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Comparative Assessment of Livestock Welfare and Productivity in Pasture Based and Intensive Feedlot Systems Under Climatic Stress

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Key Words

Livestock welfare, Climatic stress, Pasture-based systems, Feedlot systems, Temperature–humidity index, Productivity assessment.

Abstract

Addressing livestock welfare and productivity in the various production systems in the face of climate change and environmental variability has become a major challenge. This study aims to provide a comparison of livestock welfare and productivity in pasture-based and intensive feedlot production systems in climatic stress conditions, using the livestock dataset FAOSTAT and incorporating climatic indicators. The study recognizes that there are studies that do not provide integrated analysis of welfare with productivity under environmental stress. A quantitative comparative research design was utilized, which involved livestock production indicators and climatic variables such as temperature, humidity, rainfall, and Temperature–Humidity Index (THI). The data were pre-processed through data cleaning, data normalization, and a composite data welfare index. The relationships between climatic variables, welfare, and productivity indicators were analyzed using the Pearson correlation. The results showed that the pasture system had a higher welfare score (85.4) and a lower stress index (32.5), while the intensive feedlot system had higher productivity with meat production of 586.8 kg/year, milk production of 4515.7 L/year, and better feed efficiency (86.5%). The results of the correlation showed that there was a moderate relationship between the climatic stress and welfare indicators that showed the effect of climatic stress on animal welfare and production was negative. The study concludes that incorporating welfare concepts with productivity management strategies can enhance sustainable livestock production with the altered climatic conditions.

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Introduction

Livestock production systems are a vital part of the world's food security and economic sustainability, providing meat and milk and contributing to other agricultural sectors. But the climates are becoming more variable, and extreme environmental conditions are becoming a challenge for the animal welfare and productivity. In livestock production systems, climatic stress (especially heat stress) can impact physiological stability, animal behavior, health status, and production performance. The knowledge of the impact of environmental conditions on animals and their ability to adapt to these conditions has grown particularly significant for sustainable livestock production as weather temperatures keep rising (Turcios et al., 2024).

There are two main types of livestock production: pasture-based and intensive feedlot production. Pasture-based systems allow greater freedom of movement, natural behavior, and better interaction with the environment for animals, thus having a positive effect on animal welfare indicators. Research in large-scale farming systems in the Mediterranean showed that adopting pastoral and silvopastoral practices can enhance the level of welfare without compromising productive performance and decreasing the impact of pasture degradation (Ripamonti et al., 2023). Likewise, in tropical beef production systems, it was suggested that welfare assessment methods could be developed specific to the pasture systems (Romero et al., 2023). Additionally, sustainable pasture-based production has been linked to better environmental and socio-economic outcomes in livestock production (Dos Santos et al., 2024).

In contrast, intensive feedlot systems are geared towards maximizing productivity by controlling feeding, providing an optimum diet, and efficiently using resources. These systems allow better growth performance and production efficiency but may lead to welfare issues due to reduced mobility, higher stocking densities, and higher exposure to thermal stress in case of unfavorable climatic conditions (Frigeri et al., 2023). Under conditions of hot climates, environmental conditions have been shown to significantly affect animal performance, as well as economic results under feedlot systems (Turcios et al., 2024). The adaptability of different geographical areas to feedlot cattle production has also been linked to climatic conditions and environmental indexes that can be used for heat load exposure (Pokkuluri et al., 2025).

Heat stress is one of the biggest environmental problems of livestock around the world. High temperature and humidity alter respiration rate (RR), body temperature (BT), feed intake (FI), endocrine responses, and immune function with ultimate consequences on productivity. A systematic review of the community-based cattle feedlot systems in sub-Saharan areas revealed the existence of a number of challenges related to the ability of these systems to resist and adapt to heat stress conditions (Slayi et al., 2024). In other dairy systems, under a controlled environment, it was similarly found that long-term exposure to a high-temperature environment has a detrimental

effect on physiological and production parameters (Frigeri et al., 2023). The industry has also pointed out that practical heat mitigation measures to minimize losses in productivity and welfare in feedyard operations are important considerations (Dean et al., 2023).

As a result of recent developments in technology, there are opportunities to enhance livestock management in response to climatic stress. AI and precision Livestock farming techniques have proven to be powerful tools for real-time monitoring of animal health, welfare, and environment. AI-powered livestock systems have demonstrated promise in the areas of sustainable livestock management and minimizing environmental inefficiencies (Sindhu, 2024). Further, there is an intelligent system that combines predictive analytics and sensor-based monitoring, which has shown potential in heat stress management in ruminant livestock production (Rebez et al., 2024).

There are also changes in modern livestock systems, moving away from product-centric management and towards more sustainable management systems that consider productivity, animal welfare, and the environment. Studies on sustainable intensification practices in beef production have shown that combining efficient production systems with welfare-focused practices could be beneficial for beef producers and the animals in the long term (Almudhafar et al., 2024). Furthermore, farmers are becoming more aware of the importance of welfare management in their livestock production and as a key indicator of their success (Phillips, 2024).

While there is significant research on welfare assessment, climatic adaptation, and production efficiency as outcomes of production systems, there is limited research comparing welfare measures and productivity between pasture and intensive feedlot production systems under climatic stress. The focus of most previous studies has been on individual aspects like environmental effects, heat stress mitigation, or production performance. Hence, the present study is aimed to comparatively assess the welfare and productivity of livestock in a pasture-based system and an intensive feedlot under climatic stress conditions. The results of this study are hoped to offer scientific information on sustainable livestock management that is able to meet animal welfare standards and improve production.

Research Gap

Previous research has focused on either livestock productivity, welfare assessment, heat stress alleviation, or pasture or intensive feedlot systems and their sustainability aspects. Some studies have investigated the effects of climatic conditions on animal performance and environmental effects, and others on the welfare and precision technologies of livestock. But there is not a lot of research that has combined these elements into a single comparative approach that will consider both livestock welfare and productivity under climatic stress. In addition, there are only a few studies that have been conducted to evaluate environmental, welfare, and productivity indicators simultaneously, based on large-scale data sets. Hence, a thorough

comparison is necessary to make out sustainable strategies in livestock management.

Research Objectives

- To compare livestock welfare indicators for pasture-based and intensive feedlot production systems under climatic stress conditions.
- To assess the impact of climatic stress on the livestock productivity parameters such as production performance and environmental impacts.
- To be able to create a holistic assessment approach for the identification of sustainable livestock management strategies that take the need to consider animal welfare and productivity into account.

The rest of this paper will be structured as follows: Section 2 will cover the methodological aspects of the study, including the methodology, data collection, processing, variable selection, assessment of climatic stresses, and statistics. The next section will cover the conceptual model of the current investigation. Section 4 will deal with the discussion of the results and comparative analysis of livestock welfare and production under pasture and feedlot farming conditions.

Methodology

The study is of a quantitative type with a comparative research design to evaluate the welfare and productivity of the livestock under pasture and intensive feedlot systems under climatic stress. The study adopts a longitudinal analytical approach to the publicly available livestock production data, along with some climate-related data. The study aims to detect differences in animal welfare and production performance of the animals exposed to different environmental stresses.

Data Source and Collection

The main source of data used in this study is the FAOSTAT Livestock Database, which offers extensive data on livestock populations, meat production, milk production, carcass yield, and environmental indicators for several countries and years. The time frame of 2010–2025 is chosen to provide recent livestock production system trends and variations in climate. Other climate data such as temperature, humidity, and precipitation are brought in from open-source climate datasets to capture environmental stress conditions.

Data Preprocessing

The datasets collected are preprocessed to make them more consistent and reliable. There are missing values, which are dealt with by interpolation and data cleaning. Observations that have been duplicated and incomplete records are eliminated. Normalization is then used to standardize the scale of the variables, and this will allow the different livestock production systems to be compared.

Variable Selection

Input, intermediate, and output variables are included, which are linked to climatic parameters, welfare parameters, and productivity parameters. Climatic variables are the temperature, humidity, rainfall parameters, etc. Productivity indicators are obtained from the milk, meat, feed conversion efficiency, and

livestock population. Welfare assessment variables include environmental conditions and production responses that are indicators of stress.

Table 1: Variables Used in the Study

Category	Variables
Climate Variables	Temperature, Humidity, Rainfall, THI
Welfare Indicators	Stress index, Welfare score
Productivity Indicators	Meat production, Milk yield, Feed efficiency
Environmental Variables	Emission indicators, Stock density
System Variables	Pasture-based, Intensive feedlot

Climatic Stress Assessment

The Temperature–Humidity Index (THI) is commonly used to assess thermal stress in livestock production and is used to assess the stress occurring from climatic conditions. The THI is determined from temperature and relative humidity data to indicate a normal or stress level from mild to severe, as shown in equation 1.

$$\mathrm{THI} = (1.8\mathrm{T} + 32) - [(0.55 - 0.0055\mathrm{RH})(1.8\mathrm{T} - 26)] \quad (1)$$

where:

T represents the temperature in the environment (°C) and RH the relative humidity.

Welfare Index Construction

As no welfare data are available in FAOSTAT, a welfare index is created using productivity performance, climatic stress factors, environmental factors, and animal management factors. The welfare score is calculated as in equation 2:

$$\mathrm{WI} = \mathrm{w}_1(\mathrm{PP}) + \mathrm{w}_2(\mathrm{HS}) + \mathrm{w}_3(\mathrm{EI}) + \mathrm{w}_4(\mathrm{SD}) \quad (2)$$

where:

- WI= Welfare Index
- PP= Productivity performance
- HS= Heat stress factor
- EI= Environmental indicator
- SD= Stock density
- w= weighting coefficients

Statistical Analysis

Analysis is carried out using statistical methods to explore the association of climatic conditions, livestock welfare indicators, and livestock productivity parameters between pasture-based and intensive feedlot systems. In the first step, descriptive statistical measures such as maximum, minimum, mean, and standard deviation values of the collected data are calculated so that the characteristics of the data obtained are summarized. Afterwards, Pearson correlation analysis is used to establish the nature and magnitude of the relationship between climate, welfare, and productivity indicators. The values of the correlation coefficient are between −1 and +1, and the positive values show that there is a direct correlation between the variables, while the negative values show that there is an inverse correlation between variables.

The Pearson correlation coefficient is equal to equation 3:

$$\mathrm{r} = \frac{\sum(\mathrm{x_i} - \bar{\mathrm{x}})(\mathrm{y_i} - \bar{\mathrm{y}})}{\sqrt{\sum(\mathrm{x_i} - \bar{\mathrm{x}})^2 \sum(\mathrm{y_i} - \bar{\mathrm{y}})^2}} \quad (3)$$

where:

- r= Pearson correlation coefficient

- x_i= observed value of variable x
- y_i= observed value of variable y
- $\bar{x}$= mean of variable x
- $\bar{y}$= mean of variable y

The correlation analysis can be used to determine significant relationships between climatic stress factors and livestock welfare-productivity outcomes.

Conceptual Framework

The conceptual framework shows how climatic factors relate to the livestock production systems, animal welfare indicators, and the productivity outcomes. The climatic stress factors like temperature, humidity, rainfall, and Temperature–Humidity Index (THI) affect both pasture-based and intensive feedlot systems. Stress response to these environmental conditions will impact animal welfare and ultimately productivity, such as meat production, milk yield, and feed efficiency. The framework can be used to make a comparison and therefore identify sustainable practices for livestock management.

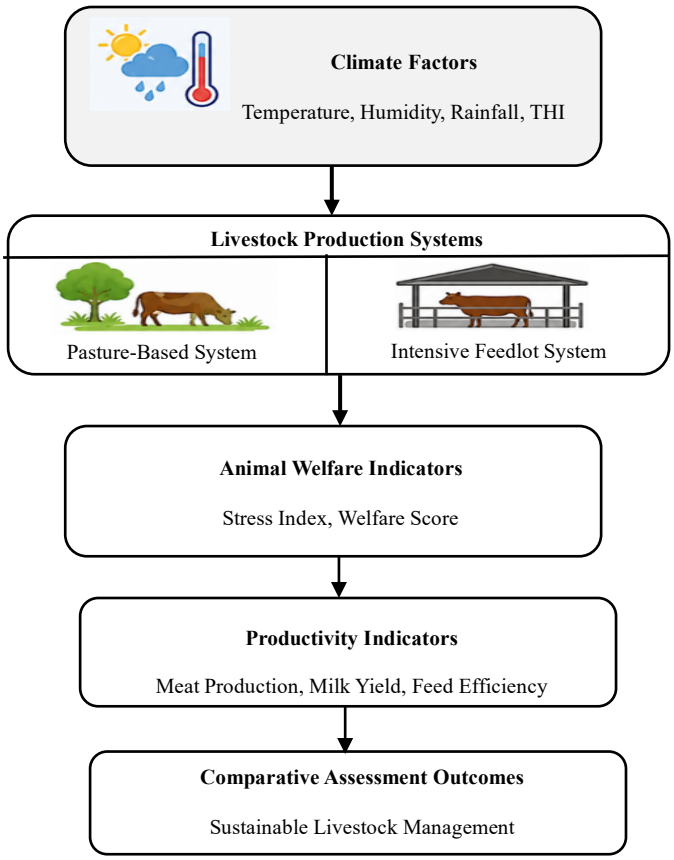

Figure 1: Conceptual Framework for Comparative Assessment of Livestock Welfare and Productivity under Climatic Stress

Figure 1 provides a conceptual framework for assessing climatic stress, animal welfare, and productivity. Both pasture and intensive production systems are impacted by climate-related factors that will in turn impact animal welfare indicators and productivity measures. Analysis of these is integrated and gives an understanding of the performance of the

livestock system relative to each other and helps identify sustainable management strategies.

Results and Discussion

There are significant differences between the welfare and productivity indicators for livestock in each of the two systems (pasture-based and intensive feedlot) under climatic stress conditions. The results indicate that climatic stress has a great effect on animal responses and production results for both management systems. Generally, the welfare scores were higher for pasture-based systems, which allowed for more freedom of movement and natural grazing practices, while intensive feedlot systems had higher productivity scores due to controlled feeding and management practices.

Pearson correlation analysis revealed that there was a negative association between climatic stress and welfare-related indicators, suggesting that high-stress climatic conditions have a negative effect on animals' welfare. Also, climatic stress had a moderate effect on production parameters, especially the feed efficiency and meat production. But intensive feedlot operations showed fairly constant levels of productivity performance regardless of the climatic treatment employed because of controlled management practices.

Table 2: Comparative Assessment of Livestock Welfare and Productivity Indicators

Parameters	Pasture-Based System	Intensive Feedlot System
Welfare Score	85.4	71.8
Stress Index	32.5	47.9
Meat Production (kg/year)	462.3	586.8
Milk Yield (L/year)	3920.6	4515.7
Feed Efficiency (%)	74.2	86.5

As can be seen from the results in table 2, the welfare performance was greater for the pasture-based system than for the intensive feedlot system, with the welfare score being 85.4 for the pasture-based system and 71.8 for the intensive feedlot system. The low values of stress indexes in the pasture-based systems indicate low exposure to climatic and environmental stress. On the other hand, intensive feedlot systems achieved higher meat production, milk yield, and feed efficiency values due to having been optimized regarding nutrition and environment management.

The performance of the livestock welfare and productivity indicators in the two production systems is compared in Figure 2. Each type of system shows itself to be better in terms of animal welfare and stress level and productivity in the intensive feedlot system. These results indicate that to sustain livestock production in climatic stress situations, productivity and welfare need to be balanced.

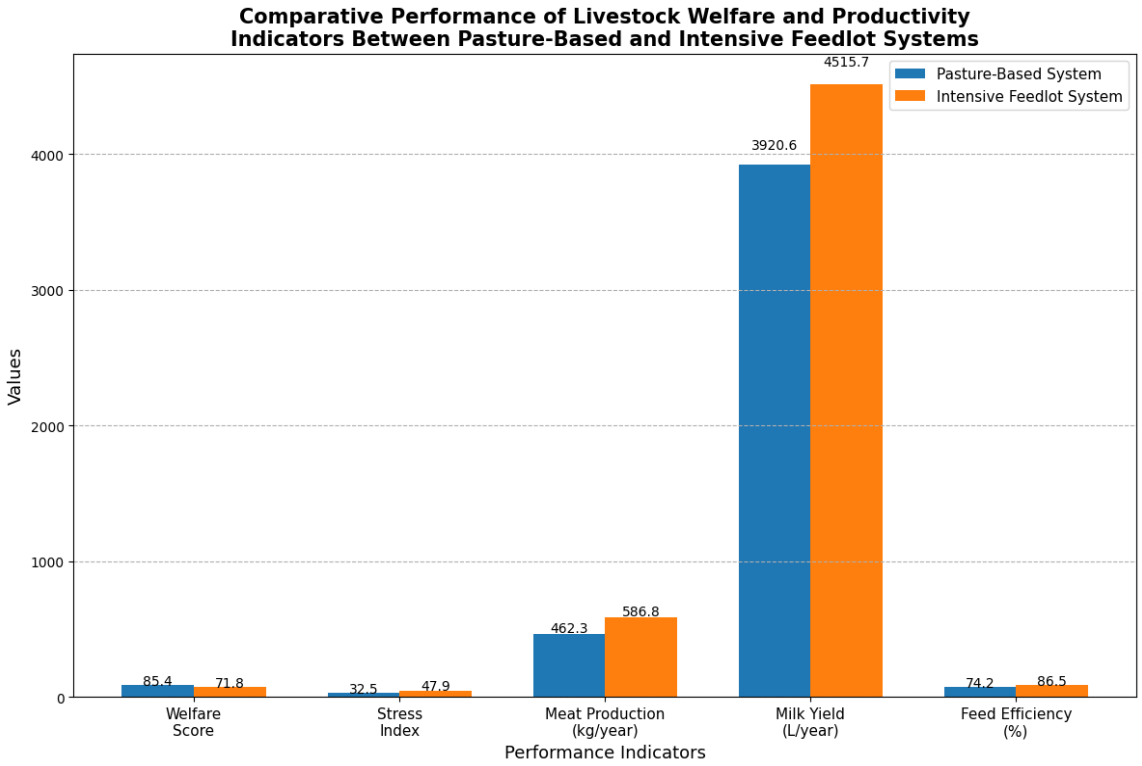

Figure 2: Comparative Performance of Livestock Welfare and Productivity Indicators between Pasture-Based and Intensive Feedlot Systems

The results obtained suggest that different livestock production systems have varying responses to climatic stress situations as well as to welfare and productivity measures. Welfare scores and stress index values were higher in pasture-based systems, as animals can move around and graze naturally and are subjected to less stress due to the confinement. But under extreme climates, there may be fluctuation in environmental exposure, which will impact consistent production. However, intensive feedlot systems demonstrated better feed conversion ratios, milk production, and meat production, as managed their feeding systems better. These productivity benefits were associated with higher levels of stress noted in feedlot systems, implying welfare issues when using feedlots under long-term climatic stress. The results reveal the need for combining welfare-based management with production-based for sustainable livestock production systems.

Conclusion

The present study aimed to compare the livestock welfare and productivity in pasture-based and intensive feedlot systems in climatic stress conditions using livestock data from FAOSTAT and environmental variables. Results of the analysis indicated that there were significant differences in the welfare and productivity of the two production systems. Welfare scores were higher and the stress index was lower in the pasture-based systems (85.4 and 32.5, respectively) than in the other systems (77.1 and 40.1, respectively), reflecting the overall welfare conditions that were higher in the pasture-based systems because of the natural

grazing behavior and increased movement flexibility. On the other hand, the intensive feedlot system had relatively high production performances in meat production (586.8 kg/year), in milk production (4515.7 L/year), and in feed efficiency (86.5%), which showed the efficiency of controlled feeding and management strategies. The statistical analysis based on Pearson correlation showed a moderate negative correlation between climatic stress variables and welfare parameters, which highlighted the negative effect of climatic stress on welfare and production parameters of livestock. Overall, the results indicate that there are welfare constraints to productivity-focused systems under long-term climatic stress. On the other hand, pasture-based systems have a moderate production level and a high welfare performance. The results in general highlight the need to consider both productivity and welfare goals in livestock production. Incorporating farm-level physiological indicators, as well as monitoring and artificial intelligence approaches, could enhance predictive analysis and/or strategies for climate-resilient livestock management in the future.

Dataset Link:

https://www.fao.org/faostat/en/#home

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