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Climate change and livestock: Impacts, adaptation, and mitigation

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ABSTRACT

Global demand for livestock products is expected to double by 2050, mainly due to improvement in the worldwide standard of living. Meanwhile, climate change is a threat to livestock production because of the impact on quality of feed crop and forage, water availability, animal and milk production, livestock diseases, animal reproduction, and biodiversity. This study reviews the global impacts of climate change on livestock production, the contribution of livestock production to climate change, and specific climate change adaptation and mitigation strategies in the livestock sector. Livestock production will be limited by climate variability as animal water consumption is expected to increase by a factor of three, demand for agricultural lands increase due to need for 70% growth in production, and food security concern since about one-third of the global cereal harvest is used for livestock feed. Meanwhile, the livestock sector contributes 14.5% of global greenhouse gas (GHG) emissions, driving further climate change. Consequently, the livestock sector will be a key player in the mitigation of GHG emissions and improving global food security. Therefore, in the transition to sustainable livestock production, there is a need for: a) assessments related to the use of adaptation and mitigation measures tailored to the location and livestock production system in use, and b) policies that support and facilitate the implementation of climate change adaptation and mitigation measures.

Contents

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1. Introduction

Human population is expected to increase from 7.2 to 9.6 billion by 2050 (UN, 2013). This represents a population increase of 33%, but as the global standard of living increases, demand for agricultural products will increase by about 70% in the same period (FAO, 2009a). Meanwhile, total global cultivated land area has not changed since 1991 (O'Mara, 2012), reflecting increased productivity and intensification efforts.

Livestock products are an important agricultural commodity for global food security because they provide 17% of global kilocalorie consumption and 33% of global protein consumption (Rosegrant et al., 2009). The livestock sector contributes to the livelihoods of one billion of the poorest population in the world and employs close to 1.1 billion people (Hurst et al., 2005). There is a growing demand for livestock products, and its rapid growth in developing countries has been deemed the "livestock revolution" (Thornton, 2010; Wright et al., 2012). Worldwide milk production is expected to increase from 664 million tonnes (in 2006) to 1077 million tonnes (by 2050), and meat production will double from 258 to 455 million tonnes (Alexandratos and Bruinsma, 2012). Livestock production is likely to be adversely affected by climate change, competition for land and water, and food security at a time when it is most needed (Thornton, 2010).

Global climate change is primarily caused by greenhouse gas (GHG) emissions that result in warming of the atmosphere (IPCC, 2013). The livestock sector contributes 14.5% of global GHG emissions (Gerber et al., 2013), and thus may increase land degradation, air and water pollution, and declines in biodiversity (Bellarby et al., 2013; Reynolds et al., 2010; Steinfeld et al., 2006; Thornton and Gerber, 2010). At the same time, climate change will affect livestock production through competition for natural resources, quantity and quality of feeds, livestock diseases, heat stress and biodiversity loss while the demand for livestock products is expected to increase by 100% by mid of the 21st century (Garnett, 2009). Therefore, the challenge is to maintain a balance between productivity, household food security, and environmental preservation (Wright et al., 2012).

There is growing interest in understanding the interaction of climate change and agricultural production and it is motivating a significant amount of research (Aydinalp and Cresser, 2008). There is still limited research regarding the impacts of climate change on livestock production (IPCC, 2014). This paper reviews the impacts of climate change on livestock production and food security, and the livestock sector's contribution to climate change. The objectives are to: (1) address the impacts of climate change on livestock production; (2) describe the impacts of the livestock sector on climate change; and (3) summarize climate change adaptation and mitigation strategies.

2. Topical review

2.1. Impact of climate change on livestock

Despite uncertainties in climate variability, the IPCC Fifth Assessment Report identified the "likely range" of increase in global average surface temperature by 2100, which is between 0.3 °C and 4.8 °C (IPCC, 2013). The potential impacts on livestock include changes in production and quality of feed crop and forage (Chapman et al., 2012; IFAD, 2010; Polley et al., 2013; Thornton et al., 2009), water availability (Henry et al., 2012; Nardone et al., 2010; Thornton et al., 2009), animal growth and milk production (Henry et al., 2012; Nardone et al., 2010; Thornton et al., 2009), diseases (Nardone et al., 2010; Thornton et al., 2009), reproduction (Nardone et al., 2010), and biodiversity (Reynolds et al., 2010). These impacts are primarily due to an increase in temperature and atmospheric carbon dioxide (CO_2) concentration, precipitation variation, and a combination of these factors (Aydinalp and Cresser, 2008; Henry et al., 2012; IFAD, 2010; Nardone et al., 2010; Polley et al., 2013; Reynolds et al., 2010; Thornton et al., 2009). The impacts of climate change on livestock production factors are presented in Fig. 1. Temperature affects most of the critical factors for livestock production, such as water availability, animal production, reproduction and health. Forage quantity and quality are affected by a combination of increases in temperature, CO_2 and precipitation variation. Livestock diseases are mainly affected by an increase in temperature and precipitation variation.

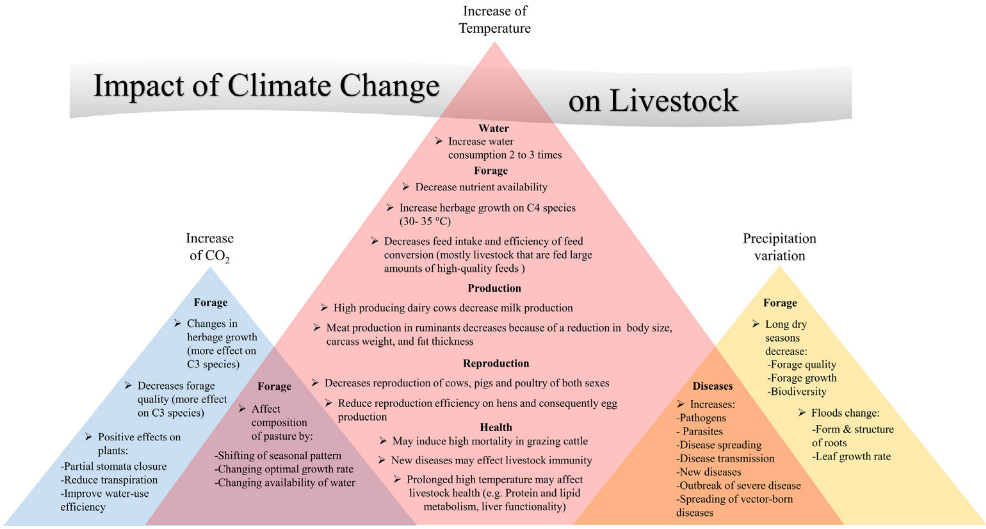

Fig. 1. Impacts of Climate Change on Livestock.

2.1.1. Quantity and quality of feeds

Quantity and quality of feed will be affected mainly due to an increase in atmospheric CO_2 levels and temperature (Chapman et al., 2012). The effects of climate change on quantity and quality of feeds are dependent on location, livestock system, and species (IFAD, 2010). Some of the impacts on feed crops and forage are:

- Increase of CO_2 concentration will result in herbage growth changes, with greater effect on C3 species and less on grain yields (Chapman et al., 2012; Hatfield and Prueger, 2011; Thornton et al., 2009, 2015). The effects of CO_2 will be positive due to inducing partial closure of stomata, reducing transpiration, and improving some plants' water-use efficiency (Rotter and van de Geijn, 1999; Wand et al., 1999).
- C4 species (which account for less than 1% of plants on Earth) are found in warm environments, and have higher water-use efficiency than C3 plants. Temperature increases to 30–35 °C could increase herbage growth, with larger effects on C4 species. However, the effects may vary depending on the location, production system used, and plant species (Hatfield and Prueger, 2011; IFAD, 2010; Thornton et al., 2009; Thornton and Herrero, 2010a,b).
- Changes in temperature and CO_2 levels will affect the composition of pastures by altering the species competition dynamics due to changes in optimal growth rates (IFAD, 2010; Thornton et al., 2008; Thornton et al., 2009, 2015). Plant competition is influenced by seasonal shifts in water availability (Polley et al., 2013). Primary productivity in pastures may be increased due to changes in species composition if temperature, precipitation, and concurrent nitrogen deposition increase (IPCC, 2007).
- Quality of feed crops and forage may be affected by increased temperatures and dry conditions due to variations in concentrations of water-soluble carbohydrates and nitrogen. Temperature increases may increase lignin and cell wall components in plants (Polley et al., 2013; Sanz-Saez et al., 2012), which reduce digestibility and degradation rates (IFAD, 2010; Polley et al., 2013), leading to a decrease in nutrient availability for livestock (Thornton et al., 2009). However, as CO_2 concentration rises forage quality will improve more in C3 plants than C4 plants. C3 plants also have greater crude protein content and digestibility than C4 plants (Polley et al., 2013; Thornton et al., 2009; Wand et al., 1999).
- Extreme climate events such as flood, may affect form and structure of roots, change leaf growth rate, and decrease total yield (Baruch and Mérida, 1995).

Impacts on forage quantity and quality depend on the region and length of growing season (Polley et al., 2013; Thornton et al., 2009). An increase of 2 °C will produce negative impacts on pasture and livestock production in arid and semiarid regions and positive impacts in humid temperate regions. The length of growing season is also an important factor for forage quality and quantity because it determines the duration and periods of available forage. A decrease in forage quality can increase methane emissions per unit of gross energy consumed (Benchaar et al., 2001). Therefore, if forage quality declines, it may need to be offset by decreasing forage intake and replacing it with grain to prevent elevated methane emissions by livestock (Polley et al., 2013).

2.1.2. Water

Global agriculture uses 70% of fresh water resources, making it the world's largest consumer (Thornton et al., 2009). However, global water demand is moving towards increased competition due to water scarcity and depletion, where 64% of the world's population may live under water-stressful conditions by 2025 (Rosegrant et al., 2002).

Water availability issues will influence the livestock sector, which uses water for animal drinking, feed crops, and product processes (Thornton et al., 2009). The livestock sector accounts for about 8% of global human water use and an increase in temperature may increase animal water consumption by a factor of two to three (Nardone et al., 2010). To address this issue, there is a need to produce crops and raise animals in livestock systems that demand less water (Nardone et al., 2010) or in locations with water abundance.

As sea level rises, more saltwater will be introduced into coastal freshwater aquifers (Karl et al., 2009). Salination adds to chemical and biological contaminants and high concentrations of heavy metals already found in waterbodies worldwide and may influence livestock production (Nardone et al., 2010). Water salination could affect animal metabolism, fertility, and digestion. Chemical contaminants and heavy metals could impair cardiovascular, excretory, skeletal, nervous and respiratory systems, and impair hygienic quality of production (Nardone et al., 2010).

There is a lack of research related to implications of reduced water availability for land-based livestock systems due to climate change (Thornton et al., 2009). Therefore, it is important to consider water availability and appropriate mitigation strategies in the context of sustainable livestock production.

2.1.3. Livestock diseases

The effects of climate change on livestock diseases depend on the geographical region, land use type, disease characteristics, and animal susceptibility (Thornton et al., 2009). Animal health can be affected directly or indirectly by climate change, especially rising temperatures (Nardone et al., 2010). The direct effects are related to the increase of temperature, which increases the potential for morbidity and death. The indirect effects are related to the impacts of climate change on microbial communities (pathogens or parasites), spreading of vector-borne diseases, food-borne diseases, host resistance, and feed and water scarcity (Nardone et al., 2010; Thornton et al., 2009; Tubiello et al., 2008).

Temperature increases could accelerate the growth of pathogens and/or parasites that live part of their life cycle outside of their host, which negatively affects livestock (Harvell et al., 2002; Karl et al., 2009; Patz et al., 2000). Climate change may induce shifts in disease spreading, outbreaks of severe disease, or even introduce new diseases, which may affect livestock that are not usually exposed to these type of diseases (Thornton et al., 2009). Evaluating disease dynamics and livestock adaptation will be important to maintain their resilience. Global warming and changes in precipitation affect the quantity and spread of vector-borne pests such as flies, ticks, and mosquitoes (Thornton et al., 2009). In addition, disease transmission between hosts will be more likely to happen in warmer conditions (Thornton et al., 2009). For example, White et al. (2003) simulated the impacts of climate change on Australian livestock, finding that livestock lost about 18% of their weight due to increased tick infestations. Wittmann et al. (2001) also used a model to simulate the response of *Culicoides imicola* in Iberia, which is the main vector of the bluetongue virus that affects mainly sheep and sometimes cattle, goat, and deer. They reported that the vector would spread extensively with a 2 °C increase in global mean temperature. However, these predicted spreads may be prevented by disease surveillance and technologies, such as DNA fingerprinting, genome sequencing, tests for understanding resistance, antiviral medications, cross-breeding, and more (Perry and Sones, 2009; Thornton, 2010). Meanwhile, there is high probability that emergence of new diseases may act as a mixing vessel between human and livestock, facilitating combination of new genetic material and their transmissibility. This makes it difficult to estimate actual disease risk because of the dependence of diseases on animal exposure and interactions factors, (Randolph, 2008).

2.1.4. Heat stress

All animals have a thermal comfort zone, which is a range of ambient environmental temperatures that are beneficial to physiological functions (FAO, 1986). During the day, livestock keep a body temperature within a range of ±0.5 °C (Henry et al., 2012). When temperature increases more than the upper critical temperature of the range (varies by species type), the animals begin to suffer heat stress (FAO, 1986). Animals have developed a phenotypic response to a single source of stress such as heat called acclimation (Fregley, 1996). Acclimation results in reduced feed intake, increased water intake, and altered physiological functions such as reproductive and productive efficiency and a change in respiration rate (Lacetera et al., 2003; Nardone et al., 2010).

Heat stress on livestock is dependent on temperature, humidity, species, genetic potential, life stage, and nutritional status. Livestock in higher latitudes will be more affected by the increase of temperatures than livestock located in lower latitudes, because livestock in lower latitudes are usually better adapted to high temperatures and droughts (Thornton et al., 2009). Confined livestock production systems that have more control over climate exposure will be less affected by climate change (Rotter and van de Geijn, 1999).

Heat stress decreases forage intake, milk production, the efficiency of feed conversion, and performance (Haun, 1997; McDowell, 1968; Wyman et al., 1962). Warm and humid conditions cause heat stress, which affects behavior and metabolic variations on livestock or even mortality. Heat stress impacts on livestock can be categorized into feed nutrient utilization, feed intake, animal production, reproduction, health, and mortality. The following presents these in more detail.

2.1.4.1. Feed nutrient utilization and feed intake. Livestock have several nutrient requirements including energy, protein, minerals, and vitamins, which are dependent on the region and type of animal (Thornton et al., 2009). Failure to meet the dietary needs of cattle during heat stress affects metabolic and digestive functions (Mader, 2003). Sodium and potassium deficiencies under heat stress may induce metabolic alkalosis in dairy cattle, increasing respiration rates (Chase, 2012).

Most of the research concerning feed intake in livestock animals has been focused on cattle. Thermal livestock stress decreases feed intake (Mader and Davis, 2004; Thornton et al., 2009; Wyman et al., 1962) and efficiency of feed conversion (McDowell, 1968), especially for livestock that are fed large amounts of high quality feeds (Haun, 1997). In the case of cattle, feed intake reduction leads to a negative energy balance and reduced weight gain (Lacetera et al., 1996, 2003). Reduction of water intake may also decrease sweating and feed intake (Henry et al., 2012).

2.1.4.2. Animal production. One of the major causes of decreased production in the dairy and beef industry is heat stress (Nardone et al., 2010) and significant economic losses have been related to this. The United States livestock industry has an annual economic loss between 1.69 and 2.36 billion US dollars due to heat stress, of which 50% occurs in the dairy industry (St-Pierre et al., 2003). High-producing dairy cows generate more metabolic heat than low-producing dairy cows. Therefore, high-producing dairy cows are more sensitive to heat stress. Consequently, when metabolic heat production increases in conjunction with heat stress, milk production declines (Berman, 2005; Kadzere et al., 2002). Heat stress also affects ewe, goat, and buffalo milk production (Finocchiaro et al., 2005; Nardone et al., 2010; Olsson and Dahlborn, 1989). In general, ewes are more sensitive to the combined temperature and relative humidity affect (the temperature humidity index) than actual temperature or relative humidity. However, the index values that trigger heat stress on ewes varies by breed type (Finocchiaro et al., 2005). Heat stress also impacts goat milk composition and amount. For example, in lactating goats, a water loss reduction mechanism is activated during hot seasons. This mechanism reduces water loss in urine in favor of milk production during seasons with limited water resources (Olsson and Dahlborn, 1989). Buffalo exposure to high temperatures also reduces milk production because it affects the animal physiological functions, such as pulse, respiration rate, and rectal temperature (Seerapu et al., 2015). However, less attention has been given to these animals because of their adaptability to warm conditions and lower demand for their milk (Nardone et al., 2010).

In the case of meat production, beef cattle with high weights, thick coats, and darker colors are more vulnerable to warming (Nardone et al., 2010). Global warming may reduce body size, carcass weight, and fat thickness in ruminants (Mitloehner et al., 2001; Nardone, 2000). The same is true in pig production, where larger pigs will have more reduction in growth, carcass weight, and feed intake (Nardone et al., 2010). Piglets' survival may be reduced because of a reduction of sows feed intake during suckling periods with temperatures greater than 25 °C, which reduces the milk yield of the sow (Lucas et al., 2000).

The poultry industry may also be compromised by low production at temperatures higher than 30 °C (Esminger et al., 1990). Heat stress on birds will reduce body weight gain, feed intake and carcass weight, and protein and muscle calorie content (Tankson et al., 2001). Heat stress on hens will reduce reproduction efficiency and consequently egg production because of reduced feed intake and interruption of ovulation (Nardone et al., 2010; Novero et al., 1991). Egg quality, such as egg weight and shell weight and thickness may also be negatively affected under hotter conditions (Mashaly et al., 2004).

2.1.4.3. Reproduction. Reproduction efficiency of both livestock sexes may be affected by heat stress. In cows and pigs, it affects oocyte growth and quality (Barati et al., 2008; Ronchi et al., 2001), impairment of embryo development, and pregnancy rate (Hansen, 2007; Nardone et al., 2010; Wolfenson et al., 2000). Cow fertility may be compromised by increased energy deficits and heat stress (De Rensis and Scaramuzzi, 2003; King et al., 2006). Heat stress has also been associated with lower sperm concentration and quality in bulls, pigs, and poultry (Karaca et al., 2002; Kunavongkrita et al., 2005; Mathevon et al., 1998).

2.1.4.4. Health. Nardone et al. (2010) presented several livestock health problems related to climate change. Prolonged high temperature may affect metabolic rate (Webster, 1991), endocrine status (Johnson, 1980), oxidative status (Bernabucci et al., 2002), glucose, protein and lipid metabolism, liver functionality (reduced cholesterol and albumin) (Bernabucci et al., 2006; Ronchi et al., 1999), non-esterified fatty acids (NEFA) (Ronchi et al., 1999), saliva production, and salivary HCO_3^- content. In addition, greater energy deficits affect cow fitness and longevity (King et al., 2006).

2.1.4.5. Mortality. Warm and humid conditions that cause heat stress can affect livestock mortality. Howden et al. (2008) reported that increases in temperature between 1 and 5 °C might induce high mortality in grazing cattle. As a mitigation measure, they recommend sprinklers, shade, or similar management practices to cool the animals. Sirohi and Michaelowa (2007) linked livestock mortality to several heat waves between 1994 and 2006 in the United States and northern Europe.

More information is needed concerning the nature and extent of how heat stress affects feed nutrient utilization and feed intake, animal production, reproduction, and health. With greater knowledge related to nutritional and metabolism processes of livestock, management practices could be adapted to increase animal performance.

2.1.5. Biodiversity

Biodiversity refers to a variety of genes, organisms, and ecosystems found within a specific environment (Swingland, 2001) and contributes to human well-being (MEA, 2005). Populations that are decreasing in genetic biodiversity are at risk, and one of the direct drivers of this biodiversity loss is climate change (UNEP, 2012). Climate change may eliminate 15% to 37% of all species in the world (Thomas et al., 2004). Temperature increases have affected species reproduction, migration, mortality, and distribution (Steinfeld et al., 2006). The Intergovernmental Panel on Climate Change Fifth Assessment Report states that an increase of 2 to 3 °C above pre-industrial levels may result in 20 to 30% of biodiversity loss of plants and animals (IPCC, 2014). By 2000, 16% of livestock breeds (ass, water buffalo, cattle, goat, pig, sheep, and horse) were lost (Thornton et al., 2009). In addition, the FAO (2007) has stated that from 7,616 livestock breeds reported, 20% were at risk, and almost one breed per month was being extinguished. Cattle had the highest number of extinct breeds (N = 209) of all species evaluated. The livestock species that had the highest percentages of risk of breed elimination were chicken (33% of breeds), pigs (18% of breeds), and cattle (16% of breeds). However, the breeds at risk depends on the region. Developing regions had between 7% and 10% of mammalian species at risk (not restricted to livestock), but between 60% and 70% of mammalian species are classified as of unknown risk. Conversely, in developed regions, where the livestock industry is very specialized and based on a small number of breeds, the mammalian species at risk were between 20% and 28% (FAO, 2007). Thornton et al. (2009) states that this biodiversity loss is mainly because of the practices used in livestock production that emphasize yield and economic returns and marginalization of traditional production systems where other considerations are also important (such as ability to withstand extremes).

Livestock and plants will be highly affected by climate change and biodiversity loss. These breeds and species cannot be replaced naturally; therefore, future work that studies the inherent genetic capabilities of different breeds and identifies those that can better adapt to climate conditions is vital.

2.1.6. Agro-ecological zones

Agricultural practices such as livestock production and management varies around the world. In order to describe these variabilities, the Food and Agricultural Organization of the United Nations and the International Institute for Applied Systems Analysis established the agro-ecological zones (AEZs) for assessing agricultural resources (FAO, 2017). These zones are defined based on climate, landform, soils, land cover, and land use (FAO, 1996). The AEZs are broadly classified into five categories including tropics, subtropics, temperate, boreal, and artic (FAO, 1996). Meanwhile, climate change variabilities and impacts on agricultural productions are not necessarily aligned with the AEZs or even can be significantly different within an AEZ, which makes it difficult to generalize the impacts of climate change on AEZs.

In general, climate change impacts within an AEZ can be both negative and positive. For example, climate change impacts in a form of increase in CO_2 level can improve the photosynthetic activity and the water use efficiency, which consequently increases crop productivity. Meanwhile, rise in average temperature can trigger plant diseases while increasing water stress, which consequently decreases crop productivity (Fischer et al., 2002). These fluctuations in crop yields are indirectly affecting livestock productivity especially in rainfed systems. At the same time, higher temperatures will directly affect livestock production by changing the animals' migration pattern and reproduction time. Therefore, livestock species with restricted habitat, small population, limited mobility, and low breeding rates will be the most vulnerable (Steinfeld et al., 2006).

The majority of worldwide ruminants are found in tropics and subtropics AEZs, especially in arid or semi-arid regions, where climate conditions limit animal productivity and yield (Herrero et al., 2012). Among climate factors, heat stress is common due to high temperature. For example, within the tropics and subtropics AEZs of Europe, North America, Africa, and Australia, heat stress resulted in increased livestock morbidity and mortality (Renaudeau et al., 2012; Seo and Mendelsohn, 2008).

Even though the largest numbers of livestock are found in the tropics and subtropics AEZs, the largest productivity is found in the temperate AEZs (Herrero et al., 2012). In these regions, the impacts of climate change ruminants' performance can be minimal (except extreme events) while crop production is expected to increase due increase in average temperature (Rowlinson, 2008; Seguin, 2008). Meanwhile, warmer winters may negatively impact animal productivity due to increase in incidences of vertebrate pests (Rowlinson, 2008).

In the boreal AEZs, the impacts of climate change on crop and livestock productions are generally positive (Bajželj and Richards, 2014; Iglesias et al., 2007). Climate change impacts in forms of increased temperature, winter rainfall, and the length of the growing season will improve crop and grass productions and the opportunity for planting new crops (Iglesias et al., 2007; Campbell et al., 2004). In addition, livestock housing costs might be reduced due to the longer growing seasons (Iglesias et al., 2007). Meanwhile, these changes may result in improving the yields in low fertile soils while reducing the yields in high fertile soils (Iglesias et al., 2007).

2.1.7. Food security

About 842 million people (one in eight people worldwide) went hungry between 2011 and 2013, not receiving enough food to maintain an active and healthy life (FAO et al., 2013). Livestock contributes greatly to food security because: (1) they are suppliers of global calories, proteins, and essential micronutrients, (2) they are produced in areas that have difficulty growing crops, (3) most of the feed for livestock is not appropriate for human consumption, and (4) they provide manure for crop production (FAO, 2011). However, there are also concerns that livestock production is detrimental to food security. First, the use of grains as feed in livestock production is a worldwide concern because they are produced for animal feed and not for human consumption. For example, in 2002, one-third of the global cereal harvest was used as livestock feed (Steinfeld et al., 2006).The bulk of the livestock feed comes from grasses and legume forage that grows on land not suitable to agriculture (O'Mara, 2012), and in many countries livestock do not receive cereal supplements. In such areas, livestock are a positive contributor to food security. The debate occurs in areas where cattle are pastured in areas perfectly suitable for agriculture, or where they are fed substantial cereal supplements. Second, climate change, mostly via an increase in temperature, may decrease intake of digestible nutrients. Therefore, livestock production may decrease through declining forage quality and quantity and/or by reducing animal feed intake. These two factors affect livestock production because animals will use the available nutrients to first maintain their physiological needs, then for growth or milk production, and finally for reproduction (Hatfield et al., 2008). Third, climate change also affects nutritional content of livestock products because of potential increases in pathogens and diseases in their food and effects on the animals themselves (Harvell et al., 2002; Karl et al., 2009; Patz et al., 2000). As new pathogens and diseases emerge and spread, pesticide and veterinary medicine use will change, consequently changing the principal transfer process of environmental contaminants to food (Lake et al., 2012; van der Spiegel et al., 2012).

Sustainable livestock production needs more research, extension, and demonstration. Livestock are an important contributor to food security, but it is important to maintain an efficient conversion of natural resources to human food to sustain a neutral food balance (FAO, 2011). This can be accomplished through efficient production of protein from livestock (FAO, 2013). However, climate change will influence this conversion by affecting the nutritional content of livestock products (Harvell et al., 2002; Karl et al., 2009; Patz et al., 2000) and reducing livestock production (Hatfield et al., 2008). Currently, the livestock sector's best approach to contribute to food security is by addressing the primacy of food balance (FAO, 2013; FAO, 2011).

2.2. Impact of livestock on climate change

Livestock contribute 14.5% of the total annual anthropogenic GHG emissions globally (Gerber et al., 2013). Livestock influence climate through land use change, feed production, animal production, manure, and processing and transport (Fig. 2). Feed production and manure emit CO_2, nitrous oxide (N_2O), and methane (CH_4), which consequently affects climate change. Animal production increases CH_4 emissions. Processing and transport of animal products and land use change contributes to the increase of CO_2 emissions (Fig. 2).

The livestock sector is often associated with negative environmental impacts such as land degradation, air and water pollution, and biodiversity destruction (Bellarby et al., 2013; Reynolds et al., 2010; Steinfeld et al., 2006; Thornton and Gerber, 2010). Increases in livestock production are expected to originate from a declining natural resource base, which will cause further environmental damage without proper natural resources management (Thornton and Herrero, 2010a,b).

2.2.1. GHG emissions

The primary livestock GHG emissions are CO_2, CH_4, and N_2O. CH_4 contributes the most to anthropogenic GHG emissions (44%), followed by N_2O (29%) and CO_2 (27%) (Gerber et al., 2013). Globally livestock contribute 44% of anthropogenic CH_4, 53% of anthropogenic N_2O and 5% of anthropogenic CO_2 emissions (Fig. 3). Higher concentrations of these gases, can be explained by lower efficiency and productivity of livestock system due to excess loss of nutrients, energy, and organic matter (Gerber et al., 2013).

The global warming potential (GWP) of CH_4 and N_2O over a 100 year time horizon differs between the IPCC (2006), IPCC (2013), and the United Nations Framework Convention on Climate Change (UNFCC, 2014). Current assessments have estimated higher GWP than what was previously thought. IPCC (2006) is most commonly used in the literature for estimating livestock GHG emissions, and reported that the warming potential of CH_4 is 25 CO_2-eq, while N_2O is 298 CO_2-eq. However,

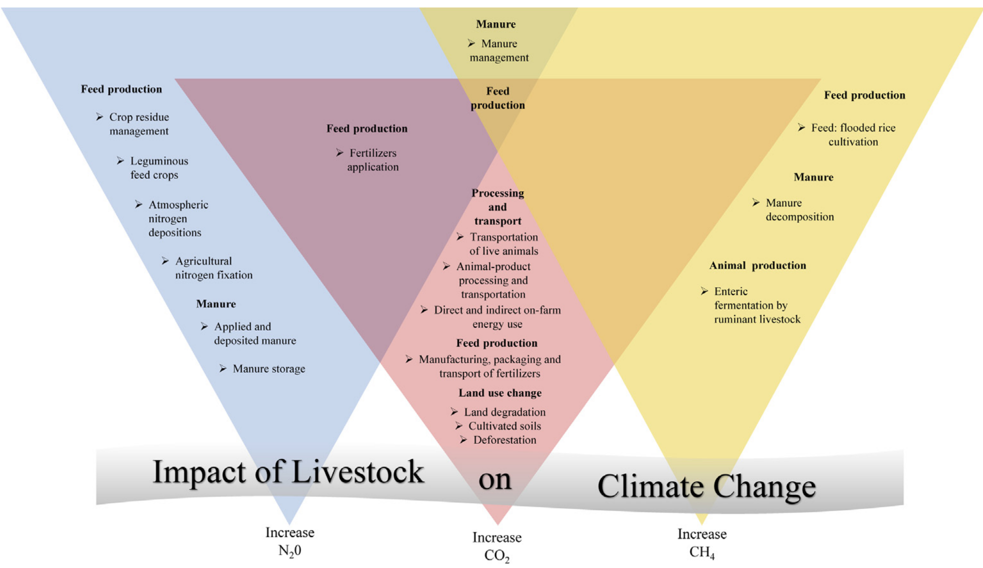

Fig. 2. Impact of livestock on Climate Change.

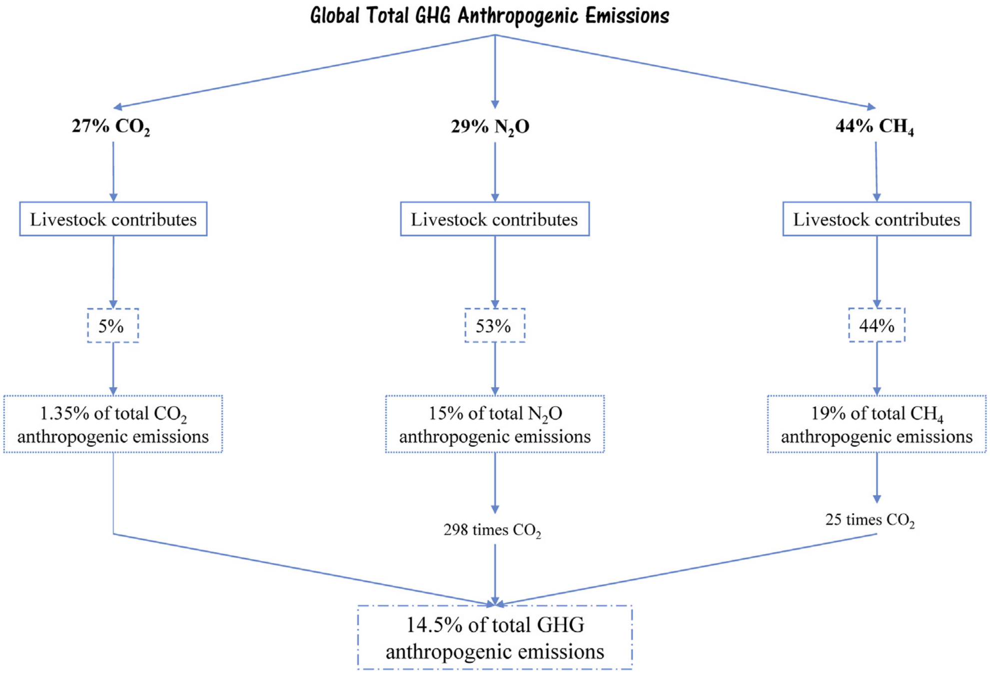

Fig. 3. Contribution of livestock to the total GHG anthropogenic emissions.

the latest IPCC (2013) reported a warming potential for CH_4 of 34 CO_2-eq, while N_2O is 310 CO_2-eq. The UNFCCC (2014) stated that CH_4 emissions have a warming potential of 21 CO_2-eq, and N_2O is 310 CO_2-eq over a 100 year time horizon.

The world's transportation sector emits around 5656 Tg CO_2-eq yr^{-1} and the livestock sector emits 7100 Tg CO_2-eq yr^{-1} (DSI MSU, 2015; Gerber et al., 2013). Emissions from livestock production contribute more GHG to the atmosphere than the entire global transportation sector. The livestock sector contributes directly and indirectly to GHG emissions, including through animal physiology, animal housing, manure storage, manure treatments, land application, and chemical fertilizers (Casey et al., 2006; Monteny et al., 2001). Direct emissions from animal sources include enteric fermentation, respiration, and excretions (Jungbluth et al., 2001). Indirect emissions refers to emissions derived from feed crops, manure application, farm operations, livestock products processing, transportation, and land use allocation for livestock production (e.g. deforestation, desertification, carbon released from cultivated soils) (IPCC, 1997; Mosier et al., 1998). In the livestock sector, indirect emissions play a greater role in the release of carbon to the atmosphere than direct emissions (Steinfeld et al., 2006).

The livestock sector's contribution of 14.5% of total anthropogenic GHG emissions was evaluated by Gerber et al. (2013) using a global livestock environmental assessment model (GLEAM). GLEAM performs an analysis of the emissions of global livestock production along supply chains. The main elements of the livestock supply chains that are analyzed by GLEAM are: herd, feed, manure, animals' energy requirement, feed intake, production, and emissions, allocation of the total emissions at the farmgate (physical farm boundaries) to co-products and services (emission per kg of product), and post-farmgate emissions (transport and processing). GLEAM also considers land use change as the conversion of forest to pasture or arable land for crops.

The contributors of the 14.5% of livestock GHG emissions are presented in Fig. 4. Enteric fermentation is the largest contributor of the sector's emissions with 39.1%, followed by manure management, application, and direct deposit with 25.9%, feed production with 21.1%, land use change with 9.2%, post-farmgate with 2.9%, and direct and indirect energy with 1.8% (Gerber et al., 2013). However, contribution to GHG emissions varies depending on the type of farming system and region. For example, intensification of any of the three major livestock production systems and expansion of industrialized (or landless) systems will increase CO_2 emissions due to greater fossil fuel use and less solar energy utilized by photosynthesis (Steinfeld et al., 2006). Gerber et al. (2013) also estimated livestock GHG emissions by region, finding that, Asia produce the highest, followed by Latin America and the Caribbean, Europe, North America, Africa, and Oceania.

2.2.2. Land use

Forests and natural habitats have been steadily converted to pasture and cropland since the 1850s (Goldewijk and Battjes, 1997). Agriculture lands cover about 38.5% of global total land area, which consists of 28.4% arable land and 68.4% permanent meadows and pasture (DSI MSU, 2015). Pasturelands have expanded by a factor of six since 1800, now covering 35 million km^2 (White et al., 2000). Agricultural land use change is related to two concepts: profit per unit of land and opportunity cost (Steinfeld et al., 2006). Profit per unit of land refers to the willingness of farmers to manage a specific land

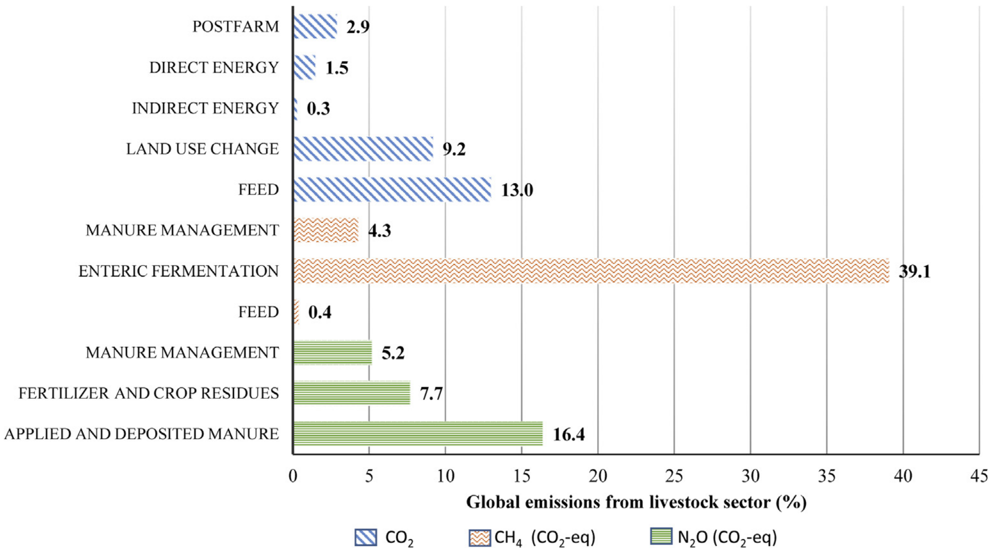

Fig. 4. Global GHG emissions from the livestock sector (Adapted from Gerber et al., 2013).

use. Profit will vary depending on several factors, such as the land's biophysical characteristics and price, access to markets, inputs, and services. The opportunity cost concept compares the social and economic cost of different ways to use the same land area. Opportunity costs include private production costs and ecosystem service costs. Therefore, when non-marketable ecosystem services have no associated cost, land use decisions are based on private profit per unit of land (Steinfeld et al., 2006).

The increasing demand for livestock products has significantly changed the natural landscape. Land degradation is the deterioration of physical, chemical, and biological properties of soil. Land degradation has been recognized as one of the drivers of land conversion from forest to croplands and pastures because producers exhaust their soil resources and thus search for more suitable land (Steinfeld et al., 2006). However, Asner et al. (2004) stated that due to climate and soil characteristics, the expansion of pasture into marginal areas is limited; therefore, they could only expand into areas with agro-ecological potential.

Land use change affects the natural carbon cycle, which consequently releases high amounts of carbon into the atmosphere, increasing GHG emissions. Natural habitats, mainly forests, sequester more carbon in soil and vegetation than croplands and pasturelands. Soil and terrestrial vegetation sequester up to 40% of global anthropogenic CO_2 emissions (The Royal Society, 2001). Furthermore, pasturelands contain more carbon than croplands. Croplands sequester 6% of global carbon, while tropical savannas and temperate pasturelands together sequester 27% (IPCC, 2000). However, soils sequester the most carbon in the terrestrial carbon cycle, and double that of vegetation (Steinfeld et al., 2006). Sundquist (1993) estimated that 1,100 to 1,600 billion tonnes of carbon is stored in soils. However, soil carbon can be lost through burning, volatilization, erosion, landuse change, and agricultural management practices (Bolin et al., 1982). Therefore, when a forest is converted to cropland and pasture by logging or burning, high amounts of carbon are released into the atmosphere (Steinfeld et al., 2006).

Latin America has converted the most land from forest to pasture and croplands, and livestock ranching is one of the drivers of this change (Wassenaar et al., 2007). In the past 40 years, forested areas in Central America decreased by almost 40%, coinciding with an increase of pasturelands and cattle herds. In addition, crops used to feed livestock also affect land use change. In 2004–2005 alone, soybean expansion replaced 1.2 million hectares of rainforest (LEAD, 2014).

Deforestation, cultivated soils, and land degradation due to livestock production are the main source of CO_2 emissions. From total livestock GHG emissions, 9.2% is attributed to land use change, where 6% is due to pasture expansion and 3.2% is due to feed crop expansion (Gerber et al., 2013). However, land use change produces other emissions in addition to CO_2. Land conversion from forest to pastureland may also reduce CH_4 oxidation by soil microorganisms, resulting in pasturelands acting as net sources of CH_4 when soil compaction from cattle hooves limits gas diffusion (Mosier et al., 2004).

Regarding the other two contributors of livestock-land use GHG emissions, Steinfeld et al. (2006) estimated that livestock-related cultivated soils produce around 28 million tonnes of CO_2 per year and livestock-induced desertification of pastures produce 100 million tonnes of CO_2 per year. Reducing pasturelands as a mitigation strategy does not suggest an increase in soil carbon stocks because the relationship between pasturelands and soil carbon sequestration is complex due to their dependence on the environment, society, and economy (IFAD, 2010). Studies suggest that pasturelands can either increase or decrease GHG emissions depending on the grazing management and history, climate and ecosystem (IFAD, 2010; Henderson et al., 2015). Therefore, grazing management that can increase carbon sequestration are: i) not exceeding pastureland carrying capacity by having an effective stocking rate, ii) rotational grazing, and iii) excluding degraded pasturelands from livestock grazing (IFAD, 2010; Tennigkeit and Wilkies, 2008).

2.2.3. Feed production

The use of manure and synthetic fertilizers for forage and feed crop production, processing of feed, and transport of feed are the most important contributors of GHG emissions related to the livestock sector (IFAD, 2010; Thornton and Herrero, 2010a,b). These make up 45% of global livestock anthropogenic GHG emissions, consisting primarily as CO_2, N_2O and NH_4 (Gerber et al., 2013).

The livestock sector contributes significantly to GHG emissions through the production of nitrogenous fertilizers used to produce crops for animal feed (Steinfeld et al., 2006). Oil, coal, and natural gas are used in fertilizer manufacture. By considering the amount of fertilizer use, packaging, transport, and application in the livestock sector, the manufacturing process of fertilizers contributes more than 40 million tonnes of CO_2 annually (Steinfeld et al., 2006). Forty percent of all the nitrogen up-take by crops comes from synthetic fertilizers (Smil, 2001). Ammonia volatilization loss from synthetic nitrogen fertilizer is an indirect contributor to GHG emissions. Between 4 to 5 million tonnes of mineral fertilizer is used for livestock feed production. The average loss due to ammonia volatilization from mineral fertilizer is about 14%. Therefore, it was estimated that the livestock sector contributes 3.1 million tonnes of global ammonia volatilization from mineral fertilizers per year (Steinfeld et al., 2006).

N_2O is another contributor to GHG emissions. Fertilizer use, agricultural nitrogen fixation, and atmospheric nitrogen deposition generally increase N_2O emissions (Bouwman, 1996). By following the same assumptions as ammonia, with a 1% average of N_2O-N (tonnes of nitrogen in nitrous oxide form) loss rate from mineral fertilizer, the livestock sector contributes 0.2 million tonnes N_2O-N of global N_2O emission from mineral fertilizer per year (Steinfeld et al., 2006). In addition, leguminous feed crops for livestock account for additional N_2O emissions. Steinfeld et al. (2006) estimated their contribution by considering the global area of soybeans used for livestock feed and doubling it to include alfalfa and clover, because there are no estimates of worldwide alfalfa and clover production. Therefore, the contribution of leguminous feed crops is more than 0.5 million tonnes per year of N_2O-N emissions. By adding both contributors (mineral fertilizer and leguminous feed crops), the total N_2O-N emissions are 0.7 million tonnes per year (Steinfeld et al., 2006). As growth in fertilizer and manure use continues, a 35–60% increase of N_2O emissions (0.9 to 1.1 million tonnes per year of total N_2O-N emissions) is expected by 2030 (Bruinsma, 2003).

On-farm fossil fuel use in livestock production produces 50% more CO_2 emissions than manufacturing N fertilizers for feed. The livestock sector includes direct and indirect (e.g. electricity) on-farm fossil fuel use, which is used for machinery operations, irrigation, heating, cooling, ventilation, production of herbicides and pesticides, and more. More than half of fossil-fuel use is attributed to feed production. By assuming CO_2 emissions from on-farm fossil fuel use are double that of manufacturing N fertilizers, and adding emissions related to livestock rearing, on-farm fossil fuels account for 90 million tonnes of CO_2 per year (Steinfeld et al., 2006).

2.2.4. Animal production

In general, livestock respiration is not counted as a net source of CO_2 emissions because they are part of the global biological system cycle. The vegetation consumed by the animal originates from the conversion of atmospheric CO_2 to organic compounds or biomass. Therefore, under the Kyoto Protocol (2005) it is assumed that the consumed amounts of CO_2 in vegetative form are equivalent to those emitted by the livestock. Conversely, the animal is a carbon sink because a fraction of the carbon consumed is absorbed in the live tissue of the animal (UNFCCC, 1998) and products such as milk.

Livestock contributes 44% of the world's anthropogenic CH_4 emissions through their normal digestive processes (enteric fermentation) and manure management (Gerber et al., 2013). Enteric fermentation and manure account for 80% of 52 agricultural emission sources (Steinfeld et al., 2006). During the animals' digestive process, enteric fermentation converts the feed consumed into digestible feed. Enteric fermentation releases a CH_4 by-product through exhalation (Beauchemin et al., 2009). Therefore, this by-product is considered an energy loss (Gerber et al., 2013). Feed composition and feed intake can vary enteric fermentation and hence methane emissions. Increasing the concentrate (high energy feeds containing cereal grains and oil meals) proportion in the animal diet can reduce methane emissions from the animal (Dourmad et al., 2008; Yan et al., 2000).

Methane emissions vary depending on production systems and regional characteristics (e.g. climate and landscape) (Gerber et al., 2013). The enteric fermentation produced by ruminant livestock (e.g. cattle, sheep, and goat) emits globally between 87 and 94 Tg of methane annually (IPCC, 2013). Mixed crop-livestock systems account for 64% of global enteric fermentation methane emissions; grazing systems account for 35%, and industrial 1% (Steinfeld et al., 2006). The high percentage from mixed crop-livestock systems reflects that two-thirds of total livestock animals are present in those systems (Steinfeld et al., 2006). The countries that contribute the most methane emissions related to livestock production are India, China, Brazil, and the United States (IPCC, 2013; Olivier and Janssens-Maenhout, 2012). India, with the largest livestock population in the world, emitted 11.8 Tg of CH_4 in 2003, from which 91% derives from enteric fermentation and 9% from manure management (Chhabra et al., 2013).

In Africa, methane emissions are expected to increase due to increases in livestock populations. Herrero et al. (2008) estimated that African cattle, goats, and sheep, which produced about 7.8 million tonnes of methane in 2000, are likely to increase to 11.1 million tonnes by 2030. If this linear relationship between methane emissions and livestock population continues, global methane emissions from livestock production may increase 60% by 2030 (Bruinsma, 2003). However, changing feeding practices and manure management could moderate methane emissions (Thornton and Herrero, 2010a,b).

2.2.4.1. Emissions by species and commodities. Animals that contribute the most to livestock GHG emissions are beef and dairy cattle, accounting for 65% of the total livestock GHG emissions (Gerber et al., 2013). Pigs, poultry, buffaloes, and small ruminants contribute about 7 to 10%. If GHG emissions are estimated based on commodities, beef cattle contribute the most with 41% of the sector's emission, followed by dairy cattle (20%), swine (9%), buffalo (8%), poultry (8%), and small ruminant (6%) (Gerber et al., 2013).

Enteric fermentation is the largest source of GHG emissions from cattle, buffalo, and small ruminants, comprising between 43% and 63% of the livestock sector emissions (Fig. 5). However, for pigs and chickens the largest source of emissions is due to feed production (between 25% and 27%), which includes fertilizer production, machinery use, and feed transportation. Enteric fermentation from pigs is much lower than in ruminants because their digestive process does not produce as much methane as a by-product (Gerber et al., 2013).

2.2.5. Manure

Livestock manure releases CH_4 and N_2O gas. The decomposition of the organic materials found in manure under anaerobic conditions releases methane (EPA, 1999). Liquid manure found in lagoons or holding tanks releases more methane than dry manure (Burke, 2001). Manure methane emissions are a function of air temperature, moisture, pH, storage time, and animal diet (EPA, 1999; IFAD, 2010). Steinfeld et al. (2006) estimated global methane emissions from manure decomposition of 17.5 million tonnes of CH_4 per year. Pig manure comprises almost half of global manure-related methane emissions. At the country level, China has the highest global methane manure-related emissions, primarily due to pig manure (Steinfeld et al., 2006).

N_2O emissions from manure storage are dependent on environmental conditions, handling systems, and duration of waste management. Manure must be handled aerobically and then anaerobically to release N_2O emissions, which is more likely to occur in dry waste-handling systems. Steinfeld et al. (2006) reported that N_2O emissions from stored manure are equivalent to 10 million tonnes N per year.

Nitrous oxide soil emissions from manure application are the largest source of global N_2O emissions (Steinfeld et al., 2006). Nitrogen emissions from applied or deposited manure are dependent on soil infiltration, organic carbon amount, pH, soil temperature, precipitation, and the plant/crop uptake rate (Mosier et al., 2004). Steinfeld et al. (2006) estimated that 1.7 million tonnes of manure soil N_2O are released per year. N_2O emissions from applied manure are 40% higher in mixed crop-livestock systems than the N_2O emissions from excreted manure deposited on pasture systems. Industrial production systems have 90% less N_2O emissions than mixed crop-livestock systems (Steinfeld et al., 2006).

2.2.6. Processing and transport

Energy costs of processing animals and their products combined with global livestock production from "market-oriented intensive systems" can be used to obtain global processing emissions. However, the source of the energy and its variation in the world is uncertain (WEC, 2015). Energy use depends on the type of livestock system and if they are small or large scale. More than half of the energy used in confinement systems is for feed production, including seed, herbicides, pesticides, and machinery. Substantial energy is also used for heating, cooling, and ventilation systems (USDA-NRCS, 2006).

Nonetheless, some approximate estimations of energy use in the livestock sector have been developed. Based on a study performed in Minnesota by Sainz (2003) of energy use for processing, Steinfeld et al. (2006) estimated that the United States

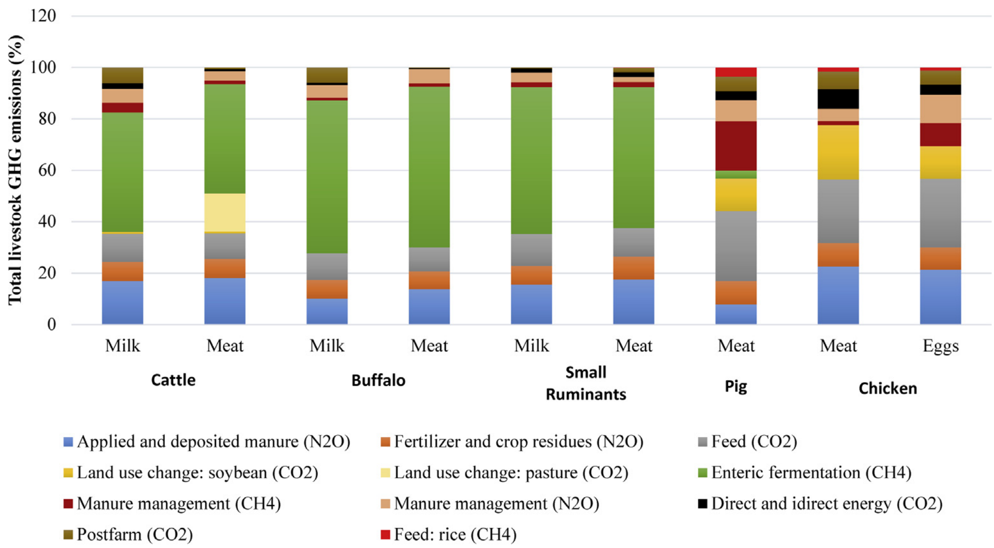

Fig. 5. Total global livestock GHG emission by specie and product (Adapted from Gerber et al., 2013).

produces a ‘‘few million" tonnes of CO_2 emissions related to total animal product and feeding processing. Following the same trend, they estimated that the world produces ‘‘several tens of millions" tonnes CO_2 emissions in animal-product processing.

Transportation of livestock products to retailers and transport of feed to livestock farms contribute to GHG emissions. Long distance shipping is the most significant GHG emitter in this category. For example, high volumes of soybean are transported long distances to be used as feed (Steinfeld et al., 2006). Annual CO_2 emissions in meat transportation based on FAO statistics for 2001–2003 was estimated to be between 800–850 thousand tonnes of CO_2 (Steinfeld et al., 2006). These estimations lead to a greater understanding of the contribution of processing and transportation to the livestock sector GHG burden. However, more research is needed to obtain approximate estimations of CO_2 emissions related to processing and transport of livestock products.

2.3. Summarizing adaptation and mitigation practices

There are several climate change adaptation and mitigation recommendations that can be made based on the above discussion. Adaptation strategies can improve the resilience of crop and livestock productivity to climate change (USDA, 2013). Mitigation measures could significantly reduce the impact of livestock on climate change (Dickie et al., 2014). Adaptation and mitigation can make significant impacts if they become part of national and regional policies (FAO, 2009b).

2.3.1. Adaptation measures

Adaptation measures involve production and management system modifications, breeding strategies, institutional and policy changes, science and technology advances, and changing farmers' perception and adaptive capacity (IFAD, 2010; Rowlinson et al., 2008; USDA, 2013). Research is needed on assessments for implementing these adaptation measures and tailoring them based on location and livestock system. This could be accomplished with GIS and remote sensing technologies applicable at broad and local scales (Thornton et al., 2008).

2.3.1.1. Livestock production and management systems. An adaptation such as the modification of production and management systems involves diversification of livestock animals and crops, integration of livestock systems with forestry and crop production, and changing the timing and locations of farm operations (IFAD, 2010).

Diversification of livestock and crop varieties can increase drought and heat wave tolerance, and may increase livestock production when animals are exposed to temperature and precipitation stresses. In addition, this diversity of crops and livestock animals is effective in fighting against climate change-related diseases and pest outbreaks (Batima et al., 2005; IFAD, 2010; Kurukulasuriya and Rosenthal, 2003).

Agroforestry (establishing trees alongside crops and pastures in a mix) as a land management approach can help maintain the balance between agricultural production, environmental protection and carbon sequestration to offset emissions from the sector. Agroforestry may increase productivity and improve quality of air, soil, and water, biodiversity, pests and diseases, and improves nutrient cycling (Jose, 2009; Smith et al., 2012).

Changes in mixed crop-livestock systems are an adaptation measure that could improve food security (Herrero et al., 2010; Wani et al., 2009). This type of agricultural system is already in practice in two-thirds of world, producing more than half of the milk, meat, and crops such as cereal, rice and sorghum (Herrero et al., 2012). Changes in mixed crop-livestock systems can improve efficiency by producing more food on less land using fewer resources, such as water (Herrero et al., 2012; Steinfeld et al., 2006).

Improving feeding practices as an adaptation measure could indirectly improve the efficiency of livestock production (Havlík et al., 2013). Some of the suggested feeding practices include, modification of diets composition, changing feeding time and/or frequency (Renaudeau et al., 2012), incorporating agroforestry species in the animal diet (Thornton and Herrero, 2010a,b), and training producers in production and conservation of feed for different agro-ecological zones (IFAD, 2010). These practices can reduce the risk from climate change by promoting higher intake or compensating low feed consumption, reducing excessive heat load (Renaudeau et al., 2012), decreasing the feed insecurity during dry seasons (Thornton and Herrero, 2010a,b), and reducing animal malnutrition and mortality (IFAD, 2010), respectively.

Shifting locations of livestock and crop production could reduce soil erosion and improve moisture and nutrient retention (Kurukulasuriya and Rosenthal, 2003). Another adaptive measure could be adjusting crop rotations and changing timing of management operations (e.g. grazing, planting, spraying, irrigating). This measure can be adapted to changes in duration of growing seasons, heat waves and precipitation variability (Batima et al., 2005; IFAD, 2010; Kurukulasuriya and Rosenthal, 2003).

2.3.1.2. Breeding strategies. Changes in breeding strategies can help animals increase their tolerance to heat stress and diseases and improve their reproduction and growth development (Henry et al., 2012; Rowlinson, 2008). Therefore, the challenge is in increasing livestock production while maintaining the valuable adaptations offered by breeding strategies, all of which will require additional research (Thornton et al., 2008). In addition, policy measures that improve adaptive capacity by facilitating implementation of adaptation strategies will be crucial (USDA, 2013). For example, developing international gene banks could improve breeding programs and serve as an insurance policy, such as has been done for plants with the *In-Trust* plant collections in the CGIAR gene banks (Thornton et al., 2008). This would be a major breakthrough that requires significant investment and international collaboration to succeed.

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2.3.1.3. Farmers' perception and adaptive capacity. One of the limiting factors for these changes to succeed is the disposition and capability of farmers to recognize the problem and adopt climate change adaptation and mitigation measures (Jones et al., 2013). Because of this, it is important to collect information about farmers' perceptions to mitigation and adaptation measures. One approach for collecting information about farmers' perceptions that has been used for mitigation and adaptation research is qualitative; using open-ended survey questions or group discussion at workshops to understand individual and group opinions (Barnes et al., 2008). By understanding farmers' perceptions and including them in rural policy development, there is a greater chance of accomplishing food security and environmental conservation objectives (Barnes, 2013; Oliver et al., 2012).

Risk perception within farmer decision-making can be increased through education, family farm succession, and social interaction among farmers and farming communities. Barnes (2013) applied a latent class clustering approach (which uses statistical methodology to construct results) to evaluate the heterogeneity of dairy farmers' risk perception of climate change. Their results show that the drivers of risk perception due to climate change are family members and the influence of succession planning. They recommended increasing the social capital of farming communities to promote acceptance of communication strategies for climate change adaptation and mitigation measures.

2.3.2. Mitigation measures

There is potential to reduce livestock sector GHG emissions through the implementation of different technologies and practices. However, they are not widely used (Gerber et al., 2013). Some of the technical options for mitigating the impact of livestock on climate change are carbon sequestration, improving diets to reduce enteric fermentation, improving manure management, and more efficient use of fertilizers (Steinfeld et al., 2006; Thornton and Gerber, 2010; UNFCCC, 2008). Mitigation measures need public policy support to be effective (Dickie et al., 2014).

2.3.2.1. Carbon sequestration. Carbon sequestration can be achieved through decreasing deforestation rates, reversing of deforestation by replanting (Carvalho et al., 2004), targeting for higher-yielding crops with better climate change adapted varieties, and improvement of land and water management (Steinfeld et al., 2006). A beef sector study performed in Brazil estimated a reduction of up to 25% of GHG emissions related to grazing land use and land use change, accomplished by improving animal and herd efficiency (Gerber et al., 2013).

Soil organic carbon can be restored in cultivated soils through conservation tillage, erosion reduction, soil acidity management, double-cropping, crop rotations, higher crop residues, mulching and more (Paustian et al., 1997; Steinfeld et al., 2006). Improving pasture management can also lead to carbon sequestration by incorporating trees, improving plant species, legume interseeding, introducing earthworms, and fertilization (Conant et al., 2001). In addition, grass productivity and soil carbon sequestration could be improved by increasing grazing pressure in grasslands that have a lower amount of grazing animals than the livestock carrying capacity (Holland et al., 1992). Improving grazing land management could sequester around 0.15 gigatonnes CO_2-eq yr^{-1} globally (Henderson et al., 2015).

2.3.2.2. Enteric fermentation. Enteric fermentation is a source of methane emissions that can be reduced through practices such as improvement of animal nutrition and genetics (US-EPA, 1999). Examples of practices for mitigating enteric fermentation are: increasing dietary fat content (Beauchemin et al., 2008; Martin et al., 2010), providing higher quality forage (Hristov et al., 2013), increasing protein content (ICF International, 2013), providing supplements (e.g. bovine somatotropin, feed antibiotics) (Boadi et al., 2004), and the use of antimethanogens (vaccines to suppress methane emissions) (EPA, 2013). However, there is high uncertainty in the efficacy of these practices because various studies have demonstrated that the initial reductions of enteric fermentation achieved are only temporary (ICF International, 2013).

A one percent increase of dietary fat can decrease enteric methane emissions between 4 to 5% (Beauchemin et al., 2008; Martin et al., 2010). However, rumens need to limit fat content to 8% of dry matter to avoid a decrease in livestock performance (Hales et al., 2012). Providing higher quality forage also results in a reduction of methane emissions because it increases digestibility (Hristov et al., 2013). An increase of protein content of feed can also improve digestibility and reduce overall methane emissions per unit of product (ICF International, 2013).

Providing supplements, such as feed antibiotics, which tend to increase weight gain and reduce feed intake per metric ton of meat produced, can reduce enteric fermentation (Boadi et al., 2004). In the case of milk, bovine somatotropin (a bovine growth hormone) increases production. An increase in milk production leads to less animals needed to produce the same amount of milk and less emissions produced (EPA, 2013). Antimethanogen vaccines are another practice that directly reduces methane emissions in the rumen. However, this is a new technology with limited research on emission reduction efficiency and animal health (EPA, 2013).

2.3.2.3. Manure management. Most methane emissions from manure management are related to storage and anaerobic treatment. Although manure deposited on pasture can produce nitrous oxide emissions, the mitigation measures are often difficult to apply because of the manure dispersion on pasture (Dickie et al., 2014). Therefore, most mitigation practices involve shortening storage duration, improving timing and application of manure, used of anaerobic digesters, covering the storage, using a solids separator, and changing the animal diets (ICF International, 2013).

Anaerobic digestion can reduce methane emissions while producing biogas (Gerber et al., 2008). Anaerobic digesters are lagoons or tanks that maintain manure under anaerobic conditions to capture biogas and combust it for producing energy or flaring. This process reduces the potential of GHG emissions by converting methane into CO_2 (ICF International, 2013). Unfortunately, anaerobic digesters are costly for producers; the best approach for implementing digesters is through policies that create enough incentive for adaptation (Dickie et al., 2014). Similar to digesters, the covering of ponds, tanks or lagoons reduces emissions by capturing and destroying methane (ICF International, 2013).

Other storage and handling practices can also reduce GHG emissions. Such practices include reducing storage time, improving housing and waste management systems to handle manure, and removing bedding from manure by using a solids separator (Dickie et al., 2014). The solids separator is mostly used in confinement systems to remove solids from manure streams that are entering the treatment or storage systems. By removing the solids from manure streams methane emissions are reduced, the time between storage system cleaning is increased, and crust formation is prevented (ICF International, 2013). These practices, compared to anaerobic digesters, are usually low-cost and low-tech. However, they require more time and effort from the producer (Dickie et al., 2014).

Adjusting animal diets can also be used as a mitigation measure, by changing the volume and composition of manure. GHG emissions can be reduced by balancing dietary proteins and feed supplements. If protein intake is reduced, the nitrogen excreted by animals can also be reduced. Supplements such as tannins are also known to have the potential to reduce emissions. Tannins are able to displace the nitrogen excretion from urine to feces to produce an overall reduction in emissions (Dickie et al., 2014; Hess et al., 2006).

2.3.2.4. Fertilizer management. Fertilizer application on animal feed crops increases nitrous oxide emissions (Bouwman, 1996). Therefore, mitigation measures such as increasing nitrogen use efficiency, plant breeding and genetic modifications (Dickie et al., 2014), using organic fertilizers (Denef et al., 2011), regular soil testing, using technologically advanced fertilizers, and combining legumes with grasses in pasture areas may decrease GHG emissions in feed production (Dickie et al., 2014).

Nitrogen use efficiency can be improved by applying the required amount that the crop will absorb and when it needs the nutrients, and placing it where the plant can easily reach it. Regular soil testing can be a part of a nutrient management plan depending on the region and crop, and improve efficiency of nitrogen use (Dickie et al., 2014). Plant breeding and genetic modifications can reduce the use of fertilizers by increasing a crop's nitrogen uptake (Dickie et al., 2014). Increasing the use of organic fertilizers would also decrease emissions because organic fertilizers do not produce as much nitrogen oxide as synthetic fertilizers (Denef et al., 2011). Furthermore, fertilizer technology has improved through regulating the release of nutrients from the fertilizer and inhibiting nitrification to slow the degradation of the fertilizer and maintain the nutrients available for the plant. However, these technologically advanced fertilizers are more costly than the other practices mentioned above (Dickie et al., 2014). In the case of pasturelands, the use of synthetic nitrogen can be reduced by combining legumes with grasses. Legumes fix nitrogen through Rhizobium bacteria; therefore, the need for supplementary nitrogen is reduced (USDA-NRCS, 2007).

2.3.2.5. Shifting human dietary trends. Most studies are focused on reducing GHG emissions on the supply-side of the livestock production system. However, less research has focused on the demand section related to consumption of livestock products. This mitigation measure goes along with the policy described in the human dimensions section of this paper (Section 2.1), where a reduction in meat consumption may significantly reduce GHG emissions. Because beef accounts for a large portion of GHG emissions from the livestock sector and it is the least resource-efficient animal protein producer (Stehfest et al., 2009), the mitigation potential is high for the beef component of the livestock sector. Research to understand why populations feel compelled to increase animal protein consumption when they rise above the poverty line is needed, as well as why those at the top of the economic ladder are compelled to improve their diets by reducing meat consumption and returning to a more vegetarian diet. This conundrum stands at the center of the challenge faced by the state of knowledge and policies surrounding the livestock sector.

3. Conclusions

Climate change will affect livestock production and consequently food security. Livestock production will be negatively impacted (due to diseases, water availability, etc.), especially in arid and semiarid regions. In addition, climate change will affect the nutritional content of livestock products, which are one of the suppliers of global calories, proteins and essential micronutrients. Conversely, livestock production also influences climate change. Deforestation due to expansion of pasturelands and croplands for livestock production contributes 9.2% of total livestock GHG emissions (Gerber et al., 2013). However, the feed production stage contributes the greatest fraction (almost half) of GHG emissions across the complete livestock production process. It is expected that this stage will further increase its contribution due to intensification of livestock production. Meanwhile, enteric fermentation is the largest GHG contributor in the animal production stage. Therefore, if livestock numbers continue to increase and feeding practices are not changed, global emissions due to livestock production will continue to increase.

Climate change adaptation, mitigation practices, and policy frameworks are critical to protect livestock production. Among the reviewed studies, diversification of livestock animals (within species), using different crop varieties, and shifting to mixed crop-livestock systems seem to be the most promising adaptation measures. By diversifying animal and crop varieties, the tolerance to climate variability (e.g. drought, heat waves) and to diseases and pest outbreaks will be improved. In addition, shifting to mixed crop-livestock systems can improve efficiency by increasing production with the use of fewer resources. On the mitigation side, improvement of animal nutrition and genetics are important because enteric fermentation is a major GHG emitter in livestock production. However, the efficacy of these practices in reducing emissions is uncertain and more research is needed concerning effective mitigation practices related to enteric fermentation.

If we want effective adaptation and mitigation measures to address climate change and livestock production, these measures should be scaled up through policy. For example, understanding farmers' perceptions and including them in policy development can improve food security and environmental conservation by promoting widespread practice adoption. In addition, a comprehensive view of costs, time, and effort required from the producer needs to be included to the policy framework to maintain sustainable production systems.

Interactions between climate change and livestock production are still not well understood, despite the amount of research performed. First, most studies were performed at a continental or regional level; to assess the most vulnerable areas, local studies will be critical. Second, most of the research concerning livestock production focuses on cattle; more studies must be performed on non-ruminants. Third, there is a gap in research related to water availability for livestock production. With projected increases in drought and declining water quality in many places on earth, it is critical to identify the regions with the best conditions for livestock production and improve the conditions for those that do not. Fourth, climate change may induce livestock diseases (e.g. outbreaks of severe diseases or new diseases), affecting animals that are not usually exposed to those diseases; there is a need to evaluate the dynamics of those diseases on livestock and how animals adapt to them. Fifth, there is a gap in knowledge related to the nutritional and metabolic processes of livestock; addressing this can improve management practices that increase animal performance. Sixth, because breeds and species are not a renewable resource, it is important to identify breeds with inherent genetic capabilities to adapt to climate change. Seventh, there are large uncertainties in using only energy costs of processing and transporting animals and their products to estimate GHG emissions at this stage of the livestock production process. Therefore, a better approximate estimation of CO_2 emissions related to processing and transport of livestock products is needed. Eight, there is a lack of information related to the current use of adaptation and mitigation measures defined by location and livestock system.

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