Production and Resources

B2 Climate-smart livestock production

Overview

This module assesses the role of livestock in climate-smart agriculture. Specifically, chapter B2-1 assesses the impact of climate change on livestock and identifies adaptation and mitigation opportunities and needs. It also presents an overview of emissions caused by livestock. Chapter B2-2 outlines the principles of climate-smart livestock, focusing on increased efficiency of resource use and building resilience. Adopting a farming system perspective, Chapter B2-3 gives insights into main strategies for achieving climate-smart livestock, and specific practices suitable for the dominant livestock production systems. Chapter B2-4 discusses the enabling environment for climate-smart livestock production.

Key messages

- Livestock accounts for 17 percent of the global calorie intake and 33 percent of the protein intake. Livestock production produces 14.5 percent of anthropogenic greenhouse gas emissions. The sector can make a large contribution to climate-smart food systems.
- Livestock’s role in adaptation practices relates primarily to the management of organic matter and nutrients, and the diversification of incomes.
- Mitigation options are available along the entire livestock supply chain. They are mostly associated with feed production, enteric fermentation and manure management.

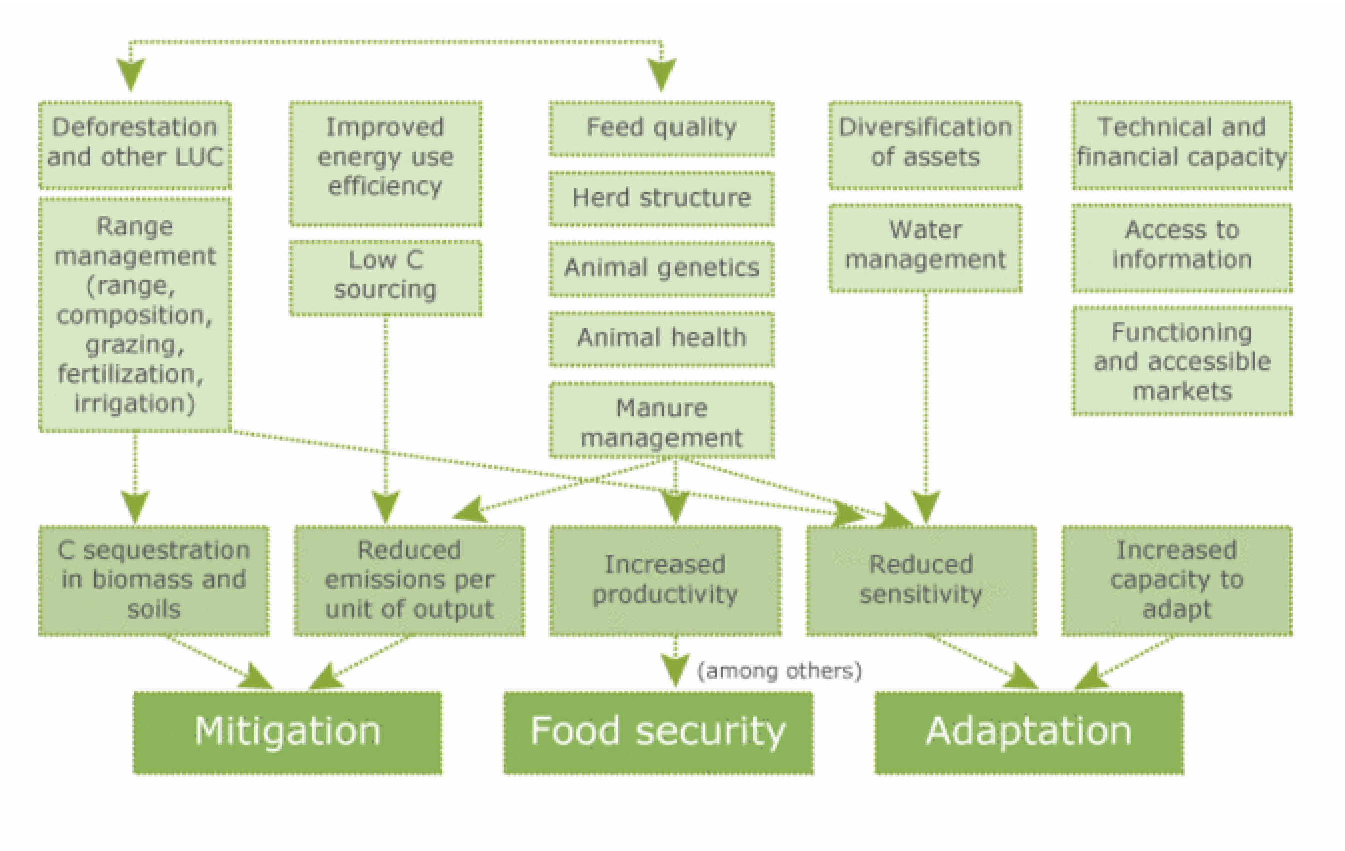
- Several climate-smart agriculture practices are readily available for implementation. These practices include grassland restoration and management (e.g. sylvopastoral systems), manure management (e.g. recycling and biodigestion) and crop-livestock integration.
- Barriers to adoption are often related to a lack of information, limited access to technology and insufficient capital. Overcoming these barriers requires specific policy interventions, as well as extension services and financing mechanisms, such as schemes for improving livestock producers' access to credit and payment for environmental services.
- A climate-smart agriculture approach that considers the entire food supply chain is particularly important for the livestock sector, given the sector’s strong interrelationship with crop production.

Livestock production and climate change

Livestock makes a key contribution to global food security. Its contribution is especially important in marginal lands where livestock represents a unique source of energy, protein and micronutrients (Chapter B2-1.1). Climate change has substantial impacts on ecosystems and the natural resources upon which the livestock sector depends. At the same time, livestock food chains are major contributors to greenhouse gas emissions (FAO, 2006).

Livestock’s role in adaptation practices is described in Chapter B2-1.2. Chapter B2-1.3 looks at climate change mitigation options available along the entire supply chain. These options are mostly associated with feed production, enteric fermentation and manure management. Figure B2.1 summarizes the contribution the sector can make to climate-smart food systems, and the technical strategies available to livestock producers for adapting to and mitigating climate change. It also highlights the institutional elements that are necessary to harness the sector’s potential to support a shift to climate-smart food systems.

Figure B2.1. Summary of technical and institutional determinants of climate-smart livestock production



Source: Gerber, 2013 (unpublished)

B2-1.1 Climate change impact on livestock production - need for sustainable production intensification and diversification

Farming is the source of livelihood for one-third of the world's population. About 60 percent of the people who rely on farming for their livelihoods own livestock. Nearly 800 million livestock keepers live on less than USD 2 a day (FAO, 2011b). Livestock production is a rapidly growing sector. It accounts for 40 percent of the global agricultural gross domestic product and is crucial for food security in all regions. In sub-Saharan Africa, more than half the population keep livestock, and one in three of these livestock keepers can be considered poor (FAO, 2012).

Livestock make a necessary and important contribution to global calorie, protein supplies and important micro nutrients such as B12, iron, calcium. They produce 17% of calories consumed globally and 33% of protein. Livestock can increase the world’s edible protein balance by transforming inedible protein found in forage[ii] into forms that people can digest. For example, in pastoral[iii] areas, livestock are the only option to turn a sparse and erratic biomass resource into edible products. On the other hand, livestock can also reduce the global edible protein balance by consuming large amounts of edible protein found in cereal grains and soybeans and converting it into small amounts of animal protein (Mottet *et al*, 2017). The choice of livestock production systems (e.g. grass-based, integrated crop-livestock) and good management practices (discussed in Chapter B2-4 and Chapter B2-5) are important for optimizing the protein output from livestock.

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. Livestock, especially small ruminants and chicken, are key to women empowerment and gender equity.

Livestock are also a major asset among rural communities, providing a range of essential services, including savings, credit and buffering against climatic shocks and other crises (see Chapter B2-4). In mixed systems , livestock consume crop residues and by-products (from agro-industrial processing) and produce manure used to fertilize crops (see module B5). Cattle, camels, horses and donkeys also provide transport and draught power for field operations, up to 81% in Northern Africa (Gebresenbet and Kaumbutho, 1997). With all these services, the contribution of livestock goes beyond agriculture and food security and directly supports education and human health.

However, as discussed in Chapter B2-2.2, livestock need to be managed carefully to maximize the range of services they provide and reduce its vulnerability to the impacts of climate change.

B2-1.2 The impact of climate change on livestock production - the need for adaptation

Climate change poses serious threats to livestock production. Increased temperatures, shifts in rainfall distribution, increased frequency of extreme weather events and consequent increased heat stress and reduced water availability are expected to adversely affect livestock production and productivity around the world both directly and indirectly (Figure B2.2):

- 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 (FAO, 2009; Thornton and Gerber, 2010).
- Indirect impacts will be experienced through modifications in ecosystems, changes in the yields, quality and type and availability of feed and fodder[vi] crops, and greater competition for resources with other sectors (FAO, 2009; Thornton, 2010; Thornton and Gerber, 2010). 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). In non-grazing systems, indirect impacts from lower crop yields, feed scarcity and higher feed and energy prices will be more significant.

Figure B2.2. Direct and indirect impacts of climate change on livestock production systems

	Grazing systems	**Non-grazing systems**
Direct impacts of climate change	- increased frequency of extreme weather events - increased frequency and magnitude of droughts and floods - productivity losses resulting from physiological stress due to higher temperatures - change in water availability, which may increase or decrease depending on the region	- change in water availability, which may increase or decrease depending on the region - increased frequency of extreme weather events, with impact being less acute than for extensive systems

	Grazing systems	Non-grazing systems
Indirect impacts of climate change	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)

These impacts are likely to be widespread. However, they will be difficult to quantify due to the uncertain and complex interactions between agriculture, climate, the surrounding environment and the economy (Kurukulasuriya and Rosenthal, 2003; Randolph, 2008).

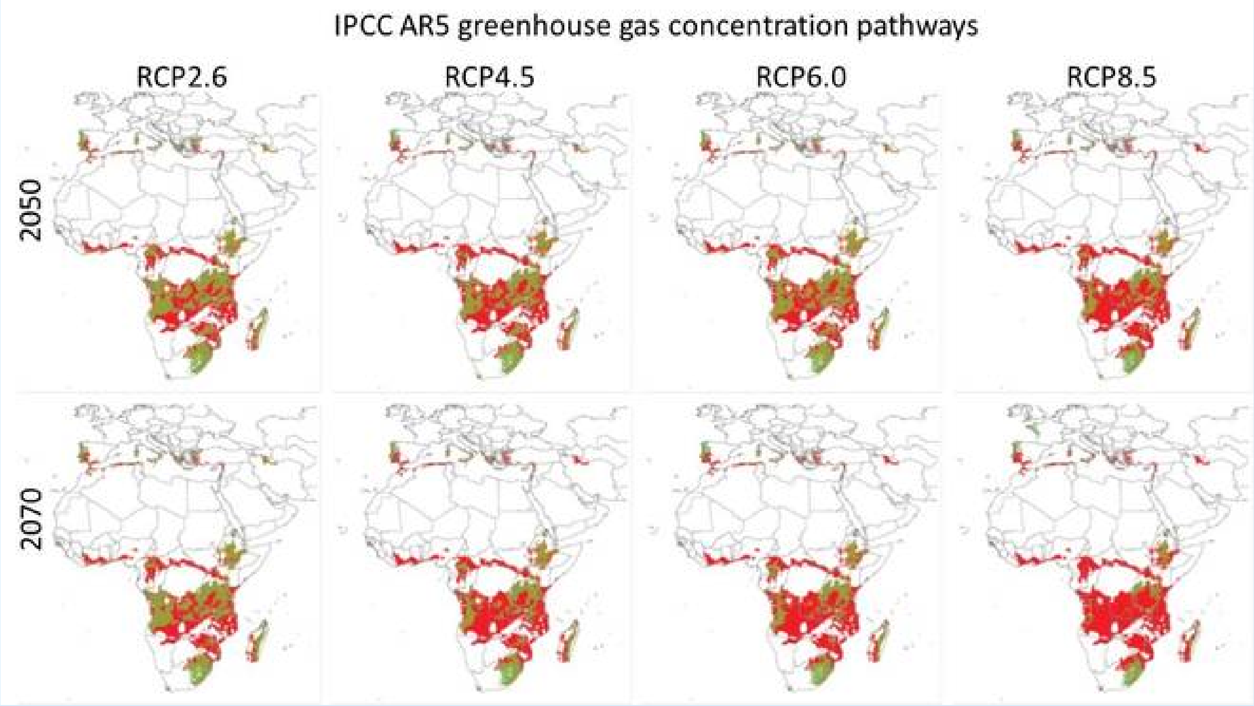
Livestock's vulnerability to climate shocks depends first on their exposure, which is determined by the duration, frequency and severity of the shocks, and the location of the stocks and related assets (e.g. feedstock, housing, water points). It also depends on their sensitivity, which is determined by the breed (see module B8-3.1 for the impact of climate change on animal genetic resources), the housing or feeding system, status of animal health (e.g. vaccination rate) and the importance of livestock to the household in terms of food security and livelihoods (ICEM, 2013). A number of other factors can increase livestock's vulnerability to climate change, especially in semi-arid and arid regions. These factors include rangeland degradation, the fragmentation of grazing areas, changes in land tenure, conflicts and insecure access to land and markets (e.g. crop residues and by-products for feed, animal products). Socio-economic factors that specifically affect disease prevalence include changes in land use, host abundance, international trade, migration and public health policy.

Box B2.1 The potential impact of climate change on breed distribution - an example from Kenya

The current geographic distribution of Kenyan Kamba cattle, as recorded in the Domestic Animal Diversity Information System (DAD-IS), was used to model their potential distribution. The system took into account several temperature and humidity characteristics of their production environment. This information served to define potential current and future habitats for this breed. Future habitats were modeled using the 'Hadley Global Environment Model 2 - Earth System' and four scenarios (representative concentration pathways: (IPPC, 2013) were selected. The differences between potential current and future habitats were mapped, revealing areas where habitat was lost and gained, and where it remained unchanged (Figure B2.3).

Analyses of this kind can potentially contribute to more informed decision-making on breed management in a changing climate. They can strengthen the capacity of national governments, livestock keepers and farmers to protect and enhance food security and manage animal genetic resources sustainably.

Figure B2.3. Modeled distribution of the Kenhan Kamba cattle under four representative concentration pathways (RCPs). Areas of habitat loss appear in red, areas of no expected change in dark green and areas of habitat gain in light green.



Source: FAO, 2015.

Impact of climate change on animal health

Infectious diseases in animals and their transmission cycles represent complex interactions between hosts, pathogens and the environment (Peterson, 2006) and mainly occur following changes in the host-pathogen-environment system (Jones *et al*., 2008). Most of these diseases are zoonotic, i.e. may be transmitted to humans, and can have serious consequences for public health, the economy of the livestock sector and biodiversity conservation (Pinto *et al*., 2008).

Climate change, in particular global warming, likely affects animal health by influencing the host-pathogen-environment system both directly and indirectly. The direct effects are more likely to influence diseases that are associated with vector transmission, water or flood, soil, rodents, or air temperature and humidity (Abdela and Jilo, 2016). Indirect impacts of climate change are more complex to disentangle and include those deriving from changes in land use and biodiversity and the attempt of animals to adapt to these climatic and environmental changes or from the influence of climate on microbial populations, distribution of vector-borne diseases and host resistance to infectious agents, feed and water scarcity, or food-borne diseases. In particular, prolonged droughts determine water and pasture shortages, which decrease livestock immunity against infectious diseases, as well as trigger livestock movements to areas at higher risk of animal diseases, determining the congregation of domestic animals around few available watering points and grazing areas in proximity to wildlife reserves. Here the risk of disease transmission is increased by the increased contact among domestic animals and between domestic and wild animals (Pinto *et al*., 2008). Grazing areas resulting from deforestation and changes in land use may expose livestock to novel pathogens due to increased interface between livestock and wildlife (Lubroth, 2012). These direct and indirect effects of climate change may be *spatial*, i.e., affecting the geographical distribution of the pathogen, host or vector, or temporal, i.e., affecting the timing of an outbreak and its intensity (Lubroth, 2012; Abdela and Jilo, 2016). However, not all organisms will respond similarly to climate change. In general, disease agents with external stages (e.g., non-host) of their life cycles, such as parasites, food-, water- and vector-borne diseases are most influenced by climatic and environmental changes. For instance, temperature increases feeding intervals and development rates of blood-feeding arthropods, while rainfall increases the availability of habitat for breeding sites. In general, global warming and changes in rainfall patterns and intensity are expected to expand the geographical and altitudinal distribution of vectors, allowing them to cross mountain ranges that currently limit their distribution (Abdela and Jilo, 2016). Furthermore, climate change can also influence livestock health through the survival of pathogens in the environment. A pathogen may emerge in new territories and host landscapes; become more aggressive, and perform a host-species jump, possibly in relation to increased host species mixing or contacts (Lubroth, 2012).

Vector-borne diseases that are strongly associated with vector amplification due to climate variability include Rift Valley fever (RVF), West Nile Virus (WNV), Bluetongue (BTV) and Trypanosomosis. For instance, RVF in East Africa is strongly associated with extreme events, such as heavy rains and floods, caused by the El Niño Southern Oscillation events, which are expected to occur more frequently in the future as an effect of global climate change (FAO *et al*., 2015). On the contrary, West Nile Virus (WNV), Bluetongue (BTV) and Trypanosomosis appear to be strongly influenced by global warming and raise in temperature (Paz, 2015). Soil-borne diseases, such as Anthrax, are also affected by precipitation variability. Livestock and wildlife likely get infected with Anthrax while grazing and ingesting forage or soil contaminated with Anthrax spores, browsing on vegetation contaminated by carrion flies, or by percutaneous exposure from biting flies, and possibly spore inhalation (WHO, 2008). Anthrax outbreaks mainly occur after heavy rains and floods followed by a dry period or with the onset of rains ending a period of drought (Blackburn *et al*., 2007; Patassi 2016). These climatic conditions favor the concentration of spores in the upper level of the soil, increasing the risk of spore ingestion by herbivores. Climate change can also impact animal health in the Arctic region. The Anthrax outbreak that affected the reindeer population and humans in the Yamalo-Nenets region of Siberia in July 2016 is suspected to be associated with global warming and the abnormal warm temperatures observed in 2016, which may have substantially reduced the snow cover, water ice and permafrost in the area (FAO, 2017a). The previous reported outbreak in the area occurred in 1941, about 75 years ago. Time-series analyses of satellite-derived climate data over the past decades suggested that the observed changes in climate and livestock production system in the region may have increased animal exposure to Anthrax infected soil (FAO, 2017a).

Disease agents whose transmission depends primarily on close host-to-host contact can also be favored by extreme weather events that may increase contacts between naive and infected populations. For instance, prolonged droughts can increase the risk of occurrence of foot and mouth disease, hemorrhagic fevers, and tuberculosis (Abdela and Jilo, 2016).

Climate change has already been shown to determine a mismatch between migratory bird nesting and peak food abundance (Both *et al*., 2006) as well as changes in migration routes and timing (Hurlbert and Liang, 2012). The scarce availability of food during nesting is a great stressor that increases disease prevalence. At the same time, climate change may reduce available habitats, determining higher congregation of birds of several species in smaller areas of remaining resources and increasing the chance of within-species and cross-species disease transmission. Changes in migration routes and timing may also favor the emergence and introduction of a pathogen carried by birds in novel areas. This scenario is a likely explanation for the recent spread of highly pathogenic H5N8 avian influenza in Africa (FAO, 2017b).

Climate variability in rainfall, temperature, humidity patterns and extreme weather events, such as floods, droughts, heatwave, are therefore considered important indicators for monitoring and predicting animal diseases occurrence. As shown by the FAO Emergency Prevention System (EMPRES) since its implementation in 1994, early warning, early detection and early response are key in the prevention and control of both old and new emerging animal diseases (Lubroth, 2012). The FAO's Global Surveillance and Early Warning System (GLEWS) actively tracks and verifies diseases rumors and disseminates confirmed disease outbreaks through the EMPRES-i Global Animal Disease Information System. FAO'S GLEWS conducts regularly risk assessments and modelling activities to provide decision makers in animal health and other stakeholders with guidance and recommendations on how to identify disease pathways, predict and prevent areas at risk of disease emergence and spread and implement rapid response and control measures on the ground. FAO'S GLEWS regularly monitors climatic and environmental risk factors using near-real time satellite-derived climate data. Using an algorithm developed by NASA and partners, a near-real time early warning system prototype for RVF has been developed using Google Earth Engine to identify and predict areas at risk of RVF vector amplification in East and West Africa (FAO, 2017).

Preventive veterinary medicine, together with adjustment of animal husbandry and social resilience represents a way of coping with the negative consequences of climate change (Lubroth, 2012).

B2-1.3 Livestock production impact on climate change - need for mitigation of climate change

The livestock sector is a major contributor to climate change, generating significant emissions of carbon dioxide (CO_2), methane and nitrous oxide. Livestock contribute to climate change by emitting greenhouse gases either directly (e.g. from enteric fermentation and manure management) or indirectly (e.g. from feed-production activities, the conversion of forest into pasture). Based on a life cycle assessment of the livestock sector, FAO estimates that it emits about 8.3 gigatonnes of CO_2 equivalent (CO_2 eq.) (GLEAM), distributed as follows.

- Land use and land-use change accounts for 0.7 gigatonnes of CO_2 eq. per year (9 percent of the sector's emissions). This figure refers to the carbon dioxide emitted from the replacement of forest and other natural vegetation by pasture and feed crops in Latin America and Soil Organic Carbon release (mineralization) from soils, such as pasture and arable land dedicated to feed production (see Box B7.3).
- Feed production releases 2.6 gigatonnes CO_2 eq. per year (33 percent of the sector's emissions). It includes carbon dioxide emissions from fossil fuels used in manufacturing chemical fertilizer and pesticides for feed crops, and and nitrous dioxide emissions from chemical fertilizer application on feed crops (grasses and legumes. It does not include the carbon released by field operations (Soil Organic Carbon mineralization).
- livestock production releases 3.7 gigatonnes CO_2 eq. per year (46 percent of the sector's emissions), including from: enteric fermentation from ruminants (as methane) and on-farm fossil fuel use (in the form of carbon dioxide).
- Manure management (mainly manure storage, application and deposition) accounts for 0.8 gigatonnes CO_2 eq. per year (10 percent of the sector's emissions) from methane and nitrous oxide.
- Processing and international transport produces 0.23 gigatonnes CO_2 eq. per year (3 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[vii] of meat and milk, measured by output weight, corresponds on average to 46.8 kg CO_2 eq. per kg of carcass weight for beef; 72 kg CO_2 eq. per kg of carcass weight for pork; 5.1 kg CO_2 eq. per kg of carcass weight for chicken; and 2.9 kg CO_2 eq. per kg of milk (FAO, 2013a and 2013b). Box B2.2 illustrates the case of substituting meat intake from livestock with low feed-conversion efficiency with livestock with higher feed-conversion efficiency[viii], such as insects.

There is significant variability in emissions across the different regions. For example, the FAO Life Cycle Assessment of greenhouse gas emissions from the global dairy sector estimated the global average at 3.0 kg CO_2 eq. However it also 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 eq. per kg Fat and Protein Corrected Milk

(FPCM). The highest emissions are estimated for sub-Saharan Africa with an average of 6.5 kg CO_2 eq./kg of Fat and Protein Corrected Milk. Greenhouse gas emissions for Latin America and the Caribbean, Near East and North Africa and South Asia, range between 3.5 and 5.6 kg CO_2 eq./kg Fat and Protein Corrected Milk (FAO, 2013a).

Results from the same study of the global dairy sector also found greenhouse gas 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 CO2 eq./kg FPCM compared to 1.1 kg CO2 eq./kg of Fat and Protein Corrected Milk for high production levels (about 8 000 kg of milk). This reflects the strong relationship between livestock intensification and greenhouse gas emissions across countries on a global scale (Gerber *et al*., 2011). This relationship is exponentially declining which means that small increases in productivity in the least intensive countries could provide the highest benefits in terms of emission intensity.

However, beyond this strong relationship across countries, there is also a strong variability within countries, where production systems and management practices play an important role.

Box B2.2 Farming insects as 'minilivestock'

The majority of insect collection occurs through wild gathering, mainly in forests. The concept of farming insects for food or feed is relatively new.

Farming insects as “minilivestock” offers great opportunities to provide food at low environmental cost, without compromising wild insect populations and contributing positively to livelihoods in the context of climate change thanks to their high feed-conversion efficiency, relatively low greenhouse gas and ammonia emissions, and lower water requirements than cattle rearing. An example of rearing insects for human consumption in the tropics is cricket farming in the Lao People’s Democratic Republic, Thailand and Viet Nam.

Insects can supplement traditional feed sources, such as soy, maize, grains and fishmeal, to meet the increasing compund demand for feed production worldwide. Insects with the largest immediate potential for large-scale feed production are larvae of the black soldier fly, the common housefly and the yellow mealworm -but other insect species are also being investigated for this purpose. Producers in China, South Africa, Spain and the United States are already rearing large quantities of flies for aquaculture and poultry feed by bioconverting organic waste.

FAO has commenced work on insect rearing for nutritional security in a technical manual on *Edible insects: Future prospects for food and feed security*.

Source: Sandra Corsi

Climate-smart livestock production strategies

B2-2.1 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 its 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. greenhouse gas emissions per unit of eggs). 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). Efficiency gains in the uses of resources can be achieved through improvements in management, technology, animal health, livestock breeds and feed crop varieties.

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. FAO (2011a) suggests that about one-third of all food produced for human consumption is wasted. Along the animal food chain, reduction of waste can substantially contribute to lowering the demand for resources, such as land, water, energy, as well as other inputs, such as nutrients.

The current prices of inputs (e.g. land, water and feed) used in livestock production often do not reflect true scarcities. Consequently, input costs do not provide disincentives for the overutilization of resources by the sector nor incentives to address 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.

B2-2.2 Risk management and system changes

Traditionally, livestock producers have been able to adapt to various environmental and climatic changes. However, expanding populations, urbanization, economic growth, increased consumption of animal-based foods and greater commercialization (Chapter B2-2.1) have made traditional coping mechanisms less effective (Sidahmed, 2008). As a result, the identification of coping and risk management strategies has become very important.

A wide array of adaptation options are available (see, for instance, chapter B8-3.3 on the sustainable use and development of animal genetic resources for climate change adaptation (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 in 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, which is comprehensively dealt with in module C5 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. Livestock can produce edible food for people from a range of inedible vegetal products. They can also move to find feed resources and endure a certain level of food and water stress. As a consequence, livestock production and marketing can help stabilize the food supplies and provide individuals and communities with a buffer against economic shocks and natural disasters. 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 are also a crucial coping mechanism in variable environments. As climate variability increases, livestock will become more valuable because it provides a range of options (e.g. mobility, use of alternative feed resources, mobilization of body reserves) to buffer the effects of this variability on food production. Box B2.3 on the drylands of Africa and the case study B2.3 on Zambia provide examples.

In addition, keeping more than one species of livestock is a risk-minimizing strategy and provides farmers with a wider range of adaptive options against climate unpredictability than if only one species is kept (Reijntjes *et al.*, 1992):

- An outbreak of disease may affect only one of the species, e.g. the cattle, and specific species or animals of specific breeds are better able to survive droughts and thus help carry a family over such difficult periods.
- Advantage can also be taken of the different reproductive rates of different species to rebuild livestock holdings after a drought. For example, the greater fecundity of sheep and goats permits their numbers to multiply quicker than cattle or camels. The small ruminants can then be exchanged or sold to obtain large ruminants.
- Different animal species exploit different feed resources. In pastoral areas, camels can graze up to 50 km away from watering points, whereas cattle are limited to a grazing orbit of on average 10-15 km. Camels and goats tend to browse more, i.e. to eat the leaves of shrubs and trees; sheep and cattle generally prefer grasses and herbs. Their different shaped mouths allow them to graze different sources.
- Different animal species supply different products. For example, camels and cattle can provide milk, transport and draught power, whereas goats and sheep tend to be slaughtered more often for meat. Chickens often provide the small change for the household, sheep and goats are sold to cover medium expenditures, while larger cattle are sold to meet major expenditures.

However, livestock production can be destabilized, particularly by climate change and events such as disease outbreaks (see Chapter B2-1.2). For many poor people, the loss of livestock assets means a collapse into chronic poverty and has long-term effects on their livelihoods. 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).

Box B2.3 Livestock as a tool for adaptation

Regions identified as the most vulnerable to climate change, such as sub-Saharan Africa and South Asia, are also regions where farmers and rural communities rely the most on livestock for food, income and livelihood support, and where livestock is expected to contribute more and more to food security and better nutrition. There is therefore an urgent need to help livestock farmers become more resilient to climate change.

Traditionally, livestock keepers have been capable of adapting to livelihood threats. In some situations, livestock keeping is itself an adaptation strategy, particularly in pastoral communities where livestock have always been the main asset to produce food. In marginal areas with scarce resources and harsh climatic conditions, pastoralism is often the only way to sustain livelihoods, in that it can produce food, contribute to economic activity and provide a range of socio-economic services (Scoones, 1996; Ashley and Carney, 1999). Livestock can be also used to diversify agricultural production, which can be part of a risk management strategy in case of crop failure (Jones and Thornton, 2009).

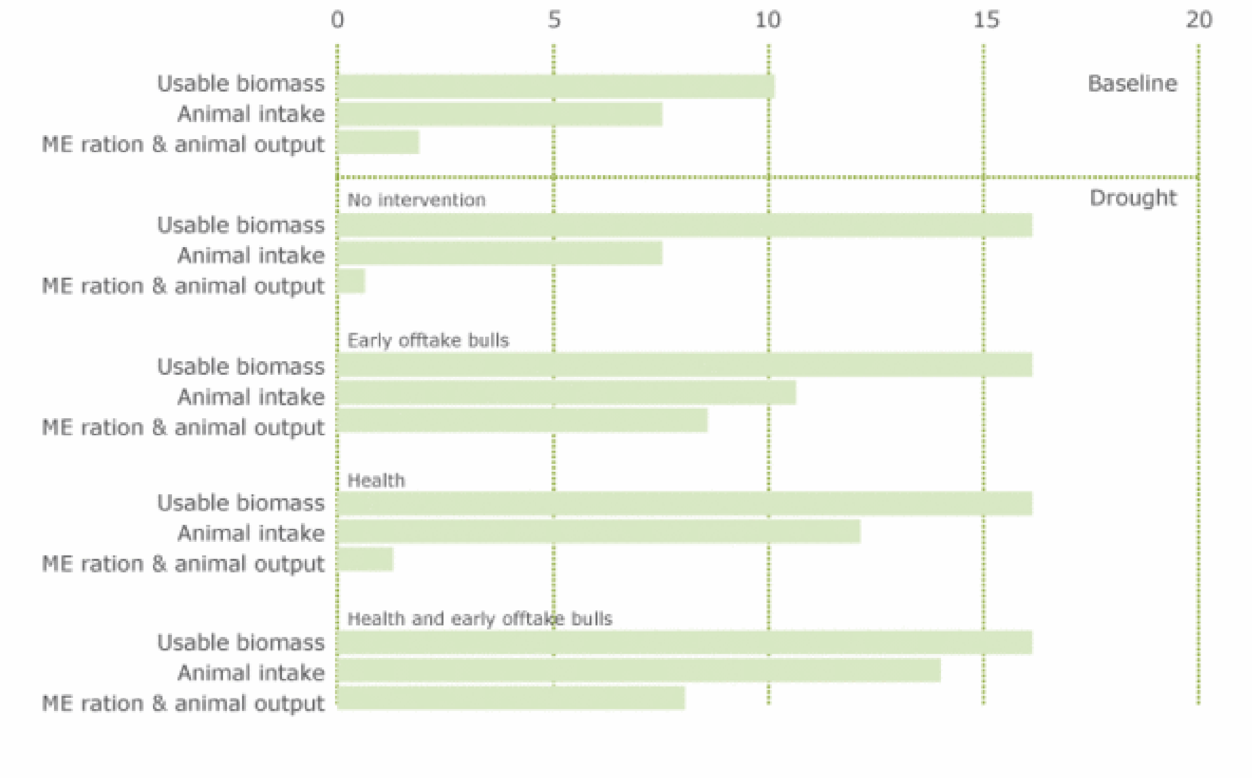
In the drylands of sub-Saharan Africa, FAO has collaborated with the World Bank, the French Agricultural Research Centre for International Development (CIRAD) and the International Food Policy Research Institute (IFPRI) and Action Contre la Faim to assess livestock production under climatic constraints and propose interventions to increase productivity and reduce the impact of climate variability on livestock outputs. The volume and quality of feed supplies were assessed, as well as the degree to which they could meet animal requirements under different climatic and intervention scenarios for the period 2012-2030.

Results show that 2.5 times more feed resource are needed in a baseline 2012-2030 scenario with similar climate than in the past (1998-2011), and 3.5 times more feed are needed in the case of drought. The assessment also showed that there is a potential for livestock's growth if feed resources are made accessible, which calls for interventions in animal mobility (corridors, security, border regulations, health, tenure), feed management (storage, processing, transport) and stratification of production to reduce grazing pressure in arid areas. Interventions in the African drylands can significantly increase the output of livestock products by 5% to 20%, if accessibility to feed is improved. Shocks brought by climate-driven variability on livestock production can be buffered through animal movements, adjustments in feed baskets, health interventions and animal offtake for market: while inter-annual variability in biomass reaches 16% in the baseline scenario, interventions can to 7 to 14% (depending on the interventions considered) in animal intake, and to 1% to 8% in animal product (Figure B2.4). Results therefore confirm that livestock is a strong asset for adaptation in pastoral areas.

Assessing the resilience of livestock production systems to drought causing lower feed availability, their potential for future growth, and the combined need for long term investments and timely policy interventions is essential to informing the planning of policy makers, as well as the international community -to better enable them in carrying out efficient and coordinated actions for climate change adaptation.

Figure B2.4

Interannual relative variability (relative standard deviation in %, high values reflect high variability) of usable biomass, animal intake in dry matter and metabolizable energy (ME)[ix] as a proxy for animal products in the baseline and the drought scenarios with different levels of interventions (from Mottet *et al*., 2015). Health interventions correspond to veterinary measures (e.g. vaccination) aimed at increasing fertility and decreasing calf and adult mortality. Early offtake of bulls is an intervention in which young male animals are sold earlier to the market.



Source: FAO, 2016

Longer-term approaches to adaptation can often 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 to address it. Research carried out now needs to be appropriate to the environment 20 to 30 years in the future. This has implications for how research is targeted and 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).

Climate-smart livestock production systems in practice

This chapter summarizes the main climate-smart agriculture strategies for land-based and landless livestock production systems (FAO, 2006). Integrated crop-livestock systems are addressed in module B5 on integrated production systems.

B2-3.1 Land-based systems

Several climate-smart options are available for land-based systems (i.e. systems depending mainly on grazing). They include reductions in enteric methane emissions through improved feed digestibility and carbon dioxide removals through soil carbon sequestration. The applicability of these options to low-input systems with infrequent human intervention tends to be quite limited because they require a high level of management. Manure management mitigation options have a high potential in landless systems but a much more limited potential in land-based systems. Climate-smart options deemed suitable for land-based systems, along with their effectiveness to satisfy multiple climate-smart objectives, are discussed below and are summarised in Table B2.1.

This chapter discusses the climate-smart practices and technologies for land-based systems. They fall into three categories: those with clear adaptation and mitigation synergies; ‘adaptation only’ options; and ‘mitigation only’ options. The chapter also identifies options for which there are risks of tradeoffs between food security, and climate change adaptation and mitigation. Climate-smart options deemed suitable for land-based systems, along with their capacities to satisfy multiple climate-smart objectives, are listed in Figure B2.5.

Figure B2.5. Summary of climate-smart agriculture practices and technologies for land-based systems, their impact on food security, climate change adaptation and mitigation, and the main constraints to their adoption.

	Impact on food security	Effectiveness of climate change adaptation practices and technologies	Effectiveness of climate change mitigation practices and technologies	Main constraints to adoption
Grazing management	+/-	+	++	lack of technical information and capacities, 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

Grazing management

Grazing can be optimized by finding the right balance among the different users of the land and adapting grazing practices accordingly. Optimal grazing leads to improved grassland[x] productivity and delivers adaptation and mitigation 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).

One of the main strategies for increasing the efficiency of grazing management is through rotational grazing[xi], in which the frequency and timing of grazing is adjusted to match the livestock’s needs with the availability of pasture resources. Through targeted temporal grazing exclusions, 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 methane emissions per unit of live weight gain (Eagle *et al.*, 2012). Rotational grazing is more suited to manage pasture systems, where the investment costs for fencing and watering points, additional labour and management that is more intensive 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 to avoid grassland degradation and adapt the grazing to the timing of vegetation growth to optimize the intake. For example, early grazing of summer pastures is a major cause of grassland degradation in Northern China (see Case study B2.1 on range management for mitigation and adaptation). Delaying grazing until the grass sprouts have reached a more advanced stage of maturity is an important sustainable grazing practice.

Furthermore, 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 (drought in particular). Land tenure reforms to deal with the encroachment of cultivated lands and other land uses that impede livestock mobility will be needed (Morton, 2007).

The most clear-cut mitigation benefits perhaps 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 (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 (e.g. milk, meat) per hectare may be lower, except in areas where baseline stocking rates are excessively high (Rolfe, 2010).

Table B2.1. Comparative advantage of mainstream agronomic practices and sustainable soil and land management practices for climate-smart agriculture

Climate-smart practices for climate change adaptation	Climate-smart practices for climate change mitigation	Climate-smart practices for climate change mitigation
Extensive grazing	**Improved grazing management**	

Climate-smart practices for climate change adaptation	**Climate-smart practices for climate change mitigation**	**Climate-smart practices for climate change mitigation**
Many extensive grazing systems are suffering from overgrazing and serious reductions in the biodiversity of the aboveground vegetation. This is a result of the effects of declining availability of land and overstocking due to inadequate livestock management. This is causing a decline in the rangeland soil quality, with depletion of biomass, erosion of topsoil by water and wind, loss of soil organic carbon and reduction of ecosystem services. This harms the soil structure and lowers resilience (e.g. through loss of deep rooting species that can cycle nutrients and water from deep in the soil profile). Excessive trampling of livestock, in particular around watering points, further damages the soil structure and the ecosystem functions it provides.	• Altering plant species composition is usually beneficial for pasture soils, as a selective increase in biodiversity can improve the quality, and usually the quantity, of soil organic carbon. This increases the range of rooting depths, which promotes nutrient and water cycling. Introducing leguminous species is particularly beneficial for fixing atmospheric nitrogen and improving soil fertility. • Rotational grazing through regularly moving livestock between paddocks intensifies grazing pressure for a relatively short period of time (e.g. 1 to 3 days for ultra-high stocking density or 3 to 14 days for typical rotational grazing), leaving a rest period for regrowth in between rotations. • Assisted natural regeneration, leaving land ungrazed for a period of up to several years to allow tree seeds already in the soil to become established, brings multiple benefits to rangeland soils. It improves nutrient cycling as nutrients are drawn from deep in the soil. It also increases soil organic carbon on the surface as leaves fall, decompose and become incorporated into the soil. Trees also offer some protection to soils, as well as to people and livestock, from periods of intense heat, which are likely to become more frequent due to climate change. • Periodic burns, which can be part of fire management, can promote the overall health and growth of rangelands. For example, in tall grass prairie, increased plant productivity after burning more than compensates for the loss of plant carbon through combustion. Use of trees also increases production and adaptive capacity.	• Compared with more highly productive pasture, rangelands have low carbon sequestration rates on a per unit basis. However, because of their vast area, they could sequester 2 to 4 percent of annual anthropogenic greenhouse gas emissions on a global basis (i.e. 20 percent of the carbon dioxide released annually from global deforestation and land-use change) (Derner and Schuman, 2007; Follett and Reed, 2010). • Fire management in rangelands is generally accepted to have a minimal to detrimental effect on greenhouse gas mitigation. Most studies found that soil organic carbon stays about the same or even decreases following repeated burns (Rice and Owensby, 2001). However, other harmful emissions (methane, smoke and aerosols) from burning are also linked to climate change, making it even less attractive as a greenhouse gas mitigation option. • Silvopasture (cultivating trees on grazing land) can store carbon in the soil and above ground, This practice may have greenhouse gas mitigation potential on up to 70 million hectares of grazing land (Nair and Nair, 2003). However, with limited field research data, the estimated soil carbon sequestration rates of 0.5 to 3.6 tonnes of CO_2 per hectare per year are largely based on expert opinions. • The above activities on pasture can bring about higher soil carbon sequestration rates than conservation activities on harvested croplands. The difference is due to the fact that in pastures, more of the plant biomass carbon is allocated to to below-ground soil carbon. In pastures, the growing season is longer, there is less soil disturbance and water is more efficiently utilized. The range in sequestration rates in pastures depends on specific local characteristics, such as soil composition, topography, climate and existing grass species. The net fluxes of greenhouse gases are also affected by nitrous oxide, or methane cycles (Conant *et al.*, 2005). Source: Adapted from FAO, 2013c

Pasture management and nutrition

Pasture[xii] management measures involve the sowing of improved varieties of pasture, typically replacing 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 pasture species, 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 organic carbon, pasture quality and animal performance (e.g. milk or meat yield). These approaches however, may not always reduce greenhouse gas emissions. Improving pasture quality through nitrogen fertilization may involve trade-offs between lower methane emissions and higher nitrous oxide emissions (Bannink *et al*., 2010). In addition, after accounting for energy-related emissions and nitrous oxide emissions associated with irrigation, the net greenhouse gas emissions of this practice may be negative on grazing lands (Eagle *et al*., 2012). Grass quality can also be improved by chemical treatments (e.g. the use of ammonia) and/or mechanical actions (e.g. chopping, grinding, and ensiling). Both synergies and trade-offs can exist between pasture management and biodiversity conservation. Biodiversity conservation can be a constraint to pasture intensification, as fertilization, sowing, irrigation and high stocking rates usually lead to grasslands that have fewer plant species and provide less resources (food, habitat) for animals, and are consequently less rich in biodiversity (Vickery *et al*., 2001; Kleijn *et al*., 2009). At the same time, grassland abandonment is also a threat to biodiversity. The highest diversity of wild species is often found in pastures with intermediate levels of management intensity (FAO, 2016a). Certain grassland management practices, such as adjusting the timing and intensity of grazing, setting up buffers to protect wild habitats, introducing supplementary feeding or nutrient management can provide multiple co-benefits for carbon sequestration, land restoration and biodiversity conservation (FAO, 2016b). The role of biodiversity conservation for sustainable agricultural intensification and climate change adaptation is addressed in module B8.

With increasing variability in climatic conditions (e.g. increasing incidents of drought), 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.

Agroforestry

Agroforestry is an integrated approach to the production of woody perennials and crops or grasses and/or animals on the same piece of land. Because it can sequester carbon in the soil, agroforestry is also important for climate change mitigation. It can also improve feed quality, which reduces enteric methane emissions. Agroforestry is an option for climate change 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 (see Box B2.4). In extensive grazing systems, controlling the ambient temperature is largely impractical. Providing some shade for the animals and sufficient water, possibly including places for them to wallow, is usually the most that can be done. 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). Agroforestry systems are discussed in module B5 on integrated production systems.

Box B2.4 Silvopastoral systems in Central and South America

In a project funded by Global Environmental Facility (GEF), 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 USD 2 000 and USD 2 400 per farm (an amount that represents 10 to 15 percent of their net income) to implement a payment for environmental services programme for 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 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 has become less frequent.

Source: FAO, 2010a

Animal breeding

As discussed in Chapter B8-3 on animal genetic resources, breeding more productive animals is a strategy to enhance productivity and thereby lower methane emission intensities. Research has started on the mitigation benefits of using residual feed intake as a selection tool for low methane-emitting animals, but findings have been inconclusive (Waghorn and Hegarty, 2011).

Crossbreeding 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 and disease resistance, and better fitness and reproductive traits compared with pure shorthorn breeds that had previously dominated these harsh regions (Bentley *et al*., 2008). In general, crossbreeding[xiii] 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 by switching 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. Improving animal husbandry through activities that ensure proper nutrition and appropriate feeding and reproductive strategies, regularly maintaining animal health and using antibiotics responsibly can improve reproduction rates, reduce mortality and lower the slaughter age. All of these measures will 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, as discussed in Chapter B2-2.1, the management of disease risks may also become increasingly important because 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 against *rumen archaea*

Because of their wide applicability, even for very low-input extensive systems with little human intervention, vaccines against microorganisms that produce methane as a metabolic by-product in low-oxygen conditions (methanogens) 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. It is applicable to all systems, particularly land-based systems that depend heavily on local feed availability and are more vulnerable to production failures. However, there are issues related to the effectiveness of climate forecasts for livestock management that need to be addressed (Hellmuth *et al*., 2007). Weather-indexed Livestock insurance schemes in which policyholders are paid in response to 'trigger events', such as abnormal rainfall or high local animal mortality rates, may be effective when 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 risks linked to climate change (UNDP, 2008). In situations where risks are unacceptably high for the private sector, 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).

B2-3.2 Landless systems

Climate-smart options are also available for intensive systems (UNFCCC, 2008; Gill *et al*., 2009). These options mainly relate to manure management for pig and dairy production and feedlots, and enteric fermentation for dairy cattle farms and feedlots. Because these systems are generally more standardized than integrated crop-livestock and grazing systems, there are fewer applicable options (see Figure B2.6).

Figure B2.6. Summary of climate-smart agriculture 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)	++	+	++	

Practices/technologies	Impact on food security	Effectiveness as adaptation strategy	Effectiveness as mitigation strategy	Main constraints to adoption
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

Source: Adapted from FAO, 2013c

Improved waste management

Most methane emissions from manure derive from swine and beef cattle feedlots and dairy cattle, where production is carried out on a large scale and manure is stored under anaerobic conditions. Greenhouse gas mitigation options include the capture of methane by using biogas collectors to cover manure storage facilities. The captured methane can be flared or used as a source of energy for electric generators, heating or lighting. An example of energy generated in this way to offset carbon dioxide emissions from burning fossil fuels is presented in Box B2.5. The climate change adaptation and mitigation benefits of production systems that integrate food and energy production are considered in module B5, while the management of energy in the context of climate-smart agriculture is addressed in module B9.

Anaerobic digestion technology harnesses microorganisms to degrade organic materials, including manure, in containers where oxygen is absent to produce methane that can be used for heating, cooking or energy production. This 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 Denmark and Germany (AEBIOM, 2009). Manure application practices can also reduce nitrous oxide emissions. Improved livestock diets, as well as feed additives, can substantially reduce methane emissions from enteric fermentation and manure storage (FAO, 2006). Energy-saving practices have also been demonstrated to be effective in reducing the dependence of intensive systems on fossil fuels.

Box B2.5 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, 2006). 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 greenhouse gas 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 geographically concentrated pig and poultry production systems. Examples of low-emission feeds include feed crops that have been produced through conservation agriculture or that have been grown in 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 integrated crop-livestock and grazing systems (FAO, 2009; Gerber *et al*., 2011). Energy is used at different stages, such as for advanced cooling technologies (e.g. sprays or fans that cool the animals), water use, and production of a range of feedstuffs. To a large extent, this protects the high-output animals used in landless systems against the direct effects of high temperatures. In these situations, the main question is economic: is the cost of adapting the production environment, including ongoing higher expenditures on inputs, is more or less than the cost of not adapting or changing the animal genetic resources by potentially switching to less productive breeds? Small-scale producers who have adopted high-output breeds but struggle to obtain the capital to purchase the inputs needed to prevent the animals from becoming overheated may find that their problems are exacerbated by climate change. Improving energy use efficiency, i.e. amount of energy used per unit of product, 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 greenhouse gas emissions, especially in countries where the energy sector is emission intensive. See Case study B2.4.

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 the 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 by either allowing the supply chains to overcome the crisis or 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, improved buffers and greater stocks may contribute to building the resilience of supply chains that rely on landless livestock systems.

Creating an enabling context and removing barriers for adoption for climate-smart livestock production

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 strengthening extension work and financing mechanisms, such as schemes for improving access to credit and payment for environmental services (see module C3 on the enabling policy environment for climate-smart agriculture and module C4 on investing in climate-smart agriculture). Multisectoral and interdisciplinary collaboration and coordination in particular is required to mitigate the impact of animal diseases under changing climatic conditions. Policies for the adaptation of animal health systems should be implemented to strengthen animal disease surveillance programmes and risk analysis at the national level. This is needed to anticipate how climate change will facilitate the emergence of threats and alter the spread and distribution of animal diseases through ecosystems. Improved coordination should be fostered across all relevant ministries and organizations, including those dealing with environment, natural resources, wildlife and agriculture.

There is still a lack of assessments of livestock production under climate constraints to support policies that aim at improving resilience in the sector (IPCC, 2014). In particular, modelling and quantifying aggregated impacts on livestock production systems still need to overcome a number of challenges (Thornton *et al*., 2015). First, more regional climate scenarios are becoming available, but they are still associated with significant uncertainties, which limit researchers' capacity to model livestock productivity under climate change. In extensive grazing and pastoral systems, the impacts of climate change on rangeland primary productivity, the mix of grass species and carrying capacity are still mostly unknown. Most models also do not take into account the management of these systems, which can play a considerable role in protecting these habitats. Second, animal diseases are affected by climate change, but future patterns of distribution need to be modelled to understand their impact on scenarios and projections. Third, the impact on groundwater availability is also an area where more assessments are needed, in particular in grazing systems. Finally, research efforts are also required to identify additional combinations of adaptation and mitigation practices that are appropriate for specific production systems and environments (e.g. combined interventions addressing the management of feed, genetic resources and manure). The potential aggregated effects that multiple changes occurring within farming systems may have on food security and the use of natural resources at the regional level also need to be better understood.

Conclusions

This module has highlighted how some livestock production practices require making trade-offs between food security, adaptation and mitigation, and that most practices offer opportunities to exploit synergies in these areas. Several climate-smart agriculture practices are readily available for implementation, such as sylvopastoral systems (see Case Study B2.2), grassland restoration and management, manure management (recycling and biodigestion) and crop-livestock integration.

This module has also highlighted that climate-smart agricultural 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 adaptation or mitigation issues requires paying attention to spill-over and feedback effects along the chain.

Acknowledgements

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Notes: The module is an update of Module 8 *Climate-smart livestock* in the Climate-Smart Agriculture Sourcebook (2013) written by Pierre Gerber (FAO) with contributions from Benjamin Henderson (OECD) and Carolyn Opio (FAO).

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