ISSN: 2998-2707

DOI: 10.33552/APOAJ.2026.02.000532

Anatomy & Physiology: Open Access Journal

Iris Publishers

Mini Review

Climate Change and Livestock: Bridging Physiology, Adaptation, and Mitigation for Sustainable Production

Fawzy Younis*

Desert Research Center, Egypt

***Corresponding author:** Fawzy Younis, Desert Research Center, Egypt

Received Date: January 30, 2026

Published Date: February 18, 2026

Abstract

This article comprehensively examines the interconnected triad of animal physiology, climate adaptation, and greenhouse gas (GHG) mitigation within livestock production systems. It argues that the physiological basis of thermoregulation defines both the sector's vulnerability to climate change (via heat stress) and its significant contribution to emissions (via enteric fermentation and manure). The analysis traces the evolution of this relationship from historical, localized interactions to the current paradigm where accelerated climate change necessitates urgent, concurrent strategies for adaptation and mitigation. The article posits that future sustainability hinges on an integrated, systems-based approach that leverages advancements in genetics, nutrition, and manure management to develop resilient, low-emission livestock systems. It concludes with targeted recommendations for researchers, policymakers, farmers, and industry stakeholders to foster this essential transition.

Introduction

Climate change represents a profound and multifaceted challenge, deeply intertwined with global food systems. Livestock agriculture sits at a critical junction within this dynamic, acting both as a significant contributor to anthropogenic greenhouse gas (GHG) emissions and as a sector highly vulnerable to climatic shifts. This essay objectively examines the nexus between animal physiology, adaptive responses in farm animals, strategies for emission mitigation, and their collective relationship with climate change across temporal scales-past, present, and future.

Physiology and the Imperative for Adaptation

At its core, the relationship between livestock and climate is governed by physiology-the study of biological functions. Farm animals are homeothermic, requiring the maintenance of a stable internal body temperature despite external fluctuations. Thermoregulation, a key physiological process, involves metabolic heat production and mechanisms for heat loss (e.g., respiration, sweating, vasodilation). When ambient temperatures exceed the thermoneutral zone-the range where an animal maintains body temperature without expending extra energy-animals experience heat stress. The physiological impacts of heat stress are extensive and detrimental to both welfare and productivity. They include increased respiration rate (panting), reduced feed intake, altered endocrine function, and compromised reproductive efficiency [1]. Furthermore, the energy diverted to cooling reduces the efficiency of energy utilization for growth, lactation, or reproduction, inherently increasing the resource and emission footprint per unit of product [2].

Adaptation: From Natural Selection to Human Intervention

In the past, adaptation was primarily driven by natural selection and traditional husbandry. Indigenous breeds in hot climates (e.g., Zebu cattle, Sahiwal) evolved physiological and morphological adaptations such as lighter coat colour, larger skin surface area, and metabolic traits that confer greater heat tolerance [3].

In the present, with accelerated climate change outpacing natural evolutionary rates, human-led adaptation strategies are paramount. These include:

1. Genetic Selection and Breeding: Modern genomics allows for the identification and selection of animals with genetic markers for thermotolerance, aiming to breed more resilient herds without compromising productivity [4].

2. Nutritional Management: Adjusting diets to include lower heat-increment feedstuffs or supplements (e.g., vitamins, minerals) that help mitigate oxidative stress caused by high temperatures.

3. Environmental Modifications: The use of shade, sprinklers, fans, and advanced ventilation systems to modify the microclimate and alleviate heat load.

These adaptive measures are essential for sustaining livestock productivity and ensuring food security in an increasingly variable climate.

Mitigation: Aligning Physiology with Lower Emissions

Simultaneously, the livestock sector must dramatically reduce its GHG footprint, primarily methane (CH_4 from enteric fermentation), nitrous oxide (N_2O from manure), and carbon dioxide (CO_2). Intriguingly, mitigation strategies often intersect with physiology and adaptation:

1. Improved Feed Efficiency: Selecting and managing animals for faster growth or higher milk yield per unit of feed reduces the total number of animals required for production and the methane emitted per unit of product (i.e., reducing emission intensity). This aligns with physiological efficiency.

2. Precision Nutrition and Feed Additives: Formulating diets to precisely meet an animal's physiological needs minimizes waste and nitrogen excretion. Novel feed additives, such as 3-nitrooxypropanol (3-NOP), directly inhibit methanogenesis in the rumen, targeting the physiological pathway of methane production [5, 6].

3. Manure Management: Advanced systems like anaerobic digesters capture methane from manure for energy, transforming a potent GHG into a renewable resource [7]. This addresses the post-excretory physiological by product.

4. Integrated and Regenerative Systems: Practices like silvopasture (integrating trees, pasture, and livestock) can sequester carbon, provide shade for animals (aiding adaptation), and enhance biodiversity [8].

The Temporal Context: Past, Present, and Future

1. Past: Historically, the livestock-climate relationship was more localized and cyclic. Herds influenced local land use, while climatic shifts over centuries drove the geographical distribution and evolution of species.

2. Present: We now observe a decisive shift. Livestock systems are both responding to increased frequency of extreme heat events and contributing approximately 14.5% of global anthropogenic GHG emissions [9]. The need for concurrent adaptation and mitigation defines the current paradigm.

3. Future: The trajectory depends on today's choices. Under high-emission scenarios, the adaptation burden may become overwhelming. Conversely, a concerted global effort toward aggressive mitigation combined with proactive adaptation can lead to a more resilient, low-emission livestock sector, with greater integration of climate risk into breeding and mainstreaming of circular bio-economy principles.

Conclusion and Synthesis

The interplay between animal physiology, adaptation, and GHG mitigation forms a critical feedback loop. Physiological limitations define vulnerability to a warming world, necessitating intelligent adaptation. Meanwhile, the physiological processes of digestion and metabolism are direct sources of emissions, presenting key leverage points for mitigation. Addressing climate change in the context of livestock requires a systems-based approach that recognizes this intrinsic link. By harnessing innovation to promote thermotolerant, efficient, and low-emitting animals, the sector can evolve to meet future food demands while contributing to climate stability.

Recommendations for a Sustainable Pathway

1. For Researchers and Policymakers:

a. Promote Integrated Research: Fund studies on the co-effects of adaptation and mitigation strategies (e.g., long-term impacts of feed additives on heat resilience).

b. Develop Holistic Metrics: Create frameworks assessing productivity, carbon footprint, and climate resilience concurrently.

c. Incentivize Integrated Systems: Support policies that favour silvopasture and regenerative agriculture.

2. For Farmers and Advisors:

a. Adopt Precision Tools: Utilize genomic selection (GWAS) for animals with combined traits of productivity, heat tolerance, and feed efficiency.

b. Implement Precision Nutrition: Reduce nutrient waste through tailored feeding to lower N_2O emissions and improve soil health.

c. Upgrade Manure Management: Transition from open storage to anaerobic digestion or composting for energy and nutrient recovery.

3. For Industry and Value Chains:

a. Build Low-Carbon Supply Chains: Develop traceability for products with low emission intensity and verified adaptive management.

b. Accelerate Feed Innovation: Collaborate to commercialize safe and effective methane-inhibiting feed additives.

4. On the International Stage:

a. Strengthen Climate Commitments: Robustly integrate livestock efficiency and adaptation targets into Nationally Determined Contributions (NDCs) [10, 11].

b. Foster Knowledge Transfer: Establish platforms for sharing expertise on adapted breeds and mitigation technologies across similar agro-ecological zones.

References

1. Renaudeau D, Collin A, Yahav S, de Basilio V, Gourdine JL, et al. (2012) Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6(5): 707-728.
2. Goopy JP, Korir D, Pelster D, Ali AI, Wassie SE, et al. (2020) Severe below-maintenance feed intake increases methane yield from enteric fermentation in cattle. British Journal of Nutrition 123(11): 1239-1246.
3. Hansen PJ (2004) Physiological and cellular adaptations of zebu cattle to thermal stress. Animal Reproduction Science 82-83: 349-360.

4. Hayes BJ, Lewin HA, Goddard ME (2013) The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. Trends in Genetics 29(4): 206-214.

5. Beauchemin KA, Ungerfeld EM, Eckard RJ, Wang M (2020) Review: Fifty years of research on rumen methanogenesis: lessons learned and future challenges for mitigation. Animal 14(S1): s2-s16.

6. Hristov AN, Oh J, Firkins JL, Dijkstra J, Kebreab E, et al. (2013) Special Topics-Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. Journal of Animal Science 91(11): 5045-5069.

7. Amon B, Kryvoruchko V, Amon T, Zechmeister-Boltenstern S (2006) Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agriculture, Ecosystems & Environment 112(2-3): 153-162.

8. Jose S, Dollinger J (2019) Silvopasture: a sustainable livestock production system. Agroforestry Systems 93(1): 1-9.

9. Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, et al. (2013) Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO).

10. Richards M, Bruun TB, Campbell BM, Gregersen LE, Huyer S, et al. (2015) How countries plan to address agricultural adaptation and mitigation: An analysis of Nationally Determined Contributions. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

11. Caré S, Belaid Y, Aoussat A (2019) A framework for assessing livestock farm resilience to climate change: The case of dairy farms. Journal of Cleaner Production 240: 118212.

Citation: Fawzy Younis*. Climate Change and Livestock: Bridging Physiology, Adaptation, and Mitigation for Sustainable Production. Anat & Physiol Open Access J. 2(1): 2026. APOAJ.MS.ID.000532. **DOI:** 10.33552/APOAJ.2026.02.000532