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Original Article

Direct and Indirect Impacts of Climate Change on Dairy Cattle Production

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Abstract

Climate change exerts significant direct and indirect impacts on dairy cattle production, posing multifaceted challenges for farmers worldwide. Direct effects include elevated temperatures influencing metabolic, endocrine, and oxidative processes, potentially disrupting glucose, protein, and lipid metabolism. Liver functionality may be compromised, affecting cholesterol and albumin levels, leading to adverse health outcomes. Indirectly, climate change contributes to alterations in microbial communities, the spread of vector-borne diseases, and compromised host resistance, creating an environment conducive to heat stress in dairy cattle. This, in turn, results in diminished reproductive capabilities, compromised health, and reduced overall productivity. To counter these challenges, various mitigation strategies are employed in dairy farming practices. Cooling systems such as fans, misters, sprinklers, and cooled waterbeds are implemented, and novel technologies like tunnel ventilation are explored. Management adjustments, including altered feeding times and the provision of shade, play a crucial role in minimizing heat stress and maintaining cattle well-being.

Introduction

Climate change stands as the foremost threat to the planet, influencing the accessibility of land and water, along with crop yields, amidst a backdrop of rapidly increasing populations, intermittently giving rise to food crises. Climate change refers to discernible shifts in climate properties, verified through statistical tests, persisting for an extended period. The indisputable warming of the global climate is accompanied by increased temperatures and more frequent, intense extreme weather events (like heatwaves, droughts, and floods), contributing to heightened climatic uncertainty (Fraser, 2009; IPCC Climate Change 2013).

Extreme climatic conditions are perceived to have detrimental effects on livestock production. Consequently, efforts to adapt to and mitigate the adverse impacts of such extremes have played a crucial role in combating the climatic influence on livestock production (Khalifa, 2003). Livestock products stand as a vital agricultural commodity for ensuring global food security. This sector supports the livelihoods of approximately one billion of the world's poorest population and engages nearly 1.1 billion people (Hurst *et al.,* 2005). Forecasts project a rise in global milk production from 664 million to 1077 million tonnes and a doubling of meat production from 258 to 455 million tonnes by 2050 (Alexandratos and Bruinsma, 2012). However, the looming challenges of climate change, intensified competition for land and water resources, and the imperative of ensuring food security pose potential threats to livestock production, particularly during a time when its role is critical (Thornton, 2010). Livestock production faces the impact of climate change through increased competition for natural resources, changes in the quantity and quality of available feeds, elevated risks of livestock diseases, heat stress, and the loss of biodiversity. Concurrently, there is an expected 100% increase in the demand for livestock products by the middle of the 21st century, as stated by Garnett, 2009.

According to the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) in 2014, the global average surface temperature is projected to increase between 0.3°C and 4.8°C by the year 2100. This temperature shift has notable implications for dairy cattle, known to experience heat stress in elevated ambient conditions. Studies, such as the one conducted by Solymosi *et al.,* 2010, have already documented a notable increase in the frequency of days leading to heat stress in various regions over recent decades.

The primary consequences of climate change, significantly impacting animal physiology, welfare, health, and reproduction, and consequently bearing relevance for livestock production, involve an increased occurrence of hot days, heat waves, warm periods, and other extreme weather events such as floods and hail (Zampieri *et al.,* 2016). It is reasonable to infer that all facets of the dairy production value chain will be subject to the influence of climate change, particularly under extreme conditions. For example, existing literature indicates that heat waves have detrimental effects on both milk yield and composition, ultimately affecting various dairy products in terms of both quality and quantity (Cowley *et al.,* 2015).

Direct effect of climate change

Climate change has discernible impacts on various facets of livestock production, encompassing animal performance, product quality, and reproduction. The altered climatic conditions can influence the physiological responses of animals, potentially affecting growth rates, feed efficiency, and overall performance. When climatic conditions, such as ambient temperature, surpass the upper threshold of an individual's thermoneutral zone, the organism must enhance heat dissipation, leading to an increase in body temperature. This heat load directly and indirectly affects the organism and its performance. Quantifying precise thermoneutral zone limits for dairy cattle is challenging due to the complex relationship between hyperthermia levels and milk production. However, the negative correlation between ambient heat and feed intake intensifies with high milk yields. The reduction in feed intake is crucial for balancing the thermal load, making high-producing dairy cattle more susceptible to heat stress (Zimbelman *et al.,* 2010).

1. **Effect on milk production**

Lactating dairy cows thrive and achieve optimal productivity within a specific temperature range known as the thermoneutral zone (TNZ), typically between 5 °C and 25 °C. This range represents the comfort zone for these cows. However, deviations from this thermoneutral zone, whether due to elevated temperatures or colder conditions, result in dairy cattle experiencing either heat stress or cold stress. In the context of dairy cows, research has focused on identifying two pivotal thresholds related to the Temperature-Humidity Index (THI) to better understand and address the impacts of environmental conditions on their well-being (Davison *et al.,* 1996). Milk production starts declining at Temperature-Humidity Index (THI) above 72 for cows without shade, while significant declines are observed above THI 78 for cows with shade and a sprinkler system. High-productivity animals with elevated endogenous heat production demonstrate increased heat tolerance. According to Bouraoui et al., 2002, there is a correlation of -0.76 between daily Temperature-Humidity Index (THI) and milk yield, and a correlation of -0.24 between THI and feed intake. When the THI surpasses 69, a decrease of 0.41 kg in daily milk yield is observed per incremental index unit.

The drop in milk production during heat stress results from diminished nutrient intake and absorption in the portal-drained viscera of cows. The shift in blood flow towards peripheral tissues for cooling disrupts nutrient metabolism, contributing to a decline in milk yield. Elevated milk production heightens animals' sensitivity to thermal stress, lowering the threshold temperature for milk losses, as discussed in reference (Berman, 2005). Moreover, the assessment of protein fractions revealed a decline in the levels of casein, lactoalbumin, IgGM, and IgA (Nardone *et al.,* 2006). Liu *et al.,* 2017 reported alterations in the triacylglycerol (TAG) profile and reduced phospholipid levels due to heat stress, potentially influencing milk fat characteristics such as fatty acid composition. In contrast, Cowley *et al.,* 2015 observed no changes in milk fat proportion during heat stress, although it tends to decrease milk protein and casein content. Regarding milk mineral content, Mariani *et al.,* 1993 identified significant seasonal fluctuations likely influenced by various factors such as feed.

2. **Effect on reproductive performance**

Cattle fertility experiences a notable decline, dropping from approximately 50% in winter to below 15% in summer, representing a reduction of about 20-27% (Chebel *et al.,* 2004). Contrary to common assumptions that dry pregnant cows are less susceptible to heat stress as they are not lactating, they face significant challenges during the dry period. This critical phase, involving mammary gland involution, can impact endocrine responses, potentially leading to increased fetal abortions, shortened gestation length, reduced calf birth weight, and hindered follicle and oocyte maturation within the postpartum reproductive cycle (Bibly *et al.,* 2008). Heat stress has the potential to damage somatic cells within ovarian follicles (theca and granulosa cells), consequently affecting estradiol synthesis (Wilson *et al.,* 1998). This, in turn, compromises oocyte growth in cows by disrupting the secretion of progesterone, luteinizing hormone, and follicle-stimulating hormone during the estrous cycle (Ronchi *et al.,* 2001).

Rensis and Scaramuzzi, 2003 proposed a hypothesis suggesting that the development of the dominant follicle occurs in an environment with low luteinizing hormone (LH), leading to diminished estradiol secretion and, consequently, a reduced expression of estrus characterized by shortened duration and intensity. In the aftermath of ovulation, damaged oocytes face decreased prospects of successful fertilization and development into a viable embryo. The capacity of zygotes to form blastocysts experiences a decline in summer conditions. Heat stress also exerts an impact on early embryo development; applying heat from day 1 to day 7 after estrus results in diminished embryo quality and developmental stage compared to embryos flushed on day 7 after estrus. During pregnancy and prepartum periods of heat stress, there is a potential decrease in thyroid hormones and placental estrogen levels, coupled with an increase in non-esterified fatty acid concentrations in the blood. These changes collectively can influence udder and placental growth, nutrient delivery to the unborn calf, and subsequent milk production (Collier *et al.,* 1982).

3. Effect on animal health

Climate change impacts on livestock diseases vary with geography, land use, disease traits, and animal susceptibility (Thornton *et al.,* 2009). Prolonged high temperatures can impact livestock by affecting metabolic rate, endocrine and oxidative status, glucose, protein, and lipid metabolism, liver function (resulting in reduced cholesterol and albumin), non-esterified fatty acids (NEFA), saliva production, and salivary HCO_3^- content (Webster, 1991; Johnson, 1980; Bernabucci *et al.,* 2002, 2006; Ronchi *et al.,* 1999). Additionally, increased energy deficits can negatively influence cow fitness and longevity (King *et al.,* 2006). Rising temperatures directly elevate morbidity and mortality risks, while indirect effects involve changes in microbial communities, vector-borne diseases, food-borne illnesses, host resistance, and challenges in feed and water availability (Nardone *et al.,* 2010; Thornton *et al.,* 2009; Tubiello *et al.,* 2008). Rising temperatures could accelerate the growth of pathogens and parasites, negatively impacting livestock (Harvell *et al.,* 2002, Karl *et al.,* 2009, Patz *et al.,* 2000). Climate change may lead to shifts in disease spread, severe outbreaks, or the introduction of new diseases to livestock not typically exposed (Thornton *et al.,* 2009). Assessing disease dynamics and livestock adaptation is crucial for maintaining resilience. Global warming and precipitation changes influence the quantity and spread of vector-borne pests like flies, ticks, and mosquitoes (Thornton *et al.,* 2009). Warmer conditions increase the likelihood of disease transmission between hosts. Studies suggest potential weight loss in livestock due to increased tick infestations and the extensive spread of disease vectors with a 2 °C temperature rise (Wittmann *et al.,* 2001). Disease surveillance and technologies like DNA fingerprinting and antiviral medications may mitigate these impacts, but the emergence of new diseases could complicate risk estimation, given their dependence on animal exposure and interaction factors (Perry and Sones, 2009, Thornton, 2010).

Indirect effects of climate change

The alteration of animal feed resources stands out as a major consequence of climate change on livestock production (Minson, 2012). Climate change and its variations can adversely affect the production and quality of feed crops and forage, water availability, animal growth, milk production, disease prevalence, reproduction, and biodiversity [Thornton *et al.,* 2009; IFAD, 2010; Nardone *et al.,* 2010). These impacts are primarily attributed to rising temperatures, increased atmospheric carbon dioxide (CO_2) concentration, variations in precipitation, or a combination of these factors (IFAD, 2010). As per the Intergovernmental Panel on Climate Change (IPCC, 2007), there is a high level of confidence that the overall impact of climate change on water resources and freshwater ecosystems will be negative, resulting from reduced quantity and quality of available water.

The rising heat stress is expected to significantly increase the water requirements for livestock, leading to overgrazing near water sources. This, in turn, contributes to land degradation and poses a threat to biodiversity (IPCC, 2007). In the case of Bos indicus, water intake is projected to rise from around 3kg per kg of dry matter intake at an ambient temperature of 10 °C to 5kg at 30 °C, and approximately 10kg at 35 °C. The adverse effects of global warming are particularly evident in grazing systems located in arid and semi-arid regions (Hoffman and Vogel, 2008). Elevated temperatures and reduced rainfall are factors that decrease yields of rangelands, contributing to their degradation. Higher temperatures are likely to decrease animal feed intake and negatively impact feed conversion rates.

The spatial distribution and availability of pasture and water are intricately linked to the pattern and abundance of rainfall (Aklilu *et al.,* 2013). Changes in rainfall patterns and temperature ranges influence feed availability, grazing areas, feed quality, as well as the incidence of weeds, pests, and diseases (Coffey, 2008). As a result, variations in climatic factors such as temperature, precipitation, and the frequency and severity of extreme events like droughts directly influence livestock yields (Adams *et al.,*1998).

Strategies to adapt climate change

Managing dairy herds during frequent and intense heat periods, especially for high-performing animals, poses significant challenges for farmers. Various strategies exist, including structural changes like cooling methods and providing ample shade (Kendall *et al.,* 2007). Management adjustments, such as altering feeding times to cooler periods like evenings and early mornings, can help minimize heat stress in dairy cattle (Legrand *et al.,* 2009). Shifting feeding times to the evening or early morning may reduce heat load during high ambient temperatures (Nikkhah *et al.,* 2011). However, Ominski et al., 2002 suggest that this doesn't affect vaginal temperature, feed intake, and performance in heat-stressed dairy cattle. Cooling systems like fans, misters, sprinklers, and cooled waterbeds, including advanced technologies like tunnel ventilation, are crucial for reducing heat stress in dairy cattle (Calegari *et al.,* 2012). Kendall *et al.,* 2007 demonstrated that a combined approach of shade and sprinklers or just sprinklers is more effective (67% and 60% reduction in respiration rate, respectively) compared to providing shade alone (30%). Avendaño-Reyes *et al.,* 2010 emphasized the importance of extending cooling periods and increasing their frequency for enhanced effects. Cooling management, including sprinklers and ventilation, positively impacts reproductive performance, as observed by Honig *et al.,* 2016. While shade is less efficient in cooling capacity, some cows (65%) prefer it over sprinklers (Schütz *et al.,* 2011). Shade not only reduces temperature but also minimizes solar radiation, with positive effects on animal performance reported by Moon *et al.,* 2015.

Conclusion

In conclusion, climate change poses both direct and indirect impacts on dairy cattle production. The direct effects include elevated temperatures affecting metabolic rate, endocrine status, and oxidative balance, leading to potential challenges in glucose, protein, and lipid metabolism. Additionally, liver functionality may be compromised, impacting cholesterol and albumin levels. Indirectly, climate change influences microbial communities, the spread of vector-borne diseases, and host resistance. These changes, coupled with altered feeding patterns, can result in heat stress, affecting the overall health, performance, and reproductive capabilities of dairy cattle. Efforts to mitigate these impacts involve the implementation of various cooling systems, such as fans, misters, and sprinklers, as well as management strategies like adjusting feeding times and providing shade. Studies have demonstrated the effectiveness of combining shade and sprinklers for a significant reduction in respiration rates, emphasizing the importance of comprehensive cooling approaches. Furthermore, advancements in cooling management have shown positive effects on reproductive performance and overall fertility. As dairy farmers face increasing challenges due to climate change, adopting sustainable practices and innovative technologies becomes imperative for ensuring the resilience and well-being of dairy cattle. The dual focus on both direct and indirect impacts, along with the integration of effective cooling systems, presents a holistic approach to safeguarding dairy cattle production in the face of a changing climate.

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