

The role modelling and farming systems research can play in redesigning grazing systems for improved productivity and environmental sustainability

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Abstract. Achieving production and natural resource outcomes from farming systems is critical with growing demand for livestock products, increasing pressure on land and water resources and the desire of farmers to improve profit and standard of living. In many countries this brings to the fore a number of policy dilemmas and conflicts in terms of pastoral household livelihood, regional economic growth and development, as well as natural resource management. By using two case studies; (1) Temperate Grasslands in Southern Australia (EverGraze project); and (2) Western Grasslands in North West China (ACIAR project), this paper considers how farming systems can be redesigned for production and environmental outcomes using modelling and farming systems research. Farming systems, as well as the regions and economies in which they operate, are complex and under constant change. The use of models combined with good science, relevant data and regional validation is essential to examine alternative systems that are better suited to changed operating conditions. Bio-economic modelling helps to understand trade-offs between production and enterprise performance and environmental sustainability over time and, most importantly, where multiple benefits from farming systems are possible. We contend that it is possible to redesign farming systems with both enterprise and environmental sustainability in mind. However the approach used to design and test alternative farming systems is important in an era of declining research resources and increasing complexity.

Keywords: Farming systems research, bio-economic model, whole farm models, profitability, environmental sustainability, EverGraze, temperate grasslands, Australia, China.

Introduction

Grassland farmers in Australia and China are under growing pressure to increase returns from livestock, to use resources more efficiently and to reduce off-site impacts. China's 400 million hectares of rangelands is highly degraded as a result of over-population, over-grazing, conversion to cropping, and adverse effects of drought (Li *et al.* 2008). In response to growing demand for livestock products, most pastoral households have increased stocking rates to maintain or increase income and standard of living. Evidence of degradation include lower plant production and biodiversity, increased frequency of rodent and grasshopper infestations, and large scale dust storms (Chen

and Wang 2000; Lu *et al.* 2005). Most dryland farming systems in southern Australia are based on annual pastures and crops or degraded perennial pastures. Over the last two decades there has been an increase in farming systems based on annual plants due to the economic viability of cropping and loss of perennials through severe and prolonged droughts. The environmental sustainability of annual-based plant systems continues to be questioned as they allow penetration of freshwater into the deep aquifers causing a rise in saline water tables, increased soil degradation and nutrient loss and do little to improve biodiversity (Masters *et al.* 2006). In both China and Australia, balancing trade-offs within farming systems, and across the broader region, between production and

environmental sustainability continue to be a major challenge.

Policies have been implemented in China and Australia to help address the decline of grasslands. The Central Government in China implemented policies, such as grazing bans (Brown *et al.* 2008), in which pastoralists trade-off grazing rights for a 5 year compensation package of grain or cash based on their estimated livestock production and the area of land (Michalk *et al.* 2010). Although about one fifth of China's rangelands having been subject to grazing bans or other rehabilitation methods since 2000, degradation continues due to over stocking. In Australia, policies have been more incentive based with funding offered to offset the cost of vegetation planting and other on-ground activities, provision of natural resource management extension services and more recently payment for environmental services. These policies have failed to address key environmental issues on a sufficient scale across the landscape.

The slow rate of change and declining government resources for improved environmental management raises the question whether farming systems can be re-designed and adopted on a sufficient scale to achieve economic and natural resources benefits for farmers and the wider community (Stoneham *et al.* 2003). The limited success of previous programs that targeted sustainable use of grasslands in north-west China has been attributed to adopting a component rather than an integrated approach (Kemp *et al.* 2011a). In Australia, grasslands research has moved towards a more integrated and farming systems approach, with programs of work such as the Temperate Pasture Sustainability Key Project (Mason and Kay 2000), the Sustainable Grazing Systems Key Project (Mason *et al.* 2003) and more recently the EverGraze project (Avery *et al.* 2009).

The EverGraze RD&E project commenced in 2003 as part of the Cooperative Research Centre for Plant Based Dryland Salinity (now the Future Farming Industries Cooperative Research Centre (FFI CRC)). The aim was to develop alternative farming systems that could substantially increase profit and reduce recharge across three states in temperate Australia. With prolonged drought and a decreasing perceived importance of dryland salinity the natural resource aim was expanded to include soils and biodiversity. The western grasslands China case study was an ACIAR project conducted in four provinces in western China. The project aim was to redesign farming systems to maintain or improve household income and rehabilitate rangeland. Both projects were seeking to develop alternative farming systems to achieve multiple positive outcomes; namely an increase in economic return with a beneficial natural resource outcome, grassland protection in north western China, and recharge management in southern Australia.

Approach to redesigning farming systems

Understanding the context

An important first step in both case studies was developing an understanding of the agriculture, community and environmental context within which farming systems operate. The approach taken in China was to use results from

household surveys undertaken by ACIAR and complement this with information from the provincial level Animal Husbandry Bureaus (Michalk *et al.* 2010). This analysis highlighted that the grassland resource belonged to the state and livestock belonged to the family and the importance of farm size and family structure. The diversity of rangeland/grassland types (desert steppe, typical steppe and alpine meadow steppe) were identified as well as those enterprises that best utilised grasslands. Other important areas that were characterised included forages grown for livestock, livestock enterprise and reasons for change in relative proportions of sheep and goats and management systems. EverGraze identified regions in the high rainfall zone (>550mm) to focus project work based on catchment contribution to recharge and dryland salinity, the proportion of the catchment grazed by livestock and the level of community interest (Catchment Management Organisation, leading producers and RD&E scientists). Literature review, consultation with researchers, farmers and catchment management organisations and the formation of regional advisory groups were all used to provide the context within which to consider the design of alternative farming systems.

Understanding biophysical responses

In both case studies understanding important biophysical responses were critical in ascertaining the potential of farming systems to achieve improved sustainability with increased economic return. In the western grasslands of China theoretical analysis of the basic relationship between animal production per head and per hectare was critical. High stocking rates exert substantive impacts on grassland sustainability which resulted in low net gain in live weight and low production of saleable product per head. In essence, the increased use of energy and nutrients for maintenance of stock along with declining plant production was contributing to inefficiencies in the system and potential existed to maintain the same level of production with reduced stocking rates. In EverGraze the relationship between a plants ability to dry the soil profile over late spring to autumn and the location of that plant in the landscape was identified as important in the management of recharge. Farming systems needed to be based around perennial pasture species as they are deep rooted, have green leaf in summer and can dry the soil profile. How perennials were then utilised by livestock became important for the profitability of these systems, and hence the relationship between pasture supply and demand was important for profitability.

It is important to recognise that biophysical response functions and surfaces are essential in farming systems RD&E. Biophysical modelling is dependent on response functions and algorithms developed through well designed component research. Over the last few decades, investment in well-designed component research has declined. Even when such research is undertaken, it is frequently compromised due to insufficient funding combined with continued pressure to only include treatments that reflect what might be adopted on farm. While this paper focuses on farming systems research, we stress that well-designed detailed component research is complementary and integral

to success of farming systems work. It is not a decision for investors to invest in one or the other but rather to strategically invest in both to achieve integrated outcomes.

Defining the question

Defining the question is one of the most important steps in farming systems research and is frequently derived from the theoretical analysis of basic biological response functions within the broader economic, region and sustainability context of the study.

EverGraze started with the question, can farming systems that increase profit by 50% and decrease recharge by 50% be developed? What was important about this question was the direct link between profit and recharge. That is if you altered the farming system for profit reasons the recharge benefit was highly likely to be achieved as a consequence. In the western grasslands case study in China there were two questions: (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 (Michalk *et al.* 2010). In contrast to EverGraze, these questions focused on the economic return and not grasslands protection and a herder could choose to adopt higher stocking rate across all their land for economic reasons and as a consequence have further negative impacts on grassland sustainability. A research question that strives for economic return together with a sustainability outcome is likely to be more effective in the design and implementation of improved farming systems.

The use of targets in the research question has advantages as well as disadvantages. In EverGraze it was important to be clear on the base case on which 50% improvement was to occur. EverGraze aimed to improve profit by 50% on current best practice in each region and to reduce recharge by 50% of the modeled recharge under the district average pasture. This approach worked well when there was benchmarking information, but was more difficult in regions where this data was incomplete or not available. While targets were useful in challenging the thinking in the design of future farming systems, they were less useful in communicating the project to farmers and agricultural advisers and had the potential to alienated target audiences. We conclude from this that the research question used to design new farming systems may not be the most appropriate question on which to base project awareness and practice change activities.

Having profit and natural resource goals clearly expressed and interdependent in the research question is important for both the design of farming systems as well as being the foundation for practice change on a scale needed to address natural resource grassland issues in both China and Australia (Sargeant and Glyde in press).

Selection of modelling approach

Bio-economic farm models are useful tools to help consider the impact of farming system change on production, economic return and environmental sustainability over time and under different regional contexts. Temporal and spatial scale was important for EverGraze when considering the

impact of farming systems on recharge.

The western grassland study in China used a modelling framework that was developed to evaluate alternative livestock management options in northern China as part of the ACIAR funded 'Sustainable Development of Grasslands in Western China project (Kemp *et al.* 2011a). A number of farms in four villages were surveyed, resulting data was used to parameterize farm level models for representative farms and the models were then used to analyse current livestock production systems and investigate the impact of alternative management options on household profitability.

EverGraze used a modelling framework that linked farming system models, GrassGro (Clark *et al.* 2000) or Sustainable Grazing System (Johnson *et al.* 2003) models depending on how well the model represented the farming system of interest, with MIDAS (Morrison *et al.* 1986), a bio-economic model, and the Catchment Analysis Tool (CAT) (Beverly *et al.* 2005), a catchment scale model that links surface and ground water systems. The models were linked via an exchange of pasture curves, soil and farm characteristics and livestock systems and paddock management protocols.

Both modelling approaches had their limitations. The ACIAR modeling framework, while able to detect change in household profit, had limited capacity to assess the environmental sustainability of the prospective change. The initial modeling approached used in EverGraze while able to consider recharge, was constrained by MIDAS operating on an annual basis. Annual pasture growth curves for each pasture type x management x place in the landscape were produced using 365 daily average values for 25 years. While the averaging of daily output over 25 years accounted for some climate variability the dynamics of farming systems was not captured in the initial EverGraze modeling approach, in particular the variability and risks inherent in prices and costs. These limitations, together with the limitations imposed by farming systems experiments (discussed below), meant that post-experimental modeling became important in further explaining the impact of variable seasons, price and changes to the farming system. Post experiment modeling also helped to assess risk analysing the variability in gross margins under a range of scenarios. Temporal and complexity differences between biophysical and economic modeling continue to be a challenge and worthy of continued research effort.

Pre-experimental/theoretical modeling

Modelling undertaken for the western grasslands in China was able to indicate that changes in the livestock enterprise (sheep for mutton, sheep for wool or goats for cashmere) and/or simple changes to the production systems (culling of unproductive livestock, changing lambing time, weaning earlier, developing better supplementary feeding regimes, grazing management and over-wintering stock in sheds) could increase net profit by 15-40% (depending on location) at current stocking rates, or conversely allow 20-40% reductions in stocking rate while holding net farm incomes at present level (Michalk *et al.* 2010). Further model development is required to assess environmental

sustainability of the proposed changes and in particular if a 20-40% reduction in SR would arrest pasture degradation. Survey results indicate that the stocking rates considered by herders to be ideal for sustainable farm income in which livestock numbers provide a buffer against drought and cold winters are likely to be too high to achieve worthwhile reductions in soil erosion. If this is the case other policy options, like payment for environmental services, may be required to bring about further stocking rates reductions.

Pre-experimental modelling for the EverGraze project was undertaken for a hypothetical farm in each catchment. The hypothetical farm was designed in consultation with regional groups using best available information. The Glenelg Hopkins catchment is presented in this paper as an example. In this catchment, the 'best practice' system was identified as a moderately productive perennial ryegrass and annual clover pasture with a stocking rate of 12.9 DSE/ha, feeding 30 kg/DSE of supplement to a traditional Merino wool producing flock. This system was shown to have the potential to generate a net profit of AU\$100/ha, which was validated against farm benchmarking data before further scenarios were considered. A highly productive perennial ryegrass pasture across the farm was modeled with a stocking rate of 24 DSE/ha and a supplementary feeding level of 39 kg/DSE. This system returned at profit of AU\$263/ha and had a small reduction in recharge when compared to the 'current best practice'. The third scenario tested was the 'triple pasture' system (tall fescue on the flats of the landscape, perennial ryegrass on the mid slopes and lucerne on the ridge). This system was not as profitable as the highly productive perennial ryegrass (scenario 2) but generated AU\$226/ha or AU\$126/ha more than the 'current best practice' system. Local producer input suggested that the reduction in profit was acceptable due to the high risk of ryegrass staggers with a farming system with 100% perennial ryegrass. The stocking rate was 22.3 DSE/ha and the level of supplementary feeding was unchanged at 39 kg/DSE. Leakage below the root zone (surrogate for recharge) in this scenario was 98 mm/year compared to 130 mm/year under the 'current best practice' system. Changing to a meat Merino production system with a focus on meat production and with surplus ewes mated to terminal sires increased profit by AU\$72/ha, AU\$146/ha and AU\$171/ha in the 'current best practice', the improved ryegrass and the 'triple pasture' systems respectively. The results for this comparison are shown in Table 1 and indicate that to achieve the most from the perennial pasture base, the livestock system needs to be responsive to improved pasture quality, and summer and autumn production and that this is most likely to occur in a system producing meat and wool with high fertility ewes.

Theoretical modelling and pre-experimental modelling provided both studies with a valuable understanding of the potential and validation of alternative farming systems to address the key questions. The process also encouraged cross-discipline discussion between soil, plant and livestock scientists, as well as economists, hydrogeologists and ecologists. Discussing model outputs with regional advisory groups also helped better understand the alternative farming systems and refine the modeled

scenarios.

Farming systems research

While the two case studies used similar approaches to this point, the approaches taken in farming system research differed. EverGraze undertook farming systems (approximately 70 ha in size) research in each catchment, whereas the western grasslands study in China relied on community discussion and demonstration to validate alternative farming systems and to achieve practice change. In China model outcomes showing that net farm incomes from livestock production could be improved, stimulated ongoing discussion about a range of new strategies to increase income and improve grasslands. Some of these management practices have now been taken up by households in each of the four demonstration villages and local officials have provided financial and other support to further develop the on-farm demonstrations, especially to improve the quality of livestock products through improved nutrition and genetics (Kemp *et al.* 2011b)

The EverGraze project conducted farming system research at six sites across three states in the high rainfall zone (>550mm) of southern Australia. These sites were referred to as Proof Sites and ran for four years at an approximate cost of AU\$250,000 to AU\$400,000 per site per year. Proof Sites were managed to best practice, including livestock genetics, and most were replicated. System attributes that were measured included soil, pasture, livestock and natural resource measurements using a common protocol across all sites. Outcomes from the Proof Sites were largely consistent with the initial modelling. However, the research exposed a number of management difficulties that were not identified in the modelling framework as well as identifying new ways to use and benefit from perennial pastures in redesigned farming systems. These understandings were later identified as critical in the development of the EverGraze Regional Packages and hence adoption of research outcomes.

The Hamilton Proof Site example was run for four years to compare the Perennial Ryegrass and the 'Triple Pasture' systems to 'current best practice'. Pasture production for all systems generally varied between 8 and 12 t DM/ha over the four years and was consistent with initial modelling predictions. The difference between modeled and measured farming system outputs included higher total pasture production under the 'Triple System' than under the Perennial Ryegrass system was due to tall fescue having higher than expected autumn and winter production with a better distribution of pasture growth across the year than perennial ryegrass. The value of lucerne for summer growth without a significant reduction to winter production was another part of the farming system that was not well represented in the initial modelling. These differences in distribution of DM production impacted on the requirements for supplementary feeding (AU\$24.82/hd and AU\$3.35/hd for the Perennial Ryegrass and 'Triple Pasture' systems, respectively in a year of a failed spring and summer rainfall) and explained some of the differences in lamb growth in spring. The 4-year average gross margins were AU\$617/ha/year and AU\$564/ha/year for the 'Triple System' (Scenario 3) and

Table 1. Production and management parameters for the improved pasture and livestock systems in the Glenelg Hopkins catchment.

	Farming system: Merino Flock ^A			Farming System: Wool-Meat Merino ^C		
	Current	Improved Perennial Ryegrass	Triple Pasture System	Current	Improved Perennial Ryegrass	Triple Pasture System
Profit (\$/ha.year)	100	263	226	172	409	397
Stocking rate (dse/WG ha)	12.9	21.6	20.1	13.4	23.5	21.6
Supplementary feeding (kg/dse)	30	39	39	36	39	41
Flock structure (% ewes)	52	52	52	84	87	87
Weaning (%)	71	71	71	114	110	114
Perennial ryegrass (% of farm)	100	100	60	100	100	60
Lucerne (% of farm)	0	0	20	0	0	20
Tall Fescue (% of farm)	0	0	20	0	0	20
Pasture growth (t/ha)	9.0	12.4	11.8	9.6	13.6	13.1
Pasture utilisation (%)	52	61	59	51	60	59
Wool income (4/ha)	451	757	705	337	567	529
Sheep sales (\$/ha)	69	118	108	263	459	458
Leakage below the root zone (mm/year)	130	121	98	130	121	98

^AStocking rate (DSE/WG ha) assumes ewes are 1.5 DSE/animal and dry sheep 1 DSE/animal. WG, winter grazed ^BFuture Triple: tall fescue on the flat, perennial ryegrass on the mid slope and lucerne on the ridges. ^C Terminal sire

Perennial Ryegrass (Scenario 2), respectively. Results compare favourably with the Average (AU\$282/ha/year) and Top 20% (\$484/ha/year) of prime lamb enterprises participating in the Farm Monitor Project in the region. Recharge estimates under all farming systems were minimal due to the dry years when the farming systems research occurred, however there was 10 mm/year less leakage below the root zone estimate under lucerne than perennial ryegrass. While the gross margins are a reflection of the seasons experienced during the field research, including a period of severe drought post experimental modelling confirmed that gross margins were similar over a 41 year period. The 'Triple System' (Scenario 3) however had lower variability in gross margin due to lower supplementary feeding costs in years with failed springs. The post experimental modelling was also able to show that a flexible sale date for lambs, enabled by perennials, higher margins could be made by growing lambs through to higher weights in January and February in 60% and 30% years respectively compared to selling lambs in December which was standard in the pre-experimental modelling.

The replicated farming system experiments undertaken in EverGraze have revealed new information about farming systems and have contributed to improving the design of alternative systems. Results have contributed to the development of model inputs, including pasture parameter sets, as well as validation and improvement of the models themselves. Outcomes from the farming system experiments were significantly influenced by the seasons in which they operated. The importance of modelling throughout the research to further understand the system and extrapolate results to other alternative farming systems, climate sequences and regions was also important in the EverGraze project. The full benefit of the EverGraze farming systems experiments has yet to be realised as the project is in its final phase of packaging information. To achieve adoption EverGraze is using a web-based approach to combine regionally relevant information from component and farming systems research, case studies, demonstrations and tools to assist with on-farm decision-

making (Sargeant and Glyde 2013). The impact of this approach and the importance of farming systems experiments within the regional package will provide further understanding on the value and cost-effectiveness of farming systems experimentation.

Future approaches to developing innovative farming systems

We argue that careful consideration is required on the overall approach to farming systems research and extension. Combinations of bio-economic modelling, component research designed to inform response functions, contexting through survey and social research, farming systems experimentation, demonstration and discussion are all important. However the combinations used need to be determined by the farming system design question. EverGraze has successfully integrated all these components of farming systems research into one large program of work. The western grasslands case study in North West China was able to achieve practice change by using theoretical modelling, village discussion and demonstration.

Given the complexity and cost of farming system experiments a cyclic approach may be worthy of consideration. There seems to be ample justification to bring together groups of multidisciplinary researchers and key stakeholders every decade or so to test and further understand the dynamics and relationships of different farming systems using new knowledge gained from component research, improved models and new questions. We should also consider new approaches to validate models and farming systems including the use of remote measurement techniques to help validate models. In Australia, farmers are now more familiar with the use of models to run scenarios to help inform decisions and there is a clear benefit in using farmers to a greater extent in model validation and understanding regional farming systems. Meat and Livestock Australia have embedded participatory research with producers in their new Feedbase Investment Program in recognition of the important role farmers can play in farming systems research. Improved data manage-

ment and access also has potential to improve model parameter sets and assist in validation of models.

Conclusions

In both China and Australia the growing demand for livestock products and the need to maintain and grow farm income is increasing the pressure on grasslands and the natural environment more broadly. It is imperative that farming systems are redesigned to be more efficient and sustainable. At the same time landscape change is required at a large scale without causing a major economic burden on the farmer, or the broader society. The two case studies explored in this paper demonstrate there are significant opportunities to improve farming systems with potential benefits to the environment. In the case of EverGraze the use of perennials can achieve profit and natural resource outcomes together reducing the need for incentives from government to achieve change. In the Chinese case study additional policy mechanisms may be needed as there was not the implicit link between increasing income and reducing grassland degradation, herders could increase stocking rate and income and have a continuing deleterious impact on grasslands. Clearly the ideal in farming systems research is to look for the win:win for production and the environment, but these are not always easy to find or possible.

While both case studies were conducted independently, there are a number of common elements to the approach used to design alternative farming systems. Both relied heavily on basic understandings of biophysical responses, both used local data and knowledge to context and understand the farming system, both used bio-economic modelling to consider opportunities to improve farming system production and return. In EverGraze the bio-economic modelling was linked to another model that could address sustainability. However, the economic model used operated on an annual basis and hence the variability of farming systems and their operating environment (markets) in Australia was not able to be fully considered. Post experimental modelling validated by Proof Site outcomes considered a range of price and season scenarios as well as different farm set-up options was important in further understanding the systems investigated. The western grasslands case study while able to consider the impact of the farming system on house hold income was not able to model the impact of changing stocking rate on grassland degradation. EverGraze has also considered off-site and catchment scale impacts of broad scale adoption of the EverGraze farming systems. This approach is likely to be feasible in China with the development of a farming systems model that can predict grassland degradation or soil loss which is the focus of on-going ACIAR funded work in western China. Where the case studies differ was the need to undertake farming system experiments to further understand and validate new farming systems. The step to undertake farming systems experiments needs to be considered carefully given the cost, consumption of research capability, complexity and outcomes.

We conclude that while there is an important role for farming system experiments, they must not come at the expense of well designed component research that develops

biological response functions that underpin models and farming system questions and understanding. Farming systems experiments should be conducted when there is a need to understand interactions between elements of farming systems as a result of combining innovations from component research. This may arise every decade or so. Further work (currently under way) will reveal how producers value modeled outputs compared to farming system research and demonstration in their decision making.

References

- Avery, A., Saul, G., Sanford, P., Behrendt, R., Friend, M., Mitchell, M., Virgona, J., Badgery, W., Lodge, G. (2009). EverGraze – Right plant, right place, right purpose. *Proceedings of the 50th Annual Conference of the Grassland Society of Southern Australia Inc.* 2009. p59-68
- Beverly C, Bari M, Christy B, Hocking M, Smettem K (2005) Predicted salinity impacts from land use change: comparison between rapid assessment approached and detailed modelling framework. *Australian Journal of Experimental Agriculture* **43**, 195-203
- Brown CG, Waldron SA, Lonworth JW (2008) Sustainable development of Western China: managing people, livestock and grasslands in pastoral areas. Edward Elgar, Cheltenham, London
- Chen ZZ, Wang SP (2000) Typical steppe ecosystems of China. Science Press, Beijing, pp 9-45, [In Chinese]
- Clark SG, Donnelly JR, Moore AD (2000) The GrassGro decision support tool: its effectiveness in simulating pasture and animal production and value in determining research priorities. *Australian Journal of Experimental Agriculture* **40**, 247-256
- Johnson IR, Lodge GM, White RE (2003) The Sustainable Grazing Systems Pasture Model: description, philosophy and application to the SGS National Experiment. *Australian Journal of Experimental Agriculture* **43**, 711 - 728
- Kemp D, Brown C, Han GD, Michalk D, Nan ZB, Wu JP, Xu Z (2011a) Chinese grasslands: problems, dilemmas and finding solutions. In: DR Kemp & DL Michalk (eds.) Development of sustainable livestock systems on grasslands in north-western China. *ACIAR Proceedings* 134, pp. 12-24.
- Kemp D, Han GD, Junk G, Langford C, Michalk D, Millar G, Takahashi T, Xu Z, Zhao ML (2011b) Demonstration farms to improve grasslands and household income in western China: what can be done and what are we learning? In: DR Kemp & DL Michalk (eds.) Development of sustainable livestock systems on grasslands in north-western China. *ACIAR Proceedings* 134, pp. 152-161
- Li XL, Yuan QH, Wan LQ, He F (2008) Perspectives on livestock production systems in China. *Rangeland Journal* **30**, 211-220
- Lu ZJ, LU XS, Xin XP (2005) Present situation and trend of grasslands desertification and the implications for rangeland management (Chapter 7)
- Mason W, Kay G (2000) Temperate Pasture Sustainability Key Program: an overview. *Australian Journal of Experimental Agriculture* **40**, 121-123
- Mason WK, Lamb K, Rusell (2003) The Sustainable Grazing System Program: new solutions for livestock producers. *Australian Journal of Experimental Agriculture* **43**, 663-672.
- Masters D, Edwards N, Silience M, Avery A, Revell D, Friend M, Sanford P, Saul G, Beverly C, Young J (2006) The role of livestock in the management of dryland salinity. *Australian Journal of Experimental Agriculture* **46**, 733-741
- Michalk DL, Hua LM, Kemp D, Jones R, Takahashi T, Wu JP, Nan ZB, Xu Z, Han GD (2010) Chapter 14: Redesigning

- Livestock Systems to Improve Household Income and Reduce Stocking Rates in China's Western Grasslands. pp. 301-324. In "Towards Sustainable Use of Rangelands in North-West China", Edited by Victor Squires, Hua Limin, Zhang Degang and Li Guolin, Springer Dordrecht
- Morrison DA, Kingwell RS, Panell DJ, Ewing MA (1986) A mathematical programming model of a crop-livestock farm system. *Agricultural Systems* **20**, 243-268
- Sargeant K and Glyde S (2013) From research to practice change – achieving adoption through regionally packaged technology and farm systems. *Proceedings of the 22nd International Grasslands Congress 2013*
- Stoneham G, Eigenraam M, Ridley A, Barr N (2003) The application of sustainability indicators to Australian Agriculture: an overview. *Australian Journal of Experimental Agriculture* **43**, 195-203