Strengthening Carbon Financing for Grassland Management in the People's Republic of China

Mitigation Options in Grassland-Based Animal Husbandry

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Foreword

Like many other countries, the People's Republic of China (PRC) is being impacted by climate change, with average mean temperature increases for the last 6 decades of 0.25°C per decade. Climate models indicate that temperatures will continue to rise. Climate-related disasters, including droughts, severe storms, and flash floods, with high social and economic costs have increased in frequency and/or intensity. Among the adverse impacts of climate change, food security in the PRC is predicted to become a serious challenge. Yields of maize, wheat, and rice are likely to decrease; and in natural ecosystems, intensification of degradation and desertification will lead to decreased productivity.

The Asian Development Bank (ADB) supports regional cooperation among the countries of Northeast Asia to combat dust and sandstorms resulting from desertification. ADB is also strengthening the capacity of the governments of the PRC and Mongolia to access carbon financing for sustainable grassland management. ADB recognizes that healthy ecosystems are more productive and resilient, and therefore it is important to provide valuable ecosystem services, such as carbon sequestration. Healthy ecosystems are the foundation of herders' natural-resource-based livelihoods.

In close cooperation with the PRC's Foreign Economic Cooperation Center in the Ministry of Agriculture, this report was prepared for the Government of the PRC, the private sector, other donors, and nongovernment organizations to raise capacity for implementing grassland carbon projects with the aim of reducing the intensity of greenhouse gas (GHG) emissions. The report summarizes potential technical measures for increasing carbon sequestration and reducing the intensity of GHG emissions from grassland-based animal husbandry. Restoring degraded grasslands and increasing the efficiency of forage utilization are key strategies for addressing sustainable grassland management. Grassland restoration can sequester carbon, primarily in grassland soils; and improving forage utilization efficiency can reduce GHG emissions per unit of livestock product output. This publication aims to (i) provide an overview of carbon mitigation options, (ii) analyze the mitigation potential of key management options for improving production efficiency, (iii) explain the relevance of mitigation activities to sustainable development, and (iv) provide recommendations for carbon finance in the PRC.

The threats posed by climate change have significant impacts on the PRC's grassland ecosystems and livestock. This knowledge product provides the inputs necessary to set up provincial and national carbon markets, and for the Government of the PRC and other stakeholders to pursue external climate financing.

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Director General
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Leadership and inspiration were provided by the staff of the Foreign Economic Cooperation Center under the Ministry of Agriculture of the People's Republic of China. Local government staff were a vital component of the project, and their participation and insights were essential.

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Abbreviations

ADB	–	Asian Development Bank
CH_4	–	methane
CNY	–	yuan
CO_2	–	carbon dioxide
GHG	–	greenhouse gas
IMAR	–	Inner Mongolia Autonomous Region
PRC	–	People's Republic of China
SOC	–	soil organic carbon

Weights and Measures

gC/m^2	–	gram of carbon per square meter
ha	–	hectare
kg	–	kilogram
SU	–	sheep unit
tC	–	ton of carbon

Executive Summary

This report summarizes potential technical measures to increase carbon sequestration and reduce the intensity of greenhouse gas (GHG) emissions from grassland-based animal husbandry in the People's Republic of China (PRC). A considerable proportion of the PRC's grasslands are degraded. Overgrazing is one of the main drivers of degradation and is primarily driven by households' short-term, income-generating strategies. There are limited options for increasing forage supply in grassland areas, and purchasing fodder is costly. Restoring degraded grasslands and increasing the efficiency of forage utilization are key strategies for addressing sustainable grassland management. Grassland restoration can sequester carbon, primarily in grassland soils; and improving forage utilization efficiency can reduce GHG emissions per unit of livestock product output.

Measures to sequester soil carbon include prohibiting grazing on degraded grasslands; converting croplands to pasture or shrubs; planting grass, legumes, or shrubs on degraded grasslands; and applying fertilizer. These measures can sequester 1.5–4.7 tons of carbon dioxide per hectare per year for up to 50 years. To balance carbon sequestration and livestock production objectives, supportive changes in grazing and livestock management are required. Reducing grazing intensity, reducing the age of livestock raised through early offtake, and improving feed and livestock housing to fatten livestock in winter are measures that can increase the efficiency of forage utilization, improve livestock productivity, and thus potentially support improved grassland management.

Improving the productivity of individual animals and herds can also reduce the intensity of GHG emissions from livestock production. Relevant measures in the PRC's grasslands include culling less-productive animals, early offtake, improved breeds and breed selection, and use of improved feeds. In general, these measures should also increase the profitability of herders' livestock enterprises, although poor integration with livestock product markets may reduce the profitability of some options.

Measures to restore degraded grasslands that can sequester soil carbon are widely promoted by government-funded programs. These programs may be sequestering 175 million–240 million tons of carbon dioxide per year. The mitigation potential of improved livestock production is likely to be less than 10% of the soil carbon mitigation potential. However, because of their effects on forage utilization efficiency and livestock productivity, efforts to improve livestock management are crucial to supporting the adoption of improved grassland management practices and addressing potential trade-offs between carbon sequestration and income generation by herders. The main government-supported grassland management programs promote a limited number of management practices, and often provide subsidies that are insufficient to offset implementation and opportunity costs. Carbon finance could potentially complement existing investments by government and herders, with carbon revenues supporting the initial investment costs of improved practices, ongoing maintenance costs, opportunity costs, and the costs of community-based grassland and livestock management institutions.

Challenges for Grassland Management in the People's Republic of China

The purpose of this report is to summarize potential technical measures for increasing the removal of atmospheric carbon dioxide (CO_2) and reducing the emission of greenhouse gases (GHGs) from grassland-based animal husbandry in the People's Republic of China (PRC).

The grasslands of western and northern PRC, including the Tibetan Plateau and the Inner Mongolian Plains, cover more than 3.9 million square kilometers.[1] The ecosystem services provided by these grasslands are of key importance at the national, regional, and global levels. Grassland ecosystems preserve biodiversity, facilitate carbon storage, maintain hydrological services, and constitute an important resource for cultural and recreational activities. A large proportion of grasslands in the PRC are also grazed by domestic livestock, and are therefore valued for their productive uses.

Official sources state that 90% of the PRC's grasslands are degraded to some degree, including 1.8 million square kilometers that are moderately or severely degraded.[2] Numerous scientific studies at the local and regional levels have reported similar findings.[3] Degradation—as evidenced by decreased vegetation cover, changes in species composition in favor of less-palatable species, declining forage biomass for livestock production, and changes in soil properties—may also be accompanied by decreases in carbon storage, water retention, and biodiversity.[4] Grassland degradation directly affects the livelihoods of several million inhabitants of grassland regions, as well as more than a billion people who are affected by sandstorms, and who depend on grasslands in the PRC for hydrological services.[5]

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1 L. Kang et al. 2007. Grassland Ecosystems in [the People's Republic of] China: Review of Current Knowledge and Research Advancement. *Philosophical Transactions of the Royal Society (Biological Sciences).* 362 (1482). pp. 997–1008.

2 Government of the PRC, Ministry of Environmental Protection. 2001. *State of China's Environment 2001.* Beijing.

3 X. Li et al. 2011. Rangeland Degradation on the Qinghai–Tibetan Plateau: Implications for Rehabilitation. *Land Degradation and Development.* 24 (1). pp. 72–80; S. Li et al. 2012. Spatial Analysis of the Driving Factors of Grassland Degradation under Conditions of Climate Change and Intensive Use in Inner Mongolia [Autonomous Region], [People's Republic of] China. *Regional Environmental Change.* 12 (3). pp. 461–474; and R. Harris. 2010. Rangeland Degradation on the Qinghai–Tibetan Plateau: A Review of the Evidence of Its Magnitude and Causes. *Journal of Arid Environments.* 74 (1). pp. 1–12.

4 W. Wang et al. 2005. The Effect of Land Management on Carbon and Nitrogen Status in Plants and Soils or Alpine Meadows on the Tibetan Plateau. *Land Degradation and Development.* 16 (5). pp. 405–415; Y. Zhao et al. 2011. Factors Controlling the Spatial Patterns of Soil Moisture in a Grazed Semi-Arid Steppe Investigated by Multivariate Geostatistics. *Ecohydrology.* 4 (1). pp. 36–48; and C. Wang et al. 2008. Response of Plant Diversity and Productivity to Soil Resource Changing Under Grazing Disturbance on an Alpine Meadow. *Acta Ecologica Sinica.* 28 (9). pp. 4144–4152.

5 ADB. 2005. *Regional Master Plan for the Prevention and Control of Dust and Sandstorms in Northeast Asia.* Manila; and J. Xu et al. 2009. The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods. *Conservation Biology.* 23 (3). pp. 520–530.

Grasslands are complex socioecological systems, and there are many factors contributing to grassland degradation in the PRC (footnote 3). Overgrazing is one of the more pervasive anthropogenic drivers. In 2008, grasslands in the 120 pastoral counties of the PRC were overstocked on average by 27%, with more than one-third of the grassland area in pastoral areas overgrazed.[6] In agropastoral areas, 105 of 144 agropastoral counties were overgrazed. Household income-generating strategies are the main reason why households (many of whom are concerned about degradation) raise more livestock than can be sustained in the long term.[7] Average per capita net incomes in pastoral counties are significantly lower than the national rural average.[8] As a response to degradation, many herders have begun to use other sources of feed, such as hay, forage, and feed grains, either cultivating it themselves or purchasing it from the market. Feed costs and poor integration into markets remain major constraints on increasing profitability of household herding enterprises.[9]

The Government of the PRC has made efforts to respond to degradation. The National Grassland Conservation and Construction Master Plan aims to "basically halt the trend in grassland degradation" by 2020, and sets out targets for the implementation of specific measures, including fencing, reseeding, cultivation of forage, establishment of grassland nature reserves, treatment of degraded and desertified areas, implementation of full or seasonal grazing prohibitions, and balancing livestock feed demand with forage availability.[10]

One major initiative has been the Grassland Retirement Program (*tuimu huancao*), which has been implemented nationwide since 2005. The program targets degraded areas, promoting exclosure from grazing in heavily degraded areas, and seasonal resting of less-degraded areas. Rotational grazing and zero grazing are also promoted. Subsidies have been provided for fencing, feed, and grass seeds for reseeding degraded areas. Biomass production in the target areas has increased.[11] Herders have responded to the program in various ways. Evaluation in the Inner Mongolia Autonomous Region (IMAR) and the Ningxia Hui Autonomous Region suggests that many herders adjusted to the lack of forage resources by decreasing livestock numbers, increasing the proportion of reproductive livestock in their herds, and practicing earlier offtake of livestock as reflected in declining

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6 B. Xu et al. 2012. Monitoring and Assessment of Forage-Livestock Balance in [the People's Republic of] China's Pastoral and Agropastoral Areas. *Geographical Research.* 31 (11). pp. 2–10; 2008 was a year of generally good rainfall in grassland areas of the PRC.

7 L. Hua and D. Michalk. 2010. Herders' Income and Expenditure: Perceptions and Expectations. In V. Squires, L. Hua, D. Michalk, D. Zhang and G. Li, eds. *Towards Sustainable Use of Rangelands in Northwest [People's Republic of] China.* London: Springer Verlag. pp. 233–253.

8 Government of the PRC, Ministry of Agriculture. 2011. Promoting Sound and Rapid Economic Development in Pastoral Areas to Improve Herders' Income. Farmer's Daily Views. (Chinese article). http://www.agri.gov.cn/V20/SC/jjps/201110/t20111011_2354171.htm

9 D. Kemp and D. Michalk, eds. 2011. *Development of Sustainable Livestock Systems on Grasslands in Northwestern [People's Republic of] China.* ACIAR Proceedings No. 134. Canberra: Australian Centre for International Agricultural Research. 189 pp.; V. Squires et al. 2010. Exploring the Options in Northwest [People's Republic of] China's Pastoral Lands. In V. Squires, L. Hua, D. Michalk, D. Zhang, and G. Li, eds. *Towards Sustainable Use of Rangelands in Northwest [People's Republic of] China.* London: Springer Verlag. pp. 41–59; and S. Waldron et al. 2007. *[The People's Republic of] China's Livestock Revolution: Agribusiness and Policy Developments in the Sheep Meat Industry.* Wallingford: CAB International.

10 Government of the PRC, Ministry of Agriculture. 2007. *National Grassland Conservation and Construction Master Plan.* Beijing.

11 Government of the PRC, Ministry of Agriculture. 2006. *National Grassland Monitoring Report, 2006–2012.* Beijing.

average weights at sale.[12] One effect of these changes has been to increase production costs for herders and reduce net returns.[13] Herders' private production of forage rarely increased significantly enough to offset their reduced access to grazing lands, so the basic driver of overgrazing is still present in many areas (footnote 9).

Many grassland management measures promoted by government programs explicitly address the balance between livestock and forage, under which livestock numbers should be adjusted to available feed resources or feed resources acquired to meet livestock growth needs. The feed balance system has been written into the revised Grassland Law (2002), and is a basic component of grassland policy. A number of programs have been implemented to increase forage and feed supply in grassland areas. The National Grassland Conservation and Construction Plan aims to promote the cultivation of forage on 30 million hectares (ha) of marginal cropland and degraded grassland, and a grassland sector industrialization plan is being implemented to increase the supply of inputs for cultivation by farmers and herders.[14] In 2009, the National Modern Forage Industry Technology Program was initiated as one of the 40 programs for subsector modernization supported by the Ministry of Agriculture (footnote 14). Integration of livestock feed with agricultural production is also a strategy increasingly adopted in some areas.[15] Grasslands are mostly located in arid and semi-arid areas where rainfall is insufficient or too variable to support crop production. In many such areas, opportunities to increase forage supply are limited, so reduction of herd size has become the focus of recent policies. In 2011, the Grassland Conservation Reward Scheme began nationwide implementation.[16] In this scheme, households are provided with financial rewards for achieving a balance between livestock feed demand and supply. As with other programs, effective implementation will be difficult if it adversely affects herders' incomes.

The key issue in livestock development in the PRC's grassland areas is to balance the protection of natural resources with production and income-generation objectives (footnote 9). A focus on the efficiency of production (i.e., product output per unit input) is critical to identify options for managing these twin objectives. Figure 1 presents a simplified representation of a range of generic on-farm options potentially available to herders. Some of these options may be adopted jointly; e.g., measures to improve reproduction are often adopted together with early offtake and stall feeding in winter. In addition to the options listed, improved marketing and diversification of income sources (including off-farm work) are important activities to increase household incomes.[17]

[12] D. Huang and J. Wang. 2004. Analysis of the Grazing Ban Policy in [the People's Republic of] China Pastoral Area. *Chinese Agricultural Science Bulletin.* 20 (1). pp. 106–109.

[13] X. Li. 2006. Empirical Research on the Effect of Grassland Retirement Program on Farmers' Benefits in Inner Mongolia [Autonomous Region]. *Agricultural Technology and Economy.* 3. pp. 63–68.

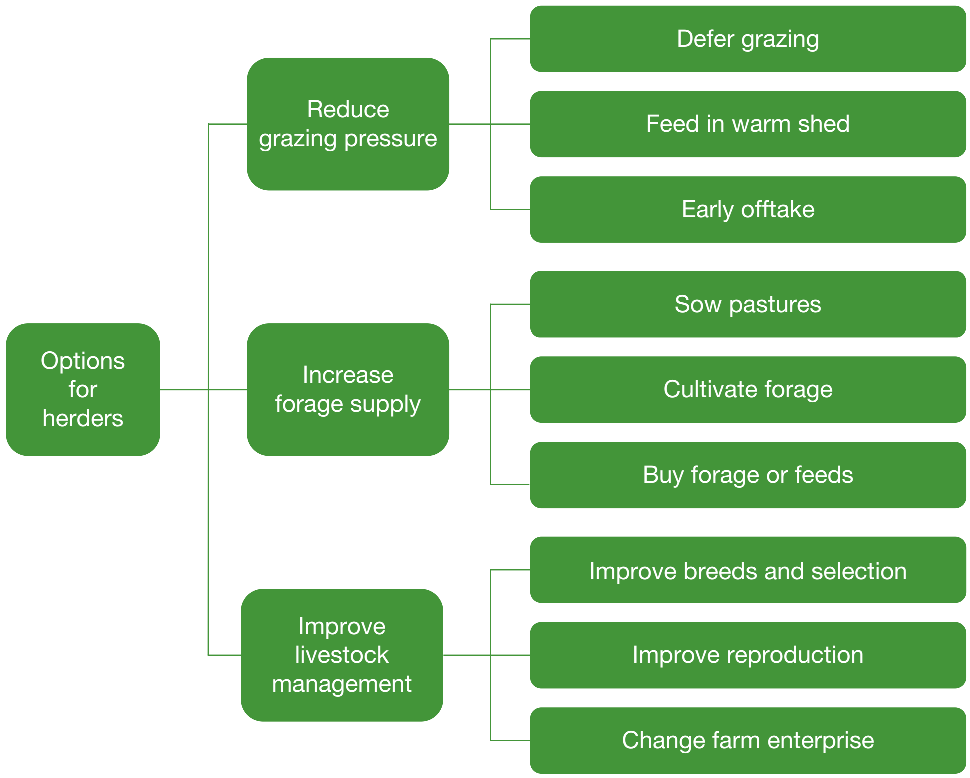
[14] Government of the PRC, Ministry of Agriculture, Grassland Monitoring and Supervision Center. 2009. National forage modern industrial technology system officially launched (Chinese article). http://www.grassland.gov.cn/Grassland-new/Item/1259.aspx

[15] D. Zhang et al. 2010. Agro-Pastoral Integration in Northwest [People's Republic of] China: A New Paradigm? In V. Squires, L. Hua, D. Michalk, D. Zhang, and G. Li, eds. *Towards Sustainable Use of Rangelands in Northwest [People's Republic of] China.* London: Springer Verlag. pp. 183–205.

[16] Government of the PRC, Ministry of Agriculture. 2011. Establishment of grassland ecological protection subsidy incentives by the Ministry of Agriculture and Ministry of Finance (Chinese article). http://www.moa.gov.cn/zwllm/tzgg/tz/ 201101/t20110111_1805095.htm

[17] C. Brown and S. Waldron. 2013. Agrarian Change, Agricultural Modernization and the Modelling of Agricultural Households in Tibet [Autonomous Region]. *Agricultural Systems.* 115. pp. 83–94.

Figure 1: Generic Options for Increasing Production Efficiency in Grasslands of the People's Republic of China



Note: "Change farm enterprise" refers to changing from selling mature sheep to selling lambs, or changing from selling meat animals to selling wool from animals.

Source: Adapted from V. Squires et al. 2010. Exploring the Options in Northwest [People's Republic of] China's Pastoral Lands. In V. Squires, L. Hua, D. Michalk, D. Zhang, and G. Li, eds. *Towards Sustainable Use of Rangelands in Northwest [People's Republic of] China.* London: Springer Verlag. pp. 41–59.

Although many of these options are known and adopted in some areas, not all of them will be feasible or beneficial in all contexts.[18]

All the options indicated in Figure 1 have implications for GHG emissions and carbon balance on farms. This offers the potential to support the restoration of degraded grasslands and increase the efficiency of production on farms through the valuation of environmental benefits. The following two chapters describe management practices that can sequester carbon or reduce the GHG intensity of livestock production, providing estimates of the quantity of GHG emission reductions that may be achieved. Lists of indicative activities that sequester carbon and reduce GHG emission are presented in the Annex.

[18] D. Kemp et al. 2013. Innovative Grassland Management Systems for Environmental and Livelihood Benefits. *Proceedings of the National Academy of Sciences.* www.pnas.org/cgi/doi/10.1073/pnas.1208063110

Technical Options to Increase Carbon Stocks

Overview of Grassland Carbon Stocks in the People's Republic of China

Natural grasslands are the most widespread land cover type in the PRC, covering about 40% of the country's land area. Grasslands make important contributions to the total ecosystem carbon balance in the PRC. The PRC's grassland biomass carbon stock is about 25% of the national forest biomass carbon stock,[19] which is much higher than the global average ratio of 4.6%.[20] While average global biomass carbon densities in grasslands are 670–978 grams of carbon per square meter (gC/m^2),[21] the average in the PRC has been estimated at about 315 gC/m^2; although the Tibetan Plateau in particular can have much greater carbon densities (Table 1).[22] Degradation of the PRC's grasslands is the main reason for the significantly lower average carbon density of these regions compared to the global average.

Land use change has a greater impact on carbon cycling in grassland ecosystems than either climate change or carbon dioxide (CO_2) concentrations.[23] The main land use changes impacting grassland carbon stocks are conversion to cultivation and overgrazing. Cultivation increases soil respiration, leading to a loss of soil organic carbon (SOC). It also replaces perennial vegetation with annual species, which reduces the proportion of primary productivity sequestered in soils, while harvesting of annuals reduces the input of carbon to soils.[24] Globally, cultivating grassland causes a loss of about 25%–30% of surface soil carbon.[25] During 1990–2000, the grassland area in the PRC decreased by more than

[19] J. Fang, G. Liu, and S. Xu. 1996. Soil Carbon Pool in [the People's Republic of] China and Its Global Significance. *Journal of Environmental Science.* 8. pp. 249–254; and J. Fang and A. Chen. 2001. Dynamic Forest Biomass Carbon Pools in [the People's Republic of] China and Their Significance. *Acta Botanic Sinica.* 43 (9). pp. 967–973.

[20] R. Whittaker and G. Likens. 1973. Carbon in the Biota. In G. Wordwell and E. Pecan, eds. *Carbon and the Biosphere.* Washington, DC: National Technical Service Information Service. pp. 281–302.

[21] J. Olson, J. Watts, and L. Allison. 1983. *Carbon in Live Vegetation of Major World Ecosystems.* Oak Ridge: Oak Ridge National Laboratory; and I. Prentice et al. 1993. Modeling Global Vegetation Patterns and Terrestrial Carbon Storage at the Last Glacial Maximum. *Global Ecology and Biogeography Letters.* 3. pp. 67–76.

[22] S. Piao et al. 2004. Spatial Distribution of Grassland Biomass in [the People's Republic of] China. *Acta Phytoecologica Sinica.* 28 (4). pp. 491–498.

[23] R. Sampson et al. 1993. Terrestrial Biospheric Carbon Fluxes: Quantification of Sinks and Sources of CO_2. *Water, Air and Soil Pollution.* 70. pp. 3–15; and G. Wohlfahrt et al. 2008. Biotic, Abiotic, and Management Controls on the Net Ecosystem CO_2 Exchange of European Mountain Grassland Ecosystems. *Ecosystems.* 11 (8). pp. 1338–1351.

[24] D. Anderson and D. Coleman. 1985. The Dynamics of Organic Matter in Grassland Soils. *Journal of Soil and Water Conservation.* 40 (2). pp. 211–216.

[25] E. Davidson and I. Ackerman. 1993. Changes in Soil Carbon Inventories Following Cultivation of Previously Untilled Soils. *Biogeochemistry.* 20. pp. 161–193.

Table 1: Above-Ground, Below-Ground, and Total Biomass and Carbon Density of the Five Main Grassland Provinces and Autonomous Regions in the People's Republic of China

Location	TAR	IMAR	XUAR	Qinghai	Sichuan	PRC
Area (10,000 km^2)	83.00	70.06	44.52	41.09	23.53	331.41
Above-ground biomass (TgC)	22.85	29.31	14.35	20.69	17.85	146.16
Below-ground biomass (TgC)	157.35	159.21	92.91	147.47	123.27	898.60
Above-ground carbon density (gC/m^2)	27.53	41.85	32.23	50.35	75.86	44.10
Below-ground carbon density (gC/m^2)	189.58	227.25	208.69	358.90	523.88	271.14
Below- and/or above-ground carbon density ratio	6.89	5.43	6.48	7.13	6.91	6.15
Total biomass (TgC)	**180.20**	**188.52**	**107.26**	**168.16**	**141.12**	**1,044.76**
Total carbon density (gC/m^2)	**217.11**	**269.08**	**240.93**	**409.25**	**599.75**	**315.24**

gC/m^2 = gram of carbon per square meter, IMAR = Inner Mongolia Autonomous Region, km^2 = square kilometer, PRC = People's Republic of China, TAR = Tibet Autonomous Region, TgC = teragram carbon (1 Tg = 1 million tons), XUAR = Xinjiang Uygur Autonomous Region.

Note: Figures for the grassland area of Sichuan Province include grassland that is now in Chongqing Municipality.

Source: S. Piao et al. 2004. Spatial Distribution of Grassland Biomass in [the People's Republic of] China. *Acta Phytoecologica Sinica.* 28 (4). pp. 491–498.

3 million ha; and soil carbon losses exceeded 100 million tons.[26] Thus, large-scale land use change in grasslands can have significant impacts on global carbon cycles. Grazing is the main use of natural grasslands. Overgrazing reduces above-ground biomass, so that in overgrazed grasslands, only 20%–50% of above-ground primary productivity returns to soils in the form of litter or dung.[27] It also increases soil respiration, thus increasing the release of soil carbon to the atmosphere.[28] Once grassland is cultivated or overgrazed, the organic carbon in the humus layer will rapidly oxidize and be released as CO_2. Grassland can therefore change from being a carbon sink to being a carbon source.

Grasslands, like other terrestrial ecosystems, rely on photosynthesis by green plants to sequester carbon. Carbon intake is then released through litter and roots, root respiration, and soil microbial respiration; and thus, the stored carbon is released back into the atmosphere. Any factor—natural or anthropogenic—that impacts on this process will influence the strength of the grassland sink or source.[29] Soils are an important part of global carbon cycles, and even small changes in the SOC pool can affect atmospheric CO_2 concentrations. Globally, soil releases about 76.5 petagrams each year in the form of CO_2 into the atmosphere, which is 12–16 times more than is emitted by fossil fuel

[26] J. Liu et al. 2004. Storage of Soil Organic Carbon and Nitrogen and Land Use Changes in [the People's Republic of] China 1990–2000. *Acta Geographica Sinica.* 59 (4). pp. 483–496.

[27] S. Wang, Y. Wang, and Z. Chen. 2003. *Grazing Ecology Management.* Beijing: Science Press.

[28] G. Cao et al. 2004. Grazing Intensity Alters Soil Respiration in an Alpine Meadow on the Tibetan Plateau. *Soil Biology and Biochemistry.* 36. pp. 237–243.

[29] L. Zhao et al. 2007. Relations between Carbon Dioxide Fluxes and Environmental Factors of *Kobresia humilis* meadows and *Potentilla fruticosa* meadows. *Frontiers of Biology in China.* 2 (3). pp. 324–332.

combustion.[30] The average density of carbon in the PRC's soils is about 10.50 kilograms of carbon per cubic meter;[31] but grassland has a higher-than-average density (12.96 kilograms of carbon per cubic meter), with alpine, subalpine, and mountain areas in southwest PRC having much higher average densities (footnote 26). The Tibetan Plateau has about 2.5% of global SOC stocks, and is therefore an important pool in global terrestrial carbon and global carbon cycles.[32] Hence, maintaining existing carbon stocks and sequestering as much additional carbon as possible are the general directions for soil carbon management in grasslands.

Sequestration Potential of Improved Grassland Management

A great deal of research has been conducted in the PRC on the impacts of various land management practices on soil carbon stocks. For degraded lands, research shows that exclosure from grazing, abandonment of cropping, application of inorganic fertilizer, and planting of shrubs on desertified lands can increase SOC content and density (Figures 2 and 3).[33] On average, these improved practices can increase average SOC content by 116% and SOC density by 68%. Application of inorganic fertilizer has the smallest effect, with an average increase in SOC content of approximately 20%. Planting shrubs on sandy lands has the biggest impact (582%), although the change in absolute carbon densities is small. Exclosure and abandoning cropping can increase SOC content by about 52%. Planting perennials on cropland can increase SOC content by 26%; but if former cropland is converted to shrubland, SOC content can increase by 111% (footnote 33).

Change in carbon content (i.e., the percentage of carbon) may not reflect change in the density of carbon in soils—measured in tons of carbon per hectare (tC/ha)—because grazing and other factors affect the compaction of soils. Fencing can increase SOC density by 4.4% per year, abandoning cropping by 5.9% per year, converting cropland to pasture or shrubs by 2.4% per year, planting shrubs on sandy lands by 7.4% per year, and applying inorganic fertilizer by 12.5% per year (footnote 33). These activities have the largest impact on SOC stocks in the first 5–10 years. After 50 years, soils will have reached saturation. During 3–28 years of exclosure from grazing, the average rate of change in soil carbon stocks (0–40 centimeters) is about 130.4 gC/m^2 per year. Abandoning cropping and letting the land naturally recover for 5–60 years gives an average rate of change in soil carbon stocks (0–30 centimeters) of 128.0 gC/m^2 per year. Planting perennial legume pasture on cultivated land for 2–4 years gives a rate of change of 56.5 gC/m^2 per year (footnote 33). Therefore, activities involving restoration of degraded lands and cultivation of leguminous pasture have significant carbon sequestration potential.

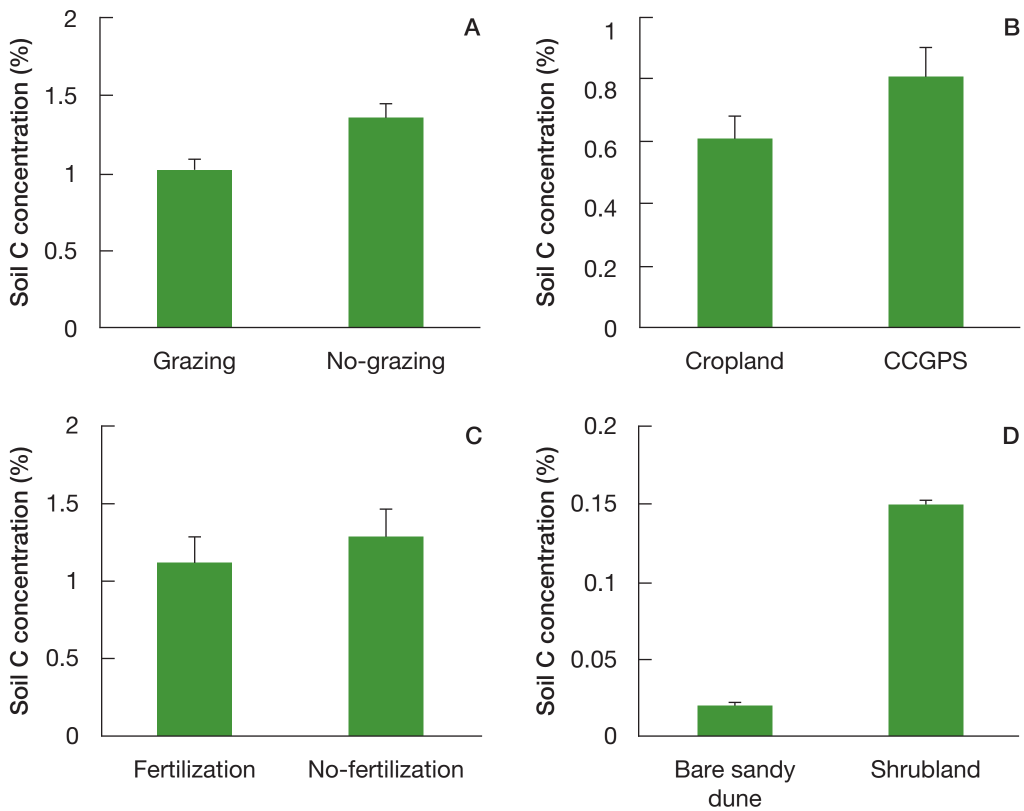
30 J. Raich and C. Potter. 1995. Global Patterns of Carbon Dioxide Emissions from Soils. *Global Biogeochemical Cycles.* 9. pp. 23–36.

31 S. Wang et al. 2000. Analysis on Spatial Distribution Characteristics of Soil Organic Carbon Reservoir in [the People's Republic of] China. *Acta Geographica Sinica.* 55 (5). pp. 533–544.

32 G. Wang et al. 2002. Soil Organic Carbon Pool of Grasslands Soil on the Qinghai–Tibetan Plateau and Its Global Implication. *The Science of the Total Environment.* 291. pp. 207–217.

33 S. Wang et al. 2011. Management and Land Use Change Effects of Northern [People's Republic of] China's Grasslands on Soil Carbon: A Synthesis. *Agriculture, Ecosystem and Environment.* 142. pp. 329–340.

Figure 2: Soil Organic Carbon Concentration for Grazing versus Exclosure from Grazing (A); Cropland versus Conversion to Grassland, Pastureland, or Shrubland (B); Fertilization versus No Fertilization (C); and Bare Sand Dune versus Establishing Vegetation (D)



CCGPS = cropland conversion to grassland or pastureland or shrubland.

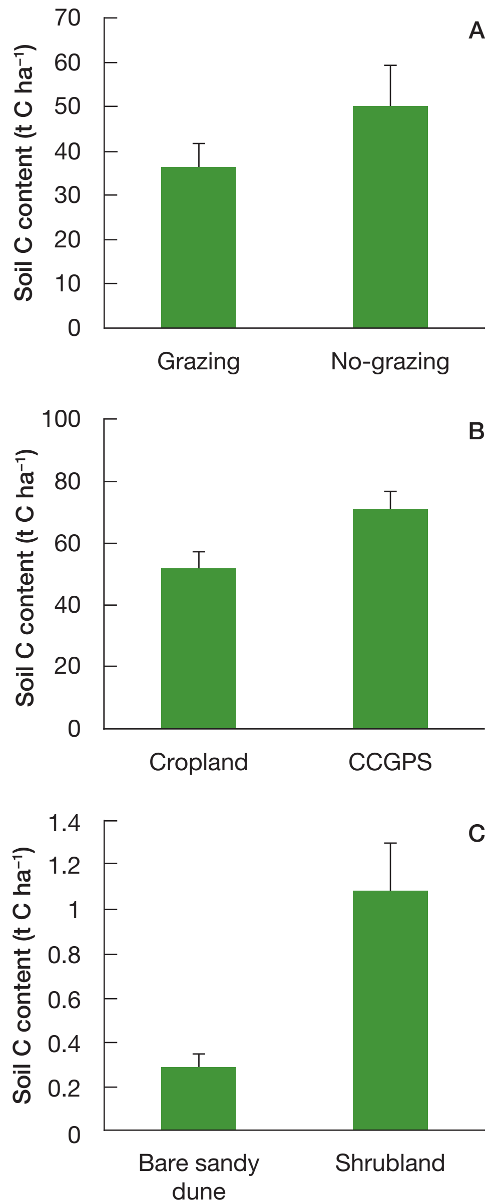
Note: All data are in percent soil carbon (C) content.

Source: Data from S. Wang et al. 2011. Management and Land Use Change Effects of Northern [People's Republic of] China's Grasslands on Soil Carbon: A Synthesis. *Agriculture, Ecosystem and Environment.* 142. pp. 329–340.

Compared with estimates from other countries, these results are broadly similar; but higher sequestration rates for some restoration practices in the PRC data probably reflect the more advanced state of degradation of the PRC grasslands before the adoption of restoration measures.[34]

[34] R. Conant, K. Paustian, and E. Elliot. 2001. Grassland Management and Conversion into Grassland: Effects on Soil Carbon. *Ecological Applications.* 11 (2). pp. 343–355; and S. Ogle et al. 2003. Uncertainty in Estimating Land Use and Management Impacts on Soil Organic Carbon Storage for US Agricultural Lands between 1982 and 1997. *Global Change Biology.* 9. pp. 1521–1542.

Figure 3: Soil Organic Carbon Content for Grazing versus Exclosure from Grazing (A); Cropland versus Conversion to Grassland, Pastureland, or Shrubland (B); and Bare Sand Dune versus Establishing Vegetation (C)



CCGPS = cropland conversion to grassland or pastureland or shrubland.
Note: All data are in tons of carbon per hectare ($tC\ ha^{-1}$).
Source: Data from S. Wang et al. 2011. Management and Land Use Change Effects of Northern [People's Republic of] China's Grasslands on Soil Carbon: A Synthesis. *Agriculture, Ecosystem and Environment.* 142. pp. 329–340.

Supporting Soil Carbon Sequestration through Improved Grazing and Livestock Management

Some of the changes in land use or management practices described in the previous section (e.g., exclosure from grazing) have trade-offs with the productive use of grasslands. However, analogous to discussions of "land-sparing" effects of agricultural intensification in relation to biodiversity conservation, improved management of grasslands can also be supported by changes in livestock management practice.[35] Some of the key options relevant to grasslands in the PRC are examined in this section.

Carbon Sequestration through Reduced Grazing Intensity

Changes in grazing intensity have direct impacts on soil carbon sequestration and also have impacts on the production yields and economic benefits (Figures 4A and 4B).[36] In general, as the stocking rate increases, yield per animal decreases because each animal is able to consume less and forage quality is lower at higher stocking rates (Figure 4A). The total yield of livestock products per hectare increases up to a certain point, after which it declines (Figure 4B). The shape of this curve means that there are two points at which each level of production per head can be achieved (e.g., "a" and "b" in Figure 4B). At point "a", production per hectare is the same as at point "b", but at a much lower stocking rate. This is because, for a given live weight at lower stocking rates, individual animals reach that weight in a shorter period of time.

Table 2: Total Weight Gain per Hectare for Yak at Different Grazing Intensities over a 2-Year Period (kg/ha)

Year	Light Grazing	Moderate Grazing	Heavy Grazing
1	70.2	55.7	32.6
2	66.5	72.9	60.9
Total	**136.7**	**128.6**	**93.5**

kg/ha = kilogram per hectare.

Source: Q. Dong, Y. Ma, and Q. Li. 2003. Effect of Grazing Intensity on Yak Growth. *Acta Prataculturae Sinica.* 11 (3). pp. 256–260.

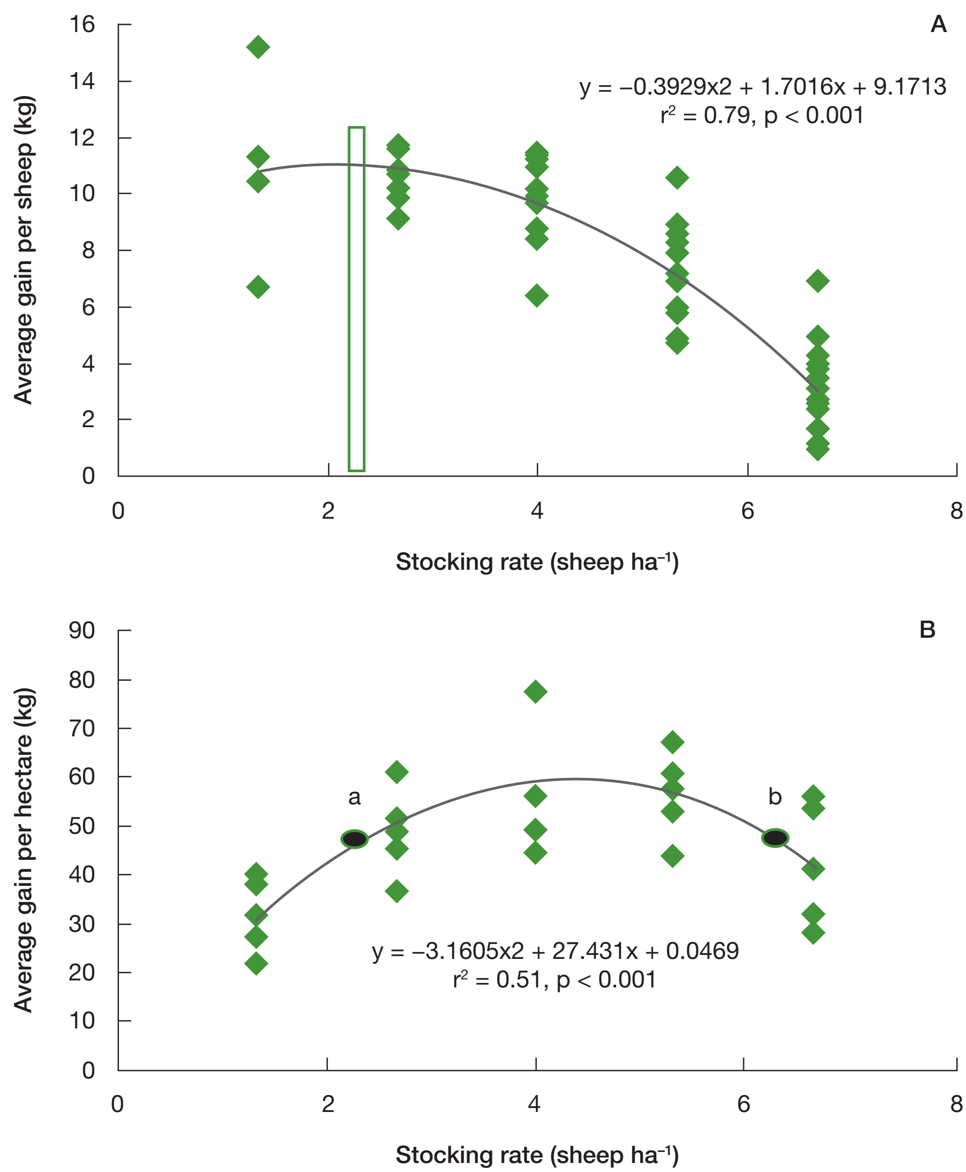
This framework for understanding the relationship between grazing intensity and economic benefits has been validated in several studies in the PRC. In yak production on alpine meadow, grazing experiments showed that both average individual weight gain per hectare and total weight gain per hectare decrease as grazing intensity increases (Table 2).[37] The maximum total weight gain per hectare can be achieved at stocking rates

[35] Land sparing refers to implementing measures that reduce the area of land required to produce a given amount of agricultural output to enhance environmental services on the land not under agricultural production. See R. Ewers et al. 2009. Do Increases in Agricultural Yield Spare Land for Nature? *Global Change Biology.* 15. pp. 1716–1726.

[36] R. Conant and K. Paustian. 2002. Potential Soil Carbon Sequestration in Overgrazed Grassland Ecosystems. *Global Biogeochemical Cycles.* 16 (4). pp. 90–91.

[37] Q. Dong et al. 2003. Study on Yak Fattening under Shed Feeding in an Alpine Cold Pasture Area. *Chinese Qinghai Journal of Animal and Veterinary Science.* 33 (2). pp. 5–7; and Q. Dong. 2006. Research on yak grazing systems and winter supplementary feeding strategies in the Three Rivers Area. Unpublished doctoral thesis at Northwest Plateau Biology Institute of the Chinese Academy of Sciences.

Figure 4: Relationship of Stocking Rate to Production Indicators



ha = hectare, kg = kilogram.
Source: Data from S. Wang, Y. Wang, and Z. Chen. 2003. *Grazing Ecology Management.* Beijing: Science Press.

of 1.67 yak/ha or 5 sheep units (SU)/ha in summer and 0.72 yak/ha or 2.16 SU/ha in winter, with an annual average of 0.63 yak/ha or 1.89 SU/ha (footnote 37).[38] A significant body of research shows that the grazing intensity with maximum weight gain is higher

[38] A sheep unit (SU) is a standard unit of equivalence for conversion between different animal types on the basis of their average daily consumption of dry matter.

than the sustainable grazing rate, and cannot continually provide stable weight gain in the long term. Research also shows that the grazing intensity that gives maximum profit per hectare is lower than the rate that gives the largest weight gain (footnote 27). Several studies have shown that the maximum weight gain and profit can be optimized by reducing the stocking rate by about 20% compared to the rate that gives maximum weight gain per hectare (e.g., footnote 37).[39]

A study conducted in the early 2000s in the alpine meadow regions of Qinghai Province found that the overstocking rate at that time was 122% in winter–spring pastures and 77% in summer–autumn pastures, or on average about 100% (i.e., about 4.2 SU/ha).[40] For long-term sustainability, therefore, stocking rates should be halved. This should not lead to a 50% decline in incomes, because the remaining animals would have more forage available and increases in individual weight gain could offset part of the loss. However, to avoid adverse impacts on herders' livelihoods, it is necessary to supplement this strategy with additional measures to raise livestock productivity by addressing feed resource availability, livestock management, and livestock product processing and marketing activities. Another study showed that for households with mixed herds of yak and sheep, reducing stocking rates by up to about 40% may yield positive returns when supplemented by cultivation of grass on degraded lands, but the up-front costs of investing in grass cultivation are prohibitively high for almost all herder households.[41]

Land Sparing through Early Offtake to Support Carbon Sequestration

For grassland-based animal husbandry, the traditional extensive grazing system based primarily on natural grasslands means that animals go through an annual cycle of fattening in summer followed by weight loss in autumn through spring.[42] This biophysical process has direct impacts on herders' economic production strategies. To achieve a certain income, herders often retain animals until they reach a larger weight. This means that annual offtake rates are low; so herd sizes are large, which creates a forage balance problem. Moreover, keeping sheep or other animals for several years means that one-third to one-half of annual weight gain during summer and autumn pastures is lost in the following winter. Thus, overall fodder utilization rates and animal productivity are low. This has a direct impact on the greenhouse gas (GHG) intensity of livestock production. A study on sheep in the Inner Mongolia Autonomous Region (IMAR) illustrates this point further.

39 L. Zhou, Q. Wang, and Q. Zhou. 1995a. Optimal Grazing Intensity in Alpine Meadow Pasture I. Grazing Intensity with Maximum Productivity of Tibetan Sheep. In Northwest Institute of Plateau Biology of the Chinese Academy of Sciences, ed. *Alpine Meadow Ecosystems.* 4. pp. 365–375; L. Zhou, Q. Wang, and Q. Zhou. 1995b. Optimal Grazing Intensity in Alpine Meadow Pasture II. Optimal Arrangement of Grazing Intensity on Rotational Pastures. In Northwest Institute of Plateau Biology of the Chinese Academy of Sciences, ed. *Alpine Meadow Ecosystems.* 4. pp. 376–390; L. Zhou, Q. Wang, and Q. Zhou. 1995c. Optimal Grazing Intensity in Alpine Meadow Pasture III. Grazing Intensity with Maximum Profit. In Northwest Institute of Plateau Biology of the Chinese Academy of Sciences, ed. *Alpine Meadow Ecosystems.* 4. pp. 391–402; L. Zhou, Q. Wang, and Q. Zhou. 1995d. Optimal Grazing Intensity in Alpine Meadow Pasture IV. Vegetation Changes and Maximum Grazing Intensity at Which Grassland Does Not Degrade. In Northwest Institute of Plateau Biology of the Chinese Academy of Sciences, ed. *Alpine Meadow Ecosystems.* 4. pp. 403–418; and H. Zhou, X. Zhao, and Y. Yang. 2004. Effects of Long-Term Grazing on Alpine Shrubland Vegetation on the Tibetan Plateau. *Grassland of China.* 26 (6). pp. 1–11.

40 S. Xu et al. 2004. Summary of Natural Biological Resource in the Source Region of the Changjiang and Yellow Rivers. *Resources and Environment in the Yangtze Basin.* 13 (9). pp. 26–31.

41 A. Wilkes et al. Estimated Climate Change Abatement Costs from Improved Grassland Management in Qinghai, [People's Republic of] China, with Analysis of Selected Finance Options. Unpublished.

42 X. Zhao, ed. 2009. *Global Change and Alpine Meadow Ecosystems.* Beijing: Science Press.

Research conducted in IMAR shows that as the age of sheep increases, the absolute increase in body weight each summer season decreases, while the absolute loss of body weight in each winter season increases (footnote 27). In its first summer, a lamb has a net weight increase of 22.75 kilograms (kg); but in subsequent years, its weight increases by 19.66 kg, 7.09 kg, 2.60 kg, and 2.71 kg. That is, each summer, the absolute net weight gain decreases as age increases, until it approaches the stable live weight of a mature sheep. By the age of 2.5 years, a sheep has reached 90% of its maximum weight. For a 4.5-year-old castrated sheep, after five summers, the accumulated weight gain is 87.32 kg (i.e., an average warm season weight gain of 17.46 kg). But, at 4.5 years old, the actual weight is 54.81 kg. The difference between these two figures represents the body weight loss over four winter seasons (i.e., an average weight loss each winter season of 8.13 kg). Therefore, half of the summer weight gain is lost in the winter. A similar result has been shown for yak husbandry in the Tibetan Plateau.[43]

Table 3 shows annual net income from weight gain per sheep at different ages. The total weight of each sheep increases with age, so its total value increases with age. However, because annual weight increase declines with age, the net return to raising sheep falls as the number of years to offtake increases. Therefore, selling lambs brings the highest annual net income, while annual net income per sheep decreases as the average age of the sheep increases. If, during any of these years, there is a snow disaster or drought and additional costs of supplementary feeding are incurred, then net income would even be lower. If animals die of disease or other causes, there would be an absolute loss. So, for castrated sheep, the lamb enterprise is the most suitable, with sales at the end of the year of birth and not later than 1.5 years old. If early weaning and improved feeding practices and livestock housing are used, then the profitability of lamb raising can be even higher.[44]

Table 3: Economic Analysis of Castrated Male Sheep Raised to Different Ages

	Age (years)				
Item	**0.5**	**1.5**	**2.5**	**3.5**	**4.5**
Total weight per sheep (kg)	22.75	42.41	49.50	52.10	54.81
Annual income from weight increase (CNY)	113.75	96.55	78.75	74.40	73.15
Income from wool (CNY)	0.00	38.00	40.80	41.80	40.90
Management costs (CNY)	0.00	3.25	38.30	61.40	59.60
Labor cost (CNY)	9.50	19.00	19.00	19.00	19.00
Feed cost (CNY)	4.20	8.40	8.40	8.40	8.40
Annual net income (CNY)	**100.05**	**68.90**	**53.85**	**27.40**	**27.05**

CNY = yuan, kg = kilogram.
Source: S. Wang, Y. Wang, and Z. Chen. 2003. *Grazing Ecology Management.* Beijing: Science Press.

[43] R. Xie et al. 2006. Research Report on Suitable Timing for Yak Off-Take. *Grassland and Animal Husbandry.* 4. pp. 22–29.

[44] D. Michalk et al. 2011. Re-Designing Livestock Strategies to Reduce Stocking Rates and Improve Incomes on Western [People's Republic of] China's Grasslands. In D. Kemp and D. Michalk, eds. *Development of Sustainable Livestock Systems on Grasslands in Northwestern [People's Republic of] China.* ACIAR Proceedings No. 134. Canberra: Australian Centre for International Agricultural Research. pp. 140–151.

Similarly, grazing intensities and the date of offtake can also have an impact on the profitability of sheep rearing, as illustrated in a study in the Xilingol region of IMAR (footnote 27). At high grazing intensities, sheep typically begin to lose weight after 20 September, because each individual sheep has less available forage. So if, for example, a sheep is sold on 5 November, it has already lost on average 1.2 kg, which if valued at CNY5/kg means an average loss per sheep of CNY6. The date of slaughtering should not be later than mid-November in the Xilingol region because by this date the maximum temperature is consistently below zero and weight loss is more pronounced. If slaughter is delayed until 5 December, a sheep will on average have lost another 2.26 kg, making a total loss of 3.46 kg, which represents a loss of CNY17.3 per sheep for the herder.

The same patterns can also be analyzed to optimize fodder utilization efficiency. Assuming an average daily dry matter intake of 2 kg/SU, forage utilization efficiency can be estimated for sheep at different ages.[45] For example, the ratio of weight gain to forage consumed for a castrated sheep is 1:13 at 0.5 years old, 1:26 at 1.5 years old, 1:37 at 2.5 years old, 1:49 at 3.5 years old, and 1:60 at 4.5 years old. This means that for lambs less than a year old, 13 kg of dry matter can create 1.0 kg of live weight, while a 4.5-year-old sheep will consume a total of 60 kg of dry matter for each net gain of 1.0 kg of meat. Thus, the forage utilization efficiency of raising lambs is 4.6 times higher than the efficiency of raising 4.5-year-old sheep. In terms of forage consumption, raising a castrated sheep to 4.5 years of age is equivalent to raising five lambs; but because the live weight of each lamb is about half the live weight of the 4.5-year-old sheep, total meat production can increase 3.5 times if lambs are raised instead.

These relationships suggest that by changing the structure of herds and the average age at offtake, changes in grazing and livestock management can support efforts to sequester carbon in grassland soils. As an illustration, if it is assumed that the live weight of two lambs is equivalent to one 4.5-year-old sheep, and that a lamb consumes 2 kg of dry matter per day and is slaughtered at 8 months old, the lambs will have consumed 2,325 kg less dry matter than the older sheep over its lifetime. This is equivalent to the yield of 0.72 ha of moderately degraded grassland. So if herd structure is changed to replace each 4.5-year-old sheep with two lambs so as to achieve the same total live weight yield, this is equivalent to excluding grazing on 0.72 ha of moderately degraded grassland. Exclusion of this area of grassland has the potential to sequester 7.37 tons of carbon (tC). If the baseline age at offtake is lower (e.g., 3.5, 2.5, or 1.5 years), then the sequestration potential of the land-sparing effect is lower, as shown in Table 4. Changes in livestock and herd management can therefore support changes in land use through a land-sparing effect.

Table 4: Potential Carbon Sequestration through Land Sparing Supported by Early Offtake of Sheep for a Given Total Live Weight Yield (tC/head)

	Baseline Age at Offtake (years)					
Change in Management Practice	1.5	2.5	3.5	4.5	5.5	6.5
Raising lambs of equivalent total live weight	1.23	3.58	6.14	7.37		
Raising yak calves of equivalent total live weight				13.71	27.42	41.13

tC = ton of carbon.
Note: Empty cells indicate livestock ages that are not applicable to the case study described in the text.
Source: Authors' calculations.

[45] A lamb cannot eat 2 kg of dry matter per day, but it drinks milk, which increases the ewe's intake; hence, 2 kg is used as an approximation.

Land Sparing through Fattening to Support Carbon Sequestration

Improved management of livestock in the winter season, including both feeding and housing, can make major contributions to livestock productivity. Numerous studies have shown that housing livestock in warm sheds during winter can reduce live weight loss for adults, increase weight gain for lambs and calves, increase birth weight, and reduce adult and peri-natal mortality; and, the effects are more pronounced when combined with supplementary feeding (footnote 37).[46] For example, with 2 months of fattening in stalls, a 2-year-old steer can achieve a weight gain of 16.8–22.6 kg depending on feed composition, compared to a weight loss of 8.8 kg under conventional daytime grazing; while a 3-year-old yak in a warm shed can gain 22.6 kg compared to 16.7 kg under daytime grazing (footnote 37).[47] By comparison, under natural grazing conditions in winter, a yak loses 6.8 kg. The input–output ratio for a 2-year-old yak is 1.16:4.52; while for a 3-year-old yak, it is 1.15:1.89; hence, fattening a 2-year-old yak has a higher economic benefit than fattening a 3-year-old yak. Male yaks that feed on milk for 5 months are 23.1 kg heavier than yaks that have a mixed milk–forage diet (footnote 43). In winter, providing 2.5-year-old yaks with a mixed diet of grazing and supplementary feed in a warm shed can reduce weight loss by 38.9 kg per head; and a 3-year-old steer on a diet of grazing and supplementary feed in summer can increase weight gain by 34.5 kg. Applying these three technologies together can increase weight gain from birth to 3.5 years by 96.5 kg, so that a yak is 260.0 kg at offtake. Therefore, across northern PRC, warm sheds are a very important infrastructure item for animal husbandry. However, raising animals in warm sheds has implications for labor and feed utilization; and not all feeding regimes will be profitable (footnote 9). Where warm sheds are heated, GHG emissions from energy use may also need to be considered.

When total live weight yield of a herd does not change, increasing the live weight per head is equivalent to reducing total livestock numbers, and pressure on grassland can be reduced. For example, if a lamb weighs 30 kg after fattening, then raising two sheep over winter in a warm shed is equivalent to raising one less lamb. If a yak is fattened to weigh 260 kg at 3.5 years old—assuming 10 kg of dry matter intake per day, and that 1 ha of moderately degraded grassland yields 2,725 kg of dry matter—then reducing one 3.5-year-old yak can potentially spare land and sequester 48 tC. Supplementary feeding and fattening for a 2- or 3-year-old yak can therefore potentially enable sequestration of 3.2–6.0 tC. If a calf is fully milk-fed, stall-raised, and fed supplements at 2.5 years and in summer at 3.0 years, then each yak can potentially enable carbon sequestration of 4.4–6.0 tC through the land-sparing effect (Table 5). Thus, as productivity gains relative to live weight in a control or baseline management system increase, the land-sparing effect becomes stronger and the theoretical mitigation potential of land sparing is larger. These estimates have not considered the emissions from fertilizer in feed production or transport of feed; but on a per animal basis, these may be insignificant depending on the type of fertilizer and the distance feed is transported.

[46] G. Han. 2006. Analysis of an Experiment on Raising Sheep in Warm Sheds in Gangcha Pastoral Area, Xunhua County, Qinghai Province. *Prataculture and Animal Husbandry.* 9. pp. 47–49; Y. Hu et al. 2001. Comparison of the Effects of Two Types of Plastic Warm Shed on Sheep. *China Herbivores.* 3 (5). pp. 32–35; and G. Wan et al. 2009. Effect of a Standardized Warm Shed in Winter on Sheep Reproduction and Lamb Survival. *Journal of Animal Science and Veterinary Medicine.* 28 (2). pp. 113–114.

[47] Q. Dong et al. 2004. Live-Weight Gain and Benefit of Feedlotting Yaks under Different Diets on Yangtze and Yellow River Source Area in Winter. Proceedings of the Fourth International Congress on Yak, Chengdu, PRC. pp. 444–452.

Table 5: Sequestration Potentially Enabled through Land-Sparing Effect of Fattening and Using Warm Sheds

Type of Livestock	Management Measure	Weight Increase Compared to Control (kg)	Animals (head) Needed to Equate to a Lamb or 3.5-Year-Old Yak	Mitigation Potential through Land-Sparing Effect of Reducing a Lamb or a 3.5-Year-Old Yak (tC)	Mitigation Potential per Animal through Land-Sparing Effect (tC)
Sheep	Warm shed	15.0	2	7.8	3.7
2.0-year-old yak	Feed mix 1	16.8	15	48.0	3.2
	Feed mix 2	20.4	13	48.0	3.7
3.0-year-old yak	Feed (no shed)	25.5	10	48.0	4.8
	Feed + shed	31.4	8	48.0	6.0
0.5-year-old yak	Milk diet	23.1	11	48.0	4.4
2.5-year-old yak	Shed + feed	38.9	7	48.0	6.9
3.5-year-old yak	Summer graze + feed	34.5	8	48.0	6.0
0.0–3.0-year-old yak	Milk + feed + shed	96.5	3	48.0	16.0

kg = kilogram, tC = ton of carbon.

Source: Livestock productivity data from R. Xie et al. 2006. Research Report on Suitable Timing for Yak Off-Take. *Grassland and Animal Husbandry.* 4. pp. 22–29. Mitigation potential estimated by the authors of this study.

Technical Options to Reduce the Greenhouse Gas Intensity of Livestock Production

Methane (CH_4) is produced during the digestive process by microbial fermentation in the rumen of ruminants. In cattle, 2%–12% of gross energy intake is lost in the form of CH_4; while for sheep, the figure is 7%.[48] CH_4 emissions are primarily related to levels of feed intake and the digestibility of feed. Methods to reduce the absolute level of CH_4 emissions include decreasing animal numbers (e.g., culling less-productive animals) and early offtake. The intensity of CH_4 emissions per unit of livestock product can also be decreased by increasing yield per animal (e.g., through a change in breed or breed selection), modifying diet, and reducing methanogen activity through feed additives.[49] Since a lower intensity of CH_4 emissions indicates more efficient utilization of feed, the general strategy of increasing feed utilization efficiency should also be in line with strategies to increase farm profitability, particularly where feeds are an increasing contributor to total farm costs. Two options of direct relevance to livestock production in the grasslands of the PRC are improving forage energy or protein utilization efficiency, and shortening raising and fattening cycles.

Improving forage energy or protein utilization efficiency. Most feed intake in extensive grazing systems is natural forage grasses, which may have lower digestibility than potential sources of supplementary feed. By changing the structure of forage consumption, providing supplementary feed, or using feed additives, enteric fermentation activity in the rumen of livestock can be changed with a resulting increase in the efficiency of energy use. This either directly reduces the total amount of CH_4 produced or reduces the intensity of CH_4 emissions per unit of livestock product produced (e.g., per kilogram of body weight or per kilogram of milk). For example, research found that supplementing natural forage species with feed concentrate increased average daily CH_4 production per sheep, but improved sheep productivity and reduced CH_4 emissions per unit of dry matter ingested.[50] A number of studies have documented the effects of improving feed quality and adjusting concentrate and/or roughage ratios on CH_4 emissions (footnote 49). Generally, these measures will increase animal productivity, although their profitability needs to be examined on a case-by-case basis.

[48] K. Johnson and D. Johnson. 1995. Methane Emissions from Cattle. *Journal of Animal Science.* 73 (2). pp. 483–492; and A. Pelchen and K. Peters. 1998. Methane Emissions from Sheep. *Small Ruminant Research.* 27. pp. 137–150.

[49] H. Dong et al. 2011. Reducing Methane Production from Livestock: Can More Efficient Livestock Systems Help? In D. Kemp and D. Michalk, eds. *Development of Sustainable Livestock Systems on Grasslands in Northwestern [People's Republic of] China.* ACIAR Proceedings No. 134. Canberra: Australian Centre for International Agricultural Research. pp.115–127.

[50] C. Wang et al. 2007. Effects of Forage Composition and Growing Season on Methane Emission from Sheep in the Inner Mongolia [Autonomous Region] Steppe of [the People's Republic of] China. *Ecological Research.* 22. pp. 41–48.

Shortening raising and finishing cycles. By reducing the length of time taken before sheep or calves are slaughtered, the total amount of CH_4 emissions or the intensity of CH_4 emissions per unit of animal product may be reduced. This also indirectly reduces nitrous oxide emissions in the management of livestock waste. The example of enteric fermentation emissions from yak shows how, even without changing the stocking rate, the total CH_4 emissions and the emission intensity changes through adjusting the age structure of a yak herd.

Research conducted on yak CH_4 emissions shows that a castrated adult male yak weighing 408 kg and consuming 6 kg of dry matter daily with a metabolizable energy of 10 megajoules/kg of dry matter emits 44.2 kg of CH_4 per year.[51] Assuming unchanged forage digestibility, a young steer weighing 145 kg and consuming 2.7 kg of dry matter per day would emit 27.3 kg of CH_4 per year. Assuming no change in stocking rate, in terms of forage consumption, one adult male is equivalent to 2.2 steers. Research also shows that a yak reaches maximum mature weight at 5 years old (footnote 43). In many areas of the Tibetan Plateau, yaks are sold at ages of up to 7 years and older, yet live weight does not increase over the 3 years of grazing between 5 and 7 years of age. Assuming a 2.5-year-old steer weighs 145 kg, while a 5- to 7-year-old mature male weighs 408 kg; in terms of total forage consumption over its lifetime, slaughtering the yak at 7 years old is equivalent to raising 9.9 heads of 2.5-year-old yaks. Assuming an annual average CH_4 emission of 35.8 kg for yak between 2.5 and 5.0 years of age, from 2.5 years to 7.0 years, a mature male yak would emit a total of 222.1 kg of CH_4. For the same amount of forage consumed, raising 9.9 heads of steer would emit 270.3 kg of CH_4, thus emitting 48.2 kg of CH_4 more than the 7-year-old yak (Table 6). But when calculated as emissions per kilogram of live weight, the emissions of the 7-year-old yak are 0.54 kg of CH_4 per kilogram of live weight, while the emissions of the 9.9 heads of steer would be 0.19 kg of CH_4 per kilogram of live weight, a significant decrease compared to the 7-year-old yak (Table 6). This is because early offtake reduces the total emissions per kilogram of live weight while increasing the total live weight produced over the period. From this example, one can see that without increasing the stocking rate, changes in the age structure of a herd can result in higher live weight sales while also reducing GHG emissions intensity.

Table 6: Emission Intensity Reduction Potential of Early Offtake of Yak

Item	Total (kg of CH_4/head)	Emissions Intensity (kg of CH_4/kg live weight)	
		Yield (kg)	**kg of CH_4/kg live weight**
Baseline[a]	222.1	408.0	0.54
Adjusted age[b]	270.3	1,435.5	0.19
Emission reduction[c]	(48.2)		0.35

( ) = negative, CH_4 = methane, kg = kilogram.

Note: Empty cells indicate that emission reduction is not applicable.

[a] Baseline data refer to emissions and yield from one head of 5- to 7-year-old yak without early offtake.

[b] Adjusted age data refer to emissions and yield from 9.9 heads of 2.5-year-old yak with early offtake.

[c] Emission reduction data refer to the difference in greenhouse gas emissions per kg live weight between baseline and adjusted age scenarios.

Sources: Y. Feng et al. 2012. Estimation of Methane Emissions in Cattle. *Chinese Journal of Animal Nutrition.* 24 (1). pp. 1–7; and R. Xie et al. 2006. Research Report on Suitable Timing for Yak Off-Take. *Grassland and Animal Husbandry.* 4. pp. 22–29. Calculation of emissions intensity by this study.

[51] Y. Feng et al. 2012. Estimation of Methane Emissions in Cattle. *Chinese Journal of Animal Nutrition.* 24 (1). pp. 1–7.

Early offtake of sheep is already common in some regions (e.g., IMAR), but is less common in some other grassland areas of the PRC (e.g., the Tibetan Plateau), indicating larger mitigation potential in these regions. Even so, research describes an example from practical experience in IMAR in which the introduction of improved breeds can further reduce time to offtake, increase profits, and support reduced stocking rates on summer pastures (footnote 18). In Siziwang Banner, rams of crossbreeds between Dorper sheep and the indigenous sheep breed are provided to members of a herder cooperative for reproduction with their existing herds. The resulting lambs reach a weight suitable for offtake within 3–4 months (i.e., before flocks graze on summer pastures), compared to 8–9 months with unimproved breeds. A local company that runs a fattening farm purchases the crossbreed lambs, paying a premium over the market price to ensure a supply of quality lambs, and fattens them before slaughter and sale to niche markets in the cities. With this opportunity, the cooperative members are able to achieve higher incomes than other herders, while also reducing the total number of animals grazing in the summer.

Assessment of Mitigation Options and Valuation Approaches

Addressing grassland degradation is a key priority for environmental sustainability and livelihood development in grassland areas of the PRC. The large size of the total area, some of which is significantly degraded, means that the potential to mitigate climate change by sequestering carbon through restoration of degraded grasslands in the PRC is substantial. Direct measures to restore degraded grasslands have measurable impacts on soil carbon sequestration. Research has estimated that achievement of the targets of the National Grassland Conservation and Construction Master Plan (footnote 10) for exclosure of degraded grassland from grazing and pasture cultivation could sequester 240 million tons of CO_2 each year (footnote 33). A consultant's report prepared under an Asian Development Bank (ADB) regional technical assistance project has estimated that a number of existing grassland management programs have a mitigation potential of about 175 million tons of CO_2 per year.[52]

These figures are approximately 12.5% and 9.0% of the PRC's total net emissions in 2005, respectively, and they do not consider potential effects on CH_4 or nitrous oxide emissions.[53] Insufficient data are available to produce a reliable estimate of the total GHG mitigation potential from improved livestock management in grasslands of the PRC. However, rough estimates based on national livestock population data and default emission factors from the Intergovernmental Panel on Climate Change suggest that the mitigation potential of improved livestock management is likely to be less than 10% of the mitigation potential of soil carbon sequestration.[54]

However, this does not mean that priority mitigation initiatives in grassland areas should solely focus on soil carbon. As this report has shown, interventions to increase livestock productivity and resource use efficiency can support the restoration of degraded grasslands through a land-sparing effect in which increased livestock productivity and feed-use efficiency reduce the amount of grasslands required to achieve the same or higher livestock product yield. To balance environmental and livelihood objectives, grassland carbon sequestration measures need to be supported by improved livestock

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52 ADB. 2013. *Grassland Recovery Incentive Mechanisms and the Influence on Carbon.* Consultant's report. Manila (TA 7534-REG).

53 Government of the PRC, National Development and Reform Commission. 2012. *Second National Communication on Climate Change of the People's Republic of China.* Beijing.

54 Government of the PRC, National Bureau of Statistics of the PRC. 2012. *China Statistical Yearbook 2012.* Beijing: China Statistical Press. In 2011, six main grassland provinces and autonomous regions (Gansu and Qinghai provinces; and Inner Mongolia, Ningxia Hui, Tibet, and Xinjiang Uygur autonomous regions) had a bovine population of 25.4 million and a combined sheep and goat population of 136.7 million. Applying emission factors of 47 kg of CH_4 per head per year for bovines and 5 kg of CH_4 per head per year for sheep and goats gives an estimated total emission of about 48 million tons of CO_2 equivalent per year. Even if total emissions were reduced by 30% for the same level of output, annual emission reductions would be about 14 million tons of CO_2 equivalent.

management. Improvements in livestock product marketing and income diversification would also help. However, exploration of these topics is beyond the scope of this study.

In 2011, the State Council issued *Opinions of the State Council on Promoting Rapid and Beneficial Development in Pastoral Areas*.[55] The document clearly annunciates the twin objectives of achieving a balanced use of the environment and reducing absolute and relative poverty in grassland areas. Forage and feed availability is a key constraint on the growth of livestock and the animal husbandry sector in these areas. The efficiency of forage and feed resource utilization is one key dimension that needs to be addressed to achieve both objectives.

The PRC has made large investments in grassland management and livestock productivity in grassland areas. About 60% of the PRC's grasslands are currently within the target area of national grassland programs (footnote 10). The recently initiated Grassland Ecology Conservation Subsidy and Reward Mechanism alone has an annual budget of CNY13.4 billion. Thus, in addition to herders' own private investments, public investments in grassland management are by far the largest source of financial support for improved grassland management. Although site-specific estimates of soil carbon sequestration rates can be relatively accurate, sequestration rates vary significantly between vegetation types and even between locations, depending on factors such as precipitation, topography, and the physical and chemical properties of the soil. Despite the large number of studies on soil carbon sequestration in grasslands of the PRC, uncertainty associated with large-scale estimates of soil carbon sequestration rates is quite high. Grasslands were not included in the GHG inventory covered in the PRC's recent national communication to the United Nations Framework Convention on Climate Change because of this high level of uncertainty (footnote 53). Significant advances in research would be required to provide a justification for increasing public investments in grassland management based primarily on carbon sequestration potential.

The national grassland programs provide subsidies for feed and forage, and support infrastructure investments (e.g., warm sheds) alongside grassland interventions (footnote 10). However, subsidies are sometimes insufficient to offset the increased costs of adopting grassland restoration practices, or to cover the costs of investing in infrastructure to improve livestock management. Many technical innovations can bring additional benefits when adopted together. Herders would also benefit from improved technical extension support, as well as marketing (footnote 18).[56] This means that innovations in grazing, livestock, and livelihood dimensions of grassland management need to be addressed in an integrated, comprehensive, and site-specific way. A number

[55] Government of the PRC, State Council. *Opinions of the State Council on Promoting Rapid and Beneficial Development in Pastoral Areas.* Beijing.

[56] J. Wu et al. 2011. Talking with [the People's Republic of] China's Livestock Herders: What Was Learnt about Their Attitudes to New Practices. In D. Kemp and D. Michalk, eds. 2011. *Development of Sustainable Livestock Systems on Grasslands in Northwestern [People's Republic of] China.* ACIAR Proceedings No. 134. Canberra: Australian Centre for International Agricultural Research. pp. 162–176; C. Brown and S. Waldron. 2013. Agrarian Change, Agricultural Modernization and the Modelling of Agricultural Households in Tibet [Autonomous Region]. *Agricultural Systems.* 115. pp. 83–94; and C. Brown, S. Waldron, and J. Longworth. 2011. Specialty Products, Rural Livelihoods and Agricultural Marketing Reforms in [the People's Republic of] China. *China Agricultural Economic Review.* 3 (2). pp. 224–244.

of methodological approaches for linking research with herders' needs and improving extension support have been demonstrated in different areas of the PRC.[57]

Carbon finance is a process based on private sources of finance provided in return for rights over the GHG emission reductions produced by improved grassland and livestock management. It has several potential functions in helping herders and other stakeholders address environmental and livelihood issues. In the context of the PRC's grassland areas, where many areas are already enrolled in some form of government program, carbon finance can potentially complement existing investments by the government and herders by helping address the shortcomings of existing investment programs and/or by supplementing existing investments. For herders, the primary benefits of adopting improved grassland and livestock management practices will be the economic benefits they can derive from increased grassland and livestock productivity in their household enterprises. However, carbon revenues can potentially help to meet the following kinds of cost:

(i) **Initial investments.** Carbon finance may be coordinated with ecological program investments to co-invest in grassland restoration, grazing management, or livestock productivity investments. Where there is a financing gap, carbon finance may supplement government and herders' investments in the same activities; or carbon finance may be used to invest in activities that are not subsidized by existing government programs (e.g., livestock product marketing) but are prioritized by herders.
(ii) **Costs of ongoing maintenance.** Many measures promoted in government programs require continued investment after the initial investment has been made, but these are not covered in the government programs. Examples include costs of continued fertilization after the establishment of cultivated pasture.
(iii) **Opportunity costs.** Subsidies provided in existing government schemes may be insufficient to cover the opportunity costs of adopting new practices. Carbon finance could help cover these costs.
(iv) **Costs of monitoring.** Carbon finance has strict monitoring requirements, and it can be used to support development of community-based monitoring mechanisms that are currently mostly lacking.

57 D. Kemp et al. 2011. Chinese Grasslands: Problems, Dilemmas and Finding Solutions. In D. Kemp and D. Michalk, eds. *Development of Sustainable Livestock Systems on Grasslands in Northwestern [People's Republic of] China.* ACIAR Proceedings No. 134. Canberra: Australian Centre for International Agricultural Research. pp. 12–23; and X. Li, A. Wilkes, and Z. Yan, eds. 2007. *Rangeland Co-management: Proceedings of an international workshop held in Diqing, Yunnan, [People's Republic of] China, 13–15 May 2006.* Beijing: China Agricultural Science and Technology Press.

Annex

Summary of Potential Livestock and Grassland Mitigation Activities

Table A.1: Potential Mitigation Activities in Grassland Management

Type of Intervention	Potential Activities
Improved grassland management	• For lightly or moderately degraded grassland (including shrub grassland types), reductions in grazing intensity and/or changes in the timing or duration of grazing, or application of organic or inorganic fertilizer, reseeding, and other conservation measures may increase soil carbon stocks. • For heavily degraded grassland (including shrub grassland types), exclosure from grazing or seasonal exclusion from grazing, or reseeding or application of organic or inorganic fertilizer or other means can increase soil carbon stocks.
Pasture cultivation	• On degraded grasslands with limited potential for natural regeneration within a reasonable period of time, cultivation of perennial grasses (including perennial legumes where suitable), and/or fertilization with manure and/or irrigation and other means can increase soil carbon stocks. • On degraded grasslands with limited potential for natural regeneration within a reasonable period of time, cultivation of biomass energy grass crops and/or application of organic or inorganic fertilizer and/or irrigation can increase soil carbon stocks as well as produce bioenergy sources. • For existing low-productivity cultivated pastures, reseeding or application of organic or inorganic fertilizer or seeding with mixed grass species and other means can increase soil carbon stocks. • For annual forage crops, changing to no-till methods or application of manure can increase soil carbon stocks.
Avoided or reduced conversion or degradation of grassland	• Canceling or reducing approved plans to convert native vegetation (including native shrub grassland as well as marsh meadow) or drain marsh meadow, etc., can reduce losses of vegetation and soil carbon stocks. • Through sustainable grassland management (e.g., suitable stocking management, reseeding with endemic species, biodiversity conservation, etc.), grassland ecosystem degradation can be prevented or reduced, and while maintaining supply of grassland ecosystem services, vegetation and soil carbon losses can be reduced.
Marsh meadow restoration and conservation	• Where marsh meadow has previously been drained and cultivated or degraded due to natural factors, abandoning crop cultivation and water management (e.g., raising groundwater levels) or other means to restore marsh meadow can lower soil organic matter decomposition, and increase soil carbon stocks. • For degraded marsh meadow, reducing grazing intensity can promote restoration and increase soil carbon stocks.
Land use conversions	• Conversion of degraded cropland to grass or perennial legumes and/or application of inorganic fertilizer can increase soil carbon stocks. • Conversion of wasteland to perennial cultivated grass or legumes or shrubs can increase soil carbon stocks and/or woody biomass. • Cultivation of bioenergy grass crops on degraded cropland or wasteland and/or application of inorganic fertilizer and/or irrigation can increase soil carbon stocks and produce bioenergy feedstock.

Note: Some management measures (e.g., application of organic or inorganic fertilizer, and irrigation) would imply an increase in project emissions and would only have net emission reduction effects where increases in carbon pools offset the increased emissions from the project.

Source: Compiled by the authors.

Table A.2: Potential Mitigation Activities in Livestock Management

Type of Intervention	Potential Activities
Increasing feed energy and protein use efficiency	• Adding leguminous grass to feed rations or adjusting the composition of feed to increase protein content can increase energy and protein utilization efficiency. Although total greenhouse gas (GHG) emissions may increase, emissions per unit of livestock product (e.g., kilogram of meat or milk) may be reduced. • Adding unsaturated fatty acids to feeds to control rumen methane (CH_4) production can increase the energy efficiency of feed utilization and reduce total emissions of CH_4 per animal. • In some situations, reducing the nitrogen content of feed ratios and/or reducing nutrients that may produce CH_4 or nitrous oxide and/or reducing total feed consumption to offtake may reduce emissions. • Adding amino acids or other additives to pig or poultry feed can increase protein utilization efficiency and reduce the total amount of protein feed used and total nitrogen deposited in dung and urine, thus reducing energy use in feed production and nitrous oxide emissions from manure.
Shortening feeding periods	• Before offtake of grazing animals (e.g., lambs or calves), 2–3 months of fattening can improve product yields and reduce GHG emissions per unit of livestock product produced. • Compared to conventional offtake practices, improved feeding and management can reduce the time to offtake, and reduce GHG emissions per unit of livestock product produced. • Substituting slow-growing breeds with faster growing breeds reduces the time to offtake and reduces GHG emissions per unit of livestock product produced.

Source: Compiled by the authors.

Table A.3: Potential Circular Economy Mitigation Activities

Type of Intervention	Potential Activities
Organic fertilizer production	• Compared to traditional manure management, separating solids and liquids can reduce water and energy use in sheds, and producing organic manure can reduce consumption of synthetic fertilizer.
Biogas energy production	• Compared to traditional waste management methods, anaerobic fermentation techniques produce biogas, which can be a source of energy, reduce nitrous oxide emissions in waste management, and save fuel wood or coal in energy use. • Compared to electricity generation from coal, using biogas to generate electricity can reduce the greenhouse gas intensity of energy.
Biogas energy production and organic fertilizer production	• Linking production of organic fertilizer to energy generation from biogas can reduce energy emissions and waste management emissions.

Source: Compiled by the authors.

Strengthening Carbon Financing for Grassland Management in the People's Republic of China: Mitigation Options in Grassland-Based Animal Husbandry

The majority of the People's Republic of China's 3.9 million square kilometers of grasslands are degraded and contribute to the emission of greenhouse gases. Restoring degraded grasslands and increasing the efficiency of forage utilization are key strategies for addressing sustainable grassland management. To balance carbon sequestration and livestock production objectives, changes in grazing and livestock management are required. This publication summarizes potential technical measures to increase carbon sequestration and reduce the intensity of greenhouse gas emissions from grassland-based animal husbandry. Carbon finance may help provide an incentive for some mitigation activities such as restoring degraded grasslands and increasing the efficiency of forage utilization.

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