MODULE 8:
CLIMATE-SMART LIVESTOCK

Overview

This module assesses the role of livestock in climate-smart agriculture (CSA). Adopting a farming system perspective, it highlights the main climate-smart strategies for the sector. The first section describes trends in the livestock sector and the contribution it makes to food security. The second section assesses the impact of climate change on livestock and identifies adaptation and mitigation needs. It also presents an overview of emissions caused by livestock. The module outlines the principles of climate-smart livestock, focusing on increased efficiency of resource use and building resilience. The last section gives insights into main strategies for achieving climate-smart livestock and covers land-based, mixed and landless systems.

Key messages

- Livestock can make a large contribution to climate-smart food supply systems.
- Mitigation options are available along the entire supply chain. They are mostly targeted to feed production, enteric fermentation and manure management.
- Livestock's role in adaptation practices relates primarily to the management of organic matter and nutrients, and the diversification of incomes.
- Several CSA practices are readily available for implementation. These practices include grassland restoration and management (e.g. sylvopastoral systems), manure management (e.g. recycling and biodigestion) and crop-livestock integration.
- Barriers to adoption are most often related to a lack of information, limited access to technology and insufficient capital. Overcoming these barriers requires specific policy interventions, including extension work and financing mechanisms, such schemes for improving access to credit and payment for environmental services.
- A CSA approach that considers the entire food supply chain is particularly relevant to the livestock sector, given the sector's strong interrelationship with crop production.

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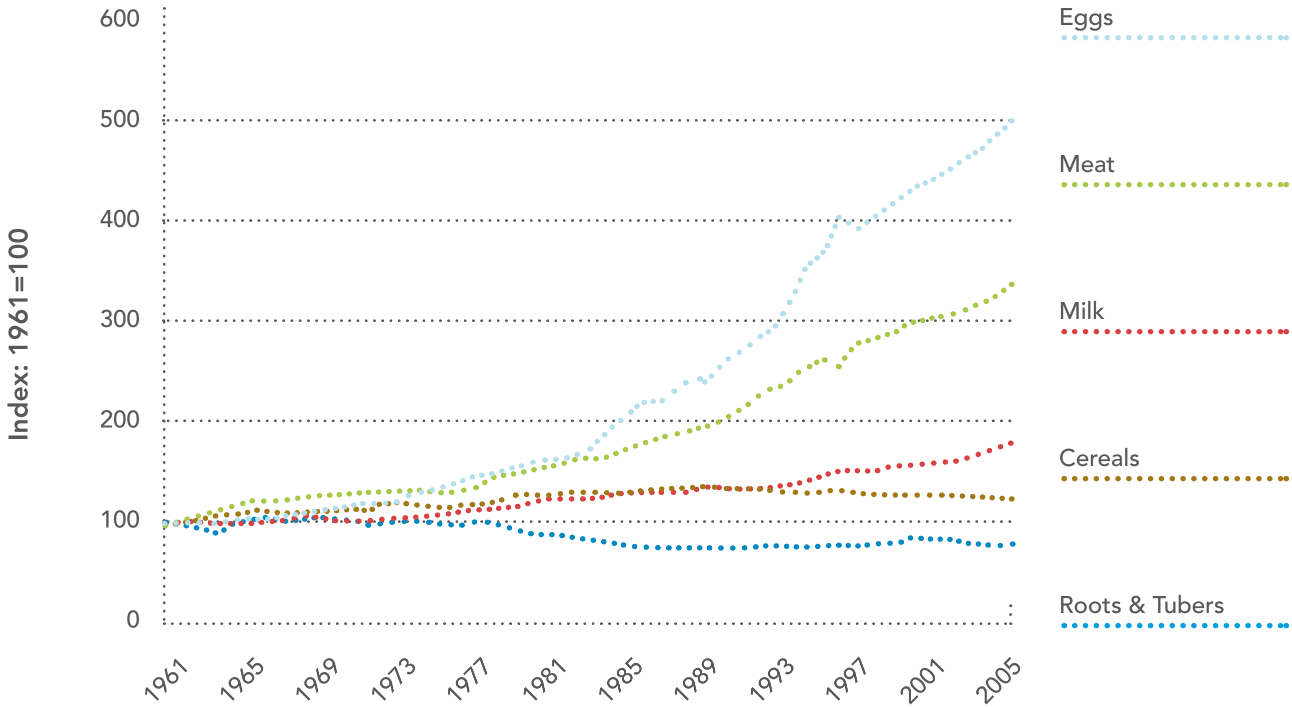
8.1 Introduction

Climate change is having substantial effects on ecosystems and the natural resources upon which the livestock sector depends. Climate change will affect the sector directly, through increased temperature, changes in the amount of rainfall and shifts in precipitation patterns. Indirect impacts will be experienced through modifications in ecosystems, changes in the yields, quality and type of feed crops, possible increases in animal diseases and increased competition for resources. At the same time, livestock food chains are major contributors to greenhouse gas (GHG) emissions (FAO, 2006a).

Sector trends

Global production of meat, milk and eggs has rapidly expanded during the last decades in response to growing demand for livestock products. This increase in demand, which has been particularly strong in developing regions, has largely been driven by expanding populations and increasing incomes. For example, between 1960 and 2005 annual per capita consumption of meat more than tripled; consumption of milk almost doubled; and per capita consumption of eggs increased fivefold in the developing world (see Figure 8.1).

Figure 8.1
Per capita consumption of major food items in developing countries



Source: FAO, 2009a

The factors that have driven growth in livestock product demand in the developing world (rising incomes, population growth and urbanization) will continue to be influential over the coming decades, although the effects will be tempered (FAO, 2006b; FAO, 2009a). Projected declines in the rate of population growth, coupled with decelerating consumption in the two countries that have mostly driven the global upsurge in consumption (China and India), are major factors that will influence future aggregate demand. Excluding Brazil and China, per capita meat consumption in developing countries is expected to increase to 26 kilograms in 2030 and 32 kg in 2050. In terms of future consumption, it is projected that a marked gap will continue to exist between developed and developing countries. This gap indicates that there is scope for further growth in the livestock sector. Driven by demand, global production of meat is projected to more than double, from 229 million tonnes in 1999/2001 to 465 million tonnes in 2050. Milk production is expected to increase from 580 to 1 043 million tonnes (FAO, 2006b).

Contribution to food security

Livestock make a necessary and important contribution to global calorie and protein supplies. However, livestock need to be managed carefully to maximize this contribution. While livestock products are not absolutely essential to human diets, they are valued and they will continue to be consumed in increasing amounts. Meat, milk and eggs in appropriate amounts are valuable sources of complete and easily digestible protein and essential micronutrients. Overconsumption causes health problems.

Livestock can increase the world's edible protein balance by transforming inedible protein found in forage into forms that people can digest. On the other hand, livestock can also reduce the global edible protein balance by consuming large amounts edible protein found in cereal grains and soybeans and converting it into small amounts of animal protein. The choice of production systems and good management practices are important for optimizing the protein output from livestock. Livestock production and marketing can help stabilize the food supplies and provide individuals and communities with a buffer against economic shocks and natural disasters. However, the food supply from livestock can be destabilized, particularly by disease outbreaks.

Access to food derived from livestock is affected by income and social customs. Access to livestock as a source of income, and hence food, is also unequal. Gender dynamics play a part in this inequality, particularly in pastoralist and small-scale farming communities, where female-headed households tend to have fewer resources and consequently own fewer and smaller livestock, and within families where the larger and more commercial livestock operations are often controlled by men. These problems are not unique to livestock, but they are prevalent among both producers and consumers of livestock products and they demand attention.

8.2 Adaptation and mitigation needs

The impact of climate change on livestock

Climate change poses serious threats to livestock production. However, these impacts are difficult to quantify due to the sector's uncertain and complex interactions between agriculture, climate, the surrounding environment and the economy. Increased temperatures, shifts in rainfall distribution and increased frequency of extreme weather events are expected to adversely affect livestock production and productivity around the world. These adverse impacts can be the direct result of increased heat stress and reduced water availability. Indirect impacts can result from the reduced quality and availability of feed and fodder, the emergence of livestock disease and greater competition for resources with other sectors (Thornton, 2010; Thornton and Gerber, 2010; FAO, 2009b).

The effects of climate change on livestock are likely to be widespread. The most serious impacts are anticipated in grazing systems because of their dependence on climatic conditions and the natural resource base, and their limited adaptation opportunities (Aydinalp and Cresser, 2008). Impacts are expected to be most severe in arid and semi-arid grazing systems at low latitudes, where higher temperatures and lower rainfall are expected to reduce yields on rangelands and increase land degradation (Hoffmann and Vogel, 2008).

The direct impacts of climate change are likely to be more limited in non-grazing systems mostly because the housing of animals in buildings allows for greater control of production conditions (Thornton and Gerber, 2010; FAO, 2009b). In non-grazing systems, indirect impacts from lower crop yields, feed scarcity and higher energy prices will be more significant. Climate change could lead to additional indirect impacts from the increased emergence of livestock diseases, as higher temperatures and changed rainfall patterns can alter the abundance, distribution and transmission of animal pathogens (Baylis and Githeko, 2006). However, the net impacts of climate change are unclear when considered in combination with other important environmental and socio-economic factors that also affect disease prevalence, such as changes in land use, host abundance, international trade, migration and public health policy (Randolph, 2008; Kurukulasuriya and Rosenthal, 2003).

Table 8.1
Direct and indirect impacts of climate change on livestock production systems

	Grazing system	Non-grazing system
Direct impacts	• increased frequency of extreme weather events • increased frequency and magnitude of droughts and floods • productivity losses (physiological stress) due to temperature increase • change in water availability (may increase or decrease, according to region)	• change in water availability (may increase or decrease, according to region) • increased frequency of extreme weather events (impact less acute than for extensive system)
Indirect impacts	Agro-ecological changes and ecosystem shifts leading to: • alteration in fodder quality and quantity • change in host-pathogen interaction resulting in an increased incidence of emerging diseases • disease epidemics	• increased resource prices (e.g. feed, water and energy) • disease epidemics • increased cost of animal housing (e.g. cooling systems)

Overview of emissions

The livestock sector is a major contributor to climate change, generating significant emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Livestock contribute to climate change by emitting GHGs either directly (e.g. from enteric fermentation and manure management) or indirectly (e.g. from feed-production activities, conversion of forest into pasture). Based on a Life Cycle Assessment (LCA), it is estimated that the sector emits about 7.1 gigatonnes of CO_2 equivalent (CO_2 eqv.), about 18 percent of the total anthropogenic GHG emissions (FAO, 2006a).

Along the animal food chain, the major sources of emissions are (FAO, 2006a):

- Land use and land-use change: 2.5 gigatonnes of CO_2 eqv. (36 percent of the sector's emissions); including forest and other natural vegetation replaced by pasture and feed crops in the neotropics (CO_2) and carbon release from soils, such as pasture and arable land dedicated to feed production (CO_2).
- Feed production (except carbon released from soil): 0.4 gigatonnes CO_2 eqv. (6 percent of the sector's emissions), including fossil fuels used in manufacturing chemical fertilizer for feed crops (CO2) and chemical fertilizer application on feed crops and leguminous feed crop (N_2O, and ammonia [NH_3]).
- Animal production: 1.9 gigatonnes CO_2 eqv. (27 percent of the sector's emissions), including enteric fermentation from ruminants (CH_4) and on-farm fossil fuel use (CO_2).
- Manure management: 2.2 gigatonnes CO_2 eqv. (31 percent of the sector's emissions), mainly through manure storage, application and deposition (CH_4, N_2O, NH_3).
- Processing and international transport: 0.03 gigatonnes CO_2 eqv. (less than 0.1 percent of the sector's emissions).

There are striking differences in global emission intensities among commodities. For example, on a global scale, the emission intensity of meat and milk, measured by output weight, corresponds on average to 46.2 kg CO_2 eqv. per kg of carcass weight (CW), 6.1 kg CO_2 eqv./kg CW and 5.4 kg CO_2 eqv./kg CW for beef, pork and chicken meat[1], respectively, and 2.8 kg CO_2 eqv./kg of milk (FAO, 2013a and b, forthcoming). There is significant variability in emissions across the different regions. For example, the FAO LCA of GHG emissions from the global dairy sector, found emissions per unit of milk products varied greatly among different regions. Emissions from Europe and North America range between 1.6 and 1.9 kg CO_2 eqv. per kg fat and protein corrected milk (FPCM) at the farm gate. The highest emissions are estimated for sub-Saharan Africa with an average of 9.0 kg CO_2 eqv./kg FPCM at the farm gate. GHG emissions for Latin America and the Caribbean, Near East and North Africa and South Asia, range between 3 and 5 kg CO_2 eqv./kg FPCM at the farm gate. The global average is estimated at 2.8 kg CO_2 eqv. (FAO, 2013a). Results from the same study of the global dairy sector also found

[1] Emission intensity estimates for beef, chicken meat and pork are based on FAO's recent work on the LCA of GHG emissions from the livestock sector (FAO 2013a and b, forthcoming).

GHG emissions to be inversely related to productivity. At very low levels of milk production (200 kg per cow per year) emissions were found to be 12 kg CO_2 eqv./kg FPCM compared to 1.1 kg CO_2 eqv./kg FPCM for high production levels (about 8 000 kg of milk). This reflects the strong relationship between livestock intensification and GHG emissions on a global scale (Gerber *et al.*, 2011).

Climate-smart livestock

Overall principles

Resource use efficiency

Given the current and projected scarcity of resources and the anticipated increase in demand for livestock products, there is considerable agreement that increasing efficiency in resource use is a key component to improving the sector's environmental sustainability. More efficient use of natural resources is a crucial strategy for decoupling growth in the livestock sector from adverse environmental impacts. Efficiency in the use of natural resources is measured by the ratio between the use of natural resources as input to the production activities and the output from production (e.g. kg of phosphorus used per unit of meat produced, or hectares of land mobilized per unit of milk produced). The concept can be extended to the amount of emissions generated by unit of output (e.g. GHG emissions per unit of eggs produced). Examples of opportunities that fall within this strategy are higher yields per hectare, higher water productivity, higher feed efficiency, improved management of manure and fertilizers and reduced losses along the food chain (Westhoek *et al.*, 2011).

Improving the feed-to-food conversion efficiency in animal production systems is a fundamental strategy for improving the environmental sustainability of the sector. A large volume of food is wasted even before it reaches the consumer. A recent FAO (2011) study suggests that about one-third of food produced is wasted. Reduction of waste along the animal food chain can substantially contribute to reducing the demand for resources, such as land, water, energy, as well as other inputs, such as nutrients.

The current prices of inputs, such as land, water and feed, used in livestock production often do not reflect true scarcities. Consequently, there is the overutilization of resources by the sector and inefficiencies in production processes. Any future policies to protect the environment will have to introduce adequate market pricing for natural resources. Ensuring effective management rules and liability, under private or communal ownership of the resources, is a further necessary policy element for improving the use of resources.

Building resilience: buffering and risk management at farm and system level

Traditionally, livestock producers have been able to adapt to various environmental and climatic changes. Now however, expanding populations, urbanization, economic growth, increased consumption of animal-based foods and greater commercialisation have made traditional coping mechanisms less effective (Sidahmed, 2008). As a result, the identification of coping and risk management strategies has become very important.

Particularly in pastoral and agro-pastoral systems, livestock are key assets held by poor people and fulfil multiple economic, social, and risk management functions. Livestock is also a crucial coping mechanism in variable environments. As this variability increases, livestock will become more valuable. For many poor people, the loss of livestock assets means a collapse into chronic poverty and has long-term effects on their livelihoods.

A wide array of adaptation options is available (see, for instance, Kurukulasuriya and Rosenthal, 2003; IPCC, 2007). Possible adaptive responses include: technological options (e.g. more drought-tolerant crops); behavioural modifications (e.g. changes in dietary choices); managerial choices (e.g. different farm management practices); and policy alternatives (e.g. planning regulations and infrastructural development). Some options may be appropriate for the short-term, others for the long-term (or both). In the short-term, adaptation to climate change is often framed within the context of risk management (see Module 15 on disaster risk reduction). Washington *et al.* (2006) outline an approach for addressing the challenges of climate change that depends on a close engagement with climate variability. Helping decision makers understand and deal with current levels of climate variability can provide one entry point to the problems posed by increasing variability in the future and the options that may be needed to build resilience. However, there are still problems to be addressed concerning the uncertainty of climate projections and projected impacts and how this uncertainty can be appropriately treated when determining response options (Wilby *et al.*, 2009).

Longer-term approaches to adaptation are often described in terms of 'climate-proofing development'. These approaches can involve system changes (e.g. a change in the set of commodities produced or the shift from extensive to mixed systems) or the adoption of new technology that is currently unavailable. There may be long lag times between the identification of a problem and the development of readily available and appropriate technology. Research carried out today needs to be appropriate to the environment 20-30 years from now. This has implications for how research is targeted as well as for the design, testing and implementation of the research. One approach may involve searching for homologues of projected future climate conditions in areas where similar conditions exist now and where breeding and selection can be carried out (Burke *et al.*, 2009).

Main strategies

This section summarizes the main CSA strategies for dominant livestock production systems: land-based systems, mixed systems and landless systems.

Land-based systems

While there are several climate-smart options available for land-based grazing systems, their applicability to low-input systems with infrequent human intervention tends to be quite limited. The main mitigation options for land-based grazing systems are reductions in enteric CH_4 emissions and CO_2 removals through soil carbon sequestration. Manure management mitigation options are much more limited in land-based systems.

The climate-smart options discussed below fall into three categories: those with clear mitigation and adaptation synergies; 'mitigation only' options; and 'adaptation only' options. Options for which there are risks of tradeoffs between mitigation, food security and adaptation have also been identified. Climate-smart options deemed suitable for land-based systems, along with their capacities to satisfy multiple climate-smart objectives, are listed in Table 8.2.

Table 8.2
Summary of CSA practices and technologies for land-based systems

Practices and technologies	Impact on food security	Effectiveness: adaptation	Effectiveness: mitigation	Main constraints to adoption
Grazing management	+/-	+	++	technical: especially in extensive systems
Pasture management	+		++	technical and economic in extensive systems
Animal breeding	+	++	++	technical, economic, institutional: especially in developing countries
Animal and herd management	+	++	+	technical, institutional: especially in developing countries
Animal disease and health	++	++	+	technical, institutional: especially in developing countries
Supplementary feeding	+	+	++	easy to implement, but costly
Vaccines against *rumen archaea*	++		+	not immediately available, may have low acceptability in some countries
Warning systems	++	+		technical, institutional: especially in developing countries
Weather-indexed insurance		+		technical, economic, institutional: especially in developing countries
Agroforestry practices	++	++	++	technical and economic

Mitigation/adaptation potential: + = low; ++ = medium

Grazing management

Grazing can be optimized by balancing and adapting grazing pressures on land. This optimization can increase grassland productivity and deliver mitigation and adaptation benefits. However, the net influence of optimal grazing is variable and highly dependent on baseline grazing practices, plant species, soils and climatic conditions (Smith *et al.*, 2008).

Perhaps the most clear-cut mitigation benefits arise from soil carbon sequestration that results when grazing pressure is reduced as a means of stopping land degradation or rehabilitating degraded lands (Conant and Paustian, 2002). In these cases, enteric emission intensities can also be lowered, because with less grazing pressure animals have a wider choice of forage, and tend to select more nutritious forage, which is associated with more rapid rates of live weight gain (LWG) (Rolfe, 2010). By restoring degraded grassland, these measures can also enhance soil health and water retention, which increases the resilience of the grazing system to climate variability. However, if grazing pressure is reduced by simply reducing the number of animals, then total output per hectare may be lower, except in areas where baseline stocking rates are excessively high (Rolfe, 2010).

One of the main strategies for increasing the efficiency of grazing management is through rotational grazing, which can be adjusted to the frequency and timing of the livestock's grazing needs and better matches these needs with the availability of pasture resources. Rotational grazing allows for the maintenance of forages at a relatively earlier growth stage. This enhances the quality and digestibility of the forage, improves the productivity of the system and reduces CH_4 emissions per unit of LWG (Eagle *et al.*, 2012). Rotational grazing is more suited to managed pasture systems, where investment costs for fencing and watering points, additional labour and more intensive management are more likely to be recouped.

In colder climates, where animals are housed during cold periods, there are also opportunities for controlling the timing of grazing. For example, early grazing of summer pastures is a major cause of grassland degradation in Northern China (see Case Study 8.1 for further information). Delaying grazing until the grass sprouts have reached a more advanced stage of maturity is an important sustainable grazing practice.

Finally, increasing livestock mobility, a traditional strategy of nomadic and transhumant herders in many parts of Africa for matching animal production needs with changing rangeland resources, can significantly enhance the resilience of these livestock systems to climate change. Land tenure reforms to deal with the encroachment of cultivated lands and other land uses that impede livestock mobility will be needed (Morton, 2007).

Pasture management and nutrition

Pasture management measures involve the sowing of improved varieties of pasture, typically the replacement of native grasses with higher yielding and more digestible forages, including perennial fodders, pastures and legumes (Bentley *et al.*, 2008). For example, in tropical grazing systems of Latin America, substantial improvements in soil carbon storage and farm productivity, as well as reductions in enteric emission intensities, are possible by replacing natural cerrado vegetation with deep-rooted pastures such as *Brachiaria* (Thornton and Herrero, 2010). However, there are far fewer opportunities for sowing improved pastures in arid and semi-arid grazing systems.

The intensification of pasture production though fertilization, cutting regimes and irrigation practices may also enhance productivity, soil carbon, pasture quality and animal performance. These approaches however, may not always reduce GHG emissions. Improved pasture quality through nitrogen fertilization may involve trade-offs between lower CH_4 emissions and higher N_2O emissions (Bannink *et al.*, 2010). Also, after accounting for energy-related emissions and N2O emissions associated with irrigation, the net GHG emissions of this practice may be negative on grazing lands (Eagle *et al.*, 2012). Grass quality can also be improved by chemical and/or mechanical treatments and ensiling.

With increasing variability in climatic conditions (e.g. increasing incidents of drought) due to climate change, there may be an increase in the frequency of periods where forage availability falls short of animal demands. In these situations, supplemental feeding can be an important adaptation strategy.

Animal breeding

Animal breeding to select more productive animals is another strategy to enhance productivity and thereby lower CH_4 emission intensities. Research has recently been done on the mitigation benefits of using residual feed intake as a selection tool for low CH_4 emitting animals, but so far findings have been inconclusive (Waghorn and Hegarty, 2011).

There is also evidence that cross-breeding programmes can deliver simultaneous adaptation, food security and mitigation benefits. For example, composite cattle breeds developed in recent decades in tropical grasslands of northern Australia have demonstrated greater heat tolerance, disease resistance, fitness and reproductive traits compared with pure shorthorn breeds that had previously dominated these harsh regions (Bentley *et al.*, 2008). In general, cross-breeding strategies that make use of locally adapted breeds, which are not only tolerant to heat and poor nutrition, but also to parasites and diseases (Hoffmann, 2008), may become more common with climate change.

Adaptation to climate change can also be fostered through the switching of livestock species. For example, the Samburu of northern Kenya, a traditionally cattle-keeping people, adopted camels as part of their livelihood strategy. This switch allowed them to overcome a decline in their cattle economy, which, from 1960 onwards, had been affected by drought, cattle raiding and animal disease (Sperling, 1987).

Animal and herd management, disease control and feeding strategies

As with all livestock production systems, there are a number of animal and herd management options for land-based systems that can enhance animal productivity, improve feed conversion efficiency and thereby reduce enteric emission intensities. Better nutrition, improved animal husbandry, the regular maintenance of animal health and the responsible use of antibiotics can improve reproduction rates, reduce mortality and reduce the slaughter age. All of these measures will therefore increase the amount of output produced for a given level of emissions. The impacts of these measures on adaptation are likely to be neutral.

In addition to enhanced animal health management to maintain and improve animal performance, the management of disease risks may also become increasingly important, as there may be an increase in the emergence of gastro-intestinal parasites due to climate change (Wall and Morgan, 2009). Breeding more disease-resilient animals is one approach to addressing this issue.

Vaccines

Because of their wide applicability, even for very low-input extensive systems with little human intervention, vaccines against methanogens (microorganisms that produce methane as a metabolic by-product in low-oxygen conditions) in the rumen are a potentially useful mitigation option for ruminants in land-based grazing systems. However, more research and development is needed before this option is ready for widespread adoption (Wright and Klieve, 2011).

Early warning systems and insurance

The use of weather information to assist rural communities in managing the risks associated with rainfall variability is a potentially effective (preventative) option for climate change adaptation. However, there are issues related to the effectiveness of climate forecasts for livestock management that still need to be addressed (Hellmuth *et al.,* 2007). Livestock insurance schemes that are weather-indexed (i.e. policy holders are paid in response to 'trigger events' such as abnormal rainfall or high local animal mortality rates) may also be effective where preventative measures fail (Skees and Enkh-Amgala, 2002). There may be limits however to what private insurance markets can do for large vulnerable populations facing covariate risks linked to climate change (UNDP, 2008). In situations where risks are unacceptably high for the private sector, recently developed public-private partnership approaches to index-based livestock insurance, in which the public sector underwrites a share of these risks, could play an important role. Indexed insurance schemes based on satellite imagery are being piloted in several areas of drought-prone northern Kenya (Barrett *et al.,* 2008; Mude, 2009).

Agroforestry practices

Agroforestry is an integrated approach to the production of trees and non-tree crops or animals on the same piece of land. Agroforestry is important both for climate change mitigation (carbon sequestration, improved feed and consequently reduced enteric methane) and for adaptation in that it improves the resilience of agricultural production to climate variability by using trees to intensify and diversify production and buffer farming systems against hazards. Shade trees reduce heat stress on animals and help increase productivity. Trees also improve the supply and quality of forage, which can help reduce overgrazing and curb land degradation (Thornton and Herrero, 2010).

Box 8.1 Silvopastoral systems in Central and South America

In a Global Environmental Facility (GEF) funded project, the Tropical Agricultural Research and Higher Education Centre (CATIE) worked with FAO, Nitlapan in Nicaragua and the Fundación Centre for Research on Sustainable Farming Systems (CIPAV) in Colombia and the World Bank to evaluate the impacts of payment for environmental services on the adoption of silvopastoral systems. From 2003 to 2006, cattle farmers from Colombia, Costa Rica and Nicaragua, received between US$ 2 000 and US$ 2 400 per farm (an amount that represents 10 to 15 percent of their net income) to implement the programme on silvopastoral systems. The programme led to a 60 percent reduction in degraded pastures in the three countries, and the area of land used for silvopastoral systems (e.g. improved pastures with high density trees, fodder banks and live fences) increased significantly. The environmental benefits associated with the project included a 71 percent increase in carbon sequestration (from 27.7 million tonnes of CO_2 eq in 2003 to 47.6 million tonnes CO_2 eq in 2006). Milk production increased by 10 percent, and farm income rose by 115 percent. Herbicide use dropped by 60 percent, and the practice of using fire to manage pasture is now less frequent.

Source: FAO, 2010a

Mixed systems

Because they serve multiple purposes, mixed livestock systems, if well managed, may be among the most promising means of adapting to climate change and mitigating the contribution of crop and livestock production to GHG emissions. There are a number of agronomic techniques and livestock management practices that have proven to be effective in delivering multiple benefits (food security, and improved climate change mitigation and adaptation). The options presented below deal with integrated mixed systems but focus on livestock-related interventions for CSA.

Integrated soil-crop-water management

Soil and water are intrinsically linked to crop and livestock production. For this reason, an integrated approach to soil and water management is vital for increasing efficiency in the use of resources, adapting to and mitigating climate change, and sustaining productivity. For example, by increasing the organic content of the soil through conservation tillage, the soil's water holding capacity increases, which makes yields more resilient and reduces erosion (Lal, 2009). Existing soil and water adaptation technologies include: minimum or zero tillage; erosion control; the use of crop residues to conserve soil moisture; and improved soil cover through cover crops. By increasing water infiltration, reducing evaporation and increasing storage of rainwater in soils, many crop management practices (e.g. mulching, green manures, conservation tillage and conservation agriculture) will help land users in areas projected to receive lower levels of precipitation adapt to climate change. Promoting the capture of carbon in the soil also mitigates climate change. Soil management practices that limit soil compaction, reduce tillage and retain crop residues lower the potential for N_2O loss, increase soil carbon and at the same time improve yields. In addition, managing pests, diseases or weeds using technologies such as the 'pull-and-push technology' can contribute to improving the availability of food and animal feed in crop-livestock systems (Lenné and Thomas, 2005).

Water use efficiency and management

In the coming decades, water management will be a critical component for adapting to climate change as well as socio-economic changes. Practices that increase the productivity of water use (defined as crop output per unit of water) may have significant climate change adaptation potential for all land production systems. A number of adaptation techniques and approaches that are specific to water management include: cultivation of crop varieties with increased resistance to extreme conditions; irrigation techniques that maximize water use; adoption of supplementary irrigation in rain-fed systems and water-efficient technologies to harvest water; and the modification of cropping calendars (timing or location) (FAO, 2011a). Descheemaeker *et al.* (2010) cite three broad strategies for improving livestock-water productivity in mixed crop-livestock systems: feed management (e.g. improving feed quality, increasing feed-water productivity, enhancing feed selection, strengthening grazing management); water management; and animal management (e.g. increasing animal productivity and health).

Sustainable soil management

Carbon sequestration in soils has the potential to mitigate climate change and bolster climate change adaptation (Pascal and Socolow, 2004). A climate-smart strategy involves creating a positive carbon budget in soils and ecosystems by using residues as mulch in combination with no-till farming and integrated nutrient management (i.e. the appropriate application of both synthetic and organic fertilizer). In addition, soil carbon sequestration delivers numerous ancillary benefits by improving soil quality and other ecosystem services. Restoration of degraded soils, through increases in soil organic carbon pools, improves production, which helps foster food security and improves nutrition. Increasing the pool of soil organic carbon is also important for improving efficiency in the use of nitrogen and potassium. Water quality also improves through a greater control of non-point source pollution (Lal, 2009).

Feed management

Herrero *et al.* (2008) estimate that crop residues can represent up to 50 percent of the diet of ruminants in mixed farming systems. While these feed resources provide an inexpensive feed source, they are usually of low digestibility and deficient in crude protein, minerals and vitamins. This low digestibility substantially limits productivity and increases CH_4 emissions. Increasing the digestibility of feed rations by improving the quality of crop residues, or supplementing diets with concentrates will reduce CH_4 emissions. Other existing feed management practices in mixed farming systems include the use of improved grass species and forage legumes. Animal productivity can be improved by using a multidimensional approach for improving the quality and thereby the utilization of food-feed crops. This can also lead to a reduction in animal numbers, lower feed requirements and reduced GHG emissions (Blümmel *et al.,* 2009).

Diversification to climate-resilient agricultural production systems

The diversification of sensitive production systems can enhance adaptation to the short- and medium-term impacts from climate change. Transitions within mixed farming systems are already occurring. In marginal areas of southern Africa, reductions in length of growing period and increased rainfall variability are leading to conversions from mixed crop–livestock systems to rangeland-based systems, as farmers find growing crops too risky in marginal environments (Thornton *et al.,* 2009). Changing the mix of farm products (e.g. proportion of crops to pastures) is an example of a farm-level adaptation option. Farmers may reassess the crops and varieties they grow, and shift from growing crops to raising livestock, which can serve as marketable insurance in times of drought. They may also introduce heat-tolerant breeds that are more resistant to drought. In a case study covering villages in three South African provinces, Thomas *et al.* (2007) found that during dry spells farmers tended to reduce their investment in crops or even stop planting altogether and focused instead on livestock production.

In most cases, these practices deliver multiple benefits. However, before long-term benefits can be reaped, there are some tradeoffs that need to be made in the short term with respect to emissions, productivity and food security. Consequently, despite the long-term benefits, poor subsistence farmers may not be willing or able to accept the short-term losses associated with some of these practices.

Table 8.3
Summary of CSA practices and technologies for mixed farming systems

	Management objective	Practices/technologies	Impact on food security	Effectiveness as an adaptation strategy	Effectiveness as an mitigation strategy	Main constraints to adoption
Crop and grazing land management	Improved crop varieties	conventional breeding (e.g. dual purpose crops, high yielding crops)	+++	+++	Uncertain	High investment costs; high prices of improved varieties, high input costs (e.g. fertilizer)
		Modern biotechnology and genetic engineering (e.g. genetically modified stress tolerant crops)	++	++	Uncertain	High investment costs, concerns with long-term potential impacts (e.g. loss of crop biodiversity, health concerns, limited enabling environment to support transfer of technology)
	Crop residue management	No-till/minimum tillage; cover cropping; mulching	+++	+++	++	Competing demands for crop residue biomass
	Nutrient management	Composting; appropriate fertilizer and manure use; precision farming	+++	++	++	Cost, limited access to technology and information
	Soil management	Crop rotations, fallowing (green manures), intercropping with leguminous plants, conservation tillage	+++	+++	++	Minimal gains over short term (e.g. short term decreases in production due to reduced cropping intensity)
	Grazing management	Adjust stocking densities to feed availability	+++	+++	+++	Risk aversion of farmers
		Rotational grazing	++	+++	+++	
Water management	Water use efficiency and management	Supplemental irrigation/water harvesting	++	++		Requires investment in infrastructure, extension, capacity building
		Irrigation techniques to maximize water use (amount, timing, technology)	++	++		
		Modification of cropping calendar	++	++		Lack of information on seasonal climatic forecast trends, scenarios
Livestock management	Improved feed management	Improving feed quality: diet supplementation; improved grass species; low cost fodder conservation technologies (e.g. baling, silage)	+++	+++	+++	High costs
	Altering integration within the system	Alteration of animal species and breeds; ratio of crop-livestock, crop-pasture	++	+++	++	Lack of information on seasonal climatic forecast trends, scenarios
	Livestock management	Improved breeds and species (e.g. heat-tolerant breeds)	++	++	++	Productivity trade-off: more heat-tolerant livestock breeds generally have lower levels of productivity
		Infrastructure adaptation measures (e.g. housing, shade)	++	+++	+	
	Manure management	Anaerobic digesters for biogas and fertilizer	+++	+++	+++	High investment costs
		Composting, improved manure handling and storage, (e.g. covering manure heaps) application techniques (e.g. rapid incorporation)	++	+	++	

Mitigation/adaptation potential: + = low; ++ = medium; and +++= high

Source: Adapted from FAO, 2009b; Smith *et al.*, 2008; World Bank, 2008

Landless systems

Climate-smart options are also available for intensive systems (Gill *et al.*, 2009; UNFCCC, 2008). These options mainly relate to manure management (pig, dairy, and feedlots) and enteric fermentation (dairy and feedlots). Because these systems are generally more standardised than mixed and grazing systems, there are fewer applicable options.

Table 8.4
Summary of CSA practices and technologies for landless systems

Practices/technologies	Impact on food security	Effectiveness as adaptation strategy	Effectiveness as mitigation strategy	Main constraints to adoption
Anaerobic digesters for biogas and fertilizer	+++	+++	+++	Investment costs
Composting, improved manure handling and storage (e.g. covering manure heaps), application techniques (e.g. rapid incorporation)	++	+	++	
Temperature control systems	++	+++	-	High investment and operating costs
Disease surveillance	++	+++	+	
Energy use efficiency		+	+++	Subsidized energy costs
Improved feeding practices (e.g. precision feeding)	+++	+	+++	High operating costs
Building resilience along supply chains	++	+++	-	Requires coordination along the chains

Mitigation/adaptation potential: + = low; ++ = medium; and +++= high

Improved waste management

Most methane emissions from manure derive from swine and beef cattle feedlots and dairies, where production is carried out on a large scale and manure is stored under anaerobic conditions. GHG mitigation options include the capture of CH_4 by covering manure storage facilities (biogas collectors). The captured CH_4 can be flared or used as a source of energy for electric generators, heating or lighting. Energy generated in this way can offset CO_2 emissions from burning fossil fuels.

Anaerobic digestion technology has been shown to be highly profitable in warm climates (Gerber *et al.*, 2008). Recent developments in energy policy have also enhanced its economic profitability in countries such as Germany and Denmark (AEBIOM, 2009). Manure application practices can also reduce N_2O emissions. Improved livestock diets, as well as feed additives, can substantially reduce CH_4 emissions from enteric fermentation and manure storage (FAO, 2006a). Energy-saving practices have also been demonstrated to be effective in reducing the dependence of intensive systems on fossil fuels.

Box 8.2
Spatial planning and recovery of nutrient and energy from animal manure - insights from Thailand

Experience from Thailand shows that improving the spatial distribution of livestock production is a cost-effective way of fostering better manure management practices. Policy makers need to pay increased attention to the spatial distribution of livestock production as it creates the right economic conditions for the recycling of manure as an input to other production activities. Of particular importance are policy instruments that ensure that animal densities are such that manure can be recycled within a reasonable distance from its production. This would reduce animal concentrations in areas, such as peri-urban neighbourhoods, with low nutrient absorption capacity.

Better distribution of livestock production increases farm profits and at the same time reduces emissions. However, relying solely on regional planning does not lead to acceptable levels of emission reductions, except in specific cases. Better distribution of livestock should be considered a basic, low-cost measure, which should be combined with the development and enforcement of regulations and communication activities.

The adoption of bio-digestion can increase farm profits by 10 to 20 percent and help reduce the environmental impact of livestock production.

A cost-efficient reduction of pollution from intensive waste production requires a combination of better spatial distribution of livestock production and pollution control measures.

Source: more information can be found at FAO, 2010b

Improved feed conversion

Carbon dioxide emissions associated with feed production, especially soybean, are significant (FAO, 2006a). Improved feed conversion ratios have already greatly reduced the amount of feed required per unit of animal product. However, there is significant variation between production units and countries. Further progress is expected to be made in this area through improvements in feed management and livestock breeding. Reducing the amount of feed required per unit of output (e.g. beef, milk) has the potential to both reduce GHG emissions and increase farm profits. Feed efficiency can be increased by developing breeds that grow faster, are more hardy, gain weight more quickly, or produce more milk. Feed efficiency can also be increased by improving herd health through better veterinary services, preventive health programmes and improved water quality.

Sourcing low-emission feed

Shifting to feed resources with a low-carbon footprint is another way to reduce emissions, especially for concentrated pig and poultry production systems. Examples of low-emission feeds include feed crops that have been produced through conservation agriculture practices or that have been grown in cropping areas that have not been recently extended into forested land or natural pastures. Crop by-products and co-products from the agrifood industry are also examples of low-emission feeds.

Improving energy use efficiency

Landless systems generally rely on greater amounts of fossil fuel energy than mixed and grazing systems (Gerber *et al.*, 2011: FAO, 2009b). Improving energy use efficiency is an effective way to reduce production costs and lower emissions. Dairy farms are seen as having great potential for energy use efficiency gains. Energy is used for the milking process, cooling and storing milk, heating water, lighting and ventilation. Cooling milk generally accounts for most of the electrical energy consumption on a dairy farm in developed countries. Cows are milked at temperatures around 35 to 37.5 degrees Celsius. To maintain high milk quality, which includes keeping bacteria counts low, the raw milk temperature needs to be lowered quickly to 3 to 4 degrees Celsius. Refrigeration systems are usually energy-intensive. Heat exchangers cooled by well water, variable-speed drives on the milk pump, refrigeration heat recovery units and scroll compressors are all energy conservation technologies that can reduce the energy consumed in the cooling system. These technologies can reduce GHG emissions, especially in countries where the energy sector is emission intensive.

Building resilience along supply chains

Landless livestock systems rely on purchased inputs. Climate change contributes to increased price volatility of these inputs, especially feed and energy, which increases the financial risks for stakeholders involved in the livestock supply chain. This is especially true where commodity stocks of inputs are kept at a minimum throughout the supply chain and buffering options against price hikes are limited. In addition, the changing disease patterns caused by climate change can quickly affect landless systems that heavily rely on transport in the supply chain. Resilience can be achieved either by allowing chains to overcome the crisis or by creating the conditions for quick recovery after the crisis. Although little experience has yet been developed in this area, greater coordination among the different stakeholders involved in the supply chain, insurance schemes, buffers and stocks may contribute to a greater resilience of supply chains that rely on landless livestock systems.

Conclusions

Livestock can make a large contribution to climate-smart food supply systems. The sector offers substantial potential for climate change mitigation and adaptation. Mitigation options are available along the entire supply chain and are mostly associated with feed production, enteric fermentation and manure management. Livestock's role in adaptation practices relates to organic matter and nutrient management (soil restoration) and income diversification. Livestock also makes a key contribution to food security, especially in marginal lands where it represents a unique source of energy, protein and micronutrients. The contribution of the livestock sector to food security could be strengthened, particularly in areas where current levels of consumption of livestock products are low.

This module has highlighted how some practices require making tradeoffs between adaptation, mitigation and food security. However, most practices offer opportunities to exploit synergies in these areas. Several CSA practices are readily available for implementation, such as sylvopastoral systems, grassland restoration and management, manure management (recycling and biodigestion) and crop-livestock integration. Barriers to adoptions are most often related to a lack of information, limited access to technology and insufficient capital. Overcoming these barriers requires specific policy interventions, including extension work and financing mechanisms, such schemes for improving access to credit and payment for environmental services (see Modules 13 on policies and 14 on financing).

Research efforts are also required to identify additional combinations of mitigation and adaptation practices that are adapted to specific production systems and environments (e.g. combined interventions addressing the management of feed, genetic resources and manure). The potential aggregated effects that changes in farming systems may have on food security and the use of natural resources at the regional level also need to be better understood.

This module has also highlighted that CSA approaches need to take into consideration production systems and supply chains. This is especially true in the case of livestock, given the strong interrelationships with crops (feed and manure management) and the wider environment. Addressing mitigation or adaptation issues requires paying attention to spillover and feedback effects along the chain.

Case Study 8.1
Range management for mitigation and adaptation, in the Three Rivers region of Northern China

Background

The restoration of degraded grasslands through sustainable grazing management (SGM) practices, including: reductions in grazing pressure on overstocked sites; the sowing of improved pastures; and better pasture management, can lock more carbon in soils and biomass, increase the water-holding capacity of the soil and enhance grassland biodiversity. More widespread adoption of SGM practices is currently hindered, in part, by the high costs individual producers face in accessing carbon markets.

The Three Rivers Sustainable Grazing Project is a pilot project in the Qinghai province of China that addresses these challenges. In the project, which covers a total of 22 615 hectares of lightly to severely degraded grazing land, yak- and sheep-herding households will select a combination of management options related to grazing intensity, grass cultivation and animal husbandry. The project's goal is to restore degraded grazing land, and thereby sequester soil carbon, and at the same time increase productivity, build resilience and improve livelihoods in smallholder herder communities. The average annual mitigation potential in the first 10 years of the project were an estimated 63 000 tonnes of CO_2 eqv. per year.

Key lessons, constraints and selection criteria

1. Technical mitigation and adaptation potential

The primary selection criteria for this project was its high carbon sequestration potential, which was linked to the prevalence of heavily degraded grazing land (38 percent of the project area), and the availability of simple and cost-effective restoration measures. For instance, the average annual sequestration potential per hectare over the entire project is estimated to be more than 3 tonnes of CO_2 eqv., compared with IPCC global estimates of 0.11 to 0.81 CO_2 eqv. for grasslands (Smith *et al.*, 2007). Also, by improving soil moisture and nutrient retention in soils, grassland restoration plays an important role in building resilience to climate change.

2. Productivity and economic returns

Assessments revealed that restoration of degraded grazing lands would also significantly enhance the productive potential of the project site. Economic returns to herders will be enhanced by including a package of complementary measures, such as the introduction of improved feeding, winter housing, post-farm processing and marketing activities. The project's capacity to deliver net economic returns is crucial, as it greatly increases the likelihood of voluntary herder enrolment, and improves the synergy between climate change mitigation and rural development objectives.

3. Carbon crediting methodology and applicability

The project activities are able to enhance the long-term productivity and profitability of the farming system. Nevertheless, during the first years of the project, carbon finance is critical to help cover the investment costs associated with grass planting, fencing and animal housing. A key constraint to accessing carbon market finance is the absence of carbon accounting methodology that is both affordable, but also sufficiently accurate for investors. To address this constraint, FAO has developed a grassland carbon accounting methodology that is currently being validated under the Verified Carbon Standard. Instead of relying solely on direct measurement, which is often prohibitively costly, this methodology uses carefully calibrated biogeochemical models in combination with the monitoring of management activities to estimate soil carbon pool changes. This important innovation significantly reduces the costs associated with measurement and verification and greatly facilitates access to carbon markets. While developed as part of the Three Rivers project, the grassland carbon accounting methodology will be applicable to sustainable grazing projects throughout the world.

4. Institutional constraints

In addition to the barriers related to biophysical and economic measurement and verification, institutional constraints also need to be considered. The project's work in this area takes into consideration institutions for monitoring and enforcement, as well as institutions for marketing livestock products, which is needed to make the SGM practices a profitable option for herders. A lack of enforcement of laws for the adoption of sustainable stocking levels is common throughout China's main grassland areas. It is important for the project to establish community-based monitoring mechanisms and build capacities to implement and monitor sustainable development in the longer-term.

Table 8.5
Summary of climate-smart indicator rankings

Indicators	Ranking (-5 to +5)
Food security	+2
Productivity	+2
Livelihoods	+3
Adaptation and resilience	+3
Climate change mitigation	+5
Water use and retention	+2
Biodiversity	+2

Source: Smith *et al.*, 2007

Case study 8.2
Developing climate-smart cattle ranch in the central region of Nicaragua

Since 2004, the Livestock and Environmental Management Programme at Tropical Agricultural Research and Higher Education Centre (CATIE) has been implementing participatory training processes in Central America with cattle producers using the farmer field school philosophy. This process has promoted the adoption of silvopastoral systems and good practices to improve income, food security, ecosystem services and adaptation to and mitigation of climate change. Seven dual-purpose farms (milked cows with calf at foot) were selected for each of the following groups: with silvopastoral system and traditional system. The first group was predominantly fed with improved pasture with trees, cut and carry fodder banks of forage grass (Pennisetum purpureum) and woody fodder (Gliricidia sepium and Cratylia argentea). Compared with traditional farming systems, the silvopastoral system farms had higher milk production per cow during the year. Farmers also earned more income and more carbon was stored in the soil (Table 8.6). The impacts of silvopastoral system innovations are clearly visible. However, sustainable participatory training processes (learning by doing) and incentive mechanisms (soft credits, certification and green markets in value chains) are required to encourage the uptake of these innovative practices. To meet the goals of CSA, farmers themselves must use their own assessments to develop design proposals that are based on silvopastoral system and good practices (e.g. efficient use and conservation of water, and manure management) and are suitable to the farm's biophysical and socioeconomic conditions. The farmers using silvopastoral system have the potential to contribute to reaching CSA objectives (Table 8.7) and would improve ecosystem health.

Table 8.6
Productive, economic and environmental performance of silvopastoral and traditional cattle farms in the Central region of Nicaragua

Indicator	Cattle ranch with silvopastoral practices	Traditional cattle ranch
Milk production (kg/cow/day)		
Rainy season	7.4	4.7
Dry season	4.4	2.9
Rank of income (US$/hectare/year)	346.3 - 519.6	227.7 – 327.8
Carbon sequestration (tonne/hectare)	11.0	5.3

Source: Chuncho, 2010

Table 8.7 Response farms with silvopastoral and traditional systems to the CSA approach functions

Variable	Cattle ranch with silvopastoral practices	Traditional cattle ranch
Food security	+3	+/-
Productivity	+4	+2
Livelihoods	+4	+2
Adaptation and resilience	+5	-1
Mitigation	+5	-1
Water use	+2	-1
Energy use	+3	-1
External inputs	+4	-2

Ranking -5 to +5

Source: Chuncho, 2010

Notes

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Acronyms

AEBIOM	European Biomass Association
CATIE	Tropical Agricultural Research and Higher Education Centre
CIPAV	Centre for Research on Sustainable Farming Systems
CO_2	carbon dioxide
CO_2 eqv.	carbon dioxide equivalent
CH_4	methane
CSA	climate-smart agriculture
CW	carcass weight
FPCM	fat and protein corrected milk
GEF	Global Environment Facility
GHG	greenhouse gas
IICA	Inter-American Institute for Cooperation on Agriculture
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
LCA	Life Cycle Assessment
LWG	live weight gain
NH_3	ammonia
N_2O	nitrous oxide
SGM	sustainable grazing management
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

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