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Climate-Resilient Livestock Production Systems

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Abstract

Livestock production faces mounting pressure from rising demand for animal-derived foods and from climate change, which threatens feed availability, animal welfare, and productivity. This article reviews strategies for building climate-resilient livestock systems. Adaptation measures include genetic improvement for heat tolerance and disease resistance, conservation of indigenous breeds, climate-smart housing, nutritional interventions during heat stress, water management, and precision livestock farming. Mitigation measures focus on reducing greenhouse gas emissions, which livestock contribute at roughly

14–15% of the global anthropogenic total, through methane-reducing diets, composting and vermicomposting of manure, anaerobic digestion for biogas and Bio-CNG, and on-farm renewable energy. Integrating adaptation and mitigation offers a practical pathway to sustainable, productive, and climate-smart livestock systems.

Keywords: Climate change, Livestock, Adaptation, Mitigation and Greenhouse gases.

1. Need for Sustainability Measures

1.1 Increasing Demand for Livestock Products: Rising incomes, urbanization, and population growth have shifted diets toward more animal-derived foods. According to the Food and Agriculture Organization (FAO), between 1960 and 2020, global meat consumption rose about threefold, milk consumption doubled, and egg consumption increased nearly fivefold (FAO, 2024). By 2030, demand is projected to rise by 80–100% for meat, 170% for poultry meat, and 65–70% for eggs (Robinson & Pozzi, 2011; Thornton, 2010). Meeting this demand under a changing climate is among the sector's greatest challenges, as conventional systems dependent on water, land, and fossil fuels are unlikely to remain sustainable.

1.2 Climate Change: Present Scenario: Climate change is among the most serious threats to twenty-first-century agriculture. Global mean temperature is now 1.1–1.3°C above pre-industrial levels, atmospheric CO₂ exceeds 410 ppm (the highest on record), and droughts, floods, heat waves, and cyclones are increasingly frequent and severe (IPCC, 2021).

1.3 Greenhouse Gases and Global Warming: Greenhouse gases (GHGs) trap outgoing infrared radiation, raising Earth's temperature through the greenhouse effect.

Table 1. Major GHGs associated with agriculture and livestock production (Gerber et al., 2013)

Gas	Major Sources	Relative Importance
CO ₂	Fossil fuel combustion, deforestation	Largest contributor
CH ₄	Enteric fermentation, manure	Highly potent
N ₂ O	Fertilizers, manure	Very high warming potential

1.4 Feed and Fodder Scarcity: Feed accounts for 60–70% of livestock production costs, making it the most critical input. Climate change threatens its availability by lowering crop yields and pasture productivity, altering forage quality, and increasing droughts and floods (Thornton, 2010; Sejian et al., 2018). India already faces deficits of approximately 23–24% in dry fodder, 11–12% in green fodder, and 29% in concentrate feed ingredients.



2. Adaptation Strategies for Climate-Resilient Livestock Production

The IPCC defines adaptation as the process through which natural and human systems adjust to changing environmental conditions, thereby reducing vulnerability and enhancing resilience (IPCC, 2022).

2.1 Genetic Improvement: Breeding programmes now target resilience alongside productivity: heat tolerance, disease resistance, feed efficiency, fertility under thermal stress, longevity, and adaptability to harsh environments (Sejian et al., 2018).

Table 2. Important candidate genes for climate resilience

Functional Category	Candidate Genes	Primary Function
Heat shock response	HSP70, HSP90	Cellular protection during heat stress
Stress response	SPAC, WRNIP1, MLH1	DNA repair and stress tolerance
Cellular integrity	SMC6, GEN1	Maintenance of genomic stability
Immune regulation	TNRC6A, CCNG	Immune adaptation
RNA metabolism	SNORA19, SLM5	Protein synthesis during stress

2.2 Indigenous Breeds: Having evolved under local conditions, indigenous breeds generally outperform exotic breeds in heat and drought tolerance, disease resistance, low-quality feed utilization, maintenance requirements, and productive life (ICAR-CRIDA, 2023).

Table 3. Examples of climate-resilient indigenous breeds

Species	Climate-Resilient Indigenous Breeds
Cattle	Sahiwal, Gir, Tharparkar, Red Sindhi
Buffalo	Murrah, Jaffarabadi
Sheep	Marwari, Malpura
Goat	Sirohi, Barbari, Jamunapari

2.3 Climate-Smart Housing: Housing is among the most effective ways to reduce heat stress and improve welfare.

- **Passive cooling:** East–West shed orientation; roofs (which absorb 60–70% of solar radiation) with high ridges, double construction, reflective or insulated materials, and white paint; shade trees.

- **Active cooling:** Fans, foggers, sprinklers, tunnel ventilation (Sejian et al., 2015).

2.4 Nutritional Adaptation:

Table 4. Feeding strategies and additives during heat stress

Category	Options
Feeding practices	Feed in cooler hours; high-quality forage; higher energy density; improved digestibility; less excess protein; antioxidants
Minerals	Zinc, selenium, chromium, copper
Vitamins	A, C, E
Electrolytes	Added to feed or water
Herbal supplements	Ashwagandha, tulsi, amla, turmeric

Table 5. Nutritional approaches for methane reduction (Gerber et al., 2013)

Strategy	Mechanism	Benefit
High-quality forage	Better digestibility	Lower methane intensity
Balanced concentrate	Increased propionate	Lower methane production
Lipids (<7% DM)	Suppress methanogens	Reduced CH ₄ emission
Feed additives	Modify rumen microbes	Improved efficiency
Precision feeding	Better nutrient use	Lower emission intensity

2.5 Water Management: Water is the most critical nutrient in heat stress; provide unrestricted clean, cool water.

2.6 Precision Livestock Farming: Wearable sensors, RFID tags, GPS, thermal cameras, smart collars, automated feeders, and artificial intelligence enable continuous monitoring, detecting heat stress, illness, and behavioural changes before clinical signs appear (Berckmans, 2014).



3. Mitigation Strategies in Livestock Production

Whereas adaptation helps livestock systems cope with climate change, mitigation reduces their contribution to greenhouse gas (GHG) emissions; climate-smart production requires both (FAO, 2013). Livestock account for approximately 14–15% of global anthropogenic GHG emissions: methane (CH₄) from enteric fermentation, nitrous oxide (N₂O) from manure and fertilizer, and carbon dioxide (CO₂) from fossil fuel use, feed production, and land-use change (Gerber et al., 2013).

3.1 Manure Management: Composting is the aerobic decomposition of organic waste into stable, humus-like material. Vermicomposting accelerates this process using earthworms (*Eisenia fetida*, *Eudrilus eugeniae*, *Perionyx excavatus*) and yields higher-quality fertilizer (Sejian et al., 2018; FAO, 2013).

Table 6. Composting versus vermicomposting

Characteristic	Composting	Vermicomposting
Process	Microbial	Earthworm + microbial
Duration	2–4 months	1–2 months
Nutrient quality	Moderate	High
GHG reduction	Moderate	Greater
Market value	Moderate	Higher

3.2 Anaerobic Digestion and Biogas: Anaerobic digestion converts manure into biogas under oxygen-free conditions and is among the most effective climate-smart technologies for livestock farms. Biogas contains 50–75% CH₄, 25–45% CO₂, 0–10% nitrogen, and traces of hydrogen sulphide and hydrogen; the residual slurry is an excellent organic fertilizer (FAO, 2013). Removing CO₂, moisture, and hydrogen sulphide upgrades biogas to Bio-CNG.

3.3 Renewable Energy on Farms: Renewable energy lowers fossil fuel dependence and the farm's carbon footprint.

Table 7. Renewable energy options

Technology	Farm Applications
Solar	Pumps, lighting, cooling
Biogas	Cooking, electricity
Wind	Water pumping
Biomass	Heat and power generation



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