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Climate-Resilient Livestock Production: Pathways to Reduce Greenhouse Gas Emissions and Enhance Sustainability

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Livestock production is an important component of global agriculture and contributes significantly to food security, nutrition and rural livelihoods. However, the sector is also a major source of greenhouse gas (GHG) emissions, mainly methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), which contribute to climate change and global warming. Methane is primarily produced through enteric fermentation and manure decomposition, while nitrous oxide emissions arise from manure handling and nitrogen fertilization in fodder production. Carbon dioxide emissions are mainly associated with feed production, transportation and farm energy use. Climate change adversely affects livestock production through heat stress, reduced feed intake, lower milk and meat production, disease outbreaks, water scarcity and fodder shortages. In recent years, climate resilient livestock practices have gained importance as sustainable approaches to reduce GHG emissions and improve productivity. Practices such as improved feeding management, rotational grazing, scientific manure management, sustainable soil and water management, improved feed conversion efficiency and climate-smart risk management can significantly reduce environmental impacts while enhancing farmer resilience and resource use efficiency. Effective communication systems, early warning mechanisms and awareness programs are also essential for promoting sustainable livestock production. Therefore, adoption of climate resilient livestock systems is necessary for minimizing greenhouse gas emissions, improving livestock productivity and ensuring long-term environmental sustainability.

Keywords: Climate-resilient livestock, Greenhouse gas emissions, Methane mitigation, Sustainable livestock farming, Climate-smart agriculture

Introduction

In pastoral and agro-pastoral systems, livestock is an integral component of global agriculture and plays a vital role in ensuring food security, nutritional supply and rural livelihoods. The sector contributes significantly to the agricultural economy through the production of milk, meat, eggs wool and draft power. Millions of small and marginal farmers depend on livestock as a major source of income and employment. However, the livestock sector is also recognized as one of the major contributors to greenhouse gas (GHG) emissions, particularly methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), which accelerate global warming and climate change. Among the greenhouse gases emitted from livestock systems, methane released through enteric fermentation in ruminants and manure management accounts for a substantial share of agricultural emissions. Nitrous oxide emissions mainly arise from manure handling and fodder cultivation, while carbon dioxide emissions are associated with feed production, transportation and energy use. According to FAO GLEAM 5 (Global Livestock Environmental Assessment Model, 2022) emissions from livestock supply chains consist of 50% methane (CH_4), 24% nitrous oxide (N_2O), and 26% carbon dioxide (CO_2). Among the livestock species, cattle are the primary contributors to GHG emissions, producing around 3.8 Gt CO_2 eq. yr^{-1} and accounting for approximately 62 per cent of all livestock emissions. Pigs, chickens, buffaloes and small ruminants contribute to 14, 9, 8 and 7 per cent, respectively, of livestock's overall emissions. In terms of commodities, meat production claims the largest share of emissions at 67 per cent, followed by milk at 30 per cent and eggs 3 per cent. In recent years, climate resilient livestock practices have gained importance as sustainable approaches to minimize environmental impacts while maintaining productivity. Adoption of such practices not only helps in reducing greenhouse gas emissions but also enhances resource use efficiency, animal health and farmer income. This article highlights the major greenhouse gas emissions from livestock and discusses various climate resilient practices that can help reduce emissions and improve sustainability in the livestock sector.

Greenhouse gases emitted from livestock

Livestock production contributes significantly to greenhouse gas (GHG) emissions, mainly methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) (Fig. 1). These gases are released through various biological and management processes associated with animal farming.

Methane (CH_4): Methane is primarily produced through enteric fermentation in ruminant animals such as cattle, buffalo, sheep and goats. During digestion, microorganisms in the rumen break down fibrous feed materials and release methane, mainly through belching. Methane is also generated from manure decomposition under anaerobic conditions, especially in poorly managed manure storage systems.

Nitrous Oxide (N_2O): Nitrous oxide emissions mainly arise from manure and urine deposition in grazing lands and agricultural soils. Soil microorganisms convert nitrogen compounds present in manure into nitrous oxide through nitrification and denitrification processes. In addition, excessive application of nitrogen fertilizers for fodder production further increases N_2O emissions.

Carbon Dioxide (CO_2): Carbon dioxide emissions in livestock systems mainly originate from feed production, transportation and farm energy use. Cultivation of fodder crops requires fuel, fertilizers, irrigation and machinery, which contribute to CO_2 release. Transportation of feed and livestock products and the use of electricity and fossil fuels for farm operations also increase carbon emissions.

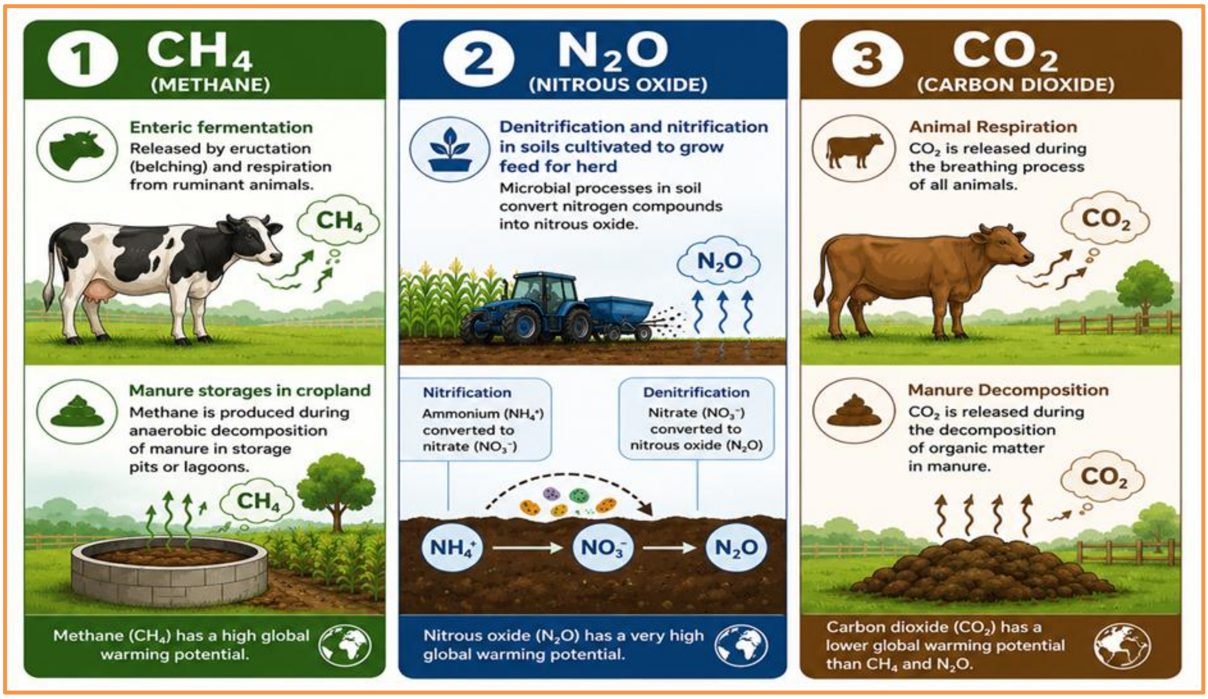

Fig. 1 Greenhouse gases emitted from livestock

Climate change effects on Livestock

Climate change has a significant impact on livestock production and animal health. Rising temperatures and changing weather patterns cause heat stress in animals, which reduces their comfort, growth and reproductive performance. Heat stress also decreases feed intake, leading to poor nutrient utilization and reduced productivity. As a result, milk yield, meat production and overall animal performance decline considerably. Climate change further increases the occurrence of diseases and pest outbreaks by creating favourable conditions for pathogens and vectors. This affects animal health and increases economic losses for farmers. In addition, irregular rainfall and prolonged drought conditions lead to water scarcity and fodder shortages, making it difficult to maintain livestock production throughout the year. Therefore, climate resilient livestock management practices are essential to minimize the adverse impacts of climate change and ensure sustainable livestock production (Fig. 2).

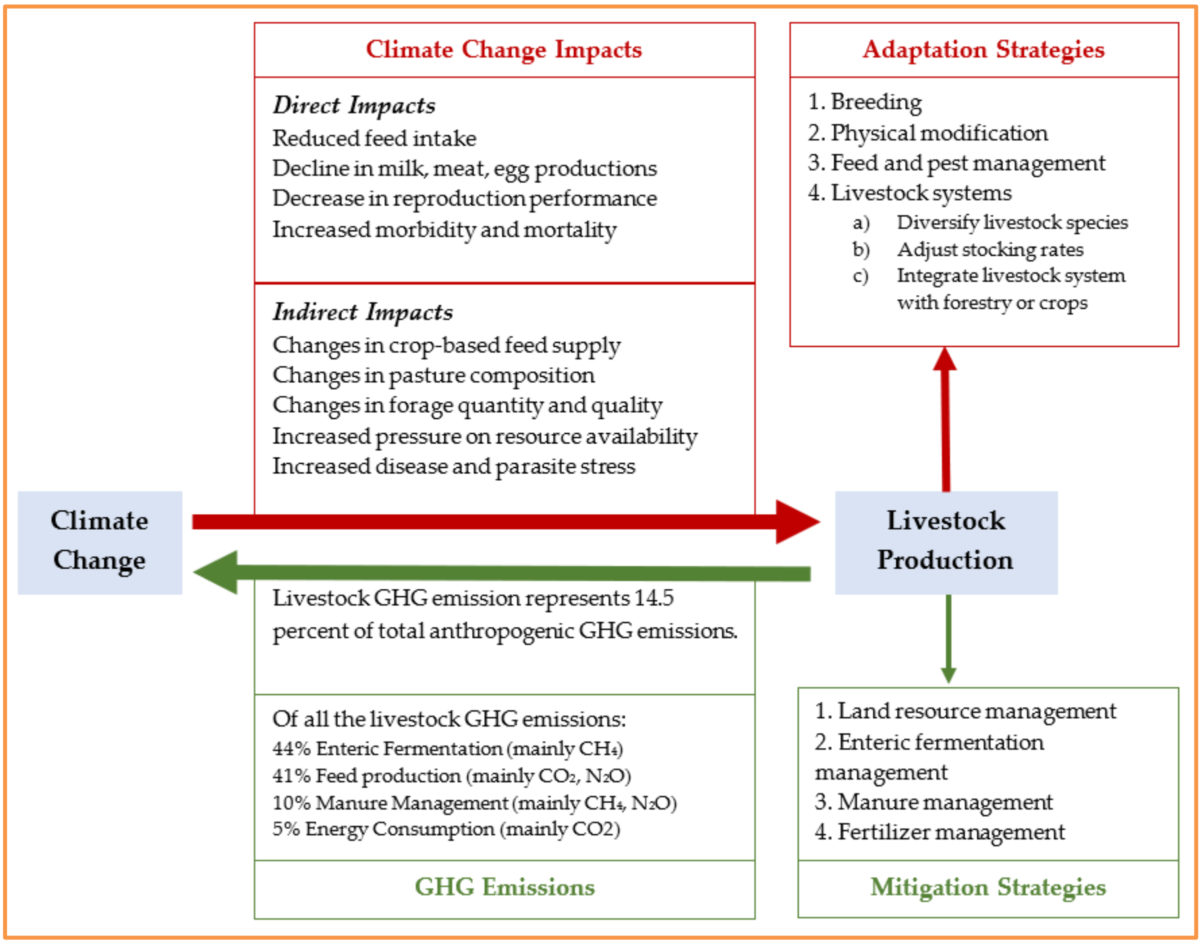

Fig. 2 Overview of the relationship between climate change and livestock production

Emission estimation

Multiplication of the heads of the livestock by emission factors provided by IPCC (1997). Tier 1 method uses default emission factors and hence only the livestock population data are required for estimation. Tier 1 method can be applied for the livestock except cattle where Tier 2 with age is recommended by IPCC (1997). The factor to which feed energy (FE) is converted to methane and depends on several interacting feed and animal characteristics - Methane Conversion Factor (MCF).

The average emission factors will standardize emission Inventory and reduce the uncertainty lies in both emission factors and total emission estimation. Methane Emission Estimation (MEE) from livestock (both from enteric and manure activities) is the sum of the product of category-wise livestock population (Pi) to respective emission factors (kg head^{-1} year^{-1}). The sum of both enteric and manure methane emissions gives Total Methane Emission (TME) per livestock. Later the emission is converted to Tera-gram year^{-1} (Tg yr^{-1}).

$$TME = \sum P_i \times (EF_{EME} + EF_{MME}) \text{ (kg yr}^{-1}\text{)}$$

where EME = Enteric Methane Emission, MME = Manure Methane Emission

Table 1 Mitigation strategies for lowering GHGs emission

Land based systems	**Grazing management**	Rotational grazing enhances the quality and digestibility of the forage, improves the productivity of the system and reduces CH_4 emissions per unit of LWG (FAO, 2013)
	Pasture management and nutrition	Improved pasture quality through nitrogen fertilization may involve tradeoffs between lower CH4 emissions and higher N_2O emissions (Bannink *et al.*, 2010).
	Animal breeding	Locally adapted breeds are tolerant to heat and poor nutrition but also to parasites and diseases (Hoffmann and Vogel, 2008).
Mixed systems	**Integrated soil-crop-water management**	Increasing the organic content of the soil, through conservation tillage, the soil's water holding capacity increases, which makes yields more resilient and reduces erosion (Lal, 2009).
	Water use efficiency and management	a. Feed management (e.g. increasing feed-water productivity, strengthening grazing management) b. Water management c. Animal management (FAO, 2013).
	Sustainable soil management	Carbon sequestration in soils has the potential to mitigate and support climate change adaptation (Pascal and Socolow, 2004).
	Feed management	Crop residues can represent up to 50 percent of the diet of ruminants in mixed farming systems (Herrero *et al.*, 2008)
Landless systems	**Improved waste management**	Improved livestock diets, feed additives, can substantially reduce CH_4 emissions from enteric fermentation
	Improved feed conversion	Treatment of animals with growth promoting substances (steroids) can result in increased efficiency of production and decrease in CH_4 emitted per kg milk (Ulyatt *et al.*, 2002).
	Sourcing low-emission feed	Decreasing dietary fiber and increasing starch and lipid will reduce CH_4 emission (Ulyatt *et al.*, 2002).
	Improving energy use efficiency	Fossil fuel energy is used for the milking process, cooling and storing milk, heating water, lighting and ventilation (Gerber *et al.*, 2011).
	Building resilience along supply chains	greater coordination among the different stakeholders involved in the supply chain, insurance schemes, buffers and stocks may contribute to a greater resilience of supply chains (FAO 2013)

Adoption constraints

Adaptation and mitigation options already exist that would allow the livestock sector to meet its economic, environmental and climate mitigation and resilience goals. Among other factors, low investment, lack of education and cultural, institutional and political barriers have led to generally low adoption rates for these actions.

- ✓ Cost is a barrier to adopting most options, and relative importance of cost varies between 20 and 50%
- ✓ Argentina, Brazil and China - limited labour force due to the lower rural population and fewer people employed in agriculture
- ✓ Ethiopia, Nigeria and Sudan - accessibility and knowledge is a constraint

Conclusion

Climate resilient livestock practices are essential for reducing greenhouse gas emissions and improving sustainable livestock production. Creating awareness among farmers about climate-smart livestock systems can help minimize climate-related risks. Providing timely climate information, seasonal forecasts and technical guidance supports better farm management during drought and extreme weather conditions. Effective communication and early warning systems should be strengthened to promote best management practices among stakeholders. Maintaining optimum stocking rates, avoiding overgrazing and adopting timely destocking measures can reduce animal losses and improve resource sustainability. Thus, climate-smart livestock management plays an important role in environmental protection, productivity improvement and long-term agricultural sustainability.

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