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Review Paper

A Sustainable Approach to Mitigating Heat Stress and Improving Microclimatic Conditions in Semi-Intensive Systems

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Key Words

Agroforestry, Livestock welfare, Microclimate, Heat stress, Vegetation buffers, Sustainable farming.

Abstract

There is an increasing challenge to livestock production systems in terms of increasing thermal stress, exploitation of poor air quality and the lack of natural shelter which have a negative impact on animal welfare, health and productivity. The present study assessed the efficiency of agro-horticultural vegetation buffers that included the strategic placement of shade trees, shrubs, and windbreaks species in terms of controlling the microclimate and enhancing welfare parameters of cattle and small ruminant confinement. A comparative study was done on field-based investigation of representative mixed livestock farms in buffered and non-buffered housing conditions in a 90 day summer period. The microclimatic conditions, such as ambient temperature, relative humidity, wind speed, and particulates, were measured continuously and welfare parameters of animals, such as respiration rate, panting score, resting behaviour, feed intake reliability, and social interactions were measured. Vegetation buffers drastically changed the microenvironment surrounding animal shelters by a reduction in ambient temperature of 1.5-3.2 o C, relative humidity stabilisation, wind velocity reduction, and up to 40 percent lowering the concentration of particulate matter relative to non-buffered systems. Animals kept near vegetation buffers had significantly better thermal comfort, which was lower respiratory stress, longer resting periods, regular food intake patterns, and the animals were less aggressive. The combined buffer systems also enhanced the quality of the environment, through mitigating the amount of dust loaded and enhancing the quality of air circulating in houses. The results reveal clearly that agro-horticultural vegetation buffers are a low-cost and climate-sensitive solution in mitigating heat stress and enhancing livestock welfare in general in semi-intensive production systems. Vegetation buffers should be integrated into the livestock landscapes to provide a sustainable solution of promoting animal welfare, protecting the environment, and managing livestock in Smart climate conditions.

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Introduction

Climate Velocity and Microclimatic Stress of Livestock Production

The livestock production systems throughout the globe are becoming more vulnerable to extreme weather variability in the form of increased ambient temperatures, unpredictable rain degrees, and extended heat waves. These alterations cause a lot of disruption to the thermal comfort of farm animals especially in tropical and subtropical climate where base temperatures are already elevated. Poor animal health, reduced reproductive performance, weak immune functions, growth rate, and productivity are serious effects of heat stress in combination with poor air quality, dust accumulation, high rate of wind, and gaseous emissions released through animal sheds. Long-term exposure to thermal stress suggests a modification in feeding behaviour, high rate of respiration, dehydration, hormonal imbalance, and low productive efficiency in rumenant. The increasing exposure to thermal extremes with the change in climate has consequently made microclimate management to be one of the most critical challenges in the production of livestock in a sustainable manner.

Conventional Microclimate Control Systems Weak Points

The current livestock housing systems are mainly based on mechanical cooling methods, which comprise ventilation fans, foggers, and evaporative cooling systems, to control thermal load in the case of livestock shelters. Although such technologies may be efficient in alleviating heat stress when put under controlled settings, they tend to consume a lot of power, costly and hard to service especially to the small holder and resource constraint farmers. The unreliability of these systems is also limited by irregular power availability in most developing areas. Besides, these artificial interventions focus on providing temporary thermal relief and promote more carbon emissions and cost production. Such restrictions have put more strain into the search of sustainable microclimate solutions with low energy consumption and nature-based solutions to microclimate regulation of livestock environments.

Buffering of Agro-Horticultural Vegetation as a Natural Climate Controller

Agro-horticultural vegetation buffers which entails carefully designed shade trees, live fences, shrubs and windbreak plant species are an ecologically viable strategy of microclimate adjustment around livestock housing units. The environmental condition is managed in vegetation buffer using various biophysical processes, such as interception of solar radiations, radiant heat load correction, evaporative cooling by evapotranspiration, reduction of wind speed, and filtration of dust and gaseous pollutants. Vegetation buffers increase the quality of air movement, stabilise the relative humidity ratio and decrease the number of particulate matter in the air around animal shelters through the creation of a controlled and controlled thermal environment. These systems contain co-benefits besides microclimate control in the form of carbon sequestration, fodder, soil

enrichment, biodiversity protection, and landscape improvements.

Research Gap and Objectives of the Study

In spite of acknowledged ecological and agronomic value of agroforestry and integrated agricultural systems, empirical data collected on a fields basis to quantify the overall effects of agro-horticultural vegetation buffers in relation to microclimate parameter and animal welfare indices in livestock housing conditions are limited. The majority of the available studies have been done in open pasture-based silvopastoral systems, or in detached shading structures without a detailed evaluation of the air quality and behavioural welfare outcome. Moreover, specific studies that combine indicators of thermal comfort, particulate pollution, and animal-based welfare indicators of semi-intensive livestock systems are limited in their geography. Against this background, the current study was carried out to assess the potential of agro-horticultural vegetation buffers both in terms of microclimate regulation and welfare promotion in cattle and small ruminant production systems with a greater objective of advancing climate-stable, energy-efficient, and animal-welfare-based livestock management reinforcement measures.

Literature Review

Problems of Heat Stress and Microclimate in Livestock Systems

The production facilities of livestock are very susceptible to the microclimatic conditions like ambient temperature, relative humidity, wind speed, and solar radiation. Heat stress developed due to prolonged exposure to high temperatures affects thermoregulation, immunosuppression, feed consumption, and develops growth, milk yield, and poor reproductive performance (Abrol, 2011; Ahmed et al., 2017). Dairy cows that are stressed by heat show high respiration rate, panting, less activeness in rumen, and water consumption thereby minimising productivity (Ainsworth et al., 2020). Temperature-Humidity Index (THI) is a popular tool of measuring the severity of heat stress with respect to dairy cattle which have a threshold value of 72 and small ruminants having 78 where considerable losses are incurred (Alam et al., 2017). Open housing systems in tropical and subtropical areas subject animals to high levels of solar radiations and dust-filled winds hence increasing heat loading and respiratory ailments (Alary et al., 2015).

The Agro-Horticultural Vegetation in the Microclimate Regulation

Agro-horticultural vegetation buffers are natural types of biological tools used in regulating the microclimate by shading, evapotranspiration, reducing wind speed, and cleaning the air. The canopies of trees would absorb the solar radiation and turn out to be of great help when it comes to cooling off radiant heat loads on animals by 40 to 60 percent (Lionello & Scarascia, 2018). Latent heat flux is boosted by evapotranspiration of foliage, reducing the temperature in the immediate surrounding by 2-4 ° C in agro forestry setup (Chericoni et al., 2025). The Casuarina, Bamboo, and Eucalyptus windbreaks minimise the wind velocity of up to 20-50 percent and thus prevents dust movement and enhances the humidity

stability in and around livestock shelters (Cos et al., 2022). Moreover, trees and shrubs will capture suspended particles and aerial pollution like ammonia, and as a result, the quality of air improves in the farmland (Cramer et al., 2018).

Vegetation Buffers and Welfare of Livestock

Environmental comfort is directly related to animal welfare. A few pieces of research have indicated that the cattle that are reared in either shaded or silvopastoral set-up display less cortisol level, slower respiration rate and better lying and resting patterns (Zittis et al., 2021; Ramani & Geetha, 2016; Surendar, 2025). Grazing small ruminants under systems with trees integrated with these animal species exhibit a better grazing efficiency system, reduced dehydration physiologic, better reproductive performance and an enhanced growth rate as a result of stabilised thermal comfort (Alary et al., 2015). The additional benefits of vegetation buffers are the buffering of social and psychological stress through shielding against wind, noises, and predators and the enhancement of the spatial heterogeneity in housing settings. High resting time and decreased aggressive interactions of vegetated systems are potent signs of enhanced welfare of animals (Ahmed et al., 2017).

Vegetation Integration as a Benefit of Productivity

Agro-horticultural and silvopastoral systems are more sustainable to the environment and livestock. It has also been demonstrated that dairy cattle kept under shade are likely to give milk yield that is 1025% higher in summer than those kept without shade (Abrol, 2011; Sountharrajan et al., 2022). Sheep and goats, which were reared in tree-integrated systems, have their greater growth rate and an increased feed efficiency as characterised by reduced thermal stress (Alary et al., 2015; Senthil et al., 2021). In addition, vegetation buffers play a role in helping to address climate change by sequestration of carbon, enhancing soil fertility, fodder diversification and boosting biodiversity increasing the long term resilience of the integrated livestock farming systems (Chericoni et al., 2025; Ochilova et al., 2025).

Research Gap

Despite the above studies that have pointed out the gains of having silvopastoral systems and artificial shade constructions, little empirical research conducted in the field has quantitatively measured the synergistic effects of agro-horticultural buffers with livestock housing on micro climatic parameters, air quality of particles and animal based welfare signifiers in semi-intensive farming conditions. The current research paper fills this knowledge gap by offering empirical evidence (quantitative data) on the environmental and welfare positive aspects of vegetation buffer systems in mixed livestock raising systems.

Materials and Methods

Description of the Study Area

Geographical Setting and Climatic Factors

The research was done in the warm summer seasons (April to June) in six sample mixed livestock farms located in semi-arid and sub-

humid agro-climatic regions. The areas are typified by aberrant seasonal temperature swings and average rainfall distributions like livestock production regions that are climate-sensitive. The mean ambient temperature of the study sites was between 23C in the early mornings to 41C in the afternoon high and the humidity in the air ranged between 40 to 75 percent of the time of the experiment. Mean annual rainfall ranged between 650 to 950mm with most rainfall being received during the monsoon. Under these climatic conditions offered a perfect natural environment to determine the capability of agro-horticultural vegetation buffers to control a microclimate during a period of heat stress in the summer season.

Animated Production Systems and Housing

The chosen farms used the semi-intensive livestock rearing that consisted of dairy cattle (Bos indicus × Bostaurus crossbreds), sheep (Ovisaries), and goats (Capra hircus). Animals were observed to be controlled in the stall feeding and controlled outdoor movement. The housing facilities were mostly open sided sheds that were made to be naturally ventilated with the roofing material being either asbestos sheets, galvanised iron and the flooring either compacted earthen surface or concrete. The sheds were laid in such a way that they could cross-ventilate and allow the sun to enter through the structure just like the conventional livestock houses in the area. All stocking rates, feeding rates, and watering rates were standardised in all the tests to ensure the study did not have any management fine variations.

Characteristics of Soils and Current Vegetation Cover

The soils used throughout the experimental area were between sandy loam and clay loam thus offering favourable edaphic conditions to support growth of different agro-horticultural plant species. Current vegetation on farms was a mix of naturally occurring and planted shade trees, fodder shrubs and windbreak species at boundaries of animal shelters and within field boundaries. The vegetation also facilitated the regulation of the microclimatic temperature as well as fodder in addition Figure 1. The animal health care approach, regular vaccination programmes, and biosecurity were the same in all of the chosen farms. Due to the relative homogeneity of the soil type, vegetation potential, and management, the major variability of the same in microclimatic conditions and animal response was clarified by the presence or absence of vegetation buffer mechanisms.

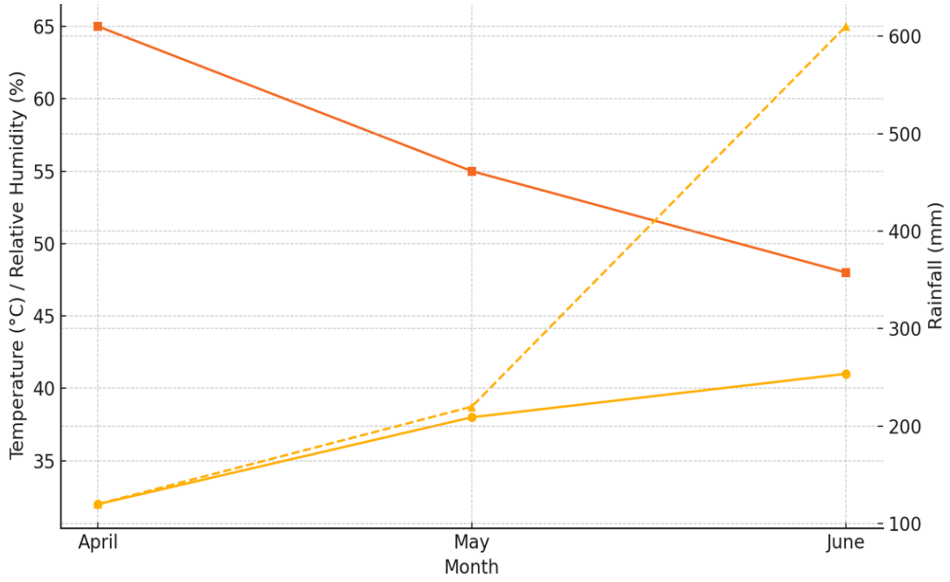

Figure 1: Combined Seasonal Variation of Ambient Temperature, Relative Humidity, and Rainfall During The Experimental Period (April–June)

Experimental Design and Treatment Structure

The General Method of the Experiments

The comparative experimental design of field-based was used to determine the effects of agro-horticultural vegetation buffering on the mechanism of micro climate control and livestock welfare in actual farm scenario. The paired system design in the study undertook the adoption of a paired-system design in every sampled farm in order to reduce environmental and management-related variance. These were two contrasting systems of housing used simultaneously; buffered housing system coupled with vegetation buffers and non-buffered conventional housing system without vegetation cover around it. The design facilitated a direct comparison of the microclimatic variables and animal based welfare variables under the same climatic and management conditions.

Treatment Systems Accounting

Buffered System (BS) was composed of livestock sheds that were surrounded by agro-horticultural vegetation buffers that were set with a minimum of 3-5 m distance between their perimeter and shelter to enable sufficient air circulation and at the same time offer effective shading and wind cover. These buffers comprised shade trees, shrubs, and windbreak species that were in multi-layered arrangement. The Non-Buffered System (NBS) in contrast, consisted of traditional open-sided livestock sheds with no vegetation or anything surrounding them and were merely exposed to the sun rays, wind and dust in motion. The two systems had a similar structural design in terms of shed orientation, roofing and flooring in order to curb architectural biasness.

Management Uniformity Animal Population Uniformity

The number and type of animals housed in each of the housing units in both treatment systems were similar to maintain similar experimental conditions. There were 10 12 dairy cattle, 1518 goats and 1620 Sheep per unit housed in the buffered and non-buffered units respectively. The similarity in age of animals, body weight and physiological state in treatments was a selection factor to reduce biological variability. Standardisation of feeding schedules, ration composition, availability of water, and health management practises were also upheld in all farms and the two housing systems. This helped in ensuring that differences in responses of animals observed majorly depended on microclimatic changes that were caused by vegetation buffers and not due to nutritional or managerial effects.

Experimental Duration and Framework of Observation

The experimental trial was carried out on a continuously basis of 90 days consistently on the peak summer season in order to get the highest amount of thermal stress that livestock undergoes. The parameters of the microclimate as well as the indicators of animal welfare were measured constantly during the period of the experiment at pre-established intervals Figure 2. The lengthy duration of the monitoring allowed determining both the immediate and the cumulative impact of vegetation buffers on environmental control and the adaptation of animal behaviour. This system of structured observation gave strong and reproducible data on the evaluation of treatment effects.

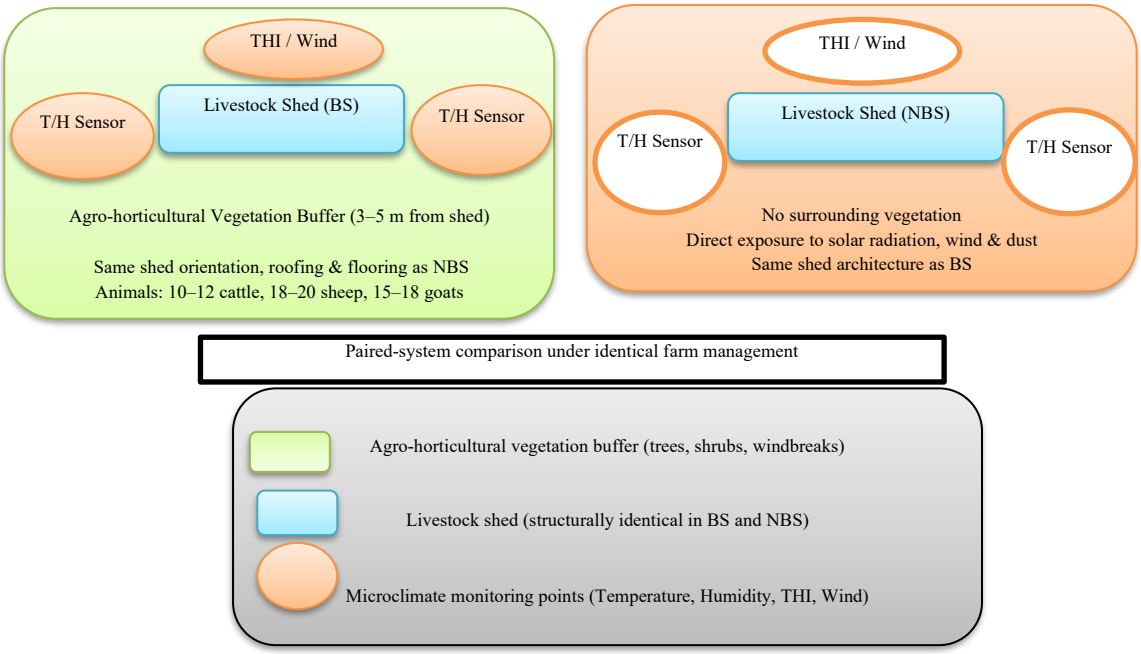

Figure 2: Schematic Representation of the Paired-System Experimental Design Comparing Buffered (BS) and Non-Buffered (NBS) Livestock Housing Systems

Vegetation Buffer Composition and Layout

Vegetation Buffer Structural Design

The agro-horticultural vegetation buffers were specifically aimed at ensuring an in-depth and horizontal security coverage of livestock shelters with the primary aim of effectively controlling the microclimatic conditions. A multi tiered structural plan was used to design the buffer configuration to achieve maximum shading, wind attenuation and purification of air all at the same time. The planting of vegetation spaced at the perimeter of the animal sheds was done to ensure that there would be enough air flowing in the airspace yet at the same time utilise the protective capacity of the plant canopy to maximum. Such built-in design guaranteed continuous modulation of the sun radiations, wind speed as well as dust motion across the day, especially during the periods of the day when there was maximum thermal strain.

Functional Layering and Botanical Composition

The vegetations in the buffers were clustered into three functional layers that are characterised by the height of plants, canopy structure, and ecological functions. The tree species like Azadirachta indica, mangifera indica and Albizia lebbeck were trees that provided shade and consequently, provided a lot of overhead cover and shaded the leaves on the soil, offering some solar interception. The mid-layer included fodder and shrub plant species such as Moringaoleifera, Leucaenaleucocephala, and Gliricidiasepium which also led to stabilisation of microclimate as well as sources of supplementary fodder sources. The outer windbreak layer comprised of tall and thick plants including Casuarina equisetifolia and Bamboo spp. which was strategically oriented to decrease the wind speed and the airborne dust inflow into livestock housing geographical regions.

Parameters of Space Lay of Configuration and Density

The density of vegetation in all the buffered systems was between 450 and 700 plants per hectare based on size of various farms, the layout of the boundaries and the direction of the shelter. Buffer width was adjusted between 6 and 12 m surrounding livestock sheds so that there was sufficient thermal and aerodynamic protection but that operations on the farm would go on unrestricted Figure 3. The canopy was built up to a height of 4-10 m and produced considerable shades during the peak time of sun ends of afternoon when the heat stress levels are inflicted the most. The spatial arrangement provided optimum interaction of vegetation structure and microclimatic modulation hence improving the protective efficacy of the buffer systems.

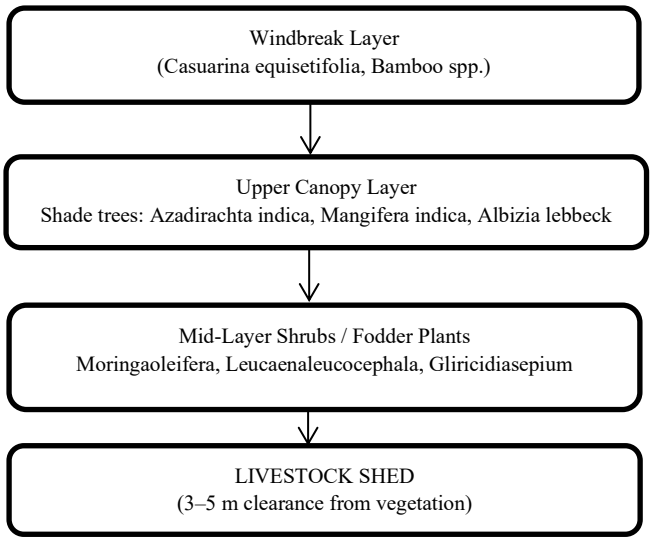

Figure 3: Flow Diagram Illustrating the Multi-Tier Vegetation Buffer Structure Surrounding Livestock Housing

Results and Discussion

Effect of Vegetation Buffers on Microclimatic Destinations

The agro-horticultural vegetation cover that existed altered microclimate considerably around shelters to livestock by enhancing thermal and atmospheric conditions. The temperature of the ambient in the buffered systems was 29.132.4 C and non buffered systems registered a higher temperature of 32.635.8 C which established a steady temperature depletion of 1.5-3.2 C which was caused by vegetation cover. Relative humidity also improved in the buffered units (58-66), whereas in the non-buffered sheds, the relative humidity was 48-55 percentage, which contributed to the alleviation of excessive heat loss through evaporation in animals. The windbreak species inhibited the movement of dust and thermal discomfort by 2235% of the wind speed. Also, concentration of PM 0 was reduced in buffered systems by 28-41 percent that showed the air-cleaning ability of the vegetation. Such positive transformations affirm that vegetation buffers are good natural controllers of microclimate because of interception of solar radiations and multiplying evapotranspiration and airborne particulates.

Impact on Physiological and Behavioural Welfare Indicators

Animals are located in the vegetation-buffered environment; thus showed much better physiological and behavioural welfare responses than those in the non-buffered system. The rate of respiration in buffered animals was lower, and the rate of panting was significantly reduced, which means that animals had to experience less thermal stress and had better thermoregulation. These animals had more lying and resting time which were indicators of greater comfort and less fatigue in moderate thermal conditions. Moreover, social behaviour in buffered systems became more stable and showed a minimal level of aggressive interaction among the animals, which implies that there is a lesser psychological stress. The following welfare gains are directly

attributable to the low heat loads and better air quality and humidity stabilisation that vegetation buffers achieved and contributed to improved and stress-free housing environment.

Effect on Feed Consumption and Performance

The vegetation buffers affected the behavioural aspects of livestock feed consumption and overall productive stability positively. There was an increase in feed intake uniformity in animals confined close to vegetation buffers over 8-12% in contrast to animals conveyed in open housing systems. Greater thermal comfort offset the decrease in appetite induced by stress that decreases stress levels so that animals could remain in their usual feeding schedules even in the hottest summer months. Body condition scores were more stable in buffered animals, which means that they had better energy balance and nutrient utilisation. Along with that, there were also less dehydration symptoms, which showed the better water balance with the stabilised humidity and the reduced heat stress. These results indicate that vegetation buffer systems in the control of the microclimate have a direct positive influence in greater physiological efficiency and productive resilience in livestock.

Comparative Sustainability of Vegetation Buffers and Artificial Cooling Systems

Agro-horticultural vegetation buffers offer low-energy, economical, and environmentally-friendly alternative to microclimate control in livestock systems than the use of mechanical-operated cooling mechanisms (like fans and foggers). Although artificial cooling provides an instant thermal relief it must be constantly fed with energy and raises operating expenses and carbon emissions Figure 4. Vegetation buffers by contrast offer passive cooling benefits on the long-run via natural biophysical processes alongside providing other ecosystem services, namely carbon sequestration, biodiversity enhancement, dust and gaseous filtration and landscape enhancement. The research confirms that vegetation buffers do not only enhance animal welfare and production, but also help in climate-sensitive livestock management where environmental sustainability is at par with economic viability (Table 1).

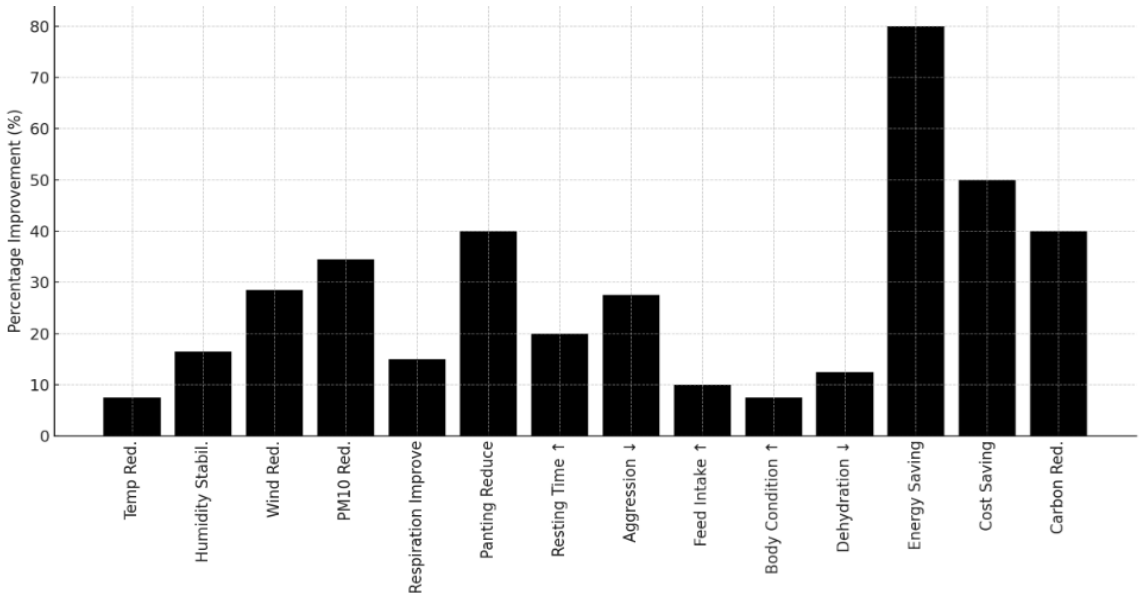

Figure 4: Combined Percentage Improvement of Buffered System Over Non-Buffered System

Table 1: Percentage Improvement of Buffered Livestock Housing Systems Compared to Non-Buffered Systems Across Microclimate, Welfare, Productivity, and Sustainability Indicators

S. No.	Indicator Category	Specific Indicator	Approx. % Improvement of Buffered vs. Non-Buffered System*
1	Microclimate	Temperature reduction (°C)	7.5%
2	Microclimate	Humidity stabilization (%)	16.5%
3	Microclimate	Wind speed reduction (%)	28.5%
4	Microclimate	PM_{10} reduction (%)	34.5%
5	Welfare (Physiological)	Respiration rate improvement	15%
6	Welfare (Physiological)	Panting reduction	40%
7	Welfare (Behavioral)	Increase in lying/resting time	20%
8	Welfare (Behavioral)	Reduction in aggressive interactions	27.5%
9	Productive Response	Increase in feed intake consistency	10%
10	Productive Response	Improvement in body condition score stability	7.5%
11	Productive Response	Reduction in dehydration symptoms	12.5%
12	Sustainability	Energy saving vs. mechanical cooling	80%
13	Sustainability	Cost saving vs. mechanical cooling	50%
14	Sustainability	Reduction in carbon emissions	40%

Conclusion

In the current research, it is conclusively found that agro- horticultural vegetation buffers are a practical, natural, and nature-based remedy to the regulation of microclimate and the welfare of livestock production systems. Strategic locations of shade trees, fodder shrubs, and windbreak species near animal shelters made a major reduction in ambient temperature up to 3.2 o C, enhancement of the balance of relative humidity and decrease of particulate air pollution during the peak summer season. These changes in the environment led to concrete welfare implications, such as less respiratory stress, a better resting behaviour, constant feeding habits, and a better body condition of cattle and small ruminants. In addition to determining immediate gains in thermal comfort and enhanced productivity, vegetation buffer helps in long-term sustainability of the farms by providing ecosystem services (carbon capturing, air purification, biodiversity, and improved landscape). Hence, agro-horticultural vegetation buffers are cost-effective and energy-efficient and climate-resilient in terms of their suitability in promoting animal welfare, enhancing environmental quality and sustainable livestock farming in climatically vulnerable areas.

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