10 Adaptation of Mixed Crop–Livestock Systems in Asia

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10.1 Introduction

The mixed farming system combining crop and livestock production, which usually is based on the interaction of arable crops such as forage crop, grain crop and oil crop, rangeland, woodland and livestock, is the dominant agricultural system of the world. It produces about half of the world's food (Herrero *et al*., 2010) and makes the largest contribution to the food supply of humans. The production system uses 90% of the total cropland, feeds 70% of sheep and goats and produces 88.5% of beef, 88% of milk, 61% of pork and 26% of poultry meat (Seré and Steinfeld, 1996; Blackburn, 1998). Approximately 84% of the total agricultural population is involved in the operation of mixed farming systems in developing countries (Blackburn, 1998). As one of the biggest developing areas, the situation in Asia is similar (Hou *et al*., 2009).

10.2 The Current Situation of Mixed Crop–Livestock Systems in Asia

Farming system evolution is the outcome of social, abiotic and biotic factors and their interactions (Ren, 1985). Various mixed crop–livestock systems exist due to the diversity of culture, environment, plants, animals and microbes, economic activities and the rich history of agricultural production in different countries. In terms of the interactions between livestock production and other components and eco-regions of farming systems, especially between plant and livestock, five types of mixed crop–livestock systems have been identified in Asia: farming systems based on rangeland; farming systems based on grain crops; farming systems based on crop/pasture rotations; agrosilvopastoral systems; and farming systems based on ponds (Fig. 10.1).

10.2.1 Farming systems based on rangeland

This type of production system is operated in the arid area (annual mean precipitation below 250 mm) of north-west China, central Asia and west Asia, of which the dominant landscape is the Gobi desert; some of the semi-arid area (between 250 mm and 500 mm annual mean precipitation), of which the dominant vegetation is steppe; the Qinghai-Tibetan Plateau and northern Russia, of which the dominant vegetation is tundra, alpine steppe or alpine meadow (Fig. 10.1). There is about 1900 × 10^4 km^2 of rangeland, which occupies 45% of the total land area in Asia. At a regional level, typical landscapes are coupled agroecosystems being made up of mountain, desert and oasis. Rivers originating in the mountain areas integrate three ecosystems of mountain, oasis and desert by supplying water and carrying the ingredients for life, while the desert supplies the existent

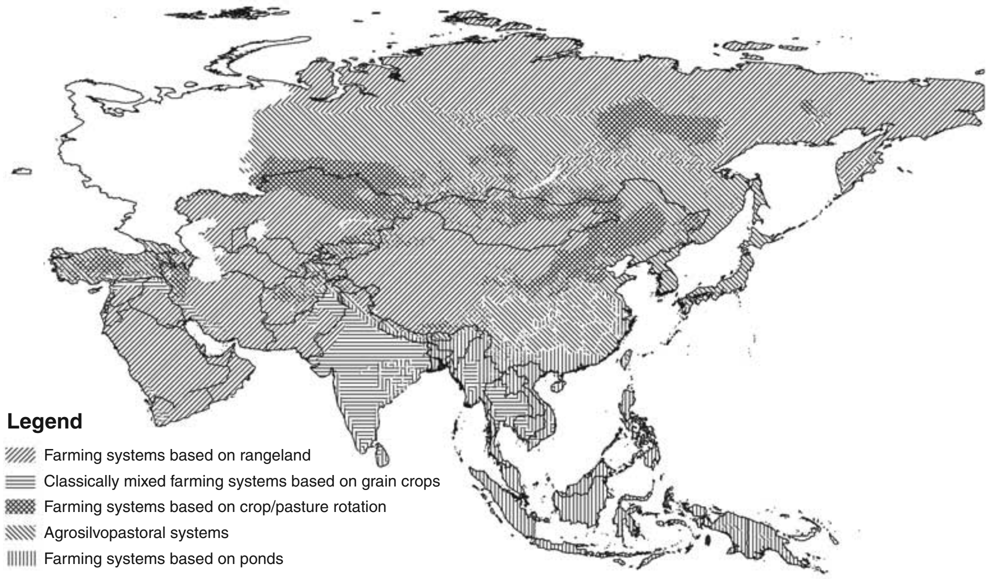

Fig. 10.1. Sketch map of mixed crop–livestock systems in Asia.

background of oasis and mountain (Hou and Li, 2001). Cropland appeared over 2000 years ago, first in natural oases, and expanded rapidly through the cultivation of the rangeland (including saline meadows, which are distributed sporadically in desert region) and the establishment of irrigation facilities both in desert and mountain regions (Hou and Li, 2001). Mountain, desert and oasis account for 43%, 53% and 4%, respectively, of the total land area in the Xinjiang Uygur Autonomous Region of China (Hou, 2007), and most of the croplands are located in oases. This kind of spatial pattern is common to many arid regions and some semi-arid regions of the world. On the whole, as a result of drought, high elevation and cold, there is over 95% of rangeland in desert, tundra and alpine areas, and the forage crop area is less than 10% of the cropland in oasis areas (Ren *et al*., 1995; Hou, 2000). Farming systems are supported by water from rivers rising in mountain areas (Ren *et al*., 1999).

Mixed farming systems based on rangeland feed about 35% of the sheep, horses and donkeys in the whole of China and produce approximately 60% of the wool and cashmere and 33% of the total milk and mutton produced in China (Nan, 2005). In arid areas of China, the main crops are cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.), which account for 31%, 20% and 14% of total croplands, respectively. Lucerne (*Medicago sativa* L.) originates from Iran, has been planted for over 2000 years and is the dominant forage crop in this kind of farming system. The main livestock in arid areas are sheep, goats, cattle and camels. In semi-arid areas of China, maize is planted in about one-third of the croplands, while the planted area of soybean (*Glycine max* (L.) Merr.) and wheat is 13% and 7%, respectively. The main livestock are sheep, dairy cattle, goats and beef cattle. In the Qinghai-Tibetan Plateau, the main crops are rapeseed (*Brassica napus* L.), hulless barley (*Hordeum vulgare* L. var. nudum Hook.f.) and wheat, for which the planted areas occupy 26%, 22% and 20%, respectively. The main livestock are yak (*Bos grunniens*) and Tibetan sheep. The sown pasture area accounts for only about 0.2% of rangeland in the Qinghai-Tibetan Plateau, 1% in the arid area and 0.2% in the semi-arid area (Hou *et al*., 2008). In the tundra area of eastern Russia, rye (*Secale cereale* L.), oat (*Avena sativa* L.), triticale (*Triticale hexaploide* Lart.) and sugarbeet (*Beta vulgaris* L.) are planted as forage crops in small areas, and reindeer (*Rangifer tarandus*) is one of the dominant livestock.

In this type of agricultural system, crop, rangeland and livestock interact with each other in the following five ways: (i) livestock graze rangeland throughout the year; (ii) livestock often graze fallow cropland and stubble cropland after harvesting the crop; (iii) livestock supply draft power and manure for crop production; (iv) crop residues and forage crops are provided to livestock mostly in the cold season; and (v) in an abundant rainfall year, herbage is harvested in the rangeland and then made into hay to feed animals in the cold season, which is one of the prevalent utilization ways in native meadow. There is a net flow of nutrient elements from rangeland to cropland in two ways: first, livestock graze rangeland during the daytime and stay overnight on fallow cropland; or, second, more prevalent in Asia, livestock excrement is collected, after the animals have grazed rangeland during the day and have stayed overnight in pens, which is then applied to cropland. This extensive type of agricultural system has a high ecological efficiency as a result of low inputs. A high ratio of rangeland to cropland such as in the farming–pastoral ecotone in northern China (e.g. Z.B. Nan, 2007, unpublished results) leads to intensive fertilization of cropland.

10.2.2 Classically mixed farming systems based on grain crops

This kind of farming system is located in the plains and oases of temperate and subtropical Asia, where crop production is possible owing to favourable conditions of water (rainfall or irrigation), temperature and soil (Fig. 10.1). It is one of the most dominant regions for maize, wheat, cotton and soybean production in the world because of the high yields of maize, cotton and wheat and the third highest yield of soybean, which is next only to North (USA and Canada) and South America (Brazil and Argentina). With abundant and high-quality grain and straw resources, this type of agricultural system seldom grows forage crops but feeds 34% of cattle, 47% of goats, 26% of sheep, 42% of donkeys and generates 58% of beef and 50% of milk production in China (Hou *et al*., 2008). And nearly 80% of buffalo is fed in India (A.K. Roy, 2013, unpublished). Interaction between crop production and livestock production occurs mainly in four ways (Wang and Zhou, 2007; Hou *et al*., 2009): (i) crop residues and grain are fed to livestock throughout the year; (ii) livestock supply manure and draft power for some crop production in the extensive systems of the developing regions, although there is an increasing level of mechanization in intensive crop production systems; (iii) livestock graze fallow cropland, stubble cropland and sparse rangeland; (iv) they also sometimes graze small grain crops such as wheat, barley and rye, which in these areas have been prevalent as multi-purpose crops (ground cover, energy, grain, forage, and so on) for a long time. The incorporation of small grain crops into grazing systems can overcome the feed gap of early spring and winter which commonly occurs in this type of farming system, and also provides the opportunity to exchange nutrient elements between different components of the farming system.

10.2.3 Farming systems based on crop/pasture rotation

This type of mixed system exists mainly in the transition zone between the nomadic and cropping areas and between the nomadic and forest areas in Asia. They are part of the Eurasian steppe and have relatively sufficient rainfall and heat, and have therefore been cultivated for crop production for a long time. Potato (*Solanum tuberosum* L.), maize, some small grains such as oat (*Avena chinensis* (Fisch. ex Roem. et Schult.) Metzg.), foxtail millet (*Tetaria italic* L.), broom millet (*Panicum miliaceum* L.) and legume crops such as soybean, pea and bean are the main crops in the region. The area planted to potato accounts for 73.4% of China's total potato crop (Hou *et al*., 2008). The main livestock are goats, sheep, beef cattle and donkeys (mule). Rainfed farming is dominant in a gulley area where the annual average rainfall is more than 250 mm and over 60% of the annual rainfall falls during the crop growing season. Frequent droughts are a key risk, especially in spring, because of large year-to-year variation in rainfall (Hou and Nan, 2006). A large number of farmers plant small grain crops in late summer or early autumn in order to utilize the rainfall and warmth for hay production (Hou and Nan, 2006). In most cases, this kind of farming operation takes place because of crop failure as a result of drought during spring or early summer. Legume crops are planted as part of the crop rotation in order to maintain or improve the fertility of cropland and to supply protein-rich fodder to livestock.

Crop production and livestock production are integrated into these systems in four ways (Hou *et al*., 2008): (i) forage crops (including some legume crops) and residues of other crops are fed to livestock in pens; (ii) livestock supply manure and draft power for crop production; (iii) livestock graze stubble cropland, fallow cropland and sparse rangeland; and (iv) livestock graze crops after failed harvests because of economic reasons as the result of serious disease and drought.

10.2.4 Agrosilvopastoral systems

Based on forest, this system is operated mainly in temperate forest areas, forest zones in the high mountains and some of the subtropical forest areas of Asia (Fig. 10.1). Dominant crops are wheat, soybean and maize in the temperate zone and rice and maize in the subtropical zone. The main livestock are cattle, goats, buffalo and deer (reindeer, wapiti, sika, river deer, etc.).

There are five ways in which livestock, crops and forestry enterprises mutually interact: (i) livestock graze in the forests; (ii) livestock graze the harvested cropland, forage cropland and fallow cropland; (iii) grain and crop residues are supplemented to livestock in pens; (iv) livestock supply draft power and manure both for crop production and timber production; and (v) forests provide shade and windbreaks for both crops and grazed livestock. Large areas of forest have been converted to cropland over a long period in these regions. Forests and cropland exchange nutrient elements through livestock movement, but there is a net nutrient flow from forestland to cropland because farmers collect manure from the pens where livestock sleep overnight, after grazing in the forest areas, and apply this manure to cropland. Both deer and goats browse trees, so they play a key role in the timber production of farming systems and forest conservation in some areas.

10.2.5 Farming systems based on ponds

Integrated systems based on ponds are located in the tropics and subtropics with good rainfall and relatively flat land (Fig. 10.1). This type of system has a relatively short history which can be traced back only about 600 years in inshore regions and gradually spreads to inland areas with abundant water resources in big river basins (Nie *et al*., 2003). This type of farming contributes over half of the rice, pork and chicken and most of the buffalo in the world, and the other main ruminant livestock are goats and cattle, which play a relatively minor role. The main crops are rice, tropical fruits and vegetables, among which the planted area of rice occupies nearly 60% of the total cropland in this region.

Interactions between livestock production and crop production in this type of system include: (i) crop residues are fed to livestock; (ii) livestock excrement together with some forage crops and crop residues are used as a resource for pond production; (iii) pond sludge together with livestock excrement are applied to cropland as fertilizers;

(iv) buffalo or cattle supply draft power for crop production; and (v) livestock graze the sparse rangeland and the cropland after being harvested. Obviously, the mixed farming systems originate from the pond production, which plays a key role in recycling nutrient elements and the economic allocation and energy exchange of the whole system (Pittaway *et al*., 1996).

10.3 Mixed Farming Systems, Climate Change and Adaptation

10.3.1 Mixed farming systems under global climate change

Global climate change threatens the sustainable productivity of farming systems at all scales, especially at the scale of species (crop cultivars or animal breeds) and ecosystems.

Impacts at species scale

Climatic factors play an important role in the productivity and distribution of crops and livestock. If the climate becomes warmer and drier, which have been identified as the main trends of global climate change in most areas of Asia (Ren *et al*., 2011), livestock with high adaptation to drought, such as goat, donkey, camel, deer, will extend their distributive areas, while other livestock with high susceptibility to climate change (such as horse, cattle, buffalo, sheep, and so on) will have their area of distribution reduced (Fan and Zhang, 1993). If the climate becomes warmer and wetter, the changes in distribution of both the above types of livestock will be reversed.

Global climate change will potentially affect the quality of animal products, although this topic has been largely ignored in much previous research. In cold regions of eastern and central Asia, livestock usually have higher meat production per capita, with higher fat content in animal products (Cheng, 1993). Global warming might result both in smaller livestock body weight and a decrease of meat production, but result in higher lean meat percentage (Cheng, 1993). In wetter regions including eastern Asia, South-east Asia and some of southern Asia, the quality of fur, wool and cashmere is usually poor, but the quality may improve if the climate becomes warmer and drier (Zhao and Qiu, 1999). In China, most of the fine-wool sheep have been bred in the cold regions, so a warmer climate could result in a negative influence on the yield and quality of fine wool. However, if precipitation increases more than evaporation, global climate change may promote animal production.

Impacts at ecosystem scale

Global climate change not only results in transforming the distribution, productivity and interaction of crop, rangeland and livestock but also affects the whole farming production system. Global warming with increased rainfall will raise the productivity of all types of farming systems, including both plant and animal production. In Asia, the area of rangeland has been forecasted to expand and that of woodland to shrink under conditions of global warming (Schellnhuber *et al*., 2013). Furthermore, increased rainfall will boost the effects of global warming. However, other models have indicated that global warming will decrease the productivity of grassland in the farming–pastoral areas of northern China and exacerbate the drought in arid regions of central and western Asia (Qiu *et al*., 2001; IPCC, 2007).

Normally, farming systems are relatively stable on an environmental gradient because the existing farm management measures could minimize the drift of farming systems under conditions of limited climatic fluctuation. All types of integrated farming systems can be characterized as part of a successional framework under the pressure of interaction among biotic factors (crops, livestock, etc.), abiotic (environmental) factors (precipitation, heat, etc.) and social factors (economics, management, etc.; see Fig. 10.2). Global climate change is another factor exerting selection pressure on the succession of farming systems. If the climate becomes warmer, management of forage crops and of the interactions between herbivore and forage will determine the stable level of the integrated farming systems (Fig. 10.2). However, increased frequency of dry and hot periods associated with global warming could be disastrous for farming systems.

Global climate change is a slow and gradual process at a large timescale, so livestock and crops could adapt themselves slowly and simultaneously (Hou and Yang, 2006; FAO, 2007; Yadav *et al*., 2011). Humans have time enough to breed new cultivars or breeds and to develop innovative management practices. However, global climate change will also induce a natural selection on the new breeds of livestock and new cultivars of crops; the influence of this is little known.

10.3.2 Adaptation of mixed farming systems to global climate change

Varieties of crop and breeds of livestock with high stress resistance

It is generally recognized that both varieties of crops and breeds of livestock with high stress tolerance have more stable and higher productivity under global climate change; this provides more options to improving farm management. A number of studies have looked at the effects of climate change on forage and animal species, and on their potential to enhance adaptation both by traditional and genetic improvement (FAO, 2007; Yadav *et al*., 2011; Redden, 2013). Furthermore, forage and livestock breeding can also contribute to climate change mitigation through reducing emissions of greenhouse gases (GHG) and raising carbon

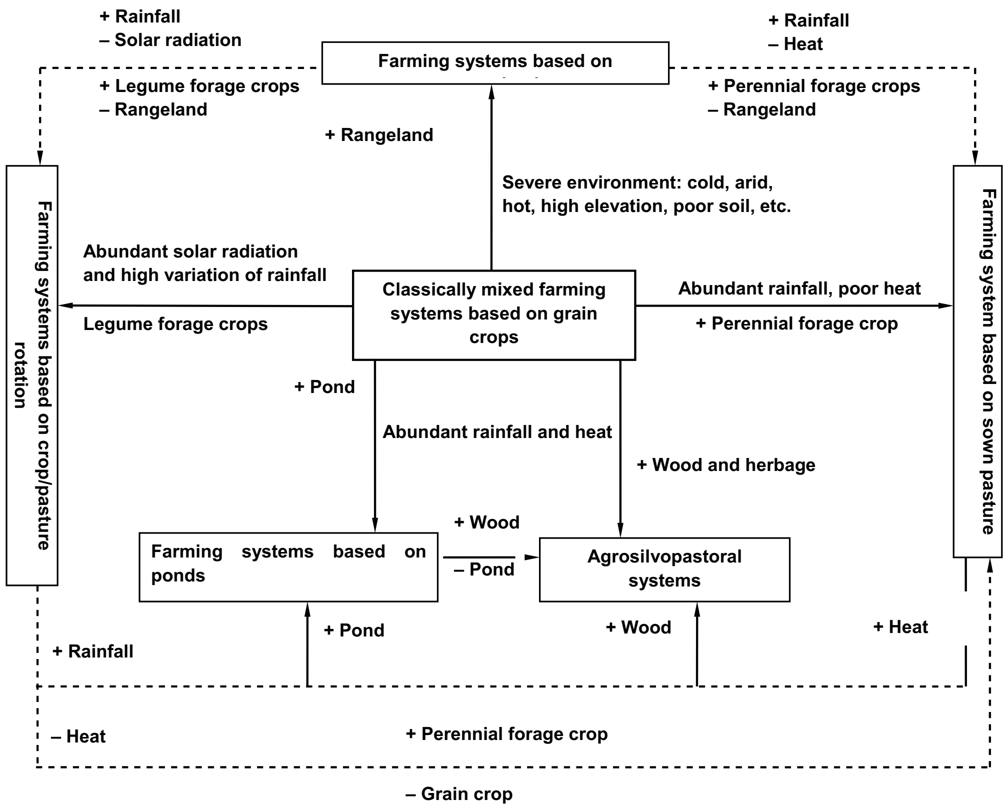

Fig. 10.2. Succession of the integrated farming systems. (Adapted from Hou *et al*., 2009.)

(C) sequestration in both grassland and livestock production. Asia has one of the most abundant germplasm resources of forage and domestic animals in the world, which can serve as the basis of new breeds.

Improvements of forage and animal breeds will decrease GHG emissions and resource use per unit of animal product (Hou *et al*., 2009). High sugar ryegrass leads to a 7.5–21.0% increase in milk yield and a 7.1–25.7% decrease in excrement nitrogen (N) (Cheng *et al*., 2011). Re-seeding native grass species with those with higher productivity or C allocation to deeper roots, or introducing legumes into grazing lands, can all promote soil C in rangeland soils and reduce N emissions (Kell, 2011; Waha *et al*., 2013). Biological N fixation of the latter displaces the need for fertilizer N, which was often used to rehabilitate the seriously degraded alpine meadow in the Tibetan-Qinghai Plateau, Mongolian Plateau and mountainous rangeland of inland arid regions (Hou *et al*., 2009, 2013, unpublished results).

The adaptive farming system

In the face of global climate change, an adaptive farming system supplies opportunities, not only for new crop varieties and livestock breeds to manifest more sustainable productivity but also for more innovative management practices to be implemented. In most Asian regions, especially in developed regions of eastern Asia and South-east Asia, integrated crop–livestock farming systems possess higher productivity and stability under conditions of global climate change through the coupling of plant production and animal production, promoting efficient use of biotic and abiotic resources, prolonging the economic chain and strengthening the interaction of all components (Hou *et al*., 2009; Burney *et al*., 2013).

The inevitable evolution of agricultural systems in Asia towards enhanced productivity due to structural optimization or better application of existing breeds and technologies is generally associated with the integration of crop production and livestock production. However, with the largest and fastest growing population in the world, the increased demand in this region for animal products must be associated with decreasing emissions per unit of product, and by controlling the increase in emissions through establishing and improving mixed farming systems. Otherwise, a vicious circle inevitably emerges between mitigation and adaptation of global climate change.

10.4 Approaches to Mitigating Greenhouse Gases through Managing Integrated Farming Systems

Asian food systems, from rangeland utilization to fertilizer manufacturing to food storage and packaging, are responsible for nearly one-third of all human-caused GHG emissions (Vermeulen *et al*., 2012). However, in terms of the components of integrated farming system, GHG emissions could be mitigated through the use of management practices on a farm scale, including rangeland management, switching to no-till, reducing fallow, managing species composition on grazing lands, adjusting management of nitrogen fertilizer and improved manure management.

10.4.1 Rangeland management

Rangeland is the dominant component of mixed farming systems and also plays a key role in the livestock production of agrosilvopastoral systems. One of the main contributors to the emission of GHGs from rangeland is the severe degradation owing to overgrazing and cultivation for crop production (Fig. 10.3a). The latter operation accounted for 40% of the loss of world total soil organic carbon (SOC) from 1850 to 1980 (Houghton, 1995). Degradation of rangeland has caused 39% loss of biomass C and 25.4% loss of SOC, equal to 0.8–1.5 times the total cropland SOC in China.

Exclusion plays an important role in rehabilitating the carbon of vegetation and the soils of rangeland (Fig. 10.3b), but long-

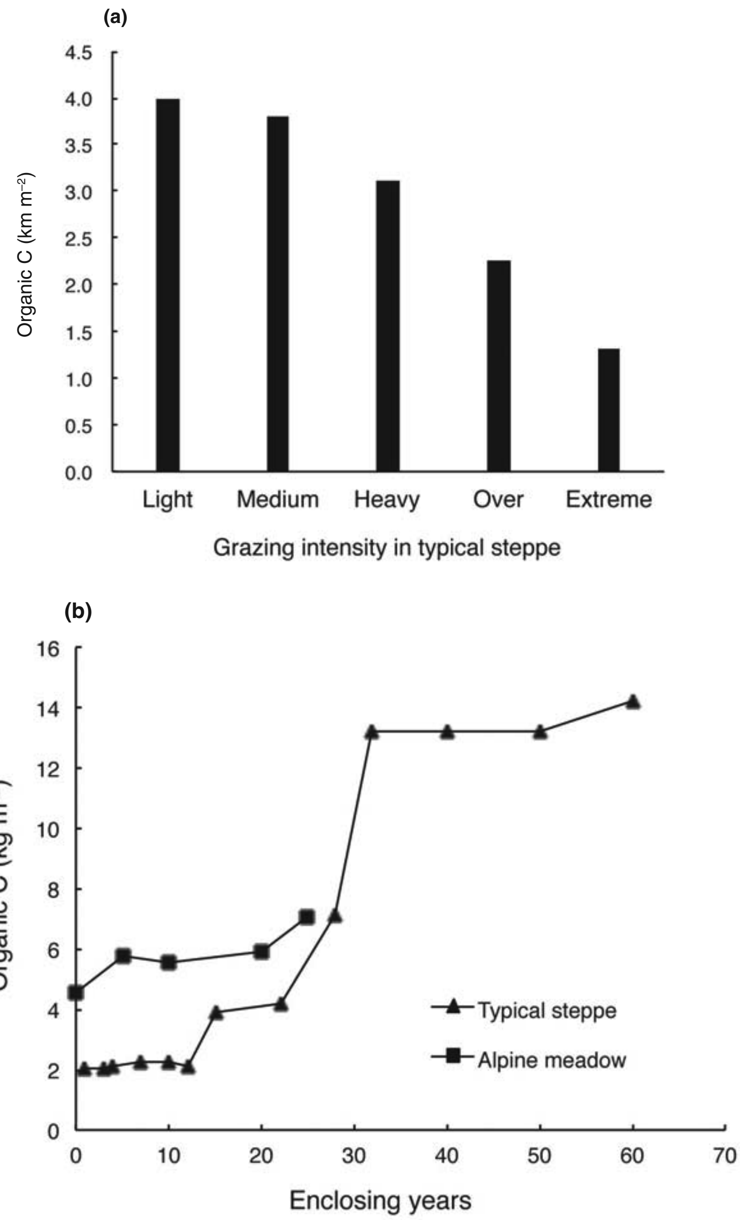

Fig. 10.3. Organic C content density (a) of typical steppe under different grazing intensities (adapted from Wang and Li, 1995) and (b) following grazing exclusion of typical steppe and alpine meadow (adapted from Jia *et al*., 2009.)

term exclusion increases grazing pressure in the other areas of the rangeland and destroys the continuity of nomadic culture and coupled human–rangeland systems (Hou and Yang, 2006; Ren *et al*., 2011). Systemic integration of livestock production and forage crop production is necessary, both to balance the livestock demand and feed supply on the range and to reduce the grazing pressure of rangeland while improving the livelihood of ranchers. Forage crops could be planted in farming regions and then transported to pastoral regions after harvest and made into hay, and could be sown in pastoral regions without destroying the fragile environment through controlling the cultivated area of rangeland.

10.4.2 Nitrogen fertilizer application in crop production

The application of fertilizer is a common approach for enhancing the productivity and quality of sown pasture, which is important to livestock production in all mixed farming systems. Because the applied N is not always used efficiently by forage crops (Galloway *et al*., 2003), improving N-use efficiency can significantly reduce emissions of nitrous oxide (N_2O) generated by soil microbes largely from surplus N, and can indirectly reduce emissions of CO_2 from industrial N fertilizer production (Schlesinger, 1999). Operations in mixed farming systems that can improve N-use efficiency include the following: (i) precisely estimating application rates based on the need of the forage crop in crop production systems and the need of livestock in grazed sown pasture, together with a further need of economic profit; (ii) using slow-release N fertilizer forms; (iii) using nitrification inhibitors, which could slow the microbial processes effectively, leading to N_2O formation; (iv) avoiding time delays between N application and plant N uptake, mostly through improving the integration of grazing and N application with irrigation or rainfall; (v) placing N fertilizers into the soil more precisely, to make it more accessible to the roots of forage crops on the premise of not reducing the profit of the whole farming system; and (vi) avoiding excess N applications, or eliminating N applications under conditions of economic benefit (Smith *et al*., 2008).

10.4.3 Manure management

Livestock is responsible for 18% of GHG emissions in the world, and a significant portion of livestock emissions results from poor manure management (Steinfeld *et al*., 2006). The dramatically increased livestock production, which has been caused by the sharp rise both in population and living standards, is leading to increasing volumes of manure to be managed, which are a source of methane (CH_4) and N_2O (Hou *et al*., 2008). Net emissions of CH_4 and N_2O depend not only on manure composition and local management practices with respect to preliminary treatment, storage and field application but also on ambient climatic conditions. The diversity of livestock production systems and their associated manure management has resulted in various patterns of nutrient management and environmental regulation (Jungbluth *et al*., 2001; Heitschmidt *et al*., 2004; Garnett, 2009). Growth in livestock populations is projected to occur mainly in intensive production systems where the largest potential for GHG mitigation may be found (Jarvis and Pain, 1994; Hao *et al*., 2001; Jungbluth *et al*., 2001). In extensive systems, there is almost no excessive emission of CH_4 from manure because it is promptly involved in the N cycle of grazing systems. There is no conflict between efforts to improve food and feed production and those to reduce GHG emissions from manure management. However, emissions from manure might be curtailed, both by altering feeding practices and by composting the manure in livestock pen-feeding systems (VanderZaag *et al*., 2013).

10.4.4 Livestock management

Livestock are important sources of CH_4 because most CH_4 is produced primarily by enteric fermentation. Adjusting feeding ration can reduce GHG emissions from livestock through feeding more concentrates, which may increase daily CH_4 emissions per capita, but almost invariably reduce the CH_4 emissions per kilogram of feed intake and per kilogram of product (Smith *et al*., 2008). High sugar ryegrass has been fed to ruminant livestock because it could increase N-use efficiency in the intestine and reduce

N excretion. Feed additives such as coconut oil and garlic in the ration can also decrease the GHG emissions of ruminant livestock. However, the effect of chemical additives in livestock rations on the food safety of humans is widely feared in the developed countries of Asia. Uncertainties also remain as to the balance of benefits resulting from reduced animal numbers or younger age at slaughter for meat production, against how the practice affects emissions when producing and transporting concentrates and other fodders, and the cost of adjusting the livestock production system from one to another.

10.4.5 Management of sown pasture

Improved agronomic practices that increase yield and generate higher inputs of residue C can result in increased soil C storage (Follett *et al*., 2001). The practices that could be used are as follows: (i) growing improved crop species or varieties such as high-sugar ryegrass; (ii) expanding crop/forage rotations which mitigate GHG emissions by multiple pathways, including reducing chemicals for the control of weeds, diseases and pests, limiting grain crop production, most of which is for livestock production in developed countries, and promoting water-use efficiency in arid and semi-arid regions; (iii) planting perennial forage crops which allocate more C below-ground and reduce GHG emissions both from annual sowing and annually trampled soil; (iv) avoiding or reducing the re-cultivation of fallow cropland and the cultivation of rangeland; and (v) reducing the intensity of cropping systems can also reduce GHG emissions because of less inputs of chemicals and fertilizers (Smith *et al*., 2008).

10.5 Conclusion

In most of the developing countries of Asia, extensively mixed farming systems are currently predominant. Compared with the intensively mixed farming systems mainly operated in the developed countries of the world, extensive systems are characterized by low input, low output and low risk (Hou *et al*., 2009). Extensive systems manage carbon more positively than intensive systems, because the low input of carbon is associated with low GHG emissions (Table 10.1).

However, there is an increasing shift from extensive mixed crop–livestock systems to intensive systems, which has resulted from the increased demands for both quantity and quality of animal products, and has resulted in serious environmental problems, such as pollution of both underground and surface water. Currently, environmental problems arising from agricultural operations are one of the great challenges facing the human race, both in Asia and in other continents. This threatens the sustainability of farming systems, long-term food security and carbon

Table 10.1. Comparison between carbon inputs and outputs in extensive and intensive mixed crop–livestock systems.

Carbon	Extensive systems	Intensive systems
Input	Very low	High
Component of input	Human labour	Chemicals, machinery, fuel energy, human labour
Output	Low	High
Component of output	Animal products	Plant products, animal products
Output/input	High	Low
Balance	Positive	Negative
Risk of management	Low	High
Response to climate change	Resilient	Susceptible

balance. An equilibrium point between the 'traditional' operation of mixed farming systems and 'modern' ones must be found to resolve the above problems.

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