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Optimizing Livestock Feed Systems: A Multi-faceted Approach for Sustainable and Resilient Animal Agriculture; A comprehensive review

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Abstract

Livestock production in Pakistan significantly contributes to the economy, with the sector contributing 56.3% of agricultural value and 19.3% to GDP. It employs over 2 million people. While crucial for food security and nutrition, livestock production faces environmental challenges. Sustainable practices are essential to mitigate these impacts and ensure the long-term viability of this vital sector. Fodders and forages are vital for sustainable livestock nutrition. They provide essential nutrients like protein (e.g., berseem: 6.9-26.7% crude protein), fiber for gut health, and energy. Diverse forages, such as grasses and legumes, enhance animal health and reduce reliance on expensive concentrates. Key practices include three-strata forage systems, agroforestry, and optimizing feed utilization. These approaches improve animal health, productivity, and overall farm sustainability. Fodders and forages promote soil health by adding organic matter, reducing erosion (through cover crops, no-till farming). This improves soil fertility and nutrient availability. Additionally, these practices can contribute to carbon sequestration through increased soil carbon storage. Overall, these benefits contribute to sustainable agriculture and mitigating climate change. Utilizing lower-cost feed sources like by-products and forages offers significant economic advantages. By reducing reliance on purchased concentrates, farmers can lower feed costs, improve profit margins, and enhance feed efficiency. This leads to cost savings, increased productivity, and improved sustainability by reducing reliance on imported feeds. Diversifying feed sources also mitigates risks associated with fluctuating feed prices and adverse weather conditions.

Keywords: *Sustainable Livestock Nutrition, Fodders and Forages, Feed Efficiency, Economic Benefits, Environmental Impact, Carbon Sequestration.*

I. Introduction

Livestock production plays a crucial role in ensuring food security and economic development, particularly in low- and middle-income countries. Livestock production provides a significant portion of the world's protein intake, with meat, dairy, and eggs being essential components of a balanced diet. In Pakistan, the livestock sector makes a significant direct contribution to the national economy. The livestock sector contributes 56.3% of the value of agriculture and 11% to the agricultural gross domestic product (AGDP) (Rehman et al., 2017). Anonymous et al., 2023 concluded that this sector provides employment to over 2 million people, with the poultry sector alone employing over 1.5 million people. Livestock contributes 19.3% to the country's GDP, which is a substantial portion considering the sector's importance in the overall economy. Thus, this sector generates foreign exchange earnings of around 2.1% of the total exports, with the poultry sector being a significant contributor.

According to the Pakistan economic survey 2022-2023, livestock products, such as milk, meat, and eggs, are essential components of the national diet, providing a significant portion of the population's nutritional needs. Livestock products offer essential micronutrients and macronutrients, which are vital for maintaining good health and preventing malnutrition. Livestock production increases the availability of animal-source foods, which are often more accessible and affordable than plant-based alternatives, especially in developing countries. Livestock production generates income and employment opportunities for farmers and other stakeholders along the value chain, contributing to local and national economic development. Livestock serve as an asset and store of wealth for many small-scale farmers, providing a safety net during times of economic uncertainty. Livestock production can be a key factor in women's empowerment, as they often play a significant role in managing and maintaining livestock, which can lead to increased economic independence and social status.

Livestock production can contribute to carbon sequestration through the use of grazing systems and agroforestry practices, which help maintain soil health and biodiversity. Livestock can help maintain biodiversity by promoting the conservation of grasslands and other ecosystems.

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Livestock are often deeply ingrained in local cultures and social structures, providing a sense of community and identity for many people(Baltenweck et al., 2020).

II. Importance of Fodders and Forages for Sustainable Livestock Nutrition

Fodders and forages play a crucial role in sustainable livestock nutrition, providing essential nutrients for animal health and productivity. Fodder trees and shrubs represent an enormous potential source of protein for ruminants in the tropics. They can help address the low levels of animal production in regions where 50-60% of feeds produced are dry bulky roughages, mainly cereal straws and stovers. –(Tahir et al., 2024) stated that an adequate moisture promotes nutrient uptake in forages, leading to higher protein and mineral content. However, heavy rainfall can cause leaching of soluble nutrients.(Paul et al., 2020) summarized that an improved livestock feeding and forages have been highlighted as key entry points to sustainable intensification, increasing food security, and decreasing environmental impact. Forage technologies encompass a spectrum of tools and practices aimed at optimizing the quality and quantity of livestock feed.

Practical technologies that can ensure the beneficial use of fodders and forages at the farm level include three-strata forage systems, integrated tree cropping systems, Agro-forestry systems, food-feed intercropping, relay cropping, alley cropping, and grazing and stall-feeding systems. For example, the three-strata forage system in Bali, involving grasses, shrub legumes, and fodder trees, has demonstrated considerable benefits in increasing forage supply and enabling higher stocking rates and live weights (Ahmad et al., 2024). Thus, optimizing the use of fodders and forages is crucial for sustainable livestock management, as they provide essential nutrients, promote animal health and productivity, and contribute to the overall sustainability of farming systems.

A. Nutritional Components

The major nutritional components of fodder crops including crude protein, ADF, NDF, carbohydrates, and fats along with some minerals are well elaborated in table no.1.

Crude Proteins

(Rehman et al., 2023) Stated that fodder crops like berseem, lucerne, and oats can have crude protein levels ranging from 6.9-26.7% on a dry matter basis. Oilseed meals and cakes are a good source of high-quality protein for livestock. Crude protein analysis is extensively used in various fields, including animal nutrition, food science, and biochemistry. It provides critical information about the nutritional composition of feed ingredients, the quality of food products, and the assessment of protein content in biological samples. The main formulas used to measure crude protein content are:

$$\textbf{\textit{Nitrogen content}}\ (\%) = (\boldsymbol{A} - \boldsymbol{B}) \times \textbf{\textit{normality of std. HCl}} \times \mathbf{14.007} \,/\, \textbf{\textit{sample mass}}$$

Where:
A = volume (mL) of std. HCl,
B = volume (mL) of std. NaOH

$$\textbf{\textit{Crude Protein}}\ (\%) = \textbf{\textit{Nitrogen content}}\ (\%) \times \mathbf{6.25}$$

Where:
6.25 is the protein-nitrogen conversion factor (Jones' factor)
The Kjeldahl method involves digesting the sample with sulfuric acid, distilling the ammonia, and titrating to determine the nitrogen content.

This nitrogen value is then multiplied by 6.25 to estimate the crude protein percentage (Salo-Vaananen & Koivistoinen et al., 1996).

Carbohydrates and Energy

(Anonymous et al., 2021) demonstrated that grains like maize, sorghum, wheat, and barley are high in energy and relatively low in fiber. Roots, tubers, and molasses are rich sources of carbohydrates and energy for livestock. The key formulas used to calculate carbohydrates and energy content in fodder crops:

$$\textbf{\textit{Total Carbohydrates}} = \mathbf{100} - (\textbf{\textit{Crude Protein}}\,\% + \textbf{\textit{Ether Extract}}\,\% + \textbf{\textit{Ash}}\,\%)$$

This formula calculates total carbohydrates by difference, subtracting the percentages of protein, fat, and ash from 100%.

A similar cubic equation to the above, but for net energy for maintenance. The specific formulas used may vary, but these represent some of the common equations to estimate different energy parameters from the proximate analysis of fodder crops. The TDN and DE values are key inputs used to derive the other energy measures.

Forages and Roughages as Fiber Sources:

Fodder crops, pastures, and agricultural by-products like cereal straws and stovers are the primary sources of fiber for ruminants. These fibrous feeds provide the structural carbohydrates that are essential for proper rumen function and animal health. These forages contain varying amounts of cellulose, hemicellulose, and lignin - the main structural components of plant cell walls. The fiber content and digestibility can be influenced by factors like plant maturity, growing conditions, and processing methods.

According to B.C. Agustinho 2023 (resource: nutrinews.com), fiber serves two critical roles in ruminant nutrition:

· Providing physical capacity and stimulating rumination/chewing, which is vital for proper rumen function and animal health.

· Acting as a substrate for microbial fermentation in the rumen, producing volatile fatty acids that are the primary energy source for ruminants.

The capacity for fiber degradation depends on the composition and organization of the fiber fraction, with cellulose and hemicellulose being more digestible than lignin. Strategies to enhance fiber digestion include mechanical, chemical, and enzymatic treatments.

Fiber

Roughages like hay, straw, grasses, and legumes are high in fiber content. Fiber is important for rumen function and gut health in ruminants. In summary, forages and roughages are the richest sources of fiber for ruminants, and optimizing their utilization is crucial for sustainable livestock nutrition and production.

Minerals

Legumes like berseem and lucerne can be good sources of minerals like calcium. Cereal grains are moderately rich in vitamins and minerals like phosphorus. The nutritional composition of fodder crops can vary widely depending on the specific crop, growing conditions, and processing methods. Incorporating a diverse range of fodder sources can help provide a balanced diet for livestock.

Can reduce dependence on purchased concentrates, lowering costs and environmental impact:

(Berton et al., 2023) Stated that lowering the proportion of purchased concentrates in dairy cow diets and relying more on home-grown forages and roughages can reduce the environmental impact of milk production. Diets with lower concentrate levels (Diet Low-C2) had a carbon footprint 30% lower than baseline diets with higher concentrate inclusion. Traditional dairy farms with lower concentrate use had 59% greater efficiency of resource use compared to more intensive systems. Reducing concentrate intake and increasing forage utilization can lower the carbon footprint of milk production by decreasing emissions from feed production and processing. Feeding less concentrates and more home-grown feeds also reduces the environmental impact of dairy systems in terms of biodiversity loss and soil carbon sequestration (Sabia et al., 2020).

Table 1: Major Field Crops of Pakistan which are used as source of Fodder Crops.

English Names	Scientific Names	Family Name	Dry matter (%)	Crude Protein (%)	Acid Detergent Fiber (%)	Neutral Detergent fiber (%)	Ash (%)	Crude Fat (%)	Nitrogen free extract (%)	Crude Fiber (%)	Source
Wheat	*Triticum aestivum*	Poaceae	88.12	10.53	---	---	---	---	71.28	2.57	(Hotea et al., 2021)
Barley	*Hordeum vulgare*	Poaceae	81.80	72.41	67.96	65.31	---	----	----	----	(Al-Baadani et al., 2022)
Spring Maize	*Zea mays*	Poaceae	34.20	6.78	27.35	52.92	4.89	1.77	62.73	23.77	(Hanif & Akhtar, 2020)
Autumn Maize			33.30	7.45	25.45	48.77	4.57	1.74	62.56	23.64	
Sorghum	*Sorghum bicolor*	Poaceae	40.55	4.77	32.17	47.57	---	---	---	---	(Inal et al., 2021)
Pearl Millet	*Pennisetum typhoides*	Poaceae	90	9.02	5.78	32.13	3.01	---	---	---	(Makarana et al., 2018)
Rice Straw	*Oryza sativa*	Poaceae	90	4.5	---	---	16	1.01	0.67	29.8	(Malik et al., 2015)
Mung bean	*Vigna radiata*	Fabaceae	---	23.8	---	---	3.31	---	---	4.57	(Dahiya et al., 2015)
Black Gram	*Vigna mungo*	Fabaceae	61.8	15.5	27.1	41.6	12.8	---	---	---	(Dey et al., 2017)
Cowpea	*Vigna unguiculata*	Fabaceae	89.6	18.1	53	58.1	14.2	---	---	---	(Gebreyowhans & Gebremeskel, 2014)
Yellow Sarsoon /Toria	*Brassica campestris*	Cruiferae	63.61	12.46	42.94	49.43	11.21	---	49.43	---	(Kılıç et al., 2021)
Taramera / Mustard	*Eruca sativa*	Cruiferae	----	21.43	---	---	9	16.10	---	8.25	(Bukhsh et al., 2007)
Cluster bean	*Cyamopsis tetragonolba*	Fabaceae	25.96	---	26.80	38.27	---	---	26.99	---	(Salama & Nawar, 2016)
Alfalfa	*Medicago sativa*	Fabaceae	----	36.96	22.45	36.33	12.89	---	---	---	(Atumo et al., 2021)

Lowering concentrate use can help reduce feed costs and improve the economic viability of dairy farms, especially in mountain areas where concentrate feeds often need to be purchased (Berton et al., 2020). However, reducing concentrate intake may also lower milk yields per cow. The economic and environmental benefits depend on optimizing concentrate levels to balance productivity and sustainability. Dairy systems that rely more on home-grown forages and less on purchased concentrates can have a lower environmental impact and improved economic efficiency. However, this needs to be balanced with maintaining adequate productivity through optimal concentrate supplementation.

B. Environmental Benefits

Promote Soil Health and Fertility by adding Organic Matter and Reducing Erosion:

Promoting soil health and fertility through the addition of organic matter and reducing erosion is a key aspect of sustainable agriculture.

Soil organic matter (SOM) is the foundation of soil quality and fertility. It contains, attracts, and holds multiple plant-available nutrients, making them readily accessible to plant roots. As organic matter breaks down, it releases these nutrients, contributing to the overall fertility of the soil (source: lebanonturf.com). Organic matter also improves soil structure, reducing the risk of erosion by acting as a binding agent. It enhances soil moisture retention, aeration, and microbial activity, all of which are crucial for plant growth and nutrient cycling (source: lebanonturf.com 2021).

Organic matter can be added to the soil through various sources, such as:

1. Crop residues and cover crops
2. Animal manure and compost
3. Green manures and legumes in rotation

4. Mulches and wood chips
Incorporating these materials into the soil helps build up organic matter levels over time. Soil erosion can lead to significant losses of organic matter and nutrients, reducing soil fertility (source: nevegetable.org) Practices that help reduce erosion include:

- Maintaining a continuous vegetative cover through cover crops or perennial crops
- Implementing conservation tillage techniques like no-till or strip-till
- Establishing buffer strips and contour farming on sloping lands
- Practicing agroforestry and incorporating trees into farming systems

These practices help protect the soil surface, improve infiltration, and reduce runoff and erosion, thereby preserving organic matter and nutrients in the soil.

Integrated Approach

According to the report of the International Atomic Energy Agency joint program with the Food and Agriculture Organization (FAO), which emphasis that the effective promotion of soil health and fertility, a combination of organic matter additions and erosion control practices is recommended. This integrated approach, along with other soil management techniques like nutrient management and pest control, can help build and maintain healthy, fertile soil that supports sustainable crop production. Adding organic matter and reducing erosion is crucial for promoting soil health and fertility. By implementing these practices, farmers can improve soil structure, nutrient availability, and overall productivity while minimizing environmental impacts.

Can Contribute to Carbon Sequestration

Carbon sequestration is a vital process that involves capturing and storing carbon dioxide (CO2) from the atmosphere, playing a crucial role in mitigating climate change. This process can occur naturally through biological means or can be enhanced through human interventions. Here's an elaboration on how carbon sequestration contributes to climate change mitigation.

A) Biological Carbon Sequestration

Biological carbon sequestration refers to the natural processes by which CO2 is absorbed and stored by ecosystems, particularly through photosynthesis in plants. Key aspects include:

Forests and Vegetation

Forests are among the most effective natural carbon sinks, absorbing CO2 during photosynthesis and storing it in biomass (trunks, branches, leaves) and soil. On average, forests sequester more carbon than they emit, with an estimated 25% of global CO2 emissions being absorbed by forests and other vegetative forms like grasslands (source: Wikipedia).

Soil Carbon Storage

Soil is a significant reservoir of carbon, containing more carbon than the atmosphere and vegetation combined. Organic matter in the soil, derived from decomposed plant and animal materials, contributes to soil fertility and stability while sequestering carbon. Practices that enhance soil organic carbon, such as cover cropping, reduced tillage, and organic amendments, can significantly increase carbon storage in soils (source: U.S. Department of Energy (DOE).

Wetlands and Aquatic Systems

Wetlands, bogs, and peatlands are also effective at sequestering carbon, as they store carbon in waterlogged conditions that slow decomposition. Aquatic environments, such as oceans, absorb a substantial amount of atmospheric CO2, but excessive carbon can lead to ocean acidification, which threatens marine biodiversity (source: nationalgrid.com 2024).

B) Geologic Carbon Sequestration

Carbon dioxide emissions from burning fossil fuels and industrial processes are a major contributor to greenhouse gases (GHGs) causing climate change (Hanif et al., 2024). Thus, geologic carbon sequestration involves capturing CO2 emissions from industrial sources and storing them underground in geological formations. This process includes:

Storage in Geological Formations

CO2 can be injected into deep rock formations, where it is trapped in porous rocks beneath impermeable layers. This method can effectively prevent CO2 from re-entering the atmosphere, thus contributing to long-term carbon storage (source: Wikipedia).

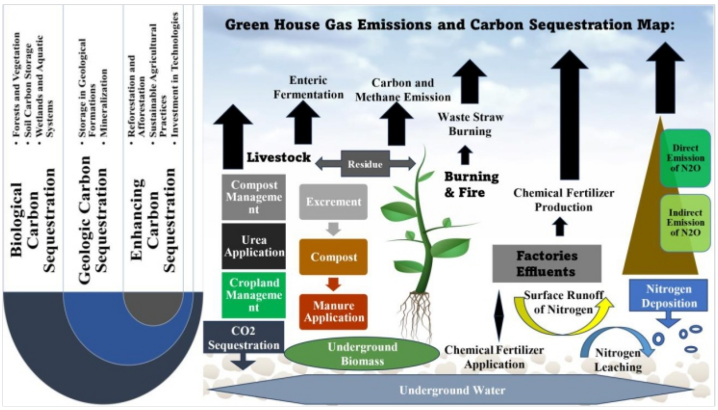


Figure 1: Concept Map of Green House Gas Emissions and Carbon Sequestration.

Mineralization

CO2 can also react with minerals to form stable carbonates, a process known as mineral sequestration. This method locks away carbon in a solid form, making it a non-volatile and long-term storage solution (source: U.S. Department of Energy (DOE).

A) Enhancing Carbon Sequestration

To maximize carbon sequestration, various strategies can be employed, which are well explained in the “Economic Times Newspaper” by (Pratyush Panda 2023):

a. Reforestation and Afforestation: Planting trees in deforested areas and establishing new forests can significantly enhance carbon uptake.

b. Sustainable Agricultural Practices: Implementing practices such as agroforestry, cover cropping, and reduced tillage can improve soil health and increase carbon storage.

c. Investment in Technologies: Developing and deploying carbon capture and storage (CCS) technologies can help mitigate emissions from industrial processes and power generation.

Carbon sequestration is essential for reducing atmospheric CO2 levels and mitigating climate change. By enhancing both biological and geologic sequestration methods, we can effectively contribute to a sustainable future. This requires collaborative efforts from governments, industries, and individuals to implement practices that promote carbon storage and reduce emissions.

C. Economic Advantages

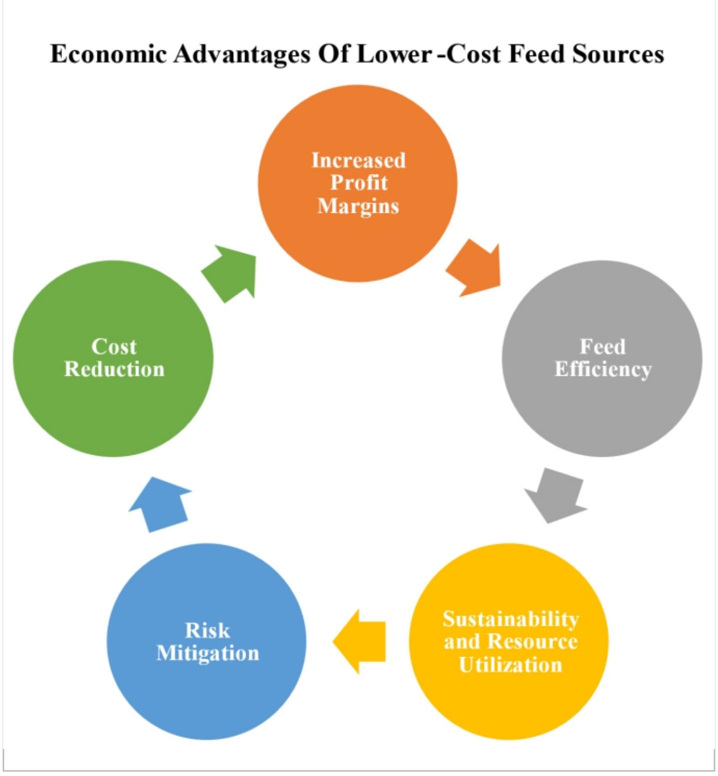
Generally Lower Cost Feed Source Compared to Purchased Concentrates.

The economic advantages of utilizing lower-cost feed sources compared to purchased concentrates in livestock nutrition are significant. The economic advantages of lower-cost feed sources are given below.

Cost Reduction

Utilizing by-products and alternative feeds can significantly lower feed costs compared to traditional purchased concentrates. For instance, by incorporating local agricultural by-products such as distillers' grains, bakery waste, or crop residues, farmers can reduce their reliance on expensive grains and protein sources like soybean meal and corn.

Studies reveled by the Bullvine in 2023 on reducing feed costs in dairy cattle, indicated that by optimizing the use of homegrown feeds, producers can lower overall diet costs while maintaining or even enhancing livestock performance. For example, replacing a portion of purchased dry hay with corn silage can lead to cost savings despite potentially higher protein costs.



Increased Profit Margins

By reducing feed costs, farmers can improve their profit margins. For instance, a dairy farm that minimizes feed waste (shrink) can save substantial amounts annually. Research shows that a 100-cow dairy could save approximately $58,400 by reducing feed shrink from high to low levels, highlighting the financial impact of effective feed management (source: dairy herd by Bohnert 2023).

The use of alternative feeds can also allow for better nutrient utilization, leading to improved animal performance without the need for expensive concentrates. This can result in higher milk production or growth rates in cattle, further enhancing profitability.

Feed Efficiency

In 2021, Geraghty reported on the All-tech website which demonstrated that, incorporating high-fiber feeds and alternative sources can enhance feed efficiency. For example, using non-protein nitrogen sources like Optigen (a product developed by Alltech, a global leader in animal health and nutrition) can improve nitrogen efficiency in dairy rations, allowing for reduced dietary protein levels while maintaining milk production. This strategy has been shown to elevate income over feed costs by increasing milk yield while lowering feed expenses.

Improved feed efficiency not only reduces costs but also minimizes the environmental footprint of livestock production by decreasing the amount of feed required per unit of output.

Sustainability and Resource Utilization

Utilizing local and alternative feed sources promotes sustainability by reducing dependence on imported feed ingredients. This not only lowers costs but also supports local economies and reduces the carbon footprint associated with transporting feed over long distances (source: Beef Cattle Research Council 2024). By effectively managing resources and utilizing available by-products, livestock producers can create a more resilient and sustainable feeding strategy that adapts to market fluctuations and resource availability.

Risk Mitigation

Relying on a diverse range of feed sources can mitigate risks associated with price volatility in traditional feed markets. When feed prices rise, having alternative feed options can help stabilize costs and maintain profitability (source: ag-proud; by Mainville in 2023). Additionally, during times of drought or adverse weather conditions that affect crop yields, alternative feeds can provide a buffer against feed shortages, ensuring that livestock nutrition needs are met without incurring excessive costs.

The challenges facing the livestock industry, including increasing global population and the need for sustainable feed production. It highlights the importance of feed formulation in addressing these challenges by optimizing feed costs, improving animal performance, and minimizing environmental impact. The paper explores current feed formulation technologies, their limitations, and the potential of advanced decision support tools to enhance the process. It emphasizes the need for a more sustainable and resilient livestock system through the integration of technology and a focus on environmental stewardship —(Akintan et al., 2024).

The economic advantages of using lower-cost feed sources compared to purchased concentrates are clear. By incorporating alternative feeds, optimizing feed efficiency, and managing resources effectively, livestock producers can significantly reduce costs, enhance profitability, and contribute to sustainable agricultural practices. These strategies not only benefit individual farms but also promote broader economic resilience within the agricultural sector.

Conclusion

Livestock production is vital for Pakistan's economy, contributing significantly to GDP and employment. However, environmental concerns like greenhouse gas emissions and resource depletion necessitate sustainable practices.

Fodders and forages are crucial for sustainable livestock nutrition. They provide essential nutrients, improve animal health, and reduce reliance on expensive concentrates. Utilizing diverse forages and implementing advanced techniques like three-strata forage systems and agroforestry enhances feed quality and availability while promoting soil health and reducing erosion. Resource-efficient feed practices, such as utilizing home-grown forages and alternative feeds, lower feed costs and minimize environmental impact. Integrating sustainable practices, including improved feed formulation and carbon sequestration strategies, enhances the economic and environmental resilience of livestock systems. Optimizing fodder use, improving feed efficiency, and promoting environmental stewardship through collaborative efforts between policymakers, farmers, and researchers are crucial for achieving long-term food security and economic development in the livestock sector.

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