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Sustainable livestock production under changing climate: A review

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Abstract
Climate is a key determinant in agricultural productivity and is projected to have a significant impact on livestock production systems. Although, the impact of climate change on the livestock sector is a bit controversial because there is a skeptical view that the livestock itself is contributing a share to global climate change. Even if the sector is contributing, we cannot completely stop the production of livestock products due to the increased demand for milk, meat, egg, pork, wool etc. by the increasing population. Thus, there is an emerging need to educate the farming community in regard and encourage them to take up livestock production in a sustainable way. This paper reviews the impacts of changing climate on sustainable livestock production and the ways to produce livestock products in a sustainable way by adapting to climate change. The direct impact of climate change on the sustainable livestock production is broadly reviewed as the effect on animal health, productivity, and wellbeing and the techniques to overcome the obstacles faced by the livestock sector due to changing climate in a sustainable way have also been detailed in the paper.

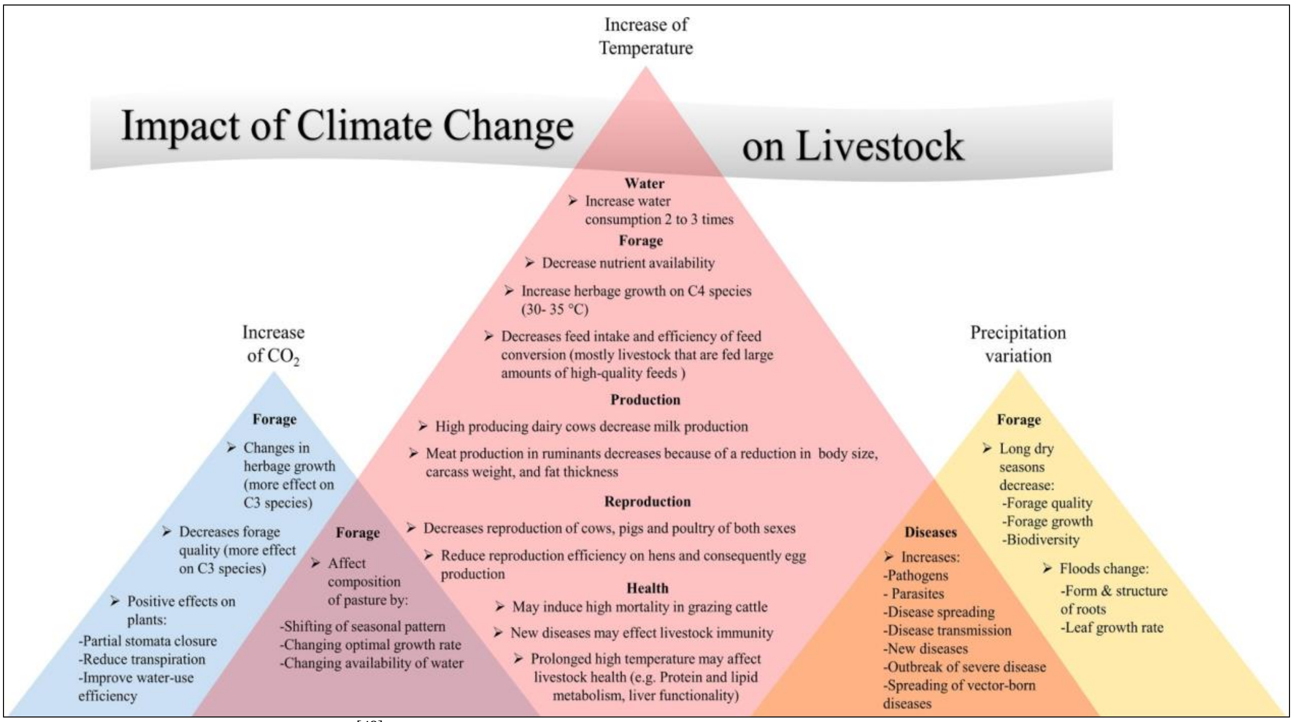
Keywords: Global climate change, impact, livestock animals, productivity, sustainability

Introduction

Domesticated animals rose in an agricultural context for diverse uses such as meat, eggs, milk, wool, fur, leather, and labor are referred to as livestock. Livestock production is considered to be an important component of the global food system. Production of livestock products in a sustainable way helps in alleviating poverty, ensuring food security, and promoting agricultural development (World Bank, 2022) [61]. Precise livestock farming is required to increase the sustainability of livestock output. There are different types of livestock production systems, and their sustainability varies greatly depending on resource quality, environmental conditions, and social and economic situations. According to Jackson (2023) [29], Climate change is defined as the long-term transformation of the Earth's climate, which includes changes in temperature, precipitation, and weather patterns. To be noted that human activities have been the primary cause of climate change, owing mostly to the use of fossil fuels such as coal, oil, and gas since 1800(Anonymous, 2023a) [5]. The current quick speed of modernity has resulted in excessive expansion in industrialization, urbanization, transportation, deforestation, and so on, generating disturbances in the ecological and environmental balance, as shown by climate change (Vataliya *et al.* 2014) [59]. Climate change is threatening not only crops but also cattle. Sejian *et al.* [52] in 2016 classified the impact of climate change on livestock into two, namely, direct and indirect impact. Heat stress is the most major direct impact of climate change on cattle production. The majority of production losses are caused by the indirect impacts of climate change, which result in reduced or non-availability of feed and water availability. Sikiru *et al.* (2023) [53] proposed various techniques to address these difficulties, including improving feed quality and efficiency, reducing greenhouse gas emissions from livestock farming, promoting animal health and wellbeing, and increasing the resilience of livestock systems to climate change. Livestock are susceptible to temperature changes and water scarcity, which is the leading cause of economic loss for both agriculture and livestock dependent countries (Reilly *et al.* 2003; Kannan and Anandhi, 2020) [47, 32]. In tropical and subtropical nations where summers are severe, increasing livestock production under the current changing climatic scenario is a jockey. According to estimates, dairy and beef production in the United States will fall by 6.8% by 2030, while India, a major dairy producing country, will lose more than 45% of its dairy farms owing to increased heat stress (Anonymous, 2022a) [3]. With this background, this review paper concentrates on the ways in which Sustainable Livestock Production (SLP) is affected by varying climate and the techniques to overcome those challenges by opting various sustainable methods.

Obstacles to SLP by climate change

Changing climate due to increase in temperature, CO_2 concentration and precipitation variation impacts livestock in various ways notably, water scarcity, quality variation in forage, production, reproduction, health etc. which is represented in the Figure. 1.



Source: Rojas-Downing *et al.* 2017 [48]

Fig 1: Impact of climate change on livestock

SLP is an important part of agriculture that tries to mitigate the negative environmental impacts of livestock farming while still ensuring the industry's long-term survival (Opio, 2020) [45]. Change in climate such as variations in temperature, rainfall, and patterns of weather creates substantial obstacles to SLP that can have an impact on animal health, productivity, and wellbeing.

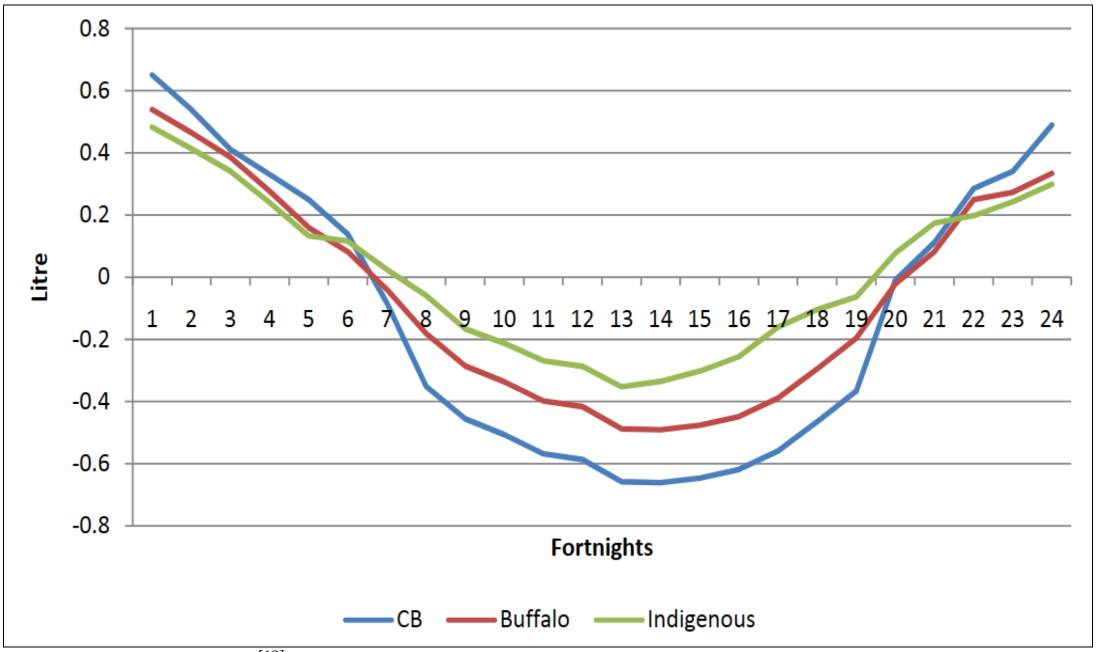
Impact on animal health: Climate change may have four major effects on animal health such as heat-related diseases and stress, adverse weather events, adaptation of animal production systems to new circumstances, and the emergence or re-emergence of infectious diseases (Forman *et al.* 2000; Magiri *et al.* 2021) [23, 34]. The emission of greenhouse gasses through various anthropogenic activities increases the global temperature which finally impairs the dairy production, animal weight, reproduction, and feed-conversion efficiency in warm regions. Due to the increased temperature, the animal starts to intake more water which in turn reduces the feed intake which may finally affect the animal's health. With minimal heat stress abatement, economic losses in the United States were projected to be $2.4 billion per year (Baumgard *et al.* 2012) [9]. McCarthy *et al.* 2001 [36] in his report submitted to Intergovernmental Panel on climate Change (IPCC, 2001) stressed that the droughts in Africa between 1981 and 1999 have been shown to cause mortality rates of 20-60% of national herds. Temperature and/or humidity increases in air have the potential to alter conception rates in domestic animals that are not accustomed to those conditions (Tubiello *et al.* 2017) [58]. The ability of animals to adapt to adverse climatic conditions is determined by the sensitivity of production to regional climate. As a result, the consequences may be favorable or negative, and they may vary among geographical regions, animal species, and adaptive capacity. However, the negative effects are most likely to be felt in tropical and subtropical regions, particularly countries with the highest current and future need for nutrition (Henry *et al.* 2018) [27]. In major livestock animals, the majority of illnesses are caused by pests, pathogens and nematodes. Development stages of most pathogens, pests and nematodes are frequently temperature dependent. Climatic variations affect the emergence and proliferation of disease hosts or vectors, as well as the breeding, development, and transmission of infections (Abdela, 2016) [1]. Pierre *et al.* 2003 [46] noticed that heat stress caused economic losses to livestock industries in the United States. The estimated total annual economic losses ranged from $1.69 to $2.36 billion. To be specific, losses in various sectors of livestock in the US were mentioned below in the Table 1.

Table 1: Estimated annual economic losses of various livestock sector in USA

Livestock Sectors	Annual Economic Losses
Dairy industry	$897 to $1500 million
Beef industry	$370 million
Swine industry	$299 to $316 million
Poultry industry	$128 to $165 million

Source: Pierre *et al.* 2003 [46]

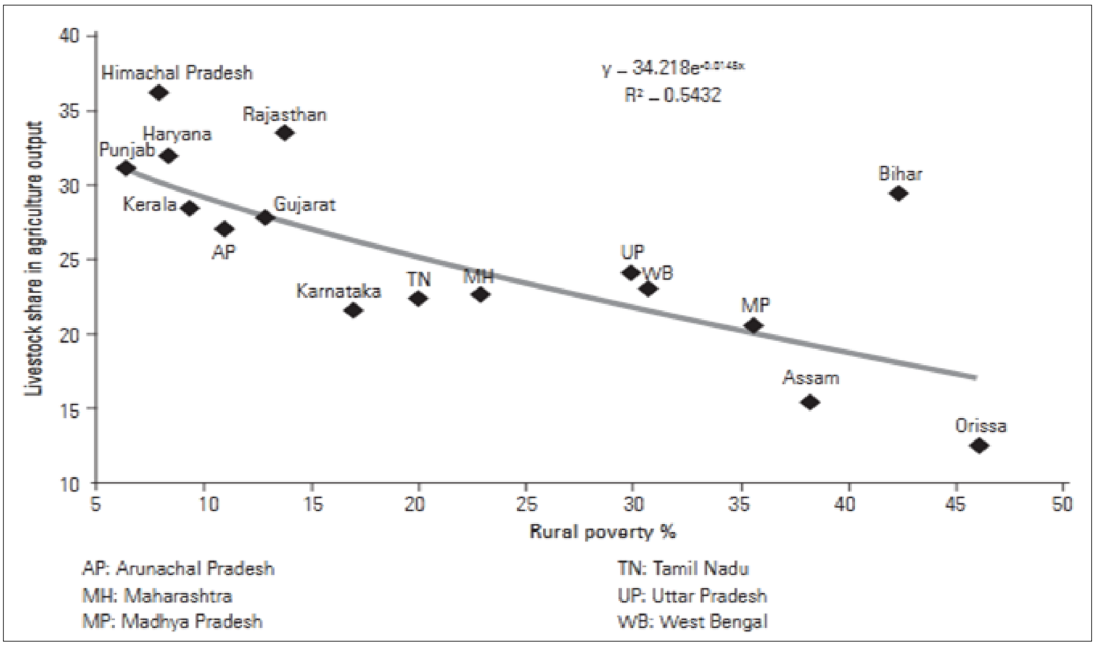
Impact on productivity: The physiological impacts of heat stress on productivity are financially detrimental to the livestock sectors. Climate change has the potential to affect the quantity and quality of products, the reliability of production, and the natural resource base on which livestock production is based. Heat stress has been shown to lower the resistance of animals to diseases as well as reproductive efficiency and productivity in general (Magiri *et al.* 2020) [34]. According to Smit *et al.* 1996 [55], climate change factors influence livestock productivity such as availability and price of grains and, fodder and pasture production and quality, changing patterns of livestock disease and the direct effect of weather on livestock health. The livestock production in Ethiopia has been impacted by climate change by causing feed and water shortage, reduced weight and productivity, mature weight issues, more conflicts, increased disease prevalence and mortality. Among those, impact on productivity was considered to be the highest (Yilma *et al.* 2009) [63]. Choudhary (2017) [12] in his doctoral research studied the Climate Sensitivity of Agriculture in Trans and Upper Gangetic Plains of India and found that the milk yield of Crossbred animals, Buffalo and Indigenous breeds decreased as the temperature increased (Figure 2). Poultry, because they lack sweat glands, are not well suited to high ambient temperatures (Chatterjee and Rajkumar, 2015) [10]. Thus, the temperature fluctuations result in decreased productivity in poultry birds. In the instance, if sows are accommodated at high ambient temperatures (29ºC vs 18°C), feed intake may drop by more than 50% during the entire lactation period, resulting in a loss of body condition much above the optimum and disadvantaged piglet growth was seen (Babinszky *et al.* 2011) [8]. Climate change was also considered as having a negative impact on cattle yield and quality features by Chingala *et al.* 2017 [11]. Under the most favorable scenario, the overall cost of Brazilian beef cattle production in the Cerrado approached US$ 2.88 per Kg, whereas under the catastrophic scenario, the cost reached US$ 4.16 per Kg, putting this economic segment's international competitiveness in jeopardy (Naas *et al.* 2010) [41].



Source: Chaudhary, 2017 [12]

Fig 2: Marginal effect of average THI (Temperature Heat Index) on fortnightly milk yield

Impact on animal wellbeing: Climate change has a significant impact on animal welfare. Since the 1800s, the Earth's temperature has risen by 1.1°C (2°F), and it is expected to climb by 2.7°C (4.8°F) by the end of the century (Anonymous, 2022b) [4]. Climate change has a negative impact on terrestrial, aquatic, and marine ecosystems. It is likely that many animals have suffered and will continue to suffer as a result of these impacts (Fey *et al.* 2015) [21]. According to a new study, the impact of climate change on animals would be "multifaceted" with "cascading impacts" across five welfare domains, including nutrition, environment, behavior, physical and mental health (Anonymous, 2023b) [6]. These domains are detailed by Mellor *et al.* 2020 [37] in his paper. Nutritional domain includes deprivation of food and water which in turn leads to malnutrition in livestock animals. Physical and atmospheric challenges such as fluctuating temperature, water and feed scarcity, reduced grazing land, uneven rainfall, severe winters, unexpected droughts and floods etc. come under environmental domains. Behavioral and/or interactive movement restrictions fall under the behavioral welfare domain. Physical and mental health domains cover thirst, hunger, anxiety, fear, pain and distress. However, with the change in climate, the animal's natural habitat gets modified which in turn affects their feeding habit, water intake, grazing period and resting period. This results in affecting the overall wellbeing of animals. As indicated by Grace *et al.* 2015 [25], livestock diseases are predicted to reduce productivity by 25%, with the poor bearing the brunt of the cost. Yilma *et al.* 2009 [63] listed the livestock based on the level of susceptibility to climate change and concluded that cattle are more susceptible to climate change (Table 2). Ali [2] in 2007 found a relationship between poverty and output share of livestock sector to agriculture sector in major states of India and summarized that as the output share decreases the poverty in the states increases (Figure. 3) and thus, the poor people dependent on livestock farming will diversify to other sectors which directly impact global food security.



Source: Ali, 2017 [2]

Fig 3: Poverty and livestock output across major Indian states, 1999 to 2000

Table 2: Livestock species and order of susceptibility

Livestock species	Order of susceptibility
Cattle	1st
Sheep	2nd
Donkey	3rd
Goat	4th
Camel	5th
Chicken	Not affected

Source: Yilma *et al.* 2009 [63]

Techniques to overcome the obstacles of climate change under SLP: Under SLP, many approaches can be employed to overcome climate change obstacles, such as boosting cattle resilience, conserving natural resources, and lowering greenhouse gas emissions etc. Some of them are detailed below.

Water management: In the first decade of the twenty-first century, India, the United States, Iran, Saudi Arabia, and China had the greatest groundwater depletion rates (Doll *et al.* 2014) [16]. Water management is an essential part for sustainable livestock production. The key area for improvement in water usage efficiency and livestock productivity is through sustainable livestock and feed base management in order to maximize production efficiency and create improved living conditions for the rural population. Moreover, the water use for livestock production should be emphasized as an integral part of agricultural water resource management, by refocusing the type of production system (such as grain-fed or mixed crop-livestock) and scale (whether intensive or extensive), species and breeds of livestock in the farm, and the social and cultural aspects of livestock farming in various countries (Schlink *et al.* 2010) [51].

On-and-off farm diversification: Diversified practices are considered as the alternative for sustainable livestock development. On-farm diversification is the recombination and reallocation of available farm resources into non-agricultural enterprises or new non-conventional crops and/or livestock. On-farm diversification in the context of sustainable livestock production might involve strategies such as crop-livestock integration, agro forestry, and pasture management. Off-farm diversification mainly aims at adding value to the available assets with the aim of increasing income by reducing the risk (Moraru and Bodescu, 2022) [39]. Off-farm diversification can include operations such as livestock products processing and marketing, as well as non-farm income-generating operations (Hussein and Nelson, 1998; Asante *et al.* 2018) [28, 7]. On-and-off farm diversification is an approach that combines on- and off-farm activities to provide extra revenue for households. This can be accomplished by producing various agricultural and non-agricultural goods and services, selling waged labor, or working for self in smaller enterprises (Hussein and Nelson, 1998) [28]. Diversification can help farmers pass on risk and adapt to shocks such as climate change. It may additionally assist to ensure the long-term sustainability of livestock production systems by decreasing their burden on natural resources and encouraging biodiversity (FAO, 2018a, Danso-Abbeam *et al.* 2021) [19, 13].

Altered rotation of pastures: Altered rotation of pastures is a sustainable livestock production method that can assist increase soil health and plant biodiversity while lowering the impact of livestock farming on environment and climate (Opio, 2020; Grandin, 2022) [45, 26]. Rowntree *et al.* 2020 [50] compared the necessary acreage for food production between the two systems, Multi Species Pasture Rotation (MSPR) which required 2.5 times more land than the Commodity Production System (COM) which is because the MSPR may regenerate land and so requires a far larger land area than COM. The practice of rotational grazing is clearly explained in the figure given below. According to the FAO (2018b) [20], integrating livestock species with complementary grazing behavior might boost overall biomass collection and productivity while decreasing health hazards associated with animal parasitism.

Modification of grazing times: For commercial livestock production, grazing management that allows for significant neglect of forage species is pernicious (Norton, 1998) [43]. Grazing management is adjusting grazing times, stocking rates, and intensity of grazing to make sure that the land is used sustainably while safeguarding livestock health and productivity (Teague and Kreuter, 2020, Opio, 2020) [56, 45]. Changing grazing schedules is one method for achieving sustainable livestock production. It entails altering the time of day when animals are permitted to graze in order to maximize feed intake and reduce heat stress. In hot and arid climates, for example, grazing should be done during cooler times of the day, such as early morning or late afternoon. This method may help animals reduce heat stress and increase productivity. Thus, modifying grazing times can aid in the restoration of soil health, ecosystem function, and biodiversity (Teague and Kreuter, 2020) [56]. Using the "Herd Effect" and limiting grazing duration to avoid regrazing forage plants can help trample down dead plants, break up hard soil crusts, and incorporate dung, urine, and plant organic matter into soils to improve soil carbon, increase water infiltration and retention, and accelerate nutrient flow for grass regrowth (Morris, 2021) [40].

Reducing greenhouse gas emissions from livestock farming: The Greenhouse Gas emissions from livestock are more compared to crop production **(**Neufeldt and Schäfe, 2008, Thamo *et al.* 2013) [42, 57]. As mentioned by Leip *et al.* 2015 [33] the livestock are blamed in European countries for the increased emissions of nitrogen, sulfur, phosphorus and greenhouse gasses. This has resulted in a gradual demonization of the livestock sector, and hence it is essential to balance the drawbacks with some rewards. To address GHG emissions, the livestock sector must challenge itself to design and execute mitigation strategies that are effective, efficient, and equitable (Moran and Wall, 2011) [37]. Diet manipulation, direct inhibitors, feed additives, propionate enhancers, methane oxidizers, probiotics, defaunation, and hormones can all help to reduce carbon emissions from animal feces (Sirohi and Michaelowa, 2007) [54].

Disease control and surveillance: The most efficient and cost-effective method of disease management is to prevent illnesses from entering and spreading in herds of livestock (Wobeser, 2002) [60]. Animal disease control is a top priority in the sustainable livestock production, owing to the high cost of infectious diseases. Some of these diseases are treatable with relatively inexpensive vaccinations. It is possible to lower disease incidence in livestock populations by implementing effective disease prevention programs and adopting appropriate livestock management techniques. Disease surveillance enables the detection of new ailments as well as changes to existing diseases. An effective and efficient surveillance system necessitates the combined efforts of relevant stakeholders working toward a common objective with a shared sense of responsibility (George *et al.* 2021) [24].

Agroforestry: Agroforestry is a land use practice that integrates trees, fodder, and livestock to build a sustainable system. Silvo pasture is a particular kind of agroforestry that has begun to gain prominence in recent years as an environmentally benign and economically viable alternative land use system (Jose and Dollinger, 2019) [30]. It entails mixing trees and livestock with forage to produce a well-planned system. According to a World Bank report 2022, between 2011 and 2018, the use of Silvo pastoral systems increased milk production by 17 per cent, reduced production costs by 18.5 per cent, and increased the mean number of cows / hectares by 23 per cent.

Continuously matching of stocking rates with pasture production: Stocking rate is an important management component in determining grazing system productivity and profitability (Fales *et al.* 1995) [18]. Matching stocking rates with pasture production entails optimizing the total number of animals grazing on a given amount of land to avoid overgrazing or under grazing. The goal is to strike a balance between the number of animals and the available pasture, which can help increase livestock productivity while reducing environmental degradation. To reach end-point objectives, stocking strategies must incorporate periodic and total forage mass, accompanying nutritional qualities, specific defoliation regimen behaviors, and weather circumstances (Rouquette, 2015) [49].

Changes in cropping calendar: Crop calendars offer information on sowing of seeds, growing of crops and harvesting of matured crops (Omran, 2020) [44]. Crop production strategies, cropping patterns, and cropping calendars, for example, will be largely similar, with the exception of crop types grown and animal and breed selection according to the specific Agro Ecological Zone (Devendra, 2012) [15]. Crop calendars for livestock feed keep track of the available supply of animal feeds month by month, similar to a 'fodder-flow' exercise. Because of labor demands (a "Labor Calendar") and the availability of crop residue as feed sources, this should be linked to the cropping system (Donkin. 2005) [17].

Cooling (indoor systems or provide shade): The most that can typically be done to decrease heat stress on animals is to provide shade. Planting trees will provide Shade and can assist animals to avoid heat stress and enhance productivity. Furthermore, indoor cooling systems can be employed to reduce the radiant heat load on feedlot cattle, hence lowering the demand for water and energy for thermoregulation (Firfiris *et al.* 2019; Maia *et al.* 2023) [22,35]. Commercial beef and dairy breeds such as Holstein, Jersey, Charolais, Limousin, Blonde d'Aquitaine, and Belgian Blue are faster growing and more productive (de Vries, 1994) [14] are considered less suited to being kept in a variety of climatic conditions and are generally kept indoors in deep winter.

Increase mobility for resources: This approach entails moving livestock to places with greater resources, especially water and pasture. By enhancing feed quality, avoiding overgrazing, and conserving natural resources, this technique can help maintain sustainable livestock production. The circular economic model based on biogas is an excellent technique to achieve sustainable livestock and poultry waste management while limiting the greenhouse effect (Xue *et al.* 2019) [62] and in turn the waste after extraction used for crop growth and the final crop residue is used as livestock feed. Intensification of livestock into the commercial small mixed-farming systems entails more zero-grazing systems and optimum allocation of available resources which in turn enables better control of parasites both echo and endo, collection and strategic use of animal wastes, and crop damage reduction (Kaasschieter *et al.* 1992) [31].

Conclusion

By reviewing various scholarly papers, it is clear that the impact on livestock due to changing climate is various which also reduces the productivity of livestock products, this in turn affects the global food security. It is also evident that the livestock sector is also contributing much to the atmospheric climate variability when compared to agriculture. Thus, there is a need for Sustainable livestock production which entails increased production and a better use of natural resources, lowering the environmental impact of livestock systems.

References

1. Abdela N, Jilo K. Impact of climate change on livestock health: A review. Global Veterinaria. 2016;16(5):419-24.
2. Ali J. Livestock sector development and implications for rural poverty alleviation in India. Livestock research for rural development. 2007;19(2):1-5.
3. Anonymous. Cattle production faces annual loss of $40 billion, due to climate change. Open Access Government. Available from Cattle production to lose up to $40 billion yearly due to heat stress (openaccessgovernment.org); c2022.
4. Anonymous. The impact of climate change on our planet's animals. International Fund for Animal Welfare. Available from the impact of climate change on our planet's animals (ifaw.org); c2022.
5. Anonymous. What Is Climate Change? Available from What Is Climate Change? | United Nations; c2023.
6. Anonymous. Impacts of climate change on animal welfare, CABI Reviews; c2023. Available from: https://dx.doi.org/10.1079/cabireviews.2023.0020
7. Asante BO, Villano RA, Patrick IW, Battese GE. Determinants of farm diversification in integrated crop–livestock farming systems in Ghana. Renewable Agriculture and Food Systems. 2018;33(2):131-49.
8. Babinszky L, Halas V, Verstegen MW. Impacts of climate change on animal production and quality of animal food products. In: Climate change socioeconomic effects. Rijeka: In Tech; c2011. p. 165-90.
9. Baumgard LH, Rhoads RP, Rhoads ML, Gabler NK, Ross JW, Keating AF, *et al.* Impact of climate change on livestock production. In: Environmental stress and amelioration in livestock production; c2012. p. 413-68.
10. Chatterjee RN, Rajkumar U. An overview of poultry production in India. Indian Journal of Animal Health. 2015;54(2):89-108.
11. Chingala G, Mapiye C, Raffrenato E, Hoffman L, Dzama K. Determinants of smallholder farmers' perceptions of the impact of climate change on beef production in Malawi. Climatic Change. 2017;142:129-41.
12. Choudhary BB. Climate Sensitivity of Agriculture in Trans and Upper Gangetic Plains of India Potential Economic Impact and Vulnerability (Doctoral dissertation, NDRI); c2017.
13. Abbeam DG, Dagunga G, Ehiakpor DS, Ogundeji AA, Setsoafia ED, Awuni JA. Crop-livestock diversification in the mixed farming systems: Implication on food security in Northern Ghana. Agriculture & Food Security. 2021;10(1):1-4.
14. Vries DMW. Do breed differences in cattle have implications for conservation management? In: Foraging in a landscape mosaic: Diet selection and performance of free-ranging cattle in heathland and riverine grassland. Wageningen; c1994, 97110.
15. Devendra C. Climate change threats and effects: challenges for agriculture and food security. Kuala Lumpur: Academy of Sciences Malaysia; c2012.
16. Döll P, Schmied MH, Schuh C, Portmann FT, Eicker A. Global-scale assessment of groundwater depletion and related groundwater abstractions: Combining hydrological modelling with information from well observations and GRACE satellites. Water Resources Research. 2014;50(7):5698-720.
17. Donkin EF. Sustainable livestock development in Africa: How do we help Africa to feed itself? SA-Anim. Sci. 2005;6:56-67.
18. Fales SL, Muller LD, Ford SA, O'sullivan M, Hoover RJ, Holden LA, *et al.* Stocking rate affects production and profitability in a rotationally grazed pasture system. Journal of production agriculture. 1995;8(1):88-96.
19. FAO. Livestock and Agro ecology: How They Can Support the Transition towards Sustainable Food and Agriculture. FAO: Rome, Italy; c2018a.
20. FAO. World Livestock: Transforming the livestock sector through the Sustainable Development Goals. Rome. 222. Available from https://doi.org/10.4060/ca1201en. 2018b.
21. Fey SB, Siepielski AM, Nusslé S, Yoshida CK, Hwan JL, Huber ER, *et al.* Recent shifts in the occurrence, cause, and magnitude of animal mass mortality events. Proceedings of the National Academy of Sciences. 2015;112(4):1083-8.
22. Firfiris VK, Martzopoulou AG, Kotsopoulos TA. Passive cooling systems in livestock buildings towards energy saving: A Critical Review. Energy and Buildings. 2019;202:109368.
23. Forman S, Hungerford N, Yamakawa M, Yanase T, Tsai HJ, Joo YS, *et al.* Climate change impacts and risks for animal health in Asia. Revue SCIENTIFIQUE ET Technique. 2008;27(2):581-97.
24. George J, Häsler B, Komba EV, Sindato C, Rweyemamu M, Kimera SI, *et al.* Leveraging sub-national collaboration and influence for improving animal health surveillance and response: A stakeholder mapping in Tanzania. Frontiers in Veterinary Science. 2021;8:738888.
25. Grace D, Bett BK, Lindahl JF, Robinson TP. Climate

and livestock disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios. CCAFS Working Paper; c2015. Available from: www.ccafs.cgiar.org

26. Grandin T. Grazing cattle, sheep, and goats are important parts of a sustainable agricultural future. Animals. 2022;12(16):2092.
27. Henry BK, Eckard RJ, Beauchemin KA. Adaptation of ruminant livestock production systems to climate changes. Animal. 2018;12(s2):s445-56.
28. Hussein K, Nelson J. Sustainable livelihoods and livelihood diversification. IDS Working Paper 69; c1998.
29. Jackson ST. climate change. Encyclopaedia Britannica. 2023. Available from: https://www.britannica.com/science/climate-change
30. Jose S, Dollinger J. Silvopasture: A sustainable livestock production system. Agroforestry systems. 2019;93:1-9.
31. Kaasschieter GA, De Jong R, Schiere JB, Zwart D. Towards a sustainable livestock production in developing countries and the importance of animal health strategy therein. Veterinary Quarterly. 1992;14(2):66-75.
32. Kannan N, Anandhi A. Water management for sustainable food production. Water. 2020;12(3):778.
33. Leip A, Billen G, Garnier J, Grizzetti B, Lassaletta L, Reis S, *et al.* Impacts of European livestock production: Nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environmental Research Letters. 2015;10(11):115004.
34. Magiri R, Muzandu K, Gitau G, Choongo K, Iji P. Impact of climate change on animal health, emerging and re-emerging diseases in Africa. African Handbook of Climate Change Adaptation; c2020. p. 1-8.
35. Maia AS, Moura GA, Fonsêca VF, Gebremedhin KG, Milan HM, Chiquitelli Neto M, *et al.* Economically sustainable shade design for feedlot cattle. Frontiers in Veterinary Science. 2023;10:1110671.
36. McCarthy JJ, Editor. Climate Change: Impacts, adaptation, and vulnerability: Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press; c2001. p. 495-497.
37. Mellor DJ, Beausoleil NJ, Littlewood KE, McLean AN, McGreevy PD, Jones B, *et al.* The 2020 five domains model: Including human-animal interactions in assessments of animal welfare. Animals. 2020;10(10):1870.
38. Moran D, Wall E. Livestock production and greenhouse gas emissions: Defining the problem and specifying solutions. Animal Frontiers. 2011;1(1):19-25.
39. Moraru RA, Bodescu D. Diversification as an alternative strategy for sustainable farm development. 2022;65(2):261-266.
40. Morris CD. How Biodiversity-Friendly Is Regenerative Grazing?. Frontiers in Ecology and Evolution. 2021;9:816374.
41. Nääs ID, Romanini CE, Salgado DD, Lima KA, Vale MM, Labigalini MR, *et al.* Impact of global warming on beef cattle production cost in Brazil. Scientia Agricola. 2010;67:01-8.
42. Neufeldt H, Schäfer M. Mitigation strategies for greenhouse gas emissions from agriculture using a regional economic-ecosystem model. Agriculture, Ecosystems & Environment. 2008;123(4):305-16.
43. Norton BE. The application of grazing management to increase sustainable livestock production. Animal production in Australia. 1998;22(1):15-26.
44. Omran ES. Exploring Changes in the agricultural calendar as a response to climate variability in Egypt. Climate change impacts on agriculture and food security in Egypt: Land and Water Resources-Smart Farming-Livestock, Fishery, and Aquaculture; c2020. p. 249-71.
45. Opio C. Livestock under climate change. Adaptation of livestock systems to climate change. Presented on koronivia Workshop On: Improved Livestock Management Systems, Including Agropastoral Production Systems and Others; c2020. Available at: Ganaderia Y Cambio Climático (unfccc.int)
46. Pierre NR, Cobanov B, Schnitkey G. Economic losses from heat stress by US livestock industries. Journal of dairy science. 2003;86:E52-77.
47. Reilly J, Tubiello F, McCarl B, Abler D, Darwin R, Fuglie K, *et al.* US agriculture and climate change: New Results. Climatic Change. 2003;57:43-67.
48. Downing RMM, Nejadhashemi AP, Harrigan T, Woznicki SA. Climate change and livestock: Impacts, adaptation, and mitigation. Climate risk management. 2017;16:145-63.
49. Rouquette Jr FM. Grazing systems research and impact of stocking strategies on pasture-animal production efficiencies. Crop Science. 2015;55(6):2513-30.
50. Rowntree JE, Stanley PL, Maciel IC, Thorbecke M, Rosenzweig ST, Hancock DW, Guzman A, Raven MR. Ecosystem impacts and productive capacity of a multi-species pastured livestock system. Frontiers in Sustainable Food Systems, 2020, 4(232).
51. Schlink AC, Nguyen ML, Viljoen GJ. Water requirements for livestock production: A global perspective. Revue SCIENTIFIQUE ET Technique. 2010;29(3):603-19.
52. Sejian V, Gaughan JB, Bhatta R, Naqvi SM. Impact of climate change on livestock productivity. Feedipedia-Animal Feed Resources Information System-INRA CIRAD AFZ and FAO; c2016. p. 1-4.
53. Sikiru AB, Velayyudhan SM, Nair MR, Veerasamy S, Makinde JO. Sustaining livestock production under the changing climate: Africa Scenario for Nigeria Resilience and Adaptation Actions. In Climate Change Impacts on Nigeria: Environment and Sustainable Development; c2023. p. 233-259.
54. Sirohi S, Michaelowa A. Sufferer and cause: Indian livestock and climate change. Climatic change. 2007;85(3-4):285-98.
55. Smit B, McNabb D, Smithers J. Agricultural adaptation to climatic variation. Climatic change. 1996;33(1):7-29.
56. Teague R, Kreuter U. Managing grazing to restore soil health, ecosystem function, and ecosystem services. Frontiers in Sustainable Food Systems; c2020, 157.
57. Thamo T, Kingwell RS, Pannell DJ. Measurement of greenhouse gas emissions from agriculture: Economic

implications for policy and agricultural producers. Australian Journal of Agricultural and Resource Economics. 2013;57(2):234-52.
58. Tubiello FN, Soussana JF, Howden SM. Crop and pasture response to climate change. Proceedings of the National Academy of Sciences. 2007;104(50):19686-90.
59. Vataliya PH, Dongre VB, Ahlawat AR, Dangar NS. Climate Change and Domestic Animal Biodiversity: Gujarat Perspective. Presented on National Seminar on Revisiting Management Policies and Practices for Indigenous Livestock & Poultry Breed as Eco- friendly Economic Producers; c2014. p. 161-168. Available at: (11) (PDF) Climate Change and Domestic Animal Biodiversity: Gujarat Perspective (researchgate.net)
60. Wobeser G. Disease management strategies for wildlife. Revue SCIENTIFIQUE ET Technique (International Office of Epizootics). 2002;21(1):159-78.
61. World Bank. Moving Towards Sustainability: The Livestock Sector and the World Bank. The World Bank. Available from moving towards sustainability: The Livestock Sector and the World Bank; c2022.
62. Xue YN, Luan WX, Wang H, Yang YJ. Environmental and economic benefits of carbon emission reduction in animal husbandry via the circular economy: Case study of pig farming in Liaoning, China. Journal of Cleaner Production. 2019;238:117968.
63. Yilma Z, Haile A, Bleich GE, Ababa A. Effect of climate change on livestock production and livelihood of pastoralists in selected pastoral areas of Borana, Ethiopia. ESAP Proceedings; c2009, 4.
64. 20th Livestock Census. Department of Animal Husbandry & Dairying. Available from 20th Livestock census 2019-All India Report | Department of Animal Husbandry & Dairying (dahd.nic.in); c2019.