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Impact of Climate Change and Livestock Production: An Updated Review

[1]VIVEK PRATAP SINGH & [2]AVANISH KUMAR SINGH

[1]SMS ANIMAL SCIENCE, MAHAYOGI GORAKHNATH KRISHI VIGYAN KENDRA , GORAKHPUR, UTTAR PRADESH, INDIA

[2]SMS AGRONOMY, MAHAYOGI GORAKHNATH KRISHI VIGYAN KENDRA , GORAKHPUR, UTTAR PRADESH, INDIA

ABSTRACT: Globally, the climate is changing, and this has implications for livestock. Climate affects livestock growth rates, milk and egg production, reproductive performance, morbidity, and mortality, along with feed supply. Simultaneously, livestock is a climate change driver, generating 14.5% of total anthropogenic Greenhouse Gas (GHG) emissions. Herein, we review the literature addressing climate change and livestock, covering impacts, emissions, adaptation possibilities, and mitigation strategies. While the existing literature principally focuses on ruminants, we extended the scope to include non-ruminants. We found that livestock are affected by climate change and do enhance climate change through emissions but that there are adaptation and mitigation actions that can limit the effects of climate change. We also suggest some research directions and especially find the need for work in developing country settings. In the context of climate change, adaptation measures are pivotal to sustaining the growing demand for livestock products, but often their relevance depends on local conditions. Furthermore, mitigation is key to limiting the future extent of climate change and there are a number of possible strategies.

KEYWORDS: livestock production; adaptation; mitigation

I. INTRODUCTION

Climate change is a major concern for current livestock systems worldwide. Global warming and its associated changes in mean climate variables and climate variability affect feed and water resources as well as animal health and production. Climate change also has implications for the processing, storage, transport, retailing and consumption of livestock products. The ability of current livestock systems to support livelihoods and meet the increasing demand for livestock products is thus threatened.

The livestock sector currently plays a key role in food supply and food security. Livestock products (meat, milk and eggs) contribute 15% and 31% of global per capita calorie and protein supply, with regional variations (FAOSTAT, 2020; see Appendix for calculation of estimates presented in the Introduction). About 30% and 6% of global ruminant meat and milk production originates from grazing systems, on land that is often poorly suited for cropping (Herrero et al., 2013). Furthermore, livestock provides a range of other services, including as a source of draught power, a means of transportation, a source of nutrients for poor soils, a source of income generation and diversification, and a form of financial capital, all of which contribute to the overall well-being and resilience of many communities (CIRAD, 2016). Over 844 million people worldwide receive some income from agriculture, and the livestock sector contributes about 40% of agricultural value-added (FAOSTAT, 2020; The World Bank, 2020a). Livestock contributions to food security and other sustainability dimensions will be affected by climate change, although the full extent and magnitude of the impacts remain unknown.

Livestock and climate change studies often focus on the climate mitigation potential of livestock and in describing adaptation practices. When studies cover climate impacts, these tend to have a relatively narrow viewpoint, focusing on specific livestock species, primary production, or on selected dimensions of risk of climate-related impacts such as climate hazards without considering vulnerability levels of different communities (e.g. of reviews, Escarcha et al. (2018); IPCC (2014); Rivera-Ferre et al. (2016); Rojas-Downing et al. (2017); Thornton et al. (2009)). In large part this

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reflects the fact that, compared to crop production, considerably less work has been published on observed and modelled climate impacts on livestock (IPCC, 2014a). It also reflects the limited number of synthetic reviews of the issue, as highlighted in Rivera-Ferre et al. (2016).[1,2,3]

In order to fill this gap, we review the risk of climate-related impacts along the land-based livestock food supply chain (i.e. from production to consumption). While not exhaustive, we aim to capture the major trends with direct implications for livestock-sourced food availability, access, utilisation and stability, and highlight key recent literature. We acknowledge that the implications of climate change go well beyond these pillars and affect the provision of goods and services (e.g. wool, hides, skins and manure, animal traction, financial instrument, etc.), human livelihoods and health, ecosystems, economies, cultures, and infrastructure in complex ways. Also, while we recognize that climate adaptation strategies and the impacts of livestock on climate change are significant considerations, these are not covered here but assessed elsewhere (e.g. FAO (2018a), Escarcha et al. (2018), Henry et al. (2018), Herrero et al. (2016), Rivera-Ferre et al. (2016), Salman et al. (2019), Sejian et al. (2015) and Weindl et al. (2015)).

This review is framed around the concept of risk of climate-related impacts, as defined by the Intergovernmental Panel on Climate Change (IPCC) Working Group II (IPCC, 2014a). Risk of climate-related impacts results from the interaction of climate-related hazards with the exposure and vulnerability of human and natural systems (Fig. 1). The analysis of this interaction represents the core of the IPCC climate impacts assessments. We use the term hazard to refer to climate-related physical events or trends that impact livestock systems (IPCC 2014). Exposure refers to the parts of the livestock supply chain that could be adversely affected, while vulnerability encompasses humans' capacity to cope and adapt to changes. The term impact is used primarily to refer to the effects of extreme weather, climate events and climate change on natural and human systems.

2.1. Feed and water resources

2.1.1. Quantity and quality of livestock feed production

Changes to the quantity and quality of livestock feed will be influenced by complex local interactions between eCO_2 concentrations, tropospheric O_3 levels, temperature, and precipitation. We first provide an inventory of how eCO_2, O_3, temperature and precipitation can affect livestock feed, then present some model projections under climate change. Livestock consume grains (especially in poultry, pig and intensive ruminant systems), crop above-ground biomass (e.g. in dual purpose crops which are both grazed and harvested), crop residues (e.g., straw or stover – key feed in mixed crop-livestock systems) as well as native and sown pastures (key feed in mixed crop-livestock and grazing-only systems). While not covered here, livestock can also be fed by-products and waste (e.g. oilseed cakes, bran, vegetable waste, brewer waste), concentrates and supplements (FAO, 2017).

2.1.1.1. Direct impacts of atmospheric CO_2 and tropospheric O_3 on feed

Research shows that eCO_2 may have both positive and negative impacts on livestock feed, although there is recent evidence that the fertilisation effects of eCO_2 and nitrogen on plant physiological processes may slow in the future as ecosystems productivity become dominated by the negative effects of higher temperatures and extreme droughts (Peñuelas et al., 2017).

Increases in eCO_2 concentrations stimulate plant primary productivity (see review in Ainsworth et al., 2020), increasing potential yields of some species. Plants with a C_3 photosynthetic pathway such as wheat, rice, soybean and temperate grasses experience greater growth stimulation than C_4 plants such as maize, sorghum, sugarcane and tropical grasses. However, the CO_2 fertilisation effects can also reduce animal feed quality (Augustine et al., 2018; Myers et al., 2014; Smith and Myers, 2018). For example, Myers et al. (2014) reported that C_3 crops other than legumes had lower grain protein concentrations under elevated eCO_2 concentration in the range 546–586 ppm (−6.3% in wheat grains and −7.5% in rice grains). The impact on C_4 crop grain was smaller. Increased eCO_2 was also found to decrease the overall mineral concentrations (−8%) and increased the total non-structural carbohydrate (mainly starch, sugars) to mineral ratios in the total biomass of non-leguminous C_3 plants (Loladze, 2014). While the nutritional quality of C_3 grasses may

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be the most greatly impacted by eCO_2 increases, it may nonetheless remain higher than C_4 grasses under elevated eCO_2 (Barbehenn et al., 2004). Increased toxicity has also been reported in some plants, with Gleadow et al. (2009) measuring a 160% increase in the concentration of cyanogenic glycosides (compounds that break down to release toxic hydrogen cyanide when plant tissue is crushed or chewed) in cassava leaves between CO_2 concentrations of 360 and 710 ppm in greenhouse experiments. Woody encroachment associated with rising eCO_2 levels and changes in fire regimes can also alter grassland ecosystem function and negatively impact the intake and quality of grazing animals' diets. Woody forages are harder for cattle and sheep to physically access as compared to goats, are less palatable, and have lower dry matter and protein digestibility compared to herbaceous plants (Archer et al., 2017).

The effects of increasing tropospheric O_3 on plant productivity at scale and the range of potential secondary effects it might have (e.g. on weeds, pests and diseases, interactions with chemicals such as pesticides) have received less attention than eCO_2 (Ainsworth et al., 2020). However, synthesis of crop responses to O_3 finds that O_3 pollution reduces crop yields to a similar level as nutrient, heat and aridity stress (Mills et al., 2018). For instance, using historical ground-level monitoring data, McGrath et al. (2015) estimated that, over the past 30 years, O_3 pollution reduced U.S. soybean and maize yields by 5–10%. Ainsworth et al. (2020) provide a review of the literature on the effect of this air pollutant on plant productivity. The topic is not yet fully understood and remains one of the key uncertainties in crop, grassland and other global terrestrial models, with significant implications on our ability to predict future atmospheric composition and global climate, net primary productivity and provision of ecosystem services.[4,5,6]

2.1.1.2. Direct impacts of water and temperature on feed

Changes in temperature and water availability can greatly affect forage and crop yields and feed quality. Sensitivity to changes in climate depends on the crop type and other environmental factors, but there is strong agreement that air temperatures above approximately 30°C–34°C generally depress cereal yields under water-limited conditions, through accelerating crop development and damaging plant cells (Carlson, 1990; D. B. Lobell et al., 2011; Meerburg et al., 2009). The maximum temperature for growth of temperate legumes and pastures is around 30–35°C, increasing to 35–50°C for tropical species (Ludlow, 1980). High temperatures are often coupled with water stress, since low soil moisture results in a decrease in evaporative cooling from the landscape (Mueller and Seneviratne, 2012) and high temperatures increase crop water loss (Lobell et al., 2013). The combination of warmer temperatures and drier conditions tends to favour C_4 rather than C_3 species (Hatfield et al., 2011; Izaurralde et al., 2011). The concentration of ergot alkaloids, and other potentially toxic secondary compounds (e.g., hydrogen cyanide in cassava and forage sorghum) are also likely to increase in response to a hotter and drier climate (Bourguignon et al., 2015; Brown et al., 2016; Gleadow et al., 2016).

Increased instability of feed supply is particularly a concern in grazing systems where it represents a major challenge for herd size and grazing intensity management (Godde et al., 2020; Sayre et al., 2013; Sloat et al., 2018). Pastures with high year-to-year precipitation variability were found to currently support lower livestock stocking rates than less variable regions (Sloat et al., 2018). Studies focused on grassland vegetation have also found that changes in seasonal climate patterns can have either positive or negative impacts on above ground biomass, depending on the nature of the change and the agro-ecological context (Craine et al., 2012; Guan et al., 2014; Peng et al., 2013; Prevéy and Seastedt, 2014; von Wehrden et al., 2010; Zeppel et al., 2014). The arrangement of climate extreme sequences such as drought sequences or number of hot days in a row, could have significant implications for the livestock sector (Stafford Smith and Foran, 1992). While less commonly researched than droughts, other hazards such as fires, heavy storms, flooding events, surface melt and icing events, as well as the appearance of new lakes, streams and marshes also disturb crop growth, reduce arable land and restrict animal access to pastures (Amstislavski et al., 2013; Pan et al., 2019). For instance, in northern Russia, nomadic reindeer herders migrate hundreds of kilometres in spring and autumn to connect summer and winter pastures. The appearance of new water bodies and change in size of existing ones due to melting permafrost can act as barriers, changing migration routes and increasing grazing pressure on the most accessible pastures (Amstislavski et al., 2013).

Changes in precipitation patterns in saline areas will also affect soil salinity and agricultural production potentials. Salinity intrusion and associated reductions in forage area have led farmers across the coastal belt in Bangladesh to look for other sources of livestock feed (Alam et al., 2017). Tajul Baharuddin et al. (2013) suggest that the predicted

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local sea-level rise for areas such as Carey Island in Malaysia would prevent oil palm production by the 21st century, due to seawater intrusion. This has implications for livestock production through potential reductions in the production of palm kernel meal, which is often fed to cattle in industrial systems. Integrated palm-cattle systems, where cattle graze under trees or are fed palm fronds removed as part of plantation maintenance, would also be impacted. Increases in the frequency, duration and intensity of heavy rainfall events, drought periods and sea level rise will also increase exposure of water, croplands and grasslands to soil contaminants with potential harmful impacts for crop and forage yield quantity and quality (Biswas et al., 2018; Lemonte et al., 2017; Marrugo-Negrete et al., 2019).

2.1.1.3. Feed yields, as projected in the future by biophysical models

At higher levels of warming, crop yields are projected to drop, especially at lower latitudes (Rosenzweig et al., 2014). This is particularly the case for maize and wheat yields which begin to decline with 1 °C–2 °C of local warming in the tropics, and drop by up to 60% under 5 °C of local warming (IPCC, 2014a). Temperate maize is less clearly affected at the 1–2 °C threshold, but would be significantly affected with warming of 3 °C–5 °C. Recent studies also show that global food production has likely already been impacted (Asseng et al., 2015; Lobell et al., 2011; Ray et al., 2019). Ray et al. (2019) estimated that the impact of observed climate change on yields of different crops ranged from −13.4% (oil palm) to +3.5% (soybean), with impacts mostly negative in Europe, Southern Africa and Australia but generally positive in Latin America. Crop yield interannual variability is likely to progressively increase in many regions (IPCC, 2014a). For instance, Müller and Robertson (2014), in a gridded modelling study reported an increase of interannual variability of more than 5% in 64% of grid cells, and a decrease of more than 5% in 29% of cases by 2050.

Regarding forage availability, as for food crops, the diversity and severity of likely impacts differ considerably by location and species. In an assessment of global rangelands, Godde et al. (2020) found that global mean herbaceous biomass is projected to decrease of 4.7% by 2050 under RCP 8.5, with 74% of global rangeland area projected to experience a decline in mean biomass. The largest regional decrease was projected for Oceania while the highest increase was found for Europe. Another study focussed on European grasslands (Chang et al., 2017) also found projected increases in grassland productivity, mainly attributed to the simulated fertilisation effect of rising CO_2. Both studies highlight projected increases in biomass inter-annual variability over some regions. Woody encroachment is also projected to occur on over 51% of global rangeland area by 2050 under RCP 8.5 according to Godde et al. (2020).[7,8,9]

In an integrated partial equilibrium modelling approach, Havlík et al. (2015) found that the climate change impacts on crop and pasture forage yields will have little effect on global milk and meat production by 2050 due to trade in animal products, which could compensate for the feed deficits in some parts of the world. However, depending on the scenario, the impacts could be more pronounced at the regional scale. The most uncertain and potentially the most severe effects were found for sub-Saharan Africa, where for example, ruminant meat production could increase by 20% by 2050 but could also decrease by 17%, depending on projected feed supply based on varying the biophysical crop model and CO_2 fertilisation assumptions.

Yield projections as above-mentioned are subject to large uncertainties. Models do not usually consider extreme events and overall increasing variability, or explicitly represent adaptation or effects such as changes in tropospheric O_3, pests, pollinators, or agricultural labour. There are also large uncertainties as to climate extremes and trends in the future (Eyring et al., 2019; Sillmann et al., 2017) and changes in management practices, historical and projected land-use patterns (Polley et al., 2017). Our understanding of ecosystems responses to climate change is also limited (Rosenzweig et al., 2014; Schewe et al., 2019), including the interacting consequences of changes in temperature, precipitation, eCO_2 and tropospheric O_3, particularly in the context where management-driven yields increases are still occurring across vast areas of croplands. Possible ecosystems transitions from equilibrium to non-equilibrium systems driven primarily by stochastic abiotic factors will likely result in highly variable and less predictable primary production. Land uses such as grazing can also regulate grasslands responses to climate change. For example, sheep grazing has been found to limit CO_2 stimulation of grassland productivity by selectively consuming legumes and forbs, plants with the greatest growth responses to CO_2 (Newton et al., 2014). The issue of uncertainty is even more significant for grass yield projections than for crops, as reference data are less available for models' development and evaluation.

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2.1.1.4. Impacts of pests, pathogens, weeds and pollinators on yields

The effect of climate hazards on pests (e.g. insect pests, pathogens), weed outbreaks and pollinators can have significant consequences for animal feed availability as reviewed in Myers et al. (2017).

Pests, pathogens and weeds are estimated to currently reduce the production of major crops by 25–40% (Flood, 2010). Increases in temperature increase winter survival of insect pests and rates of herbivory (Bale et al., 2002), and alter the spatial distribution of pests and pathogens. Bebber et al. (2013) reported an average poleward shift of pest and pathogen distribution of 2.7 km per year since 1960, though there is substantial variation among taxonomic groups. Under climate change, the spatial mismatches between pests and natural predators may be exacerbated in some regions, weakening biological control systems (Selvaraj et al., 2013). In some instances, weather extremes can weaken crop defences and create niches for pests and weed outbreaks (Rosenzweig et al., 2001). In other cases, extreme events can reduce pests and weeds, and as such support crop establishment and growth (Young, 2015). Recent intense desert locust outbreaks across East Africa, Asia and the Middle East have been linked to a series of cyclones causing warm and wet conditions (Salih et al., 2020). In Ethiopia, as per April 2020, nearly 200,000 ha of cropland were damaged by the insects, leading to the loss of over 356,000 tons of grain and thousands of tons of crop residues, a key livestock feed in the country (FAO, 2020). An additional 1.3 million hectares of pasture were affected, reducing pastoral areas by as much as 61% in the Somali region. Increases in eCO2 concentrations may also influence the weed composition and crop defences in complex ways (Zvereva and Kozlov, 2006), including reducing the effectiveness of herbicides (Ziska and Goins, 2006; Ziska and George, 2004). Shifting pest and disease patterns may increase the use of pesticides, some of which (i.e. dioxins) can pass on to animal products. These toxins can remain in soils for extended periods, and can contaminate animal feeds and water sources, particularly in conditions with alternating periods of drought and floods that are more likely with climate change (van der Spiegel et al., 2012).

More unstable weather, including more humid and cloudier conditions will lead to more on-farm post-harvest losses of animal feed, especially in developing countries with hot climates where most smallholders rely on the sun to dry their crops and forages before storage (Hodges et al., 2011). Contamination by toxins will likely also be higher (van der Spiegel et al., 2012). For instance, maize and sorghum can become contaminated by aflatoxins, particularly in drought conditions. While concentrations at harvest are usually not poisonous, the storage of grains under damp or poorly aerated conditions can lead to mould and the poisoning of animals and consumers. Increases in pest infestation frequency or intensity under climate change will also result in higher crop losses where storage facilities are inadequate.

While all grasses and most staple food grains such as maize, wheat, rice and sorghum are wind or self-pollinated, some crops used as livestock feed in industrial and mixed crop-livestock systems are animal pollinator-dependent to varying levels (e.g. soybean, cowpeas, pigeon peas, broad beans, rapeseed, oilseed rape, oil palm and some vegetable and fruit crops) (Klein et al., 2007). Climate change impacts on pollinators include changes in the abundance and distribution of both flowering plants and pollinators (Abrol, 2011; Hegland et al., 2009; IPBES, 2016; Memmott et al., 2007), and the timing of flowering and pollinator emergence and migration (Parmesan and Yohe, 2003), causing a mismatch in pollinator availability and crops to be pollinated. This contributes to reductions in the breadth and nutritional value of feed for pollinators (Ziska et al., 2016), which in turn decreases pollinator abundance. Increases in eCO2 concentrations also affect the nutritional value of key forages for pollinators (Ziska et al., 2016). While the net effect of climate change on pollinators remains uncertain, studies indicate that a reduction in animal pollination would decrease yields of numerous pollinator-dependent food crops (Klein et al., 2007).[10,11,12]

II. DISCUSSION

Direct effects of climate change on livestock

The most significant direct impact of climate change on livestock production comes from the heat stress. Heat stress results in a significant financial burden to livestock producers through decrease in milk component and milk production, meat production, reproductive efficiency and animal health. Thus, an increase in air temperature, such as that predicted by various climate change models, could directly affect animal performance. Fig.1 describes the various impacts of climate change on livestock production.

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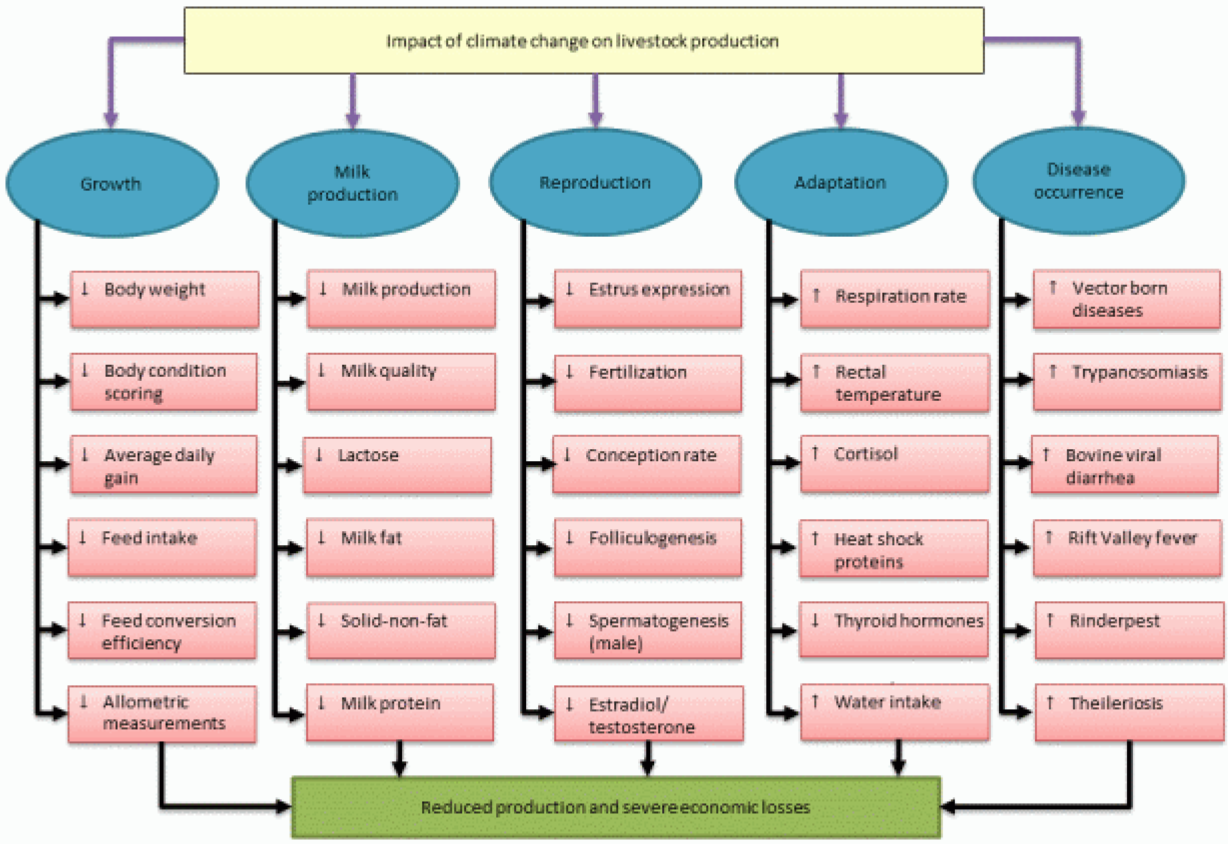

Fig. 1. Impact of climate change on livestock production

Indirect effects of climate change on livestock

Most of the production losses are incurred via indirect impacts of climate change largely through reductions or non-availability of feed and water resources. Climate change has the potential to impact the quantity and reliability of forage production, quality of forage, water demand for cultivation of forage crops, as well as large-scale rangeland vegetation patterns. In the coming decades, crops and forage plants will continue to be subjected to warmer temperatures, elevated carbon dioxide, as well as wildly fluctuating water availability due to changing precipitation patterns. Climate change can adversely affect productivity, species composition, and quality, with potential impacts not only on forage production but also on other ecological roles of grasslands (Giridhar and Samireddypalle, 2015). Due to the wide fluctuations in distribution of rainfall in growing season in several regions of the world, the forage production will be greatly impacted. With the likely emerging scenarios that are already evident from impact of the climate change effects, the livestock production systems are likely to face more of negative than the positive impact. Also climate change influences the water demand, availability and quality. Changes in temperature and weather may affect the quality, quantity and distribution of rainfall, snowmelt, river flow and groundwater. Climate change can result in a higher intensity precipitation that leads to greater peak run-offs and less groundwater recharge. Longer dry periods may reduce groundwater recharge, reduce river flow and ultimately affect water availability, agriculture and drinking water supply. The deprivation of water affects animal physiological homeostasis leading to loss of body weight, low reproductive rates and a decreased resistance to diseases (Naqvi et al., 2015). More research is needed into water resources' vulnerability to climate change in order to support the development of adaptive strategies for agriculture. In addition, emerging diseases including vector borne diseases that may arise as a result of climate change will result in severe economic losses.[13]

Concept of multiple stressor impacts on livestock

Animals reared in tropical environments are generally subjected to more than one stressor at a time. Multiple stressors greatly affect animal production, reproduction and immune status. Most studies which have investigated the effects of

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environmental stress on livestock have generally studied one stressor at a time because comprehensive, balanced multifactorial experiments are technically difficult to manage, analyze, and interpret (Sejian et al., 2010). When the animals were subjected to heat and nutritional stress as separate stressors the impact of these was not as detrimental to growth and reproductive performance, as was the case when the animals were subjected to both stressors at the same time (Sejian et al., 2011). The combined stressors had major effects on growth and reproductive parameters. In addition, the adaptive mechanisms exhibited by these animals were different for individual stressors compared to combined (heat and nutritional) stressors (Sejian et al., 2010). Hence, when two stressors occur simultaneously, the impact on the biological functions necessary for adaption and maintenance during the stressful period may be severe (Sejian et al., 2013). Hence any research pertaining to climate change effects on livestock must address multiple stressors.

Impact of climate change on livestock production

Animals exposed to heat stress reduce feed intake and increase water intake, and there are changes in the endocrine status which in turn increase the maintenance requirements leading to reduced performance (Gaughan and Cawsell-Smith, 2015). Environmental stressors reduce body weight, average daily gain and body condition of livestock. Declines in the milk yield are pronounced and milk quality is affected: reduced fat content, lower-chain fatty acids, solid-non-fat, and lactose contents; and increased palmitic and stearic acid contents are observed. Generally the higher production animals are the most affected. Adaptation to prolonged stressors may be accompanied by production losses. Increasing or maintaining current production levels in an increasingly hostile environment is not a sustainable option. It may make better sense to look at using adapted animals, albeit with lower production levels (and also lower input costs) rather than try to infuse ‘stress tolerance’ genes into non-adapted breeds (Gaughan, 2015).

Impact of climate change on livestock reproduction

Reproductive processes are affected by thermal stress. Conception rates of dairy cows may drop 20–27% in summer, and heat stressed cows often have poor expression of oestrus due to reduced oestradiol secretion from the dominant follicle developed in a low luteinizing hormone environment. Reproductive inefficiency due to heat stress involves changes in ovarian function and embryonic development by reducing the competence of oocyte to be fertilized and the resulting embryo (Naqvi et al., 2012). Heat stress compromises oocyte growth in cows by altering progesterone secretion, the secretion of luteinizing hormone, follicle-stimulating hormone and ovarian dynamics during the oestrus cycle. Heat stress has also been associated with impairment of embryo development and increase in embryonic mortality in cattle. Heat stress during pregnancy slows growth of the foetus and can increase foetal loss. Secretion of the hormones and enzymes regulating reproductive tract function may also be altered by heat stress. In males, heat stress adversely affects spermatogenesis perhaps by inhibiting the proliferation of spermatocytes.

Impact of climate change on livestock adaptation

In order to maintain body temperature within physiological limits, heat stressed animals initiate compensatory and adaptive mechanisms to re-establish homeothermy and homeostasis, which are important for survival, but may result reduction in productive potential. The relative changes in the various physiological responses i.e. respiration rate, pulse rate and rectal temperature give an indication of stress imposed on livestock. The thermal stress affects the hypothalamic–pituitary–adrenal axis. Corticotropin-releasing hormone stimulates somatostatin, possibly a key mechanism by which heat-stressed animals have reduced growth hormone and thyroxin levels. The animals thriving in the hot climate have acquired some genes that protect cells from the increased environmental temperatures. Using functional genomics to identify genes that are up- or down-regulated during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and to the creation of therapeutic drugs and treatments that target affected genes (Collier et al., 2012). Studies evaluating genes identified as participating in the cellular acclimation response from microarray analyses or genome-wide association studies have indicated that heat shock proteins are playing a major role in adaptation to thermal stress.

Impact of climate change on livestock diseases

Variations in temperature and rainfall are the most significant climatic variables affecting livestock disease outbreaks. Warmer and wetter weather (particularly warmer winters) will increase the risk and occurrence of animal diseases, because certain species that serve as disease vectors, such as biting flies and ticks, are more likely to survive year-round. The movement of disease vectors into new areas e.g. malaria and livestock tick borne diseases (babesiosis, theileriosis, anaplasmosis), Rift Valley fever and bluetongue disease in Europe has been documented. Certain existing

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parasitic diseases may also become more prevalent, or their geographical range may spread, if rainfall increases. This may contribute to an increase in disease spread for livestock such as ovine chlamydiosis, caprine arthritis (CAE), equine infectious anemia (EIA), equine influenza, Marek's disease (MD), and bovine viral diarrhea. There are many rapidly emerging diseases that continue to spread over large areas. Outbreaks of diseases such as foot and mouth disease or avian influenza affect very large numbers of animals and contribute to further degradation of the environment and surrounding communities' health and livelihood.

There is considerable research evidence showing substantial decline in animal performance inflicting heavy economic losses when subjected to heat stress. With the development of molecular biotechnologies, new opportunities are available to characterize gene expression and identify key cellular responses to heat stress. These tools will enable improved accuracy and efficiency of selection for heat tolerance. Systematic information generated on the impact assessment of climate change on livestock production may prove very valuable in developing appropriate adaptation and mitigation strategies to sustain livestock production in the changing climate scenario. As livestock is an important source of livelihood, it is necessary to find suitable solutions not only to maintain this industry as an economically viable enterprise but also to enhance profitability and decrease environmental pollutants by reducing the ill-effects of climate change.

III. RESULTS

There is little doubt that climate change will have an impact on livestock performance in many regions and for most predictive models the impact will be detrimental. The real challenge is how do we mitigate and adapt livestock systems to a changing climate? Livestock production accounts for approximately 70 % of all agricultural land use, and livestock production systems occupy approximately 30 % of the world's ice-free surface area. Globally 1.3 billion people are employed in the livestock (including poultry) sector and more than 600 million smallholders in the developing world rely on livestock for food and financial security. The impact of climate change on livestock production systems especially in developing countries is not known, and although there may be some benefits arising from climate change, however, most livestock producers will face serious problems. Climate change may manifest itself as rapid changes in climate in the short term (a couple of years) or more subtle changes over decades. The ability of livestock to adapt to a climatic change is dependent on a number of factors. Acute challenges are very different to chronic long-term challenges, and in addition animal responses to acute or chronic stress are also very different. The extents to which animals are able to adapt are primarily limited by physiological and genetic constraints. Animal adaptation then becomes an important issue when trying to understand animal responses. The focus of animal response should be on adaptation and management. Adaptation to prolonged stressors will most likely be accompanied by a production loss, and input costs may also increase. Increasing or maintaining current production levels in an increasingly hostile environment is not a sustainable option.[11,12]

Livestock produces the majority of greenhouse gas emissions from agriculture and demands around 30% of agricultural fresh water needs, while only supplying 18% of the global calorie intake. Animal-derived food plays a larger role in meeting human protein needs, yet is still a minority of supply at 39%, with crops providing the rest.[3]:746–747

Out of the Shared Socioeconomic Pathways used by the Intergovernmental Panel on Climate Change, only SSP1 offers any realistic possibility of meeting the 1.5 °C (2.7 °F) target.[93] Together with measures like a massive deployment of green technology, this pathway assumes animal-derived food will play a lower role in the global diets relative to now.[9] As a result, there have been calls for phasing out subsidies currently offered to livestock farmers in many places worldwide,[11] and net zero transition plans now involve limits on total livestock headcounts, including substantial reductions of existing stocks in some countries with extensive animal agriculture sectors like Ireland.[10] Yet, an outright end to human consumption of meat and/or animal products is not currently considered a realistic goal.[94] Therefore, any comprehensive plan of adaptation to effects of climate change, particularly the present and future effects of climate change on agriculture, must also consider livestock.
This section is an excerpt from Greenhouse gas emissions from agriculture § Livestock.[edit]

Livestock and livestock-related activities such as deforestation and increasingly fuel-intensive farming practices are responsible for over 18%[95] of human-made greenhouse gas emissions, including:

- 9% of global carbon dioxide emissions
- 35–40% of global methane emissions (chiefly due to enteric fermentation and manure)
- 64% of global nitrous oxide emissions (chiefly due to fertilizer use.[95])

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Livestock activities also contribute disproportionately to land-use effects, since crops such as corn and alfalfa are cultivated in order to feed the animals.

In 2010, enteric fermentation accounted for 43% of the total greenhouse gas emissions from all agricultural activity in the world.[96] The meat from ruminants has a higher carbon equivalent footprint than other meats or vegetarian sources of protein based on a global meta-analysis of lifecycle assessment studies.[97] Small ruminants such as sheep and goats contribute approximately 475 million tons of carbon dioxide equivalent to GHG emissions, which constitutes around 6.5% of world agriculture sector emissions.[98] Methane production by animals, principally ruminants, makes up an estimated 15-20% global production of methane.[99][100] Research continues on the use of various seaweed species, in particular Asparegopsis armata, as a food additive that helps reduce methane production in ruminants.[101]
Worldwide, livestock production occupies 70% of all land used for agriculture, or 30% of the land surface of the Earth.[95] The way livestock is grazed also affects future fertility of the land. Not circulating grazing can lead to unhealthy compacted soils. The expansion of livestock farms affects the habitats of native wildlife and has led to their decline. Reduced intake of meat and dairy products is another effective approach to reduce greenhouse gas emissions. Slightly over half of Europeans (51%) surveyed in 2022 support reducing the amount of meat and dairy products people may buy to combat climate change - 40% of Americans and 73% of Chinese respondents felt the same.

IV. CONCLUSION

Climate change is a major threat to animal agriculture through its potential effects on heat stress, food and water security, extreme weather events, vulnerable shelter and population migration. Among the climatic variables, temperature and humidity are common environmental stressors that have detrimental effect on growth, puberty, quality, and developmental competence of oocytes as well as milk production. These stressors are likely to increase in intensity due to the effects of climate change and can have significant impacts on milk production, oocyte maturation, fertilization, and embryo development. Elevated temperature has deleterious effects on oocyte growth, protein synthesis, or formation of transcripts required for subsequent embryonic development. A thorough understanding of the impact of temperature on ovarian function will help in developing managemental paradigm for minimizing thermal stress on embryo. Using functional genomics to identify genes that are up- or downregulated during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and toward the creation of therapeutic drugs and treatments that target affected genes.[13]

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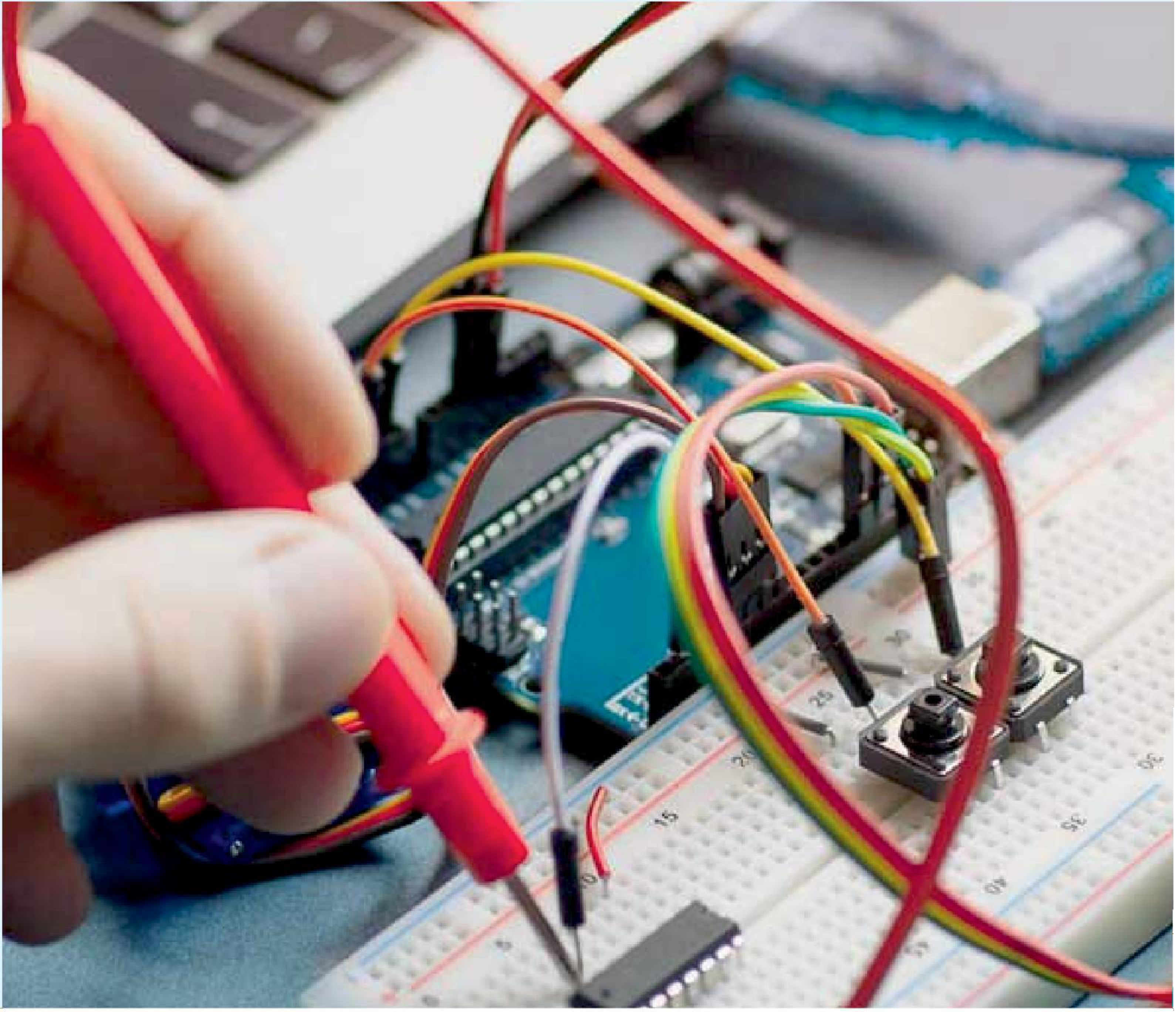

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