Adaptation of livestock systems to climate change; functions of grassland, breeding, health and housing

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In dit rapport is de beschikbare kennis beschreven en zijn relevante onderzoeksvragen geformuleerd die verband houden met 1) grasland gebaseerde productiesystemen en de uitstoot van broeikasgassen en 2) de aanpassing van veehouderijsystemen aan klimaatverandering. Dit om nadere invulling te kunnen geven aan onderzoek en andere acties op het gebied van adaptatie en mitigatie. Oplossingen kunnen worden gevonden in de combinatie van ondersteunende infrastructuur voor de ontwikkeling van de landbouw en de introductie van publiek-private samenwerking in onderzoeksprogramma’s. Het voorzien in veterinaire diensten, financiële diensten, kennisinfrastructuur en beleid voor landgebruik is essentieel voor het behouden en het verbeteren van de agrarische productie.

This report presents the available knowledge and relevant research questions related to 1) grassland based livestock production systems and GHG emissions, and 2) adaptation of livestock systems to climate change, to provide information for prioritization research and other actions on adaptation and mitigation. Solutions can be found through the combination of enabling infrastructure for agricultural development and introducing public-private cooperation into research programmes. The provision of veterinary services, financial services, a knowledge infrastructure and governance of land use are essential for maintaining and improving agricultural productivity.

Photo cover Eddy Teenstra

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Foreword

Animal production affects climate change through emissions of greenhouse gasses. On the other hand climate change will affect animal production. Changes in temperatures and precipitation and erratic rainfall patterns will increase stress on animals and feed crops. These facts combined with the increasing global demand for animal products, urges the need for the development of resilient and more productive animal production systems.

Direct and indirect effects of climate change on animal production ask for urgent solutions. Research is needed in the fields of breeding, housing and health of livestock combined with feed supply and system research.

Against this background the Dutch Ministry of Economic Affairs requested Wageningen UR to make an inventory of available knowledge and identify research questions related to 1) grassland based production systems and greenhouse gas emissions, and to 2) adaptation of livestock systems to climate change. The outcome of this study should enable the Ministry to prioritize research on livestock production systems.

Both subjects are mainly worked out by literature search and interviewing colleague experts from the Netherlands and abroad. We thank all who participated and provided the input to complete this report.

We trust this report contributes to the Dutch intention and ambition to enhance the focus on climate-resilient food-systems and to improve global food security.

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Summary

Climate is changing and this urges the need for the development of resilient and more productive animal production systems to lessen the impact on animal production and to improve global food security. The key challenge is to make livestock systems and grassland use more sustainable to meet the aims of improving food security, adapting to climate change and mitigating greenhouse gas emission. Research is needed in the fields of breeding, housing and health of livestock integrated with feed supply and livestock system research. This report presents the available knowledge and relevant research questions related to 1) grassland based production systems and GHG emissions, and 2) adaptation of livestock systems to climate change, to be able to prioritize research on adaptation and mitigation.

Nevertheless, to make food-systems climate-resilient and to improve global food security, not only research is needed but also attention needs to be paid to governance, market access, education and food chain development.

Grassland
Ruminants convert grass into edible protein and this is favourable to increase food supply. The trade-off of animal protein production is the substantial contribution of livestock to greenhouse gas emissions. Whereas livestock contributes to greenhouse gas emission, grassland has an important mitigation potential due to carbon sequestration in the upper soil layers.
The total grassland area is declining mainly due to human-induced modifications, which include conversion to arable land, urbanization, desertification, fire, overgrazing, fragmentation, and introduction of invasive species. Especially grasslands with better water supplies that have been converted to crop production. Therefore grazing is often relegated to the more marginal lands, unfit for cropping, where the population often completely depends on livestock for its livelihood. Conversion of grassland has led to problems of access to water for stock and wildlife, loss of lean season grazing, obstruction of migration routes and fragmentation of wildlife habitats.
Improving the sustainability of grassland use is an important mitigating measure to stop the negative spiral of climate change and the increasing pressure on food security. Seasonality of forage supply is characteristic for almost all grazing lands. To deal with lean seasons (winter or dry season) sufficient forage supply by making hay or silage is an important measure to improve sustainable grassland use. Especially during unproductive periods, providing adequate rest from grazing is essential to maintain sufficient soil cover and productive swards.

Productivity of grasslands in arid and semi-arid environments is not primarily limited by rainfall. Low availability of nitrogen and phosphorus is a more serious problem than low rainfall. Intensification of production systems appears to be indispensable to provide food security, but this is only sensible when this is done in a well-integrated manner to guarantee sustainable natural resource use. To save the system balance realistic expectations of the productive capacity of the resource must be addressed. Converting grassland for domestic livestock to cultivated land can only increase food security when adequate nutrients are available to sustain plant production and to maintain soil fertility. Nutrient harvests from cropland often exceed nutrient inputs, and soil nutrient depletion is a principal concern. The manure of transhumant herds remains vital to sustaining cropland productivity in many rangeland/cropland farming systems. Making the most efficient use of animal manures depends critically on improving manure handling and storage, and on synchrony of mineralisation and manure supply with crop uptake. Alternative sources for nutrients needed for pastures, fodder crops and food crops have to be found in human and industrial wastes.

Breeding
Improvement of livestock genetic resources that are efficient and well adapted to extreme temperatures, low quality diets and greater disease challenges is necessary in order to address the challenges of adapting to climate change and increasing food production. For the main livestock

sectors, only a relatively small number of breeding companies or breeding organisations are global providers of high quality, specialized breeding stock. These are mainly situated in OECD countries. The global supply of breeding material is business driven with a fierce competition between breeding companies.
High productive breeds can improve food production but in practice those breeds often cannot keep their expected productivity in more extreme climatic or endemic disease situations. Therefore, quick replacement of locally adapted breeds by 'indiscriminate' cross-breeding should be avoided, due to the loss of adapted traits and lower economic benefits. Well-considered breeding programmes adapted to local environments have to be seen as long term investments. These sustainable breeding programmes could be initiated and implemented by Public Private Partnerships to bridge countries' public and private interests.

Health
It is likely that climate change is affecting the distribution and seasonality of important infectious diseases, impacting both animal and human health. Not only higher temperatures but also heavy precipitation events and flooding, will increase the risk of outbreaks of diseases transmitted by arthropod and water borne vectors. It is generally accepted that the geographic range of Bluetongue Virus and West Nile Virus transmitted by arthropod vectors recently moved northwards to the northern hemisphere. Although climate change can augment the need for animal health care, it does not directly ask for new veterinary knowledge. Developing an effective veterinary service is probably the most important strategy for dealing with climate change in developing countries and it is also essential to improve livestock production, contributing to food security.

Housing
Housing and management measures can prevent problems due to extreme climate conditions like heat stress but they are only feasible in capital-intensive livestock systems. The function of housing is to match the needs of animals and humans to reach a higher livestock productivity with reduced inputs. As a consequence of housing, the demand for labour is changing and capital is needed to acquire supplementary feed and fertilizer, and to invest in buildings, storage and transport. Expert knowledge is needed for feed conservation, animal nutrition and manure treatment. To give better guarantees for profitable investments, governmental and institutional support to smallholders is essential to create a more stabilized food market.

1 Introduction

Climate is changing (IPCC, 2013) and this directly will affect livestock and crop production, through increased temperature, changes in the amount of rainfall and shifts in precipitation patterns (FAO, 2013). Agriculture not only has to adapt to climate change it is also an major contributor to climate change. The global livestock sector contributes a significant share to anthropogenic greenhouse gas emissions (GHG), but it can also deliver a significant share of the necessary mitigation effort (Gerber *et al.,* 2013).The livestock sector faces the difficult challenge of having to reduce its GHG emissions while responding to a significant demand growth for livestock products driven by a growing world population, rising affluence and urbanization (Gerber *et al.,* 2013).

This report presents the available knowledge and relevant research questions related to 1) grassland based production systems and GHG emissions, and 2) adaptation of livestock systems to climate change, to be able to prioritize research on adaptation and mitigation.

Ad 1) Grassland based production systems and GHG emissions
Grassland is the main feed for ruminants worldwide and has a huge potential in improving food security. Food security can be improved via the animal products meat and milk, which are directly linked with grassland productivity and grassland utilization.
Grassland is a very efficient user of nutrients and water relatively, has a potential for carbon sequestration and hence can be considered as a low emission resource. Due to mismanagement and increasing occurrence of weather extremes the potential is not fully used. Moreover, grassland is often marginal land, with no alternative exploitation and no other options for grass utilization are available yet. These are adequate reasons to increase research on the possibilities of improving grassland utilization by livestock combined with low GHG emissions or high C-sequestration. The main focus in the survey (Chapter 2) has been on grassland management, grassland utilization and grazing systems. Water and nutrient use efficiency play an important role in productivity.

Ad 2) Adaptation of livestock systems to climate change
Widening the scope of the Livestock Research Group to adaptation is needed the coming years to be able to develop resilient and more productive systems. These productive systems have a dimension of feed and roughage supply for livestock and are linked with the system approach of croplands and grassland. However also direct and indirect effects of climate change on animal production ask for urgent solutions. Therefore, what additional research is needed in the fields of breeding, housing and health of livestock combined with feed supply and system research?

To meet the aims of enlarging food security, adapting climate change, mitigating greenhouse gas emission, in general the key challenge is to make livestock systems and grassland use more sustainable. Key words to achieve this are adaptation and mitigation.

In this report the two mentioned research questions have been worked out with a focus on the function of grassland, breeding, health and housing in perspective of increasing livestock production and climate change adaptation. Because the Dutch Ministry asked for a quick survey, this report is not an exhaustive review of literature available. It attempts to assign crucial aspects in the function of grassland, breeding, health and housing by looking at those functions in an integrated manner. Although in the first research question climate change was not addressed specifically, climate change affects grassland productivity and plays a role in grassland degradation and loss of carbon which contributes to GHG. Therefore for grassland the aspect climate change and adaptation has also been taken into account.

2 Food security and climate risk

2.1 Climate change

To adapt to climate change, characteristics of climate change needed to be identified. The Intergovernmental Panel on Climate Change (IPCC) is the predominant institute that quantifies and qualifies the effects of climate change. The following (limited) selection of summarized research results of the IPCC (2013) give an impression of recent findings:

- Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years.
- The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 (0.65 to 1.06) °C, over the period 1880 to 2012, when multiple independently produced datasets exist.
- The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 will likely be in the range of 0.3°C to 0.7°C (medium confidence). Relative to natural internal variability, near-term increases in seasonal mean and annual mean temperatures are expected to be larger in the tropics and subtropics than in mid-latitudes (high confidence).
- Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe.
- It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is very likely that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur
- Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterwards. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951). For other latitudes area-averaged long-term positive or negative trends have low confidence.
- Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases.
- Global mean sea level will continue to rise during the 21st century due to increased ocean warming and increased loss of mass from glaciers and ice sheets.

Climate change will affect the agriculture sector directly, through increased temperature, changes in the amount of rainfall and shifts in precipitation patterns (FAO, 2013). Especially shifts in precipitation patterns resulting in more intense and longer droughts as well as heavy precipitation events will directly affect agricultural production and incomes. Furthermore, heavy rainfall damages crop yields because of destroying crop canopies and floods. Therefore food production is facing climate pressures, while at the same time food production has to increase from the perspective of food security.

Agriculture not only has to adapt to climate change it is also a major contributor to climate change, especially livestock food chains. According to *Livestock's long shadow* (FAO, 2006) the livestock sector is a major contributor to climate change, generating significant emissions of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20). Livestock contributes to climate change by emitting GHGs either directly (e.g. from enteric fermentation and manure management) or indirectly (e.g. from feed-production activities, conversion of forest into pasture).

In Gerber *et al*. (2013) it is stated that 7.1 gigatonnes is 14.5 % of the human-induced GHG emissions. Starting from 7.1 gigatonnes CO2-eq per annum Gerber *et al.* (2013) assessed the following contribution of the livestock sector to GHG emissions: beef and cattle milk production account for the majority of emissions, respectively contributing 41 and 20 percent of the sector's

emissions. While pig meat and poultry meat and eggs contribute respectively 9 percent and 8 percent to the sector's emissions. The strong projected growth of this production will result in higher emission shares and volumes over time. Feed production and processing, and enteric fermentation from ruminants are the two main sources of emissions, representing 45 and 39 percent of sector emissions, respectively.
Manure storage and processing represent 10 percent. The remainder is attributable to the processing and transportation of animal products. Included in feed production, the expansion of pasture and feed crops into forests accounts for about 9 percent of the sector's emissions. Cutting across categories, the consumption of fossil fuel along the sector supply chains accounts for about 20 percent of sector emissions.

2.2 Climate-smart agriculture

The challenge of climate change has been addressed in the World Bank Annual Report 2013. Investment in agriculture should be essential to meet the demands of a growing global population. The world needs to produce approximately 50 percent more food by 2050 for a projected population of 9 billion (is 7.2 billion). The FAO even stated that the global demand is projected to increase by 70 percent to feed a population estimated to reach 9.6 billion by 2050 (Gerber *et al.*, 2013). Furthermore, over one billion people around the world are undernourished because they lack easy and consistent access to affordable food and also in that perspective food production has to increase.

According to the World Bank there support of climate-smart agriculture can provide a triple win for agriculture, the climate, and food security. Climate-smart farming techniques increase farm productivity and incomes and make agriculture more resilient to climate change while contributing to mitigation as well. Climate-smart agriculture also includes innovative practices such as better weather forecasting, drought- and flood-tolerant crops, and risk insurance (www.worldbank.org/climatechange).

The State of Food and Agriculture (FAO, 2009a) reported the rapid pace of livestock sector change in the last decades. As a consequence a widening dichotomy within the sector has been manifested in terms of the scale, intensity and efficiency of production and in unforeseen social, nutritional, animal health and environmental implications. These changes and the speed with which they are occurring have created systemic risks for livelihoods, human and animal health and the environment. It was concluded that to meet the challenges and constraints of the twenty-first century, the livestock sector requires appropriate institutions, research, development interventions and governance that reflect the diversity within the sector and the multiple demands placed upon it.

In the sourcebook *Climate-smart agriculture* (FAO, 2013) it is stated that addressing food security and climate change challenges has to be done in an integrated manner. To ensure food security and adapt to climate change, food production has to become more resilient. The challenge is to increase production and to mitigate climate change as well by reducing the intensity of emissions. To reach sufficient impact this asks for a worldwide implementation but the focus has to be on the developing countries that are more at risk of food security and of climate risk. In addition, developing countries have less means, policies and institutions to address these challenges.

Research efforts are required to identify additional combinations of mitigation and adaptation practices that are adapted to specific production systems and environments (e.g. combined interventions addressing the management of feed, genetic resources and manure). The potential aggregated effects that changes in farming systems may have on food security and the use of natural resources at the regional level also need to be better understood (FAO, 2013).

In Gerber *et al.* (2013) increasing production efficiency has been brought up as key to reduce emissions, because there is a direct link between GHG emission intensities and the efficiency with which producers use natural resources. For livestock production systems, nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) are the three main GHG emitted by the sector, with losses of nitrogen (N), energy and organic matter undermining efficiency and productivity. Possible interventions to improve production efficiency and to reduce emissions include use of better quality feed and feed balancing, improved breeding and animal health to shrink the (unproductive) herd overhead, improved manure management to increase the recovery and recycling of nutrients and energy contained in manure, and improvements in energy use efficiency along supply chains.

Grassland carbon sequestration is addressed (Gerber *et al.*, 2013) as a promising mitigation potential. The global offset is about 0.6 gigatonnes CO_2-eq per year. Nevertheless on the contrary there is an ongoing process of grassland degradation (FAO, 2006) and this process has to be stopped in the first place. Furthermore a range of promising technologies such as feed additives, vaccines and genetic selection methods have a strong potential to reduce emissions but require further development and/or longer timeframes to be viable mitigation options

2.3 Livestock systems

Seré and Steinfeld (FAO,1996) developed a classification and characterization of the world's livestock systems enabling detailed studies of livestock environment interactions by livestock systems and by impact domains. The characterisation is as follows:

1. **Solely Livestock Systems (L)**: Livestock systems in which more than 90 percent of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds and less than 10 percent of the total value of production comes from non-livestock farming activities.

    a. **Landless Livestock Production Systems (LL)**: A subset of the solely livestock systems in which less than 10 percent of the dry matter fed to animals is farm produced and in which annual average stocking rates are above ten livestock units (LU) per hectare of agricultural land. The following additional differentiation is made:

        i. *Landless monogastric systems (LLM):* A subset of LL in which the value of production of the pig/poultry enterprise is higher than that of the ruminant enterprises.
        ii. *Landless ruminant systems (LLR)*: A subset of LL in which the value of production of the ruminant enterprises is higher than that of the pig/poultry enterprise.

    b. **Grassland-based Systems (LG)**: A subset of solely livestock systems in which more than 10 percent of the dry matter fed to animals is farm produced and in which annual average stocking rates are less than ten LU per hectare of agricultural land.
        i. Temperate and tropical highland (LGT)
        ii. Humid/sub-humid tropics and sub-tropics (LGH)
        iii. Arid/semi-arid tropics and sub-tropics (LGA)

2. **Mixed Farming Systems (M)**: Livestock systems in which more than 10 percent of the dry matter fed to animals comes from crop by-products, stubble or more than 10 percent of the total value of production comes from non-livestock farming activities.

    a. **Rainfed Mixed Farming Systems (MR)**: A subset of the mixed systems in which more than 90 percent of the value of non-livestock farm production comes from rainfed land use, including the following classes.
        i. Temperate and tropical highland (MRT)
        ii. Humid/sub-humid tropics and sub-tropics (MRH)
        iii. Arid/semi-arid tropics and sub-tropics (MRA)

    b. **Irrigated Mixed Farming Systems (MI)**: A subset of the mixed systems in which more than 10 percent of the value of non-livestock farm production comes from irrigated land use, including
        i. Temperate and tropical highland (MIT)
        ii. Humid/sub-humid tropics and sub-tropics (MIH)
        iii. Arid/semi-arid tropics and sub-tropics (MIA)

In Appendix 1 the characteristics of livestock production for ruminants, pigs and poultry are given.

The grassland-based (LG) and mixed farming systems (M) are further characterized in agro-climatic terms, based on temperature and length of growing period (LGP) during which crop growth is possible. According to (Robinson *et al.*, 2011) the three agro climatic categories are defined as:

1. Arid and semi-arid: LGP ≤ 180 days.
2. Humid and sub-humid: LGP > 180 days.
3. Tropical highlands or temperate. Temperate regions are defined as those with one month or more of monthly mean temperature below 5 ºC, corrected to sea level. Tropical highlands are defined as those areas with a daily mean temperature during the growing period of 5–20 ºC.

Ad 1. This category is found under two contrasting socio-economic environments: on the one hand, in sub-Saharan Africa and the Near East and North Africa regions, where it constitutes a traditional way of subsistence for important populations, and on the other hand, it is found in Australia, parts of western United States and southern Africa, where private enterprises utilize public or privately owned range resources in the form of ranching. The system is of very limited importance in Central and South America, Asia, Eastern Europe and CIS countries.

Ad 2. This category is found mostly in the tropical and subtropical lowlands of South America: the *llanos* of Colombia and Venezuela as well as the *Cerrados* of Brazil.

Ad3. The cases located in tropical highlands comprise parts of the highlands of South America and eastern Africa. The cases in temperate zones include southern Australia, New Zealand, and parts of the United States, China and Mongolia.

3 Adaptation and mitigation of grasslands

3.1 Introduction

Grasslands are among the largest ecosystems in the world and cover about 40 percent of the terrestrial area excluding Greenland and Antarctica (White *et al.*, 2000). According to the World Resources Institute (White *et al.*, 2000) these ecosystems provide livelihoods for nearly 800 million people, along with forage for livestock, wildlife habitat, carbon and water storage, renewable energy, recreation, and tourism. Grasslands include the savannahs of Africa, the steppes of Central Asia, the prairies of North America, and the llanos and Cerrados of South America. The largest stretches of grasslands are found in Sub-Saharan Africa and Asia. The five countries with the largest areas of grasslands are Australia, Russia, China, the United States and Canada, each supporting over 3 million square kilometres of grasslands.

The better-watered parts of many of the world's great grassland zones have been developed for arable farming, notably in the North American Prairie, the South American Pampas and the East European Steppe, and grazing is now often relegated to the more marginal lands unfit for cropping, where the population is often completely dependent on livestock for its livelihood (FAO, 2005).

Grassland as a term is used in many contexts and therefore more specific definitions are desired especially when it is used in an international context, like in this study. The term refers to natural ecosystems as well as to grazing land for commercial purposes and it includes the conditions necessary for the existence of grassland. The Oxford Dictionary of Plant Sciences (Allaby*,* 1998) gives a succinct definition:

"Grassland occurs where there is sufficient moisture for grass growth, but where environmental conditions, both climatic and anthropogenic, prevent tree growth. Its occurrence, therefore, correlates with a rainfall intensity between that of desert and forest and is extended by grazing and/or fire to form a plagioclimax in many areas that were previously forested."

An international terminology for grazing lands and grazing animals was published by Allen *et al.* (2011). The objective has been to develop a consensus of terms and definitions to ensure clear international communication regarding grazing lands and grazing animals. Terms included in this publication have relevance to both domesticated and wild grazing animals.
The definitions given are generic with some potential for overlap (i.e. grassland). The term grassland bridges pastureland and rangeland and may be either a natural or an imposed ecosystem. Some of the definitions of grazing land types imply current land use and some are based on potential vegetation or land capability. General definitions for grazing lands (Allen *et al.*, 2011) are as follows:

Pastureland. Land (and the vegetation growing on it) devoted to the production of introduced or indigenous forage for harvest by grazing, cutting, or both. Usually managed to arrest successional processes.

Grassland. The term 'grassland' is synonymous with pastureland when referring to an imposed grazing-land ecosystem. The vegetation of grassland in this context is broadly interpreted to include grasses, legumes and other forbs, and at times woody species may be present. There are many descriptive terms for pastureland /grassland that take into account their age and stability.

Rangeland. Land on which the indigenous vegetation (climax or sub-climax) is predominantly grasses, grass-like plants, forbs or shrubs that are grazed or have the potential to be grazed, and which is used as a natural ecosystem for the production of grazing livestock and wildlife. Rangelands may include natural grasslands, savannahs, shrublands, steppes, tundras, alpine communities and marshes.

Grasses using C4 and C3 photosynthesis (Slack and Hatch, 1967) are found worldwide. C4 grasses are mostly confined to low latitudes and altitudes, whereas C3 species dominate at higher latitudes and elevations (Edwards *et al*., 2010). These patterns correlate best with temperature. In the evolutionary history of grass carbon dioxide also played an important role.

Among the numerous functions of grassland, in this survey the emphasis was on the use of extensive grasslands for domestic ruminant nutrition and improving food security potential. Ruminants can convert grass into protein valuable for human consumption and this is favourable to increase valuable food supply. A mayor trade-off of animal protein production is the substantial contribution of livestock to greenhouse gas emission. The IPCC foresees a growing meat consumption in the coming decades (IPCC, 2007) and therefore the contribution of livestock to GHG emissions will increase. Whereas livestock contributes to greenhouse gas emission, grassland has an important mitigation potential due to carbon sequestration in the upper layer of the soil (IPCC, 2007; FAO, 2009b; Soussana *et al.*, 2009). Unfortunately the grassland area is declining mainly due to human-induced modifications (White *et al.*, 2000). These include conversion to arable land, urbanization, desertification, fire, overgrazing, fragmentation, and introduction of invasive species. Consequently both increasing livestock and declining grassland enlarges the contribution to greenhouse gas emission and reinforces climate change. Improving the sustainability of grassland use is an important mitigating measure to stop the negative spiral of climate change and the increasing pressure on food security. A key factor is balancing grass productivity and grass uptake by ruminants.

Grasslands as an ecosystem provide in the livelihoods of millions of people (White *et al.*, 2000) and thus also socio-economic aspects play an important role in improving the sustainability of grassland use. Finally, individual farmers have to carry out pasture management improvements or farm concept changes. It is essential to understand the livelihood of communities or individual farmers and to look at the functioning of farms in an integrated matter.

3.2 Grassland management

3.2.1 Ecological development and sustainable use

Climate is an important factor in the establishment of livestock systems. In the livestock classification system of Sere and Steinfeld (FAO, 1996) three agro-climatic categories are distinguished (see also paragraph 2.2.2):

1. Arid and semi-arid: LGP ≤ 180 days.
2. Humid and sub-humid: LGP > 180 days.
3. Tropical highlands or temperate.

In relation to those agro-climatic categories different grassland-based systems are distinguished. A brief summary according to Sere and Steinfeld (FAO,1996) is as follows:

Ad 1. Extensive grazing mainly by pastoralists in sub-Saharan Africa (Sahel), near east (Bedouin in Syria) and North Africa regions and ranching in Australia, parts of western United States and southern Africa

Ad 2. Extensive as well as intensive grazing systems with a widely varying grass productivity largely depending on rainfall patterns and the extent of fertilizer inputs and irrigation.

Ad 3. Extensive rangeland grazing in tropical and subtropical lowlands of South America and tropical regions in west and central Africa. Also more intensive pasture sown systems are found in South America.

In Grasslands of the World (FAO, 2005) a number of grassland systems are described in detail. It brings together information on the characteristics, conditions, present use and problems of the world's main natural grasslands by nine area or country studies. Seasonality of forage supply is a characteristic of almost all grazing lands, so the strategies for dealing with lean seasons (winter or dry season) are described.

No grassland is entirely natural, and there are many degrees of interference (FAO, 2005) such as: fire, whether spontaneous or lit by man; grazing by livestock or wild herbivores, clearing of woody vegetation either to improve grazing or originally for cropping, subdivision with or without fencing; provision of water points to extend the grazing area or season; and various "improvement "techniques such as oversowing with pasture grass and legume seeds – with or without surface scarification and fertilizer. In many types of grassland, the presence of fire is a key factor in preventing the invasion of woody species, which can significantly affect ecosystem carbon stores (Jackson *et al.*, 2002).

Thus, climatic circumstances as well as interference greatly influence the ecological development of grassland. Concerning livestock keeping, grazing management is crucial for sustainable grassland use. The key factor is that the grazing intensity has to be adjusted by the grassland productivity. Undergrazing leads to a higher mass of old grass and the increase of shrubs, negatively impacting the cost of production and nutrition value. Overgrazing leads to destruction of grassland and increases the chance of erosion. Finally in arid areas overgrazing leads to desertification as actually happened in the sub-Sahara area (FAO, 2006) and Mongolia (Liu *et al.*, 2013). Therefore, forage has to convert into animal products while simultaneously the grassland ecosystem has to be maintained. In Figure 1 a diagram of the ecological development of grassland in broad outlines is shown in relation to moisture availability and grassland interference. Moisture availability is a result of global radiation which determines the crop evaporation level, climate which determines precipitation level and intensity and soil texture which determines moisture hold capability. Furthermore productivity is depending on soil fertility and nutrient supply.

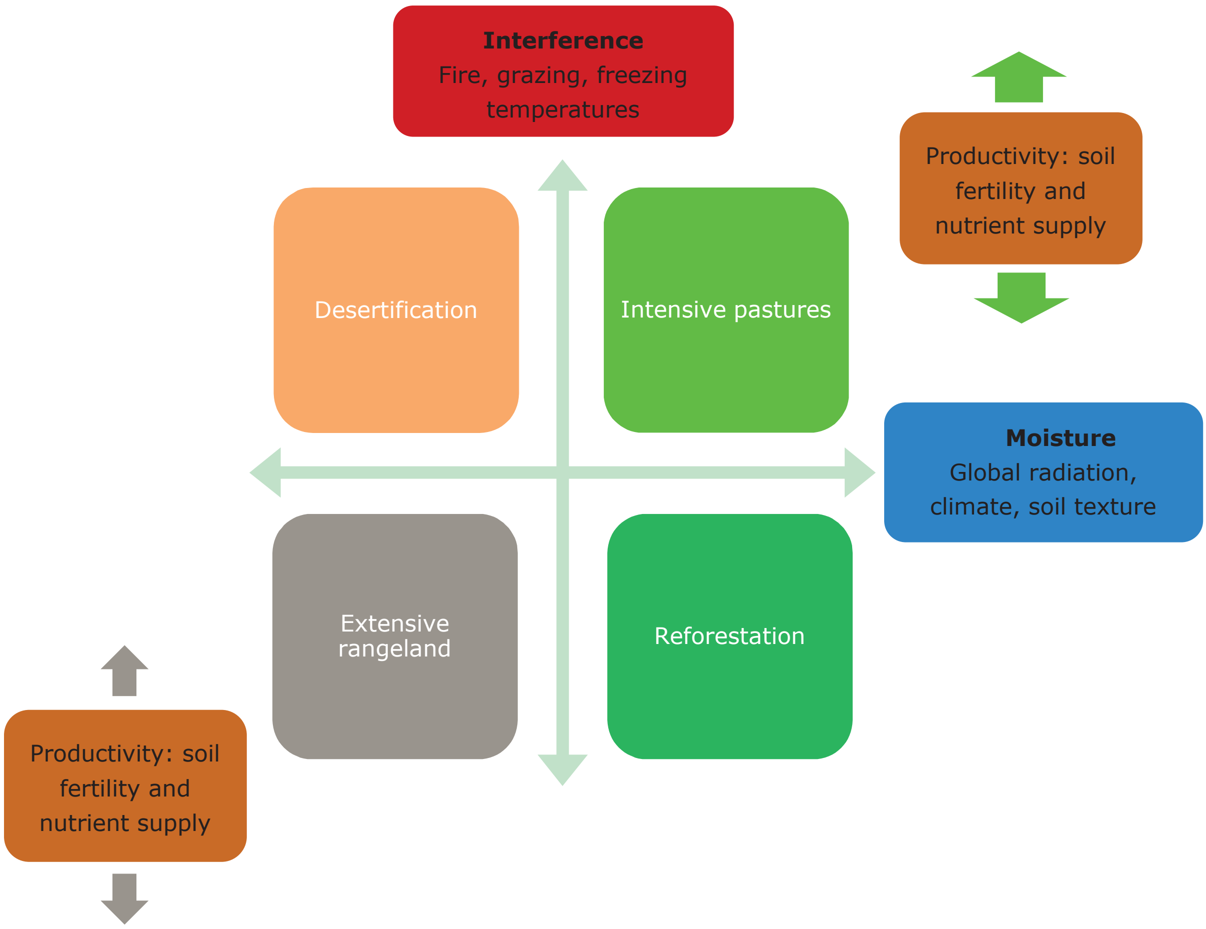


Figure 1. *Schematic view of the ecological development of grassland in relation to moisture availability and grassland interference. Productivity depends on soil fertility and nutrient supply.*

The figure shows that grassland turns into forest under extremely wet situations and/or a lack of interference and under opposite conditions, grassland degrades and finally turns into desert. The latter introduces loss of carbon and therefore contributes to greenhouse gas emission.

According to the FAO (2005) grazing systems can be roughly divided into two main types – commercial and traditional, with the traditional type often mainly aimed at subsistence. In FAO (2005) both systems are described as follows: commercial grazing of natural pasture is very often large-scale and commonly involves a single species, usually beef cattle or sheep. Traditional livestock production systems are very varied according to climate and the overall farming systems of the area. They also use a wider range of livestock, which are often mainly kept for subsistence and savings, and are frequently multi-purpose, providing meat, milk, draught, fibres and frequently fuel in the form of dung-cakes. In many cultures the number of livestock is associated with social standing. Many traditional systems are sedentary, and these are usually agro pastoral, combining crop production with livestock that can utilize crop residues and by-products and make use of land unsuitable for crops. Extensive grasslands, however, are frequently exploited by mobile systems, transhumant or nomadic, where herds move between grazing areas according to season; some move according to temperature, others follow feed availability.

From an agricultural point of view good grazing management is essential to provide grassland degradation. According to Jones (2006) the grazing process needs to be carefully managed, using intermittent grazing and resting to stimulate the growth of new leaves and to provide pruned roots as organic matter for soil biota. In many sites throughout temperate Australia, excavated plant roots were examined and it appeared that the roots of grasses form a mirror image of the tops. In general terms, the removal of leaf area through grazing results in root pruning, while resting from grazing enables root strengthening. Continuous root pruning reduces root biomass, slows nutrient cycling, exhausts plant reserves and ultimately causes plant death. However, grasses also degenerate if overrested. Five criteria for good grazing management were given:

1. understanding how to use grazing to stimulate grasses to grow vigorously and develop healthy root systems
2. using the grazing process to feed livestock AND soil biota
3. maintaining 100% soil cover (plants, litter) 100% of the time (NO exceptions)
4. rekindling natural soil forming processes
5. providing adequate rest from grazing without overresting

In Grasslands of the World (FAO, 2005) it was concluded that the management of communally held grassland is generally in great difficulties due to unclarified grazing rights. This obstructs pastoralists to modify their grazing systems to increase productivity and efficiency of grassland use and to prevent grassland degradation. It was concluded that the overall management of extensive grazing lands should be done within a wide framework on a very large, landscape scale so that it is effective in dealing with the whole range of pastorals resources and products, covers the migration territories of transhumant groups as well as conserving wildlife. In addition in Sourcebook Climate-smart agriculture (FAO, 2013) a landscape approach is suggested to achieve the multiple objectives of climate-smart agriculture including improvement of sustainable grassland use. Not only technical measurements are of importance for sustainable grassland use, but also socio-economic aspects play a crucial role. According to the FAO (2013) in a landscape approach, the management of production systems and natural resources covers an area large enough to produce vital ecosystem services, but small enough to be managed by the people using the land which is producing those services. A landscape approach builds on the principles of natural resource management systems that recognize the value of ecosystem services to multiple stakeholders. To achieve healthy ecosystems, participatory and people-centred approaches and management structures are needed. This approach will simultaneously improve the resilience of production systems and people’s livelihoods.

In textbox 2.2 a case is presented in which is suggested how in the highlands of Ethiopia grassland management can be improved to increase dairy production by changing the traditional one-cut system to a two-cut system. An important restriction for implementing a two-cut system is removing the fear of farmers of losing income.

Box 2.2. Improving grassland management in the Ethiopian highlands
by Eddy Teenstra, Wageningen UR Livestock Research

Grasslands in the highlands of Ethiopia (> 2000 m) are characterised by moderate temperatures, above average rainfall, poorly drained and with shallow topsoil. All land is state owned. Local communities use it for communal grazing and individual hay making. Overgrazing and the absence of fertilization has resulted in vast areas with low quality and low production. Traditionally the (mainly) smallholder farmers cut the grass for hay once a year at the end of the long rain season (app. October). Subsequently a major part of the hay is bought by traders and middle man with the objective to sell it to small and middle scale dairy farms in the urban and peri-urban areas. However, due to the poor quality in energy as well as in protein, especially on the commercial farm with crossbreeds, the milk production of the genetically improved animals stays far below their genetic potential.

Low productive grassland (June – before start rain season)

Hay making (November)

Hay purchase by urban smallholder

Two cuts per year
Hay quality in general can be improved by cutting the grass at a younger stage. Traditional habits and the fear of losing yield (lower income from hay sales) prevent a change in cutting regime. Still, with proper care and perhaps some manure application (which is not common) it should be possible to have a second cut, again at a younger growing stage. In the end the total hay yield in kilos is expected to be about the same as in the traditional one-cut system but with improved feeding value (in energy and protein). Using 'two-cut hay' in dairy husbandry will increase milk production and reduce methane production at rumen level and emission per unit of output.

Reduce risks
The challenge will be to find farmers who are willing to change from a one-cut to a two-cut system. The fear of losing income could be countered by an on-farm research pilot in which the converted farmers will receive a guaranteed price similar to traditional 'one-cut hay'. The pilot should also give answers on the best timing for the second cut, the effect of manure application (including logistics), the effects on quantity and (feeding) quality and finally the implications for a quality based payment system.

[Photos Eddy Teenstra]

3.2.2 Natural resources and productivity

Especially in arid and semi-arid environments, quantity and quality of grass production is very low due to a short length of growing period, a small amount of annual rainfall and poor soil fertility. Therefore in pastoral systems livestock production is mainly providing local markets and supporting own subsistence (FAO, 2000). Pastoral livestock systems in sub-Saharan Africa or the Middle East (Bedouin), find their basis in overcoming droughts by moving around with ruminants, following the availability of water and rough fodder to feed their animals (Ayantunde *et al.* 2011). Despite water availability, grassland use and livestock production depend very much on soil quality. For example extensive ranching systems are found on soils with a poor soil fertility. Here grass production mainly provides beef and wool production for local and commercial markets. In Latin America tropical savannahs are of such low quality that they have to be burnt in order for cattle to graze the young regrowth (FAO, 1996). Soil fertility can be improved by fertilizer inputs but this is only possible when benefits exceed the costs and when access to markets is provided. Especially milk production depends a lot on market access because raw milk is very perishable. In developed countries dairy production is profitable due to the relative high economic value of dairy products and the relative high productivity in terms of animal output per animal or per hectare of land. This led to an intensive use of highly productive grassland due to fertilizer inputs, improving pastures by sowing highly productive and digestible grass species, the use of legumes and fencing. Sometimes even irrigation is applied.

Given the nutrient supply, moisture availability is the most modifying growing factor. Doorenbos and Kassam (1979) addressed the relationship between crop yield and water use by a simple linear equation where relative yield reduction is related to the corresponding relative reduction in evapotranspiration. A yield response factor represents the effect of a reduction in evapotranspiration on yield losses and is dependent on the crop and crop stage. For grass the yield response factor is 1; therefore as transpiration decreases, due to moisture deficit, the yield decreases at the same rate.

The primary thought is that productivity of grasslands in arid and semi-arid environments is limited by rainfall. Breman and De Wit (1983) analysed natural rangeland productivity in the Sahel environment, a semi-arid transition zone between the desert and the savannahs of West and Central Africa. Due to the single short rainy season the productivity is relatively low. Nevertheless it was concluded that low availability of nitrogen and phosphorus is a more serious problem than low rainfall. Improved soil fertility leads to the use of more water by the vegetation, improved water-use efficiency, and thus higher production. This was not applicable to soils with relatively low water availability due to low water retention or absorption capacity or water loss because of runoff (sloping area). In the Sahel countries, water limits growth at the border of the Sahara. This changes over rapidly to growth limited by nitrogen (and phosphorus) with increasing rainfall to the south. Biomass increases then, but the protein content decreases. Due to selective grazing, ruminants provide herbage with a higher protein content than can be predicted on the basis of pasture evaluation alone (Breman and De Wit, 1983; Ayantunde *et al.*, 1999).

Dickhoefer *et al*. (2010) studied ligneous and herbaceous vegetation on grazed and ungrazed sites in the Hajar Mountains of Oman (semi-arid subtropical mountain region) to evaluate the possibilities of improving pasture management to maintain fodder production. Basically grazing of low productive rangeland was alternated with resting periods to allow natural vegetation to recover. In the studied case goats were grazed. Also feral donkeys increased the grazing intensity. It was concluded that sustainable use of the natural fodder resources through improved pasture management is a valuable alternative to intense supplement feeding or the introduction of zero grazing management.

Despite conservative coordinated grazing, temporarily increased supplement feeding of goats at the homestead, shorter grazing times and grazing only parts of the herds were recommended management measures to reduce grazing pressure. This is especially important during germination and at early growth stages of the ligneous and herbaceous vegetation.

Together with the control of the increasing number of feral donkeys, management based on scientific and traditional knowledge could therefore allow for stocking rates that exceed conservative recommendations and the current number of animals grazing the mountain pastures.

3.2.3 Nutrient cycle and productivity

In perspective of grassland management in pasture systems, fertilizer inputs, additional nutrition and sometimes irrigation are management measures to control grass and animal productivity. Moreover, additional nutrition and nutrient uptake by grass are communicating vessels; the less grass is available for grazing the more additional nutrition is needed to maintain animal productivity. Also grass quality plays an important role in this context. Fodder quantity and quality has to be examined in perspective of the production level of animals; highly productive animals are more demanding of feed supply and nutrition value. This has to be considered when local breeds are exchanged for specialized breeds or crossbreds (see chapter 4).
In developed countries with a well-developed dairy chain and relatively high milk prices it is easier to supply additional feed, which can be obtained by regional markets and imports. Conversely, developing countries mostly produce meat and dairy products to provide for their livelihood or to produce for local markets with a lot of economic uncertainties. There are limited or no possibilities to buy additional fertilizers or feeds so the only possibility to increase animal production is to increase the efficiency of grassland use.

Beside input costs and output benefits, the profitability of milk production is highly dependent on the efficiency of nutrient cycling. Especially of great importance is an effective conversion of grass into milk production and a high nutrient recovery of manure into grass production. This demands knowledge about nutrient and grassland management. In developed countries with intensive grassland use, this knowledge is getting more sophisticated due to increasing prices for additional land, feeds and fertilizer inputs. It is often seen that in developing countries there is a lack of knowledge about nutrient cycles, which means that agricultural productivity is highly dependent on the soil nutrient resources.

From an agricultural point of view grasslands produce forage for domestic ruminants which convert indigestible crude fibres for human in highly valued food products of milk and meat. Ruminants also provide wool and leather. As a consequence of animal production there is a net removal of nutrients. Aside from the return of nutrients by deposed manure and urine of grazing animals, nutrients have to be added to compensate nutrient use by milk, meat and reproduction (gestation) and nutrient losses in soil and animal. Especially nitrogen (N) is relatively mobile and losses occur in the form of gasses N_2O (nitrous oxide) and NH_3 (ammonia) volatilization, $N0_3$ (nitrate) leaching and N_2 (nitrogen gas) volatilization. Therefore, uptake and recycling of nutrients have to be balanced, directly by additional fertilization using manure, chemical fertilizer or organic wastes (see paragraph 4.3.3) or indirectly by additional foraging. The uptake of nutrients by plants is highly dependent on temperature and soil moisture availability, which is a result of precipitation, evaporation, soil texture, soil organic matter content and rooting depth.

A schematic nutrient cycle is presented in Figure 2, illustrating the inputs and outputs and the main conversion processes.

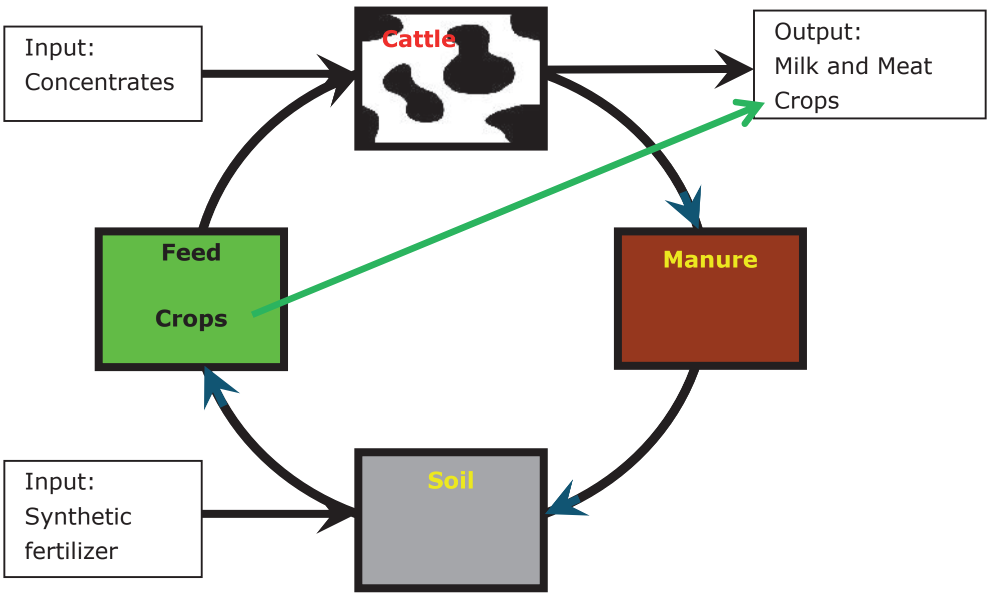


Figure 2. *Simplified scheme of nutrient cycling in livestock systems*

Livestock production per definition is accompanied with a loss of nutrients, which has to be compensated with sufficient inputs, whether this is supplementary feed (crop residuals, concentrates or co-products) or synthetic fertilizer. The use of legumes can supply N as well.

In livestock systems outputs consists of milk and/or meat. An important part of nutrients remain in the system due to the return of nutrients by manure. Nutrient surpluses accumulate in the soil by sequestration of organic matter or are lost by leaching, runoff or gaseous emissions in the case of N. Nutrient flows and nutrient mobility determine the amount of losses and the route of emissions.

Compared with grazing systems in mixed cropland systems (see definition Seré and Steinfeld (FAO, 1996) Chapter 2), the output versus the input of nutrients is substantially higher due to the direct exhaust of nutrients (see Figure 2). The prospects for crop growth are determined by the availability of natural resources and the possibilities for nutrient inputs. In the Sahel of West Africa plant nutrients for crop growing are provided by manure, which are mostly derived from grazing rangelands. According to Powell *et al.* (2004) livestock plays a major role in concentration and redistribution of nutrient resources both within and between farms, and in harvesting of forage (and nutrients) from areas of common land. The agricultural production was evaluated in semi-arid sub-Saharan Africa with a focus on West Africa. Most livestock derived their feed almost exclusively from natural rangeland and crop residues, and livestock manure was an important soil fertility amendment. However, most farmers had insufficient livestock and therefore manure to sustain food production. Nutrient harvests from cropland often exceed nutrient inputs, and soil nutrient depletion was a principal concern. Fertilizers are generally unavailable and are not used in most cropping systems. According to Powell *et al.* (1996) facing cropping in the Sahel, the principal challenge is how to achieve sustainable increases in grain production while maintaining or enhancing soil resources. Although animal manure is perhaps the most important soil fertility amendment farmers apply to cropland, the nutrient transfer mechanisms, and the ability of rangelands to support nutrient harvesting by livestock, are poorly understood.

On a regional scale, rangelands nutrient balances are in equilibrium (even in situations of intense grazing pressure, due to nitrogen returns by rain/dust, soil microorganisms), whereas croplands have a negative balance due to the offtakes of nutrients by crop products as food and crop residues as feed (Powel *et al.*, 1996). Livestock must be managed so they do not deplete the nutrient supply of rangelands in order to increase the manure supply for improving cropland productivity (Powel *et al.*, 1996). Corralling animals overnight on fields between cropping seasons is a possibility to reduce cropland deficits (Powell et al., 1996; Powell et al., 2004). Land use and tenure policies that inhibit livestock mobility and therefore, farmers' access to the manure of pastoralist herds, will greatly undermine the resilience of Sahelian rangelands. This increases the need for other external nutrient inputs such as fertilizers to prevent declines in soil fertility and crop yields (Powel *et al.*, 1996).

Furthermore, the available manure has to be used efficiently. Making the most efficient use of animal manures depends critically on improving manure handling and storage, and on synchrony of mineralisation with crop uptake (Rufino et al., 2006). Especially the urine fraction, which represents apparently one half of the N amount, is easily lost when animal husbandry is mostly sedentary with no facilities to collect manure (specifically urine) properly. The availability of manure and the efficiency of manure use is treated in Chapter 6.

When access to external nutrient inputs is limited, mixed farming can provide nutrients for crop growth with manure, while fodder crops and crop residues provide feed for livestock. There are many forms of mixed farming systems with different advantages and disadvantages. Opportunities for crop-animal systems exist in low and high input systems (Van Keulen and Schiere, 2004). According to Van Keulen and Schiere (2004), a good understanding of mixed farming can be achieved by using several forms of system thinking that focus on biophysical, socio-economic and dynamic aspects of system behaviour respectively and apparent contradictions between advantages and disadvantages. For the spatial and temporal changes in mixed farming, different driving forces can be identified, such as access to fossil fuel, introduction of synthetic fertilizers, population growth, increasing human welfare, market protection and price development.

Figure 3, derived from Van Keulen and Schiere (2004) and originally based on Breman and de Wit (1983), shows how in the semi-arid sub-Saharan Africa spatial and suggested temporal changes in mixed farming are related to average annual rainfall and increased population pressure. It was noted that rainfall as a 'driver' of system behaviour from North to South in Sub-Saharan conditions was similar to the US Great Plains (from East to West), the Indian sub-continent (across the Karachi - Bombay latitude), and the Western part of Australia (from North to South).

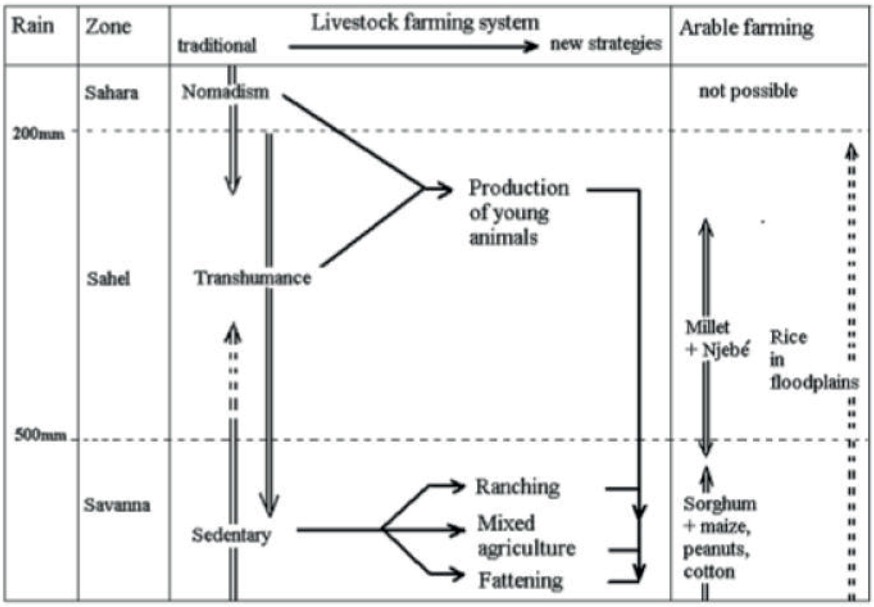


Figure 3. Spatial and suggested temporal changes in mixed farming in relation to average annual rainfall (top to bottom) and increased population pressure (left to right in central and right hand column (Van Keulen and Schiere, 2004), originally based on Breman and de Wit, 1983).

In Grasslands of the World (FAO, 2005) a wide variety of grassland systems are described where the majority of the systems have some interaction with crop production and fodder production or agro pastoralism. The exceptions to this include the grasslands systems in Mongolia, Tibet Autonomous Region, China and, to a lesser degree, Patagonia, which are purely pastoral. Cultivation of grassland has led to problems of access to water for stock and wildlife, loss of lean season grazing, obstruction of migration routes and fragmentation of wildlife habitat.

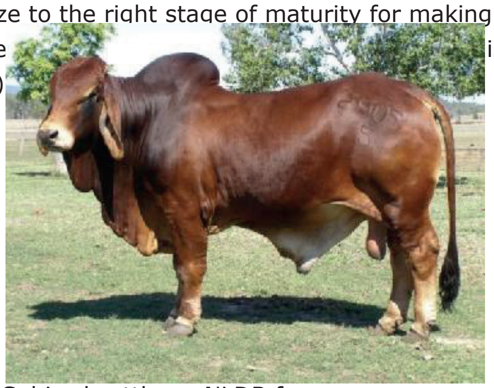
In OECD countries the change from traditional mixed and extensive systems to more intensive systems has probably had a positive effect in improving land- and water-use efficiency but negative effects on water pollution, energy consumption and genetic diversity (FAO, 2009a). Therefore intensification of production systems appears to be indispensable to provide in food security, but this is only sensible when this is done in a well-integrated manner to guarantee sustainable natural resource use.

In textbox 2.1 a case is described about the development of grazing lands in Sri Lanka to increase self-sufficiency in milk production. All aspects of production have to be examined following an integrated approach to improve production on an environmental and economic sustainable way. The main purpose is to increase the recourse efficiency.

Box 2.1. Development of grazing lands in Sri Lanka.
by Adriaan Vernooij, Wageningen UR Livestock Research
In spite of various research and development project, farm grown or improved pastures are not practiced to any great extent in Sri Lanka especially among smallholdings due to socio-economic limitations. These limitations are: unavailability of land, lack of inputs, lack of establishment and management experiences, low awareness of improved forage technology and poor animal production outcomes. However, among middle level holdings and large scale farms, there is a considerable trend for improved pasture and fodder utilization. The government of Sri Lanka stimulates medium to larger scale farms as part of the policies to increase self-sufficiency in milk production. Napier grass is the most commonly used fodder under small scale mixed farming circumstances. For grazing purposes, Guinea grass (Panicum maximum), has been introduced and become naturalized in most ecological zones, ecosystems and habitats with the exception of hilly and semi-arid parts of the country.

Cattle grazing on typical dry land zone land in Sri Lanka.

The National Livestock Development Board is the leading party stimulating larger scale farming, based on use of grazing lands as the main provision of fodder. The NLDB operates 28 medium to large scale farms. One of these, Menikpalana farm has 1148 cows. The total area is 757 ha., but only 155 ha fodder is grown with kikuyu, Brachystegia, Napier, maize and sorghum. This year 14 acres of sorghum was grown. In this area there was 5 months of rain, the fodder production went d ize to the right stage of maturity for making silage. R e is spread on th)



Guinea grass on research station   Sahiwal cattle on NLDB farm

Improving fodder production is one the main topics to be addressed in the future dairy development plans of Sri Lanka and training capacity is mobilised from universities and NLDB to jointly develop the capacity to improve the fodder base as part of the future milk production ambitions.
[Photos Adriaan Vernooij]

3.2.4 Grassland degradation

In a global assessment of land degradation and improvement (Bai *et al.*, 2008) which was based on long-term, remotely sensed normalized difference vegetation index (NDVI) data, results indicated land degradation on ca. 24% of the global land area with degrading areas mainly in Africa south of the equator, South-East Asia and south China, north-central Australia, the Pampas and swaths of the Siberian and north American taiga; 1.5 billion people live in these areas. Moreover degradation was over-represented in cropland at the global scale. Globally, there was little correlation (r = 0.12) between land degradation and the aridity index; 78% of degradation by area is in humid regions, 8% in the dry sub-humid, 9% in the semi-arid and 5% in arid and hyper-arid regions. Main sources of degradation were subsequently water erosion, wind erosion and mineral depletion. No specific information is mentioned in Bai *et al.* (2008) about grassland degradation, probably due to a lack of historical information as was noticed in FAO (2005). In the concerning report it was concluded that many grasslands are in poor condition. Most communally or traditionally managed grasslands show some degree of degradation, and many are seriously damaged. According to FAO (2006) about 20 percent of the world's pastures and rangelands, with 73 percent of rangelands in dry areas, have been degraded to some extent, mostly through overgrazing, compaction and erosion created by livestock action. Cultivating grassland can accelerate degradation of the remaining grassland (FAO, 2005), because it is usually the best soils and areas along watercourses and other water sources that are developed first. These soils have usually been lean-season or emergency grazing lands of pastoral groups and their clearing can upset grazing systems.

The aim of increasing food security can easily lead to an irresponsible expansion of livestock with the risk that grassland is not productive enough for forage supply, especially when nutrient supply and water availability is not sufficient. This can lead to grassland degradation and finally a less productive system. This actually happened in the Cerrado region in Brazil (Landers, 2007). The Cerrado region is one of the most important cattle production regions in Brazil. Regarding the Cerrado region agricultural activities are livestock production based upon grazing the Cerrado combined with cropping soybean and maize. Grasslands in the Cerrado can roughly be divided into two types: native grasslands and improved pastures with Brachiaria (Urochloa spp.) being the main sown species. These pastures have been established from the mid 70's by ploughing Cerrado and sowing Brachiaria (Landers, 2007). Soils in the Cerrado are relatively poor and soil fertility is highly dependent on soil organic matter. Most soils have originally low pH and low P too. P fertilization and liming are a must for a reasonable agronomic productivity. Due to poor grassland management and particularly overgrazing, grasslands in the Cerrado, both native and pasture with Brachiaria, became degraded.

A restoration program should stop degradation and increase productivity. Recent studies in AnimalChange confirmed that pasture restoration is the most promising measure to reduce GHG for the cattle sector in Brazil (Barioni, 2013), from both economic and carbon point of view. There are different types of pasture degradation. One that is very typical in the Cerrado is related to decreasing soil fertility caused by nutrient exhaustion, usually N. After deforestation, there is usually a reasonable quantity of N and other nutrients due to mineralization of Soil Organic Matter (SOM). But mineralization decreases over time and so does pasture productivity. When stocking rates are not adjusted for the decreasing productivity, overgrazing speeds up pasture degradation. Taking degradation of soil fertility, research should be carried out in defining optimum levels of inputs and productivity for each region so that farmers can better adjust stocking rates and inputs to a level that is economical and environmentally sound. The lack of good models for predicting pasture productivity and herbage mass monitoring methods is a problem in this context. Soil C dynamics should be part of these models. There are no models that have been extensively tested in Brazilian grasslands conditions. Of course data on soil C dynamics for grasslands would be crucial as shown in AnimalChange with the development of the model coined EAGGLE.

With the background of technical matters like soil fertility, grass productivity and adjusting stocking rates, socio-economic aspects play an important role in grassland degradation. According to FAO (2006) overgrazing can be reduced by implementing grazing fees and by removing obstacles to mobility on common property pastures. Land degradation can be limited and reversed through soil conservation methods, silvopastoralism, better management of grazing systems, limits to uncontrolled burning by pastoralists and controlled exclusion from sensitive areas.
Easdale *et al*. (2014) emphasize that degradation in arid rangelands is a complex socio-ecological problem because it appears to be trapped in a vicious circle of desertification-marginalization-impoverishment. Three global political and economic factors are considered to have strongly contributed to the marginalization of arid rangelands and their products: (1) worldwide application of western-anchored paradigms in resource management and their effect on rangelands, (2) the fossil fuel based Green Revolution, and (3) capitalism concepts used to regulate agricultural trade and corresponding tools and policies. Opportunities to end this marginalization-desertification spiral at the international scale include the implementation of real changes in the current general economic rationale under which resources are allocated, and raising awareness about environmental side-effects and product quality.

3.3 Carbon sequestration

In White *et al.* (2000) carbon stores were assessed in grasslands and other terrestrial ecosystems. Grasslands store approximately 34 percent of the global stock of carbon (C) in terrestrial ecosystems while forests store approximately 39 percent and agro-ecosystems approximately 17 percent. By far the largest pool is the soil organic matter, which accounts for approximately two-thirds of the total C pool with approximately 9 kg $C.m^{-2}$. More C is stored in high- and low-latitude grasslands than in mid-latitude grasslands. In high latitudes, grassland soils high in organic matter make up this difference; in low latitudes, grassland vegetation is more extensive than in mid-latitudes. The large amount of land area covered by grasslands as well as the relatively unexplored potential for grassland soils to store C, has increased interest in the C cycles of these ecosystems. According to IPCC (2006) the C cycle includes changes in C stocks due to both continuous processes (i.e., growth, decay) and discrete events (i.e., disturbances like harvest, fire, insect outbreaks, land-use change and other events). Continuous processes can affect C stocks in all areas in each year, while discrete events (i.e., disturbances) cause emissions and redistribute ecosystem C in specific areas (i.e., where the disturbance occurs) and in the year of the event.

According to FAO (2010) chapter VII (Amezquita *et al*.) research results indicate that improved and well-managed pasture and silvopastoral systems should be regarded as attractive alternatives from the economic and environmental viewpoints, especially because of their capacity to recover degraded areas and their potential to sequester C. In addition in Smits *et al*. (2008) restoration of degraded lands is mentioned as a prominent agricultural practice to mitigate greenhouse gas emissions. The findings of five years of research (2002–2007) targeting tropical ecosystems suggested that in terms of C accumulated in the total system (soil + plant biomass), the native forest presented the highest levels of all land uses in all ecosystems, followed by improved pasture, a silvopastoral system, natural regeneration of degraded pastures and, finally, degraded pasture or soils. The C accumulated in the soil accounts for a very high percentage of the total C of the system: 61.7 percent in native forest, 90 percent in a silvopastoral system and 95–98 percent in pasture systems). In terms of carbon accumulated in the soil, improved, well-managed pasture and silvopastoral systems showed comparable or even higher levels than the native forest, depending on local climatic and environmental conditions. The research results generated by the concerning international project have been published also in Mannetje *et al.* (2008).

The main factors that influence the accumulation and sequestration of C according to FAO (2010) Chapter I (Jones) are past and current land-use changes; agricultural management, including the horizontal transfer of hay/silage and manure deposition and application, soil texture, vegetation composition and climate. The amount of organic matter in the soil at a given moment is the net result of additions from plant and animal residues and the losses through decomposition. The C in the soil is present in a complex association with the soil particles and it is the nature of this relationship that ultimately determines how long the C remains in the soil and therefore the C sequestration potential of the soil.

Grasslands accumulate soil organic C and N over time until an equilibrium is achieved. Regular renovation induces temporary losses of organic C and N, somewhat lowering the equilibrium level. Converting grasslands to croplands leads to significant losses of organic soil C and N and the equilibrium level of soil organic C will be significant lower. In Vellinga and Hoving (2012), patterns of accumulation and losses of soil organic C and N were shown over time for permanent grassland. This grassland is regularly renovated by ploughing, while 50-year-old grassland is ploughed and converted to arable or ley arable systems with different rotational length (see Figure 4). The concerning process of accumulation and loss of soil organic C and N was based on the Introductory Carbon Balance Model (ICBM) by Andren and Kätterer (1997). This model consists of a long term process of decades that determines the equilibrium level and the short term process of a few years that determines the loss of soil organic C and N due to the land use type; the release of soil organic matter during the short arable phase and the sequestration of C and N during the subsequent short grassland phase lead to a deviation around the long term equilibrium. The long term equilibrium level and the deviation around it depend both on the number of years of grassland and arable in the rotation.

Figure 4. Patterns of soil organic C and N accumulation and losses on permanent grassland over time for (1) situations with regular renovation by plowing and (2) plowing of 50 year old grassland and converting it to arable or ley systems with different rotation lengths. ‘‘Actual’’ losses from conversion, rotation and renovation and so-called ‘‘potential’’ losses are distinguished. The latter represents the

continued N accumulation on grassland until equilibrium conditions are reached (Vellinga and Hoving, 2010).

In Sousana *et al.* (2009) the following range of management practices are given to reduce C losses and to increase C sequestration for temperate managed grasslands, focusing on Europe: (i) avoiding soil tillage and the conversion of grasslands to arable use, (ii) moderately intensifying nutrient-poor permanent grasslands, (iii) using light grazing instead of heavy grazing, (iv) increasing the duration of grass leys; (v) converting grass leys to grass-legume mixtures or to permanent grasslands.

According to FAO (2010), improved grazing land management may prove to be a cost-effective method for C sequestration, particularly taking into account the side benefits of soil improvement and restoration and related social and economic benefits for livestock keepers.
In FAO (2010) it is recommended that research, practice and policy strategies must simultaneously be put in place to fully establish the appreciation for and use of grasslands and silvopastoral systems as a significant means of increasing ecosystem health and food and nutrition security, and also to ensure that grassland managers are recognized for their contribution to sustainable food-producing landscapes.

3.4 Adaptation and mitigation

Because of the wide range in variety of grassland systems, each specific situation demands its own solution to adapt to short and long-term climate shifts. In general, adaptation occurs by adjusting grassland use to grassland productivity. Seasonality of forage supply is characteristic for almost all grazing lands (FAO, 2005). To deal with lean seasons (winter or dry season), sufficient forage supply, by making hay or silage, is an important measure for improving sustainable grassland use.

In pastoral systems, livestock mobility is crucial to provide sufficient forage supply. It promotes optimal utilization of spatially heterogeneous availability of forage and water resources. Mobility also avoids degradation as it allows herdsmen to move their animals around and thus balance the stocking rate with the availability of rangeland resources (Ayantunde *et al.*, 2011). Furthermore, when there is limited access to markets, it is not possible to sell livestock in extreme drought events. This restrains adjusting livestock intensity to forage availability.

Grassland use and grassland development are linked, directly or indirectly, to the status, trends and opportunities of livestock and livestock product markets (FAO, 2000). According to FAO (2000) grasslands are dynamic ecosystems and therefore are often a changing resource. Short- and long-term shifts in climate affect their productivity and must be accepted as a feature of the system if sustainable use is to be realized. Furthermore, technical solutions cannot be expected to restore "balance" to the system; population pressures and unrealistic expectations of the productive capacity of the resource must first be addressed. The concerning FAO report focusses on pastoralism and shows an integrated approach to land, forage and livestock resource assessment that facilitates quantification of the resources, understanding of resource component inter-relationships, prediction of environmental impact, estimation of livestock support capacity, and appraisal of development options.

3.5 Research questions

- How to organise management and governance systems to get more insight into the productivity of grassland according to the available natural resources and the possibilities of livestock use?
- Hence, can the landscape approach (FAO, 2013) be of value?
- How to organise practical education/stimulation programs for smallholders to improve nutrient management, forage supply and making hay or silage (especially to deal with lean seasons)?
- How to improve C sequestration in the soil organic matter? Insight into soil C dynamics related to grassland use, soil fertility, nutrient use and climate is desired.

4 Adaptation of livestock systems to climate change

4.1 Breeding

4.1.1 Introduction

Global human population is expected to increase to 9 billion people in 2050. Due to the growing population size, growing incomes and changing consumer behaviour, we also expect an increased demand for animal products or animal protein. Given the limited carrying capacity of planet earth this would imply that efficiency of animal protein production should increase and at the same time ecological footprints should be reduced. Projections of temperature rise and increase of CO_2 concentrations (IPCC, 2007) indicate that both mitigation and adaptation responses and actions will be required (Gerber *et al.,* 2013). Further improvements can be expected from breeding and feeding to increase the efficiency per unit of product. In this context the efficiency loss due to health problems should not be underestimated. The OIE (World Organisation for Animal Health) estimated for example that about 20% of production loss is due to unhealthy animals.

Sustainable intensification, adaptation to current and future production environments, and competition for natural resources are key issues for the global production of animal protein, and also for the farmers and livelihoods dependent on livestock. Improvement of genetic resources that are efficient and well adapted to extreme temperatures, low quality diets and greater disease challenges is needed to deal with those challenges.

4.1.2 Breeding solutions

In general, enhanced productivity levels and intensification will also result in lower greenhouse gas emissions per unit of product. One of the assumptions here is that certain breeds or genetic resources are well adapted to local production environments. This may become more vulnerable when climate change will result in more variable and extreme circumstances. Locally adapted breeds have been developed over centuries and are well adapted to the local climate. However, production levels of local breeds are usually lower, compared to specialized, more widely used breeds.
For the main livestock sectors there are relatively small numbers of breeding companies or breeding organisations that are global providers of high quality, specialized breeding stock, and they are mainly situated in OECD countries (e.g. the United States of America, Canada, Australia, New Zealand, France, Germany and The Netherlands). The global supply of breeding material is business driven with a fierce competition between breeding companies. The demand driven supply of breeding material contributes to more productive and efficient livestock production and to global food security under sufficient conditions.
Through crossbreeding strategies between local breeds and specialized breeds, the productivity gap between both categories of breeds can be reduced in a short period of time. However, often, complete replacement of local breeds by specialized, high productive breeds is not a sustainable strategy in the long run. Balanced crossbreeding strategies are needed because highly productive, specialized breeds often cannot keep their expected productivity in more extreme climatic or endemic disease situations. Especially breeds heat stress in tropical or sub-tropical regions can cause disappointing results for specialized, highly productive breeds in the long run. Because of heat stress, highly productive breeds often produce at the expense of health and vitality with the risk of being replaced much faster than locally adapted breeds.
Although crossbreeding strategies can be beneficial, in practice they are often not sustainable in the long run. Successful crossbreeding strategies require proper planning of pure breeding and cross-breeding, or development of synthetic breeds.

Quick replacement of locally adapted breeds by 'indiscriminate' cross-breeding should be avoided, due to the loss of adapted traits and lower economic benefits.

Breeding policies of tropical countries or countries with extreme or variable conditions should be directed towards increasing productivity based on well-considered breeding programmes paying strict attention to climate adaptive qualities of local breeds. One strategy is to improve productivity of locally adapted breeds. Crossbreeding techniques are mostly used to increase productivity faster, but with this approach it is important to maintain a good balance between productivity and securing climate adaptive qualities as well. In addition to the improvement of well-adapted local breeds, new or synthetics breeds could be developed to fit the needs of farmers in specific environments.

4.1.3 Developing more productive climate adaptive breeds

Well-considered breeding programmes are needed to develop breeds that have a higher production while maintaining climate adaptive qualities*.* Breeding programmes are long term investments, while there is often a short term focus to increase production and lack of long term policies. For breeding companies, developing specific breeds for specific environments is costly and often not economically feasible for the breeding industry to invest in. To bridge public and private interests, breeding programmes could be initiated by Public Private Partnerships and investments of leading breeding companies in tropical countries or countries with extreme or variable climates. In practice this seems to be hard to organise, especially when government interest and government investments are limited. Specifically countries with capital are able to invest in long term breeding programmes. A good example of a successful new synthetic breed of dairy cattle, that is productive and well adapted to tropical environments, is the "Girolando" (see Box 4.1.1).

Box 4.1.1 New created breed Girolando

The Girolando is created in Brazil by crossing Gir cattle with Holstein bulls. Gir cattle is one of the principal Zebu breeds originating in India and is resistant to high temperatures and tropical diseases. The Girolando is known for its good productivity and adaptation to tropical climate. One of the leading Dutch breeding companies CRV has also developed business and a breeding program in Brazil and is also involved in breeding of Girolando cattle and marketing of semen of Girolando.

[Photo Arthur Mariante, Brazil]

4.1.4 Management solutions

The impact of extreme and variable climate conditions like heat stress can be reduced by housing and management measures. Proper housing can prevent heat stress especially when temperature and air refreshment rate can be regulated. However, this is only feasible for capital-intensive livestock systems. In countries where capital is available, industrial, specialized breeds can effectively increase production more or less independent of climate conditions. The global providers of high quality genetic material sell their genetic products often together with advice to customers about proper housing and management. Improvement of housing and management can be seen as a climate adaptive measure by itself.

Box 4.1.2 Pig breeding in Brazil

Brazilian pork production is mainly based on feeding energy dense diets (corn and soy), to growing-finishing pigs. Corn is also increasingly used as an input for renewable fuels. As soy can be used directly for human consumption, it faces an increasing demand on the global market. Moreover, both corn and soy are competing for arable land with other crops. This can potentially increase the costs of Brazilian pork and also its environmental impact. The dependence on corn and soy can be decreased by searching for alternative ingredients, potentially with different characteristics. For instance, more fibre in pig feed will yield more internal heat production, which is especially counterproductive in the tropical climate in parts of Brazil. This implies, that next to searching for alternative feed ingredients, genetic selection can increase feed efficiency, which helps the pork sector to be more sustainable. The use of natural resources will decrease as well as the dependency for soy and corn on the global market.

4.1.5 The global need for more robust animals

Herbivores in sub-tropical and tropical areas are the most vulnerable and are directly affected by climate change. From the perspective of food security the aim is to increase productivity. In the case of extreme or variable climate conditions, production increase is only possible by using well adapted breeds. Locally adapted breeds will continue to play an important role as a genetic resource base for (cross)breeding programmes to enhance productivity. In developed – northern located – countries the trend is also to increase sustainability of highly productive cattle by improving robustness, fertility, longevity and health traits. These traits have become more important for farmers in developed countries and in temperate climates. Farmers increasingly demand cattle with less health problems and – due to increasing farm size – cows that require less individual attention. More robust breeds in general have larger adaptive possibilities to short term climate fluctuations that could also be expected in more temperate climates.

Box 4.1.3 Indian National Dairy Plan

The aim of the Indian National Dairy Plan (NDP), implemented by the National Dairy Development Board (NDDB) is to increase productivity in existing herds through a focused programme for breeding and feeding (see also Appendix 2). This will be achieved by improved genetics of milk producing animals in a consistent and continuous manner and by optimized use of scarce natural resources. By the end of the NDP it is planned to have high genetic merit bulls available at semen stations for semen production. A set of breeds has been identified to be included in a progeny testing program (Holstein Friesian, Holstein Friesian crossbred, Jersey crossbred, Sunandini cattle and Murrah and Mehsana buffalo), and another set of breeds for pedigree selection programmes (including Rathi, Kankrej, Tharparkar, Gir, Sahiwal, Hariana, Nili Ravi, Jaffarbadi, Banni and Pandharpuri buffalo). More info at: http://www.nddb.org

4.1.6 Integrated system approach

Taking into account the need to increase productivity in dairy animals, together with climate change projections, there is an urgent need to strengthen collaborative research in genetics and nutrition. In other words, to better utilize genetic diversity, to improve thermal tolerance and robustness of animals, and to make optimal use of available natural resources. More research is needed on both animals *as systems* and animals *in systems*. An integrated approach is needed to improve efficiency and robustness of animals in the dairy sector.
The 'genomic revolution' offers new opportunities to understand genetic variation and to utilize genetic variation for improvement of efficiency and health of dairy animals. With genomic information it will be possible to predict – early in life – the productivity and health in different production environments. From a global perspective, breeding goals may have to be adjusted to account for higher temperatures, lower quality diets and greater disease challenges. Species and breeds that are well adapted to such conditions may become more widely used. Although *Bos Taurus* breeds are generally speaking productive dairy breeds, *Bos Indicus* breeds have other important features related to heat stress and disease tolerance (Hoffmann, 2010; Banos *et al.,* 2013; Piper *et al.*, 2009).

There is a need to further develop scientific knowledge and to use the latest technology to improve productivity and adaptive traits, in order to breed more robust animals for different production environments and climatic conditions. An important question for tropical and subtropical environments is how to organise long term breeding strategies that will contribute to food security and that will fit farmer needs. In this context, collection of quality data on all relevant traits is one of the most relevant components of a successful breeding program. One suggestion is to set up Public Private Partnerships between breeding industry and national governments, to implement breeding programmes and to organise data collection. GRA and FAO can play an important role to propagate those development perspectives.

4.1.7 Research question

- How to organise (cross)breeding programmes (at a national level) to breed animals which are well-adapted to local production environments and can cope with changing and extreme climatic circumstances? Establishing Public Private Partnerships between breeding industry and national governments or institutions is an effective approach to deal with this challenge.

4.2 Health

4.2.1 Introduction

Livestock diseases reduce productivity, can infect humans and harm animal welfare. Livestock production contributes to farm livelihood in developing countries and provides in the growing global demand of meat and milk (FAO, 2006). It is likely that climate change is affecting the distribution and seasonality of important infectious diseases, because the transmission of infectious diseases is strongly influenced by temperature, humidity, and rainfall (Patz and Uejio in Institute of Medicine, 2008). This impacts both animal and human health. Nevertheless there is still a lack of strong evidence of the impact of climate change on vector-borne diseases (Kovats *et al*., 2001 and Laferty *et al.*, 2009).

Among the list of animal diseases, arthropods and water-borne diseases are the most vulnerable to climate change. Current evidence suggests that inter-annual and inter-decadal climate variability have a direct influence on the epidemiology of vector-borne diseases (Githeko *et al.*, 2000). In addition, it is generally accepted that the geographic range of vectors is changing. Viruses transmitted by arthropod vectors like Bluetongue Virus and West Nile Virus recently moved northwards to the northern hemisphere. It is unknown if the manifestation of intestinal parasites is geographically changing. More obvious is that the susceptibility to parasites and also to bacterial and viral pathogens will increase due to higher temperatures and extreme weather events, mainly in arid tropical and subtropical areas. Van den Bossche and Coetzer (2008) stated that temperature and humidity changes will also affect the spatial and temporal distribution of the pathogens of non-vector borne diseases (see paragraph Non-vector borne diseases).

4.2.2 Vector borne diseases

In Institute of Medicine (2008) vector-borne diseases are described as follows:
"From the perspective of infectious diseases, vectors are the transmitters of disease-causing organisms; that is, they carry pathogens from one host to another. By common usage, vectors are normally considered to be invertebrate animals, usually arthropods, but they may also include fomites (an inanimate object or substance), or rodents which carry the agent from a reservoir to a susceptible host. Vectors of human disease are typically species of mosquitoes and ticks that are able to transmit viruses, bacteria, or parasites to humans and other warm-blooded hosts."

Agriculturally important vector-borne diseases are Bluetongue, Rift Valley Fever (RVF), African trypanosomiasis, West Nile Virus, and avian influenza. Vectors of livestock diseases are mosquitoes, ticks and midges that transmit Bluetongue Virus and Schmallenberg Virus. Infectious diseases are transmitted either actively by biting or passively by flies which can pick up infectious agents on the outside of their bodies and transmit these through physical contact. Many vector-borne diseases also have zoonotic potential. Zoonotic diseases are diseases of vertebrate animals that can be transmitted to humans. These include for example Lyme disease, tick-borne encephalitis, West Nile virus, Leishmaniasis and Crimean-Congo haemorrhagic fever. An overview of common vector-borne infections of man and animals is given in Appendix 3, Table 1 (Hunter, 2003; Gubler, 2009).

According to Tomley and Shirley (2009) infectious diseases of livestock are a major threat to global animal health and welfare and their effective control is crucial for agronomic health, for safeguarding and securing national and international food supplies and for alleviating rural poverty in developing countries.

The transmission range of vector-borne diseases is affected by factors like travel of humans, international trade, migratory birds and animal movement (livestock) that introduces new geographic areas (Institute of Medicine,2008). Well-known examples of viruses that have recently expanded their geographic range are West Nile Virus and Dengue. Many infectious diseases are strongly influenced by seasonal or anomalous changes in weather, which suggests that they would also be influenced by longer term climatic changes (Patz *et al.*, 2000). Actually, the influence of climate change on changing geographic ranges for Bluetongue Virus and West Nile Virus has been published in more recent papers (see next paragraph).

4.2.3 Climate change

*Vector- and water-borne disease*s
According to the IPCC (2007) the frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour. It is very likely that hot extremes and heavy precipitation events will continue to become more frequent. Therefore not only higher temperatures but also heavy precipitation events and flooding, will enlarge the risk of outbreaks of diseases transmitted by arthropod vectors and waterborne vectors. In Hunter (2003) the potential impact on human health from primarily waterborne infections is considered under the headings; heavy rainfall events, flooding and increased temperature. Relations between those events and outbreaks of diseases are described. Examples of water and sanitation borne diseases are Toxoplasmosis (protozoa), cholera, Hepatitis A and E, Salmonellosis and Campylobacteriosis (bacteria). An overview of microbial pathogens linked to drinking water or recreational water contact is given in Appendix 3, Table 2 (Hunter, 2003).

Purse *et al*. (2006) suggested that the spread of Bluetongue Virus (BTV) since 1998 across 12 countries and 800 km further north in Europe has been driven by recent climate changes in the European climate, which have allowed increased virus persistence during winter. Changes in BTV incidence were shown more likely to be associated with spatio-temporal changes in temperature than changes in other factors, such as agricultural land-use, animal health systems, increases in livestock

trade and increases in host density. It was also stated by Purse *et al.* (2006) that, unless the redefined distributional limits of BTV and its vectors in Europe, local transmission risk will depend on complex local interactions between a range of abiotic and biotic factors. The challenge is to understand these interactions at a finer spatial resolution for risk prediction.
Lafferty (2009) found little evidence that climate change has already favoured infectious diseases (historical yellow fever epidemics in the United States), but specified that many factors can affect infectious disease, and some may overshadow the effects of climate.
According to Van den Bossche and Coetzer (2008), for the African situation there is also much evidence of associations between climatic conditions and infectious diseases, but estimating the real impact of climate change on livestock health over a long period of time is challenging. For example, it is difficult to separate non-climatic from climatic influences.

Non-vector-borne diseases
Temperature and humidity changes will affect the spatial and temporal distribution of the pathogens of non-vector borne diseases that spend a period of time outside the host and are thus very sensitive to such changes (Van den Bossche and Coetzer, 2008). These pathogens include:

- the infective spores of anthrax and blackleg
- the viruses causing peste des petits ruminants (PPR) and foot and mouth disease (FMD), contained in wind-borne aerosol droplets
- the agents causing dermatophilosis, haemorrhagic septicaemia, coccidiosis and haemonchosis.

On the one hand wet conditions due to excessive rainfall directly provide a favourable environment for growth of bacteria and the development of diseases like dermatophilosis. Indirectly excessive rainfall create temporary water bodies in which the intermediate snail host of *F. hepatica* survives or provide floods which enlarges the risk of diseases like foot rot (Van den Bossche and Coetzer, 2008). Also outbreak of directly transmitted viruses have been reported to be associated with the rainfall season (Murray *et al.*, 2012)

On the other hand drought can also enlarge the risk of spreading directly-transmitted diseases between animals. Drinking water and grazing shortage causes mass movements of livestock and wildlife, animal congregations and sharing of water and food resources contribute substantially to the spread of important African transboundary diseases, such as FMD, PPR and contagious bovine pleuropneumonia (Van den Bossche and Coetzer, 2008). Also soil-borne diseases, such as anthrax, can occur during drought, especially in overgrazed or very dry areas.

4.2.4 How to adapt?

Anticipating on plausibly changing risks by climate change is out of the range of influence of individual farmers and should be of concern of governmental policy. In low productive non-western livestock systems, frequent diseases are tolerated and therefore productivity could be increased by pest and disease control. From the perspective of animal health, it is mainly the deficit of available (financial) means that stops the efficiency improvement of livestock production and it is not primarily a lack of veterinary knowledge. Finally food security should be the driving force to address the need of improving animal health and not only climate change adaptation. In general livestock owners may benefit from developing appropriate policy measures and institutional support to cope with all animal health problems. Although climate change can enlarge the need of animal health care, it does not directly ask for new veterinary knowledge.

Semenza and Menne (2009) proposed to build an integrated network for environmental and epidemiological data for multivariate analyses and predictions. Insights from these analyses could guide adaptation strategies and protect population health from impending threats related to climate change. Essentially, adaptation to climate change and variability will depend to a certain extent on the level of human and animal health infrastructure in the affected regions (Githeko et al., 2000; Forman et al., 2008; Van den Bossche and Coetzer, 2008).

Developing an effective animal health service, associated surveillance and emergency preparedness systems and disease control and prevention programmes is perhaps the most important strategy for dealing with climate change in many African countries (Van den Bossche and Coetzer, 2008). According to Forman et al. (2008), in Asian developing countries the need for strong and efficient veterinary services is irrefutable, combined with good coordination of public health services, as many emerging human diseases are zoonosis. It is also stated that Asian developing countries have acute weaknesses in their veterinary services, which jeopardises the global surveillance network essential for early detection of hazards. Indeed, international cooperation within and outside of Asia is vital for mitigating the risks of climate change on animal health in Asia. Those findings are probably not only related to Asian developing countries but to developing countries in general.

4.2.5 Research questions

- How to assess the impact of climate change on vector borne-diseases?
- How to set up or improve risk management of occurring and spreading infectious diseases in the framework of climate change as well as food security?
- How to organise an effective and sustainable animal health service in developing countries, with adequate disease control and prevention programmes

4.3 Housing

4.3.1 Introduction

Housing can be part of a livestock production system but the necessity of a stable depends on the livestock species, the intensity of the production system and the environmental factors in the broadest sense like climate zone, economic reality, labour availability, cultural system, etc..
To evaluate the need of housing as a result of climate change, or the effect of climate change on animals and humans in an already existing housing system, it makes sense to look at the functions of livestock housing. Livestock housing might be a prestige item but the only real function of housing is to match the needs of animals and humans compared to a situation without housing. Those needs can be:

- Protection from heat (sun), cold, wind, rain, mud
- Isolation from other farm animals, humans, predators
- Provision with feed, water, comfort
- Prevention of feed wastage, injuries, animal waste spoilage
- Improvement of ease of feeding, handling, milking, feeding, cleaning
- Higher productivity / reduced inputs

From the perspective of climate change it is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent (IPCC, 2007). Therefore more protection of livestock from extreme climatic influences is needed and (simple forms of) housing can contribute to this. Besides higher temperatures and higher humidity, there may be increasing health risk and decreasing product quality. This demands for climate control by a suitable natural ventilation system; adequate refreshment of air and air movement at the animal level. In this chapter we did not work out mechanical ventilation although this is an important item in industrial livestock production. We placed housing in a wider context as adaptation measure to climate change. Introducing housing in extensive livestock systems like grazing and mixed farm systems has drastic consequences, because it is completely changing the livestock system. Instead of livestock gathering feed by itself, feed has to be supplied and manure has to be removed. Also the demand for labour changes. Thus housing cannot be an aim in itself but is part of a system.

4.3.2 Housing as part of a livestock system

An indirect effect of climate change can be a reduction of local feed availability due to drought, which can be a serious effect of climate change. Especially grazing animals like cattle, dairy cows, buffaloes, camels and small ruminants have to cover larger distances to feed themselves. The consequence is a

higher risk of overgrazing. Also the amount of crop residues available for animal feeding can be reduced by drought. For smallholder farmers this leads to inefficient livestock production and specialization can be needed to improve production from the perspective of food security (see next paragraph).
In general housing is introduced 1) when feed availability during grazing is uncertain and additional feed has to be supplied/bought, 2) when rainfall, heat stress and humidity is harming livestock productivity and 3) to improve nutrient efficiency on the level of animal and soil. The availability of economic means is an important precondition.

Ad. 1. In proportion to the need of additional feed, feed has to be transported over bigger distances or even has to be imported as is common in western countries, especially in industrialized livestock systems. Materials like soybeans, rape seed, corn, wheat, barley, etc. are imported to produce feed concentrates. Perishable wet by-products and roughages are mostly locally available. Expertise is needed to manage transport, storage and conservation of perishable products and to compose feed rations.

Ad. 2. Heat stress and high humidity influence the cost of productivity especially concerning lactating dairy. Shading by sheltering and eventually additional cooling by using the shade provided by trees or by sprinkling the roof with water, can improve the living conditions and therefore production can increase. The higher the potential productivity of animals, the more important is it to protect animals from extreme climatic influences. Introducing highly productive crossbreds or purebreds significantly enlarges the need for housing. Khongdee *et al*. (2010) found that under arid conditions Friesian crossbred cows housed under modified roofing (shade cloth vs. normal roof) produced significantly more milk than cows housed under normal roofing.

Ad. 3. Especially when the local soil fertility is poor, housing can help to concentrate the availability of nutrients by storing manure and supplying manure geared to the nutrient needs at different stages of crop growth. Unfortunately manure is often seen as a waste and is not treated as a valuable fertilizer for food and feed production. The undesired practice of getting rid of manure by dumping can cause nuisance and environmental pollution.

Disadvantages of housing are the introduction of extra losses of ammonia due to direct contact between manure and urine and the emission of non-CO_2 greenhouse gasses methane which mainly releases from the anaerobic storage of liquid manure, and nitrous oxide, mainly from aerobic storage of solid manure and after manure application. Under tropic or sub-tropic conditions, ammonia losses are relatively high due to high temperatures. Most of the inorganic nitrogen is lost very quickly and is not available for crop growth. Manure treatment like anaerobic digestion to produce biogas (with 60 % methane) as an energy source is seen as an effective climate mitigation measure to reduce methane emission (FAO, 2013).

4.3.3 Housing and livestock productivity

Housing can play a crucial role in increasing food production, due to improved nutrient use efficiency (soil and animal) and protecting animals from extreme climatic influences, which subsequently can be necessary for the introduction of high(er) production breeds. Farmers in the Ea Kar district, Vietnam adapted a stall-fed system to specialize beef production by fattening cattle and cow-calf production (Stur *et al.*, 2013). A low input grazing system has been transformed to a farm-grown fodder system. To further improve the growth rate of cattle, supplementary feeding was introduced using cassava meal, rice bran and other farm-grown crops and crop by-products. How those farmers provided the nutrients for crop growth was not mentioned but obviously this is a crucial aspect of increasing productivity.
Given the moisture availability for crop growth, nutrient availability is an important limiting condition to increase livestock production. This can be improved either directly by an improved feed supply or indirectly by nutrient supply in kind of organic or inorganic fertilizer or organic wastes derived from industrial, fodder and food cycles (Kirchmann *et al.*, 2004). In figure 5 the recycling of plant nutrients and the role of animals (livestock) is shown.

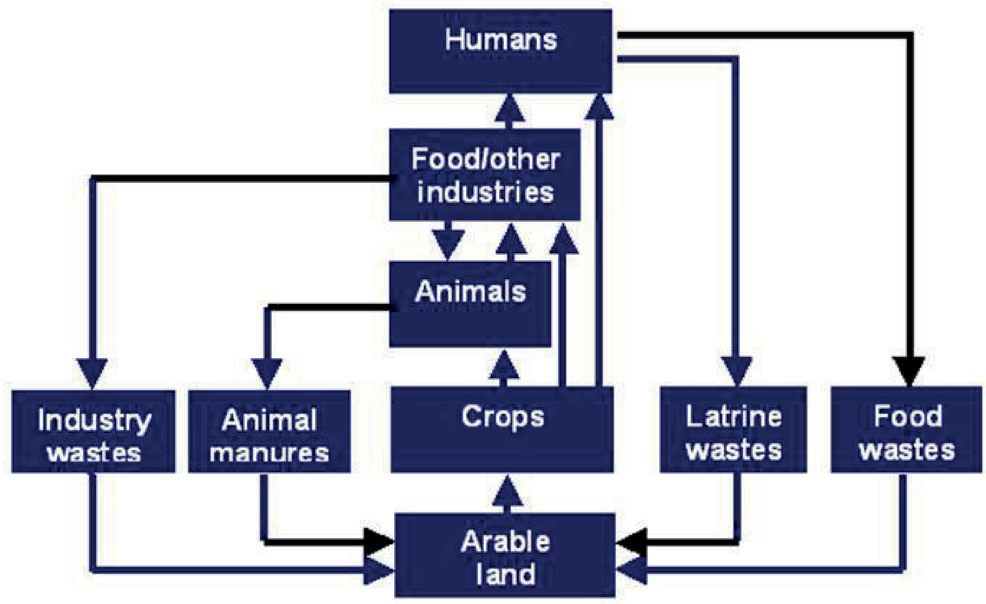


Figure 5. *Recycling of plant nutrients through wastes derived from the industry, fodder and food wastes (adapted from Kirchmann et al., 2004) and the role of human and animal waste (livestock). Input of extra nutrients is a limiting condition for extra crop and livestock production.*

Parrot et al. (2009) found that the closer farmers live to their crop field, the more likely they will adopt the practice of using domestic wastes for agricultural purposes. Consistent to this, Giller et al. (2006) found that manure is applied to fields close to the homestead. This probably means that also on a higher geographic level, distance will play an important role in applying urban waste in agriculture.

4.3.4 Nutrient use efficiency

As a consequence of intensifying livestock by improved housing, feed, manure and waste products have to be stored, (possibly) processed and transported in order to use nutrients efficiently. Especially storing and processing of feed needs to be done properly to prevent nutrient losses and to save costs. Perishable fresh by-products that are not directly supplied to livestock may have to be conserved by drying or ensiling to prevent decay. Expert knowledge is needed to properly manage conservation. When silage pits are not hermetically packed they will start to rot and the nutritional value will decline rapidly. Provision of housing means that livestock is not foraging themselves but that farmers have to compose a feed ration of different available materials. This is also asking for intimate knowledge of animal nutrition.

Manure has to be considered as a valuable fertilizer for crop growth. This means that nutrient losses should be avoided. On the one hand nutrient losses pollute the environment and on the other hand those losses are not available for production. A proper (concrete and covered) manure storage prevents draining away of the liquid fraction. Also other organic wastes need to be stored when they can easily contribute to pollution and cannot be directly applied on crop or grazing land. Making the most efficient use of animal manures depends critically on improving manure handling and storage, and on synchrony of mineralisation with crop uptake (Rufino et al., 2006). For smallholder farmers in Africa efficient management of nutrients in manure is a key to improved crop production because manure is often the only input available (Rufino et al., 2007). Manure provides a wide range of nutrients like N, P, K, Mg, Ca, S, Zn, Cu, Co, Se and organic matter C.

According to Giller et al. (2006) spatial patterns of resource use are consistent across different tropical farming systems. Farmers preferentially allocate manure, mineral fertilizers and labour to fields close to the homestead, resulting in strong negative soil fertility gradients away from the homestead. This means that intensifying livestock easily can increase the spatial difference in resource use, which leads to inefficient nutrient use and eventually environmental pollution. Intensifying livestock should increase nutrient efficiency. Therefore, productivity degradation of remote fields needs to be at least prevented or ideally, productivity of those fields should be improved from the perspective of food security.

Animal housing design can have a significant indirect impact on NH_3 and CH_4 emissions from animal manure, because it determines the method used to store and process manure and eventual litter (Hristov et al., 2013b). In Hristov (2013) the effects of manure systems on GHG and NH3 emissions is summarized:

> *Animal housing may affect GHG emissions through the method used to collect, store and process manure and litter. Farm yard manure and deep litter manure handling systems tend to produce higher N_2O emissions than slurry-based systems. Straw-based bedding and solid manure handling systems also tend to increase N2O emissions compared with liquid manure handling systems. In general, manure systems in which manure is stored for prolonged periods of time produce greater NH3 and CH4 emissions compared with systems in which manure is removed daily. Slatted floor manure systems tend to decrease GHG and NH3 emissions compared with deep litter systems. But long-term storage of slurry in deep pits and silos, as is predominant in many intensive dairy cattle and pig production systems, enhances CH_4 emission because of anaerobic storage conditions. In general, the effect of housing for ruminant animal on CH4 emissions is relatively small because the animal is the main source of CH4; N2O emissions from ruminant housing are also usually negligible. However, housing and manure systems have a greater impact on NH3 emission from animal operations.*

To reduce CH4 emission from manure storage, anaerobic digesting is a recommended mitigation measure and can provide family farms with biogas for energy supply (see Box 4.3.1).

Box 4.3.1 Improving manure utilization in Kerala, India

Manure Management Improvement Program: Use of anaerobic digesters is a recommended GHG mitigation strategy that has significant potential to capture and destroy most CH_4 from manure. Small family digesters (6-10 m^3) reduced GHG emission between 23 and 53 % compared to families without biogas. Smallholder farmers in general appreciate solid manures as fertilizer but liquid manure (e.g. liquid slurry and digestate) is often considered as waste. This is attributed to the lack of appropriate equipment for transport and for land application of liquid manure in smallholder farming systems.

Photo: Labour-intensive manual application of digested pig slurry as fertilizer in a tropical orchard (Kerala, India)

4.3.5 Introducing housing and economic preconditions

Capital is needed to invest in buildings, manure storage, transportation and further equipment. Availability of financial means is a crucial factor. Investments are only feasible when there is a market for livestock products. Governmental and institutional support to smallholders is essential to create a more stabilized food market, which gives better guarantees for profitable investments. In Ea Kar, Vietnam a value chain approach that linked farmers and local traders to markets was an important factor in how smallholder crop and livestock farmers took advantage of the rising demand of meat in urban centres. By supplying better quality meat to urban markets they achieved higher sale prices and they reduced labour inputs by moving from grazing to stall feeding (Stur et al., 2013). Aside from a strong market demand for quality meat, other factors for the successful transmission were the introduction of farm-grown fodders; a participatory, systems-oriented innovation process; and technical support over a sufficiently long time period to allow innovation processes to become sustainable.

4.3.6 Research questions

- How to organise system-oriented programmes to improve food security in a sustainable matter?
- How to increase manure nutrient efficiency?
- Which incentives can be used to decrease ammonia and greenhouse gas emissions?

5 Key messages

Grassland

Importance:

- Ruminants convert grass into protein for valuable human consumption and this is favourable to increase valuable food supply. The trade-off of animal protein production is the substantial contribution of livestock to greenhouse gas emission and other nutrient losses to the environment.

- The total grassland area is declining mainly due to human-induced modifications, which include cultivation, urbanization, desertification, fire, livestock grazing, fragmentation, and introduction of invasive species. Particularly the more productive grasslands (good water supply, fertile soils) have already been converted to arable land. Grazing is often relegated to the more marginal lands, unfit for cropping, where the population is often completely dependent on livestock for its livelihood.

- Most communally or traditionally managed grasslands show some degree of degradation, and many are seriously damaged, mostly through overgrazing, compaction and erosion created by too high animal numbers.

- Ensure the availability of adequate nutrients to maintain soil fertility. Nutrient depletion is a serious threat to the productivity of grasslands. It is often a more serious constraint to productivity than water availability.

Adaptation and mitigation options:

- Seasonality of forage supply is characteristic for almost all grazing lands. To deal with lean seasons (winter or dry season), sufficient forage supply by making hay or silage is an important measure to improve sustainable grassland use. Especially during unproductive periods, providing adequate rest from grazing is essential to maintain sufficient soil cover.

- Nutrient management is key: more efficient use of animal manure and extra inputs to compensate for nutrient exports via meat and milk. Management and good governance systems to provide rest periods have to be introduced, especially for the communal pastures, where overgrazing is a serious problem.

- The aim of increasing food security can easily lead to an irresponsible expansion of livestock production. Unrealistic expectations of the productive capacity of grazing lands according to the available natural resources must first be addressed.

- An important mitigation potential is carbon sequestration in the soil organic matter.

Breeding

- The global supply of highly productive, specialized breeding material is business driven with a fierce competition by private companies and focused on intensive livestock systems.

- Housing and management measures can prevent problems due to extreme climate conditions like heat stress but are only feasible in capital intensive livestock systems.

- Hence, genetic material is often not adapted to the variability of (extreme) climatic situations in smallholder systems in developing countries. As a consequence, there is a need to enhance productivity of well-adapted and robust local breeds.

- Well-considered breeding programmes, adapted to local environments (including the many smallholders), are long term investments.

- Breeding programmes should be initiated and implemented by Public Private Partnerships to bridge a country's public interests and private interests.

Health

- It is likely that climate change is affecting the distribution and seasonality of important infectious diseases, which impact both animal and human health.
- Not only higher temperatures but also heavy precipitation events and flooding, will enlarge the risk of outbreaks of diseases transmitted by arthropod and water-borne vectors.
- Although climate change can increase the need of animal health care, it does not directly ask for new veterinary knowledge.
- Developing an effective veterinary service is probably the most important strategy for dealing with climate change in developing countries and it is also essential to improve livestock production, which contributes to food security.

Housing

- Housing can be an effective method to improve productivity. It requires more capital and labour for feed and manure management.
- To give better guarantees for profitable investments, governmental and institutional support to smallholders is essential to create a more stabilized food market.
- Manure (nutrient) management is key to maintain and increase land productivity.
- As well as investments, a knowledge infrastructure is needed to support farmers on feed conservation, animal nutrition and manure treatment

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Appendix 1. Livestock production systems

Table 1. Ruminant production systems (Robinson *et al.*, 2011)

System	Characteristics
Grassland-based (or grazing) systems	Livestock production systems in which more than 10 percent of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than ten livestock units per ha of agricultural land
Mixed systems	Livestock production systems in which more than 10 percent of the dry matter fed to livestock comes from crop by-products and/or stubble or more than 10 percent of the value of production comes from non-livestock farming activities

Table 2. Pig production systems (Gerber *et al.*, 2013)

System	Housing	Characteristics
Industrial	Fully enclosed: slatted concrete floor, steel roof and support, brick, concrete, steel or wood walls	Fully market-oriented; high capital input requirements (including infrastructure, buildings, equipment); high level of overall herd performance; purchased non-local feed in diet or on-farm intensively produced feed
Intermediate	Partially enclosed: no walls (or made of a local material if present), solid concrete floor, steel roof and support	Fully market-oriented; medium capital input requirements; reduced level of overall herd performance (compared with industrial); locally-sourced feed materials constitute 30 to 50 percent of the ration
Backyard	Partially enclosed: no concrete floor, or if any pavement is present, made with local material. Roof and support made of local materials (e.g. mud bricks, thatch, timber)	Mainly subsistence driven or for local markets; level of capital inputs reduced to the minimum; herd performance lower than in commercial systems; feed contains maximum 20 percent of purchased non-local feed; high shares of swill, scavenging and locally-sourced feeds

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Table 3. Chicken production systems (Gerber *et al*., 2013)

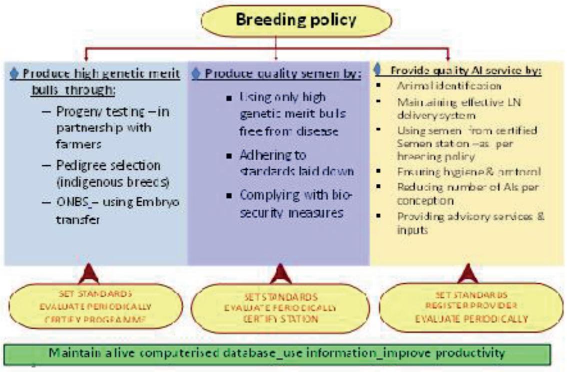
System	Housing	Characteristics
Broilers	Broilers assumed to be primarily loosely housed on litter, with automatic feed and water provision	Fully market-oriented; high capital input requirements (including Infrastructure, buildings, equipment); high level of overall flock productivity; purchased non-local feed or on-farm intensively produced feed
Layers	Layers housed in a variety of cage, barn and free-range systems, with automatic feed and water provision	Fully market-oriented; high capital input requirements (including infrastructure, buildings and equipment); high level of overall flock productivity; purchased non-local feed or on-farm intensively produced feed
Backyard	Simple housing using local wood, bamboo, clay, leaf material and handmade construction resources for supports (columns, rafters, roof frame) plus scrap wire netting walls and scrap iron for roof. When cages are used, these are made of local material or scrap wire	Animals producing meat and eggs for the owner and local market, living freely. Diet consists of swill and scavenging (20 to 40 percent) and locally-produced feeds (60 to 80 percent)

Appendix 2. Breeding policy India (National Dairy Development Board)

Source: http://www.nddb.org/English/Services/AB/Pages/Animal-Breeding.aspx

A steady increase in the productivity of cattle and buffaloes is achievable by improving their genetic potential in a scientific manner. To do so, it is necessary to: (i) build infrastructure for genetic evaluation and production of high genetic merit bulls through genetic improvement programmes such as Progeny Testing, Pedigree Selection, Open Nucleus Breeding System; (ii) build infrastructure for production of disease free high quality semen doses from bulls produced through genetic improvement programmes; (iii) build infrastructure for artificial insemination (AI) services using only quality semen produced from high genetic merit bulls at the doorstep of producers; (iv) establish systems of regulation for bull production, semen production and AI delivery, and (v) build infrastructure for capturing data of all events as they happen and providing timely information to all stakeholders for monitoring, decision making and planning.

A good model for successful Genetic Improvement



The key goals set for achieving a steady genetic progress in the cattle and buffalo population under NDP include: raising the percentage of breedable animals inseminated from the current level of about 25 % to 35% by the end of NDP I and 50% by the end of NDP II; increasing the production of high quality disease free semen doses from the current level of 66.8 million to 100 million by the end of NDP I and 140 million by the end of NDP II, and making available about 900 bulls annually by the end of NDP I and 1200 by the end of NDP II for semen production, the majority of them produced through progeny testing and pedigree selection programmes and a small number through import of exotic purebred bulls or equivalent embryos so as to meet 100% bull replacement requirement of all semen stations in the country.

Top

Appendix 3. Vector-borne diseases and microbial pathogens linked to water

Table 1. Examples of vector-borne diseases of clinical importance (Hunter 2003; Gubler 2009)

Disease	Pathogen	Vector	Animal reservoir	Geographical distribution
Viruses				
Dengue	Flavivirus	Mosquito	Primate, humans	Africa, Caribbean, Pacific, Far East
Japanese Encephalitis	Flavivirus	Mosquito	Birds	Japan, Far East
West Nile	Flavivirus	Mosquito	Birds	Africa, India, Europe and North America
Murray River encephalitis	Flavivirus	Mosquito	Birds	Australia, New Guinea
St Louis encephalitis	Flavivirus	Mosquito	Birds	America
Yellow fever	Flavivirus	Mosquito	Primate, humans	Africa, South and Central America
Eastern Equine Encephalitis	Alphavirus	Mosquito	Birds	North America
Crimean-Congo haemorrhagic fever	Nairovirus	Ixodic tick	Rodents, sheep	Europe, Africa, Middle East, Central Asia
Tick-borne encephalitis	Flavivirus	Ixodic tick	Rodents	Former USSR, Europe
Rift Valley Fever	Phlebovirus	Mosquito	Not known	Africa
Bluetongue virus	Rhabdovirus	Culicoides flies	Cattle, sheep, goats	Tropical and subtropical parts of the world. Recent Europe [1)]
Rickettsia				
Murine typhus	*Rickettsia typhi*	Flea	Rats	Tropical countries
Rocky Mountain Spotted fever	*R. rickettsii*	Ticks	Rabbits, rodents, dogs	USA
Boutonneuse fever	*R. conorii*	Tick	Dogs, rodents	Africa, Mediterranean, Middle East
Bacteria				
Bartonellosis	*B. bacilliformis*	Sandflies	Humans	Western Slopes of the Andes
Plague	*Yersinia pestis*	Flea	Rodents	Africa, Asia, South America, USA
Lyme disease	*Borrelia burgdorferi*	Ticks	Rodents	Europe, North America
Relapsing fever	*B. recurrentis*	Lice	Rodents	Ethiopia, Burundi, Peru, Bolivia, North Africa, India, Asia, China
Relapsing fever	e.g. *B. duttoni*	Ticks	Rodents	East, Central & South Africa
Protozoal parasites				
Malaria	*Plasmodium* spp.	Mosquitos	Primates, humans	Widespread in tropics
African trypanosomiasis	*Trypanosoma brucei*	Tsetse flies	Ungulates	Africa
American trypanosomiasis	*Trypanosoma cruzei*	Triatomine bugs	Dogs, cats, oppossum	Central and South America
Leishmaniasis	*Leishmania* spp.	Sandflies	Dogs, rodents	Africa, Central & South America

[1)] Purse et al. (2006)

Table 2. Microbial pathogens linked to drinking water or recreational water contact (Hunter 2003)

Organism	**Disease**	**Transmission**
Helminths		
Schistosoma spp.	Schistosomaisis	Contact with surface water infected with free swimming cercariae
Dracunculus medinensis	Dracunculiasis	Drinking water
Protozoa		
Giardia duodenalis	Giardiasis	Faecal oral spread through drinking water or recreational water
Cryptosporidium parvum	Cryptosporidiosis	Faecal oral spread through drinking water or recreational water
Cyclospora cayetanensis	Cyclosporiasis	Faecal oral spread through drinking water
Entamoeba histolytica	Amebiasis	Faecal oral spread through drinking water
Toxoplasma gondii	Toxoplasmosis	Drinking water contaminated by feline animals
Free-living amoebae	Amoebic meningoencephalitis	Aspiration of infected surface water into nose
Algae		
Cyanobacteria	Various	Toxins in drinking water or direct contact with surface water blooms
Pfiesteria piscicida	Estuary-associated syndrome	Toxins in water
Bacteria		
Vibrio cholerae	Cholera	Drinking water
Salmonella spp.	Salmonellosis	Occasional outbreaks with drinking water
Salmonella typhi	Typhoid	Drinking water
Shigella spp.	Shigellosis (bacillary dysentery)	Both drinking and recreational water
Campylobacter spp.	Campylobacteriosis	Both drinking and recreational water
Enterotoxigenic *E. coli*		Drinking water
Enterohaemorrhagic E. coli		Drinking water and recreational water contact
Yersinia spp.	Yersiniosis	Drinking water
Francisella tularensis	Tularaemia	Drinking water
Helicobacter pylori		Drinking water
Mycobacteria spp. not *M. tuberculosis*	Varies	Potable water systems in hospitals, some recreation
Viruses		
Hepatitis A and Hepatitis E viruses	Viral hepatitis	Drinking and recreational water contact
Various, esp. Norwalk-like viruses	Viral gastroenteritis	Drinking and recreational water contact
Enteroviruses	Various, including poliomyelitis	Drinking and recreational water contact

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The mission statement of Wageningen UR (University & Research centre) is ‘To explore the potential of nature to improve the quality of life’. Within Wageningen UR, nine specialised research institutes of the DLO Foundation and Wageningen UR have joined forces in order to contribute to the solution of pressing questions in the field of healthy food and living environment. With around 30 branches, 6,000 employees and 9,000 students, Wageningen UR is one of the most prestigious knowledge institutes in its field worldwide. The integrated approach to problems and the collaboration between different disciplines, form the core of Wageningen’s unique approach.

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Together with our clients, we integrate scientific know-how and practical experience to develop livestock concepts for the 21st century. With our expertise on innovative livestock systems, nutrition, welfare, genetics and environmental impact of livestock farming and our state-of-the art research facilities, such as Dairy Campus and Swine Innovation Centre Sterksel, we support our customers to find solutions for current and future challenges.

The mission of Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine specialised research institutes of the DLO Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 9,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.