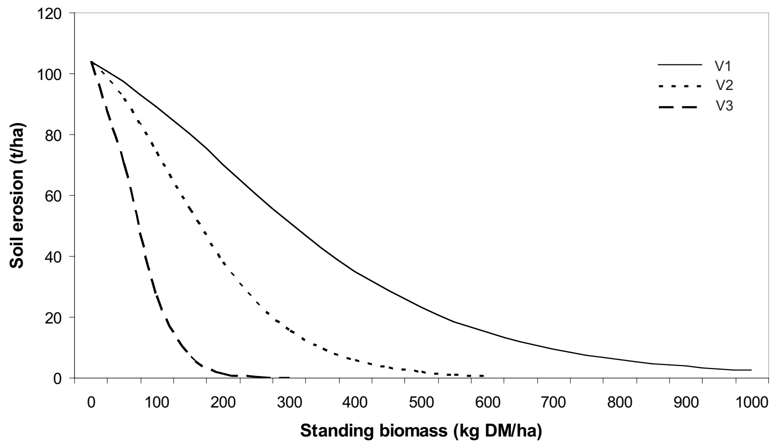

Figure 3. Modelling estimates of the relationship between wind erosion and average standing biomass for poor (V1) to reasonably productive (V2) to highly productive (V3) grassland species in Siziwang Banner, Inner Mongolia Autonomous Region (DM = dry matter)

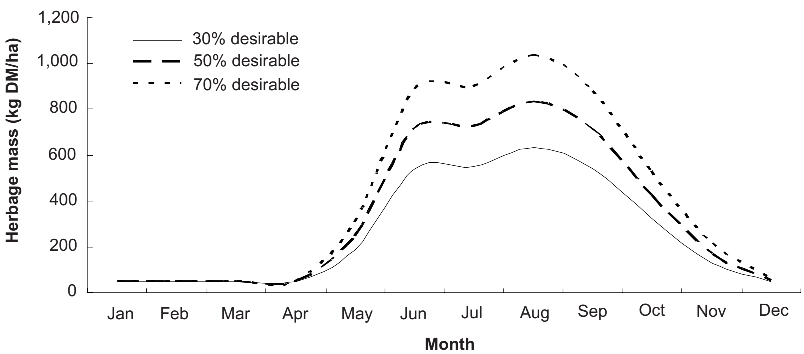

Figure 4. Estimates based on experiments and surveys of the potential (ungrazed) green herbage mass (kg dry matter (DM)/ha) for different grassland compositions in Siziwang Banner, Inner Mongolia Autonomous Region

does individual plant size, resulting in reduced herbage mass and an increase in the proportion of less palatable species (Wang et al. 1996).

Stocking rates, rainfall and herbage mass

Herbage mass is dependent upon stocking rates and seasonal rainfall, as shown by data from the grazing experiment (Figure 5). As rainfall or stocking rate decreased, there was a decline in the average herbage mass for the growing season. This decline was rapid when rainfall was less than 200 mm during the growing season and thereafter probably reached minimal values below 150 mm. The apparent upturn at lowest rainfall values is probably an artefact of the quadratic surface fitted. Similarly, as stocking rates increased, the average herbage mass declined, reaching minimal values at 3 sheep equivalents per hectare. The interaction between rainfall and stocking rate was not significant, suggesting that the effects of these factors are simply additive.

Biodiversity

The Siziwang grazing experiment showed that, with increases in stocking rate, there was a small but significant overall decline in the Shannon-Wiener biodiversity index (0.56 for no grazing to 0.51 for the highest stocking rate) but not in the Simpson index (0.64–0.63). The decline was greater at the highest stocking rate and in drier years (the full dataset is presented in Wang Zhongwu (2009)). Between years, the Shannon-Wiener index varied from 0.42 in the driest year to 0.66 in the wettest, and the Simpson index from 0.53 to 0.70. The year-by-year small changes in indexes were associated more with the amount of herbage grown and the average herbage mass, probably dependent more upon precipitation than any overall stocking rate effect.

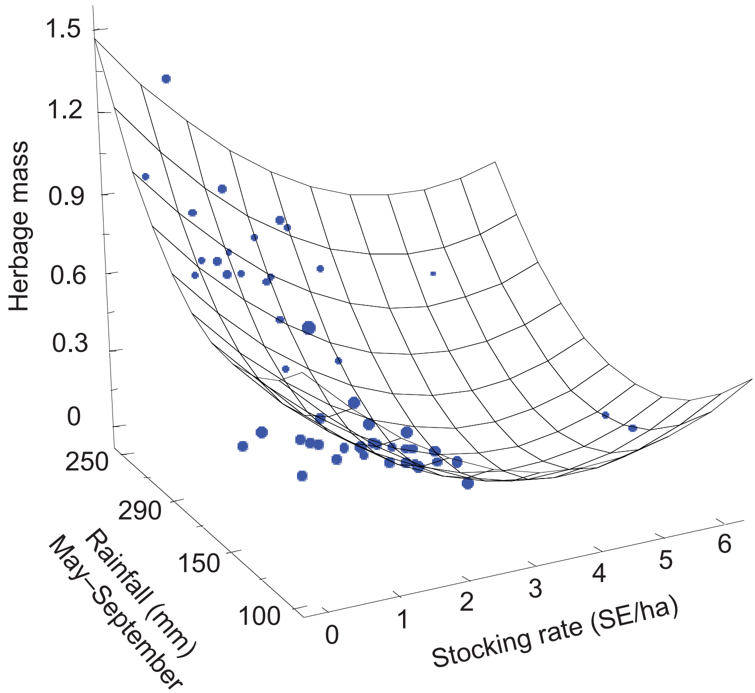

Figure 5. Interaction between annual rainfall, annual stocking rate (as 50 kg sheep equivalent (SE)) and average summer herbage mass for desert steppe at Siziwang Banner, Inner Mongolia Autonomous Region, from 2004–2008 inclusive. A quadratic surface has been fitted to the data to show trends (adjusted R^2 0.69, $P < 0.001$, quadratic terms significant, but not the interaction between rainfall and stocking rate).

Marginal increases in minor species occurred when there was more grassland growth. Those minor species may have been there in less productive years but, due to the grazing pressure, some may not have been observed.

There were significant relationships between biodiversity indexes and annual precipitation (Figure 6). Both the Shannon-Wiener and Simpson biodiversity indexes increased, then remained stable, once precipitation exceeded 220 mm. A conservative conclusion is that diversity declined when precipitation was less than 200 mm but was maximised and relatively constant above that value. Such a conclusion may make some ecological sense as the average annual precipitation at the site is 190 mm.

Discussion

The biodiversity indexes were significantly related to the ANPP over the study period. The 5 years of data showed that biodiversity indexes increased until ANPP was about 500 kg DM/ha and thereafter remained stable (Figure 7).

Soil erosion due to wind degrades the soil resource, contributing significantly to grassland degradation (Li et al. 2008). The reduction of soil depth from the loss of topsoil and nutrient removal from the soil surface layers would directly reduce plant growth and soil biological activity. Vegetation characteristics have important effects on soil surface condition, as the rate of wind erosion is affected by plant cover, height and the standing crop of a plant community (Li Junran et al. 2007) readily measured as herbage mass. The type of vegetation and its biomass have varying effects on wind speed at the soil surface and soil erodability. Wind erosion primarily removes the finer soil particles and the organic matter in surface soil (Chepil 1957), depleting soil fertility and degrading soil structure (Lal 2003) with consequent effects on soil produc-

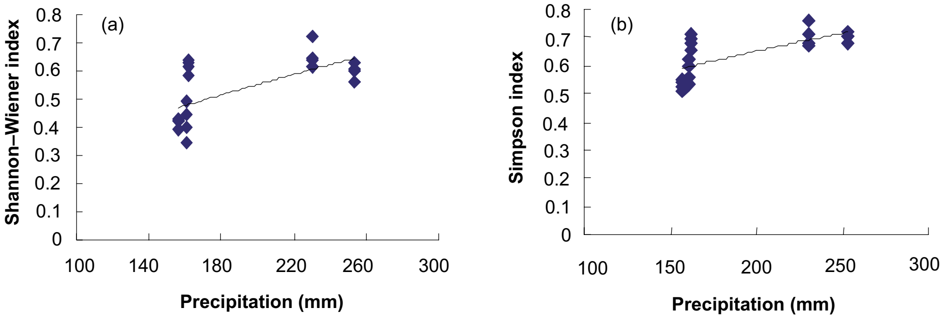

Figure 6. The relationship between annual precipitation and diversity represented by (a) the Shannon-Wiener index and (b) the Simpson index. Fitted lines are to show trends. See text for explanation.

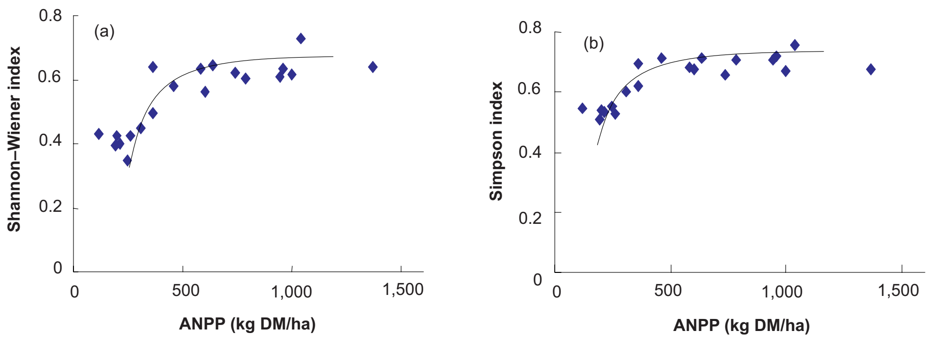

Figure 7. The relationship between above-ground net primary production (ANPP) and biodiversity indexes—(a) Shannon-Wiener index; (b) Simpson index—at Siziwang Banner, Inner Mongolia Autonomous Region (DM = dry matter)

tivity (Zhao et al. 2006). Given the negative impact on soil fertility (Ward et al. 2001), long-term soil erosion will reduce farm annual income due to reduced grassland productivity. Studies in China have generally found that wind-driven soil erosion decreases with an increase in vegetative coverage (Shi Peijun et al. 2004; Li Ning et al. 2005). Increasing the herbage mass should retain more litter on grasslands and aid restoration of soil fertility.

The role of biodiversity in these grasslands is important as there needs to be sufficient species to adequately exploit the available resources to sustain grassland productivity and functions. In the grazing experiment, only small changes in biodiversity were detected. Higher levels of biodiversity were associated with higher levels of ANPP and herbage mass. This supports the argument promoted by Tilman et al. (1996) that productivity is directly related to biodiversity (Naeem et al. 1994). There are other studies, however, that have shown a decline in productivity with greater biodiversity (e.g. Kemp et al. 2003). The outcome depends upon the functional types of species present.

Biodiversity was higher in years of increased precipitation and when grassland productivity was higher. This result is consistent with the intermediate disturbance hypothesis for plant species richness (Grime 1979). The grazing experiment showed that herbage mass and biodiversity were greatest in years at, or above, average rainfall (190 mm). This suggests that most species are surviving through drier years and under current high stocking rates, as only a few extra species were identified in better years—possibly species less tolerant of stress. This could be reflecting that the current species are survivors and those more sensitive to grazing pressure and degraded conditions have disappeared. Maintaining more species within the grasslands then depends upon precipitation rates and on stocking rates that maintain higher levels of herbage mass. In practice, minimal levels of herbage mass could be set that enable species to survive in the grasslands and to minimise soil erosion. Further research is needed to resolve the levels of herbage mass that are optimal for minimising dust storms in early summer.

The frontline defence to reduce wind erosion of grassland soils is to maintain sufficient herbage mass on the grasslands. The grazing experiment and modelling based on its results and data from the international literature showed that herbage mass could be increased with appropriate vegetation types, reduced stocking rates and in seasons with higher precipitation. Managing the grasslands to maintain higher levels of herbage mass would, in turn, maintain biodiversity. Sustainable stocking rates then need to be devised that retain a high level of herbage mass through the whole year. That would suggest the aim needs to be to attain a high level of herbage mass by the end of summer and then prohibit grazing until the grasslands have regenerated in the following early summer. It is likely that stocking rates need to be reduced by 50% or so to reduce wind erosion of soil. As discussed in these proceedings such reductions in stocking rates could also improve household incomes. The results presented here suggest that the goal should be to attain at least 500 kg DM/ha on the grasslands through the year to maintain species and minimise wind erosion.

Stocking rates are an inadequate management guideline for these grasslands. Traditionally, stocking rates are set as animals/ha, irrespective of seasonal conditions. Flexibility is needed in adjusting animal numbers to cope with varying seasons. A constant grazing pressure could be applied as a utilisation rate, e.g. animals to consume no more than 30% of the available forage. However, emphasis may need to change from animal numbers to use of the state of the grasslands to minimise soil erosion and sustain grassland species. The data presented in this paper indicate how maintenance of minimal herbage mass is an alternative management criterion that could lead to substantive benefits. Experiments to investigate the benefits and costs of managing stocking rates to maintain a herbage mass of 500 kg DM/ha throughout the year are needed at the main site used for the study reported here. Such investigations need to be long term so as to enable assessment of the value of this strategy for rehabilitating grasslands. This may mean no grazing at any stage in dry years. Use of such a criterion needs to be backed by further research to define what is a suitable level of herbage mass for each grassland type and condition.

Acknowledgments

We sincerely thank the herders, village leaders and Banner officials and students who gave us every help and much of their time to do this study. The work was done as part of ACIAR-funded project LPS/2001/094, 'Sustainable development of grasslands in western China' and National Basic Research Development Program (973 Program, No. 2007CB106800), National Science and Technology Supporting Program during the 11th five-year plan period (2006 BAD16B01, 2008BAD95B03, 2009A40020201, 20090306), and a grant (20071501, 20080706) from the Inner Mongolia Science and Technological Committee, China.

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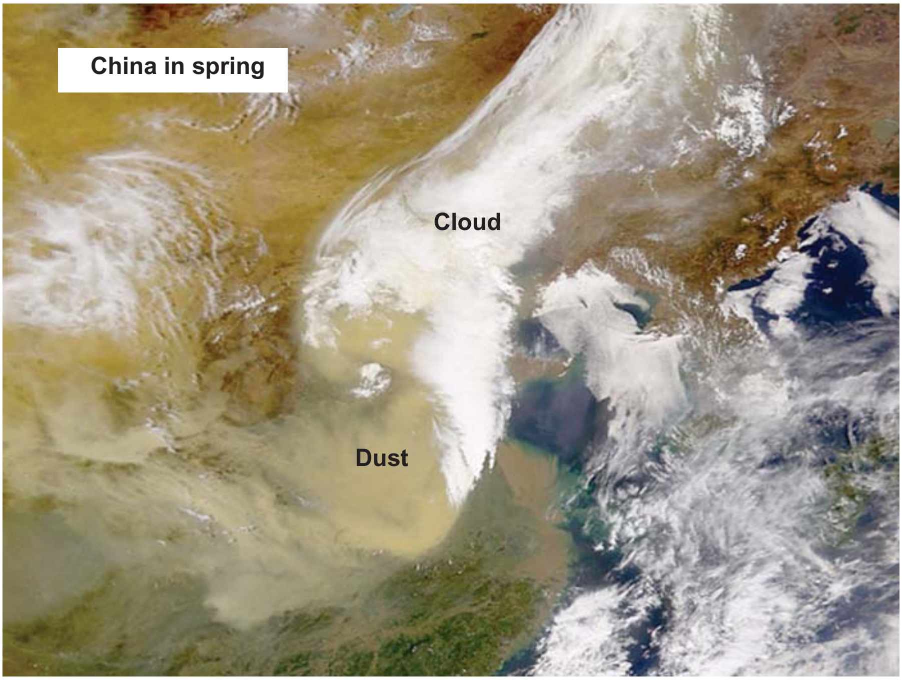

Satellite image of dust from degraded grasslands blowing over northern China in spring. [Photo: courtesy US National Aeronautics and Space Administration]

Professor Wu Jianping conducts a herder raining session on concepts of precision livestock management (*StageONE* model) in Gansu province [Photo: Wu Jianping]

A meeting with herders at a village in Siziwang Banner, Inner Mongolia Autonomous Region in early winter. The meeting, to initiate demonstration farms, was in the house of Buhechaolu (second from right), the village leader. [Photo: D.R. Kemp]
[Note: Chinggis Kahn's name is actually spelt backwards on the wall hanging.]

Delivering solutions to smallholders

Typical steppe at Taipusi Banner, Inner Mongolia Autonomous Region, recovering following imposition of a grazing ban. Farm subsidies are needed to achieve such an improvement. [Photo: D.R. Kemp]

Re-designing livestock strategies to reduce stocking rates and improve incomes on western China's grasslands

David Michalk, David Kemp, Han Guodong, Hua Limin, Nan Zhibiao, Taro Takahashi, Wu Jianping and Xu Zhu

Abstract

The results and implications of the study of grassland livestock systems in four counties in western China are considered from the perspective of general outcomes that would apply across the region. Two key questions were evaluated using farm system models: (1) can changing the current livestock production system to an alternative enterprise, or (2) can changing key management practices in current enterprises, increase household profit at the same stocking rate (SR) or maintain profit at a lower SR? The model analyses indicated that changes in the livestock enterprise (mutton, wool or cashmere) and/or simple changes to the production system (e.g. culling unproductive stock, changing lambing time, weaning earlier, developing better supplementary feeding regimes and grazing management, overwintering stock in warm sheds) should initially lift net farm incomes by 15–40% (depending on the location) at current stocking rates, or should allow 20–40% reductions in stocking rates while holding net farm incomes at present levels. At three of four study sites, a reduction in stocking rates with the existing enterprise would improve net income from livestock. At the fourth site the same net income can be achieved at lower stocking rates but requires changing the enterprise from mutton to wool production. Lambing times could be moved from winter closer to summer, to better align feed demand with grassland forage supply. Pen feeding in warm sheds improves animal performance and net incomes. Better ration formulations can improve the efficiencies of animal production. Simple grazing rotations, grazing bans in early summer and restricting grazing to April–November all had no or positive effects on net income from livestock, supporting the view that improving the efficiencies of livestock production does provide opportunities to improve grassland condition. Sale of unproductive animals to reduce stocking rates provides finance that can be used to better feed the remaining animals and make other farm improvements.

Introduction

The twin problems of low household incomes from grassland livestock farming systems and degraded grasslands dominate the many policies and programs being implemented across northern and western China. Underlying them is the objective to find ways of reducing animal numbers, without reducing household incomes. In 1949 the grasslands appeared to be a productive, under-utilised resource and this led to dramatic increases in the numbers of people and animals living across the grasslands (Li et al. 2008). As the pressures on resources increased, the amount available to individual households decreased, productivity per animal arguably also decreased and the response of farmers was to further increase animal numbers (Chen et al. 2003).

It is clear that grassland degradation and its associated environmental problems will continue at an escalating rate unless new approaches to livestock

Pp. 140–151 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.

management are adopted to restore a reasonable balance between grazing capacity and livestock numbers in China's extensive pastoral and semi-pastoral areas. Chen et al. (2003) estimated that the current livestock numbers grazing China's grasslands are more than double the number considered to be the safe (survival) carrying capacity. This raises policy quandaries and conflicts as to whether to treat grassland degradation as a resource management issue or as a pastoral-household livelihood issue (Brown et al. 2008) although, as we argue here, it is both. The current stocking rates are probably not sustainable and cannot be taken as a reference point for the future. A better alternative is to use a business model and assess net household financial returns from livestock to decide on sustainable stocking rates.

Chinese scientists and officials have been challenged to revise policies and management strategies to ensure the future of grassland resources within a market economy (Dong et al. 2007). Given the fragile state of China's grasslands and the ineffectiveness of past management policies, the Central Government has introduced more drastic resource management policies such as grazing bans (Brown et al. 2008) in which pastoralists trade off grazing rights for a 5-year compensation package of grain and cash based on their grassland productivity and the area of land that is removed from grazing. Despite about one-fifth of China's grasslands having been subject to grazing bans or other rehabilitation methods since 2000, degradation continues, primarily because little or no attention has been given to reducing livestock numbers. This has led to the perception by many commentators that livestock enterprises are the main cause of the problem and that further development of the ruminant livestock sector in China should be curtailed. However, rather than being viewed as the cause for degradation, livestock enterprises should be seen as central to the solution when correct management strategies are applied (Michalk and Kemp 1994).

The aim of this chapter is to focus on some of the general points that have emerged from the work presented in these proceedings, ones that overlie the earlier analyses, to show how livestock production systems can be re-designed to shift the current emphasis from livestock numbers to product quality as the main driver to stabilise or increase household incomes and provide high-valued livestock products that meet the consumption patterns of China's expanding and increasingly affluent urban population (Ma et al. 2004). A shift to production efficiency as the main driver of livestock production should result in a large number of animals of low productivity being replaced by fewer but better fed animals of higher potential. This would then provide solutions to the Chinese problems of grassland degradation and associated greenhouse gas emissions through reduced stocking rates, while at the same time maintaining or increasing the supply of livestock products (Herrero et al. 2009; Kemp et al. 2011). Details of more specific changes that apply to individual areas are given in the case study chapters in these proceedings.

Criteria for re-designing livestock systems

The work presented in these proceedings is underpinned by an analysis of basic animal production relationships. This identified that substantive reductions in stocking rates would lead to higher productivity per head, with consequent increased ability to attract price premiums for livestock products, faster turn-off of young animals and generally better animal condition that should carry forward into higher fecundity (Kemp et al. 2011). The adoption of reduced stocking rates would then provide the opportunities to rehabilitate grasslands and improve environmental services through the reduction in grazing pressures and/or tactical rests at key times of the year. It is assumed that if farmers see higher net financial returns coming from re-designed livestock systems the rates of adoption will be much greater than would apply if financial gains were not so clear.

Fundamental to achieving these outcomes is a shift in focus of both policy advisors and farmers away from livestock numbers as the measure of success, to efficiency measures such as product output per resource unit. This reflects the limited success of previous programs targeting sustainable use of China's grasslands, which can be partly attributed to adopting a component rather than an integrated approach to identifying solutions (Kemp et al. 2011). Some have tried to devise ways of balancing the apparently conflicting objectives of grassland protection and income generation (Niu and Chen 1994; Xin et al. 2000; MOA 2003) but few have come up with sound proposals that can help the smallholders in the northern and western regions to increase their income and protect the environment.

The bioeconomic modelling system (Takahashi et al. 2011) developed to evaluate alternative livestock management options in northern China's grasslands was used through the case studies presented in these proceedings (Han Guodong et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng et al. 2011) to first evaluate the performance of typical farms, then investigate various options for the livestock enterprise and grassland improvement that could be the initial changes on a pathway of improvement. While the biophysical characteristics of current farms obviously place some limits on the options that would be applicable, it is important to take a step back and consider how solutions could come from changing the enterprise or the management practices, or a combination of both. The re-design of livestock production strategies needs a focus on not only financial efficiencies, but also on related production efficiencies, including their suitability for the systems under study. Models cannot evaluate all aspects of a strategy and hence interpretation is critical.

Matching livestock feed demands to forage supplies

Matching livestock demands with available feed supplies is the key to efficient livestock production. Analysis of the relationship between the demands of the current enterprises and feed supplies using the modelling framework developed in the Australian Centre for International Agricultural Research (ACIAR) project indicated an inefficient use of limited energy resources due to a poor match between feed supply and livestock feed requirements.

In Taipusi, for example, a mutton production enterprise with January–March lambing had a major feed deficit from September to early May (Figure 1a). Similar misalignment was apparent in the current combination of enterprises and management practices at Huanxian, Sunan and Siziwang (Figure 1).

Unlike other parts of China, livestock production practices in the project villages are based mainly on local multipurpose activity and it is only the leading producers that are transitioning to a market-oriented and vertically integrated business (Ke 1998). The current use of available forage resources combined with poor livestock management practices highlight opportunities to select an enterprise that better suits the available feed supply or to change management tactics to improve efficiency of the current enterprise to maintain or improve household profitability.

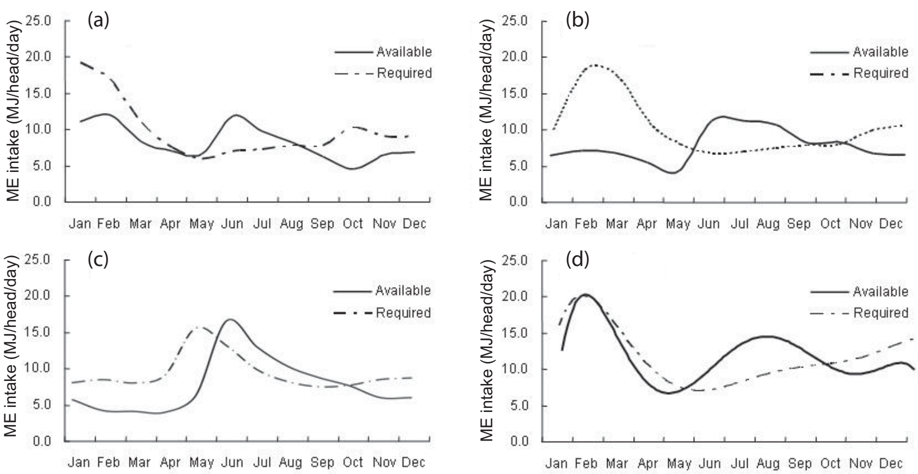

Figure 1. Estimates showing actual metabolisable (ME) energy available to ewes throughout the year in relation to maintenance requirements at the same live weight for current enterprises in (a) Taipusi Banner, Inner Mongolia Autonomous Region (mutton sheep and January lambing), (b) Siziwang Banner, Inner Mongolia Autonomous Region (mutton sheep and February lambing), (c) Sunan county, Gansu province (fine-wool sheep and April lambing) and (d) Huanxian county, Gansu province (Tan mutton sheep and January lambing)

Changing the current enterprise

In addition to improving net household incomes, a key objective of re-designing livestock production systems is to achieve a substantial reduction in stocking rate. To warrant a change, the alternative livestock enterprise needs to either increase net household income from livestock at the same stocking rate or maintain current net household income at a lower stocking rate. The whole-farm model (*StageTWO* model, Takahashi et al. 2011) was used to estimate net incomes from mutton sheep, fine-wool sheep and cashmere goats using the available feed resources (grasslands and what can be obtained locally) at the different sites.

These analyses showed that in some sites the current enterprise was best suited to the forage and financial resources of the typical household whereas at other sites a change in enterprise would have positive economic and environment impacts. In Sunan county, for example, at the optimal stocking rate for fine-wool sheep, a change to mutton sheep would potentially reduce net farm return by 30% (Figure 2a). At the optimal net farm return for fine-wool sheep no significant reduction in stocking rate or increase in net farm return would be achieved by changing to cashmere goats. This confirms that fine-wool production is the enterprise better suited to Sunan county. In contrast, the modelling predicted that, at the optimal stocking rate for the current mutton enterprise at Huanxian, a change to fine wool increased net farm return by 20% (Figure 2b). More importantly, at the current new net livestock income for mutton sheep, a fine-wool enterprise would generate the same income but with a 25% reduction in stocking rate (Figure 2b). For Taipusi it was concluded that fine wool had only a marginal financial advantage over mutton sheep, although both were substantially better than cashmere goats, reflecting the high volatility of the market price of cashmere. On the desert steppe at Siziwang, analyses suggested that fine wool would increase net income over mutton by up to 50%, with the optimal stocking rate remaining at 0.35 ewes/ha for both production systems (data not presented).

These examples indicate that, to achieve an increase in household profitability, a reduction in stocking rate, or possibly both, investigation of the potential impact of changing enterprise is warranted for grassland-based livestock production. In each of these cases, they suggest that fine wool was as good as, or better than, mutton production. Fine-wool profitability is greater at higher stocking rates in some instances, but it is not certain that it would be sustainable, as the *StageTWO* model does not have any mechanism to evaluate if the grasslands could support those extra animals for longer periods. A switch to fine wool may need to be buttressed by regulations that limit stocking rates and protect farmers from adverse financial effects. Farmers have traditionally produced mutton from the grasslands, but in the current degraded state of pastures the costs of doing so are greater than for fine wool. For fine-wool production it is not as important to maximise animal growth rates, hence feeding closer to maintenance better suits these conditions. Thus, even at the same stocking rates fine-wool sheep could be managed to reduce grazing pressure, as their feed demand can be limited.

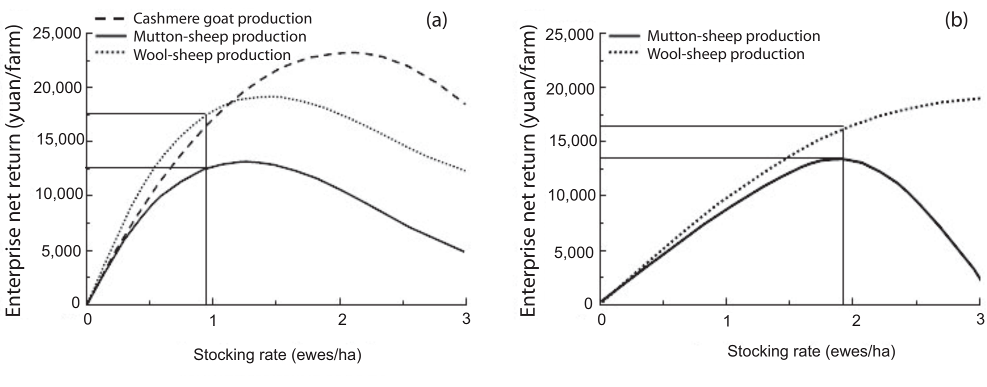

Figure 2. Predicted effects on net livestock financial returns from changing live-stock enterprises in (a) Sunan and (b) Huanxian counties, Gansu province. The vertical lines indicate current stocking rates.

Changing management to improve efficiency of livestock enterprises

The same criteria of increasing profitability at the same stocking rate or maintaining profitability at a lower stocking rate can be applied to identify ways to improve the efficiency of current enterprises. As an initial objective was to encourage practice-change in the near future, in this section we investigate options relative to the current livestock enterprise. To change the enterprise is more a medium-term goal. Experience gained from improving current practices would then apply to new enterprises. We were conscious that adoption of new technology is likely to be more rapid if the changes required are simpler.

Improving animal management: reproductive efficiency

Increasing productivity and reproductive performance of female animals generally improves economic and biological efficiency of livestock production enterprises (Wang and Dickerson 1991). The success of a sheep and goat operation depends on the number of offspring raised, weaned and marketed each year. From a management perspective, reproductive performance can be enhanced by strategies such as improving weaning rate, changing lambing time to correlate better with feed supply, and early weaning. The impacts of these management strategies were investigated using the ACIAR model framework.

Increasing weaning rate

Maintaining high levels of reproductive performance, defined as the percentage of females that produce one or more offspring, combined with effective mothering ability (ability to raise offspring to weaning), is a critical component of efficient livestock production. Many Chinese sheep breeds are noted for high fecundity (Feng et al. 1996) but, as is generally the case for commercial sheep production worldwide (Notter 2008), the weaning rate in the project areas was well below the minimum objective of producing at least one lamb per ewe with satisfactory growth of the offspring. For example, the 70% weaning rate calculated from the household survey in Siziwang was well below the 150% lambing reported possible for Mongolian mutton sheep (Turner 1965). The low weaning rate was not due to mortality, because households reported lamb survival rates of more than 95% indicating that either low ovulation rates or early abortion are the probable causes of low weaning rate. This reproduction wastage can be remedied by improved nutrition and early weaning.

Increasing weaning rates effectively increases revenue from lamb sales and reduces feed consumed by non-lambing ewes (Table 1). Current farm

Table 1. Predicted effects of increasing weaning rate to either increase lamb number with a typical ewe flock or to maintain current lamb numbers with a reduced ewe flock in Siziwang Banner, Inner Mongolia Autonomous Region

Weaning rate (%)	Size of ewe flock (no.)	Lambs weaned (no.)	Non-performing ewes (no.)	Feed cost of non-performing ewes (¥)
Increased lamb crop with current ewe flock				
70	180	126	54	3,600
80	180	144	36	2,400
90	180	162	18	1,200

Weaning rate (%)	Size of ewe flock (no.)	Lambs weaned (no.)	Non-performing ewes (no.)	Feed cost of non-performing ewes (¥)	Reduction in ewe flock (no.)	Feed cost saved by reducing ewe flock (¥)
Maintaining current lamb crop with reduced ewe flock						
70	180	126	54	3,600		
80	180	144	36	2,400	23	1,533
90	180	162	18	1,200	17	1,134

practice is not to sell non-performing ewes, hence their sale would not add to revenue and the wool cut from such animals is worth very little. However, this first strategy increases the effective stocking rate (depending on the weaning rate increase) even if practices changed and all non-lambing ewes were culled to achieve a 90% weaning rate. Alternatively, increasing the weaning rate but aiming to only maintain the current lamb number would reduce ewe flock size by respectively, 13% and 22% at 80% and 90% weaning rates (Table 2). The second strategy fits better with reducing animal numbers without reducing income.

Weaning rate increases of this magnitude can be achieved by precision sheep management focused on maintaining ewes in good body condition through pasture management, feed supplementation or strategic weaning (see below). Simple management procedures such as tagging for identification of ewes and their offspring, and recording of key performance information (e.g. live weight, body condition, lamb growth rate) are central to identifying non-productive ewes for culling. The 'fat and condition-scoring' systems (Shands et al. 2009) that are used as management tools for small-tail breeds in Australia (Langford et al. 2004) need to be modified for application to fat-tail breeds because important production parameters such as lamb weaning rates, lamb weaning weight and wool cut are all a function of ewe body weight or body condition. It was evident in the farm surveys that simply applying to sheep in China the condition-scoring techniques applicable to Australian animals underestimated their subsequent performance.

Changing lambing time

The current time of lambing in the project villages is highly influenced by ewe condition, which usually peaks in late summer (September) at the end of the growing season (Figure 1). At all sites, typical households join ewes at this time because it generally leads to higher lambing rates at current stocking rates. Traditionally, winter-born (January–February) lambs are sold in September at 7–8 (Taipusi) to 18 months of age (Huanxian) to minimise the amount of supplementary feed required over winter. However, increased consumer demand for meat provides both motivation and opportunity to modify the traditional lambing schedules (Notter 2008). Furthermore, the modelling highlighted a mismatch between livestock energy demands and current feed supplies to support winter lambing practices (Figure 1).

Analyses showed that at some villages, shifting lambing time had practical and economic advantages whereas at others the current lambing time was optimal. For example, shifting lambing time from January to July at Taipusi provided a better fit of livestock requirements and energy supplied by grasslands and supplementary feed sources (Figure 3). A similar improvement was observed at Siziwang when lambing was moved from February to April (Figure 3). In Taipusi, where the current stocking rate is high (3 ewes/ha), lambing in July generated a 45% increase in net farm return, due to a substantially lower cost for feed supplement compared with January lambing. More importantly, lambing in July would allow the ewe stocking rate to be reduced by 20% (0.6 ewes/ha) and still generate a 15% higher farm profit than is possible with January lambing at the current ewe stocking rate. In contrast, at Siziwang, where the optimal ewe stocking rate is low (0.35 ewes/ha), there was no economic advantage gained by changing lambing time. If the stocking rate were substantially increased, then February lambing would be better because of the high feed costs required to finish lambs to market condition over winter.

Early weaning

Early weaning has been used as a management strategy to improve feeding efficiency and potentially reduce stocking pressure on grasslands. For sheep and goats, early weaning is defined as removing the lamb or kid from the mother at 3 months of age or younger. The underlying principle is that the efficiency of converting forage sources into milk and then into lamb growth is about 24%, compared with more than 30% where the lamb directly consumes forage (Graham and Searle 1970). Additional production efficiency may be gained in improved ewe reproductive performance (ovulation and conception) due to retention of ewe body condition resulting directly from a shortened lactation period.

Weaning is a major event in the life of a lamb and usually affects growth. For this reason, successful early weaning depends on the lamb's ability to utilise solid food. When available feed is adequate there is little advantage to early weaning, but when there is little herbage, milk production may virtually cease within 2 months of lambing (Corbett 1966). This is the norm for livestock enterprises in western China, where grasslands are degraded, especially when winter lambing is practised, as is the case in the project areas. Early weaning will deprive the lambs of only small quantities of milk, if any.

Some reports of early weaning of lambs have shown this practice has the potential to increase productivity in western China. One recent study in Gansu (Table 2) compared the survival and growth rate of lambs weaned at 30, 45 and 60 days with that of unweaned lambs. Mean daily weight gain of weaned lambs from day 75 to 120 was 277 g/head/day compared with only 145 g/head/day for unweaned lambs. In addition, early weaning maintained ewe body condition. For example, weaning lambs at 30 days of age increased ewe live weight by 5.2 kg over that of ewes with lambs. In turn, this additional body condition increased breeding efficiency, with ewes returning to oestrus 30 days earlier than ewes with lambs. These results indicate that early weaning provides a practical means to increase weaning rate by maintaining ewes in better condition. This could effectively reduce ewe flock size and at the same time maintain or increase net farm income.

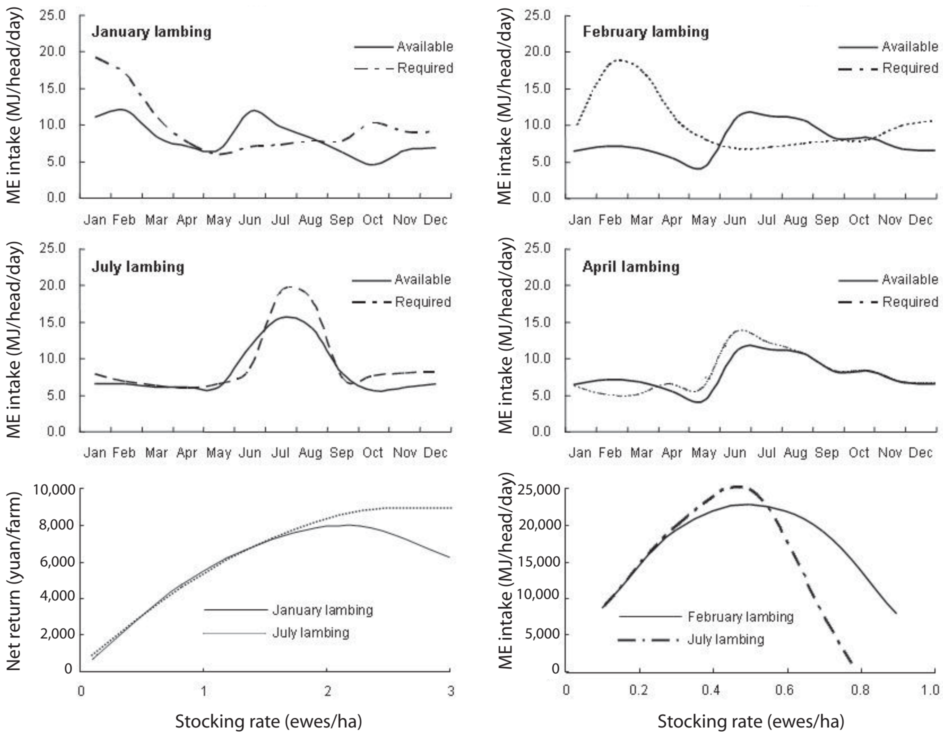

Figure 3. Change in energy balance between available and maintenance requirement for ewes lambing at different times in Taipusi Banner (left-hand plots) and Siziwang Banner (right-hand plots), Inner Mongolia Autonomous Region, and the impact on net livestock financial returns at different stocking rates (ME = metabolisable energy) (Sources: Han Guodong et al. 2011; Zheng Yang et al. 2011)

Table 2. Live weight of lambs weaned at 30, 45 and 60 days compared with unweaned lambs, Gansu province (Source: Wu Jianping and others, unpublished data)

Live weight at	Unweaned	Weaned at		
		30 days	45 days	60 days
Day 75	13	16	17	19
Day 120	24	29	34	37

Improving animal nutrition: feeding efficiency

Feed resources and nutrition constitute the principal technical constraints to ruminant production throughout Asia (Devendra and Sevilla 2002). The efficient use of forage resources, either directly through planned grazing management systems, or indirectly through the tactical use of pen feeding least-cost rations, use of sown forages and investing in infrastructure (e.g. warm livestock sheds) will future enhance per animal performance and overall productivity (Devendra 2000). The least-cost ration components of the *StageTWO* (Takahashi et al. 2011) model demonstrated the established finding that evaluating feeds on the basis of least-cost per unit of energy results in greater feeding efficiencies. It was evident in many discussions with farmers that they did not understand this issue well enough. As a result, their ability to plan better rations was limited.

Similarly, knowledge of how to estimate the amount of a forage crop to grow and when to use the crop was limited. Considerably less supplementary feed was grown or purchased each year than animals actually required. For the typical households in Gansu province and the Inner Mongolia Autonomous Region, small areas of sown forage and warm livestock sheds combine to consolidate the benefits of implementing strategies to improve reproductive efficiency and help to ensure that products meet rising market quality specifications.

Artificial pastures

Improving the feed base to enhance livestock production efficiency involves the search for forage crops or pasture species that produce high-quality feed to supplement the low-quality base ration. The provision of high-quality green feed poses a significant challenge for livestock producers in the project area. The household survey showed that only in Huanxian county was there significant investment in lucerne and silage maize (Wang Xiaoyan et al. 2011). In Taipusi, Siziwang and Sunan, where low rainfall and temperatures limit the potential of artificial pastures, households buy either grain or higher quality hay to complement smaller amounts of meadow hay harvested from summer-rested areas.

Demonstrations have been set up as part of the United Nations Development Programme Global Environment Facility (GEF) component of the World Bank Gansu–Xinjiang Pastoral Development Project in several additional counties in Gansu (Hua Limin et al. 2008). Using a range of species, including oats, sainfoin, lucerne and forage maize, these demonstrations clearly indicate that production efficiency and income per animal of collaborating households were higher than those of control households. The net result was that demonstration households maintain the same net farm return as control households. For example, demonstration households in Suzhou district had 25% fewer sheep and 10% fewer goats; demonstration households in Anding district reduced sheep flocks by 16% and stopped grazing the grasslands; and demonstration households in Liangzhou county reduced goat herds by 16% (Hua Limin et al. 2008). These findings again demonstrate the potential to reduce the number of animals per household while maintaining household profitability.

Management to improve the quality of livestock products

The economic analyses presented in these proceedings assume no increase in product quality with improved management, although it is likely that will occur because China's meat and fibre markets are increasingly demanding higher quality products (Waldron et al. 2007). Livestock producers will need to further improve their technical base to ensure that these market requirements are satisfied consistently. While there are structural changes towards specialist household producers as well as commercial, large-scale enterprises, 73% of China's sheep and 63% of its dairy production are accounted for by smallholders (MOA 2003). As market specifications become more developed, it will become increasingly difficult for small households to both breed and finish animals efficiently. This means that further development of the modelling framework is needed to incorporate aspects related to product quality and genetic improvement to help small households identify the most suitable combinations of livestock product and breeding system. The modelling presented here, which shows clear benefits from a range of tactics, has been purposefully conservative to build confidence in the outcomes recommended.

Infrastructure changes: using warm sheds to improve feed efficiency

Warm (greenhouse or solar) sheds (Huang et al. 1995) have emerged as important infrastructure for raising livestock in western China where mid-winter temperatures often drop to –30 °C and below. At these temperatures, the low-quality forage consumed is insufficient to maintain live weights and body temperature. Livestock suffer significant weight loss over the protracted winter, even when housed in traditional sheds, as the inside temperature is often below –10 °C (Huang et al. 1995). In contrast, warm sheds that incorporate a fixed or moveable solar collector in the roof and on part of the wall on the south-facing front of the shed maintain an inside temperature in January of about 5 °C during the day and just above 1 °C at night (Huang et al. 1995). Under these conditions livestock either maintain or increase live weight over the winter period, without changing the type or amount of forage made available to livestock.

The high economic and social benefits of greenhouse sheds were demonstrated in Sunan county (Table 3) as part of this project. As was reported by Huang et al. (1995) for cattle, all classes of sheep housed in the warm shed gained weight over winter, whereas all animals in the conventional shed lost weight. In effect, the warm shed substitutes capital for energy, which means that its impact is greatest when the base nutrition is moderate to low. The *StageTWO* model output (Figure 4) for a combination of warm shed investment and pen feeding predicts that current net returns from a fine-wool enterprise with January lambing could be generated with a significant reduction in stocking rate. The use of terminal sires to produce high-quality lambs from part of the fine-wool flock would further increase net farm returns through higher growth rates and improved carcass quality. The use of more productive animal genetics in China depends upon improving the use of feed supplies so that such potential can be expressed.

Changing management to improve grassland condition

The prime aim of this chapter is to analyse general strategies to re-design grassland livestock produc-

Table 3. Comparison between adult ewes, replacement ewes and lambs housed in warm or conventional sheds in Sunan county, Gansu province (Source: Ma Zhifen 2008)

Indicator parameters	Livestock in warm shed			Livestock in conventional shed		
	Adult ewes	Replacement ewes	Lambs	Adult ewes	Replacement ewes	Lambs
Mean initial live weight (kg)	43.5	31.8	21.0	42.4	30.1	23.4
Mean final live weight (kg)	48.6	41.6	27.9	35.1	25.1	22.4
Live-weight gain (kg)	5.1	9.8	6.9	–7.3	–5.0	–1.0
Live-weight gain (%)	12	31	33	–17	–17	–4

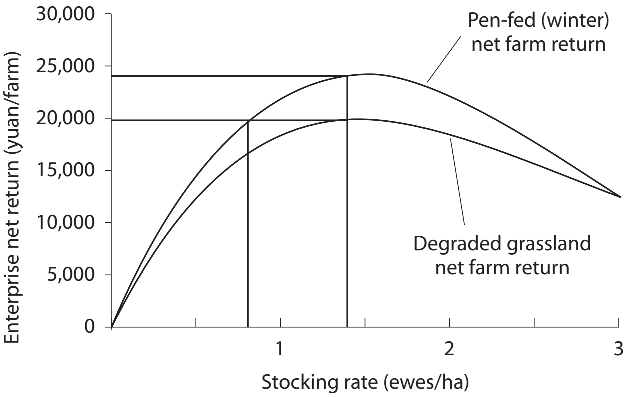

Figure 4. Net financial return for livestock for a fine-wool enterprise with January lambing with and without pen feeding in a warm shed, Sunan county, Gansu province (Source: Ma Zhifen 2008)

tion systems to reduce stocking and, at the same time, maintain household income. It is appropriate to consider some of the broader implications that changes to livestock management have on grassland condition. Are the impacts of stocking rate reductions of the order predicted at the household level sufficient to reverse current trends in grassland degradation?

Table 4. Summary of potential (general) options identified by modelling to reduce stocking rates in Gansu province and the Inner Mongolia Autonomous Region

Principle or management factor	Caveat	Experimental sites			
		Huanxian	Sunan	Taipusi	Siziwang
Change enterprise	Maintain current net farm return	Change to wool; reduce stocking rate (SR) by 25%	No change	Change to wool; reduce SR by 25%	?
Increase weaning rate (WR)	Maintain current net farm return	?	?	?	70–90% WR; reduce SR 22%
Change lambing time	Maintain current net farm return	?	Reduce SR 35%	Reduce SR 38%	No difference; negative at high SR
Early weaning (45 days)	?	Increase weaning rate through early return to oestrus and better ewe condition			
Pen feeding and warm shed combination	Maintain current net farm return	?	Reduce SR 42%	?	?
Artificial pastures	?	Demonstrations indicate reduction in SR of 10–25%, depending on current grassland condition			
Precision management (genetics for wool and meat quality; live-weight gain	?	Expected to increase product output, product quality and profitability/ewe			

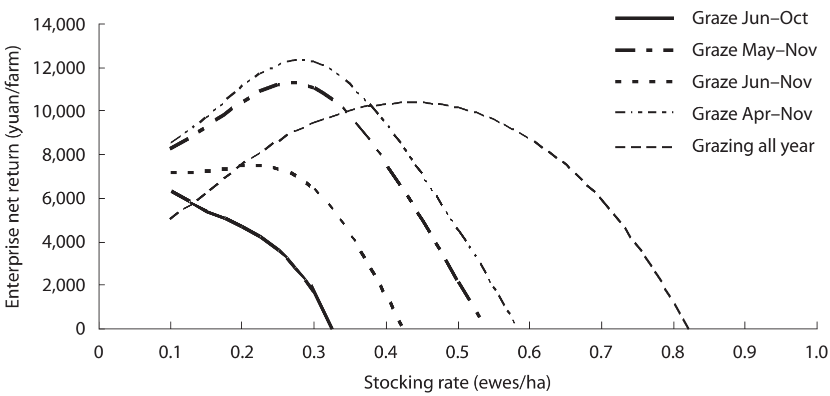

Figure 5. Total net livestock income under different grazing strategies and a range of stocking rates. Grazing strategies were combined with pen feeding in non-grazing periods.

Management tools for grassland improvement that are linked to livestock production include changes to stocking rate and changes to grazing season. It is clear from research in western China that reducing livestock stocking rates releases extra biomass that can be used to sustain the remaining animals in a better condition thereby increasing productivity and/or contributing to the re-building of ecosystem function. The large number of options identified by modelling are being complemented with field demonstrations showing small households how they can reduce stocking rate and maintain current farm income (Table 4).

Changing grazing season by implementing strategic rests will increase the opportunities for additional biomass production, species recruitment, retention of cover at critical times and an improvement in biodiversity through changes in species composition over time that will bolster resilience. The capacity of grasslands to respond to strategic rest was shown in Taipusi where a seasonal grazing ban imposed from early April until late May each year doubled available biomass in August to 1.6 t/ha (Zheng Yang et al. 2011). Similar investigations at Siziwang (Han Guodong et al. 2011) indicated that grazing restricted to the growing season was more profitable than year-round grazing (Figure 5) especially when stocking was at the typical farm rate of about 0.35 ewes/ha. However, irrespective of stocking rate, net farm return declined when grazing was reduced to 5 months or less, due to the current costs of providing supplementary feed. Analyses at Huanxian (Wang Xiaoyan et al. 2011) showed that, due to high feed costs, the decline in net farm income when grazing was confined to the summer–autumn period. That scenario analysed the value of rotational grazing and found no significant difference in income generation compared to year-round grazing. This is an important finding because it confirms that rotational grazing could provide good opportunities for rehabilitating grasslands, provided the strategic rest periods are based on the phenologies of the key species.

Conclusion

Despite opportunities arising from the growing demand for livestock products, China's livestock sector is facing threats from increasing pressure on land and water resources, and it is an imperative that the efficiency of livestock production be improved. The current livestock production system across the four villages studied is still based upon a traditional 'management for survival' strategy, especially at the household level. Using household survey data and modelling approaches, this work has identified a range of management options that, if adopted, could improve the sustainability of small livestock producers in western China. By considering a change in livestock enterprise to better match feed resources, changing management of current enterprises and/or improving the feed supply using known and existing technologies, households have the potential to achieve significant stocking rate reductions across a range of grassland types and conditions, and livestock enterprises, without incurring penalties in net farm income.

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Demonstration farms to improve grasslands and household incomes in western China: what can be done and what are we learning?

David Kemp, Han Guodong, Gemma Junk, Colin Langford, David Michalk, Geoff Millar, Taro Takahashi, Xu Zhu and Zhao Mengli

Abstract

Previous chapters have outlined tactics and strategies that can be employed to maintain and/or improve net household incomes from livestock, and then provide opportunities to improve grassland management by reducing stocking rates. Those tactics and strategies can be grouped into key areas, with components that can be implemented within current farm structures, while other aspects are more medium term. Central to many of the changes that can be implemented is the need to identify which animals to keep or cull. The *StageONE* model was developed to identify the best to worst animals and a strategy for culling. The extra cash generated from culling the least productive animals can then be used to finance farm improvements. An initial study was done on 12 demonstration farms to first cull extra animals and then provide better feeding and housing for the remainder. In general, the farms involved showed benefits, but not as great as expected. The experience gained in implementing change on farms is discussed.

Introduction

The challenges of improving the grasslands and household incomes in western China are considerable. While it is generally acknowledged that overgrazing is a major cause of the current state of grasslands, it is still a major problem to reduce animal numbers sufficiently to enable grassland rehabilitation without causing any fall in household incomes. Reorganising farms may enable amelioration of the grassland problem and identification of a pathway to income improvement.

The modelling work done within Australian Centre for International Agricultural Research (ACIAR) project LPS/2001/094, 'Sustainable development of grasslands in western China', and reported in papers in these proceedings (Kemp and Michalk 2011) has identified a set of changes that could be made on farms to improve incomes and opportunities for grassland rehabilitation. Various proposals have been made and a subset is presented here of the initial and subsequent points that need to be considered as farm improvements occur. These points are listed under subheadings below. Under each subheading the first item covers what can be done at the start of a farm improvement program; the second identifies activities to be introduced after the first changes are implemented.

This paper reviews the work done during 2007–08 in the Inner Mongolia Autonomous Region that has taken the outcomes from the ACIAR project and tested them on demonstration farms, in a supplementary project funded by the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF). Only the first stage work has been investigated to date. This paper discusses the plans developed and the experiences of implementing them on farm. This required the development of a tool for separating which animals to keep or cull and to decide on cut-off points where benefits for income

Pp. 152–161 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.

could be maximised. Future stages are outlined, as farm improvement is a continuing process. General directions can be set, but the detail of how changes are implemented is subject to many influences, not the least being the attitudes and beliefs of the herders.

Farm improvement

The earlier chapters in these proceedings have outlined the results of farm surveys and modelling and various general considerations for farm improvement. The tactics and strategies for farm improvement can be grouped into several key areas. In each area there are, as noted above, initial changes that herders can employ to improve incomes while reducing stocking rates. In addition, consideration needs to be given to what should be the subsequent changes to farm practice that will build upon the initial changes with minimal disharmony. These areas are outlined below. In this chapter any change in enterprise, such as from mutton to fine-wool production is not considered, rather only those initial changes based on use of existing resources.

Finance

1. A critical issue in making any changes on farms is to minimise the transition cost for herders as they change their livestock farming system. The ideal is to make any changes self-financing. As obtaining suitable lines of credit is difficult, the solution proposed is to cull the least productive animals and use the proceeds therefrom to finance, first, more and better quality fodder and, subsequently, more efficient animal genotypes.
2. As farm changes occur and herders start producing more animals, that should attract better premiums in the market, then ways for herders to have a more equitable role in markets need to be considered. Farmer marketing associations are one possibility. This will probably require some local consensus as to the type of animal production herders within the region will engage in.

Grassland management

1. Better management of grasslands is critical for their rehabilitation. There are several components involved:

   1.1 Stocking rates need to be reduced and grazing confined to when animal production from grass can be optimised. The available data show that animal growth is positive only when the grass is green and when the herbage mass is above some minimal values. Reduced stocking rates means that more forage would be available per head, and hence greater production per head would be possible, provided that individual households have control over their own grazing lands. That means that, in many areas, grazing should be confined within June to September.

   1.2 Stocking rates need to be reduced to enable better opportunities for plants to regenerate and build reserves to survive the winter. There is no evidence that grazing through autumn, winter and spring provides any net benefits to animals and, arguably, it damages the grasslands. The energy costs of walking and maintaining body heat typically exceed the energy obtained from grazing minor amounts of frosted grass. No grazing should occur through autumn, winter and spring. That would have the added benefit of retaining more groundcover, which could improve plant growth in the following summer and help to reduce dust storms. Animals should be fed in warm sheds and yards in autumn, winter and spring, to reduce damage to the grasslands and to improve animal performance as discussed below.
2. When stocking rates are reduced to where the more productive animals can deliver more animal product and hence improve incomes, it will then be possible to introduce improved grazing practices designed to increase the amount of herbage available per head and to help foster grassland regeneration. Some form of rotational grazing is arguably the way forward. Tactical rests are useful to enable plants to flower, set seed and recruit new plants of desirable species. Rotational grazing can be introduced through subdivision fencing and/or exercising control by herders. Research is needed to resolve which are the better grazing tactics and strategies.

Animal management

Animal management (and feeding, as in the section below) needs to move from the current practice of survival to at least preventing weight loss, i.e. for maintenance, and then managing for a more consistent level of production.

1. The first step to move from survival to maintenance requires that all animals on a farm be tagged, weighed, condition scored and classed to identify the more productive animals. Tools have been developed to then analyse those data and select the better animals to keep (described below). It is anticipated that up to half the animals on many farms could be sold, aiming for sales at the end of summer to reduce pressure on winter fodder stores. At least that level of cull will be required to enable a start to rehabilitation of grasslands. The remaining animals then have access to more fodder and should thereby be more productive. The expectation is then that net incomes per household are likely to increase (Han Guodong et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng Yang et al. 2011). The proceeds from sale of the animals that are culled can then provide extra cash to purchase more and better quality fodder for autumn, winter and spring so that the remaining animals are better fed and more productive. More attention needs to be paid to routinely monitoring all animals and using better designed yards (see below) so that any health problems can be quickly identified and treated.
2. Once animal numbers are significantly reduced, attention can be directed to resolving the breeding objectives, e.g. for lamb meat, mutton, wool, cashmere etc. The broad goal is to assess how best to move from maintenance to managing animals for a consistent, higher level of production. Other changes that need to be considered are whether to focus on breeding or finishing systems for livestock, or simply fibre production with higher quality animals. With reduced numbers of more productive animals it would also be appropriate to then review the livestock management calendar, e.g. when should lambs, calves, kids be born and when should they be sold.

Animal feeding

1. At present in western China, through the autumn, winter and spring most animals are fed for survival only. To justify significant reductions in stocking rates and to provide opportunities for grassland rehabilitation, animal production per head needs to increase so that there is no decrease in net household income from livestock. A reduction in animal numbers should mean an increase in the amount of stored feed available per head. That provides the mechanism to improve animal production.
   - 1.1 The strategy for feeding the animals kept on the farm needs to be revised to ensure optimal use of better quality fodder. The fodder typically stored on farms can be broadly classified into three groups: feeds that result in weight loss, weight maintenance or weight gain, provided a sufficient quantity is fed. The better quality feed should be used around critical times, such as at lambing. The amounts fed need to be at least marginally above current rates and, in many instances, a doubling in feeding rate could be justified.
   - 1.2. Animals would be better pen fed throughout the autumn, winter and spring, inside warm, 'greenhouse' sheds to minimise the energy losses due to cold weather.
2. As animal numbers are reduced and feed rations revised, more attention can then be paid to obtaining larger amounts of better quality feed and eliminating the poorest feed sources. The plants used for the poorer fodder could be harvested earlier and made into silage. Much work needs to be done on improving the quality of stored feed. Lucerne (alfalfa) and maize are key feed sources, but often the quantities available on farms are below requirements for animal production. Some changes may be needed in regulatory environments so that herders can increase the area sown, or to encourage neighbouring districts to grow more for sale.

Infrastructure

1. Many farms have limited facilities to help manage livestock. That limits the treatment of animals and restricts routine tasks to when neighbours and family members are available to help. Key improvements that can be made are to convert sheds to warm 'greenhouses', where such are required, and modify yards with races, pens and creeps so that all animals can be regularly checked with limited labour.
2. As farms develop, the boundary fencing needs to be fixed so that animals are confined when required, neighbouring animals cannot graze fields and herders are able to do other farm tasks

during the day. Water supplies can be further developed so that the need to walk significant distances to water each day is reduced. Water needs to be near sheds so that animals can have a drink in protected areas. Allied to this will be the need to ensure all animals are adequately identified.

Selecting the animals to keep on farms in western China

It was evident on the farms surveyed in northern and western China that significant improvements in farm productivity could be achieved by first identifying those animals that would be the more productive and culling the others. This means livestock improvement can start with the existing flocks, then as incomes improve, better quality animals can be introduced and the other recommendations noted above implemented. Methodologies were then developed to do that, based on some basic measurements on existing livestock. This section outlines the initial procedures developed for the *StageONE* model to identify which animals to keep or cull. Future studies are needed to develop the methodology to make these decisions on the basis of a greater range of farm data so that the predictions are more accurate. In this case, average effects of, for example, wool and lamb production were used, whereas these are likely to vary more with the condition of individual animals. The methodologies being developed here are the first steps for China in developing local systems for the precision management of livestock.

All the sheep and goats in each flocks on 12 farms in two villages, Siziwang and Taipusi in Inner Mongolia, were monitored. Starting in June 2007, 4,500 animals across the farms were eartagged and then their live weight, fat score, and teeth and udder condition measured. These data were then used to estimate the financial value during the next year for each animal over 1 year old. This was done by estimating the probable weaning percentage then, in the case of females, the notional weight of lamb or kid produced. The value of meat from that lamb or kid was then estimated, as much of the farm income came from meat. No data are available on individual production of wool or cashmere, or on individual lambing and kidding performance males. In general it was assumed that, given the typically low fat scores for sheep and goats in China, they produce more lambs and kids than would animals in Australia. Australian data could therefore not be directly used; only the likely form of the relationships. This may reflect genetic differences and that, from soon after birth, lambs and kids are separated from their mothers and handfed, reducing the lactation stress on their mothers. Maiden animals (1–2-years old) do not produce a lamb or kid until soon after 2 years old. To avoid ranking them lower than was reasonable, these young animals were assumed to produce a lamb or kid within the year.

No estimate of value was made for the lambs or kids born from future offspring, or of the meat or fibre produced. However, if a ewe or doe produces a lamb or kid, and is in good condition, such animals would normally rank high and the risk of culling these better animals was considered minimal. Future work needs to consider evaluating lifetime performance versus these estimates for 1 year. Further research to define these relationships in China is clearly warranted.

Animals under 1 year of age were ranked separately from the others to check for any with basic faults that would influence their productivity. Those data are not considered here. The numbers of those animals to be retained would depend upon the flock structure and this differed between farms. The numbers and types of replacement animals depend to a large degree on the current flock structure and animals culled.

The data collected were then used to construct the *StageONE* model for livestock improvement using the postulated impacts on production of meat, fibre and progeny to then value each adult and maiden animal. Costs were deducted and the animals ranked from the most to least productive. The factors involved in the model are discussed below.

Animal species and subgroups: sheep or goats were subdivided into younger and adult animals. These were animals less than 1 year old, maidens (young females) 1–2 years old and mature animals over 2 years old. There were some special categories, e.g. for lambs produced by embryo transfer that were being raised under contract to a feedlot and would not be considered in the potential flock for a farm. Their performance related to external genetics, extra supplements and not much to the ewe wherein they developed. Those ewes were then considered to have 'potential' for lamb production similar to the others in that flock. Animals were further grouped into females, males and wethers.

Animal breeds suffer from poor classification arising from somewhat indiscriminate breeding practices. It was decided to group the animals on their primary product, i.e. fibre or meat, and assume all within a group would produce a similar quantity and quality of product. As flocks become better selected then opportunities will exist to differentiate further.

Tooth counts were used to estimate age. The groups were: lamb, milk (approximately 1+ years old), 2, 4, 6, 8,\ and '10' mature teeth. A tooth code of 10 was used for sheep and goats where the animal's mouth was badly broken and it was not possible to determine age correctly. Some animals examined had no teeth. The base weaning percentage was first estimated from the age of animals, assuming a 5% rise from maidens to 95% for two-tooth animals, then a decline with age to only 30% for animals without teeth. Then, within the range of live weights for that animal group, the base weaning percentage was varied by up to ±5 depending upon the actual live weights for that group, larger animals having the higher percentages.

Tooth condition affects animal performance. A scale of tooth wear was developed with an associated penalty for weaning percentage. Animals with few useful teeth could not be expected to consume grass adequately and they were scaled from those with some chips (15% lower weaning percentage than the 'standard' for their age) to those with almost no teeth (an added 50% decline in weaning percentage).

Udder condition will influence the ability of a mother to successfully rear a lamb or kid. A qualitative judgment was made of the udder condition in each adult female. Where udders in spring were dry to lumpy and in very poor condition the notional weaning percentage was reduced by 50–75%.

Fat score (body condition) is known to have a major influence on an animal's health and on the ability of females to rear young. Scales that might apply in Australia were not considered appropriate, as the sheep in China seem to perform better than would be expected from international data. Many sheep go through the winter and rear lambs under relatively poor body condition due to the way they are managed by herders for 'survival', using practices for harsh conditions that have evolved over centuries. Penalties for weaning percentage were imposed for only the lowest fat scores. Where fat scores were only 1.5, then a 5% reduction in weaning was estimated, while a fat score of 1 attracted a penalty of 20%.

The same scale was used for sheep and goats. However, it is known that, as their body condition deteriorates, goats will often abort a foetus, whereas sheep in similar condition will not. This often leads to 90% of ewes in a flock producing lambs, whereas in the same flock only 50% of the goats produce kids. A stronger penalty for goats could be imposed once further work identifies how best to predict that characteristic.

Further work will be needed to resolve appropriate scales to estimate fat scores for fat-tail Mongolian sheep. They may give a low fat score but, if fat reserves can be readily mobilised from the tail, then their condition may be underestimated.

Fibre production (wool and cashmere) depends to some extent upon animal age (reflecting body size). A scale was developed for relative production versus age. Then, using the average fleece yield for different sheep types and goats, the approximate production per head for different age classes was derived (Table 1). In the absence of any data on fibre quality the average price (yuan/kg) was used.

Meat production 'value' was estimated from the average weight of lambs or kids per ewe or doe,

Table 1. Assumed relationship between age and fibre production (kg/head) for mutton, wool and cashmere animals

Tooth count	Relative production	Mutton	Wool	Cashmere
	Average fibre yield/head	*2.00*	*3.50*	*0.70*
milk	0.60	1.20	2.10	0.42
2	0.85	1.70	2.98	0.60
4	1.00	2.00	3.50	0.70
6	1.00	2.00	3.50	0.70
8	0.85	1.70	2.98	0.60
10	0.50	1.00	1.75	0.35
	Price (¥/kg)	*6.0*	*12.0*	*126.0*

measured in September (Table 2). By multiplying a standard lamb or kid live weight by the summed weaning percentage it was then possible to estimate the amount and value of meat each female could produce. This approach was taken to index the relative value of a female. In practice few lambs or kids would be sold, but it was considered that the relative benefits of the breeding and production performance of each female would be similar in ranking to this approach. Further data are needed to estimate how lamb weights in September relate to birth and weaning weights and to ewe live weight and condition.

Feed costs through autumn, winter and spring are a major animal production cost. As feeding regimes are difficult to discern and often all animals are fed in common, the average feed cost per head was used to then estimate the net revenue per adult animal. Similarly, a common cost for animal husbandry (veterinary cost) was used. Veterinary costs were surprisingly low (typically ¥4/head/year) reflecting a significant local subsidy. These costs varied between farms and were individually estimated.

Summing effects

Using the above criteria, the estimated percentage weaning for each animal was derived by simply summing the various factors, based on age, teeth, fat scores, udders etc. Where the sum of base weaning percentage and additional penalties due to teeth or udder condition etc. resulted in values below zero, the result was set to zero. The final percentage weaning for each animal was then multiplied by the estimated lamb or kid weights to derive a value in progeny. The value of wool and cashmere was then added to that and variable costs subtracted. This simple budgeting approach was in part used to illustrate to collaborators how these indexes can be simply derived. As noted through this section, the initial parameters were based on general estimates but, if further data were collected from farms, it should be possible to then develop more accurate per-animal estimates. This is an obvious area for future on-farm research and development.

While some obvious assumptions had to be made to estimate the productive capacity of individual animals as outlined above, the modelled data were calibrated against a record of which animals should be kept or culled made at the time the original measurements on flocks were done. That record was based upon Australian experience in classifying animals. This process meant some adjustments in initial values resulting in the methodology outlined here.

Identifying animals to keep, query or cull

The methodology developed to classify livestock in the first year of a transition to a better, reorganised system is illustrated in Figures 1 and 2. The cumulative gross margin (in RMB, where A$1 ≈ ¥5) is plotted against animal ranking from the best to worst. The emphasis developed here is on not reducing net financial returns, while significantly reducing animal numbers. It is important to emphasise that this approach aims to minimise transition costs during the initial phase of farm reorganisation and not simply to aim for the current ideal economic solution. Money gained from selling the least productive animals can then be used to better feed the remaining animals, purchase better quality livestock and improve overall management of the farm.

Figure 1 is for the initial results for one of the demonstration farms at Siziwang (denoted as SE1). This farm has the best-quality livestock of all the farms within the project. It is used here to illustrate that even in this case there is room for improvement. On this farm there are sheep and goats for both meat and fibre production. Figure 2 is for a different farm (SE2) with an initial feed cost that was half that of farm SE1 and where the potential responses to increased feed supply were greater.

The animals are ranked in descending order from those producing the higher estimates of annual income to the least. Point A on each figure is the estimate of the gross margin for all the livestock on the farm at present. Working back from point A to B shows where the same net income can be achieved

Table 2. Average live weights of lambs and kids in September (notional sale time) and price per kg live weight. These are average values across 12 farms surveyed.

	Mutton	Wool	Cashmere
Lamb/kid sale weight in September (kg)	20.0	20.0	18.0
Lamb/kid slaughter price (¥/kg live weight)	8.0	8.0	6.0

with fewer livestock, i.e. retaining those that are more valuable. When livestock numbers are reduced but the amount of fodder available remains the same this allows for more fodder per head which, in turn, would result in an increase in animal product. The upper curve then reflects estimates of these responses. Point C is where the net financial returns is the same as at A or B, but with better fed animals. There is a smaller difference between these curves for SE1 than SE2 as SE1 already spends more on fodder per head than its neighbours. The upper curve has double the fodder cost for the better livestock up to point D. Point D is where the total feed cost is the same as at present, i.e. as applies to the lower curve at point A. On the upper curve after D there is a declining rate of fodder supplied until the last animal is fed the same as for the lower curve. It would not be realistic to feed all animals at the higher rate, especially the poorer ones, many of which are making a net loss.

One option for reducing animal numbers is then at B, and the vertical line at E estimates the net income for better fed animals. Thus, reducing the number of animals and feeding them better is expected to result

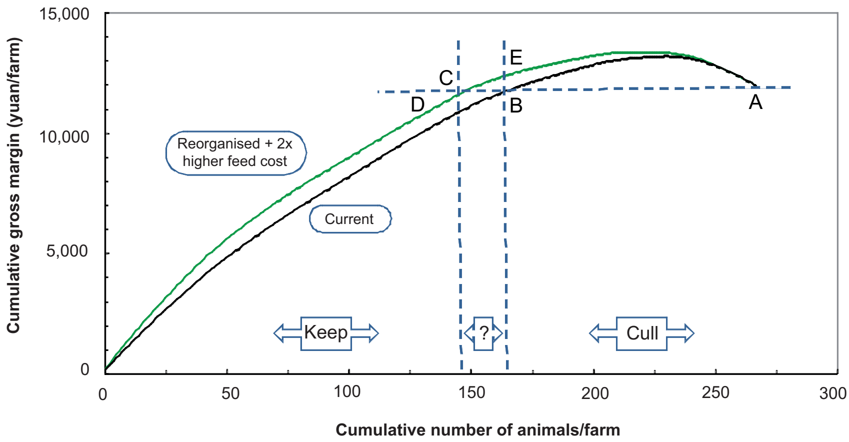

Figure 1. Estimated cumulative value from best to worst animals on demonstration farm SE1 at Siziwang Banner, Inner Mongolia Autonomous Region, in 2007. All livestock were less than 1 year old.

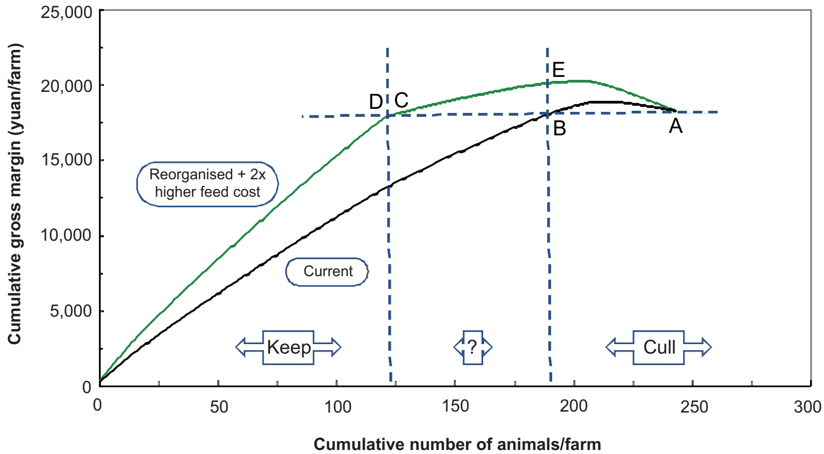

Figure 2. Estimated cumulative value from best to worst animals on demonstration farm SE2 at Siziwang Banner, Inner Mongolia Autonomous Region, in 2007. All livestock were less than 1 year old.

in higher net income than at A, the current net farm income. A second option is to reduce animal numbers to the vertical line at point C. This may not increase net income but neither does it reduce it. It is likely, however, that these estimates are conservative, as all animals have been treated the same in this analysis, whereas the better animals are likely to do even better.

The animals to keep are then those to the left of the vertical line at C, the culls are those to the right of the vertical line at B, while marginal animals would be those between the two vertical dotted lines. Which animals to keep or cull in this zone would depend upon the likely feed supply and what animals need to be retained to improve flock structures. In this zone it is likely that the total feed costs will be higher than at present. The difference can be financed by the sale of culled animals.

The lower curve is maximal between points A and B. This does not reflect the economic optimum as fixed costs need to be taken into account, which shifts the optimum closer to B.

Initial demonstrations

The implementation of these proposed changes on farms commenced through 2007 and 2008. The farms involved in this work did reduce their livestock numbers by the order suggested, but they sold more of the better animals! Analyses were made of the benefits achieved by herders from their own culling of livestock in response to our proposals and what we anticipated would be the benefits from our proposals. These effects show (Tables 3 and 4) that while they did achieve an improvement in incomes (actual cull + current feeding rate) it was less than could have been the case (recommended cull + improved feeding) and has not enhanced their ability to improve incomes in the future, as the remaining stock had lower production potential. In both tables the recommended cull maintained net income in comparison to no change, but provided approximately twice that net income in cash from sales of culls. Improved feeding did increase net income, but as the gain in net income was less than

Table 3. Changes in sheep and goat numbers in 2008 in Siziwang Banner, Inner Mongolia Autonomous Region, and the impact on net income (yuan) from no change, actual culls and recommended culls. Estimates are averages for three demonstration farms where animals were fed at current rates or fed at approximately twice normal rates, i.e. same amount of fodder per farm fed to fewer animals.

Scenario	Feeding rate/head	Animal number/farm	Total feed cost/farm	Net income/farm	Cull sales	Net income + sales
No change	current	249	11,472	15,460	0	15,460
Actual cull	current	153	6,957	10,631	23,040	33,671
Actual cull	improved	153	11,465	12,060	23,040	35,100
Recommended cull	current	134	6,127	12,441	27,680	40,121
Recommended cull	improved	134	11,451	15,497	27,680	43,177

Table 4. Changes in sheep and goat numbers in 2008 in Taipusi Banner, Inner Mongolia Autonomous Region, and the impact on net income (yuan) from no change, actual culls and recommended culls. Estimates are averages for three demonstration farms where animals were fed at current rates or fed at approximately twice normal rate, i.e. same amount of fodder per farm fed to fewer animals.

Scenario	Feeding rate/head	Animal number/farm	Total feed cost/farm	Net income/farm	Cull sales	Net income + sales
No change	current	103	2,053	8,146	0	8,146
Actual cull	current	54	1,073	4,436	11,760	16,196
Actual cull	improved	54	2,032	5,734	11,760	17,494
Recommended cull	current	41	813	5,250	14,880	20,130
Recommended cull	improved	41	2,060	8,516	14,880	23,396

the cost of additional feed at Siziwang, this was in an area of diminishing returns. At Taipusi, extra feeding resulted in greater gains in net income. The economic optimum feeding rate for these livestock needs to be determined with more on-farm work. The extra cash, while valuable for the household, was designed to enable farm improvement, e.g. building warm sheds and better yards, purchasing better quality livestock etc. Some herders are interested in doing that, but it became evident that the complexity of changes is more than they are used to dealing with.

Review of progress

These initial on-farm results described above were reviewed to identify what herders had done and the areas requiring further work. These points are summarised in terms of the categories for change on farms described earlier:

Finance

The demonstration farms, which received advice on the greater number of animals to cull, sold more livestock than the controls, i.e. they accepted the general point that income could be improved with reduced animal numbers. This provided extra household income that can in part help finance farm improvements.

Grassland management

Herders reduced stocking rates after summer, even in common grazing lands, although they kept grazing through autumn, winter and spring. Early summer grazing bans to help rehabilitate grasslands were accepted, but a winter grazing ban was not. Winter grazing greatly reduces groundcover, increases soil erosion rates and accentuates weight loss in livestock. There is a poor understanding of an animal's energy balance, leading to the belief that any 'pick' is better than nothing.

Animal management

Animal numbers were reduced by the order of numbers recommended, but herders did not keep the best and cull the worst: rather, the reverse applied. Taipusi herders sold more of the larger animals than did herders at Siziwang. Herders appreciated the need to reduce animal numbers. Siziwang herders supported recommendations more strongly than the poorer herders at Taipusi, but traders demanded the better animals rather than the cull animals offered by herders. It was clear that the herders were happier from selling more livestock because they had more cash during a difficult year. How the additional income was used needs to be resolved. Herders feel they are in a weak position when dealing with traders, especially when the traders buy livestock and livestock products on-farm. Local officials recognise that the highly individualist trader-dominated marketing system can, in some cases, work against the interests of herders, but they also recognise that the traders play an indispensable role in the local livestock economy. Various forms of training, registration and management of traders have been attempted but it is an extremely demanding task due to the itinerant nature of the traders. As a result, there have been widespread efforts to develop alternative marketing channels, including the construction of physical marketplaces, the introduction of marketing agencies (especially for wool), direct contracts or agreements with processors for sheep, cattle and milk, and the development of cooperatives, associations and 'small livestock raising areas'. All of these alternatives involve a set of complex and challenging issues that have yet to be tackled effectively, but doing so would deliver major benefits to smallholders in western China. Training herders in how to deal with traders is a clear need.

Animal nutrition

While herders supported plans to feed appropriately, they did not buy increased amounts of high-quality fodder, or enough feed to supply their animals through the whole autumn, winter and spring. They are wary of expense and unfamiliar with the large responses that are possible. Their focus was clearly on achieving survival of animals, rather than maintaining them in the best condition possible.

Infrastructure

All herders used warm sheds, but still grazed on cold days. The benefits of the warm sheds were then limited. At Taipusi, one herder who was not in the monitoring group, did split his flock and those that were kept in a warm shed and did not graze in winter were reported to be larger in spring. This occurred with no change in the feeding regime. There is a poor understanding of how to use warm sheds effectively. Animals may be kept in overnight but still taken out on cold days. There is a need for rules about when to graze, based on temperature, wind speed etc. No yard improvements were made, which means most animals are not inspected in any systematic way. Inspections of all animals seem to be made only twice a year, in spring and in autumn.

Some general points emerged from the experiences of this project:

- Herders are very focused on the short term, e.g. today and the next few weeks. Even if they want to think further ahead, local officials often see any planning beyond 6 weeks as their responsibility to develop and then advise herders.
- Farms are not often seen as a business and have traditionally been viewed as a means of survival. There needs to be training in developing a farm plan and promotion of the concept that cash in the hand is not necessarily the best way to run a business.
- Subsistence/survival thinking tends to dominate the approach to farming livestock. This aligns with some residual thinking that livestock numbers are as important as animal size and productivity. Some innovative herders still want to have the most animals, even although they acknowledge they may not get as much money for them. If animals survive the winter, that is regarded as success, even if those animals lost 20–30% of their live weight and lambs or kids have a birth weight of 2–3 kg and very poor growth rates. Precision livestock management is a new concept and needs to be developed through a research and development program.

These considerations suggested that a way forward is to use demonstration farms involving local herders to investigate alternative production systems designed to improve incomes and grasslands. Local farms should be leased for this purpose. Demonstration farms would enable faster change and would help to foster local discussions among herders.

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Talking with China's livestock herders: what was learnt about their attitudes to new practices

Wu Jian-ping, David Michalk, David Kemp, Yang Lian and Gong Xuyin

Abstract

Chinese herders and their pastoralism are experiencing major transitional processes from being subsistence–survivors to market-engaged producer–managers. At the same time the resources upon which their livelihoods depend are degrading. Chinese herders in northern and western China are coping passively with changing markets as they pursue profitability while being uncertain about how to overcome the pasture degradation caused by overstocking. Technical support programs, as distinct from government campaigns, have been few and, in general, improvements in grassland resources have been limited, except when government has imposed grazing bans and provided subsidies to remove livestock from the landscape. Herders are the key people in managing these vast natural resources and their goals are now more to grow their livestock businesses than simply survive. Recent experience has been that meaningful technical assistance within constructive working programs with herders is essential to enable change towards sustainable pasture management. This paper discusses the success of an Australian Centre for International Agricultural Research project in Sunan county, Gansu province, and what has been learnt in association with herders in extending advice on better livestock management to reduce stocking rates and improve household incomes from livestock farming systems that are largely dependent on grasslands. On-farm demonstrations are a vital part of any new applied research and development program.

Introduction

Effective transfer of technology plays a pivotal role in increasing the benefits to farmers and ensuring the future sustainability of agricultural production. Agricultural extension is a deliberate process of increasing farmers' awareness of options to change agricultural practices, followed by the adoption of improved technology and skills from any source (agricultural research, agricultural education and a vast complex of information-providing businesses) to enhance production efficiency, profitability and environmental values (Roling 1988; Nagel 1997).

Agricultural extension in China is traceable as far back as 3,000 years ago and, since the formation of the People's Republic, China has maintained the world's largest public extension service network (Shao and Bruening 2002) which, in this decade, still comprises more than 385,000 extension agents (Mei 2005). However, agricultural extension and farmer education have undergone considerable change in China, brought about by the transition of the nation's economic system from a planned to a market-based economy. As Chinese farmers gain more freedom to make their own management decisions, the 'top-down' extension approach that played such a significant role in promoting technological progress and agricultural development from 1952 to 1982 (Zhu 1995; Fan 1996; Huang Jukin and Rozelle 1996; MOA 1999) has become progressively less effective. Ding (2006) reported that, despite consistent improvement over the years, the transfer of scientific and technological innovation into China's agricultural sector remains low compared with developed countries.

This reflects the nature of the top-down approach, which is best described as 'administrative intervention': agricultural extension and farmer education

Pp. 162–176 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.

were seen as government instruments for implementing agricultural development using methods more akin to a political campaign (Shao and Bruening 2002). In practice, the programs were so closely focused on government policy that different socioeconomic conditions and resources in the communities where new technology was implemented were not given sufficient consideration, and local interests were poorly represented (Liu 1998). More importantly, farmers were not involved in the extension planning or evaluation because, under the centrally planned economy and commune model, farmers were considered only as the labour force needed to achieve production goals (Liu 1998).

To keep in pace with the shift from collective to household agricultural production (Lin 1987, 1988) and to accommodate growing concern for sustainability and equity (Lin 1988), China is re-focusing extension by developing ‘bottom-up’, demand-driven, cooperative systems to replace the top-down paternalistic model (Yang Yinghui 1993). The goal of a strong, bottom-up process is to help small farmers to identify their needs and develop solutions through considering appropriate and acceptable technology. This requires close engagement, because farmers operating in a market economy do not necessarily believe extension agents or adopt new technologies without taking the opportunity to subject the information to close and personal scrutiny as part of their risk assessment. Access to credible information and the trustworthiness of extension agents are important to mitigate risk related to the adoption of new agricultural practices (Sligo and Massey 2007), and participation is empowering because farmers take an active role in defining their own needs which, in turn, heightens their awareness of local conditions and strengthens their capacity for self-reliance (Ondrusek et al. 2003).

The use of participatory methods, together with greatly improved cooperation between research, education and extension providers, has resulted in the transformation and transfer of modern hi-tech agricultural achievements. This is moving Chinese agriculture from traditional practices to use of modern systems (Ding 2006). This is most apparent in the cropping and horticultural sectors where small-farm households are now the managers of land resources and are making their own decisions on how to achieve the best economic returns and reduce risk from market fluctuations (Liu 1998). The combination of technology transfer and market development has improved both productivity and product quality, the latter to meet the demands of China’s large urban population. Quality improvement is evident in China’s agricultural exports, the value of which has grown from US$400m to $1.5 billion a year in a decade, a trend that is not likely to be reversed. This confirms that small rural households can be successfully mobilised and trained to supply the new, high-value domestic and international markets (Swanson 2006).

In western China, however, where herders rely primarily on grasslands to sustain ruminant production enterprises, it has been, for several reasons, more challenging to achieve technology transfer comparable to that achieved in intensive agricultural production systems. Poverty is endemic in western China where rural households have poor asset stocks (natural, physical and human capital) and limited inflows of capital such as finance, technology, information and talent (Wu and Pretty 2004). In general, these impoverished herders have insufficient skills and knowledge to make decisions in a market economy. Traditionally, their skills reflected survival needs, and they are additionally handicapped by a severe lack of market information (Liu 1998). Studies show that households with low innovative capacity are unlikely to adopt new management practices unless major barriers (information, credit or selling risk) are removed (Wu and Pretty 2004).

Formulating and implementing innovative extension programs to remove these barriers is essential if there is to be a significant rural development breakthrough in these marginal areas where remoteness and inaccessibility limit progress (Delman 1991; Wu 2003). The papers in these proceedings have documented the changes that have occurred on the grasslands in recent years and the initial steps herders can take that provide opportunities to simultaneously maintain or improve household incomes and rehabilitate grasslands by stocking with fewer animals. This paper discusses how various practice changes identified through Australian Centre for International Agricultural Research (ACIAR) Project LPS/2001/094 on the ‘Sustainable development of grasslands in western China’ can be effectively extended to herders. More importantly, the experience gained to date by working with herders, particularly in the Sunan Yughur Autonomous County in western Gansu province, provides a good foundation on which more effective livestock extension programs can be built.

Changing livestock production systems and herders' perspectives

Despite China's strong and sustained economic growth, poverty persists, especially in remote rural areas. Income inequalities between eastern and western China have widened, and the income gap between rural and urban residents has become much bigger since the late 1970s. Although herders in western China are experiencing major transitional changes from subsistence–survivors to market-orientated producer–managers, the rate of change is slow compared with that shown by farmers in eastern China. This slow adaptation to the market economy is explained by a combination of traditional values and inadequate extension of new technologies to remote and inaccessible areas (Delman 1991; Wu 2003).

As in eastern China, the introduction of the Household Personal Responsibility System in 1979 (Lin 1987, 1988) changed the paradigm for livestock production in the west of the country. Under this policy all livestock and rangeland resources that originally belonged to the state and were used communally were re-distributed to each householder according to family size at that time, based on a contract between government and herders (Dong et al. 2007). The initial response of herders to land-use rights and the free market was mostly passive: they accepted whatever prices the traders offered for their produce and simply maintained higher livestock numbers, or increased them, in order to maintain or improve household incomes from their pastoral activities, typical of what Neidhardt et al. (1996) describe as a keeper/survivor mode. Unfortunately, although increases in livestock numbers were initially encouraged by central-government policies that started in 1950 (Zhao Ziyang 1981), the severe overgrazing that followed rapidly degraded the grassland resources (Wang et al. 2006; Han et al. 2008; Han Guodong et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng Yang et al. 2011). The problem was compounded by expansions of cropping into unsuitable grassland environments (Wang 2000; Ren et al. 2001) and climate change impacts (Zhao et al. 2004; Zhou et al. 2005). These destructive management practices have caused one of China's most important environmental challenges, evident in the loss of groundcover, unacceptable levels of soil erosion, loss of biodiversity and the disappearance of wetlands (Smil 2004).

Due to this severe degradation, the sustainability of livestock production is now in question (Zhang et al. 2007) unless solutions are found to maintain or improve household income under circumstances in which fewer animals are dependent upon the grasslands and increased efficiency is achieved in animal production. The message promoted in these proceedings—that incomes can be maintained and then improved with fewer animals being dependent upon the grasslands, thereby providing opportunities for grassland rehabilitation—is being accepted by local officials and herders. However, that message needs to be supported by technical advisory programs aimed at providing the detailed information required for such messages to be accepted and effectively implemented by herders.

One of the foremost challenges in promoting sustainable livestock practices is to first change the mindset of herders and farmers from a subsistence to a commercial focus. To achieve this paradigm shift it is essential to understand why subsistence herders place so much emphasis on livestock number rather than productivity as their production goal, especially in the more remote pastoral areas of China. Some researchers (e.g. Bai et al. 2002) reason that this tradition of maximising livestock number is based on the cultural value placed on livestock as wealth and is the prime cause of grassland degradation. Others, however, point out that ownership of large numbers of animals can be viewed as a rational risk-avoidance strategy resulting in a better post-disaster recovery in regions where droughts or blizzards frequently cause high livestock losses (Simpson et al. 1994; Wu and Yan 2002; Miller 2005; Harris 2010).

While both may be partially true, as the herder population increases there is an inevitable increase in the livestock population which reaches a threshold at which rangelands start to degrade (Zhang et al. 2004; Zhou et al. 2005). Once this level of utilisation is reached, herders nevertheless seem to knowingly continue to graze grasslands at stocking rates well above those considered to be sustainable. Respondents (sample size 400) from herding households surveyed across China's grassland regions indicated that grassland condition had changed significantly due to increased grazing pressure since the implementation of the Household Responsibility of Grassland policy (Dong et al. 2007). Harris (2010) concludes that '…the lack of power to negotiate higher prices for produce and …

a lack of secure land tenure have favoured short-term benefit over long-term perspective of rangeland sustainability'. This indicates that overgrazing is inevitable unless income-generating opportunities for herder households are improved.

The combination of technology and the market is fundamental to responding to herders' demands for more livestock management options to enable a shift in production method away from the current practices that continue to over-exploit the already degraded rangelands (Han et al. 2008). For example, the market could function as a control mechanism to limit stocking densities if herders' profits received from growing animals faster and producing heavier, better quality carcasses exceeded those generated from current production systems (Harris 2010), as is argued through papers in these proceedings. In turn, fair market value for higher quality products may stimulate the development of specialised production systems that have efficiency and product quality as clear production goals—again as noted through these proceedings. If there is to be a breakthrough for rural development in these marginal and remote areas, then appropriate innovation is a necessary precondition.

Technical progress has been slower and improvements in efficiency much lower for Chinese ruminant production enterprises compared with those in the pig and poultry industries (Rae et al. 2006). This reflects the limited success of previous programs targeting sustainable use of China's grasslands, which can be partly attributed to adopting a component rather than an integrated approach to identifying solutions (Kemp et al. 2011a). Bioeconomic farm models provide the means to assess the combined impacts of policy changes and technological innovations on household economics and identify best mix of livestock enterprises and management practices. Using household survey data and whole-farm modelling approaches (Takahashi et al. 2011), various papers in these proceedings (Han Guodong et al. 2011; Kemp et al. 2011a, b; Michalk et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng Yang et al. 2011) have identified a range of management options which, if adopted, could improve the sustainability of small livestock producers in western China. By considering change in livestock enterprise to better match feed resources, changing management of current enterprises and/or changing feed supply, households have the potential to achieve significant stocking rate reductions across a range of grassland types and livestock enterprises without incurring any penalty in net farm income.

This implies that, at least for the four case-study counties (two in Gansu province—Sunan and Huanxian; two in the Inner Mongolia Autonomous Region—Siziwang and Taipusi) included in the ACIAR project, appropriate technology and markets are now sufficiently developed to progressively shift from subsistence to production efficiency as the main driver of livestock management. Adoption of these key finding remains a formidable challenge given the difficulties confronting extension in the inaccessible areas of western China.

New approaches to support management changes

Herders are the key players who implement practices that directly determine the degradation or rehabilitation of grasslands, as well as the productivity and value of the livestock they manage to generate household needs and incomes. However, many herders developed their values and learnt their management skills initially from the perspective of surviving within a generally harsh environment and then within the context of a planned economy, common resource ownership and cultural traditions. Transition to a market economy requires new skills to deal with the technology and decision-making that underpin the management of new livestock production systems within a commercial context. This transition is not related to the resource base of an individual herder, but rather to the criteria and processes they use to allocate their limited resources to various aspects of livestock production. The training, education and self-awareness of the local people are important for achieving economic, social and environmental sustainability.

Capacity development through tailored education and targeted training are keys in the process of change that builds knowledge and self-confidence to a level where herders are willing to take the risk and apply new technologies to a competitive, market-oriented livestock industry about which they still have ignorance and uncertainty. Without direct and effective extension, the emerging markets in China will be supplied by large-scale producers using modern production systems but, if extension is properly structured and focused, small-scale producers can also use their limited local resources to supply domestic markets (Swanson 2006), thereby helping to reduce rural poverty, which is still of major concern in northern and western China. While learning is a cognitive activity of individual people, it is influenced by social forces, and a person's perceived credibility and trust built through everyday interactions either enhances or undermines learning (Bogenrieder 2002).

This means that, to demonstrate change, understanding herders' cultural values and attitudes to change is just as important to developing effective communication and learning processes as it is to implementing an adaptive extension system based on conducted trial-and-error processes operated by farmers in their fields (Prandl-Zika 2008). Both formal and informal information channels can affect perception (Zube and Sell 1986). Continuous knowledge transfer and exchange of experiences between farmers, agricultural trainers and scientists should accompany these processes to build locally adapted solutions. To involve farmers in a process of education and exchange from the very beginning will influence the success of new strategies to a large degree and will encourage them to find their own appropriate solutions. This contrasts with conventional extension processes in which innovations are generated from a central plan with detailed prescriptions for strict implementation without modification to suit local conditions, an approach that is unlikely to be effective. This means that promoting livestock innovations requires flexible processes, close relationships and effective communication to adapt new technologies to meet the specific needs of herders in particular locations and communities. In turn, village-based projects ensure that policy links to practice in a way that leads to the development of a sustainable, effective system of livestock management extension.

Application of new extension approaches in Sunan county

In the ACIAR project we placed initial emphasis on talking directly with herders in developing the extension programs considered here. This was done through a series of semi-structured interviews with 52 herders in Kangle and Dahe townships in Sunan. Three key areas for discussion were the importance of animal production to household income, the effects of grassland condition on profitability and herders' attitudes toward government policies.

As a basis for this communication with herders, it was necessary to first understand the general background of Sunan county grassland and livestock resources, the changes in human population and the impact of government policies that currently guide grassland and livestock management. These aspects are reviewed in the following sections. Based on the adage that people 'can never be convinced by words', the ACIAR extension and training programs showed by example the kinds of changes to grassland and livestock management that have strong 'win–win' impacts on household profitability and environmental conditions. Such activities provided the best opportunities for active participatory learning by households.

Grassland resources and livestock production in Sunan

Sunan Yughur Autonomous County (37°28' to 39°49'N; 97°21' to 102°13'E) is located in the middle section of Qilian Mountains, which are on the northern end of the Tibetan–Qinghai Plateau and the southern edge of the Hexi Corridor (part of the ancient Silk Road). Sunan county has been part of Zhangye prefecture in Gansu province since 1954 (Zhou and Yang 2006). The landscape of Sunan county is 90% mountainous with the balance as undulating hilly plains (see also Yang Lian et al. 2011). Altitude ranges from 1,400 to 5,560 m (Wu 2001). Winters are cold with an average January temperature of –12.5 °C and summer temperatures are moderate with a maximum daily average of 27 °C in July. Long-term average annual rainfall is 325 mm with most precipitation received in June–August. Evaporation exceeds 1,600 mm/year. Temperatures and precipitation are highly variable, spatially and temporally. Sunan has experienced serious droughts in recent years, with the lowest rainfall of 150 mm/year in the past 30 years recorded in 1991.

Pastoralism in Sunan county had been nomadic for centuries, with strong Buddhist beliefs influencing herders' culture and flock management. Although herders have gradually settled in permanent communities since the middle of the 20th century, following a number of government resettlement incentives, Sunan remains one of the key pastoral counties in Gansu with more than 67% of the population deriving their livelihood directly from livestock production (Wu 2001). Like most counties that are located in the Qilian Mountain area, Sunan has a large area of usable rangeland resource (1.4 million ha, Table 1) accounting for about 58% of the county area and equivalent to an average of about 38 ha/person. A description of the climate, geography and current condition of grasslands in Sunan county is given by Yang Lian et al. (2011).

Despite government policies that have encouraged individual households to settle on allocated areas of land under the responsibility system (Lin 1987, 1988), herders in Sunan still follow a restricted form of seasonal rotational grazing with pastoral areas divided into three distinct areas (Yang Lian et al. 2011): winter grasslands at lower altitudes (1,500 to 2,000 m) where herders' main house, sheds and yards are located; spring–autumn grasslands which are a transitional area between winter and summer grazing lands; and summer alpine meadows at the highest altitudes (2,400 to 3,000 m). These grasslands are classified as alpine meadow and alpine steppe vegetation, with average groundcover of 50–60% and fresh biomass production of 1–1.3 t/ha/year (Hua and Michalk 2010; Yang Lian et al. 2011). Studies show that winter pasture is the most degraded because herders graze their animals there from October through May. Feed deficiency during winter remains the key problem of the production system, which depends on year-round natural grazing. There is only a small area of arable land to provide supplementary forage. Livestock production is based primarily on grassland resources (Table 1).

Livestock production is focused on fibre and some meat production. Sunan has become the main production area for Gansu alpine fine-wool sheep, with herds exceeding 500,000 head and a county-wide output of 1,250 t/year of 21.0–22.5 micron wool. The Sunan Fine Wool Association has created the wool brand called *Sai Mei Nu*. The productivity and quality of grasslands has degraded severely over the last 3 decades because of overgrazing. According to government statistics, because of pasture degradation the carrying capacity of the pasture has declined from 0.59 sheep units/ha in 1977 (Longworth and Williamson 1993) to 0.46 currently. This reflects earlier increases in animal numbers that started in the 1950s.

Changes in human population in Sunan county

With a land area of 2.4 million ha (Table 1) and a current population of only 36,450 (Figure 1) Sunan County is, by Chinese standards, sparsely populated. The population is composed of 10 different ethnic groups, of which the main ones are Yughur, Tibetan, Han, Hui and Mongol. The China national census in 2000 reported a Yughur population of 13,719, mainly centred in the three townships of Minghua, Dahe and Kangle of Sunan county. This means that nearly 90% of the Yughur population is settled in the Sunan Yughur Autonomous County. Few signs of ethnic or gender discrimination can be detected within the community (Bahry 2009).

Due to special family policies and the traditions of the minority peoples, the population of Sunan has changed little since 1978 (Figure 1). However, unlike other regions of China where socioeconomic changes have seen a decline in the proportion of households raising livestock (Zhang 2006) the number of rural households in Sunan has

Table 1. Land-use patterns in Sunan Yughur Autonomous County (Source: adapted from Wu 2001)

Category	Area (ha)	Percentage of total
Grasslands:		
spring–winter	753,200	31.4
summer–autumn	646,800	27.0
Cultivation	4,700	0.2
Sown pasture	6,700	0.3
Forestry	86,000	3.6
Housing and roads	2,500	0.1
Industry	4,700	0.2
Unusable land (including permanent snow cap and watershed)	895,400	37.3
Total	2.4 million	100.0

Sources: Agricultural and Animal Husbandry Department of Sunan County (1987); Bureau of Animal Husbandry of Sunan County (1999) increased (Figure 2), indicating that fewer herders are leaving the livestock sector than is the case in other counties in Gansu province. Family-planning policies stipulate that farmers and minority groups in China can have two children. The data suggest that a large number of young people are staying in Sunan county and establishing their own livestock enterprise and households. This may pose challenges for future sustainability as the land resource available per household becomes smaller as it is divided among successive generations.

Although herders still graze their livestock using a transhumance system, most of the herding population has become sedentary in townships and smaller settlements, a trend that started in the 1980s (World Bank 2007). Families are separated during spring and summer, with working-aged men and women looking after livestock in alpine grassland areas while senior people and children remain at the home base. More recently, some households have hired Han herders from their neighbourhood to tend livestock in spring and summer, costing about 10% of their income (World Bank 2007).

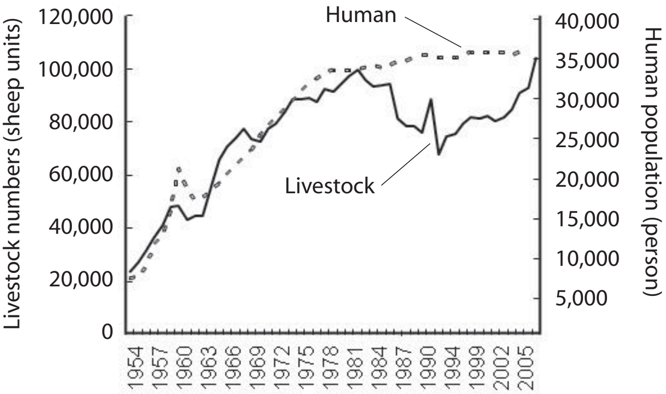

Figure 1. The change in trend of human population (dashed line) and livestock numbers (sheep units (SU)—solid line) in Sunan county, Gansu province between 1954 and 2005 (Source: Hua and Michalk 2010)

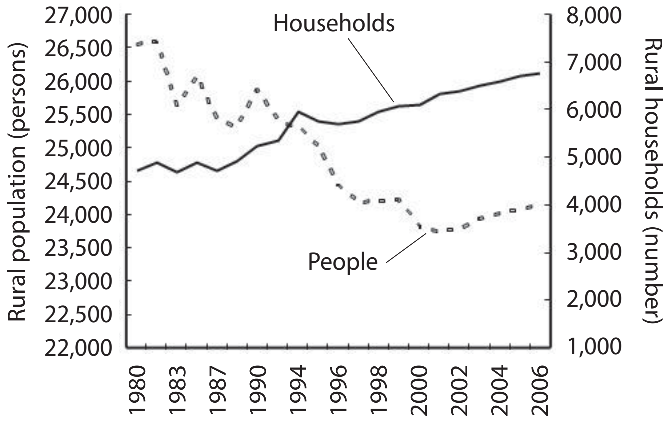

Figure 2. Relationship between the number of rural households (solid line) and the rural population (dashed line) in Sunan county, Gansu province, 1980 to 2006 (Source: after Hua and Michalk 2010)

Household incomes and dependence on livestock production

Using Sunan county statistics (1968–2008) and village-level information collected from household surveys conducted in Dacha village (2005–2007), Hua and Michalk (2010) showed that livestock enterprises still accounted for more than 90% of household gross income (¥27,510) in 2008. Although off-farm income has tripled in Sunan county since 2001, it still accounts for only about 10% of income generation by households or individuals. In Dacha village, off-farm work, which includes labour for the construction industry, sales of Chinese medicines collected from grasslands and subsidies, generated less than ¥2,300/year (Hua and Michalk 2010).

The data of Hua and Michalk (2010) indicate that there have been large increases in farm expenditure on fixed assets, which suggests that herders are actively investing in farm infrastructure (warm livestock sheds, some fences) in order to increase their production efficiency through a shift to more specialised pen-feeding operations. Since most herders lack cash reserves it was expected that one consequence of implementing new grassland policies such as the 'grazing ban' would be that households would sell livestock to establish a feed balance to match the reduced availability of grazing land. However, rather than reduce livestock numbers, households significantly increased their bank and personal loans in 2006 to establish or extend the size of their warm sheds and feeding pens (Hua and Michalk 2010).

This has led to an increase in livestock numbers of about 10,000 head and in the gross income (a 27% increase to ¥7,608/person) derived from meat and wool sales in Sunan since 2006. These increases reflect some positive changes in management that have increased turn-off rates. In Hongshiwo village, for example, the proportion of ewes in the flock was increased to 60–75% by reducing the number of wethers, and lambs were sold at 100 days of age to oasis areas in the Hexi Corridor, which increased household gross income threefold. This contrasts with the former management pattern of a lower number of ewes (45% of flock) and selling lambs at 1 year of age or older (Zhou and Yang 2006). These results indicate that herders in Sunan are willing to adopt new technology and management systems to improve livestock production efficiency. Some indication of the benefits of changing practices on net financial returns is given by Yang Lian et al. (2011).

Application of government policies to Sunan

As in most of north-western China, grassland degradation had become a noticeable problem in Sunan by the 1970s (He 1999). In recent years, a series of national grassland rehabilitation policies has been implemented in Sunan to protect and restore the grasslands, including re-settlement and 'grazing bans'. Indications are that degradation has not been significantly reduced by re-settlement into nearby towns (Mailisha 2004), although herding households may have benefited from improved health and educational services. Other researchers (e.g. Fan et al. 2005) comment that most of these policies are not very successful and that now nearly 90% of households in some locations still graze their sheep and goats at some time on the prohibited grasslands.

This means that, in spite of higher household profitability and changes in livestock management, more still needs to be done in Sunan to halt rangeland degradation, which has seen the area of excellent to good condition grasslands decline from about 990,000 ha to some 530,000 ha since monitoring commenced in 1983 (Chen et al. 2005). Sunan government policy embodies four basic strategies to overcome the problems of grassland degradation: controlling growth in livestock numbers; improving the quality of livestock; increasing the productivity per animal; and fencing grasslands to facilitate the use of rotational grazing systems (Longworth and Williamson 1993). Unfortunately, due to the climate and topography, Sunan herders have no other income sources except that from grazing on the grasslands. This makes creating opportunities to reduce stocking rates while maintaining household incomes a vexing imperative, because it is clear that continuing with the current management system is unsustainable. The financial analysis of households clearly shows a desire to change livestock production methods to arrest rangeland degradation in Sunan (Hua and Michalk 2010) and, as shown by Yang Lian et al. (2011), viable options exist to achieve reductions in livestock numbers. This is evident in the investment herder households have already made in new infrastructure such as fences and warm sheds, as has also happened throughout much of north-western China (Dong et al. 2007).

Structured conversations with Sunan herders on animal management

The lack of direct communication and interaction between farmers and extension professionals inevitably results in a mismatch between the information provided and the perceived needs of rural clients (Zhao 2000). Two qualitative techniques are used in social research to define opinion and probe the underlying motivations and feelings of respondents: focus-group discussions and individual in-depth interviews (Webb 1995; Hennink 2007). These techniques were used to communicate with herders in Sunan. In the focus-group discussions, five or more individuals were invited to discuss a range of topics, with the conversation moderated by a facilitator. For the in-depth discussions with individuals, a semi-structured interview used extensive probing to get a single respondent to talk freely and to express detailed beliefs, underlying motivations and feelings on specific topics (Webb 1995). Using both techniques helped to achieve a broad overview and a detailed understanding of how herders cope with grassland degradation and choose new technologies to link with the market economy within the framework of national grassland rehabilitation policies.

This process built awareness of the aims and activities of the ACIAR project and developed a trust that enabled herders to work closely with the ACIAR team during the training program. Since farmers will not follow extension recommendations unless they are convinced that it is in their interests to do so, it was crucial to actively engage herders in the decision-making process for farm demonstrations from the first stages of their planning and implementation. This undoubtedly improved uptake of new technologies, as the demonstrations were considered to be more appropriate and acceptable. Following national government policies that universities add extension to their teaching and research activities (Li et al. 1995; Gao and Zhang 2008), academic staff from Gansu Agricultural University actively participated in many of the ACIAR programs, such as training lead farmers, supervising adaptive research in demonstration villages, and taking part in annual production planning sessions.

The outcome was that the program produced meaningful solutions for transitioning of herders from the 'subsistence to the producer' stage supported by proper technical information and guidance in grassland and livestock management. It also created reassurance about the future of livestock enterprises in Sunan. The dialogue with herders provided the ACIAR team with deeper insights into the local situation. We believe that the integrated extension approach piloted in Sunan has the potential to serve the interests of both policy-makers and farmers.

During the ACIAR project, the team always kept household surveys and analyses of herders' needs in mind in order to develop research recommendations that were in accord with needs and relevant in practice (Table 2). As a result, informal feedback and continuing participation in training and extension activities indicated that the program was welcomed by herders. Even where the herders did not agree with the researchers, or they questioned the effectiveness of the solutions the project provided to them, the herders always told the team that the project was valuable and continued their involvement. Some solutions, such as changing lambing time and providing more supplementation to the ewes, and pen feeding sheep during the harsh winter, were acknowledged as relevant to them, but may not be viable because of financial or skill constraints. The cost of providing supplementary feed to Sunan is high. The Gansu Agricultural University team is still working in Sunan with those who want change and to learn new things from the project. The researchers gained confidence and experience from this process. They are regularly invited by local government or line departments to lead or join development programs because these agencies trust the team to accomplish the task in the way they are expected to or in which the herders support. The current economic momentum in China provides incentives to herders to change their enterprise and/or modify how their livestock production system is managed, such as changing lambing time, fattening lambs in sheds and using higher energy content feeds, as discussed in these proceedings. Households may vary in the investments they make. Some may choose to build warm sheds, some may purchase better quality rams from other areas and yet others may purchase higher quality feeds from agriculture areas. The change in herders' attitudes has shown that they have benefited from meaningful training and extension.

Most of herders considered that the extension services and training program were helpful and relevant (Table 3). Women have a lower education level and less opportunity to work with trainers, and they expressed the view that the project results were less likely to be integrated into their farming operation. More men than women said the bulletins are useful for their farming practice, which may also reflect differences in education levels.

The survey data (Table 4) showed that the national grassland grazing ban policy (GBP) that is deeply influencing the herders' thinking has been extensively promoted by government agencies, even in remote areas like Sunan. However, unlike the survey results reported by Dong et al. (2007), which showed that 95% of households in China's northwestern grassland region accepted the GBP, for economic or cultural reasons half the herders in Sunan did not like or accept the GBP (Table 4). Of those households that accepted the GBP, only one-third did so because they thought that it would generate long-term improvement to grassland condition. This is almost the reverse of the finding of Dong et al. (2007) that 76% of those endorsing the GBP did so because they thought it would lead to more sustainable grassland use.

Despite negative attitudes to the GBP, Sunan households did agree that alternative livestock production strategies such as raising livestock in sheds were a more efficient way to product meat and fibre and were willing to use pen feeding as long as

Table 2. Responses of herders in Sunan county, Gansu province, to grassland management and forage development issues

Issue	Responses from males (27)	Responses from females (4)
Current processes used for development of village grassland management plans	70% little or no input into planning	50% some input into planning
Degree of increased grassland quality since 2004 arising from changed practices (affected by climate variability in the previous few years)	60% noticeable or significant improvement	75% noticeable or significant improvement
Users perceptions of the value of a participatory grassland management methodology	60% some to lots of benefits	75% some to lots of benefits
Normal strategy to ensure availability of feed throughout the year	60% have no specific strategy in place	75% have at least minimal feed requirements
Condition of ewes at end of winter with new practices (herder described conditions and enumerator scored them)	75% show weight loss of less than 10%	75% show weight loss of less than 10%
Access to feed and forages from artificial pasture	68% do not have access to artificial pastures	75% do not have access to artificial pastures

Table 3. Responses from herders, technicians and officials in Sunan county, Gansu province, to general questions on the value and potential of training and extension services

Question	Percentage of respondents agreeing			
	Herders		Technicians	Officials
	Male	Female		
Are the extension services and training programs helpful and relevant?	73	70	95	99
Can the new project methodologies be incorporated into their operations?	60	45	90	95
Are the extension bulletins useful?	60	35	100	100

the problems related to high inputs could be solved (Table 4). This was the same issue identified by Dong et al. (2007). However, as is generally the case throughout north-western China, the number of households that have successfully implemented pen-feeding programs is still below 50%. This probably reflects their limited business skills and a survival focus on minimising cost as a way of sustaining incomes, even if better nutrition of livestock meant the return per animal increased. In turn, this means that there is still a long way to go in providing technical training to achieve greater uptake of new management systems. Part of this training relates to literacy which is a major limitation to extending policies and technologies in China's grassland areas (Dong et al. 2007).

A significant minority of herders identified options for investment that they consider would improve their own incomes (Table 5). However, due to capital limitations they would like the government to provide subsidies to improve the productivity of their pasture and livestock. The herders want training programs on animal nutrition and animal disease control as they see livestock as their real property from which they can make money. They would then be more comfortable about investing in that area themselves. In contrast, grassland fences are infrastructure that herders consider governments should pay for and erect to facilitate implementation of grazing bans and rotational grazing systems. There are currently major problems in keeping the neighbours' livestock from grazing their lands. Unfortunately, funding for fencing was limited in the national project. Herders would like the government to launch a new project for rotational grazing to help rehabilitate and then maintain the grasslands in a better state.

Due to the large gap in incomes between rural and urban areas, the herders are particularly concerned about the future for their children (Table 5). Because of the poor life and harsh environment, the herders do not want their children to become herders too. However, the cost of education is increasing as the level of education improves, which causes considerable stress for the rural poor. This can result in

Table 4. Responses to questions on grassland policy from herder households in Sunan county, Gansu province

Questions	Yes (%)	No (%)
Do you know the grassland ban policy (GBP)?	99	1
Do you accept GBP?	50	50
Why do you accept GBP?		
It is a good measure for improving the grassland condition	36	
It is compulsory national policy	60	
Influenced by neighbours	4	
Why don't you accept the GBP?		
It's difficult to get feed resource		75
The native feed resources are wasted		2
It is contrary to tradition		23
Are you willing to rear livestock in sheds?	90	10
Is stall feeding more efficient than grazing?	90	10
What's the major problem in stall feeding of livestock?		
High inputs		72
Insufficient forages		11
Expensive concentrates		13
Labour shortages		4
What's your choice if grazing grasslands is banned?		
Sell the animals	15	85
Rear the livestock in sheds	60	40
Graze illegally	3	97
Follow others	22	78

herders grazing more livestock in an effort to increase their incomes to pay for their children's education, which increases the stocking rate on their pasture with potential longer term cost to their incomes.

Identifying research, development and training needs

The effective association with herders discussed in this paper is an essential early step in preparing livestock households to transition to the market economy by helping them to discuss new ideas for moving into more productive and profitable methods of livestock raising (e.g. as shown by the reduction in weight loss now occurring (Table 2) compared with that on typical farms, as discussed by Yang Lian et al. (2011)). The dialogue with herders has also benefited the researchers by providing an opportunity to understand how the recommendations being developed for improving incomes need to be adapted to local needs. For example, the modelling work done (Yang Lian et al. 2011) showed that changing the lambing time would help maximise the utilisation of summer pasture and minimise the feed energy gap during the cold season, thereby reducing feed costs. However, herders do not think in the same way: they consider that late spring – early summer lambing would lead to a lighter lamb body weight at sales in the autumn and a lower price obtained (though the modelling by Yang Lian et al. (2011) took that into account). This highlighted the clear need to objectively test these proposals in on-farm demonstrations and to include information about the effect of changing lambing times in training on animal nutrition. An associated issue is pen feeding in warm sheds through winter and the benefits of that have now been demonstrated on farms (Yang Lian et al. 2011). That work focused on the ewes. The next step would be to resolve all the costs and benefits for lambs to see the impacts on their weight as well as the predicted gains for pasture condition.

Even if the on-farm research and development (R&D) done shows clear benefits for any new practice it is acknowledged that not all herders will adopt it. Many will still operate in a traditional way, as that is what they are familiar with. Some may feel they do not have the resources (limited land and numbers of animals, finance and knowledge) to make a change. The size of a benefit to implement change for some herders may need to be large and be perceived as having very low risk before they move. Nevertheless, in the process discussed in this paper it was evident that the more sceptical herders were still very keen to see on-farm R&D done in their area to help them acquire knowledge about improving the ways they manage their livestock and other resources. This clearly supports the view that when modelling and experiments show benefits, then on-farm demonstrations in close collaboration with herders, to develop and adapt recommendations to their needs, are essential. A further benefit of that approach would be a better perspective on future R&D needs, to guide researchers and maximise the benefits of the work they do. Of

Table 5. Responses of herder households in Sunan county, Gansu province, to questions about areas they would invest in and the future for their children

Questions	Response (%)
In what areas do the herders expect more investment and management skills training?	
Warm pens	16
Animal nutrition training	19
Grassland fencing	12
Grassland improvement (re-seeding, rotation)	16
Animal disease control	19
Market skills	18
What expectation do herders have for their children if grassland degradation continues?	
Become herders	4
Move away from home town for education and access to college or university	96

considerable importance in these processes is the goodwill developed between herders, researchers and the many officials, local to national, who have been involved in the research and have supported the delivery of those recommendations identified as producing clear benefits.

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China's grassland livestock farming systems: strategies and tactics for improvement

David Kemp, Han Guodong, David Michalk, Nan Zhibiao, Wu Jianping and Xu Zhu

Abstract

The challenge facing herders and the Chinese Government is how to rehabilitate the vast areas of degraded grasslands across northern and western China without causing a decline in household incomes. The research results presented in these proceedings have shown that the initial step required of reducing stocking rates will maintain or increase net household incomes from livestock. Additionally, changing enterprises from mutton to fine wool, introducing better nutrition, using warm sheds, changing breeding management etc. can all be implemented within existing structures and would further improve incomes. Demonstration farms are needed, however, to enable local herders to understand and then effectively implement these initial changes. A core issue is to improve the efficiencies in livestock production to enhance the quality of products marketed. Better quality products will attract the price premiums that are developing, reinforcing win–win outcomes. Training to assist herders to move from survival to production thinking will be important. Subsequently, attention can then be paid to resolving better grassland management strategies to enable the more desirable species to recover. In some areas government payments may be needed to reduce stocking rates below financial optima for grassland rehabilitation. The rates of change in grassland condition are slow, and current grazing bans are arguably too short and without adequate follow-on practices to achieve the outcomes desired. The range of options that can be readily implemented is discussed as are needs for future research and development.

Introduction

The Chinese Government has been cognisant for some time of the degraded state of grasslands through the north and west of the country and the consequences for livelihoods and the environment. That recognition has been reinforced by the passing of several 'grassland laws' from 1984 on (first in the Inner Mongolia Autonomous Region, then nationally) and the implementation of major government programs for western development, the latter often in association with international agencies. In his annual report to the National People's Congress in March 2007, Premier Wen Jiabao put the sustainable development of western China and parallel protection of the environment at the top of the government's agenda. The twin problems of low household incomes and degraded grasslands are at the core of western Chinese programs and ways of tackling them have been discussed throughout these proceedings.

The case studies previously presented have clearly demonstrated that animal numbers and grazing pressures have dramatically increased since 1950 (Han Guodong et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng Yang et al. 2011). Elderly herders have often noted that when younger they 'had trouble finding the cattle in the grass, but now can see the mice'! Deserts have been expanding at alarming rates, particularly from the 1950s to the 1990s (Wang Xunming et al. 2008). The rapid change in fortunes for the grasslands has

Pp. 177–189 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.

been accentuated by the perception after 1949 that the grasslands were an under-utilised resource that could grow productive crops and support more people and livestock than had applied historically. That was not always universally supported (Ren et al. 2001) and the concerns expressed have been substantiated, with cropping areas being reduced to the more favourable environments and constraints placed on the use of groundwater and surface water from rivers for irrigation. The status of these systems today is that 90% of the grasslands are degraded to some degree (Lu et al. 2006) and their recovery has to deal with the twin problems of finding ways of improving household incomes while reducing the grazing pressures across the landscape. As proposed by Ren et al. (2001) solutions will best come from an integrated approach to livestock farming systems. Previously, technical solutions were often being proposed without due consideration of their wider effects within the farming system, such as increasing the areas sown to supplementary forage crops that were then used to increase animal numbers but not the efficiency of animal production (Brown et al. 2008). The imposition of an agricultural, cropping model onto a pastoral landscape is now acknowledged as inappropriate, as portrayed in the best-selling novel *Wolf Totem* (Jiang 2008).

The research results presented in these proceedings, while portraying the problems and difficulties, invite optimism that realistic solutions for the twin grassland problems can be achieved. The types of solutions that have emerged have been developed from a farm-level focus, but they align with national policies and thence the strategies developed through the layers of government in China (Brown et al. 2011; Waldron et al. 2011). The directions developed from this research align with the ways markets are developing and the ways in which more proactive herders are changing practices. Often those herders are trialling tactics that can produce important gains. However, changing many practices at once on a farm is difficult, particularly to resolve which components will prove the more effective. The modelling presented in these proceedings allows testing of the benefits of each component and of combinations of components, hence providing more comprehensive information than can be derived through experiments or on-farm demonstrations within a short time frame. This chapter discusses key aspects of the work presented in these proceedings that indicate viable directions for improving net household incomes in ways that then provide opportunities to improve grasslands. Also covered are some of the deeper issues that need consideration.

Policies and market development as drivers of change

Fifty years ago Chinese policies clearly favoured the idea that more livestock could be supported on the grasslands and that this would improve household incomes. Initial improvements did occur, but the rate of progress relative to the incomes of non-rural households in China has now been severely curtailed. Chinese officials have recognised the need to change direction to achieve sustainable use of China's 400 million ha of grasslands. Over recent decades the quality of grassland resources has declined, with wind erosion reducing soil fertility and the proportion of more-desirable grassland species declining. The net effect is that livestock productivity is well below international standards. For example, cows can take 4 years to produce a calf compared with 2–3 years in other countries. Prices for livestock products have increased and this has partially compensated for declining productivity. This has lessened the urgency to change practices, even although the Chinese authorities have long recognised the warning signs.

Chinese publications (e.g. Zhao Yongxi 1998) have often argued that the current state of grasslands is simply a reflection of past policies. That may be partially true, but the corollary that simply changing the policy will correct the current problems is unlikely to achieve sustainable outcomes within a reasonable time. Chinese herders now operate in a market economy and the factors that drive their decision-making must now be market based (Waldron et al. 2011). Government does have a role and, in China, that is integrated within the market economy, but it is evident from many discussions that the research team have had that many decisions made by herders are based on the prices received for livestock products, without the benefit of cost–benefit analyses. For those reasons, much of the work presented in these proceedings focuses on finding farm-level solutions that provide the incentives for herders to change practices in ways that either maintain household net incomes or lead to greater net incomes with reduced animal numbers

(Michalk et al. 2011). An initial ideal was to find solutions that were entirely market based and set future directions that were less dependent upon government support as that support may not be readily available in the future. But in the current transition phase to sustainable systems the market may not provide adequate drivers and hence strategic government support will be vital.

A key issue is to resolve the extent to which markets can provide the drivers to change practices on farms and, in particular, reduce grazing pressures while maintaining or improving net household incomes. Where market drivers are still developing (e.g. price differentials based on product quality) and therefore limited, there is then the case for government to provide interim support to achieve national goals. An obvious case is where the modelling has shown that, at the prices available when the survey work was done, it was economic to feed animals in warm sheds for only 6 months of the year (Han Guodong et al. 2011). The result is that animals graze for 3 months of the year when there is no, or very little, grassland growth and a high likelihood of damaging the pasture and restricting its future recovery and productivity. While data on this issue are limited, recent on-farm demonstrations (arising from this project) of feeding animals all winter showed the herder that grassland growth in the following summer was better than expected and better than that of the neighbours (Han Guodong, pers. comm.). Based on the data available there is a good case then for government support to subsidise feed costs sufficiently so that it is profitable for a herder to not graze for 9 months of the year.

However, it is important to note that the modelling work done in this area did not consider any price premiums for livestock that were better fed through winter, as suitable market information was not available. Neither were reliable biological data on performance of animal breeds with characteristics preferred by urban consumers. Future projects need to obtain that information. It is likely, however, that markets in China for meat, for example, would develop a premium for better managed animals as carcass weights and the proportion of meat consumed increases. Signs of this occurring are evident as incomes in urban areas are increasing and consumers are demanding higher quality food and reliable certification systems to verify food quality. This is already the case in China's dairy industry (Hu 2010). In the future, market signals could be adequate to achieve such objectives and government could then focus more on the research and development (R&D) needed to optimise the grassland livestock farming system.

Moving from 'survival' to 'production' thinking

The livestock herders of northern and western China have come from a long-established system that focused on animal survival for much of the year, with short periods of growth over summer. This fits within the second and third categories of the 'user ... keeper ... producer ... breeder' model outlined for African livestock herders (Neidhardt et al. 1996). The herders no longer hunt ('user') as there are no wild animals left, a few have become sophisticated 'breeders' in recent years using advanced technologies such as embryo transplants to improve the quality of their animals, but most seem to operate over the range of 'keeper ... producer'. This is reflected in the common practices encountered in the work reported in these proceedings, where animals are allowed to lose 20–30% of their live weight through the 9 months from the end of one summer to the start of the next. Feeding strategies are based on no more than maximising survival. This applies to mature and new animals born in winter, the latter being carefully managed to reduce stress on their mothers and to achieve minimal growth until summer when sufficient grass is available. Overall weaning percentages[1] are low (Michalk et al. 2011) and, along with low average animal growth rates, that means potential incomes are considerably below what is possible. A survival strategy is often followed by herders, whose status is reflected in the number of animals they have. In earlier periods the price received per animal did not vary much with size, whereas Chinese markets now price animals more on the amount of product (i.e. meat, fibre, milk) they provide. It was evident during the interviews done through this work that some herders had a personal goal of maximising animal numbers, i.e. status, even although these

[1] Note that in China 'weaning percentages' are often calculated on the number of, for example, lambs born that survive to 3 months of age (a 'survivor' model), not on the number of weaned lambs per ewe. The true cost of current practices is therefore often significantly underestimated.

same herders were, at the same time, often the leaders in improving the productivity of livestock within their district. They understood the dilemma and would acknowledge that reducing grazing pressures was a worthwhile goal. In such cases the limited area of grazing land available is probably the key driver and, where they can access additional land by renting it, they are then more comfortable about reducing average stocking rates.

Using the more profitable livestock enterprise for each region, modelling in the case studies showed that better nutrition of the animals and reduced stocking rates improved net income from livestock. The financial gains from doing this were evident (Han Guodong et al. 2011; Wang Xiaoyan et al. 2011; Yang Lian et al. 2011; Zheng Yang et al. 2011) and these gains were probably conservative as no differential market prices were used to reflect better production characteristics. However, herders will not automatically adopt these improved practices. They need to shift their thinking towards a production-oriented system, rather than simply survival of their livestock, to achieve the potential gains in income identified. They have limited experience in taking that step. To become 'producers', herders will probably need training and local demonstration of benefits before they commit. Also, demonstrations would enable determination of better estimates of benefits than those that currently apply in the models.

A production-oriented focus will be critical for providing opportunities to rehabilitate grasslands. The modelling done shows that focusing on production efficiency should, in all instances investigated, result in significantly lower stocking rates and hence grazing pressures. The extent that those changes occur will vary with district and herder attitudes, but any reduction in grazing pressure through the year provides opportunities to rehabilitate grasslands by enabling desirable species to produce more growth, reproduce and potentially recruit more new plants, i.e. become more competitive with the less-desirable species that have become more dominant in the grasslands. If herders retain a survival approach then animal numbers will not fall, net income from livestock will remain low and there is likely to be no improvement in grassland condition.

Rates of change

One of the core issues in the background to the work reported here are the rates of change in household incomes and grassland condition that can be achieved. Over recent years the Chinese authorities, as a means to rehabilitate grasslands, have imposed grazing bans ranging from for short periods (e.g. at the start of summer) to the whole year. The bans have been accompanied by subsidies of various forms. In Inner Mongolia, government programs have sought to progressively ban grazing from much of the 70 million ha of grazing lands. Where grazing bans have been imposed and rigorously enforced, benefits for the grasslands are evident. However, the recovery takes time as it involves not only restoring the more-desirable species to a level that previously applied in the sward, but also enabling soil fertility to recover. This can be a medium- to long-term process depending upon prevailing environmental factors and the degree of grassland degradation incurred through past management.

One of the few datasets available is that for a Xilinghote grassland and it shows (Figure 1) that, in a more favourable environment within Inner Mongolia, the restoration of botanical composition and of productivity took many years, although arguably faster than would occur in drier regions. After cessation of grazing all species initially increased their biomass. Annual and perennial forbs and shrubs then gradually declined to a steady state within 5 years. Perennial grasses started to increase in biomass after 4–5 years and, by 15 years, were reaching a steady state. It took 10 years before there was a noticeable increase in the biomass of perennial monocots and that increase continued for 20 years. Total sward productivity took 10–15 years to reach what could be the ceiling yield for the site under current fertility levels. This was for a relatively higher rainfall area of Inner Mongolia and a grassland in which propagules of all these species had remained. These rates of change need to then be considered in relation to grazing bans for which subsidies may last only 5 years and where no follow-on management program to restrict grazing and aid recovery is implemented.

Solutions for grassland recovery will ultimately depend upon finding strategies that not only promote recovery but also which herders are happy to employ because their incomes improve. The incentive to overgraze needs to be minimised. The papers in these proceedings show how a focus on improving the efficiencies of livestock production can create the conditions for achieving the twin goals of income and grassland improvement. Household net incomes can undoubtedly be further enhanced as market signals strengthen to transition production objectives from a quantity to a quality focus. In the short term, government regulations have a role to play in remediating the more severely degraded landscapes. They would be difficult to apply over the medium to long term, however, unless herders could move their enterprises from dependence on grasslands to reliance on other forage sources and pen-feeding approaches or, alternatively, move to areas where they could earn an income through other means. There is anecdotal evidence to suggest that, when subsidies for grazing bans are removed, the local herders revert to previous grazing practices, even if they acknowledge the benefits that the rest from grazing has achieved. Other evidence provides a more positive outlook. Dong et al. (2007), for example, reported from an extensive survey of livestock producers across China's major rangeland regions that herder households in the north-west gave the highest endorsement to adopting new grazing practices (95% support for 'grazing ban') and rearing livestock in sheds (72%) in spite of the acknowledged difficulties and costs incurred in procuring alternative feed supplies.

Crucial to resolving these contrary opinions is effective training. Extension workers interviewed by Dong et al. (2007) reported that technical training in a wide range of topics, including forage and grazing management, animal feeding and breeding, marketing and alternative enterprises was a key component to effective implementation of change in the livestock industry. Currently, the rangeland industry comprises small businesses, large markets and a low level of technology and it is difficult for herders to grasp a new initiative for livestock production while they are caught up in the existing systems and marketplaces (Han et al. 2008). Unless there is a clear demonstration of the technical and financial benefits from changing practices, herders will follow the established practices that enabled them to survive in the past. As Hua and Michalk (2010) pointed out from an analysis of technology change in Sunan county, to maintain momentum for sustainable development of production systems it is an imperative that financial support be continued for participatory training programs.

Stages of change

The proposals for change considered through the papers presented in these proceedings deal mostly with the initial steps that farmers can make to improve incomes and provide opportunities to

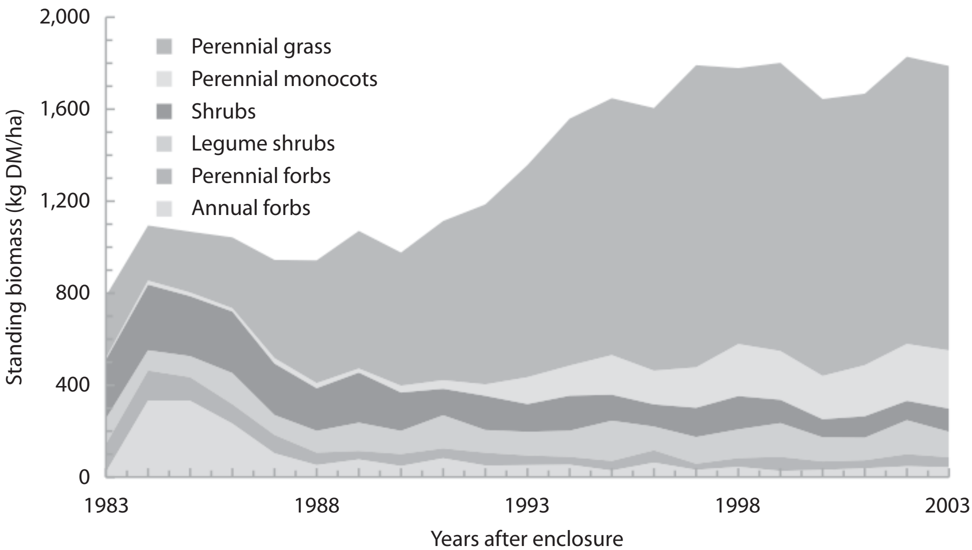

Figure 1. Changes in annual productivity of plant functional groups over 20 years after exclosure from grazing, Xilinghote, Inner Mongolia Autonomous Region (Source: data provided by Liu Zhongling, Inner Mongolia University)

reduce grazing pressures so that some grassland recovery is possible. Pathways for improvement can be considered as a series of stages or steps, in each of which gains can be made without resolving all the major problems. The ultimate goal of sustainable solutions is still some way off, as the possible pathways to those solutions have not been fully investigated, nor are they absolutely predictable.

Throughout the papers in these proceedings a series of questions was set within which various stages of development could be envisaged. These points are discussed here with some thoughts as to the next series of changes that may be applied and which would be important in future work.

1. Enterprise

An overriding question that each herder needs to consider is 'what is a better livestock "producer" system/enterprise'? The underlying assumption is that a 'producer' model is superior to a 'keeper' model as the analyses made in earlier chapters show that a focus on productivity rather than simply on animal number would improve incomes at stocking rates lower than current levels. The choices investigated came from what herders are currently doing. In general, cattle production did not emerge as viable in any of the case studies. No exhaustive analyses were made of cattle systems as the preliminary financial work did not suggest they were viable in the contrasting counties included in this project. This does not exclude one or two cows for domestic use but, in general, better returns can be obtained from sheep and goats. This reflects, in part, the current state of grasslands in the four locations. The relative merits of sheep versus goats varied across the case studies, driven by the relative prices received for meat, wool and cashmere and the production costs incurred. Farms often have both sheep and goats, reflecting a longer term view that they could then optimise income over time, depending upon markets. While that strategy is sensible from a survival/keeper model perspective, it limits incomes because herders seem reluctant to change, in response to market prices, the relative numbers of sheep and goats they keep. However, to optimise production from a single focus on meat, wool or cashmere will probably require herders to engage more in marketing to improve their market power and achieve better and more-consistent returns for their produce.

Industry associations, some involving commercial firms, have been formed across China as a government initiative to provide services, help herders improve their market share and deliver government policies (Waldron et al. 2007). These associations vary in their aims but, so far, only a few have improved market systems in the case study areas considered here. One such example is the Sunan Fine Wool Association, which has created the wool brand called *Sai Mei Nu* and which markets the wool from the 500,000 Gansu alpine fine-wool sheep with a countywide output of 1,250 t/year of 21.0–22.5 micron wool. Herders from the association have visited the Nanjing auctions to gain a better appreciation of quality targets. In general, associations like the Sunan example offer some potential for improvement, but to improve farm returns over the medium to long term they need to have access to working models of viable livestock options that utilise likely market trends.

One of the medium-term trends envisaged for grassland livestock farming is for herders to become specialised, by resolving if they should be breeding and/or finishing livestock for markets. This would enable livestock to be optimised for markets and would better align with grassland productivity within a region. This will be a significant change for many who traditionally have bred all their replacement livestock and 'finished' them to varying degrees for local markets. Typically, this applies for sheep and goats, where income is generated from fibre (wool and cashmere), meat (animals of all ages) and the sale of animals to other herders for their use. This fits with the 'survivor' model of herders, but often means that no one product is produced at an economically optimal level. An alternative is for farms in areas where the feed supply is limited to focus on fibre production and use better breeding technology to improve the quality of replacement animals within the flock. This may entail the use of cross-breeding systems on at least part of the flock to produce animals that meet market targets for carcass size and fat content. Surplus animals (including all animals from terminal crosses) can then be sold at weaning (ideally 12 weeks of age) to others to be grown out for the meat market. In more favourable regions where forage production is more reliable and/or supplementary feed is cheaper, herders could concentrate upon finishing animals for the meat markets. These trends are starting to emerge in China and need to be fostered by relevant authorities. Markets are already providing price premiums (interviews indicated a 50% premium per kg of meat) for animals that produce more of the better quality meat demanded by consumers in the eastern cities of China. There are good arguments for reducing, across the grasslands of China, the number of animals that herders aim to grow out to marketable size for meat, as the available forage supply limits intake and potential productivity. These grasslands could be better used for maintenance of breeding livestock. Future modelling needs to examine these strategies with appropriate sets of parameters that reflect likely market trends.

2. Animal management

Once the general direction for the livestock enterprise has been resolved, it is then important to identify the changes needed in the type, numbers and management of animals. As part of this work, the *StageONE* model was developed (Kemp et al. 2011; Takahashi et al. 2011) to help herders identify the more productive animals to keep and those that should be culled. Current practice is often for traders to arrive at a farm and demand the best animals, rather than the herder identifying which ones they wish to sell. The age structure and productive capacity of flocks in the case studies done were well below potential and this would significantly reduce the income from livestock. The analyses presented in the case studies were conservative, as they assumed current livestock management and selling practices rather than a flock-optimising model.

The *StageONE* model was designed to help sort out the existing flocks to enable herders to increase their income from the animals they had. Applied over a few years this should result in a better age structure in flocks and higher rates of fecundity, with a higher proportion of young stock from which more productive animals can be selected. This strategy requires herders to bargain more effectively with traders to sell appropriate animals. In the longer term, traders would benefit from having access to a larger number of better quality and productive animals, which would have a higher value through the market chain. Training programs for both herders and traders will be needed to facilitate this change.

The *StageONE* model can be extended to include additional genetic information on the production potential of animals, based on more direct measurements of individual animal performance. Those developments would include, as discussed earlier, evaluating alternative enterprise structures to help reinforce those broader decisions. This work will require a range of studies to evaluate the genetic traits of local breeds and potential gains that can be made through selection and cross-breeding programs similar to those proposed by Snowder and Fogarty (2009). Part of that work would include comparing Chinese results with those in the international literature to identify where standard international best practice procedures such as the use of estimate breeding values (Fogarty et al. 2006), fat-scoring (Shands et al. 2009) and precision management (Atkins 2005; Atkins et al. 2006) could be used in models to improve the genetic structure and productivity of Chinese flocks.

3. Animal nutrition

One of the larger changes in livestock management that can improve incomes while reducing the number of animals is to change the animal feeding strategy through the year. Traditional practice of feeding for survival means that animals are fed at sub-maintenance levels for 9 months of the year. A consequence is the compensatory gain that then occurs over summer, which creates an illusion that the grasslands are more productive than is arguably the case. If animals are fed to maintenance levels through winter, the expectation is that summer growth rates could then be less than currently occurs. That is not a problem in absolute terms as total animal live weights will be greater than at present. The *StageTWO* model assumes that animals are fed to maintenance levels and that the optimal net financial returns from improved strategies will be greater than apply in current practice (Han Guodong et al. 2011). In that case the price per kg of animal sold was the same for current and improved practices, although it is now likely that a premium will apply to larger, better fed animals.

The modelling presented in earlier chapters supports the view that if animals are better fed through the winter months the greater will be their productivity (in terms of both growth and reproductive performance) and the net financial returns from livestock. Conservative parameters were set for the models, based on determining least-cost rations from the feed sources that were readily available locally at local prices, and with no price premiums, e.g. per kg of meat, wool or cashmere for better fed animals. Just as importantly, no adjustment was made for improvement in weaning rate (Fogarty et al. 2006) and weaning weight (Hatcher et al. 2008) as comparative Chinese data were not available to decide on suitable parameters. The exclusion of these adjustments could have been why it was not financially viable to feed animals at maintenance rates through the colder seasons for more than 6 months at any of the case study sites, even although this was more profitable than current practice. Future modelling is needed to build in alternative feeding strategies that incorporate lifetime animal performance and likely trends in market prices for different types of animals. Investigations are needed to identify cheaper feed sources (per unit of energy) from the supplement options possible within each region.

4. Grassland management

An aim of this work was to find ways to reduce animal numbers to create opportunities to facilitate grassland rehabilitation, i.e. to identify how a better livestock 'producer' system can improve the sustainability of the grasslands. The general assumption is that by reducing the grazing pressure (measured as average stocking rates) desirable plant species would then have more opportunities to grow, reproduce and increase their proportion in the sward. The case studies, for example, showed how animal numbers can be reduced, how animal demand can be better aligned to feed supply, thereby reducing grazing pressures at some times of the year, and how the time animals are fed in warm sheds improves incomes and reduces the time they would be damaging the grasslands. More plant material is retained through winter, reducing soil fertility loss due to wind erosion and improving regrowth rates in spring / early summer). These assumptions, which are based on general experience, could not be tested in the work reported here. They invite investigation in grassland research.

In China, grazing bans have been imposed by local authorities to rehabilitate degraded systems. Improvements have been achieved but, when grazing bans cease, herders often revert to their previous stocking rates. As discussed earlier, the length of grazing bans may have been insufficient to achieve worthwhile, longer lasting gains in some instances. There are alternative strategies requiring investigation. These would include assessing the impact of stocking rates at 50% of current practice in comparison with current practice and tactical rests at different times of the year. The benefits of early spring rests on grassland condition have been demonstrated previously (Michalk et al. 2011) but tactical rests at other times have not been systematically studied.

The benefits of rotational grazing have often been speculated upon in China (Li et al. 2003) and the limited work reported in Chinese and international journals has been confined to Inner Mongolia (Han et al. 1990; Su Yong-Zhong et al. 2005). As noted above, the further investigation of tactical rests such as those proposed by Li et al. (2001) would strengthen the basic data from which appropriate systems of rotational and deferred grazing could be developed for other grasslands in western China. Such investigations could consider the spatial sequencing of rests to enable the progressive improvement of grasslands around a particular farm. Unlike in Australia, on many Chinese farms it is probably uneconomic to have subdivision fencing. Nevertheless, within a herding system it is possible to rotational rest and graze areas, provided the herder understands what needs to be done and can implement such a strategy. This would require studies to define grazing practices for specific grassland types and their current condition, combined with training programs for herders to implement them effectively.

5. Infrastructure changes

Farms in China have a relatively simple structure: there is often just one field or paddock and one watering point (near the household and yards). Sheds are often old and cold, and handling yards are simple and not suited to efficient working with livestock. What else needs to change to improve the productivity of the livestock system?

In the analyses presented, the main change in infrastructure investigated was the use of warm sheds. Warm (or solar or greenhouse) sheds (Huang et al. 1995) have emerged as important infrastructure for raising livestock in western China where mid-winter temperatures often drop to –30 °C. At these temperatures, the low-quality forage consumed is insufficient to maintain live weight and body temperature, resulting in significant weight loss over the protracted winter, even when housed in traditional livestock sheds where the inside temperature is often below –10 °C (Huang et al. 1995). In contrast, warm sheds maintain an inside temperature in January of about 5 °C during the day and just above 1 °C at night (Huang et al. 1995). Under these conditions livestock can either maintain or increase live weight over the winter period, provided there is a moderate quantity of reasonable fodder available. At worst, weight loss is minimised. These differences in live weight show clear financial benefits from keeping animals in warm sheds although the cold seasons, in part compensating for limited supplementary fodder (Han Guodong et al. 2011). Warm sheds are widely recognised as being of considerable value and various domestic and international (e.g. World Bank) programs have encouraged their use. There will likely be a long-term requirement for warm sheds as it may not be possible to produce enough high-energy supplementary feed across the colder regions of China to enable animals to survive the harsh winters in old-style sheds. Having enough suitable sheds for all the livestock on a farm and managing the sheds to minimise respiratory and other health problems among the animals can be constraints, the latter being a matter requiring continuing investigation. Herders do not always use warm sheds efficiently. Animals are still taken out to graze and put into the shed only in the evening, instead of restricting any outside activity to warmer periods and managing the shed to maximise the amount of warmth retained within it. Animal weight loss is largely a reflection of the average temperatures they experience, accentuated by how much walking they need to do. Herders need ongoing training in the optimal use of warm sheds.

The initial studies on demonstration farms (Kemp et al. 2011) indicated that animal condition was not monitored by herders as frequently as might have been expected. Animal health was checked by local officials on farms in spring and autumn, but otherwise there was limited treatment of animals unless they were obviously in poor condition or ill. Farms do not have yards for the easy capture, inspection, treatment and monitoring of animals. Families and neighbours need to be gathered together in order to capture and examine animals. Yards with a race (maybe in a warm shed for use throughout the year) would enable routine inspection of animals, earlier detection and treatment of problems, and consequent productivity gains for livestock. Animals in poor condition could then be kept separately for treatment.

Herders have traditionally brought animals back to the homestead or camp at midday so the herder can eat and rest, returning with the animals to grazing areas in mid-afternoon and coming home in late afternoon. The animals are provided with water for drinking only when back near the household. This applies in all weathers. On larger properties this means extensive periods of walking, with consequent higher energy requirements and weight loss. The provision of additional water points and grazing throughout the whole day, particularly through summer, are likely to significantly improve animal performance. Additional watering points can also be used on larger properties to manage when and how long different parts of the landscape are being grazed.

6. Finance and social implications

Implementing change on farms to improve incomes and to provide opportunities to rehabilitate grasslands needs to be done within the social and financial constraints that apply. A goal in this work has been to minimise the transition costs as herders change from current practices to any new system. The various alternative tactics and strategies investigated for each case study were influenced by this goal. From an analysis of sustainable rangeland management in China, Groom et al. (2008) concluded that, in order to achieve long-term sustainability, new programs should target policy issues such as land markets, increase tenure security and access to credit. Access to suitable lines of credit remains a significant constraint to the development of livestock industries, and current banking regulations make it almost impossible for commercial banks to lend money to poor herders (Hua and Michalk 2010). Without completely reforming the banking system, one of the ways to provide initial capital is through microcredit projects. Microcredit projects such as the Gansu Xinjiang Pastoral Development Project (Soderstrom et al. 2003) have played a pivotal role in technology transfer to poor households in western China (Park and Ren 2001).

Modelling showed that reductions in stocking rates, coupled with other feeding and management strategies, resulted in increased net income from livestock. That meant surplus animals could then be sold and the proceeds from sales used to finance more and better quality supplementary feed, build warm sheds and/or buy better quality livestock.

However, it would be unlikely that all the funds obtained from selling surplus livestock would be allocated to farm improvement as incomes for livestock-producing households are often around the poverty line. The allocation of these additional funds to farm improvement assumes a move from 'survival' to a more business orientated, production focus. This transition was evident in a financial analysis of Dacha village households in Sunan county reported by Hua and Michalk (2010) that clearly showed that herder households have already made some investment in new infrastructure such as fences and warm sheds without significant support from local banks. Since a business model requires longer term planning than herders often consider, effective training is needed to help herders better understand the credit options available to them so they can change practices and reap the full benefits of any change. In the near future, new land-tenure arrangements need to be resolved in China so that herders can access credit based on their access to land. At present they can borrow funds only against the buildings, moveable assets and livestock they have, which restricts the numbers of those who would like to develop a larger, more commercial enterprise.

Livestock management in China is labour intensive as herding is the norm. Households traditionally had 3–4 generations living together and each member was involved in various aspects of managing their livestock. However, that no longer applies as children attend school and family members often leave home to find work elsewhere in China. The reduction in the effective household workforce means that less can be done around the farm. The changes proposed here—culling inefficient animals, feeding in warm sheds and other practices—can be accommodated within the reduced household workforce. With reduced requirements for herding, children are better able to attend school, which then provides them with improved job prospects to transition from agriculture to other sectors of the Chinese economy. Interviews on farms often revealed that women now take the principal role in managing the livestock and running the farm business while the men pursue other activities or seek work elsewhere. The proposal that yards be re-designed with a race also enables a reduced workforce to manage the livestock better and without having to wait until all family members are home, e.g. at New Year.

Potential outcomes

The work outlined in the papers in these proceedings identifies pathways that would be expected to lead to substantial economic and other benefits, some within a short time frame using minimal additional resources, others longer term.

Economic benefits

The economic benefits from adopting the tactics and strategies outlined in the work reported here would apply at two scales: a macro scale that affects regional activities and a micro scale that applies to the individual herder family. At the macro scale, rehabilitating grasslands will produce long-term economic benefits via the stabilisation of the landscape, such that some form of livestock production remains viable and cultural practices are maintained. There will be further economic benefits from a reduction in off-site effects, such as dust storms and river siltation which are conservatively estimated to cost China US$7 billion per annum in lost agricultural production. At the on-farm scale we anticipate the on-farm pathways outlined will increase the net income from smaller, more efficient flocks and herds producing goods of higher value. This will be a novel approach for China and a shift from thinking of agricultural products as bulk commodities. In China there is already evidence that a 20% increase in wool prices from clean fleeces (resulting in minimal dust and fault) can be achieved by feedlotting animals, and 50% margins exist for better quality meat from shed-fed animals.

Across northern and western China where this project was done there are 16 million people (Brown et al. 2008) directly dependent upon livestock for at least three-quarters of their income and another 30 million people closely dependent upon grasslands. The mean annual income per household from livestock in 2005 was only ¥7,250, or ¥1,500 per head (<A$300). These incomes are among the lowest in China, the per-capita annual income for rural China as a whole being ¥2,200. Even if the benefits of this project achieved an average increase in income of only 10% over all households that would result in an annual benefit of ¥2.4 billion (approx. A$490m) for the 3.3 million households involved. At a 10% annual adoption rate of that 10% benefit the annual net gain is still ¥240m. It is anticipated that, for farms that adopt project outcomes, the net income gains could be initially of the order of

50%. These benefits would flow to some farms during the later stages of the project and increase over the medium to long term. As discussed above, the changes proposed here are only the first steps and further work is needed to build upon these initial gains.

Environmental outcomes

Rehabilitating grasslands is driven by the need to improve incomes on the one hand and to overcome the massive problems in environmental degradation occurring in western and northern China on the other, with off-site effects in eastern China and Korea and Japan. Overgrazing has resulted in the loss of biodiversity and soil, increasing desertification, siltation in major river systems and an increasing frequency of dust storms, particularly in spring. Restoring plant cover will significantly reduce all these problems. There are no simple answers, but reducing the grazing pressure must occur, driven by good policies, changes in husbandry practices and equitable markets. Without strong drivers for change, herders will simply continue to choose the management system that generates the most benefit at least risk to themselves and their families (Harris 2010). Harris concludes that ‘the lack of power to negotiate higher prices for produce and … lack of secure land tenure have favoured short-term benefit over long-term perspective of rangeland sustainability’. This indicates that overgrazing is inevitable unless the income-generating opportunities are improved.

This project has identified how reorganising the livestock production system provides opportunities for grassland rehabilitation. It is acknowledged that some species already lost from grasslands may not be recovered, and some wild animals may never return unless more national reserves are created and stocked. These are historical problems that cannot be redressed at a farm scale. The population pressures in these regions are so high that the highest priority has to go to providing food, fibre, fuel and an income for people, but within a framework that minimises any environmental impact. However, as pointed out by Hua and Michalk (2010), by empowering herders with new technical knowledge through targeted training, and increasing their confidence and decision-making skills through effective on-farm demonstrations, innovative production systems will emerge that improve household incomes under conditions in which fewer animals are dependent upon rangelands, thereby providing opportunities for grassland rehabilitation.

Government support

In 2009 the Communist Party of China Central Committee and State Council released plans which included that:

> The grass and livestock balance system shall be put into practice, the grazing prohibition, grazing land resting and rotational grazing shall continue, indoor and pen raising shall be promoted, and the construction of artificial grazing land and water projects in pasturing areas shall be conducted properly.

The implications of this plan are that much of the work done in China and reported in these proceedings is having a beneficial effect and the strategies proposed will be the subject of further development. It is anticipated this will lead to more research funding for our Chinese collaborators.

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These sheep on the desert steppe in Siziwang Banner, Inner Mongolia Autonomous Region, being taken out to graze each day in early winter would lose less weight if kept in a warm shed. [Photo: D.R. Kemp]