AGRICULTURAL AUTOMATION, CLIMATE CHANGE-ACTION AND FOOD SECURITY: GLOBAL ISSUES & LOCAL PERSPECTIVES

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Published By:

Society for Agriculture, Environmental Resources & Management (SAEREM)

First published 2026

SAEREM World

Nigeria

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

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Typeset in Times New Roman

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AGRICULTURAL AUTOMATION, CLIMATE CHANGE-ACTION AND FOOD SECURITY (GLOBAL ISSUES & LOCAL PERSPECTIVES)

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Printed at: SAEREM

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

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Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous Agricultural Automation, Climate Change-Action and Food Security issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which Agricultural Automation, Climate Change-Action and Food Security issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue Agricultural Automation, Climate Change-Action and Food Security necessary in policy making process that will stimulate increase in food production and environmental sustainability. Agricultural Automation, Climate Change-Action and Food Security**:** *Global Issues & Local Perspectives* is organized in three parts. Part One deals with The Concept of Agricultural Automation, Part Two is concerned with The Concept of Climate Change-Action and Part Three deals with the Concept of Food Security

Eteyen Nyong; October 2026

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Chapter Twelve

Climate-Smart Livestock Production: Adaptation, Mitigation and Sustainable Strategies for Resilient Livestock systems

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1. INTRODUCTION

Livestock production is an important component of global agriculture, contributing to food and nutritional security through the provision of meat, milk, eggs and other animal-derived products. Beyond its contribution to human nutrition, the livestock sector supports the livelihoods of millions of people through employment, income generation, agricultural trade and the provision of assets that can be used to manage household economic uncertainties. In developing countries, particularly across sub-Saharan Africa, livestock also contributes to rural development, household resilience and the sustainability of mixed crop–livestock farming systems. Consequently, maintaining productive, profitable and environmentally sustainable livestock systems is essential to meeting increasing demand for animal-source foods while supporting the livelihoods of livestock-dependent communities (World Bank, 2021).

Despite these benefits, livestock production is increasingly challenged by climate change. Rising temperatures, prolonged heat waves, changes in rainfall distribution, recurrent droughts, flooding and other extreme weather events are altering the environmental conditions under which livestock are raised. These changes affect animals directly through heat stress and associated physiological disturbances, and indirectly through changes in feed availability, pasture productivity, water resources, disease occurrence and the distribution of parasites. The resulting effects may include reduced feed intake, slower growth, impaired reproductive performance, lower milk and egg production, increased mortality and declining farm profitability. The severity of these impacts varies according to livestock species, breed, age, physiological status, production system, geographical location and the capacity of farmers to implement appropriate management practices (IPCC, 2022).

Heat stress is particularly important in tropical and subtropical environments, where high ambient temperatures and humidity can exceed the thermoregulatory capacity of susceptible animals. Under these conditions, animals may reduce feed intake to limit metabolic heat production, thereby compromising nutrient utilization, growth, reproduction and productive performance. In poultry, heat stress can adversely affect body weight gain, feed conversion efficiency, egg production and physiological stability. In cattle, it may reduce milk yield, reproductive efficiency and feed intake, while small ruminants and pigs may also experience changes in physiological function and productivity. Furthermore, changes in rainfall patterns can reduce pasture availability and quality, increase seasonal feed shortages and intensify competition for water. These effects demonstrate that climate change presents a complex challenge involving the interaction of animal physiology, nutrition, health, environmental conditions and farm management (Cheng *et al*., 2022).

The relationship between livestock production and climate change is, however, bidirectional. Although livestock systems are vulnerable to climatic changes, they also contribute to greenhouse gas emissions through enteric fermentation, manure management, feed production, energy consumption and land-use change. Methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are among the principal greenhouse gases associated with different components of livestock

production. Enteric methane is particularly relevant to ruminant production, while manure handling, fertilizer use for feed production and changes in land use contribute additional emissions. The magnitude of these emissions varies with animal species, feeding practices, productivity, manure-management systems and the broader production environment (FAO, 2018; Gerber *et al*., 2020).

This dual relationship creates an important challenge for the livestock sector. Production systems must become more resilient to climatic disturbances while also reducing greenhouse gas emissions and other environmental pressures. Strategies designed exclusively to increase productivity may not necessarily minimize emissions, while some environmental interventions may impose additional costs or reduce production if they are poorly designed or implemented. For example, improved animal housing may reduce heat stress but require substantial investment, while certain feed additives intended to reduce methane emissions may be too expensive or unavailable to smallholder farmers. Similarly, livestock intensification may improve feed efficiency and reduce emissions per unit of animal product in some circumstances, but its overall environmental benefits depend on feed sourcing, manure management, land use and production practices. These interactions highlight the need to assess climate-related interventions in terms of their effects on productivity, adaptation, environmental performance, animal welfare and economic viability.

Climate-smart livestock production has emerged as an integrated approach to addressing these interconnected challenges. It is commonly understood through three broad objectives: sustainably increasing livestock productivity and contributing to food security; strengthening the capacity of livestock systems and farming communities to adapt to climate change; and reducing or avoiding greenhouse gas emissions where feasible. These objectives are interrelated, although achieving them simultaneously may involve trade-offs that depend on local environmental, economic and institutional conditions. Climate-smart livestock production therefore requires more than the adoption of isolated technologies. It involves the coordinated application of appropriate genetic resources, improved animal nutrition, effective housing, sustainable pasture management, efficient water use, animal-health interventions, agroforestry, improved manure management and integrated crop–livestock systems.

Adaptation strategies are intended to reduce the vulnerability of livestock to climate-related stresses and strengthen their capacity to maintain acceptable levels of health and productivity under changing environmental conditions. Such strategies include the selection and conservation of locally adapted breeds, improved housing and ventilation, provision of shade and adequate drinking water, climate-resilient feeding systems, pasture restoration, appropriate stocking rates and early-warning systems for climatic hazards. Mitigation strategies, on the other hand, seek to reduce greenhouse gas emissions or enhance carbon storage through practices such as improving feed efficiency, optimizing nutrient utilization, adopting suitable dietary interventions, improving manure handling, integrating trees into livestock systems and strengthening the links between crop and animal production. The effectiveness of these approaches depends on the production system,

available resources, local climate, technical capacity and the ability of farmers to sustain their implementation over time.

The importance of these strategies is particularly evident in developing countries, where livestock production frequently operates under constraints such as limited access to finance, inadequate extension services, insufficient climate information, poor infrastructure and increasing costs of feed and other production inputs. In many smallholder systems, farmers may recognize the effects of climate change but lack the resources required to adopt improved technologies. Consequently, climate-smart livestock interventions must be technically appropriate, economically feasible, socially acceptable and adaptable to local production conditions. Indigenous knowledge and locally available resources should be considered alongside scientific innovations to develop solutions that farmers can implement and maintain. Research, extension services, supportive policies, appropriate financing and collaboration among farmers, government agencies, universities and the private sector are therefore essential to successful implementation (World Bank, 2021).

Against this background, climate-smart livestock production provides a framework for reconciling the need for reliable animal-source food production with the urgent requirement to strengthen climate resilience and reduce environmental impacts. Its success depends on understanding the direct and indirect effects of climate change on livestock, evaluating the effectiveness of adaptation and mitigation strategies, and identifying combinations of interventions that are appropriate for different production systems. A context-specific approach is particularly important because no single intervention can be expected to deliver the same productivity, resilience and environmental benefits under all climatic, ecological and socioeconomic conditions.

PROBLEM STATEMENT

Climate change presents a growing challenge to the productivity, resilience and sustainability of livestock production systems. Increasing temperatures, heat stress, irregular rainfall, droughts, flooding and changing disease patterns threaten animal health, reproductive performance, feed availability, water supply and overall production efficiency. These challenges are particularly serious in regions where livestock farmers depend on natural pastures, seasonal water sources and rain-fed feed production. As climatic variability intensifies, the ability of livestock systems to maintain consistent production and support rural livelihoods may become increasingly constrained.

At the same time, livestock production contributes to greenhouse gas emissions through enteric fermentation, manure management, feed production and associated land-use activities. The sector therefore faces the challenge of adapting to the consequences of climate change while reducing its contribution to further environmental degradation. Addressing only one side of this problem is insufficient. Adaptation without attention to emissions may leave important environmental pressures unresolved, while mitigation measures that disregard animal health, productivity and farmers' livelihoods may be difficult to sustain. A balanced approach is required to improve

production efficiency, strengthen resilience and reduce environmental impacts without undermining food security or the economic viability of livestock farming.

Although several adaptation and mitigation practices are available, their adoption and effectiveness remain constrained by financial limitations, inadequate infrastructure, limited access to technical knowledge, weak extension services and differences in local production conditions. Some interventions require substantial initial investment, while others may produce different outcomes depending on animal species, breed, feeding system, climate and management practices. Furthermore, improving one component of livestock production does not automatically guarantee simultaneous improvements in productivity, climate resilience and greenhouse gas reduction. The absence of appropriate integration, monitoring and economic assessment may therefore limit the practical benefits of individual interventions.

The central problem is consequently how to develop and implement livestock production strategies that can maintain or improve animal productivity, strengthen resilience to climatic stresses and reduce environmental impacts under diverse ecological and socioeconomic conditions. This requires an integrated assessment of adaptation and mitigation options, with particular attention to their technical effectiveness, economic feasibility, environmental implications and suitability for smallholder and commercial production systems.

2. Climate Change and Its Implications for Livestock Production

Climate change involves long-term changes in temperature, precipitation and other characteristics of the climate system. Agriculture is particularly vulnerable because biological production depends strongly on environmental conditions. Climate change is increasingly recognized as one of the major constraints to sustainable livestock production, particularly in tropical and subtropical regions where livestock are frequently exposed to high ambient temperatures, variable rainfall, droughts and other climatic extremes. Livestock production is influenced by climate through complex interactions between the animal, its production environment, feed resources, water availability, disease ecology and farm management systems. Consequently, the effects of climate change on livestock should be considered from both direct and indirect perspectives (IPCC, 2022).

2.1 Direct and Indirect Effects of Climate Change on Livestock Production

Direct effects occur when climatic variables such as ambient temperature, relative humidity, solar radiation, wind speed and extreme weather events act directly on animals. These factors can alter body temperature, feed intake, metabolism, growth, milk production, reproduction, immunity and survival.

Indirect effects occur through changes in feed and forage availability, water resources, pasture quality, disease and parasite distribution, feed prices and the wider livestock production environment. Recent assessments indicate that climate change is already affecting livestock

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

production in Africa and that these effects are likely to intensify as temperatures increase and rainfall becomes more variable (IPCC, 2022; Cheng *et al.*, 2022).

The distinction between direct and indirect effects is important because the two pathways frequently interact. For example, drought may reduce pasture availability, which causes nutritional stress; nutritional stress may reduce immunity; and weakened immunity may increase susceptibility to disease. Similarly, high temperature may reduce feed intake directly while simultaneously reducing the availability and quality of feed resources. Thus, climate change represents a multidimensional challenge to livestock production rather than merely a problem of increased temperature.

2.2 Direct Effects of Climate Change on Livestock

Heat stress and Thermal Discomfort

Heat stress is one of the most important direct effects of climate change on livestock. Animals maintain their body temperature within a relatively narrow physiological range. The severity of heat stress is influenced not only by temperature but also by relative humidity, solar radiation, air movement, animal size, coat characteristics, production level, physiological status and adaptation of the breed. When environmental conditions increase the amount of heat gained by an animal beyond its capacity to dissipate heat, thermal stress develops. Under heat stress, animals initiate behavioural and physiological responses such as increased respiration rate, panting, sweating where possible, increased water consumption, reduced physical activity and changes in feeding behaviour. Prolonged exposure can result in oxidative stress, endocrine disturbances, impaired immunity, reduced growth and reproductive failure. Severe heat stress can eventually result in mortality (Madziga, 2021; Sailo & Das, 2023).

Recent climate projections demonstrate that heat stress is becoming an increasingly important constraint to livestock production in Africa. Rahimi *et al.* (2021) reported increases in severe and dangerous heat-stress events for dairy cattle, beef cattle, sheep, goats, pigs and poultry in East Africa. Their projections further indicated that dangerous heat-stress conditions are likely to become more frequent and persistent in the future, with poultry and pigs among the particularly vulnerable species.

2.3 Direct Effects on Large Ruminants

Large ruminants, particularly cattle, are important sources of meat, milk, draught power, manure and income in many African production systems. However, cattle are highly sensitive to combinations of high temperature and humidity, particularly high-producing dairy animals whose metabolic heat production is substantial.

Heat stress in cattle may cause reduced dry-matter intake, increased respiration rate, altered endocrine function, reduced growth, impaired feed efficiency, lower milk yield and deterioration

in reproductive performance. Dairy cattle are generally more susceptible than beef cattle because milk synthesis generates considerable metabolic heat. In West Africa, future climatic conditions are projected to increase the frequency and duration of heat-stress conditions affecting dairy cattle (Heinicke *et al.,* 2020).

The reproductive consequences of heat stress include reduced conception rate, altered oestrous expression, impaired embryo survival and increased calving intervals. In bulls, prolonged exposure to high temperatures may compromise semen quality and reproductive capacity. Consequently, climate-induced heat stress can reduce both the immediate productivity and long-term reproductive efficiency of cattle herds.

Beef cattle may have greater heat tolerance than high-producing dairy cattle, particularly indigenous breeds adapted to tropical environments. Nevertheless, prolonged exposure to heat, drought and inadequate feed and water can substantially reduce growth and body condition. Therefore, breed adaptation is an important component of climate-resilient cattle production

Persistent heat stress can reduce growth, milk production, reproductive efficiency and animal welfare. In reproductive animals, elevated temperature may interfere with spermatogenesis in males and reproductive hormonal activity in females (Renaudeau *et al.,* 2012; Nyika, 2021).

The economic consequences may be substantial because interventions such as mechanical cooling, sprinklers and additional water supply may increase production costs. Consequently, genetic selection, appropriate housing, shade provision, improved nutrition and management of feeding time can provide complementary approaches to heat-stress management.

2.4 Direct Effects on Dairy Cattle

Dairy cattle deserve particular attention because milk production is highly sensitive to environmental heat load. Heat-stressed cows reduce feed intake as a mechanism for limiting metabolic heat production. Unfortunately, reduced feed intake decreases the availability of nutrients for milk synthesis, resulting in reduced milk yield and changes in milk composition.

The effects extend beyond milk production. Heat stress can alter rumen function, nutrient utilization, immune responses and reproductive efficiency. High-producing cows are particularly vulnerable because genetic selection for high milk production has increased metabolic heat production.

In West Africa, climatic projections indicate that dairy cattle will increasingly experience conditions associated with heat stress (Heinicke *et al.,* 2020). At the continental scale, the IPCC (2022) similarly identified increasing heat stress as a major risk to African livestock production. Adaptation therefore requires combinations of shade provision, improved ventilation, adequate

water supply, appropriate feeding strategies, genetic selection for heat tolerance and adjustment of management practices.

2.5 Direct Effects on Small Ruminants

Sheep and goats occupy an important position in African livestock production because they can survive under relatively harsh environmental conditions and contribute meat, milk, skins, fibre and household income. Their smaller body size, behavioural flexibility and ability to utilize a variety of vegetation types make them important components of climate-resilient livestock systems.

Nevertheless, small ruminants are not immune to climate change. High temperatures can increase respiration rate, alter feed and water intake, reduce growth and reproductive performance and increase physiological stress. Prolonged heat exposure can also influence immune and metabolic functions.

Recent research has demonstrated that the response of sheep and goats to heat stress involves physiological, metabolic and genetic mechanisms. Individual breeds differ considerably in their ability to tolerate heat, making genetic adaptation and selection for thermo-tolerance important components of future production systems (Carvalho *et al*., 2022).

The relative resilience of goats is particularly important in dry and semi-arid environments. Goats can browse shrubs and woody vegetation and therefore may exploit feed resources that are unavailable to cattle and sheep. However, increasing drought frequency and degradation of rangelands can still place substantial pressure on small-ruminant production.

2.6 Direct Effects on Non-Ruminants

Poultry

Poultry are particularly vulnerable to high environmental temperatures. Chickens lack functional sweat glands and depend largely on behavioral and respiratory mechanisms for heat dissipation. Consequently, high temperatures can rapidly affect feed intake, growth, feed conversion efficiency, immunity, mortality and product quality.

Broiler chickens are especially susceptible because modern genetic selection has produced rapid growth and high metabolic activity. During heat stress, birds reduce feed intake to limit metabolic heat production. This reduction in nutrient intake contributes to slower growth and poorer feed efficiency. Heat stress can also alter intestinal integrity, nutrient utilization, oxidative status and immune function (Nawaz *et al*., 2021; Brugaletta *et al.*, 2022).

In laying birds, high environmental temperature can reduce egg production, egg weight and eggshell quality. In breeding birds, heat stress can compromise reproductive performance and hatchability. These effects are particularly important in tropical countries where poultry production is expanding to meet increasing demand for affordable animal protein.

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Heat stress is therefore not simply an animal-welfare problem; it is an important economic and food-security challenge. Nutritional interventions, environmental modification, genetic selection and improved housing design have all been identified as potential approaches for reducing the effects of heat stress in poultry (Kumar *et al*., 2021; Kennedy *et al*., 2022).

Pigs

Pigs are also highly susceptible to environmental heat stress because they have limited ability to dissipate body heat through sweating. High temperatures may reduce feed intake, growth rate, reproductive performance and overall production efficiency.

Heat stress in breeding sows can reduce reproductive performance, while growing-finishing pigs may experience slower growth and altered carcass characteristics. Recent reviews indicate that summer heat stress can cause economically important reductions in farrowing performance and growth in pigs (Renaudeau *et al*., 2022).

Climate change may additionally influence pig production indirectly through reduced availability of feed crops, changes in pathogen distribution and increased risks associated with feed contamination, including mycotoxins (Renaudeau *et al.*, 2022). Consequently, climate adaptation in pig production must address both the thermal environment and the feed supply chain.

2.7 Indirect Effects of Climate Change on Livestock

Changes in Feed and Forage Availability

One of the most important indirect effects of climate change is its influence on feed resources. Livestock production depends on pasture, forage crops, crop residues, agro-industrial by-products and cereal-based concentrates. Climate change can alter the quantity, quality and seasonal availability of these resources.

Drought, irregular rainfall and increasing temperature can reduce pasture productivity and accelerate pasture degradation. The IPCC (2022) reported that climate change is already affecting livestock systems in Africa through changes in precipitation and reduced fodder availability. Future projections indicate substantial reductions in rangeland productivity in several African regions.

Reduced feed availability has consequences beyond nutrition. When livestock lose body condition, reproductive performance declines, disease susceptibility may increase and mortality can occur

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during severe droughts. Feed shortages may also increase competition among livestock keepers for available grazing resources.

In West Africa, increasing attention is being given to alternative feed resources, including crop residues, agro-industrial by-products, fodder trees, legumes, insects and other unconventional feed materials. However, the nutritional value, safety and environmental implications of many alternative feed resources remain insufficiently characterized (Alimi *et al.*, 2024).

Decline in Feed Quality and Nutrient Utilization

Climate change may also influence the nutritional quality of crops, pasture and forage. Increased temperature, drought and changes in rainfall can alter plant growth, nutrient composition, fibre concentration and digestibility. Such changes may reduce the nutritional value of available forage. Lee *et al.* (2017) reported that increasing temperature can reduce forage nutritive value and may increase methane emissions. Reduced rainfall can decrease pasture availability and increase competition for feed resources. Since feed represents a major component of livestock production costs, climate-induced feed shortages can simultaneously affect animal performance and farm profitability.

For ruminants, deterioration in forage quality can reduce voluntary feed intake, rumen fermentation efficiency and nutrient availability. For intensive monogastric systems, climate-related crop failures may increase the cost and reduce the availability of maize, soybean meal and other feed ingredients.

The effects may therefore extend beyond the farm. A decline in crop production can increase feed prices, which raises the cost of animal production and may reduce farmers' profitability. This demonstrates the interconnected nature of crop and livestock systems under climate change.

Water Scarcity

Water is fundamental to livestock survival, thermoregulation, feed intake, digestion, milk production and overall productivity. Climate change can reduce water availability through drought, declining surface-water resources and increased evaporation, efficient water management, rainwater harvesting, storage facilities and improved watershed management can therefore contribute to livestock resilience (Boelee *et al.*, 2013). Livestock require adequate quantities of good-quality water for drinking, thermoregulation, feed intake, digestion and production. Climate change may increase water demand while reducing the reliability of traditional water sources. Climate change can also modify the distribution and abundance of vectors such as ticks and flies. Changes in temperature and humidity can influence the developmental cycles of parasites and pathogens, potentially exposing livestock populations to diseases previously uncommon in particular areas (Baumgard & Rhoads, 2012).

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Water requirements increase during periods of heat stress because animals increase water consumption to support thermoregulation. Consequently, the combination of increased temperature and declining water availability creates a particularly serious challenge for livestock in dry land and semi-arid environments.

African pastoralists have already reported reduced access to water during drought periods, together with declining animal performance and increased mortality. The IPCC (2022) identifies water availability during drought as a major concern for livestock-dependent communities across Africa.

Climate Change, Diseases and Parasites

Climate change can indirectly affect livestock by modifying the ecology and geographical distribution of pathogens, parasites and disease vectors. Temperature and rainfall influence the survival, reproduction and geographical distribution of ticks, mosquitoes, flies and other vectors.

Changes in climatic conditions may therefore expose livestock populations to diseases in areas where those diseases were previously uncommon. For example, the IPCC (2022) reports evidence of climate-related expansion of some tick species in parts of eastern and southern Africa.

Changes in disease patterns may have serious consequences because disease outbreaks can cause mortality, reduced growth, reduced milk production, reproductive failure and increased expenditure on veterinary treatment. Disease risks can become particularly severe when climatic stress is combined with poor nutrition and inadequate management.

Climate Extremes and Livestock Production

Climate change is also associated with increasing concern about extreme events, including droughts, floods, heat waves and storms. These events can cause sudden livestock losses by destroying pasture, contaminating water supplies, damaging animal housing and disrupting transportation and markets.

Drought is particularly damaging to pastoral and mixed farming systems because prolonged shortages of pasture and water can cause progressive loss of body condition, reproductive failure and mortality. Flooding, on the other hand, may cause animal deaths directly while also increasing the risk of infectious disease and disrupting feed supplies.

Thus, livestock vulnerability is determined not only by average climatic conditions but also by the frequency, intensity and duration of climatic extremes.

2.8 Differential Effects among Livestock Species

The impact of climate change is not uniform across livestock species. Dairy cattle may be particularly vulnerable to heat because of their high metabolic heat production, whereas indigenous

cattle may possess greater thermo-tolerance. Goats often demonstrate considerable adaptability to harsh environments, while sheep may vary substantially among breeds. Poultry and pigs can be highly vulnerable to high ambient temperatures because of their limited thermoregulatory capacity. Rahimi *et al.* (2021) demonstrated that dangerous heat-stress conditions are increasing across several livestock species in East Africa, while the IPCC (2022) emphasizes that cattle, goats, sheep, pigs and chickens are all likely to experience increasing heat stress under continued warming.

Table1: Summary of Direct and Indirect effects of climate change in livestock

Livestock group	Major direct effects	Major indirect effects
Large ruminants – beef cattle	Heat stress, reduced growth, impaired reproduction, mortality	Reduced pasture, water scarcity, disease and parasite pressure
Dairy cattle	Reduced feed intake, milk yield, fertility and immunity	Reduced forage quality, water scarcity, feed-price increases and disease
Sheep	Heat stress, reduced growth and reproduction	Pasture degradation, water shortages and parasite/disease changes
Goats	Heat stress, reduced feed intake and reproduction	Reduced browse resources, drought and disease
Poultry	Reduced feed intake, growth, egg production, fertility and survival	Higher feed costs, reduced crop production and disease pressure
Pigs	Reduced feed intake, growth and reproductive performance	Feed shortages, pathogen changes and mycotoxin risks

2.9 Implications for Climate-Resilient Livestock Production

The increasing effects of climate change require livestock producers to move from reactive management towards proactive adaptation. Adaptation strategies should be species-specific, production-system-specific and location-specific.

Important adaptation strategies include the use of heat-tolerant breeds, improved housing and ventilation, provision of shade, reliable access to clean drinking water, strategic feeding, improved

pasture management, conservation of forage and development of alternative feed resources, improved disease surveillance and appropriate adjustment of stocking rates.

Nutritional strategies are particularly important because nutrition influences the ability of animals to cope with environmental stress. In poultry, for example, nutritional interventions involving antioxidants, probiotics, phytobiotics, minerals and dietary manipulation have been investigated as approaches for reducing the physiological consequences of heat stress (Abdel-Moneim *et al.*, 2021). This area is particularly relevant to tropical poultry production because dietary strategies can complement environmental and genetic approaches.

Genetic improvement also offers considerable potential. Selection for heat tolerance, disease resistance and efficient utilization of locally available feed resources can improve livestock resilience. However, genetic approaches should not replace improvements in management because resilience is most effectively achieved through an integrated approach.

3. Climate-Smart Livestock Production

Climate-smart livestock production can be conceptualized around three broad objectives:

1. Maintaining or increasing productivity and food security;
2. Increasing resilience and adaptation to climate change; and
3. Reducing greenhouse gas emissions and other environmental impacts.

These objectives are interconnected but cannot always be achieved simultaneously. A strategy that improves one objective may impose costs on another. Therefore, climate-smart livestock development should emphasize context-specific combinations of practices rather than assuming that every intervention produces a universal "triple win."

The need for integrated approaches is particularly important in developing countries, where livestock farmers frequently operate under resource constraints and have limited access to technologies, finance, extension services and infrastructure (Thornton & Herrero, 2015; Ogunyiola *et al*., 2022).

4. Adaptation Strategies for Climate-Resilient Livestock Production

a. Genetic improvement and climate-resilient breeds

Genetic improvement provides a long-term strategy for developing livestock capable of performing under climatic stress. Locally adapted breeds often possess characteristics that enable them to tolerate heat, poor-quality feed, parasites and locally prevalent diseases.

Selection programmes can therefore incorporate traits such as heat tolerance, disease resistance, reproductive efficiency and feed efficiency. Indigenous genetic resources should also be conserved

because they provide valuable reservoirs of adaptive traits (Radeny *et al.*, 2022; Ayalew *et al.*, 2023).

Community-based breeding programmes can be particularly useful in low-input production systems because they allow farmers to participate directly in the identification and selection of animals with desirable characteristics.

b. Improved housing and heat-stress management

Housing design is an important component of climate adaptation. Adequate ventilation, shade, appropriate stocking density and access to clean drinking water can reduce the physiological burden associated with high temperatures. Where economically feasible, cooling systems and water sprinklers can be employed. However, high-energy cooling systems may increase production costs. Therefore, passive cooling through shade, ventilation, appropriate orientation of buildings and tree integration should also be considered.

c. Climate-resilient feeding and nutrition

Nutrition is central to climate adaptation. Animals receiving nutritionally balanced diets are better positioned to withstand climatic stress. Higher-quality feeds can improve nutrient-use efficiency and productivity while reducing the amount of feed required per unit of animal product. Circular feeding systems that utilize agricultural residues and locally available feed resources may reduce dependence on external feed inputs. Such systems can simultaneously reduce waste and improve resource-use efficiency.

Precision feeding is another important strategy. It involves matching nutrient supply more closely to animal requirements, thereby reducing nutrient wastage and environmental losses. Recent evidence indicates that precision feeding can contribute to reducing the environmental footprint of livestock production (Llorens *et al.*, 2024).

d. Pasture and grazing management

Pasture management can increase resilience to rainfall variability and drought. Appropriate stocking rates, rotational grazing, deferred grazing and restoration of degraded pasture can improve vegetation cover, soil quality, water infiltration and forage availability. Improved grassland management may also increase soil carbon storage. Conant *et al.* (2017) demonstrated that grassland management can influence soil carbon stocks, indicating the potential for grazing systems to contribute to climate mitigation.

e. Early-warning systems

Early-warning systems enable farmers and institutions to anticipate climate-related risks such as drought, floods, heat waves and disease outbreaks. Weather information can support decisions

concerning animal movement, feed conservation, water storage, stocking rates and disease prevention. For smallholder farmers, the usefulness of early-warning systems depends on the accessibility and reliability of climate information and the capacity of farmers to respond to warnings.

5. Mitigation Strategies in Livestock Production

Adaptation protects livestock systems from climate impacts, whereas mitigation seeks to reduce emissions or increase carbon storage. Several mitigation strategies can be integrated into livestock systems.

a. Agroforestry and silvopastoral systems

Agroforestry integrates trees with crops and/or livestock. Trees can provide shade, improve microclimatic conditions, contribute organic matter, reduce erosion and store carbon.

Silvopastoral systems are particularly relevant to livestock production because trees and livestock can occupy the same production landscape. Trees provide shade and shelter while contributing to soil improvement, biodiversity and carbon sequestration. However, agroforestry must be carefully planned. Trees may compete with crops or pasture for water, nutrients and sunlight. Species selection, tree density and spatial arrangement should therefore be adapted to local environmental conditions (Mercer, 2004; Quandt, 2020).

b. Dietary manipulation

Animal nutrition provides an important pathway for reducing emissions. Dietary strategies can alter fermentation processes, improve feed efficiency and reduce methane formation in ruminants. Feed additives such as condensed tannins, essential oils and seaweed-derived compounds have attracted considerable attention as potential methane-mitigation technologies. However, their effectiveness depends on dose, animal species, basal diet, production system and environmental conditions (Gerber *et al.,* 2020; Benetel *et al.,* 2022; McGurrin *et al.,* 2023).

Lipid supplementation can also reduce methane emissions, although excessive lipid inclusion may adversely affect feed intake and fibre digestion. Therefore, dietary mitigation should be based on an appropriate balance between emission reduction, animal performance and feed cost.

c. Improving feed efficiency

Improving feed efficiency reduces the quantity of feed required to produce a given quantity of animal product. This can reduce emissions associated with feed production and decrease nutrient losses.

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Genetic selection for feed-efficient animals is therefore potentially valuable as a long-term mitigation strategy. Feed efficiency traits such as residual feed intake have been investigated as possible indicators for reducing methane emissions, although the relationship is not always consistent across production systems (de Haas *et al.*, 2021; Manzanilla-Pech *et al.*, 2022).

d. Nitrogen management

Nitrogen losses from livestock systems can contribute to N_2O emissions. Excessive nitrogen fertilization of feed crops and inefficient utilization of dietary nitrogen can increase environmental losses. Improving nitrogen-use efficiency therefore requires attention to both crop production and animal nutrition. Balanced diets and precision feeding can reduce excessive nitrogen excretion, while appropriate fertilizer management can reduce N_2O emissions associated with feed production (Snyder *et al.*, 2014).

e. Manure management

Manure is both an environmental challenge and a valuable agricultural resource. Poorly managed manure can produce methane and nitrous oxide and may contribute to water and air pollution.

Improved storage, composting, appropriate land application and anaerobic digestion can reduce emissions while recovering nutrients. Anaerobic digesters can capture methane from manure and convert it into biogas for energy, while the resulting digestate can be used as fertilizer.

f. Integrated Crop–Livestock Systems

Integrated crop–livestock systems provide an important pathway towards climate-smart agriculture. Crop residues can be utilized as animal feed, livestock manure can be returned to crop fields, and nutrients can be recycled within the farming system.

This integration can reduce dependence on external inputs, improve nutrient cycling and diversify farm income. Herrero *et al.* (2010) emphasized the importance of mixed crop–livestock systems as a pathway towards sustainable intensification.

For smallholder farmers, integration can also improve resilience because households are not entirely dependent on a single agricultural enterprise. Diversification may therefore provide both ecological and socioeconomic benefits.

g. Diversification of Livestock Species

Diversification of livestock species can contribute to climate resilience. Non-ruminants such as poultry and pigs generally produce substantially less enteric methane than ruminants because they do not possess the same ruminal fermentation system.

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Increasing the proportion of poultry and pigs within suitable farming systems can therefore contribute to diversification while providing relatively rapid production cycles. This approach may be particularly useful where drought and feed scarcity create significant risks for large ruminants.

However, diversification should not be interpreted as a universal replacement for ruminant production. Ruminants are capable of converting fibrous resources unsuitable for human consumption into valuable food products and play important ecological and socioeconomic roles. Species selection should therefore reflect local resources, market conditions, environmental constraints and household objectives.

6. Synergies and Trade-Offs in Climate-Smart Livestock Production

A major challenge in climate-smart agriculture is that interventions do not necessarily produce simultaneous benefits for productivity, adaptation and mitigation.

A **synergy** occurs when achieving one objective also contributes positively to another. A **trade-off** occurs when an intervention improves one objective while creating disadvantages for another (Klein *et al.,* 2005; Duguma *et al.,* 2014).

For example, improved livestock productivity can reduce emissions intensity because fewer animals may be required to produce the same quantity of food. Conversely, increased productivity may require greater quantities of high-quality feed, veterinary services or energy, potentially increasing production costs and resource use. Agroforestry illustrates another potential trade-off. Trees may sequester carbon and provide shade, but excessive tree density may reduce crop or pasture productivity through competition for light, water and nutrients. Similarly, water-storage infrastructure can improve adaptation during drought but may require substantial initial investment. Smallholder farmers may therefore be unable to adopt such technologies without credit, subsidies or other financial mechanisms.

The central lesson is that climate-smart interventions should be evaluated using multiple indicators rather than focusing exclusively on GHG reduction.

7. International Experiences and Lessons for Developing Countries

Several countries have demonstrated the potential of integrated climate-smart livestock approaches.

In Latin America, climate-smart livestock programmes have combined improved pasture species, rotational grazing, forage conservation and manure management. Such interventions demonstrate

that environmental improvement can occur alongside improvements in feed efficiency and farm profitability.

In Kenya, agroforestry and silvopastoral approaches have been promoted to provide shade, improve soil conditions and increase livestock resilience during drought. In Brazil, integrated crop–livestock systems and sustainable pasture management have been associated with improved resource utilization and carbon sequestration.

Precision livestock technologies in countries such as Australia demonstrate the potential of sensors, automated weighing, thermal imaging and data analytics to support timely decisions concerning feeding, health and reproduction. These experiences demonstrate that climate-smart livestock production does not depend on a single technology. Rather, successful systems combine practices that are compatible with the local agroecological and socioeconomic environment.

8. Constraints to Climate-Smart Livestock Adoption

a. Technical constraints

Many farmers lack adequate knowledge about climate-smart technologies and their management requirements. Effective extension services and farmer education are therefore essential.

b. Economic constraints

The initial cost of climate-smart technologies can be prohibitive. Improved housing, water-storage infrastructure, precision livestock technologies, improved genetics and manure-management systems may require investments beyond the financial capacity of smallholder farmers.

c. Institutional constraints

Weak institutions, inadequate policies and limited access to agricultural finance can restrict adoption. Effective climate-smart livestock development therefore requires coordination among governments, research institutions, extension agencies, financial institutions, private companies and farmers.

d. Land-tenure constraints

Unclear land ownership can discourage farmers from making long-term investments in agroforestry, pasture restoration and other land-management practices because the benefits may take several years to materialize.

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e. Measurement and monitoring challenges

Quantifying GHG emissions and carbon sequestration can be technically difficult and costly. Reliable measurement is nevertheless necessary for evaluating the actual environmental benefits of climate-smart interventions.

9. Policy and Institutional Requirements

Climate-smart livestock production requires supportive policies that address both production and environmental objectives. Governments should strengthen agricultural extension, improve access to climate information, support livestock research and provide financial mechanisms that reduce the cost of adopting appropriate technologies. Research institutions should focus on locally adapted solutions rather than simply transferring technologies developed under different production conditions.

In Africa, particular attention should be given to technologies that are affordable, scalable and compatible with smallholder farming systems. Climate-smart strategies must improve farmer livelihoods rather than impose environmental objectives that farmers cannot economically sustain.

10. Future Directions

Future climate-smart livestock research should increasingly move beyond individual interventions and examine integrated production systems. Research priorities should include:

- development of heat-tolerant and disease-resistant livestock;
- precision nutrition and precision feeding;
- locally available feed resources and circular feeding systems;
- phytogenic and other dietary strategies for reducing methane emissions;
- improved manure management;
- agroforestry and silvopastoral systems;
- integrated crop–livestock production;
- low-cost water harvesting and storage;
- digital technologies and precision livestock farming;
- life-cycle assessment of livestock interventions; and
- socioeconomic assessment of climate-smart technologies.

Particular emphasis should be placed on evaluating the economic feasibility of proposed interventions. A technically effective technology that farmers cannot afford is unlikely to achieve meaningful adoption.

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11. CONCLUSION

Climate change poses a multidimensional threat to livestock production through heat stress, declining feed quality, water scarcity, disease risks and extreme weather events. At the same time, livestock production contributes to climate change through methane, nitrous oxide and carbon dioxide emissions.

Climate-smart livestock production offers an approach for addressing these interconnected challenges. Adaptation can be strengthened through climate-resilient genetics, improved housing, nutrition, pasture management, water conservation and early-warning systems. Mitigation can be enhanced through agroforestry, integrated crop–livestock systems, improved feed efficiency, dietary manipulation, nitrogen management and improved manure handling.

12. RECOMMENDATIONS

Based on the challenges associated with Climate-Smart Livestock Production: Adaptation, Mitigation and Sustainable Strategies for Resilient Livestock systems, the following recommendations are proposed.

1. **Adoption of climate-smart livestock production practices**:
Livestock farmers should adopt climate-smart production practices that simultaneously improve animal productivity, strengthen resilience to climate variability and reduce greenhouse gas emissions. Such practices should be tailored to local climatic conditions, production systems, available resources and farmers' socioeconomic circumstances.

2. **Improvement of animal nutrition and feed efficiency**:
Greater emphasis should be placed on improving the quality, availability and utilization of livestock feed through balanced ration formulation, precision feeding, improved forage production and the strategic use of locally available agro-industrial by-products. The use of appropriate feed enzymes, probiotics, phytogenic additives and other scientifically validated feed technologies should be encouraged where they demonstrate measurable benefits for animal performance, nutrient utilization and environmental sustainability.

3**. Development of effective heat-stress management strategies**:
Livestock and poultry farmers should implement appropriate heat-stress management practices, including adequate ventilation, provision of shade, reliable access to clean drinking water, suitable stocking densities and adjustment of feeding schedules to cooler periods. In poultry production, particular attention should be given to maintaining appropriate house temperature and humidity, especially during periods of extreme heat.

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4. Promotion of climate-resilient animal breeds:
Governments, research institutions and livestock development agencies should support the identification, conservation and improvement of animal breeds with desirable traits for heat tolerance, disease resistance, reproductive efficiency and productive performance under local climatic conditions. Breeding programmes should balance climate resilience with productivity, animal welfare and the conservation of indigenous genetic resources.

5. Strengthening livestock health management:
Veterinary services, disease surveillance and preventive healthcare should be strengthened to address climate-sensitive livestock diseases and parasites. Early-warning systems and accessible veterinary extension services should be developed to help farmers anticipate and respond to disease outbreaks associated with changing climatic conditions.
Improvement of water and pasture management: Sustainable water harvesting, efficient water-use practices, pasture restoration and the cultivation of drought-tolerant forage species should be promoted. Farmers should also be encouraged to conserve feed through haymaking, silage production and other appropriate feed-preservation techniques to reduce seasonal feed shortages.

6. **Improved manure management and renewable energy utilization**:
Livestock farmers should adopt environmentally sound manure-management practices, including appropriate manure storage, composting, anaerobic digestion and biogas production where technically and economically feasible. These practices can improve nutrient recycling, reduce environmental pollution and, under suitable conditions, lower greenhouse gas emissions while providing additional energy and soil-fertility benefits.

7. Integration of agricultural automation and digital technologies:
Agricultural research institutions, technology developers and government agencies should promote accessible digital technologies for livestock production. Temperature and humidity sensors, automated feeding and watering systems, animal-health monitoring devices and digital decision-support tools should be developed and adapted to local production conditions. Particular attention should be given to affordable technologies suitable for smallholder farmers rather than focusing exclusively on capital-intensive commercial systems.

8. Strengthening research and innovation:
Universities, research institutes and private-sector organizations should intensify research into climate-smart animal nutrition, heat-stress mitigation, alternative feed resources, low-emission livestock production and climate-resilient management systems. Research should prioritize locally available resources and generate evidence on technical effectiveness, economic feasibility,

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environmental impacts and practical applicability under Nigerian and other sub-Saharan African conditions.

13. REFERENCES

bdel-Moneim, A. E., Shehata, A. M., Khidr, R. E., Paswan, V. K., Ibrahim, N. S., El-Ghoul, A. A., (2021). Nutritional manipulation to combat heat stress in poultry – A comprehensive review. *Journal of Thermal Biology*, 98, 102915. https://doi.org/10.1016/j.jtherbio.2021.102915

Alimi, N. A., Assani, A. S., Worogo, H. S., Baco, N. M., & Traoré, I. A. (2024). Livestock feed resources used as alternatives during feed shortages and their impact on the environment and ruminant performance in West Africa: A systematic review. *Frontiers in Veterinary Science*, 11, 1352235. https://doi.org/10.3389/fvets.2024.1352235

Ayalew, W., Wu, X., Tarekegn, G. M., Chen, M., Liang, C., Tessema, T. S. (2023). Signatures of positive selection for local adaptation of African native cattle populations: A review. *Journal of Integrative Agriculture*, *22*, 1967–1984. https://doi.org/10.1016/j.jia.2023.01.004

Baumgard, L. H., & Rhoads, R. P. (2012). Ruminant nutrition symposium: Ruminant production and metabolic responses to heat stress. *Journal of Animal Science*, *90*, 1855–1865. https://doi.org/10.2527/jas.2011-4675

Brugaletta, G., Teyssier, J. R., Rochell, S. J., Dridi, S., & Sirri, F. (2022). A review of heat stress in chickens. Part I: Insights into physiology and gut health. Frontiers in Physiology, 13, 934381. https://doi.org/10.3389/fphys.2022.934381

Benetel, G., Silva, T. S., Fagundes, G. M., Welter, K. C., Melo, F. A., Lobo, A. A (2022). Essential oils as in vitro ruminal fermentation manipulators to mitigate methane emission by beef cattle grazing tropical grasses. *Molecules*, *27*, 2227. https://doi.org/10.3390/molecules27072227

Boelee, E., Yohannes, M., Poda, J. N., McCartney, M., Cecchi, P., Kibret, S., (2013). Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa. *Regional Environmental Change*. https://doi.org/10.1007/s10113-012-0287-4

Cheng, M., McCarl, B., & Fei, C. (2022). Climate change and livestock production: A literature review. *Atmosphere*, *13*, 140. https://doi.org/10.3390/atmos13010140

Conant, R. T., Cerri, C. E., Osborne, B. B., & Paustian, K. (2017). Grassland management impacts on soil carbon stocks: A new synthesis. *Ecological Applications*, *27*, 662–668. https://doi.org/10.1002/eap.1473

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

de Haas, Y., Veerkamp, R. F., de Jong, G., & Aldridge, M. N. (2021). Selective breeding as a mitigation tool for methane emissions from dairy cattle. *Animal, 15,* 100294. https://doi.org/10.1016/j.animal.2021.100294

Duguma, L. A., Minang, P. A., & Van Noordwijk, M. (2014). Climate change mitigation and adaptation in the land use sector: From complementarity to synergy. *Environmental Management, 54*, 420–432. https://doi.org/10.1007/s00267-014-0331-x

Erdaw, M. M. (2023). Contribution, prospects and trends of livestock production in sub-Saharan Africa: A review. *International Journal of Agricultural Sustainability, 21*,1–15. https://doi.org/10.1080/14735903.2023.2247776

Food and Agriculture Organization (FAO). (2013). *Tackling climate change through livestock: Major cuts of greenhouse gas emissions from livestock within reach*. Rome: FAO.

Food and Agriculture Organization (FAO). (2018). *Climate-smart livestock production: Opportunities and challenges for mitigation and adaptation*. Rome: FAO.

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities*. Rome: FAO.

Gerber, P. J., Henderson, B., & Makkar, H. P. S. (Eds.). (2020). *Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO_2 emissions*. FAO Animal Production and Health Paper No. 177. Rome: FAO.

Godde, C., Mason-D'Croz, D., Mayberry, D., Thornton, P. K., & Herrero, M. (2021). Impacts of climate change on the livestock food supply chain: A review of the evidence. *Global Food Security, 28,* 100488. https://doi.org/10.1016/j.gfs.2020.100488

Heinicke, J., Hoffmann, G., Amamou, H., & Ates, S. (2020). Will dairy cattle production in West Africa be challenged by heat stress in the future? Climatic Change, 161, 665–685. https://doi.org/10.1007/s10584-020-02733-2

Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., et al. (2010). Smart investments in sustainable food production: Revisiting mixed crop–livestock systems. *Science, 327,* 822–825. https://doi.org/10.1126/science.1183725

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Intergovernmental Panel on Climate Change (IPCC). (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report. Cambridge University Press.

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report. Cambridge: Cambridge University Press.

Kennedy, G. M., Lichoti, J. K., & Ommeh, S. C. (2022). Heat stress and poultry: Adaptation to climate change, challenges and opportunities for genetic breeding in Kenya. *Journal of Agriculture, Science and Technology*, 21(1), 49–61. https://doi.org/10.4314/jagst.v21i1.6

Klein, R. J. T., Schipper, E. L. F., & Dessai, S. (2005). Integrating mitigation and adaptation into climate and development policy: Three research questions. *Environmental Science & Policy*, *8*, 579–588. https://doi.org/10.1016/j.envsci.2005.06.010

Kumar, M., Ratwan, P., Dahiya, S. P., & Nehra, A. K. (2021). Climate change and heat stress: Impact on production, reproduction and growth performance of poultry and its mitigation using genetic strategies. *Journal of Thermal Biology*, 97, 102867. https://doi.org/10.1016/j.jtherbio.2021.102867

Lee, M. A., Davis, A. P., Chagunda, M. G. G., & Manning, P. (2017). Forage quality declines with rising temperatures, with implications for livestock production and methane emissions. *Biogeosciences*, *14*, 1403–1417. https://doi.org/10.5194/bg-14-1403-2017

Llorens, B., Pomar, C., Goyette, B., Rajagopal, R., Andretta, I., Latorre, M. A., (2024). Precision feeding as a tool to reduce the environmental footprint of pig production systems: A life cycle assessment. *Journal of Animal Science*. https://doi.org/10.1093/jas/skae225

Madziga, I. I. (2021). Impact of climate change on livestock productivity: A review. *Nigerian Journal of Animal Production*, 48(4), 149–164. https://doi.org/10.51791/njap.v48i4.3006

Manzanilla-Pech, C. I. V., Stephansen, R. B., Difford, G. F., Løvendahl, P., & Lassen, J. (2022). Selecting for feed efficient cows will help to reduce methane gas emissions. *Frontiers in Genetics*, *13*, 885932. https://doi.org/10.3389/fgene.2022.885932

McGurrin, A., Maguire, J., Tiwari, B. K., & Garcia-Vaquero, M. (2023). Anti-methanogenic potential of seaweeds and seaweed-derived compounds in ruminant feed: Current perspectives, risks, and future prospects. *Journal of Animal Science and Biotechnology*, *14*, 145. https://doi.org/10.1186/s40104-023-00946-w

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Mercer, D. E. (2004). Adoption of agroforestry innovations in the tropics: A review. *Agroforestry Systems, 61*, 311–328. https://doi.org/10.1023/B:AGFO.0000029007.85754.70

Nawaz, A. H., Amoah, K., Leng, Q. Y., Zheng, J. H., Zhang, W. L., & Zhang, L. (2021). Poultry response to heat stress: Its physiological, metabolic, and genetic implications on meat production and quality including strategies to improve broiler production in a warming world. *Frontiers in Veterinary Science*, 8, 699081. https://doi.org/10.3389/fvets.2021.699081

Nyika, J. (2021). Climate change on fertility and reproductive processes of female livestock. In *Climate Change and Its Impact on Fertility* (pp. 263–277). Hershey: IGI Global.

Ogunyiola, A., Gardezi, M., & Vij, S. (2022). Smallholder farmers' engagement with climate smart agriculture in Africa: Role of local knowledge and upscaling. *Climate Policy, 22*, 411–426. https://doi.org/10.1080/14693062.2021.2023451

Quandt, A. (2020). Contribution of agroforestry trees for climate change adaptation: Narratives from smallholder farmers in Isiolo, Kenya. *Agroforestry Systems*. https://doi.org/10.1007/s10457-020-00535-0

Radeny, M. A., Rao, E., Ogada, M. J., Recha, J. W., & Solomon, D. (2022). Impacts of climate-smart crop varieties and livestock breeds on the food security of smallholder farmers in Kenya. *Food Security, 14*, 1511–1535. https://doi.org/10.1007/s12571-022-01307-7

Rahimi, J., Mutua, J. Y., Notenbaert, A. M. O., Marshall, K., & Butterbach-Bahl, K. (2021). Heat stress will detrimentally impact future livestock production in East Africa. *Nature Food*, 2, 88–96. https://doi.org/10.1038/s43016-021-00226-8

Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, J. L., & Collier, R. J. (2012). Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal, 6*, 707–728. https://doi.org/10.1017/S1751731111002448

Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, J. L., & Collier, R. J. (2022). Review: What have we learned about the effects of heat stress on the pig industry? Animal, 16(Suppl. 2), 100349. https://doi.org/10.1016/j.animal.2021.100349

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T. M., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management, 16*, 145–163. https://doi.org/10.1016/j.crm.2017.02.001

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Sailo, L., & Das, R. (2023). Heat stress in livestock: Impacts and ameliorative strategies—A review. [Journal details should be verified against the publisher record before final submission].

Snyder, C. S., Davidson, E. A., Smith, P., & Venterea, R. T. (2014). Agriculture: Sustainable crop and animal production to help mitigate nitrous oxide emissions. *Current Opinion in Environmental Sustainability, 9*, 46–54. https://doi.org/10.1016/j.cosust.2014.07.005

Rust, J. M., & Rust, T. (2013). Climate change and livestock production: A review with emphasis on Africa. South African *Journal of Animal Science*, 43(3), 256–267. https://doi.org/10.4314/sajas.v43i3.3

Thornton, P. K., & Herrero, M. (2015). Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. *Nature Climate Change, 5*, 830–836. https://doi.org/10.1038/nclimate2754

World Bank. (2021). *Moving towards sustainability: The livestock sector and the World Bank*. World Bank.

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6