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Climate Change And Its Impact On Livestock Production Systems: Adaptation Strategies And Future Direction

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ABSTRACT
Climate change poses significant challenges to global livestock production systems, with rising temperatures, altered precipitation patterns, and the spread of diseases threatening animal health and productivity. This review examines the impacts of climate change on livestock, focusing on heat stress, water scarcity, and shifts in disease dynamics, which can reduce productivity and compromise food security. It explores adaptation strategies, including genetic selection for climate resilience, management practices to mitigate heat stress and integration of precision livestock farming technologies. Additionally, the review highlights the importance of policy frameworks and international cooperation in supporting these adaptation efforts. Livestock production is a crucial component of global food systems, particularly in developing countries, where it provides essential nutrients, income, and employment. Therefore, understanding how to adapt to climate change is vital for ensuring sustainable livestock farming. The paper also identifies research gaps and future directions, emphasizing the need for cross-disciplinary approaches that bring together climate scientists, veterinarians, agricultural economists, and policymakers to develop comprehensive strategies for climate-resilient livestock systems.

Keywords: Climate change, livestock production, adaptation strategies, heat stress, precision livestock farming

Introduction

One of the global concerns that affect ecosystems, the economy, and societies all around the world is climate change as a result of the enhanced emission of greenhouse gases. The Intergovernmental Panel on Climate Change IPCC also supports the above information and estimates that the overall global average surface temperature has been increased by about 1.1°C during the late 19th century and it is expected to increase between 1.5°C to 5°C by the year 2100 depending on the future emission of greenhouse gases (IPCC, 2021). It is a phenomenon characterized by alterations in temperature, change in the rainfall, severe and frequent occurrence of natural disasters, and rising sea level (Seneviratne et al., 2021). These climatic changes affects the environment, food, water resources (Muluneh, 2021). These changes are more dangerous for human agriculture, which is a part of human civilization at the present time and, therefore, it needs adaptation and measures to reduce the negative impact. Climate has had many noticeable effects on the crop yield, availability of water and pests and diseases in the last few decades (Gomez-Zavaglia et al., 2020). For instance, extreme weather conditions particularly climate change led to the 2010 Russian heat wave which resulted in low production of wheat and thus affecting the grain markets (Götz et al., 2016). Among the various challenges that are likely to affect agriculture and food production, climate-induced challenges are most vulnerable for livestock production systems. Heat stress has become one of the significant factors that affect both animal health and productivity (Lacetera, 2019). Savsani et al. (2015) highlighted the effects of rising temperatures are that feed intake reduces, reproduction diminishes, and the mortality rate goes up in livestock. Climate change also leads to water scarcity which in turns minimizes the water available for use in livestock and feed crops production. Droughts and changes in rainfall patterns have led to water scarcity which poses a threat to the health and productivity of the livestock (Cai et al., 2015). It also impacts on the incidence and distribution of diseases and pests due to climate change (Skendžić et al., 2021). The increase in temperature and alteration of rainfall will shift the breeding grounds of vectors like the ticks and mosquitoes which will cause emergence of diseases like African swine fever and avian influenza (Sonne, 2022). These changes have various impacts on livestock health and production in the global level. This paper aims at discussing the direct and indirect effects of climate change on the production systems of livestock. The review will also focus on the measures of adaptation including breeding for climate tolerance, minimizing heat stress in animals, and improving animal health through technology. It will also discuss the extent to which adaptation policies and international collaboration will help in the process of adaptation. This review aims to provide a systematic synthesis of various research related to the impacts of climate change on the livestock production, thus making it beneficial to researchers, policymakers and practitioners in the field of sustainable agriculture and food security (Britto & Bijale, 2024).

Types of Livestock Production Systems

The livestock production systems referred to the methods and measures that were employed to rear animals for the main purpose of consumption, milk production, egg production, wool production or any other related products. The three types of such systems are intensive, extensive, and a combination of both intensive and extensive types. These are the factors that are used in these systems and the systems depend on the environmental, economical and social factors (Duru & Therond, 2015).

Intensive Livestock Production Systems

The characteristics of Intensive Livestock Production Systems include high stocking densities and the use of new technologies on animal care, feed, and diseases (Cronin et al., 2014). The animals are kept in pens or cages and their diet is given through feed formulated in these systems. This is usually the case in the developed countries where demand for animal products is high and efficiency of production is of essence. Poultry, swine, and dairy farming are all intensive system, found in United States, Brazil as well as China (MacLachlan, 2015).

Extensive Livestock Production Systems

Extensive Livestock Production Systems are the ones where animals roam large areas of land and feed mostly from pasture through extensive low-intensity grazing systems (Wróbel et al., 2023). Population density, coupled with the availability of land is inversely proportional to the sustainability of this system. It is common in Sub-Saharan Africa, Central Asia, and Australia and Latin America regions. Cattle, sheep, and goats are often associated with extensive systems where animals graze on natural vegetation and require less supplemental feed (Derner et al., 2017).

Mixed Livestock Production Systems

Mixed Livestock Production Systems comprise of a combination of more intensive and extensive systems. Integrating crop-livestock farming systems often combine both agricultural sectors of crop production and livestock raising to fulfill the capacity needs of both systems in a mutually symbiotic relationship (Bell et al., 2014). An example is that manure is used to fertilize crops in exchange for animals for feed with crop residues. The mixed systems are prevalent in South Asia, Southeast Asia, and part of Europe enabling farm income diversification and increasing farmers' resilience to climatic and market fluctuations (Baker et al., 2023). However, within each type, livestock production systems can have scale and intensity which vary by region and the particular needs of the local population. For example, extensive systems are prevalent in some developing countries whereas intensive systems of agriculture are more common in industrialized countries (Clapp & Ruder, 2020). The technological improvements, use of genetically modified feed, or precision livestock farming are blurring the lines in these systems and leading to hybrid systems that attempt to optimize both productivity and sustainability as shown in Table 1.

Table 1. Overview of Livestock Production Systems: Types, Characteristics, Benefits, Challenges, and Regional Distribution

Type of Livestock Production System	Characteristics	Common Regions	Livestock Associated	Benefits	Challenges	References
Intensive Livestock Production Systems	High stocking densities, and advanced technologies for animal care, feed, and disease management. Animals housed in confined spaces were fed formulated feeds.	Developed countries such as the United States, Brazil, and China.	Poultry, swine, and dairy farming.	High production efficiency, optimized for meeting high demand for animal products.	Environmental concerns related to intensive feed use and waste management, reliance on confined spaces.	Cronin et al., 2014; MacLachlan, 2015
Extensive Livestock Production Systems	Animals roam large areas of land and feed mostly from pasture through low-intensity grazing systems.	Sub-Saharan Africa, Central Asia, parts of Australia, and Latin America.	Cattle, sheep, and goats.	Sustainability in regions with abundant land requires less supplemental feed.	Lower productivity in terms of feed conversion, potentially less efficient in areas of low land availability.	Wróbel et al., 2023; Derner et al., 2017
Mixed Livestock Production Systems	Combination of intensive and extensive systems. Integrates crop-livestock farming for mutual benefit, such as using manure to fertilize crops.	South Asia, Southeast Asia, and parts of Europe.	Varies, but typically includes a combination of animals raised for meat, milk, and other products.	Increased resilience to climatic and market fluctuations, and farm income diversification.	Balance between intensive and extensive practices, potential challenges in managing both systems effectively.	Bell et al., 2014; Baker et al., 2023; Clapp & Ruder, 2020

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Role in Global Food Security

Livestock is of great importance for global food security and economic development especially in developing countries. Current livestock products such as meat, milk, and eggs are important sources of high-quality protein, essential fats, and micronutrients essential for human nutrition and particularly important in low-income countries (Zhang et al., 2016). Livestock generate about 40% of global agricultural GDP, and over 1.3 billion people make their living from livestock, whether directly through farming or through associated sectors like processing, shipping, and retail(Hoque et al., 2022). Livestock is a key component of smallholder farming systems in many regions of the world, including Sub-Saharan Africa and South Asia, and provides not only food and nutrition but also income, manure for fertilizing crops, and draught power for agricultural activities (Otte et al., 2019). Livestock is an asset that can be sold or used as a form of insurance in the case of economic shocks and therefore is an important part of poverty alleviation strategies in these areas. Sale of livestock and products derived from them can significantly enhance the income level of the households and contribute to the development of the local economy (Fava et al., 2021). It also provides employment to the people in addition to its food and economic value. The livestock sector is a major employer in both developed and developing countries. Large scale farms in developed countries offer employment in such areas as veterinary services and transportation while smallholder farmers in the developing countries depend on livestock for food and market (Owen et al., 2020). In some cases, livestock production also empowers women in economic aspects especially when farming is gendered (Doss et al., 2018). However, livestock still has a significant contribution in the global food security. This is on account of factors such as climate change, diseases, and shifts in consumer preferences, which are exerting more pressure on livestock production systems in fragile areas (Sekaran et al., 2021). Weather is also an important factor which affects Livestock in terms of animal health and productivity and also affects the availability of feed and water for the animals (Rojas-Downing et al., 2017). This could also be caused by changes in the preferences of what people want to eat, as seen in a rapidly urbanizing population which can have major economic consequences as shown in Figure 1.

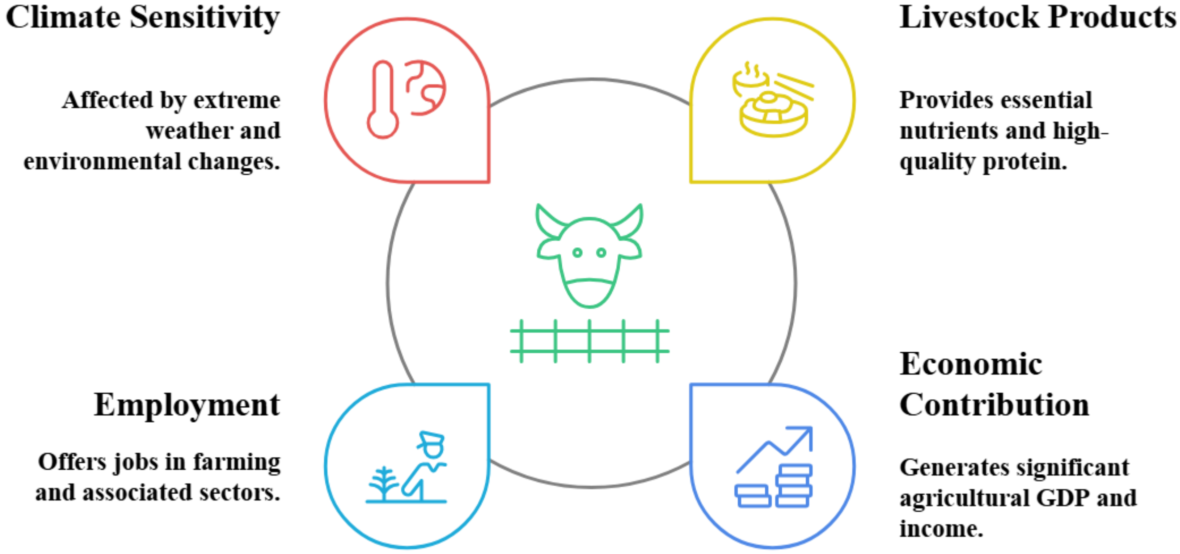

Figure 1. Factors contributing to livestock's role in Food Security

Climate Change and Its Impact on Livestock Production

Temperature Variability: Effects of Heat Stress

Temperature variability is a most direct and immediate manifestation of climate change on livestock systems. More frequent and severe heatwaves have been caused by increased global temperatures and have a huge impact on animal health and productivity. Specifically for livestock, heat stress is problematic because animals are less able to regulate body temperature during periods of extreme heat, resulting in a variety of physiological effects (Das et al., 2016).

Heat stress can reduce feed intake for ruminant species such as cattle, sheep, and goats thereby reducing growth rates and milk production. Furthermore, prolonged exposure to high temperatures can cause dehydration which can cause electrolyte imbalances and worsen health problems (Al-Dawood, 2017). For example, heat stress has been shown to reduce milk yield and poor reproductive performance in dairy cows because of the effect of heat on fertility (Hansen, 2019). In addition, grazing conditions are affected by temperature changes. Pasture growth is reduced and the nutritional value of forage may be degraded as temperatures rise. In some places, the drought features can exacerbate the loss of available grazing land and farmers increasingly become dependent on supplementary feed, also boosting written costs. Heatstroke is a serious illness that can be fatal if not treated appropriately, and livestock are at higher risk of heat-induced illnesses, including heatstroke (Burhans et al., 2022).

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Water Availability: Changes in Water Resources, Droughts, and the Impact on Livestock Hydration and Pasture Quality

Water is vital for livestock and is used directly or indirectly from sources such as precipitation, and this has been influenced by climate change. Water shortage is being compounded by factors such as droughts, decrease in rainfall, and changes in rainfall pattern particularly in the arid and semi-arid regions. This water scarcity impacts on direct supply of water to the livestock and availability of water for irrigation of pastures and feed crops (Akinmoladun et al., 2019). Water is a very essential commodity to farming and especially in livestock farming for drinking, temperature regulation and to provide crops to feed the livestock. Water resources are scarce in the arid regions of the world and water has become a scarce and a competitive commodity between humans, animals and crops. For extensive systems where animals feed on natural pastures since the animals are very sensitive to changes in the quality and quantity of the available pastures due to rainfall (Henry et al., 2018). Due to the water shortage, farmers have to buy other sources of water like transported water or stored water which may be costly and time consuming. Global warming also impacts the quality of water supply in addition to the quantity of water supply. The warmer temperatures can lead to pollution of water sources with bacteria and pathogens that are dangerous for the livestock. Also, the productivity of the forage crops depends on the fluctuations in the water supply and demand. Pasture quality is low in many areas because of inadequate water supply that leads to low nutrient quality and productivity of grazing livestock (Melak et al., 2019).

Feed and Forage Production: Climate Change Effects on Forage Crops, Feed Resources, and Feed Costs

Feeding and fodder are the basic foundations of livestock farming; therefore, climate change impacts greatly affect the production of livestock farms. Such high temperatures and changed precipitation may affect the yields and the protein content of the forage crops and hence there will be a shortage of feed for the livestock. When temperatures are raised, forage crops have shorter durations, and rainfall patterns are likely to affect the yields. These changes are more apparent in the rain-fed feed crop production areas (Giridhar & Samireddypalle, 2020). The climate change is also influencing the range spread of invasive plant species that are less nutritious and more challenging to control and also contributes to the feed shortage. Forage crops may also be affected or even destroyed by natural disasters for example floods which are expected to occur frequently due to climate change (Praveen & Sharma, 2019). Fluctuations in forage production lead to fluctuations in feed prices for farmers and many of them are forced to buy extra feed, which brings additional costs to the production process. Crop failures can also mean that there is an increased demand for feed which can in turn mean greater demand for supplies pumping down farmers, with inflation too. The dependence on supplementary feed also means that there is a dependence on external resources that may not always be available or affordable. Such disruptions in the supply chain for feed and rising costs, which will flow through to livestock producers and consumers, may result. Feeding shortages occurring in regions where grain production is impacted by climate change have knock-on effects on the entire food system, costing more money and causing more food insecurity.

Disease and Pest Control: Altered Disease Dynamics, Vector-Borne Diseases, and the Role of Climate in Pest Control

Diseases and pests that affect livestock are being altered in their distribution and intensity due to climate change. Changes in precipitation patterns, along with warmer temperatures, are making it easier for vector-born disease to spread throughout the world because outbreaks of some disease vectors such as mosquitoes, ticks, and flies have occurred as the temperatures and humidity increase. For instance, diseases such as malaria, bluetongue virus, and African swine fever are spreading to regions where they did not exist before due to favorable environmental conditions (Biswas, 2022). Breeding patterns and a pest's lifecycle are also influenced by rising temperatures and altered precipitation. In the areas where climate change results in warmer winters, pests that would be dead due to cold are now ok and even reproduce more, thus creating more danger of infestations due to being more (Skendžić et al., 2021). The cycle of pest resistance then worsens, leading to the need for more intensive control measures such as greater application of pesticides on the crops, with potential adverse environmental and economic ramifications (Bottrell et al., 2018).

Moreover, climate change will undoubtedly increase the occurrence and severity of extreme weather events, including storms and floods, which would suit particularly well for the growth and spread of pests and pathogens. For instance, insecticides can be washed away by flood and there can be formation of water pools that may act as breeding grounds for mosquitoes (El-Sayed & Kamel, 2020). These changes may lead to various effects on animal health and production; the effects may include high mortality rate, slow growth rate and low reproductive rate.

Livestock Productivity and Health: Impact on Milk, Meat and Wool Production

Climate influences the efficiency of the enterprise, health of a particular animal, and its weight gain. Due to heat stress, higher temperatures, loss of feed and water supplies, there is a decline in milk, meat, and wool production. High temperatures affect the quantity and quality of milk produced by dairy cattle in various ways. A study has shown that heat stress reduces milk yield and at the same time increases somatic cell count which is a measure of the quality of milk (Mehdid et al., 2019). Likewise, in cattle and sheep, there are effects such as decrease in meat production because of low feed intake, poor weight gain, and low conception rates.

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Heat stress also impacts on wool production because sheep can moult and this results in loss making to the wool producers (Gowane et al., 2017). The other critical issue is heat stress's impact on reproductive health. Elevated temperatures in many species can impair fertility, reducing conception rates and increasing abortion rates, decreasing productivity (Krishnan et al., 2017). In the worst cases, heat stress can kill, especially in young, sick, or weak animals. In addition, climate change can increase mortality rates through a combination of heat stress, water scarcity, disease, and inadequate feed (Godde et al. 2021). Temperature extremes already weaken weakened livestock replete with malnutrition or disease and the stress of environmental conditions worsens the health problems putting the population at greater risk of mortality as shown in Figure 2.

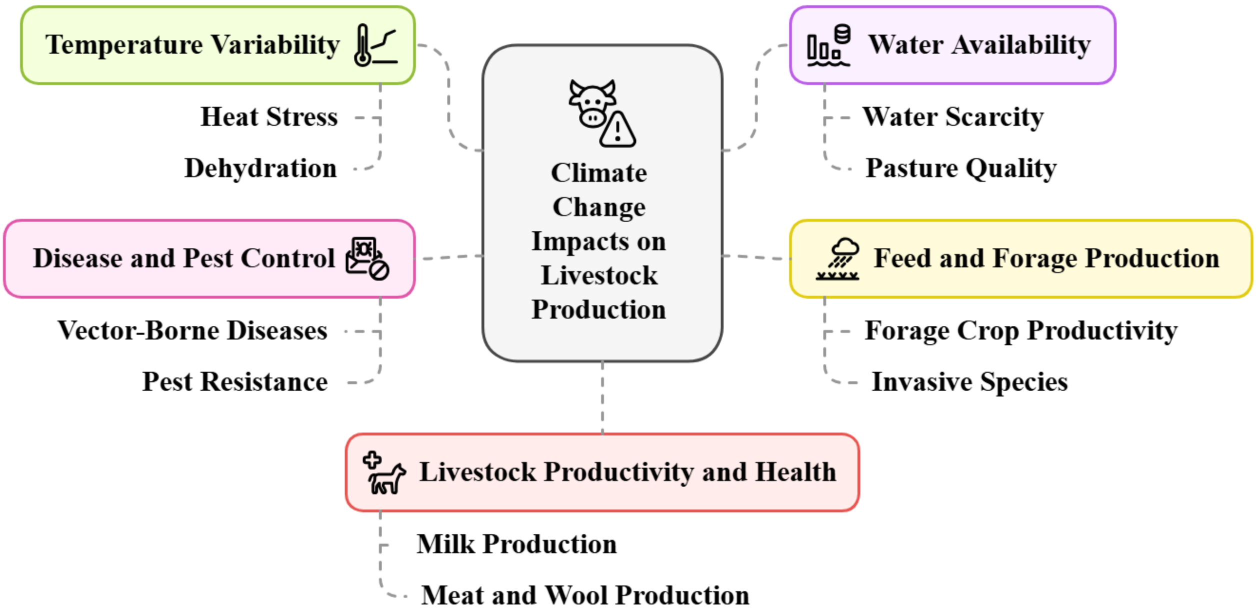

Figure 2. Climate Change and Impact on Livestock Production

Adaptation Strategies for Livestock Systems

Genetic Adaptation: Breeding for Climate Resilience

Genetically adapted breeds are one of the most promising strategies to improve livestock system resilience to climate change. The selection and breeding of animals that are more tolerant to extreme climate conditions including heat, drought, and disease (Osei-Amponsah et al., 2019) is genetic adaptation. One example would be the use of heat-tolerant cattle for example the *Bos indicus* breeds in regions with hot temperatures and humidity. *Bos indicius* breeds have developed tolerance to heat stress better than *Bos taurus* breeds (McIntosh et al., 2023). Like breeding disease-resistant livestock, the breeding of disease-resistant livestock is an important adaptation strategy in areas where climate change is expected to further spread infectious diseases. For example, enhancing the genetic quality of the livestock that is less vulnerable to parasites such as the ticks and worms is crucial where warmer weather permits the spread of these pests (Burrow et al., 2019). As the genomics advance, more and more specific genes have been found to be related to disease resistance, and animals can be produced that are better equipped to deal with health issues due to climate change (Arya et al., 2024). Also, genetic improvement involves choosing animals that are better in the use of the available resources in the environment. This also encompasses breeding of animals that feed or drink less (Tesema et al., 2019) especially in the areas where feed and water may be scarce due to climate change.

Management Practices: Modifying Feeding, Housing, and Healthcare Systems to Cope with Climate Stresses

The alterations in the livestock management practices are inevitable in order to avoid the negative impacts of climate change. Some of the changes include feeding systems where the livestock are fed adequately during the periods of stress in the environment. For instance, it is explained that provision of liquids during the periods of droughts when pasture is scarce can help in sustaining productivity of the livestock (Kubkomawa et al., 2015). It entails grazing of dry pastures or use of feedstuffs such as silage and hay which can be conserved to be fed to the animals during the dry seasons (Halmemies-Beauchet-Filleau et al., 2018). Similarly, feeding schedules can also be made in a way that the animals feed during cooler times of the day like early morning or in the evening thus reducing the effects of heat stress. The housing systems must also be modified to enhance protection of the animals from hot or cold conditions. For instance, when it comes to hot weather conditions, measures such as shading or installation of cooling systems in the animals can help

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reduce the extent of heat stress in such animals. There are also some areas that use ventilated barns with an automated cooling system to help the animals stay cool during hot weather, thus improving both their health and production levels (Rong & Wang, 2023). Housing systems should also be made to prevent disease transmission, which is more common under warmer and humid environments. Adjustment of health care systems involves enhancing the disease surveillance and including the climatic health hazards. As the effects of climate change are manifested in more cases of diseases, whether due to heat or vector-borne diseases, the practices in veterinary medicine must evolve. It entails constant check up on animals and intervention measures to prevent effects of climate stressors (Stephen & Duncan, 2022).

Technology Integration: Use of Precision Livestock Farming Technologies

Mitigation of climate change requires the incorporation of technology into livestock systems as one of the measures. Precision livestock farming (PLF) is the processes that involve the application of technologies in the health, welfare, and productivity control of livestock and other animals (Aquilani et al., 2022). Temperature monitoring is one of the important technologies in this area. For example, temperature sensors can be used in identifying the body temperature of animals and determining the onset of heat stress before it reaches a dangerous level (Sejian et al., 2022). These technologies help farmers in getting alarms when a situation is adverse and they can take appropriate measures like switching on the cooling systems or changing the feeding times. The other part of PLF is the disease prediction systems. Farmers can estimate the possibility of disease occurrence with the help of environmental sensors connected to health monitoring systems for determining the state of weather, for example, the increased level of rainfall or change in temperature to figure the spread of vector-borne disease (Lowe & Codeço, 2024). Early warnings can be provided by these systems, giving the early warning of disease and allowing the farmers to take action in advance of the disease—among these actions, vaccination or parasite abatement resulting in significantly reduced overall health risks to livestock. Another aspect of precision farming is automated systems of feed and water management. These systems enable farmers to assess and control feed and water resulting in more efficiency of usage and less waste. Additional advanced climate control systems within the housing units will also assist in regulating the internal environment for the animals regardless of the prevailing weather conditions.

Water and Feed Management

Due to climate change, water resources will be scarce and therefore proper management of water is very important for the continuation of livestock farming. This can be done by incorporation of water saving measures including rain water harvesting, efficient irrigation and re-use of water. However, the facilities used in water storage can be enhanced to allow provision of water to the livestock during dry season or any other period of less rainfall (Ncube & Shikwambana, 2017). This means that there are other feed sources which are very important in feed management in order to address the challenges brought about by climate change. There is also high susceptibility to drought and loss of traditional feed resources; it is vital to look for other feed resources. For instance, they stated that the utilization of food waste and other byproducts from the agriculture and food industries can help reduce the reliance on conventional feed crops (Makkar, 2018). One of the other strategies of the further adaptation is the promotion of forage systems which are less sensitive to the climate conditions. This is like developing of the drought resistant forage species or the system of rotational grazing to improve the use of the land at the time of low water availability (Kimaru, 2023).

Climate-Resilient Breeding

Another key aspect of sustainable development of the long-term strategies for livestock systems is breeding for climate resilience. It is about selecting animals that are better suited to the physical and environmental challenges that are brought by climate change. There is a need to replenish breed stocks with those that are heat tolerant, disease resistant, and can survive under extreme weather conditions for long to make livestock farming sustainable. Breeding has been concentrated on improving the heat tolerance among cattle and other livestock in tropical areas. For instance, hybrid cattle breeds like Brahman Cross, combine the heat tolerance of *Bos indicus* with the high productivity of *Bos taurus* breeds to solve the problems of extreme heat and humidity (Widyas et al., 2022). Selection for improved production traits is also being done to include resistance to diseases such as tick-borne diseases or respiratory infections to make the livestock in general more resistant (Naskar et al., 2015).

Policy and Education

Climate change in livestock systems has a policy and education implication. They should formulate and put into practice policies that would enhance the use of climate-smart livestock practices. It targets to provide financial incentives to farmers for making use of water efficient technologies, better management of pastures and adopting climate smart breeds. Subsidizing or offering tax credits to farmers that are incorporating adaptive technologies or structures is a way of considerably cutting down the costs of adaptation. This means that extension services are necessary to help in disseminating information on the effects of climate change and its impacts on livestock production. To enhance the resilience of the agricultural sector, farmers' awareness on climate adaptation, access to new technology, and training on climate smart practices must be pursued (Zakaria et al., 2020). Other services that are provided by extension include;

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promotion of new breeding practices, feeding and watering strategies and disease control measures as highlighted in the table 2 below.

Table 2. Key Adaptation Strategies for Livestock Systems to Address Climate Change

Adaptation Strategy	Description	References
Genetic Adaptation: Breeding for Climate Resilience	Breeding livestock that are more tolerant to extreme conditions such as heat, drought, and disease, e.g., using heat-tolerant *Bos indicus* cattle.	Osei-Amponsah et al., 2019; McIntosh et al., 2023; Burrow et al., 2019; Arya et al., 2024; Tesema et al., 2019
Management Practices: Modifying Feeding, Housing, and Healthcare Systems	Changes in feeding systems (e.g., liquid feeding during droughts), housing adaptations (e.g., shaded areas, cooling systems), and improved healthcare (e.g., disease surveillance).	Kubkomawa et al., 2015; Halmemies-Beauchet-Filleau et al., 2018; Rong & Wang, 2023; Stephen & Duncan, 2022
Technology Integration: Use of Precision Livestock Farming Technologies	Use of technology to monitor and manage livestock health and productivity, including temperature sensors, disease prediction, and automated feed and water management.	Aquilani et al., 2022; Sejian et al., 2022; Lowe & Codeço, 2024
Water and Feed Management	Optimising water use through rainwater harvesting, efficient irrigation and water storage and other feasible feed sources like food waste.	Ncube & Shikwambana, 2017; Makkar, 2018; Kimaru, 2023
Climate-Resilient Breeding	Breeding animals that are more adapted to the physical and environmental challenges of climate change, focusing on heat tolerance and disease resistance.	Widyas et al., 2022; Naskar et al., 2015
Policy and Education	Implementing policies to support climate-resilient livestock practices, including financial incentives and subsidies, alongside educating farmers on climate adaptation.	Zakaria et al., 2020

Future Directions

Some potential future research directions and research gaps are necessary to ensure that efficient and sustainable solutions for livestock production systems affected by climate change are developed. Integration of emerging technologies into livestock management, genetics, and control of diseases is one of the most promising areas. Precision Livestock Farming (PLF) technologies including wearable sensors for recording animal health and welfare status are the most promising technologies to facilitate on-time response measures for heat stress and disease detection. Combined with genomics breakthroughs such as CRISPR gene editing, these technologies may be able to help produce livestock breeds that are more adapted to diseases, pests, and heat stress that are all exacerbated by climate change. For mitigating the effects of climate-induced disease outbreaks, it is also imperative that innovations in disease control will produce better vaccines and better early warning systems. The development of climate adaptation strategies must be considered concerning sustainability. Adaptation practices must be long-term sustainable for them not to deplete natural resources and cause harm to the environment. For example, food waste and algae-based feeds can be promising feed sources to provide feed shortages, however, there are many issues to consider with scalability and economic viability. Water management technologies such as rainwater harvesting and efficient irrigation also have a crucial role in sustaining livestock systems by safeguarding livestock systems from water scarcity effects that are a direct result of climate change. Farmers, particularly those in developing nations, must be able to afford this technology and have it tailored to their local situations. Furthermore, agroecological techniques like rotational grazing and the adoption of drought-tolerant forage species will support the resilience of livestock systems while maintaining biodiversity and soil health.

Climate change is a complex phenomenon and its effects on livestock cannot be solved with just one discipline. Therefore, the integration of climate science, veterinary science, agricultural economics, and policy needs to be orchestrated by working together to combat the multiple facets of the problem inherent in climate change. Climate scientists can make important contributions to predict climate projections and long-term trends which are valuable for the formulation of adaptive management strategies. Veterinarians are specialists in the management of animal health and agricultural economists can come up with economic viability of adaptation strategies. Effective policies to support the adoption of new technologies and practices at the farm level are very important to policymakers. This by-need sense will transmit to robust adaptation strategies socially, ecologically, and economically sustainable. Finally, policies are needed at the stronger end to back adaptation in livestock systems. Policies need to be developed by governments that encourage the adoption of such climate-smart practices as the breeding of climate-resilient livestock, and investments in sustainable water and feed management. These policies should help farmers cover the financial barrier to the adoption of innovative technologies and practices. In addition, it is necessary for international cooperation as climate change is a global problem.

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Policy frameworks need to be aligned across borders, especially in regions where the systems related to livestock are interconnected. Agriculture must be included in international climate agreements with specific provisions for agriculture, including that livestock production is included in global climate action plans. A solid policy framework will contribute to the general promotion of climate-resilient practices and the sustainability of livestock systems in the long run.

Conclusion

Finally, climate change is an increasingly pressing global issue for the impact on livestock production systems. Climate change including rising temperature, heat stress, water scarcity, and changing disease patterns pose direct and indirect risks to livestock health and productivity as well as food security. Livestock production, with its importance as a component of the global food system, is of vital importance in developing countries, and hence we must be able to develop effective adaptation strategies. To mitigate the effects of climate change on livestock systems, adaptation efforts such as genetic selection for heat-tolerant and disease-resistant breeds, adaptation of precision livestock farming or other technologies and sustainable use of systems are necessary. In addition, policy interventions that offer material incentives to encourage climate-resilient practices are important to the transition to more climate-resilient livestock production systems as is international cooperation. However, there is still access to technology, knowledge dissemination, and financial resources for the wider take up of these strategies. In the future, such cross-disciplinary research, joining climate science, veterinary expertise, agricultural economics, and the making of the whole policy, needs to be done to encourage a full range of responses to the multilayered character of climate change. In the end, this changes not only the technological and managerial aspects of the livestock system innovation but also the policy and education side to empower the farmers, particularly in the vulnerable regions to cope with climate change.

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