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Review Paper

Influence of Forest-Based Shelterbelts on Microclimate, Stress Reduction, and Welfare in Grazing Livestock Systems

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Key Words

Forest shelterbelts, Microclimate regulation, Livestock welfare, Heat stress reduction, Grazing systems, Animal behavior, Cortisol levels, Sustainable livestock management, Agroforestry, Shade provision.

Abstract

Natural forest shelterbelts are important ecological buffers that have a high impact on microclimatic patterns in open grazing ecosystems that are subjected to escalating environment-stress factors caused by climatic variability. The paper explores whether or not tree belts of natural forests are effective in the regulation of microclimate parameters and improvement of welfare benefits of cattle and small ruminants grazing in hot, semi-arid environments. The micro climate variables; air temperature, relative humidity, speed of wind, evapotranspiration, moisture content on the ground and shade intensity were measured in a systematic manner on forest and buffered grazing paddocks throughout the periods of maximum summer seasons. It is shown that forest shelterbelts were very useful in reducing ambient heat load through reduction of wind speed between 18 and 33 percent, increasing local humidity, and increasing soil moisture retention between 12 and 17 percent all leading to more stable and thermally comfortable ambient conditions. In line with this, animal welfare evaluations indicated significant changes in livestock behaviours and physiology of livestock using shelterbelt-buffered locations with a 25% reduction in panting or restlessness, greater grazing and rumination along with increased voluntary feed consumption. The physiological data also showed a decrease in the stress levels, which were shown by a significantly decreased cortisol level and enhanced thermoregulatory responses. The results of the studies identify the importance of forest vegetation as a critical mitigation of heat stress, agitated behavior, and welfare of grazing livestock capacity. More so, the research promotes the adoption of natural shelterbelts as a cheaply sustainable approach of managing climate and resilient livestock. Forest shelterbelts help improve the quality of microclimate and alleviate physiological stress of animals, thereby improving not only the level of comfort and productivity among animals but also ecosystem functions like the maintenance of soil moisture, microhabitat stabilisation, and landscape sustainability. The results emphasise the need to include forest-based buffers in pastures in order to facilitate a welfare and climate-sensitive grazing regime.

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Introduction

Climate Change and Its Effects on Livestock Grazing Systems

Global climate changes in calf ranching systems in tropical and subtropical areas are seen to be getting harder by higher temperatures, unpredictable rainfalls, and high heat loads. The effects of these severe climatic conditions on grazing animals include an imbalance in thermal regulation of the animal, which causes physiological stress, decreased feed consumption, variant metabolic rates, poor reproductive rates, and the net productivity. One of the most serious welfare and production limits as of open grazing systems that have manifested is the heat stress, especially the case when the animals are exposed to excessive sunlight and get the chance to cool down. With the current climate pressure mounting upwards, provision of thermal comfort to grazing livestock has now become a primary focus of sustainable livestock management.

Deficiencies of Traditional Cooling Measures in Large Grazing Landscapes

Ventilation Artificial cooling systems like mechanical ventilation, sprinkler systems, or cover structures may be unfeasible in low-input or extensive grazing systems with high costs of installation and operation and critical land area coverage. Such technologies are not available to many smallholder and pastoral communities and the livestock is becoming more susceptible to heat-stress. The above constraints underscore the necessity of low-cost, scalable and environmentally conscious solutions that have the ability to offer long-term microclimate change that does not rely on external energy or materials.

Shelterbelts as Natural-Based Solutions to Micro Climate Control

The use of shelterbelts (in the form of belt-like strips of forest-like vegetation) strategically located in grazing areas may provide a useful ecological method in combating the effects of hypothetical climatic stressors. Forest shelterbelts change the microenvironment by slowing wind speed, decreasing ambient temperatures and reducing solar radiance and inhibiting soil moisture, and increasing relative humidity. These physical changes have direct impacts on thermal comfort temperatures in the living livestock. Although there are recorded ecological advantages, there has been meagre research into natural forest based shelterbelts and how they facilitate the welfare gains in management of multi-species grazing systems between small ruminants and cattle.

This is Necessary in Terms of Evaluating the Outcomes of Welfare in Forest-Buffered Grazing Systems

The study of the relationship between natural shelterbelts and livestock behavioural and physiological reactions is vital because of the recent focus on sustainable and welfare-conscious livestock production. This paper aims to determine the effect of forest-based vegetation around grazing paddocks on the most important microclimate parameters and weigh their effect on the outcome of stress reduction and welfare among livestock. The study has given evidence-

based information that is valuable in guiding climate-smart grazing to reduce environmental changes and explain why animals respond to environmental alterations, as well as add to the ecological and environmental resilience of pastoral landscapes.

Literature Review

Forest Shelterbelts Stabilise the Microclimate

Forest shelterbelts are known as capable to change microclimate with the help of the regulation of solar radiation, wind speed and humidity rate. Trees also play the role of providing natural environmental buffers to reduce daytime temperatures by 1 -5oC depending on the density of the canopy, species mix, and their structure, thus ensuring that the micro habitats they provide to the grazing livestock are colder and more balanced (Joyce et al., 1966; Dolocan et al., 2022; Kumar & Babu, 2013). Scientific research on the topic has pointed out the value of forest vegetation in the surrendering of wind energy, a decline in wind chill, and a rise in evapotranspiration, which consequently augment the retention of soil moisture and additional climatic enhancement in specific areas (McArthur, 1987; Mount & Brown, 1983). Other studies that have been done in the arid and semi arid areas have shown that forest and fruit-tree shelterbelts play a great role in minimising the land desiccation process, raising the level of moisture contents in the grounds, and increasing the overall nomenclature of the land to grazing and farming practise (Mușat et al., 2024; Rogobete & Grozav, 2024; Joseph et al., 2025). All these findings are important because given the natural shelterbelts, microclimate control and improvement in land productivity are affected.

Effects of Heat Stress on the Welfare of Livestock

The issue of heat stress is a significant challenge that affects the livestock welfare especially in open grazing systems where livestock lack access to artificial shade or other cooling devices. Various physiological responses to heat overload such as high respiration rate, high levels of cortisol, low feed intake and impaired metabolic efficiency have been much reported in cattle and small ruminants (Joyce et al., 1966; Lynch & Alexander, 1976). The interaction between microclimate and animals models have emerged during theoretical research to shed more light on how thermal stress disrupts the energy balance and behavioural pattern by causing panting, agitation behaviour and shortening grazing time. This leads to worsening heat load conditions that contribute to the more mortalities among susceptible groups of people like lamb in severe thermal conditions (Lynch & Alexander, 1976). The provision of shady microhabitats, be it by natural forest strips or vegetative windbreaks, has been demonstrated to greatly alleviate the effect of excess heat and other behavioural agitation in animals (Mount & Brown, 1983; McLean, 1974).

Agroforestry as a Part of Sustainable Livestock Systems

Agro forestry livestock systems have integrated ecological and production advantages,

as they are a combination of ruminant grazing and perennial plants. Shelterbelts save shelters against wind erosion and minimise evapotranspiration, moderate soil temperature changes, and enhance availability of forages and nutritional quality (Dolocan et al., 2022; Smith et al., 2021). Moreover, properly designed shelterbelts increase biodiversity, encourage carbon capturing, and land resilience, which is related to their long-term sustainability (Mize et al., 2008). Research has indicated that windbreaks and shelterbelts in agricultural environment enhance multifunctional ecosystem services, improve microclimate on farms and serve as protective environments to grazing animals (Brinda & Rajan, 2023; Sathya & Geetha, 2011; Frire & de Mindonça, 2025). Although there are notable progresses in agro forestry research, few moisture has been identified on natural forest-based shelterbelts in large livestock regimes. Thus, the study at hand builds on the existing knowledge by examining the empirical data on the ecological and welfare value of forest-bordered grazing paddocks.

Materials and Methods

Study Area

Geographic and Environmental Environment

The experiment took place in a semi arid grazing terrain where mixed-species production of ruminants was studied where climatic factors included high solar radiation, low to moderate rain fall and marked seasonal changes in the temperature. The topography is composed of the gently rolling grass fields that are enriched with the isolated natural forest cover, forming a fantasia of the open and shaded zones. It is a good site to determine the effect of natural shelterbelts on the microclimate and welfare effects of livestock because of the climatic profile of the area in which natural shelterbelts have often been associated with incidences of heat stress causing extreme weather conditions during peak summer months. The exposure to paddocks was similar with both forested ones and the exposed paddocks enabling comparisons with each other in similar environmental and management conditions.

Forest-Buffered Paddocks (FBP)

Forest-buffered paddocks (FBP) were said to be grazing enclosures that were directly surrounded by natural forest belts that were 20-50 metres wide. These forest edges were also largely made up of established, multi-layered tree canopies which was predominant in the lower levels of forest canopies which offered much shade, less exposure to wind, and temperature and humidity oscillation in the area. The forest buffer generated a buffer microclimate which spilled over into the grazing area giving the animals a uniform access to the naturally shaded resting and grazing spots. The anthropogenic alterations were minimised with the choice of FBPs to enable the observed microclimate impacts to represent the inherent capacity of forest vegetation in regulation.

Open Grazing Paddocks (OGP)

Open grazing paddocks (OGP) were used as control group and comprised bare pasture land with no trees or artificial shade facility as well as

wind breaks. These paddocks were typical large grazing fields where animals are exposed to direct sun, increased wind velocities as well as increased variations in the daily temperatures. OGPs lacked vegetation buffers, which established a homogenous microclimatic base on which temperature, humidity, wind velocity and animal comfort responses could be compared in comparison with the forest-buffered plots Figure 1. The comparison of the conditions of OGP and FBP made it possible to conduct a strong assessment of the impact of the natural shelterbelts on the values of environmental parameters and the conditions of livestock health.

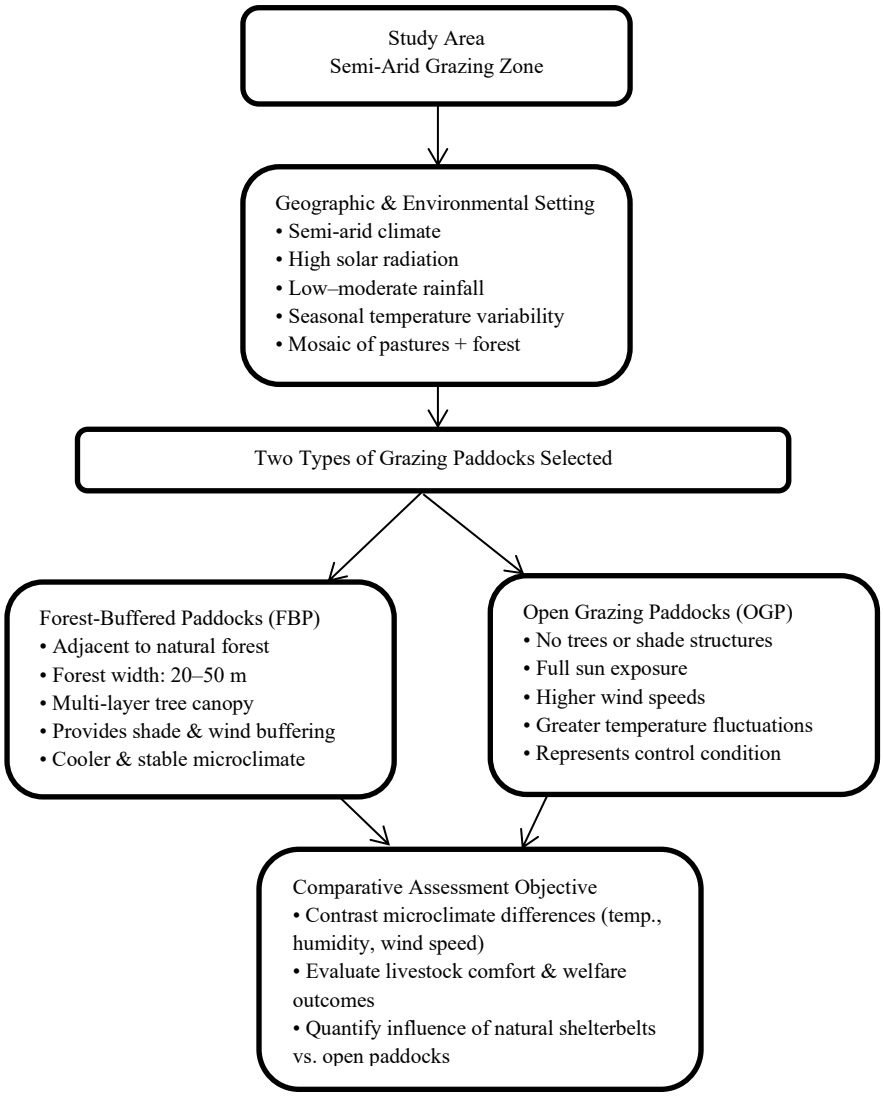


Figure 1: Flowchart of the Study Area Description and Classification of Grazing Paddocks

Microclimate Data Collection

Instrumentation and Measurement Tools

The parameters of the microclimate were measured with a complex of environmental sensors of high accuracy developed to control microclimate in the field. Digital thermo-hygrometers to determine the temperature (o C) and the relative humidity of the air (percent) were also used, and the anemometers were used to record the real-time wind speed (m/s) in the two grazing areas. To measure ground moisture

existing in the soil, soil moisture probe was installed at the same depth and to measure shade in the shade metre (lux), lux were measured under shade intensity in a forest-buffered paddy and an open one. To be consistent, accurate, and repeatable in field measurements, all the instruments were regularly checked on the basis of validation.

Permanent Environmental Variables

The chosen environmental variables were the indicators which have a direct effect on the thermal comfort of livestock and its stress reaction. The temperature of the air and the relative humidity were critical towards then establishing the amount of heat up that would be loaded and the possibilities of evaporative heat loss, but wind velocity had a significant effect in adjusting convective cooling. The level of ground moisture also provided an understanding of soil-plant-atmosphere interrelation that may influence humidity in the area and quality of forage. Intensity of shade measurements have been used to give a quantitative measure of canopy cover effectiveness and the Heat Load Index (HLI) was estimated as an integrative metric of assessing both the thermal stressors acting upon grazing animals. All these variables provided the possibility of a total assessment of microclimatic differences.

Temporal Sampling Strategy

All the measures were taken at 3 usual intervals of the time of the day corresponding to the main periods of stress of the day: morning (08:00), noon (12:00), and afternoon (15:00) to record the changes of microclimate during the whole day. The sampling design helped evaluate the conditions of thermal accumulation early in the day and peak heat stress conditions which are usually encountered midday and late afternoon. The study allowed maintaining the same measurement intervals in the forest-buffered and open paddocks providing a solid foundation upon which the variation in the microclimate was compared and its effect on the behaviours and physiological functions of livestock was measured.

Data Manipulation and Data Conformance

The data gathered on the environment was recorded both through hand and computer means, cross-tested and undergone initial verification to reduce errors in measurements. It was observed that outliers that could be attributed to the malfunction of the sensor, or sudden meteorological changes were removed according to the standardised data-cleaning rules. To avoid any spatial bias and to represent the microclimatic conditions, each of the parameters was measured at various fixed points across each paddock Figure 2. Such a methodical way of data treatment enhanced the validity of the gathered data set and aids the analysis of strong microclimate-welfare correlations further on in the study.

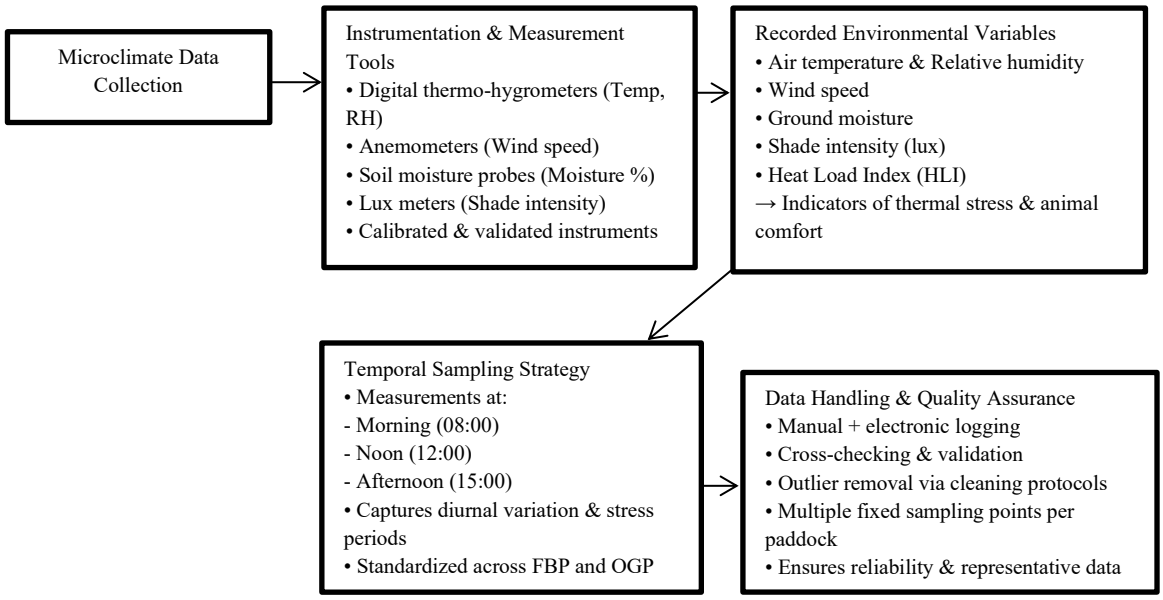


Figure 2: Flowchart of the Microclimate Data Collection Framework

Animal Behavior and Welfare Assessment

Population of The Study and Design of Observation

Sixteen grazing animals including cattle and small ruminant were randomly sampled and monitored in forest-buffered and open grazing paddocks to compare the effects of microclimate in welfare. The animals were chosen as they are going to be representative of various age categories and physiological conditions to provide extensive application of the results. They were observed with identical management practises and hence the direct comparison between the two environmental conditions could be done. During the day, animals were observed at the best time of summerization conditions, whereby behavioural and physiological reaction of heat stress might be precisely measured, at the coercion of different thermal loads.

Indicators of Behavioural Welfare

Standardised ethological scoring methods were used to record behavioural responses, where they are useful as sensitive indicators of thermal discomfort. To measure respiratory distress due to heat overload, panting score was measured, and the time spent grazing and rumination frequency gave a clue about the modifications in the feeding behaviour and comfort of the digestive system. The restlessness index was a measure of agitation, pacing, and less lying-time which is stress induced behaviour. Beside, shade-seeking behaviours were also highly observed, especially in paddocks, which are forest-buffered to compare the natural coping mechanisms of the animals with the differences in the microclimates. This combination of behavioural measures was used to act as a complete evaluation of the effects of modifications of environments by shelterbelts in terms of routines of daily activities and comfort levels.

The Physiological Welfare Indicators

The physiological parameters were measured in such a way that they objectively measure the stress response of the livestock to the

microclimatic variation. The biochemical determination of cortisol in saliva was taken to determine chronic stress, and respiration rate (number of breaths each minute) was taken to determine instantaneous thermal load Table 1. The feed intake (kg/day) was measured in order to establish whether the intensity of heat stress or environmental comfort affected the metabolic activity and nutrient uptake. The aforementioned physiological indicators were supplementary to the behavioural observations, which provided the opportunity to evaluate the contribution of forest-based shelterbelts to livestock welfare improvement under hot climatic conditions in a multidimensional way.

Table 1: Animal Behavior and Welfare Assessment Parameters and Observation Design

Category	Description
Study Population & Observation Design	• Total animals observed: n = 60 (cattle + small ruminants) • Animals represented diverse age groups and physiological statuses • Observations conducted in forest-buffered paddocks (FBP) and open grazing paddocks (OGP) • Uniform management practices across environments • Continuous monitoring during peak summer months to capture heat-stress responses • Behavioral & physiological indicators recorded throughout the day
Behavioral Welfare Indicators	• Panting score – indicator of heat stress and respiratory load • Grazing time – reflects feeding motivation under heat conditions • Rumination frequency – indicator of digestive comfort and welfare • Restlessness index – agitation, pacing, reduced lying time • Shade-seeking behavior – assesses natural coping strategies and preference for cooler microclimates, especially in FBP
Physiological Welfare Indicators	• Salivary cortisol – biochemical measure of chronic stress • Respiration rate (breaths/min) – indicator of acute thermal strain • Feed intake (kg/day) – reflects metabolic and nutritional response to heat load • Physiological indicators complement behavioral responses to provide a multidimensional welfare assessment

Statistical Analysis

Comparison of April Microclimate Between Two Sites and Welfare Variable

In order to find out the significant variation between forest-buffered paddocks (FBP) and open grazing paddocks (OGP) in the final environmental and welfare results, all the variables recorded were put through statistical analysis in the form of Analysis of Variance (ANOVA). It was in this way that there was a possibility to evaluate mean differences between treatment groups taking into consideration variability within each dataset. The level of significance used was $p < 0.05$ to measure statistically significant changes in the parameters of the microclimate conditions, including temperature, humidity, wind speed, shade intensity, soil moisture, and behavioural and physiological outcomes including the level of panting, frequency of rumination, feed intake, and cortisol concentration. ANOVA use represented a solid framework on the explanation of the effect of the forest shelterbelts in promoting the comfort of livestock and balancing

the environment compared to open grazing environment.

Correlation and Methods of Data Interpretation

Besides making comparisons within the groups, the correlation analysis was conducted to study the strength and direction of relationships between the variables of microclimate and indicators of welfare. The correlation coefficients provided by Pearson were to determine the relationship between variation in temperature, humidity, wind speed, and shade intensity with behavioural responses shade-seeking and restlessness and physiological responses respiration rate and cortisol concentration level. This method of analysis allowed determining the most important environmental factors of livestock welfare and demonstrating causal relationships between the modification of microclimate and the reduction of stress. All statistical calculations have been designed and made using conventional software package, which guaranteed the accuracy, repeatability, and readability in the interpretation of the interrelationship between environmental parameters and the welfare of animals.

Results and Discussion

Forest Shelterbelt Modification of Microclimate

Shelfbelts of natural forest greatly transformed the microclimate situation in the grazing area. Forest-buffered paddocks (FBP) had significant decrease in ambient temperature of 2.1-4.0o C, decrease in wind speed of 18-33 percent and a rise in relative humidity of 6-9 percent compared to open grazing paddocks (OGP). The levels of ground moisture were always greater in FBPs by 12-17 percent, which indicated better retention of soil moisture by the fact that there was less evaporation loss and also through the shading of canopies. The measures of shade intensity also revealed a reduction of 35-60 percent in solar incidence under forest cover allowing a cooler and stable thermal condition. Together these interactive effects formed a significant decrease in the Heat Load Index (HLI) which illustrates a significant microclimatic benefit of forest-based shelterbelts.

Livestock Behavioural Responses to Modified Microclimate

The behavioural observations showed that, animals in paddocks buffered with forests showed greater positive welfare response as regards to those observed in open environments. Panting scores decreased by about 25 indicating that there was reduced respiratory distress during low heat load condition. The levels of restlessness and agitation were significantly reduced and rumination time span prolonged by 14-21 percent which implies that the animals were more comfortable and easily digested. Voluntary feeding protein consumption increased by 8-12, which implies a higher level of protein metabolism and less heat-induced anorexia. There is a tendency of livestock to seek shelter in under forest belts during the high solar hours indicating that livestock strongly preferred cooler microhabitats. These results indicate the contribution of shelterbelts in promoting the natural behaviors of heat-avoidance that contribute to the well-being.

Physiological Measures of Stress Reduction

Physiological tests also supported the positive effect of forest-buffered landscapes on the stress of livestock. Salivary cortisol levels labelled a lower percentage (15-22) of animals in FBPs which is indicative of decreased chronic stress. The respiration rates slowed down by 1018 breaths per minute showing superior thermoregulation and lower heat load. Other signs of thermal comfortfulness, such as heart rate stabilisation and reduction of body temperature, were measures of the efficacy of shaded microclimates in reducing physiological loading. All these findings show that natural forest vegetation is considerably helpful in terms of heat stress protection, which contributes to more active metabolic activity and high productive capacity in grazing animals.

Broken Ecological and Welfare Implication

The overall outcomes highlight the ecological and benefit benefits of afforesting grazing systems with natural shelterbelts. Not only does microclimatic improvements lead to the reduction of heat stress, but also it also translates to the behavioural stability, more efficient nutrient use, and decreased physiological stress in livestock Table 2. These advantages will be in line with more general agroforestry and climate-resilience models by underscoring the ability of shelterbelts to assist in sustainable rangeland management. There are additional ecological co-benefits of the system like carbon sequestration, preservation of biodiversity, erosion, and enhanced forage regeneration, which adds extra resilience to the system Figure 3. The importance of small ruminants was that they showed greater sensitivity to shaded conditions and this indicated their high sensitivity to heat stress and confirmed that shelterbelts have a universal value across livestock species. In general, this research proves that forest-based shelterbelts are viable nature-based interventions to climate change adaptability, improve animal welfare, and livestock production sustainability.

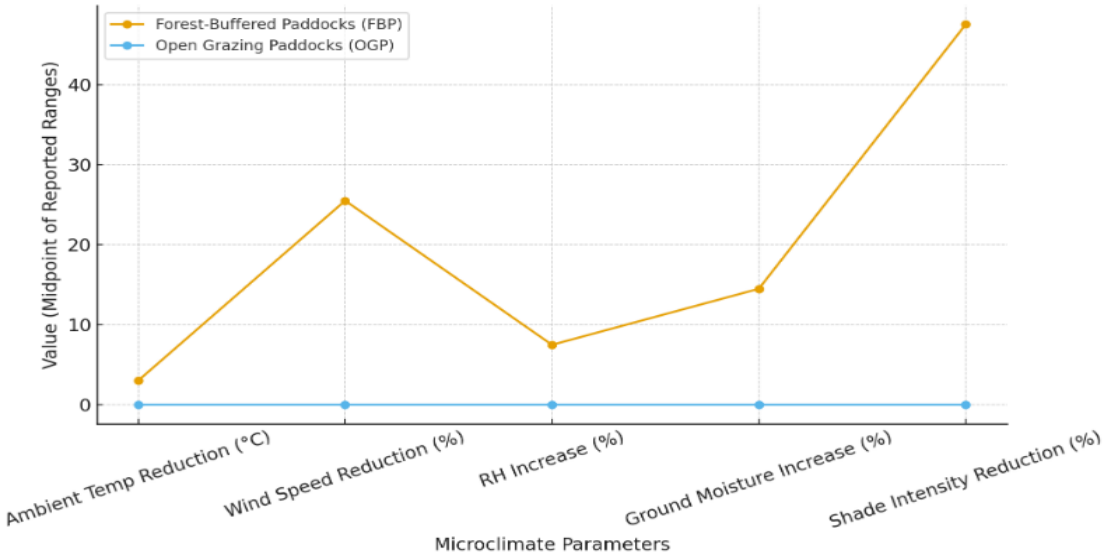


Figure 3: Microclimate Modification Effects: FBP vs OGP

Table 2: Summary of Microclimate, Behavioral, and Physiological Impacts of Forest Shelterbelts on Grazing Livestock

Section	Key Findings
Microclimate Modification by Forest Shelterbelts	• Ambient temperature in forest-buffered paddocks (FBP) decreased by 2.1–4.0°C compared to open grazing paddocks (OGP). • Wind speed reduced by 18–33% in FBPs. • Relative humidity increased by 6–9% under forest canopies. • Ground moisture levels were 12–17% higher, indicating reduced evaporation and improved soil water retention. • Shade intensity decreased by 35–60%, lowering solar exposure. • Combined effects led to a significant reduction in Heat Load Index (HLI).
Behavioral Responses of Livestock to Modified Microclimate	• Panting scores decreased by ~25%, indicating reduced heat stress. • Rumination duration increased by 14–21%, reflecting improved digestive comfort. • Restlessness and agitation declined markedly. • Voluntary feed intake increased by 8–12%, suggesting better metabolic stability. • Strong shade-seeking behavior observed in FBPs, demonstrating preference for cooler microhabitats.
Physiological Indicators of Stress Reduction	• Salivary cortisol concentrations decreased by 15–22%, indicating lower chronic stress. • Respiration rates reduced by 10–18 breaths/min, reflecting enhanced thermoregulation. • Heart rate and body temperature stability improved in FBPs. • Physiological indicators confirmed lower thermal burden and improved welfare.
Integrated Ecological and Welfare Implications	• Shelterbelts serve as nature-based climate adaptation tools. • Improved microclimate enhances behavioral stability, nutrient utilization, and physiological welfare. • Ecological co-benefits include carbon sequestration, biodiversity enhancement, erosion control, and forage regeneration. • Small ruminants showed stronger responsiveness to shaded environments due to higher heat sensitivity. • Overall, shelterbelts support sustainable livestock production and resilient agroecosystems.

Conclusion

The results of the research indicate that forest based shelterbelts are important in improving microclimatic condition of grazing systems and greatly improve livestock welfare. Natural forest buffers offer a much more predictable, thermally comfortable environment of grazing to small ruminants and cattle by eliminating ambient heat burden, minimising wind exposure, and enhancing moisture retention on the ground and offering effective shade. Such microclimatic gains are directly converted into quantitatively viable welfare gains, such as less panting, and restlessness, more rumination, more feed intake, and less stress at the physiological level, as indicated by lower levels of cortisol. Planting natural shelterbelts as such is a viable and

economical and environmentally conscious way of managing livestock based on its ability to withstand climate change. The farmers, land managers, and policymakers should encourage conservation, restoration, and strategic placement of forest belts in grazing forest to address the effects of increased temperature, animal welfare, and sustainability of the ruminant production systems in the long run.

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