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Recent advances in livestock management practices for sustainable rural livelihoods

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Abstract

Livestock plays a pivotal role in sustaining rural livelihoods in developing countries, particularly in India, by contributing to income generation, employment, nutritional security, and resilience against climatic and economic shocks. Despite its importance, the livestock sector continues to face challenges such as low productivity, fodder scarcity, disease prevalence, and increasing climate stress. In recent years, significant advances in livestock management—ranging from improved feeding and fodder management, preventive animal healthcare, precision livestock farming (PLF), climate-smart livestock practices, to waste-to-wealth and circular livestock systems—have opened new opportunities for enhancing sustainability and inclusiveness. The present paper adopts a descriptive and analytical approach based on secondary data to review recent advances in livestock management practices and assess their contribution to sustainable rural livelihoods. Evidence from national and international sources indicates that integrated adoption of improved livestock practices can increase livestock income by 30-60%, generate 20-30% additional employment, enhance women's participation and decision-making power, and significantly reduce production and income risks. The findings suggest that while advanced technologies such as PLF hold long-term promise, low-cost and knowledge-intensive interventions—balanced feeding, preventive healthcare, climate-smart housing, and manure management—deliver the highest and fastest returns for smallholders. Strengthening institutional support, extension services, and access to credit is essential to scale these benefits and promote inclusive, resilient, and sustainable rural development.

Keywords: Livestock management, precision livestock farming, climate-smart livestock, rural livelihoods, sustainability

Introduction

Livestock plays a vital and multifaceted role in rural economies, particularly in developing countries such as India, where it contributes significantly to food security, employment generation, income diversification, and poverty reduction. The livestock sector supports millions of small and marginal farmers by providing regular cash income through milk, meat, eggs, wool, and other by-products, while also serving as an important source of nutritional security, especially in terms of high-quality animal protein and micronutrients. In addition, livestock acts as a critical risk-mitigation asset for rural households, helping them cope with crop failures, market uncertainties, and climatic shocks. Despite its immense socio-economic importance, the productivity and profitability of the livestock sector remain constrained by several structural and technological challenges. Low genetic potential of animals, inadequate and imbalanced feeding practices, seasonal scarcity of quality fodder, prevalence of infectious and parasitic diseases, and limited access to veterinary and extension services continue to hinder optimal livestock performance. Moreover, increasing climate variability, rising temperatures, frequent droughts, and extreme weather events have further aggravated stress on livestock systems, adversely affecting animal health, reproduction, and productivity. These challenges disproportionately impact smallholder farmers, women, and landless households who rely heavily on livestock for their livelihoods. In recent years, rapid scientific and technological advancements have opened new pathways for transforming livestock management systems in a sustainable and inclusive manner. Innovations such as precision livestock farming, climate-smart livestock practices, improved breeding and reproductive technologies, balanced ration formulation, fodder conservation techniques, advanced disease surveillance, and digital advisory services have demonstrated significant potential to enhance productivity while reducing costs and environmental footprints. Simultaneously, increased emphasis on animal welfare, waste-to-wealth approaches, and circular livestock production systems has strengthened the link between livestock development and environmental sustainability.

These recent advances not only improve animal performance and farm profitability but also contribute to broader rural development goals by generating employment, empowering women, promoting entrepreneurship, and enhancing resilience against climate and market risks. Therefore, understanding and integrating modern livestock management practices is crucial for ensuring sustainable rural livelihoods. In this context, the present paper reviews recent advances in livestock management practices and examines their role in strengthening sustainable rural livelihoods, with a particular focus on smallholder-based production systems.

Research Methodology

The present study adopts a descriptive and analytical research design based on a comprehensive review and synthesis of secondary data. The study aims to examine recent advances in livestock management practices and assess their contribution to sustainable rural livelihoods. A qualitative-analytical approach has been employed to integrate technological, economic, environmental, and social dimensions of livestock development.

Source of data

He study is primarily based on secondary data collected from a wide range of authentic and reliable sources, including:

- Research articles published in national and international peer-reviewed journals
- Reports and publications of organizations such as FAO, ICAR, World Bank, IFAD, and Department of Animal Husbandry and Dairying (Government of India)
- Conference proceedings, policy briefs, working papers, and extension manuals
- Government statistics, livestock census data, and official databases
- Books and review articles related to livestock management, rural development, and sustainability

Results and Discussion

1. Contribution of Livestock to Rural Livelihoods

Analysis of secondary data unequivocally establishes livestock as a core pillar of rural livelihoods in India and other developing economies. Unlike crop agriculture, which is seasonal and highly climate-sensitive, livestock provides regular and year-round income, making it a critical livelihood stabilizer for rural households. Estimates reported by the Department of Animal Husbandry and Dairying and the FAO indicate that the livestock sector contributes 28-30% of agricultural Gross Value Added (GVA) and approximately 5-6% of national GVA, despite occupying limited land resources. Livestock supports the livelihoods of nearly 70-75% of rural households, either as a primary or supplementary source of income. The sector is particularly important for small and marginal farmers, who own more than 65% of the country's livestock population, and for landless households, for whom animals such as goats, poultry, and dairy cattle serve as movable and liquid assets. In rainfed, drought-prone, and tribal regions, livestock contributes 35-50% of total household income, significantly reducing income volatility and distress migration. A notable feature of livestock-based livelihoods is their strong gender dimension. Women contribute nearly 60-70% of total labour in livestock activities, including feeding, milking, health care, manure management, and marketing of milk and eggs. Livestock ownership and control over small animals enhance women's economic participation, decision-making power, and financial inclusion, making livestock development a powerful instrument for gender-inclusive rural growth. From a nutritional perspective, livestock plays a crucial role in improving food and nutrition security. Animal-source foods contribute more than 40% of dietary protein intake in rural areas and are key sources of essential micronutrients such as calcium, iron, zinc, and vitamin B12. Regular access to milk, eggs, and meat helps address hidden hunger and malnutrition, particularly among children and women.

Table 1: Contribution of Livestock to Rural Economy (India)

Indicator	Value
Share in Agricultural Gross Value Added (GVA)	28-30%
Share in National Gross Value Added (GVA)	5-6%
Rural households dependent on livestock	~70-75%
Small and marginal farmers owning livestock	>65%
Share of women workforce in livestock activities	60-70%
Contribution to rural protein intake	>40%
Share in income of rainfed agricultural households	35-50%

These results confirm that livestock functions as a risk-buffering and income-stabilizing enterprise, especially in regions where crop productivity is uncertain due to climate variability and market fluctuations. The steady and diversified income stream from milk, eggs, meat, and small ruminants enhances household food security, smoothens consumption, and reduces vulnerability to shocks. Consequently, livestock emerges not merely as a subsidiary agricultural activity but as a strategic pathway for inclusive, resilient, and sustainable rural livelihoods.

2. Impact of Improved Feeding and Fodder Management

Secondary studies consistently demonstrate that improved feeding and fodder management is among the most cost-effective and scalable interventions for enhancing livestock productivity and farm profitability, particularly for smallholder systems. Feed and fodder expenses account for nearly 60-70% of the total cost of milk production, making nutritional management a decisive factor in determining net returns. According to synthesis of evidence from ICAR and FAO, India faces a persistent fodder deficit of about 11-12% for dry fodder, 35-36% for green fodder, and 28-30% for concentrates, which directly constrains animal productivity. Adoption of balanced ration feeding, mineral mixture supplementation, and fodder conservation techniques such as silage and haymaking has been shown to significantly improve milk yield, feed-use efficiency, and animal health. Balanced ration feeding aligns nutrient supply with physiological requirements, reducing both underfeeding and wastage of costly concentrates.

Feeding Practice	Milk Yield (litres/day/animal)	% Increase
Traditional feeding	6.0-7.0	-
Balanced ration	8.0-9.5	25-35%
Silage-based feeding	9.0-10.5	30-45%

Empirical evidence indicates that balanced ration feeding increases feed conversion efficiency by 15-20% and reduces cost per litre of milk by ₹2-3, resulting in an additional annual income of ₹12,000-18,000 per animal. Silage-based feeding systems, particularly during lean summer and drought periods, further enhance productivity and income by stabilizing feed availability and quality, with annual gains of ₹18,000-25,000 per animal reported in several field studies. Improved feeding practices also contribute to environmental sustainability. Optimized nutrition reduces enteric methane emissions per unit of milk produced by 10-15%, lowers nitrogen excretion, and minimizes feed wastage. Efficient use of crop residues through technologies such as urea-treated straw and complete feed blocks improves residue recycling while reducing pressure on grazing lands. Beyond productivity gains, improved feeding and fodder management enhances livelihood resilience. Reliable fodder availability reduces seasonal fluctuations in milk production, stabilizes cash income, and prevents distress sale of animals during droughts and fodder-scarce periods. These benefits are particularly significant for small and marginal farmers, for whom even modest productivity gains translate into substantial improvements in household income and food security.

Overall, the evidence confirms that feed optimization offers high economic returns with relatively low investment, making it a cornerstone of sustainable livestock intensification. When combined with improved health care and housing, feeding and fodder interventions play a pivotal role in enhancing income, reducing production risk, and lowering the environmental footprint of livestock systems.

3. Effect of Animal Health and Biosecurity Measures

Animal health management is a critical determinant of livestock productivity, profitability, and livelihood security. Secondary evidence from national and international studies clearly demonstrates that preventive animal health and biosecurity measures—including vaccination, deworming, hygienic housing, quarantine of sick animals, and improved farm sanitation—significantly reduce disease incidence, mortality, and economic losses. According to estimates compiled by the ICAR and the Department of Animal Husbandry and Dairying, livestock diseases cause annual economic losses exceeding ₹1.2-1.5 lakh crore in India, primarily due to reduced productivity, mortality, treatment costs, and trade restrictions. Traditional livestock systems are characterized by reactive treatment-based approaches, leading to high disease prevalence and recurring expenditure on veterinary care. In contrast, adoption of preventive healthcare and biosecurity protocols has been shown to drastically reduce disease burden and improve animal performance.

Table 3: Reduction in Disease Incidence through Preventive Healthcare

Parameter	Traditional system	Improved health management
Annual disease incidence (%)	25-30	8-12
Mortality rate (%)	6-8	2-3
Veterinary cost (₹/animal/year)	High	Reduced by 20-30%
Milk yield loss (litres/animal/year)	350-450	<150

Field studies further indicate that vaccination and deworming programmes alone generate a benefit-cost ratio (BCR) ranging from 1:6 to 1:9, making preventive animal health interventions among the most economically rewarding investments in livestock production. Regular vaccination against diseases such as Foot-and-Mouth Disease (FMD), Hemorrhagic Septicemia (HS), and Black Quarter (BQ) improves milk yield by 8-12% and enhances reproductive efficiency through reduced disease-induced stress.

Preventive healthcare also plays a crucial role in asset protection, particularly for small and marginal farmers. Loss of even one milch animal can push poor households into indebtedness or distress sale of assets. Reduced mortality and morbidity therefore strengthen livestock's role as a financial safety net, enhancing household resilience to economic and climatic shocks. Improved animal health additionally lowers the need for antibiotics, contributing to reduced antimicrobial resistance (AMR) risks and better public health outcomes. Overall, the evidence strongly confirms that systematic animal health and biosecurity management improves productivity, reduces costs, and safeguards livelihoods, especially in smallholder systems. Scaling up preventive healthcare through public veterinary services, mobile clinics, and community-based animal health workers is essential for sustainable and inclusive livestock development.

4. Role of Precision Livestock Farming (PLF) Technologies

Precision Livestock Farming (PLF) represents a major technological advancement in modern livestock management, integrating sensor-based monitoring, automation, data analytics, and digital decision-support systems to optimize animal health, reproduction, and productivity. Evidence from secondary studies conducted by ICAR, FAO, and international dairy research networks indicates that PLF technologies deliver substantial gains in reproductive efficiency, early disease detection, and input-use efficiency, particularly in dairy production systems. PLF tools such as automated heat detection collars, activity sensors, rumination monitors, milk conductivity sensors, and infrared thermography enable real-time monitoring of animal behaviour and physiological parameters. These technologies significantly improve the accuracy and timeliness of management decisions, reducing reliance on visual observation and manual labour.

Table 4: Benefits of Precision Livestock Management

Parameter	Conventional system	PLF-based system
Heat detection accuracy (%)	60-65	90-95
Reduction in disease detection time	-	40-60%
Increase in conception rate (%)	-	10-20
Reduction in calving interval (days)	-	30-45
Increase in lifetime milk yield (%)	-	12-18

Improved heat detection accuracy under PLF systems leads to timely artificial insemination, reducing missed heats and lowering the number of services per conception. As a result, calving intervals are shortened by 30-45 days, which translates into higher lifetime milk yield and improved

reproductive longevity. Studies report an average increase of 12-18% in lifetime milk production per animal under PLF-supported management. From an economic perspective, PLF adoption improves net farm profitability by 18-25% within 2-3 years, despite higher initial investment costs. Savings arise from reduced labour requirements (15-20% reduction in labour cost), lower veterinary expenses due to early disease detection, and more efficient feed utilization. Early identification of metabolic disorders and mastitis also reduces milk losses and antibiotic usage by 25-35%, contributing to improved animal welfare and public health outcomes. Although PLF technologies are often perceived as suitable only for large commercial farms, emerging evidence shows that cooperative-based models, dairy producer companies, and shared-service platforms significantly enhance accessibility for smallholders. Under such models, costs of sensors, software, and technical support are shared across multiple farmers, making PLF economically viable even for herds of 2-5 animals. Digital advisory services linked with PLF data further strengthen extension outreach and decision-making at the farm level.

Overall, the findings suggest that PLF technologies play a crucial role in transitioning livestock systems from experience-based to data-driven management. While their large-scale adoption among smallholders requires institutional support, capacity building, and credit facilitation, PLF offers strong potential to improve productivity, profitability, animal welfare, and sustainability in the long run. When integrated with improved feeding, health care, and housing, PLF emerges as a key driver of smart, resilient, and future-ready livestock systems.

5. Climate-Smart Livestock Practices and Resilience

Climate change has emerged as one of the most serious threats to livestock-based livelihoods, particularly in tropical and subtropical regions. Rising temperatures, frequent heat waves, prolonged droughts, and erratic rainfall patterns adversely affect feed intake, milk yield, fertility, animal health, and survival rates. According to assessments by the FAO and ICAR, heat stress alone accounts for 10-25% losses in milk production annually in large parts of South Asia, translating into substantial income losses for dairy farmers. Climate-smart livestock practices—such as heat-stress mitigation measures, improved housing design, strategic feeding, climate-resilient fodder varieties, and water-efficient management—have demonstrated significant potential to enhance productivity and resilience under changing climatic conditions. These interventions aim to both adapt livestock systems to climate variability and reduce vulnerability to extreme weather events.

Table 5: Impact of Climate-Smart Interventions

Indicator	Without intervention	With intervention
Milk yield loss during heat stress (%	20-25	5-10
Animal fertility decline (%)	15-20	<5
Feed intake reduction (%)	10-15	3-5
Calving interval increase (days)	40-60	<20
Heat-related morbidity (%)	18-22	6-8

Field studies indicate that improved housing designs (adequate ventilation, higher roof height, orientation, shading, and reflective roofing materials) combined with cooling measures such as fans, sprinklers, and misting systems can reduce body temperature by 1.5-2.5 °C, leading to 8-15% higher milk yield during summer months. Similarly, incorporation of heat-tolerant and drought-resilient fodder crops (such as sorghum, bajra, and multi-cut forage varieties) improves feed availability and quality under water-stressed conditions, reducing seasonal production fluctuations. From an economic perspective, climate-smart interventions help farmers avoid income losses of ₹20,000-25,000 per animal per year during severe heat-stress periods. Reduced fertility losses and shorter calving intervals further enhance lifetime productivity and profitability. Importantly, these practices minimize distress sales of animals during droughts and heat waves, preserving livestock assets that are central to rural household security. Beyond productivity gains, climate-smart livestock management strengthens adaptive capacity and livelihood resilience. By stabilizing output and income, these practices enable households to better cope with climatic shocks, reduce vulnerability, and maintain food security. When integrated with early-warning systems, weather-based advisories, and insurance mechanisms, climate-smart livestock practices form a critical pillar of climate-resilient and sustainable rural livelihoods.

Overall, the evidence confirms that climate-smart livestock interventions significantly mitigate the adverse impacts of climate change on animal productivity, income stability, and household resilience. Scaling up these practices through targeted extension services, climate-responsive policies, and institutional support is essential for safeguarding the future of livestock-dependent rural communities.

6. Waste Management and Circular Livestock Systems

Waste management has emerged as a critical component of sustainable livestock development, transforming traditional disposal-oriented practices into income-generating and resource-efficient circular systems. Livestock manure, when scientifically managed through enterprises such as biogas production, composting, vermicomposting, and bio-slurry utilization, contributes significantly to income diversification, cost reduction, and environmental sustainability. According to estimates synthesized from the FAO and the ICAR, India generates more than 3 billion tonnes of livestock manure annually, representing a vast but underutilized bio-resource. Manure-based enterprises play a crucial role in closing nutrient loops and reducing dependence on external inputs. Household- and community-level biogas plants convert animal waste into clean energy for cooking and lighting, while the residual bio-slurry serves as a high-quality organic fertilizer. Composting and vermicomposting further enhance nutrient recycling and soil health.

Table 6: Economic Benefits of Manure Management

Output	Annual Benefit (₹/household)
Biogas (fuel savings)	6,000-8,000
Compost/bio-slurry	4,000-6,000
Reduced fertilizer cost	15-20%
Total additional income / savings	10,000-15,000

Empirical studies indicate that adoption of biogas technology reduces household expenditure on LPG,

firewood, and kerosene by 20-30%, while simultaneously lowering indoor air pollution and drudgery for women. Bio-slurry application improves soil organic carbon by 0.15-0.25%, enhances nutrient-use efficiency, and increases crop yields by 8-12% when integrated with crop production systems. Reduced reliance on chemical fertilizers also lowers production costs and mitigates environmental degradation. From an environmental perspective, circular livestock systems significantly reduce greenhouse gas emissions, particularly methane released from unmanaged manure. Controlled anaerobic digestion in biogas plants captures methane for productive use, contributing to climate change mitigation. Improved sanitation and waste handling further reduce contamination of water bodies and lower the risk of disease transmission, benefiting both animal and public health. At the livelihood level, waste-to-wealth approaches strengthen income stability and resilience, especially for small and marginal farmers. Additional income from compost sales, savings on energy and fertilizers, and improved crop productivity collectively enhance household economic security. These systems also create local employment opportunities in construction, operation, and maintenance of biogas and composting units. Overall, the evidence confirms that manure management and circular livestock systems provide multiple co-benefits—economic, environmental, social, and health-related. When integrated with crop production, these systems enhance farm sustainability, reduce external input dependency, and support the transition toward resource-efficient and climate-resilient rural livelihoods. Scaling up circular livestock systems through policy incentives, credit support, and extension services is therefore essential for sustainable livestock-led rural development.

7. Overall Livelihood Outcomes

The integrated adoption of improved livestock management practices—covering nutrition, health care, housing, climate resilience, precision technologies, and waste management—results in significant and measurable improvements in rural livelihoods. Evidence synthesized from national and international secondary studies clearly indicates that livestock-led interventions generate multiplicative livelihood impacts, particularly for small and marginal farmers. According to consolidated findings from the FAO, ICAR, and the Department of Animal Husbandry and Dairying, households adopting a package of improved livestock practices experience 30-60% growth in livestock-derived income, driven by higher productivity, reduced mortality, and lower input costs. In many smallholder systems, livestock income contributes an additional ₹25,000-60,000 per household per year, significantly enhancing disposable income and consumption stability. Employment generation also shows strong positive trends. Improved livestock systems create 20-30% additional on-farm employment, particularly through activities such as fodder cultivation, milk processing, animal health services, waste recycling, and value addition. Livestock enterprises provide year-round employment, reducing seasonal underemployment commonly associated with crop agriculture.

A particularly notable outcome is the enhanced participation and empowerment of women. Women account for 60-70% of labour input in livestock systems, and improved management practices increase women's control over income from milk, eggs, and small ruminants. Studies report 15-25% increases in women's decision-making power related to household expenditure, savings, and asset management in households adopting improved livestock practices. Livestock-based interventions also substantially reduce production and income risks. Preventive healthcare, climate-smart housing, improved feeding, and insurance-linked advisory services reduce vulnerability to disease outbreaks, heat stress, and feed scarcity. Evidence indicates a 40-60% reduction in income variability and a sharp decline in distress sale of animals during climatic shocks and market downturns.

Table 7: Overall Impact of Improved Livestock Management on Rural Livelihoods

Indicator	Improvement Range
Household livestock income	+30-60%
Additional annual income	₹25,000-60,000 per household
Employment generation	+20-30%
Women's labour participation	60-70%
Women's decision-making power	+15-25%
Production and income risk	Reduced by 40-60%
Asset security (mortality loss)	Reduced by 50-70%

The cumulative evidence demonstrates that recent advances in livestock management significantly enhance rural livelihoods by increasing income, expanding employment, empowering women, strengthening asset security, and improving environmental sustainability. Importantly, the largest and most consistent benefits are observed when multiple interventions—balanced feeding, preventive healthcare, climate-smart housing, waste management, and improved market access—are implemented together rather than in isolation.

Overall, the findings clearly establish that while high-end technologies such as precision livestock farming offer strong long-term potential, basic, low-cost, and knowledge-intensive management improvements deliver the highest and fastest returns for smallholders. Scaling these benefits across rural regions requires effective institutional support, strengthened extension services, capacity building, access to affordable credit and insurance, and convergence of livestock development with rural livelihood and climate policies. When supported appropriately, livestock management emerges as a powerful pathway for inclusive, resilient, and sustainable rural development.

Conclusion

The present review clearly demonstrates that recent advances in livestock management practices have a positive, measurable, and transformative impact on sustainable rural livelihoods. Livestock emerges not merely as a subsidiary agricultural activity but as a strategic livelihood asset, particularly for small and marginal farmers, landless households, and women. Evidence synthesized in this study shows that improvements in feeding and fodder management, preventive animal healthcare, precision livestock farming technologies, climate-smart practices, and circular waste management systems significantly enhance productivity, income, employment, and resilience while reducing environmental footprints. Among the various

interventions reviewed, basic and cost-effective management practices—such as balanced ration feeding, fodder conservation, vaccination and biosecurity, improved housing, and manure recycling—offer the highest benefit-cost ratios and are most suitable for smallholder-dominated production systems. Advanced technologies like precision livestock farming further strengthen efficiency, reproductive performance, and disease management, particularly when adopted through cooperative and shared-service models. The study also highlights the strong gender and equity dimensions of livestock development, with women contributing a major share of labour and gaining increased economic participation and decision-making power through improved livestock systems. Furthermore, climate-smart livestock practices play a crucial role in reducing vulnerability to heat stress, droughts, and extreme weather events, thereby safeguarding livelihoods under changing climatic conditions. Overall, the findings establish that sustainable livestock development requires a systems-based and integrated approach, supported by effective extension services, institutional strengthening, access to affordable credit and insurance, and convergence of livestock policies with rural development and climate adaptation frameworks. When appropriately supported, livestock management can serve as a powerful pathway for inclusive growth, poverty reduction, climate resilience, and sustainable rural livelihoods.

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