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# Global Warming and Livestock in Dry Areas: Expected Impacts, Adaptation and Mitigation

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## 1. Introduction

In most developing countries livestock is the key asset for rural people providing multiple economic, social and risk management functions. Rangelands contribute to the livelihoods of over 800 million people including poor smallholders. The arid area of the globe is home for extensive livestock production mainly based on small ruminants (Ben Salem & Smith, 2008). The most important sheared characteristic of such zones, despite the high variety of biotopes, is aridity with a very erratic pattern of rainfall and extended periods of high temperatures. These two factors together with a higher frequency of extreme climatic events will be amplified under the perspective of global warming thus affecting negatively food availability through the seasons of the year. The impacts that climate change will bring about are expected to exacerbate the vulnerability of livestock systems and to reinforce existing factors that are simultaneously affecting livestock production systems such as rapid population and economic growth, increased demand for food and products, and increased conflicts over scarce resources (e.g. land tenure, water, and feed). There is an urgent need for detailed assessment of climate change impacts in each production system and for identifying appropriate options that can help livestock keepers adapt to climate change. This chapter summarizes current knowledge on global warming, discusses its impacts on the different components of the production systems and reports technical options to overcome negative effects of climate change on the livestock productivity and health and sustainability of livestock-based production systems. The approach recommended to transfer and adopt these options is also discussed.

## 2. Common knowledge on global warming

Human activity is changing climate on earth and many of these changes are now admitted to be inevitable. The main question raised today is on the magnitude of such changes and on their links with human activity. Even though certainties related to details of these changes are lacking, most available scenarios on climate change converge towards a global warming together with a reduction in average rainfall and in increase in climatic variability both in terms of frequency and the limits reached by extremes.

During the last century, the globe temperature has increased by 0.7°C. The variation of rainfall in time and in space has undergone wide changes and the level of sea water rose by approximately 25 cm. The increase in temperature has already affected the biological systems on earth. Changes have been observed in species distribution, the size of populations, seasons of reproduction and migration of animals and a higher occurrence of parasites and diseases in the forest system (Watson, 2008). Several examples can be given, however the authors have chosen to report on predictions from their country of origin where, average temperature, as a result of global warming, is expected to rise by 2.1°C in 2050 with a sharp decline of rainfall and an increase of climate variability (GTZ, 2007). The south will be exposed to the highest increases of average temperature and will undergo more frequent successions of dry years. Water availability will decline by 28% in 2030 and agricultural yields generated by dry farming will decline by 50% in 2050. Beef, sheep and goat production will be greatly affected particularly in the centre and the south and losses up to 80% can be recorded during drought years.

Globally, most of the available scenarios on climate change and their relationship with agriculture are pessimistic and predict a negative effect of global warming on production outputs. From another point of view, there is a consensus as to the difficulties to pinpoint the impact that can be attributed to global warming. Levels of agricultural production including livestock produces, are subject to important interactions between factors such as the use of inputs, the market forces and agricultural policies mainly subsidies and incentives. In addition, inter annual climatic variability is a major determinant of agricultural yields and this will not allow easy isolation of the effect attributed to global warming. Therefore, a large body of the available literature is based on prediction models and several trends remain very conceptual.

## 3. World consumption trends of livestock products

Livestock production including poultry has a significant contribution to human nutrition, agriculture and rural economy. Products and services provided by the livestock sector include meat, milk, eggs, fiber, traction animals, organic manure and fuel.

Livestock production represents 40% of the world agricultural production and contributes to the livelihoods and the food security of nearly one billion people around the world. At the global level, livestock contribute with 15% of total food energy and 25% of dietary protein (FAO, 2009a). Products from livestock provide essential micronutrients that are not easily obtained from plant based foods.

In agricultural economics, livestock has the fastest growth rate as a result of an increase in incomes and technological and structural evolutions. This is particularly true in developing countries of many areas of the globe. The sustained improvement of incomes and rapid urbanization during the last three decades in parallel to a population growth have prompted a higher demand on meat and other animal products particularly in developing countries (FAO, 2009a). These trends and the challenges they entail were identified a decade ago by Delgado et al. (1999), who launched the term “livestock revolution” to describe the process that is transforming the sector. In this respect and to meet the increased demand on livestock products, the World Bank has estimated that meat production should increase by 80% between 2000 and 2030. For this, available animal resources should be used more efficiently while it is essential to preserve natural resources and to prevent pollution of the environment.

In many developing countries, livestock keeping is a multifunctional activity. Beyond its direct role in generating food and income, livestock is a valuable asset, serving as a store of wealth, for credit and a safe survival mechanism during times of crisis.
Consumption of livestock products has increased rapidly in developing countries over the past decades, particularly from the 1980s onwards. Growth in consumption of livestock products per capita has markedly exceeded growth in consumption of other major food commodity groups. Since the early 1960s, consumption of milk per capita in the developing countries has almost doubled, meat consumption more than tripled and egg consumption increased by a factor of five (FAO, 2009b).

## 4. Relationship between global warming and livestock

Climate change represents a special "feedback loop", in which livestock production both contributes to the problem and suffers from the consequences.
The possible effects of climate change on food production are not limited to crops and agricultural production. Climate change will have tremendous consequences for dairy, meat and wool production, mainly arising from its impact on grassland and rangeland productivity. Heat distress suffered by animals will reduce the rate of animal feed intake and result in poor growth performance (Rowlinson, 2008). Lack of water and increased frequency of drought in certain countries will lead to a loss of resources. Consequently, as exemplified by many African countries, existing food insecurity and conflict over scarce resources will be exacerbated. Such effects will be moderate in extensive systems where animal resources are often local breeds tolerating environment stressors such as increased temperature and extreme climate variability.
In areas threatened by global warming such as the Middle East and North Africa, a higher incidence of transboundary diseases is feared. Some diseases with a major economic impact in particular those transmitted by ticks will have a wider spread.
The agriculture sector is the world's largest user of natural resources and, like any productive activity; livestock production has an environmental cost. The livestock sector is also often associated with policy distortions and market failures, and therefore places burdens on the environment that are often out of proportion to its economic importance. For example, livestock contribute less than 2% of global gross domestic product but produce 18% of global greenhouse gas emissions (Steinfeld et al., 2006). There is thus an urgent need to improve the resource use efficiency of livestock production and to reduce the negative environmental fallouts produced by the sector.
Livestock is therefore perceived as a contributor to global warming and public policies across the world should be designed in a way where increased and more intensive animal production should not exacerbate the environment by reducing contribution to global warming and by ensuring a sustainable use of the natural resources.
Climate change may also alter the integrity of the rural populations exposing men and women to other constraints and pushing them to make other choices like migration of men for work. Other categories of the society (women and young persons) may therefore be in a more vulnerable situation.
The Intergovernmental Panel on Climate Change (IPCC, 2007) concluded that anthropogenic greenhouse gases, including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and halocarbons have been responsible for most of the observed temperature

increase since the middle of the twentieth century. Agriculture, particularly livestock, is increasingly being recognized as both a contributor to the process of global warming and a potential victim of it. In the following, we will attempt to separate both sides of the interaction between global warming and livestock: the impact of livestock production on global warming and the effects of global warming on livestock production.

### 4.1 Impact of livestock on climate change

Livestock contribute to climate change by emitting greenhouse gases, either directly (e.g. from enteric fermentation) or indirectly (e.g. from feed-production activities, deforestation, overgrazing, etc.). Greenhouse gas emissions can emanate from all the main steps of the livestock production cycle. Emissions from feed-crop production and pastures are linked to the wide use of chemical fertilizers and pesticides, to soil organic-matter losses and to transport (use of fossil fuels). When forest is cleared for pasture and feed crops, large amounts of carbon stored in vegetation and soil are also released into the atmosphere. In contrast, when good management practices are implemented on degraded land, pasture and cropland can turn into net carbon stores, sequestering carbon from the atmosphere. Contributions of livestock activities to carbon cycle may therefore have an important impact on the process of global warming. At the farm level, CH4 and N2O are emitted from enteric fermentation and manure. In ruminant species, CH4 is exhaled as a by-product of the process of fermentation of fibrous feedstuffs in the rumen. Nitrous oxide is released from manure during storage and spreading, and CH4 is also generated when manure is stored in anaerobic and warm conditions.

### 4.2 Impact of climate change on livestock

Some of the greatest impacts of global warming will be visible in grazing systems in arid and semi-arid areas (Hoffman & Vogel, 2008). Increasing temperatures and decreasing rainfall reduce yields of rangelands and contribute to their degradation. Higher temperatures tend to reduce animal feed intake and lower feed conversion rates (Rowlinson, 2008). There is also evidence that growing seasons may become shorter in many grazing lands, particularly in sub-Saharan Africa. The probability of extreme weather events (droughts, floods) is likely to increase. In the non-grazing systems, which are characterized by the confinement of animals (often in climate-controlled buildings), the direct impacts of climate change can be expected to be limited and mostly indirect resulting from reduction of yields and increased prices of the main feed used in animal production (OECD–FAO, 2008). The development of energy-saving programs (biocarburants) may also result in increased energy prices. A warmer climate may also increase the costs of keeping animals cool by the building of adapted housing and the use of cooling devices. With higher temperatures, all countries are likely to be subject to increased animal-disease incidence but poor countries are more vulnerable to emerging diseases because of inappropriate veterinary services.

Despite all the expected negative impacts of global warming on livestock, some positive effects can be addressed. For example, higher winter temperature can reduce the cold stress experienced by livestock raised outside. Furthermore, warmer winter weather may reduce the maintenance energy requirements of animals and reduce the need for heating in animal housing (FAO, 2009a).

## 5. Effect of global warming on the main components of the livestock environment

### 5.1 Grazing land

Livestock is the world's largest user of land resources, with grazing land and cropland dedicated to the production of feed representing almost 80% of all agricultural land. The sector uses 3.4 billion hectares for grazing and 0.5 billion hectares for feed crops (Steinfeld et al., 2006); the latter figure corresponds to one-third of total cropland.

In arid and semi-arid rangelands, animal pressure is increasing because of low productivity, conflict over this resource and an arbitrary common use. As a consequence, the expansion of land used for livestock development can contribute to deforestation in some countries, while intensification of livestock production through maximization of the number of grazing animals can cause overgrazing in others.

Approximately 20% of the grazing lands and rangelands of the planet are degraded and this percentage is expected to rise until 73% in dry areas (UNEP, 2004). Degradation of rangeland has tremendous consequences on the environment mainly, soil erosion, degradation of the vegetation cover, emission of carbon, loss of biodiversity and alteration of the water cycle. Global warming is expected to further contribute to this degradation process and according to Thornton et al. (2006), large areas of the African continent will have a reduction of the length of the growing period of the vegetation by 20% in 2050. Regions gaining 5% or more in length of the growing period occupy considerably less than 1% and examples are limited to the North African coast and to a small area to the south of the Great Rift Valley in Ethiopia. Furthermore, under forest grazing systems, global warming is expected to increase the incidence of fires and this will reduce even further the available grazing land.

### 5.2 Soil

Any trend for climate change will have an impact on soils. Most scenarios of climate change predict a small variation of average rainfall but large variation of extreme meteorological events. Such trend will increase the risk of floods as well as the the frequency and the succession of dry years. Droughts and floods will cause a more important degradation of the soils and therefore a loss of the production potential for grazing and cropping. In many parts of the world, the impact of climate change will be an additional pressure on soils already undergoing advanced degradation processes. Erratic and reduced rainfall resulting from climate change will accentuate salinization of soil and water. While at the lower levels of salinity (<15dS/m) both legumes and grasses with moderate salt tolerance are capable of producing 5-10 tons of edible dry matter/ha/year, however at high salt concentrations (> 25 dS/m) production levels drop and plant options decrease significantly. However, even at these high salinities there are a range of halophytic grasses and shrubs that will produce 0.5 and 5 tons of edible dry matter/ha/year, respectively (Masters et al., 2007). Many plants growing in saline environments accumulate a range of secondary compounds. For example, most of halophytes which grow easily in saline soils (e.g. *Atriplex nummularia* L.) contain high levels of oxalic acid (Ben Salem et al., 2010).

Twice of the quantity of carbon in the atmosphere is stored in the soil. The manipulation of carbon sequestration into soils might offer a potentially useful contribution to climate change mitigation. Rangeland practices have a relevant potential to sequester carbon. These practices include management of stocking rate, rotational or adaptive grazing and enclosure grassland from livestock grazing. Reduced grazing intensity would result in increased soil carbon stocks. However, it seems that the relationship between grazing and soil carbon sequestration is a complex phenomenon involving environmental, social and economic issues. Grazing management affects soil carbon stocks by influencing the balance between inputs and outputs from the soil.

### 5.3 Water

Coupled with population growth and economic development, climate change impacts will have substantial effects on global water availability in the future. Changes in rainfall patterns and other water balance components like potential evapo-transpiration resulting from the increase of temperature will contribute substantially to water scarcity. The drier conditions expected in some areas like Mediterranean basin or South Africa will cancel the positive potential impact of higher CO2. Water competition between different strands of human activity will be one of the defining issues. The global demand for non-irrigation water will increase by two-thirds by 2025 (Rosegrant et al., 2005). But due to the restricted availability and the price of water the agricultural demand for water will increase slowly. Therefore, a decline of crop production and an increased competition for the outputs of arable agriculture are expected. Developing water harvesting techniques, appropriate water management and the integrated involvement of research and development to improve water-use efficiencies are laudable and necessary objectives to achieve. Strategic feed sourcing, conserving of water and enhancing animal productivity provide multiple options for increased livestock water productivity (LWP, i.e. the ratio of the net beneficial animal products and services produced in an agricultural production system to the amount of water depleted as a cost of producing them). Increasing LWP through better management of livestock-water interactions holds promise for sustainably improving livelihoods of rural people and making more fresh water available for other human needs (Oweis & Peden, 2008).

### 5.4 Plant

In general, animals are less sensitive to climate change than crops because they can move to seek for consumable vegetation and can access to feed. Changes in the primary productivity of crops, forages and rangelands could be observed in areas affected by climate change. Increased temperatures coupled with water scarcity and irregular rainfall patterns would affect the optimal growth rates of many forage and range species. The substitution of some crops that used to be cropped for fodder production (e.g. Maize) by others (e.g. Sorghum and millet) more suited to drier environments should be emphasized. Probabilities of germination and establishment decreased with a decrease in precipitation and increased with an increase in precipitation (Peters et al., 2010). These authors observed reductions in recruitment (73-80%) for all vegetation types with 50% less rainfall. However, reductions in rainfall below 25% of current amounts would reduce recruitment to low levels (<0.03). A small decrease in rainfall coupled with fewer but more intense storms may result in an increase in establishment. Peters et al. (2010) concluded that in addition to plant-soil feedbacks that favor shrub growth, soil water availability effects on the germination and establishment of grass seedling is another important constraint. As temperature and the level of CO2 change the competition dynamics of plant species and the floristic composition of rangelands will be exacerbated. The increase of $CO_2$ level will result in increased growth and a dominance of woody vegetation (i.e. fodder shrubs and trees) at the expense of herbaceous vegetation. Climate change may impact negatively on the nutritive value of consumable biomass through increased lignification of plant tissues and accelerated synthesis of specific secondary compounds. These compounds have different mechanisms of action, for example tannins form insoluble complexes with proteins rendering them unavailable to rumen microflora and the host animal. However, oxalates precipitate calcium and magnesium, thus limit their use in metabolic and digestive patterns occurring in the animal body. The direct and indirect impacts of climate change on space distribution of plants and their growth and quality justify the need to develop appropriate strategies for better use of fodder vegetation in the livestock-based production systems.

### 5.5 Pathogens and their hosts

In dry areas global warming is expected to increase the extent and intensity of aridity leading to a complex situation marked by changing patterns of interaction between hosts, pathogens and men within their environment. The potential impact of global warming on livestock health will be reviewed in the context of dry areas focusing on pathogens and their transmission and the hosts and their exposure and susceptibility to pathogens.

#### 5.5.1 Pathogens and their transmission

The climatic changes induced by global warming exert a selection pressure that will modify the biodiversity of pathogens (Lovejoy, 2008), their biomass and the epidemiology of the infections they cause. Pathogens that are able to maintain and disseminate better in drought conditions would be expected to become dominant in areas where aridity would be increased under the influence of global warming. In general, it could be expected that pathogens having the lowest basic reproductive ratio or Ro (number of secondary cases produced in a population of naïve hosts after the introduction of one primary infected host, Morand & Guégan, 2008) would be the most vulnerable to the changes induced by global warming.

Among all pathogens, macroparasites are certainly those which development is the most highly conditioned by the variation of abiotic factors driven by climate changes (Morgan & Wall, 2009). Livestock species living in dry areas are exposed to different parasites, agents of specific diseases, or vectors of other pathogens. Ticks are widespread parasites in dry areas, for example in Tunisia up to 15 species infesting livestock have been identified (Bouattour et al., 1999). In the context of global warming that drives aridity northward in Tunisia, and more generally in North Africa, the most thermophilic tick species with low host selectivity like *Hyalomma dromedarii* could be expected to increase their distribution area. This tick species is usually found in arid and hyper-arid regions closely associated to the presence of camel. The tropism of this tick species is a strong biological advantage for emergence as its immature and adult stages could feed on different ungulates in addition to camels (Walker et al., 2003). *H. dromedarii* could establish and reproduce in other regions of Tunisia as observed after introduction of infested camels for instance for tourism activities. In Mauritania *Hyalomma dromedarii* has been identified, in conditions of cohabitation of cattle and camels, as an emerging natural vector of tropical theileriosis (d'Oliveira et al., 1997), a severe cattle disease due to the protozoan *Theileria annulata*. This emergence could be reproduced elsewhere particularly if camels will move to traditional regions for cattle rearing in North Africa. The potential emergence of a new natural vector of tropical theileriosis will modify drastically the epidemiology of this disease particularly in term of periods and context of transmission. In endemic regions these changes might lead to emerging new epidemiological profiles for tropical theileriosis to which animal health decision makers and farmers should adapt in terms of control strategies. This emergence of epidemiological patterns for already endemic pathogens should be clearly taken into account when assessing potential effects of global warming in term of animal and even public health.

Fasciolasis due to *Fasciola hepatica* is a helminthiasis of which the geographical distribution and local impact are highly influenced by climatic factors (Mas Coma et al., 2008). Fasciolasis is emerging or re-emerging in several regions of Latin America, Africa, Asia and Europe (Mas Coma et al., 2008). In Tunisia, the endemic zones for fasciolasis have been usually limited to the humid and sub-humid zones of the North West (Akkari et al., 2011) and to some oases of the South West of the country (Ayadi et al., 1993). In recent years, the severity of fasciolasis has been reported to increase according to several field observations. Furthermore, new foci of disease have been recorded in different regions of the semiarid and arid zones of Tunisia (unpublished data). This trend is probably resulting from the interaction between several factors directly or indirectly linked to global warming: i) Extension of irrigated areas and dams in the country, especially in the arid regions, ii) mobilisation of water resources from the humid regions of the North West, the usual habitat zone of the lymneid snail *Galba truncatula* the intermediate hosts of *F. hepatica*, to other regions, iii) occurrence, in the last 10 years, of repeated episodes of severe floods particularly in the North of the country, iv) longer suitable periods for the reproduction of the intermediate hosts with subsequent increased abundance of infective stages of *F. hepatica* on vegetation cover, due to retraction of the length of the cold (winter) season. In addition to rendering more frequent the application of control measures, increased number of parasites generations will increase the risk of occurrence of acquired resistance to anti-parasite molecules.

However, it must be emphasised that macroparasites populations, due to their longer generation time, expand slowly and need more time to become detected by the animal owner. However, these changes could be already initiated in several dry areas under the influence of both of global warming and human activities, as emphasised with the two examples developed above.

Vector borne pathogens are amongst the disease agents that are expected to get through important changes under the effect of global warming and particularly those having a wide spectrum of hosts including men and a high spreading potential. Arboviruses are probably the group showing the highest potential for emergence under the effect of global warming. The bluetongue invasion in North Africa and Europe is a good example of the risk of extension of an arbovirus far away of its usual distribution zones. The capacity of this virus to spread has been amplified by several factors reviewed by Purse et al. (2008), in particular: i) a host preference for a wide range of ruminants probably continuously distributed across agro-ecosystems, ii) wide range of susceptible vectors (Culicoides) with different ecology, iii) vectorial capacity influenced by temperature, iv) presence of silent infected animals sources of transmission to vectors, and v) over-wintering ability of the virus in the vector and eventually in the ruminant host. The occurrence of bluetongue virus epidemics in Tunisia since 1998 is emphasising the risks of introduction of pathogens from sub-Saharan Africa, most certainly with animal transboundary movements. Furthermore, extension of irrigated zones has certainly increased, across the country, the availability of habitat zones suitable for the development of *Culicoides*. The same mechanisms that are underlying the spread of bluetongue virus across the Mediterranean region could globally apply to other arboviruses and in particular the Rift Valley Fever virus (RVF), a pathogen transmitted by vector mosquitoes of the genera *Aedes* and *Culex* which are common in North Africa and the Middle East. Epidemics of RVF were initially described in semi arid and humid zones of East Africa, endemic or epidemic foci were therafter reported in semi arid areas of northern Senegal, Saudi Arabia and in irrigated zones in Egypt and Yemen (Martin et al., 2008). Changes directly or indirectly induced by global warming could enhance risks for RVF epidemics and in particular, heavy rainfall, building of dams and water storage structures for irrigation purposes, and extreme variation in rainfalls with combination of periods of drought and very heavy rainfall (Van den Bossche & Coetzer, 2008). Endemic vector transmitted diseases might be affected by global warming although on a lesser scale than with arboviruses agent of transboundary diseases. For instance, the epidemiology of piroplasmoses (infection due to piroplasmids of the genus *Babesia* and *Theileria)* could experience important changes in particular in regions where the vector tick species are hibernating during the cold season. This phenomenon of hibernation contributes in the regulation of pathogen biomass due to increased mortality in the vectors and probably also in the pathogen itself. It could be expected, as described with other parasites (Morgan and Wall, 2009), that any reduction or even alleviation of this overwintering process in response to extension of the warm periods of the year, will result in enhancing tick biomass as well as piroplasmid infection rates and intensities within the tick. Consequently, the risks and severity of piroplasmid infections in target hosts could increase above usual during the transmission season. In the case of tropical theileriosis this phenomenon could explain the higher tick infection rates and intensities recorded in regions where the vector ticks are active the year round in contrast to regions where theses vectors are going through a hibernation process (Darghouth et al., 2010).

The effect of global warming has been poorly assessed on several pathogens such as telluric helminths and protozoa, and non vector borne viruses and bacteria agents of epizootic or enzootic infections. As global warming is expected to increase ambient temperature and reduce soil and air moisture in dry areas ,pathogens that are known to be more susceptible to these changes would be expected to become less prevalent. However, it is important to remind that these stressing conditions could be moderated by particularities regarding the biology and the transmission of the pathogen itself as for instance, high contagious transmission (example of Foot and Mouth Disease virus), presence of terrestrial intermediate hosts (example of Anoplocephalid cestodes), intrinsic resistance of the exogenous forms of pathogens, presence of long lasting adults forms of macroparasites or infection state in the ruminant hosts, hypobiotic larvae in the case of helminths, and finally survival of pathogens/vectors in suitable microenvironment from where they could pass to their hosts. Based on the above discussion on pathogens it is rather difficult to draw general considerations, each relevant pathogen should be analysed in the context of global warming taking into account its vulnerability to the expected changes.

### 5.5.2 Host susceptibility and exposure to pathogens in dry areas

In addition to its direct effect on pathogens and their transmission, global warming will also influence the host susceptibility to pathogens and the factors of exposure to these agents. Host susceptibility is likely to play an important role in changes affecting animal health under the influence of global warming. Global warming will directly affect the wellbeing of livestock due to increased ambient temperature (Van den Bossche & Coetzer, 2008), furthermore more frequent episodes of severe drought will affect the availability of food and eventually the quality of water particularly in dry areas. These environmental stresses are likely to affect the capacity of innate and acquired immunity of livestock to pathogens (Sheldon & Verhulst, 1996). In the hyper-arid zones of the extreme south east of Tunisia, subnormal concentrations of globulins were recorded in 40% ewes during the lactation season in a severe drought episode, although the body conditions of animals remained acceptable. Consequently, the antibody response of the ewes to pathogens (or vaccination) might be harmed leading to risks of reduced immuno-competence against a range of pathogens and to less effective colostral transfer of immunity to lambs (Darghouth & Gharbi, in press). The question of host susceptibility should be also considered in case of emergence of new pathogens to which livestock has not co-adapted. The role of high host susceptibility has been considered in the rapid spreading of bluetongue virus serotypes within the European sheep flock (Purse et al., 2008). A similar phenomenon could also apply for the bluetongue epidemics recently recorded in Tunisia. High host susceptibility could also deeply influence the epidemiology of enzootic diseases as for example with tropical theileriosis. In this last case, it was observed in a Tunisian cattle herd exposed to the infection that disease incidence surveyed over 8 years increased dramatically, from 7.7 to 52% following progressive replacement of local cattle by Friesian phenotype in the herd. This evolution was recorded in the absence of any change in the enzootic state of tropical theileriosis (Darghouth & Gharbi, in press).

Exposure to pathogens is governed by different factors, for simplification we will consider in this part only those regarding the hosts and their management system.

Extensive loss in biodiversity has already been largely initiated under the influence of human activities in several regions of the world. In dry areas, global warming could be accounted as an additional factor worsening this loss at an extended scale. Pathogens intensity and spread are inversely related to host species diversity as spread of host specific pathogens is increased within the remaining species (Morand & Guégan, 2008). This loss in diversity might also represent an important force of selection for new trophic behaviours particularly for tick and insect vectors. The potential consequences of this "trophic shift" in term of pathogen transmission have been already outlined above with the example of the tick species *Hyalomma dromedarii*.

Global warming is expected to introduce important changes in animal management practices, which at their turn could increase the risks of emergence or re-emergence of pathogens and epidemiological profiles for diseases. The occurrence of extreme drought episodes in dry areas could enhance important migrations of livestock toward less affected zones. When occurring these migrations represent important risk factors for the spread of pathogens particularly those more prevalent in dry areas, such as for instance in the case of Tunisia, *Brucella mellitensis* infection which is by far more frequent in the arid regions of Tunisia by comparison to the North of the country (Hdia et al., 2009). Furthermore, the increased livestock density that could occur in the hosting regions might represent an additional factor enhancing the spread of specific pathogens particularly those highly transmissible or contagious. The challenges that farmers will face in dry areas under the effect of global warming, will most probably re-orientate the priorities of stockowners toward the mobilisation of resources and means for animal food, particularly at the light of recent increases of the international prices of crops. As a consequence there is a strong risk of marginalisation of animal health expenses given to the herds and subsequently an increased vulnerability to various pathogens. This question of vulnerability should be also addressed at the level of livestock production systems, for instance in Tunisia it is anticipated that cattle farms of small size will have a better resilience to global warming than will do big intensive modern units. By itself, this change, if occurring, will modify the epidemiology of major cattle diseases in Tunisia since the disease/exposure risk factors associated to small cattle units are not qualitatively and quantitatively similar to those prevailing in large cattle units as observed for instance with tropical theileriosis in Tunisia (Darghouth et al., 2010).

## 6. Livestock response to environmental factors affected by global warming

Global warming may strongly affect production and reproduction performances of farm animals and impact worldwide on livestock production (Nardone et al., 2010).

### 6.1 Heat stress

High ambient temperatures compromise reproductive efficiency of farm animals in both sexes and hence affect milk and meat production. There is a range of thermal conditions under which animals are able to maintain a relatively stable body temperature through behavioural and physiological mechanisms (Bucklin et al., 1992). Heat stress includes not only temperature and solar radiation, but also humidity and wind speed. Adjustments for humidity can be made using the temperature-humidity index (NOAA, 1976; Hubbard et al., 1999) which has been adapted for use in the livestock safety index (Livestock Conservation Institute, 1970). McDowell et al. (1976) suggested that the temperature–humidity index (be used as an indicator of thermal climatic conditions. This index is calculated from the relative humidity and the air temperature of a particular day according to the equation defined by Kadzere et al. (2002): THI=0.72 (W+D) +40.6
where W is wet bulb and D is dry bulb temperature in °C. Adjustments for solar radiation and wind speed have been also developed and should be considered when predicting heat stress (Mader et al, 2006).

#### 6.1.1 Effect on milk production

There is a particular temperature zone in which lactating dairy cows feel comfort and produce at an optimal level. Lactating dairy cows prefer ambient temperatures ranging from 5°C and 25°C, the 'thermoneutral' zone (TNZ) (Roenfeldt, 1998). When environmental temperatures move out of the thermoneutral zone (or comfort zone) dairy cattle begin to experience either heat stress or cold stress.
In dairy cows, studies have considered two critical THI thresholds (Davison et al., 1996): Milk production starts to decline at THI above 72 for cows which have no access to shade, but important declines occur at THI above 78 for cows having access to shade and a sprinkler system (Jones & Hennessy, 2000). High productive animals having high endogenous heat production, exhibit tolerance to heat. Holstein dairy cow is the primary target of heat stress relief, followed by feedlot cattle (Berman, 2005).
The stage of lactation is an important factor affecting dairy cows' responses to heat. Johnson et al. (1988) observed that the mid-lactating dairy cows were the most heat sensitive compared to their early and late lactating counterparts while Sharma et al. (1983) concluded

that after 60 days of parturition (early lactation), climatic conditions affect cow performances and decreased its capacity to cope with heat stress.

Lactating dairy cows feel heat stress, when the rectal temperature is above 39.4°C. To cope with heat stress the cow should allocate more energy to maintain the body temperature at the expense of the amount of energy needed for milk production. Reducing dry matter intake, and therefore heat generated during ruminal fermentation and body metabolism, help maintain heat balance. Decreased feed intake has been recognized as one of the main reasons for reduced milk yield (Beede & Collier, 1986).

The reduction in milk production caused by heat stress could be the result of decreased nutrient intake and nutrient uptake by the portal drained viscera of the cow. Blood flow shifts to peripheral tissues for cooling purposes, alter nutrient metabolism and contribute to lower milk yield. The decrease in energy intake results in a negative energy balance, and partially explains why cows lose significant amounts of body weight and body score when subjected to heat stress (Lacetera et al., 1996; Rhoads et al., 2009).

During late pregnancy and the early post partum period, hot environment negatively affects milk quality, leads to lower colostrum net energy fat and protein content. In addition, the analysis of protein fractions showed a reduction in percentages of casein, lactoalbumin, IgG and IgA (Nardone *et al.*, 1997, 2006).

Due to the reproductive seasonality of sheep in the middle latitudes of the northern hemisphere, physiological drop in milk yield which occurs during late lactation in summer often hides the negative impact of high temperature on milk production. Ambient temperatures in late spring and summer often exceed the thermal neutral zone (5°C to 25°C) of sheep (Curtis, 1983; Costa et al., 1992). Hot climate induces a marked increase in rectal temperature, and respiration rate, which increases energy requirements for maintenance by 7 to 25% (NRC, 1981). This may result in respiratory alkalosis due to reduction in blood CO2 (Habeeb et al., 1992). Feed intake decreases in heat-stressed sheep (Abdalla et al., 1993), due to both the effort of reducing heat production (Yousef, 1987; West, 1994) and the slower feed transit throughout the digestive tract (Christopherson, 1985). Under these conditions, body reserves of fat and nitrogen are used to supply energy through gluconeogenesis at the expense of the mammary gland, especially in early lactating animals (Jones et al., 1990; Amaral-Phillips et al., 1993).

Also, high temperatures decrease milk production in goats and affect its composition (Olsson & Dahlborn, 1989).

### 6.1.2 Effect on growth performances

Birth weight and survival of neonatal lambs was improved when shade was provided during late pregnancy (Hopkins *et al.*, 1980). This suggests that heat stress has an effect on the uterine environment, substantially reduces the total embryo cell number and placentome size resulting in smaller size of lambs. They would also be more susceptible to dehydration during the early stages of life. Temperatures ranging between 15°C and 29°C do not seem to have any effect on growth performance. The effects of high ambient temperature on growth performance are induced by the decrease of the anabolic activity and the increase in tissue catabolism (Marai et al., 2007). This decrease in anabolism is essentially caused by a decrease in voluntary feed intake of main nutrients. The increase in tissue catabolism occurs mainly in fat depots and/or lean body mass. Lamb production is deleteriously affected by exposure to heat stress and this causes an economic loss.

### 6.1.3 Effect on reproduction performances

High ambient temperatures compromise reproductive efficiency of farm female and male animals. Cattle's fertility is reduced from around 50% in winter to less than 15% in summer A drop can occur in summer of about a 20–27% (Thatcher & Collier, 1986; Chebel et al., 2004). In practice, dry pregnant cows are not protected from heat stress because they are not lactating, and it is incorrectly assumed that they are less prone to heat stress. The dry period is particularly crucial since it involves mammary gland involution and can affect endocrine responses that may increase foetal abortions, shorten the gestation length, lower calf birth weight, and reduce follicle and oocyte maturation associated with the postpartum reproductive cycle (Bilby et al., 2008).

The somatic cells within the follicles (theca and granulosa cells) could be damaged by heat stress. Heat stress affects ovarian follicles and induces a decrease in estradiol synthesis (Wilson et al., 1998). It compromises oocyte growth in cows by altering progesterone, luteinizing hormone, and follicle-stimulating hormone secretions during the oestrus cycle (Ronchi *et al.*, 2001). Rensis & Scaramuzzi (2003) hypothesised that the dominant follicle develops in a low LH environment resulting in reduced estradiol secretion inducing poor expression of oestrus by reducing its length and intensity. High temperature can reduce the drive for sexual behaviour, leading to "silent oestrus" in 35% of ewes (Sawyer et al., 1979).

Once ovulation occurs, the damaged oocyte has reduced chances of fertilizing and developing into a viable embryo. The ability of zygotes to develop blastocyst was reduced during summer (Al-Katanani et al., 2002). Heat stress can also affect the early developing embryo. When heat was applied from day 1 to day 7 after estrus, there was a reduction in embryo quality and stage from embryos flushed from the reproductive tract on day 7 after estrus (Putney et al., 1989). During pregnancy and prepartum heat stress could decrease thyroid hormones and placental estrogen levels, while increasing non-esterified fatty acid concentrations in blood; all of which can alter growth of the udder and placenta, nutrients delivered to the unborn calf, and subsequent milk production (Collier et al., 1982a).

In male, semen quality (concentration, number of spermatozoa and motile cells per ejaculate) is lower in summer than in winter and spring (Mathevon *et al.*, 1998). Heat stress reduces libido of rams and causes sperm damage, reducing fertility which will affect flock production.

Buffaloes' ovarian activity decreases in hot summer and increases during winter and spring; the lowest sexual activity occurred in summer season (Zeidan, 1989). Oestrous cycle is suppressed (Williamson & Payne, 1971). Anoestrus occurred in heat stressed animals (Bond *et al.*, 1960). Despite the evidence of some intrinsic hormonal constraints (Madan 1987), the problem of long intercalving periods seems to be due to environmental factors, and can be controlled by the farmer (Sastry & Tripathi 1988). Buffaloes protected from high ambient temperature and direct solar radiation, and adequately fed exhibit higher reproductive performance (Acharya & Bhat 1989). Management practices involving provision of shade and application of water to the skin surface reduces the adverse effects of a hot environment and improves oestrous expressivity and thus reduces breeding seasonality.

### 6.2 Drinking water

Water has several important functions in the animal body such as regulation of body temperature, elimination of waste products from the body via urine, feces, and respiration;

transport of nutrients and other compounds into and out of cells; electrolyte balance in the body; and as a fluid environment for the developing foetus. Water is needed to make saliva for swallowing feed and for chewing. In addition a milking cow needs water for milk production. Domesticated animals can live about sixty days without food but only about seven days without water. Livestock should be given all the water they can drink because animals that do not drink enough water may suffer stress or dehydration. The total requirements of water to produce world-wide animal products per year is approximately 2800 km3 of water, which represent 7.8% of the net precipitation on land masses of the globe (36,000 $km^3$=107,000 km3 total precipitation−71,000 $km^3$ evapo-transpiration) (Nardone et al., 2010).

Lactation and high environmental temperatures are major elements that drain body water and consequently increase the demand for water by animals. The amount of water a dairy cattle will drink is influenced by the quantity of dry matter ingested. Milking dairy cows consume 4 to 5 kilograms of water per kilogram of milk they produce. Of this amount, drinking water provides 80 to 90% of these needs, with the remainder coming from moisture found in feeds. Dairy cows are able to cope with a sustained restriction of total water intake to almost 50%.

Intake of water is intermittent, while the loss of water is continuous. During the dry season, intermittent watering had a negative effect on the growth rate of sheep. Live weight loss associated with water deficit could be ascribed to a reduction in feed and water intakes, together with loss in the body water.

The reproductive performance of the pregnant ewes is also adversely affected by water deprivation, since the rates of abortion and stillbirths, as well as the lamb mortality rate, rise as the ewes are deprived from drinking-water.

Goats are considered highly suitable animals for rearing in such areas, as they were the first domesticated in hot and arid regions of the world. Desert goats seem to be the most efficient among ruminants in regard to their ability to withstand dehydration (abioja et al., 2010). During periods of water shortage, goats activate several water saving mechanisms that would result in minimizing their water losses and therefore increasing their capacity to withstand water deficit ( Silanikove, 2000b).

Water intake in buffaloes increases with increasing environmental temperature, exposure to direct solar radiation and the ratio of water intake/food consumption also increase.

Total dissolved solids (TDS), total soluble salts (TSS), and salinity (S) are physiochemical properties of water used to assess water quality. Saline is one of the more common causes of high TDS water, but the effect on water intake and animal performance is likely to be less than when the same TDS level is a result of high sulfate combined with magnesium and/or sodium. When TDS levels in water are less than 3,000 ppm, there is little to no effect on cattle, although at first introduction there may temporarily be a mild case of diarrhea. Between 3,000 and 5,000 ppm TDS, the effects on milk production and animal performance are variable; however, high TDS water is more likely to decrease milk production during summer months (Jaster et al., 1978; Challis et al., 1987; Sanchez et al., 1994; Solomon et al., 1995). The TDS guidelines suggest that water containing less than 5,000 ppm TDS may be offered to lactating cattle, but water containing more than 7,000 ppm is unacceptable for all cattle (NRC, 2001). High salts reduce water intake, in turn will reduce feed intake, which reduces overall performance.

## 7. Adaptation of livestock to potential stressors from global warming

### 7.1 Animal breeding

In an attempt to match animal genetic resources with production systems to achieve livestock development objectives, a substantial body of information will need to be sought out, collated and scrutinized. This will include information on government policies and legal instruments that affect livestock production (including how they promote or inhibit development strategies); the country's major production systems (human development objectives that need to be addressed, the capacity and motivation of farmers to participate in development strategies and the environmental sustainability of the production systems); and historical and predicted future trends for each production system (i.e. social, market and environmental trends – including the predicted effects of climate change) (FAO, 2010).

To further stress the environmental dimension in livestock production, we report the policies and legal instruments related to some environmental issues that need to be considered when developing livestock development and breeding strategies (FAO, 2010):

- Soil erosion associated with grazing systems;
- Depletion of soil nutrients;
- Disposal of animal waste;
- Water availability and management;
- Water pollution;
- Gaseous emissions associated with climate change;
- Forest conservation and management; and
- The integration of livestock management with the management of wild flora and fauna.

Animal genetic resources can be used in various ways to achieve livestock development objectives. Strategies may be based on the use of locally available breeds, introduced breeds, or both. The breeds chosen may provide the basis for straight- or cross-breeding schemes. It is essential to ensure that the animal genetic resources used are well matched to the production systems in which they will be kept, taking account of the development objectives and planned development strategies for these systems. Evidence gathered in the last 10 to 15 years has yielded ample evidence that in many cases local breeds provide a good fit to these needs; in such cases a decision to use a locally available breed will be appropriate (FAO, 2010). In extensive production systems, locally thriving breeds show great adaptation to the prevailing environment including the occurrence of extreme climatic events (droughts, temperature rise, water scarcity, etc.).

Ruminants are a major source of green house gas emission especially methane (Wall & Simm, 2008) hence contributing to global warming. In many parts of the world, livestock development programs are no longer based on the increase of livestock population and several developed countries are now adopting adjustment policies to stop growth of livestock population. Such strategies should also be implemented by developing countries or regions that are threatened by overgrazing and that are facing large disproportions between livestock population and the size of the grazing space. For these countries, under the most pessimistic scenarios of global warming and the reduction of the grazing space, strategies to develop livestock must target a substantial improvement of the productivity through genetic improvement of traits that are economically important. Basically, the same levels of production can be achieved while keeping less animals hence protecting the environment and reducing negative effect on global warming. If these objectives are to be reached by the introduction of exotic animals, additional cost investments are needed to provide adequate housing and cooling facilities. In the long term, such investments might hamper the profitability of livestock breeders.

### 7.2 Adaptation mechanisms to global warming

Climate change will accentuate water and food scarcity and alter their quality. This situation is acute mainly in dry areas where most of small ruminants, buffaloes and camels are raised. In absence of farmer intervention, these animals will be exposed to underfeeding and or to water deprivation or restriction. They may also face other environmental stresses like high temperatures. To cope with these nutritional and environmental stresses farm animals developed some adaptation mechanisms allowing them to survive and even to produce and reproduce when raised under these harsh conditions. Some of these mechanisms are reported below.

#### 7.2.1 Behavioural, digestive and metabolic mechanisms

Metabolic and hormonal mechanisms and behavioural regulations could be involved to help the animal cope with different stressors resulting from climate change. We report here few examples of adaptive mechanisms:

- Severe underfeeding is associated with body reserve mobilisation and the establishment of mechanisms for saving limiting metabolites (glucose and amino acids) and a reduction in the basic metabolic and energy expenditure through reduced movement and walking by the animal (Blanc et al., 2006). Body reserves appear to play a fundamental role in restoring the energy balance. Fat-tailed sheep like the Barbarine breed cope with underfeeding better than thin-tailed sheep (Ben Salem et al., 2010). Fat-tailed sheep have a capacity to deposit and mobilise body reserves from the tail (fat) and the rest of the body.
- The capacity of the kidney to concentrate urine and its ability to reduce water loss during dehydration is directly related with the relative kidney medullary thickness (RTM). The greater the RTM, the greater the ability of the kidney to reabsorb water. Sustained water restriction resulted in the activation of water saving mechanisms. Plasma vasopressin concentration increases with the extend length of dehydration in lactating goats. This will reduce the renal secretion which contributes to the water saving mechanism. Short period of water deprivation is rather beneficial to range lambs and kids; it improves diet digestibility and nitrogen retention. The passage of ingesta through the digestive tract will slow down allowing more time for micro-organisms to digest available feed. Concentration of protozoa in the rumen increases because of dehydration which leads to more efficient utilization of nutrients and the rate of fermentation increases.
- To the question how they can cope with salty water, sheep and goats excrete more urine and increase the filtration rate to reduce the high salt load resulting from their high consumption of saline water. Exposure to saline water results in an induction of enzymes in the ileum, liver and kidney. The main enzyme is NaK ATPase that increases the pumping of sodium out of cells and potassium return to the intracellular space. The induction of this enzyme is a powerful adaptive mechanism.

#### 7.2.2 Physiological mechanisms

Substantial progress has been made in the last quarter-century in delineating the mechanisms by which thermal stress influences performance of animals. Heat-stress sensitivity and tolerance influences all the reproductive features, from estrus behavior to seminal characteristics and embryonic survival (Silanikove, 2000a,b; Kadzere et al., 2002; West, 2003; Roth, 2008; Hansen, 2009; Nienaber and Hahn, 2009). These deleterious effects of heat stress are the result of either the hyperthermia associated with heat stress or the physiological adjustments made by the heat-stressed animal to regulate body temperature. Many effects of elevated temperature on gametes and the early embryo involve increased production of reactive oxygen species. Genetic adaptation to heat stress is possible both with respect to regulation of body temperature and cellular resistance to elevated temperature. The adaptive capabilities of animals and livestock production systems are key elements when an animal faces different environmental insults. Acclimation to thermal stress is now identified as a homeorhetic process under endocrine control. The process of acclimatization occurs in 2 phases (acute and chronic) and involves changes in secretion rate of hormones, as well as in amount of receptors in target tissues. The time required to complete both phases is weeks rather than days. In addition, biometeorology has a definitive role when implementing a rational management to meet the challenges of thermal environments. Under heat stress, either reductions of heat load or increase of heat loss are the primary management tools. Actions to mitigate environmental heat insults may be based on risk management, by considering perceived thermal challenges, assessing the potential consequences and acting accordingly. Appropriate actions include: shadow, sprinkling, air movement, or active cooling.

The ability of ruminants to adapt to marginal production systems is partially determined by their capacity to develop appropriate compensatory responses to counteract different environmental stressors (Silanikove, 2000b; Smith & Dobson, 2002). Despite the fact that most of small ruminants in the world are raised in the dry and humid tropics, limited information is available on the effect of thermal stress on reproduction of this species. Traditional goat production systems under arid and semiarid conditions have been developed under restricted conditions of both water and food supply besides high temperatures (Nagy, 1994; Silanikove, 2000a,b). Under this scenario, goats have exerted metabolic and renal compensatory responses throughout some neuroendrocrine controls related to an efficient use of both metabolic and water reserves (Silanikove, 2000a,b).

When facing stress, goats activate two response mechanisms:

- a short-term activation of the hypothalamic-hypophyseal-adrenal axis with the concurrent increase in cortisol release.
- a middle-term adaptation response to stress, which is characterized by a decrease of cortisol to basal levels (Minton, 1994).

## 8. Strategies to mitigate climate change

Research and development options should be emphasized to help mitigate negative impacts of climate change. Cost-effective and feasible options at the farm level should be considered while developing short or long-term mitigation strategies. Obviously, these strategies are not universally applicable but are specific to each production system and location.

### 8.1 Reducing enteric methane production

A set of nutritional strategies proved efficient in reducing methane emissions in ruminants. We report in this section some of these options depicted from the reviews by O'Mara et al. (2008) and Martin et al. (2010).

- Replacing roughages with concentrates results in increased proportion of propionate in the rumen, thus less hydrogen available for CH4 production.
- Feeding legume forages results in less emission of CH4 than grass-based diets.
- Feeding ensiled forages reduces methanogenesis.
- Improving pasture management is associated with decreased CH4 emissions due to improved livestock productivity and a reduction of dietary fibre.
- Administering plant extracts (condensed tannins, saponins, essential oils) reduces CH4 emissions. Tannins have a direct effect on methanogenesis and indirect effect on hydrogen production due to lower feed degradation. Saponins, glycosides available in many plants, have direct effect on rumen microbes. They decrease protein degradation and favour at the same time microbial protein and biomass synthesis. Saponins induce protozoa suppression. Essential oils contain many biologically active molecules which have antimicrobial properties. Some compounds in essential oils are toxic to methanogens.
- Supplementing ruminants with lipid sources (fat or oils) impacts negatively on methanogenesis by toxicity to methanogens, causes defaunation thus suppresses protozoa associated methanogens and decreases fibre digestion.
- Administering ionophores like monensin in the diet results in a shift of bacterial population from gram positive to gram negative organisms with a concurrent shift in the fermentation from acetate to propionate (Moss et al., 2000).

### 8.2 Carbon sequestration

The success of strategies of greenhouse gas mitigation depends on the use of appropriate tools to reduce carbon losses and to increase carbon sequestration. Soussana et al. (2010) reviewed a set of management practices that help achieve these objectives. We report below some of these practices that refer to grassland carbon sequestration:

- avoiding soil tillage,
- moderately intensifying nutrient-poor permanent grasslands,
- avoid heavy grazing,
- grass-legumes association rather than grass only.

### 8.3 Livestock health control

Although of being essential in facing the changes induced by global warming in animal health, the preparedness of veterinary authorities and stockowners to this important issue remains questionable in several countries located within dry areas. Taking into account the presence of important interregional differences in animal productions systems, pathogens background and risk factors for pathogens transmission and disease occurrence, it seems more appropriate to draw up realistic guidelines for livestock health strategies combating the impact of global warming in dry areas.

Maintaining immuno-competant animals in dry environment evolving gradually toward increased aridity will represent the first priority regarding animal health, this is not only important in regard to animal response to pathogens but also for an optimal efficacy of vaccinations and most particularly those targeting transboundary diseases. Non-sustainable systems based on subsidised feed complements are likely to be the first to collapse in dry areas under the effect of global warming, particularly with the current international market prices of their intrans. This collapse might generate additional risks of occurrence/

emergence and propagation of diseases, as it may be an indirect cause of stress impacting the health conditions of livestock. Species and production systems that are resilient to aridity should specifically be privileged. Camel is probably one of the species that should be considered as an alternative to ruminants in arid areas of Africa and Asia for the production of meat, in this context it is worth to envisage appropriate strategies for encouraging the extension of this species toward dry areas located outside of its usual distribution zones. In Tunisia for instance, camels grazed on rangelands of the hyper-arid region of the South East of Tunisia were shown to present much less biochemical disorders related to a diet deficient in proteins and misbalanced in minerals than do sheep. Local knowledge contributing to increase sustainability of livestock productions systems must also be valorised, for instance stockowners of the Tunisian south select their rams and ewes on resilience to drought conditions during the most difficult feeding period of the year. In arid and semi-arid regions of eastern and southern Africa pastoralist communities have developed autonomous adaptation strategies based on optimised management of resources including transhumance, diversification of economic strategies, use of different livestock species in the same herd, and intensification of resources use (Vand den Bossche & Coetzer, 2008). Similar strategies were also developed by agro-pastoral communities in hyper-arid zones of North Africa.

Any comprehensive mitigation strategy targeting the effect of global warming on livestock health should specifically be based on risk assessment of the probabilities of emergence and re-emergence of pathogens as well as of epidemiological profiles for already established diseases. A multidisciplinary approach was adopted in France for this purpose; 20 diseases, the incidence and distribution of which are prone to global warming effects, have been identified. These diseases were assessed further for their potential animal health, human health and economic impacts and their probability of occurrence. This approach has resulted in identifying a final list of 6 pathogens, the most likely to emerge or re-emerge, and also in recommending practical measures for monitoring risks of their occurrence. In practice, this approach will afford an objective basis for carrying out epidemio-surveillance operations and recommending appropriate prevention programmes specifically focusing on the expected impact of global warming on livestock health and even human health if zoonotic pathogens are at risks of emergence or re-emergence. It is important to emphasise, in the context of dry areas that this approach may also concern diseases that are absent in a considered dry zone but present in other bioclimatic zones of the same country, as for instance the case *F. hepatica* that spread out to arid zones of central Tunisia. The opposite situation needs also to be considered, as some pathogens could be more prevalent in dry zones of a specific country; any massive migration or transfer of livestock out of this zone, under the effect of extreme drought, could be an important factor of re-emergence of the pathogen in the rest of the country as outlined above with the example of small ruminants brucellosis in the arid and hyper-arid zones of Tunisia. Implementing epidemio-surveillance operation in the context of global warming raise also the question of preparedness of institutions and particularly of local diagnostic laboratories and the staff involved in identifying emerging pathogens.

The success of field implementation of epidemio-surveillance programs will greatly depend on the presence of enough skilled personnel and also on participation of stockowners. Stockowners must be even be involved in preparation phases of strategies coping with the effect of global warming on livestock health, emphasising the needs for a reliable stockowners representativeness through professional bodies totally independent of governmental administrations. This will ensure that specific field requirements necessary for an optimal monitoring of the risks of disease are properly understood and subsequently accepted by the end users. For instance, the issue of animal or herds identification is essential for any epidemio-surveillance system; its acceptance by stockowners could only be guarantied on the basis of a participatory approach.

In addition to the above mentioned technical options, recommended development solutions to mitigate GHG include:

- Participatory approach involving all concerned stakeholders (farms, herders, technicians, scientists, etc.) for sustainable management of natural resources.
- Involvement of target communities in the whole process of identifying, transferring and adopting appropriate solutions.
- Regulations and incentives for better management of natural resources and improvement of livestock production systems are keys to support livestock keepers better cope with climate change risks.
- Settlement of appropriate risk management mechanisms and preparedness measures.
- Awareness efforts should be made to share knowledge on climate change with target communities to anticipate negative impacts and to enable development organisms to assist livestock keepers.
- Development and research organisms should agree on methodological tools targeting reforestation, rehabilitation of degraded rangelands, livestock manure management, and improved feeding management.
- Local knowledge should be valorised while establishing strategies to adapt to climate change and to mitigate GHG emissions.

## 9. Conclusions

The growing human population and its increasing affluence will increase the global demand for livestock products. But the expected big changes in the climate globally will affect directly or indirectly the natural resource base, the animal productivity and health and the sustainability of livestock-based production systems. Global warming is expected to introduce an additional level of pressure for livestock production systems in dry areas, the challenge that it will cause might, hopefully, result in the emergence of novel sustainable models for livestock productions and for disease prevention opening the way forward to sustain this challenge. A battery of technical and environmentally friendly options have been recommended by scientists to help livestock keepers cope with climate change and to protect ecosystems against negative impacts of global warming (e.g. green house gas emissions, carbon sequestration, etc.). In addition to the technical options, communities based participatory approach involving all stakeholders should be considered for successful transfer and sustainable adoption of recommended technical packages in areas exposed to global warming. Additional efforts are needed to develop methodological tools for communities' development under the climate change context. We should remind that farmers already have a wealth of indigenous knowledge on how to deal with climate variability and risk, but well-targeted capacity building efforts are needed to help farmers deal with changes in their systems that go beyond what they experienced in the past.

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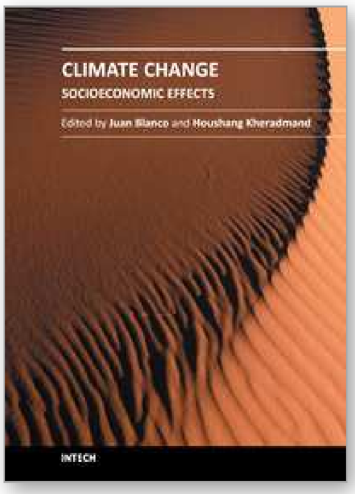


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This book shows some of the socio-economic impacts of climate change according to different estimates of the current or estimated global warming. A series of scientific and experimental research projects explore the impacts of climate change and browse the techniques to evaluate the related impacts. These 23 chapters provide a good overview of the different changes impacts that already have been detected in several regions of the world. They are part of an introduction to the researches being done around the globe in connection with this topic. However, climate change is not just an academic issue important only to scientists and environmentalists; it also has direct implications on various ecosystems and technologies.