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Review

Assessing the Economic Viability of Sustainable Pasture and Rangeland Management Practices: A Review

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Abstract: The livestock sector is crucial for global food security and economic development, particularly in developing nations, as it supports the livelihoods of approximately 1.3 billion people. However, with the global population expected to reach 9.2 billion by 2050, the sector must address increasing demand for livestock products while ensuring environmental sustainability. This study used the available literature to evaluate the economic viability of sustainable pasture and rangeland management practices to enhance livestock production. The key findings demonstrate that strategies such as rotational grazing and nitrogen fertilization can decrease winter feed costs by up to 40% while simultaneously improving pasture productivity and animal weight gains. Initial investments in these improved forage practices offer high internal rates of return, indicating their profitability. To guide sustainable pasture production and rangeland management, we propose a conceptual framework that balances cultivated pastures and natural rangelands. This framework assesses critical factors, including input costs, expected outputs (enhanced biodiversity and livestock production), and interventions to mitigate land degradation. For successful adoption of these practices, targeted policies are essential. Governments should develop financial support mechanisms for smallholder farmers, improve transportation infrastructure for efficient feed logistics, and provide technical assistance to educate producers on sustainable practices. Engaging stakeholders to align policies with local needs is also vital. By implementing these strategic interventions, the resilience of livestock systems can be strengthened, contributing to long-term sustainability and supporting food security and rural community well-being.

Keywords: food security; livestock production; pasture economy; pasture management; sustainability

Academic Editor: Sanzidur Rahman

Received: 11 March 2025
Revised: 24 March 2025
Accepted: 24 March 2025
Published: 25 March 2025

Citation: Rapiya, M.; Mndela, M.; Truter, W.; Ramoelo, A. Assessing the Economic Viability of Sustainable Pasture and Rangeland Management Practices: A Review. *Agriculture* **2025**, *15*, 690. https://doi.org/10.3390/agriculture15070690

1. Introduction

The livestock sector plays a crucial role in the global food system, contributing significantly to poverty reduction, food security, and agricultural development [1,2]. It represents a major source of income, accounting for 40% of agricultural output in developed countries and 20% in developing nations [3,4]. This sector supports the livelihoods and food security of approximately 1.3 billion people worldwide [2]. However, over the past few decades, the global human population increased from around 3 billion to 7 billion, and it is estimated to be 9.8 billion by 2050 [5,6]. This population growth, combined with changes in dietary preferences and rising incomes in emerging economies, has created an unprecedented demand for livestock products [1]. Consequently, the livestock sector faces increasing pressure to meet the nutritional needs of a growing and changing population. In response to this demand, global production of livestock products such as meat and milk has significantly increased over the past 30 years, with production rising by approximately 43% and 55%, respectively [7]. This increase in livestock production is attributed to both the expansion of grazing lands and the intensification of grazing systems [1]. These expansion and intensification dynamics place pressures on grazing lands, including rangelands and planted pasturelands (cultivated pastures), which are the main sources of feed in livestock production systems globally [8]. This intensification and expansion can lead to soil degradation and the depletion of critical ecosystem services, thereby undermining the sustainability of pasture and livestock production systems [9]. As a consequence, these pressures threaten the health of pasturelands and food security, as the capacity to produce sufficient, nutritious feed for livestock is reduced, impacting overall agricultural productivity and resilience [10].

Recently, it has been reported that feed costs can account for up to 70% of total costs in typical livestock production systems [11]. This substantial financial burden highlights the need for more sustainable approaches to livestock production. One promising solution lies in the availability of grazing land, which presents an opportunity for farmers to enhance extensive livestock production, particularly in beef cattle production. By utilizing grazing pastures for livestock production, farmers can reduce reliance on purchased feed. Furthermore, increasing the efficiency of livestock production without utilizing additional land can be achieved through improved grazing management and pasture production practices [12,13]. In developing countries, where agriculture serves as a primary livelihood for many, the economic viability of grazing lands and their compatibility with ecological conservation are paramount concerns [14]. Consequently, understanding the economics of various grazing management and pasture production strategies is essential, especially as their feasibility can vary significantly based on the costs associated with implementation [15]. Moreover, the economic feasibility of sustainable pasture and rangeland management is determined by the balance between resource inputs and outputs, such as pasture establishment costs, management practices, livestock growth performance, and the revenue generated from final products, all of which influence financial returns [16]. Despite the growing recognition of sustainable management practices, there is currently no comprehensive study that evaluates the economic viability of both rangelands and planted pastures. Therefore, this review aims to assess the economic sustainability of pasture and rangeland management practices, focusing on their impact on livestock production, financial profitability, and the livelihoods of farmers. To achieve this objective, the study reviews the literature on the following specific objectives: first, it evaluates the cost effectiveness of different grazing management and pasture production strategies to enhance livestock growth and overall efficiency; and second, it investigates the financial returns from implementing sustainable rangeland management practices, with a focus on input costs and market prices for livestock products. This study provides a comprehensive understanding of the economic aspects of sustainable pasture and rangeland management, ultimately guiding future practices and policies in this vital sector. As noted in [17], the economic viability of the beef industry in many countries depends significantly on its ability to limit costs, particularly those related to animal feed.

Over the past 60 years, animal production has undergone significant transformations driven by advances in modern technology, the development of improved animal breeds, and enhanced grazing management practices. Additionally, the use of growth promoters, feed additives, and various financial incentives have played crucial roles in these changes.

However, while these advancements offer significant benefits, they can also contribute to the emergence of antibiotic-resistant bacteria, posing risks to both animal and human health. This challenge underscores the need for a balanced approach that carefully considers the socio-economic and environmental trade-offs involved [18,19]. In particular, while technological innovations can improve productivity, they may also lead to increased resource consumption and environmental degradation if not managed sustainably. Therefore, achieving a balance between economic growth and ecological integrity is crucial for ensuring the long-term sustainability of the agricultural sector. Sustainable pasture management or organic livestock farming plays a pivotal role in this balance, as it not only helps to enhance the natural productivity of grazing lands but also ensures a consistent and high-quality forage supply for livestock [20]. By preventing land degradation and mitigating climate change, which can otherwise lead to higher feed costs and reduced long-term productivity, sustainable pasture management supports the economic viability of the livestock industry, particularly the beef sector. This integrated approach protects both ecological health and economic performance, encouraging a resilient and sustainable future for the industry.

2. Global Trends in Livestock Production and Their Economic Implications

Livestock production is a major user of land around the world, using about 30% of the Earth's terrestrial surface for grazing and growing feed [21,22]. This sector represents a significant economic asset, valued at a minimum of $1.4 trillion. Since the 1960s, livestock production has grown considerably (Table 1), highlighting its important role in shaping agricultural landscapes and economic conditions, especially in developing countries [12]. Livestock systems are becoming increasingly organized in long market chains, providing jobs for at least 1.3 billion people globally and directly supporting the livelihoods of around 600 million smallholder farmers in poorer regions [23]. Currently, livestock is one of the fastest-growing agricultural sectors, particularly in developing nations, where it contributes 33% of agricultural GDP and is expected to continue rising. This growth is largely due to the increasing demand for livestock products, driven by factors such as population growth, urbanization, and rising incomes in these areas [24]. With the global population projected to reach approximately 9.15 billion by 2050, mostly in developing countries [25], the demand for livestock and the resources needed to support it will continue to grow (Table 2).

Table 1. Global trends in livestock numbers, growth rates, and carcass mass (1961–2050).

		No. Animals (m)			No. Animals A.G. (% p.a.)		Carcass Mass (kg/Animal)		
Region	**Livestock**	**1961**	**2007**	**2050**	**1961–2007**	**2007–2050**	**1961**	**2007**	**2050**
Developed	Cattle	352	318	320	−0.4	0.0	163	271	283
	Sheep and goats	577	389	460	−0.9	0.4	15	17	18
	Pigs	248	288	294	0.4	0.1	71	87	92
	Poultry	2568	5239	7212	1.6	0.7	1.3	1.9	1.9
Developing	Cattle	692	1215	1712	1.3	0.8	150	166	209
	Sheep and goats	779	1526	2478	1.5	1.1	12	13	17
	Pigs	176	629	846	2.5	0.7	49	74	81
	Poultry	1867	13,921	29,817	5.0	1.7	1.1	1.4	1.6

Table 1. *Cont.*

		No. Animals (m)			No. Animals A.G. (% p.a.)		Carcass Mass (kg/Animal)		
Region	**Livestock**	**1961**	**2007**	**2050**	**1961–2007**	**2007–2050**	**1961**	**2007**	**2050**
Globally	Cattle	1 045	1 532	2 032	0.8	0.6	158	202	227
	Sheep and goats	1356	1915	2939	0.8	1.0	14	14	17
	Pigs	424	917	1141	1.6	0.5	65	79	84
	Poultry	4435	19,160	37,030	3.6	1.5	1.3	1.6	1.7

Source: Alexandratos and Bruinsma [26].

Table 2. Growth rates of demand and production, percent p.a.

Demand (All Commodities—All Uses), Total	1990–2007	2007–2030
Developing	3.5	1.7
Developed	0.4	0.6
Globally	2.3	1.4
Production (All Food and Non-Food Commodities)		
Developing	3.4	1.6
Developed	0.3	0.7
Globally	2.2	1.3

Source: Alexandratos and Bruinsma [26].

Numerous studies underscore the vital role of livestock in supporting livelihoods and the economy in developing countries. For instance, ref. [27] revealed that livestock farming often uses resources inefficiently, leading to environmental issues. By enhancing the efficiency of animal husbandry, these problems can be mitigated while still providing essential benefits like food and income. Manure management is also significant; it serves as a valuable fertilizer on small farms but can pollute water on large industrial farms. Balancing these factors is crucial for sustainable agriculture. Another study [28] explored livestock's contributions to economic development and poverty reduction, emphasizing its importance for the livelihoods of the poor as demand for livestock products rises. However, due to trade protection measures in wealthier nations, developing countries have shifted from being net exporters to net importers of livestock products, destabilizing global prices and harming local producers. This scenario highlights the need for increased investment in livestock production to meet demand and improve rural incomes. Pica-Ciamarra [29] investigated the livestock-asset positions of rural households in 12 developing countries, aiming to understand livestock's role in economic growth and poverty alleviation. They found that while many rural households keep livestock, poorer households tend to have more animals, while the very poor often lack the resources to invest in even small livestock. Boyazoglu [30] emphasized the need for adaptive and sustainable livestock production systems to manage the impacts of rapid technological changes and evolving socio-economic conditions in marginal regions.

3. Cost–Benefit of Pasture Management Practices

Livestock production occurs in different types of systems, which can vary widely. Some systems are based mainly on grazing animals in areas with fewer people, called pastoral or pasture-based systems. Others combine raising animals with growing crops, commonly found in busier rural regions. There are also more intensive systems located near cities, where livestock can be raised in smaller spaces [28,31]. One of the biggest challenges in these livestock systems is the high cost of animal feed. Feed can make up about 75% of the total costs of raising animals, depending on the type of livestock. For instance, during the winter months, the costs of feeding animals can reach 60–65% of total production costs [32]. Research has shown that for cattle farms, the expenses for feed, bedding, and pasture usually amount to around 60% of overall costs, and winter feed alone can make up about 32% of those costs [31,33]. A study by Nyambali [34] found that the costs of hay grass and lucerne varied significantly between normal precipitation and drought conditions, costing $0.01 and $0.20, respectively, under normal conditions, and $0.30 and $0.22 during drought. Additional costs associated with feeding cattle during the winter include collecting and transporting feed, feeding the animals, and managing manure. By extending the grazing period outdoors, farmers could potentially reduce winter feeding costs by up to 40%, making beef farming more economically viable (Table 3) [35]. Table 3 presents an analysis of the daily winter forage costs per animal, taking into account fluctuating estimated forage production costs and corresponding loss percentages. As winter approaches, understanding these costs becomes crucial for livestock producers, as they directly impact both the budget and overall profitability during the colder months. For instance, at a 15% loss, the cost per animal increases from $1.41 at $80 per ton to $2.12 at $120 per ton. Similarly, a 35% loss at a $100 per ton production cost raises the daily cost from $1.76 to $2.31 per animal. These figures emphasize the importance of managing forage losses effectively and considering storage improvements or alternative feeding strategies to mitigate costs, especially when production costs are high.

Table 3. Daily winter forage costs per animal.

	Estimated Forage Production Cost per Ton			
	Loss (%)	**$80/t**	**$100/t**	**$120/t**
Estimated forage stored and losses	15	$1.41	$1.76	$2.12
	25	$1.60	$2.00	$2.40
	35	$1.85	$2.31	$2.77

NB: If the daily intake/cow is 13.61 kg per; Source: Burdine [33].

Furthermore, techniques such as planted pastures and effective grazing management systems can help to reduce feed costs on farms. Research conducted across various regions has highlighted the significant economic benefits of implementing sound pasture management practices (Table 4). For example, in Brazil, Souza [36] demonstrated that applying 180 kg N/ha of nitrogen fertilizer resulted in a profitability rate of 17.76%, a payback period of 2.79 years, and a substantial net present value (NPV) of USD 5926.03 at a 6% tax. Similarly, Shelton [37] found that Leucaena-grass pastures in Australia boosted animal production by up to four times, generating annual revenues of approximately $69 million, alongside environmental benefits such as nitrogen fixation.

In the USA, a mixed approach to managing woody plant encroachment yielded an NPV that surpassed traditional methods by $16,500 [38]. Also, a study by Ethridge [39] in Mexico and the USA revealed that while rangeland seeding was often not financially viable, certain species like blue grama offered promising returns. In Slovakia, Fürtner [40] showed that switching to poplar short rotation coppice resulted in significantly lower economic returns than traditional crops, highlighting the importance of prudent crop selection. In Kenya, improved forage varieties yielded higher profitability when sold as hay; however, high input costs remained a challenge [41]. Lastly, a study by Badgery [42] in China found that lower stocking rates improved both livestock productivity and environmental health, emphasizing the economic and ecological advantages of moderate grazing practices. Therefore, optimized fertilizer use in pasture management can significantly increase profitability, while high-productivity pastures, despite their high initial costs, offer long-term financial benefits. Moreover, mixed-species grazing has been shown to outperform traditional management practices in terms of profitability. Efficient grazing management and land use are crucial for balancing profitability, sustainability, and ecosystem health.

Table 4. Summary of successful studies on the economic benefits of pastures.

Region	Techniques Used	Key Findings	Reference
Brazil	The study follows a structured methodological approach, including experimental design, data collection, economic evaluation, multivariable analysis, and sensitivity analysis to assess the impact of nitrogen fertilization on forage production, animal performance, and economic viability.	The study found that applying 180 kg N/ha was the most cost-effective fertilizer level for beef cattle production in tropical pastures. This treatment resulted in 17.76% profitability, a 2.79-year payback period, and an internal rate of return of 35.79%, with net present values of USD 5926.03 (6% tax) and USD 1854.35 (12% tax).	[36]
Australia	The review explored the adoption, benefits, and challenges of *Leucaena*-grass pastures in northern Australia.	The study observed that Leucaena pastures increase animal production by up to four times, increasing profitability, with current plantings valued at $69 million per year, and are expected to expand to 300,000–500,000 ha by 2017. These pastures also offer significant environmental benefits, including nitrogen fixation and methane reduction, although concerns about its environmental weed status and the need for a cost–benefit analysis persist.	[37]
USA	This study evaluated five technologies for managing woody plant encroachment in rangelands, including cattle grazing with various combinations of prescribed fire and goat grazing, to determine the highest expected economic returns while considering costs, benefits, and additional revenue opportunities.	This study found that mixed-species grazing with breeding goats and prescribed burning was the most economical, with a $16,500 higher net present value (NPV) than traditional management. Stocker goat operations were too costly, but late-season supplementation was a cheaper option than season-long feeding.	[38]
Mexico and USA	The study assessed the factors affecting rangeland seeding success, using data from trials to model the impact of environmental and management variables on plant establishment and evaluating the economic feasibility of seeding.	The study tested how well native and introduced grasses grow and whether seeding is worth the cost in the Chihuahuan Desert. It was found that seeding is generally not a good financial investment. If seeding is necessary, blue grama and Lehmann lovegrass are the best cost-effective options with little or no seedbed preparation.	[39]
Slovakia	The study used a sequential mixed-methods approach, integrating both quantitative economic modeling and qualitative expert interviews, to assess socio-economic and environmental impacts, including soil organic carbon modeling and regional value-added calculations.	The study examined the sustainability of switching from annual crops to poplar short rotation coppice (SRC) in Western Slovakia. Poplar SRC had a much lower economic return (€2.21 ha^{-1}) than corn maize (€12.20 ha^{-1}) and winter rye (€9.80 ha^{-1}), with a long payback time of 14.13 years. It also provided the lowest regional value added (€1.80 ha^{-1}) compared to corn maize (€10.80 ha^{-1}) and winter rye (€8 ha^{-1}).	[40]
Kenya	The study used field measurements, expert consultation, secondary data, and a literature review to assess profitability through discounted free cash models, with key economic indicators such as Present Value (NPV), Internal Rate of Return (IRR), and Return on Investment (ROI) for different forage varieties and agronomic management scenarios.	The study assessed the profitability of improved forage varieties in Western Kenya. Selling forage as hay was more profitable than selling it fresh due to higher market prices. However, high input costs like excessive fertilizer use reduced profitability, highlighting the need for better farmer training.	[41]
China	The study utilized various techniques, including experimental grazing treatments with different stocking rates, measurement of herbage mass, and monitoring of sheep liveweight gain and greenhouse gas emissions, to evaluate the impact of grazing management on livestock productivity and grassland health.	The objective of the study was to assess how stocking rates and grazing management affect livestock production, grassland composition, and ecosystem services in China's grasslands. Lower stocking rates improved both greenhouse gas mitigation and profitability, with a reduction of 30–50% below district averages, proving to be beneficial in the desert and typical steppe. Maintaining an herbage mass above 0.5 t DM ha^{-1} was key for profitability and ecosystem services, with moderate grazing pressure showing the best results in the typical steppe.	[42]

Collectively, these studies suggest that maintaining moderate grazing pressure and lower stocking rates in rangelands improves both profitability and ecology services by reducing greenhouse gas emissions and preserving good rangeland conditions. In planted pastures, applying optimal fertilizer levels and integrating nitrogen-fixing plants can enhance productivity and economic returns while minimizing environmental risks. However, high input costs, such as excessive fertilization or expensive seeding efforts, can lower profits. This emphasizes the importance of conducting better cost–benefit analyses and providing training for farmers.

3.1. Planted Pastures

Pastures, which consist mainly of grasses and legumes, are vital for providing livestock with essential nutrition, especially in developing countries where they support the production of nutrient-dense foods like meat and milk [43]. The value of these cultivated forages is determined by the area they cover, their yield, and market price [44]. However, achieving high forage production requires effective management practices. Pasture maintenance costs, including expenses for fertilizer, lime, seed, machinery, and clipping, typically range from \$50 to >\$150 per ha, depending on factors like fertility and cutting frequency [45]. For instance, irrigating established pastures with 19 to 25 mm of water is crucial for optimizing production [46]. Furthermore, Table 5 outlines the operational costs associated with forage cultivation, which include seeds priced at \$1 per kilogram per hectare, fencing materials at \$2 per count per hectare, and manure at \$0.35 per load. Fertilizer costs are \$0.40 per kilogram per hectare, while essential agronomic practices, such as ploughing and weeding, are each priced at \$1.69 per hectare. Irrigation costs are estimated at \$1.69 per millimetre per hectare, with additional costs for cutting and storage of fodder, housing maintenance, and transportation, all valued at \$1.69 per short task. Effective management of these inputs is critical to optimizing yields, ensuring cost efficiency, and maintaining the long-term profitability of forage production systems. Given the significant expenses involved, strategic and sustainable management of pastures is essential to sustaining their productivity and economic viability.

Table 5. Inputs and unit costs for the operational stage of forage cultivation.

Item	Units	Unit Price $ (U.S. Dollars)
Seeds	Kg/ha	1
Fencing materials and posts	Count/ha	2
Manure	Load	0.35
Fertilizer	Kg/ha	0.40
Plough	ha	1.69
Weeding	ha	1.69
Irrigation	1 mm/ha	1.69
Cut and storage fodder	Short days	1.69
Housing maintenance	Short tasks	1.69
Transportation	Short tasks	1.69

Source: Ng'ang'a [47]. NB: with the assumption that future prices of inputs and outputs would increase by 1% per year in real terms, beyond the rate of inflation.

Several studies have highlighted the extensive economic benefits of nitrogen (N) fertilization in pasture production, emphasizing its role in enhancing both efficiency and sustainability. For instance, Smith [48] conducted research in Australia showing that strategic nitrogen application, tailored to the specific nitrogen status of plants, can significantly improve nitrogen use efficiency, reduce inputs and losses, and maintain pasture yield. The study used DairyMod version 5.7.5 to test seven fertilizer strategies. These strategies included flat, seasonal, and precision agriculture approaches. The goal was to optimize nitrogen use efficiency. This is an important factor due to rising fertilizer costs and the increasing demand for sustainable agricultural practices. The findings highlight that fertilizing according to plant nitrogen requirements is the most efficient method, outperforming fixed-rate or soil nitrogen-based strategies, and should be prioritized, especially given the high cost of slow-release fertilizers. Similarly, the study by Souza [36] employed a randomized experimental design with four nitrogen fertilization treatments to assess tropical pasture management for beef cattle. The treatments focused on monitoring animal performance and adjusting stocking rates to manage pasture height. Economic evaluations, including profitability and sensitivity analyses, were conducted using principal component analysis and factor analysis to evaluate the impacts of different factors on production costs and profitability. The findings revealed that applying 180 kg of nitrogen per hectare resulted in significant financial gains, with an internal rate of return (IRR) of 35.79% and a net present value (NPV) of USD 5926.03 at a 6% tax rate, making it the most profitable fertilization level tested in the study. Further supporting these findings, Euclides [49] assessed the economic returns from varying nitrogen levels in Mombaça guinea grass. The study used a randomized complete block design with nitrogen treatments (100, 200, and 300 kg N/ha), measuring soil composition, forage mass, and canopy height, while managing grazing and stocking rates. Animal performance was also monitored, and forage quality was analyzed using NIRS. Statistical and economic analyses, including partial budget and Benefit–Cost Ratio (BCR) calculations, were applied to assess the impact of nitrogen treatments. The findings revealed that increasing nitrogen from 100 to 200 kg N/ha provided the best return on investment, with USD 3.73 earned for every additional dollar spent. However, transitioning from 200 to 300 kg N/ha resulted in diminishing returns of only USD 1.60 per dollar invested, despite achieving the highest net profit per hectare. Furthermore, these studies consistently indicate that nitrogen fertilization improves pasture yield, nitrogen use efficiency, and overall profitability, particularly when nitrogen application is adjusted to plant-specific requirements. These outcomes are effectively assessed through the evaluation of animal performance, the adjustment of stocking rates, and economic analyses, including profitability and sensitivity assessments, which collectively provide a detailed understanding of the effects of nitrogen treatments on both productivity and financial viability.

Despite these economic advantages, excessive or improper use of nitrogen fertilizers can contribute to soil degradation, water pollution through nitrate leaching, and greenhouse gas emissions, particularly nitrous oxide. Additionally, the high costs associated with nitrogen-fertilized pastures have driven research into more sustainable alternatives such as integrating legumes and grasses within intensive pasture systems [50]. Ref. [51] emphasized the importance of identifying effective grass-legume combinations for establishing productive crop-livestock integration systems under no tillage, allowing better adaptation to the bio-edaphoclimatic conditions of the Brazilian Cerrado. In this context, innovative practices such as pasture cropping, which enhances the area of perennial forages in mixed livestock and cropping systems by directly sowing annual species into an established living perennial pasture [52], have emerged. Additionally, intercropping the simultaneous planting of two or more crops in the same field has gained traction across various environments worldwide, offering potential benefits in terms of biodiversity and resource efficiency [53]. Together, these strategies represent vital approaches to optimizing pasture productivity and sustainability in agricultural systems, balancing economic benefits with environmental considerations. Importantly, smallholder farmers, who often operate under resource constraints [54], can particularly benefit from these innovations. By adopting more cost-effective and sustainable practices such nitrogen-efficient fertilization, legume and grass integration, and intercropping, smallholders can improve pasture productivity while reducing input costs. These practices offer a pathway to increase the resilience and profitability of smallholder farming systems, ensuring long-term sustainability and food security.

3.2. Grazing Management Systems

In a time of high-cost inputs, pasture-based livestock production systems offer an effective means of maintaining soil and plant integrity while promoting the growth of healthy ruminants [55]. In recent decades, significant research has focused on the interactions between grazing herbivores and pasture vegetation [56]. The productivity of pastures is typically assessed by measuring animal output per acre or per head throughout the grazing season. This productivity reflects the combined effects of forage growth and the efficiency with which animals convert forage into animal products [44]. Investments in rangelands have primarily aimed at enhancing livestock production by increasing forage availability grazing areas [57,58]. Livestock farming plays a crucial role in the global economy, particularly in developing countries, where it serves as a vital source of food and income for households. Proper grazing and rangeland management practices can significantly improve productivity and provide essential employment opportunities [12,58]. To promote sustainable management of rangeland resources and improve livestock production while protecting rangelands from degradation, various management strategies have been implemented globally [59–61]. However, some of these practices have not achieved the expected levels of productivity, leading to continued challenges in enhancing the well-being of pastoral communities and preventing rangeland degradation [62,63].

Furthermore, sustainable grazing management plays a critical role in the restoration and sustainable use of degraded grazing lands. Studies suggest that well-planned and adaptively managed systems, such as those with short grazing periods, are key to maintaining healthy rangelands [64–67]. These systems emphasize retaining sufficient plant cover and litter, which protects the soil and promotes rapid plant regrowth. By allowing adequate time for grazed plants to recover and adjusting livestock numbers to match available forage, grazing can support both ecosystem functions and livestock nutrition, ultimately benefiting productivity and profitability [66,67]. In recent years, several approaches to managed grazing have emerged, including multi-paddock grazing, holistic planned grazing, and mob grazing [65]. While rotational and continuous grazing are often seen as equally effective on rangelands [68,69], implementing and maintaining these systems can come with additional costs, as highlighted by Burdine [45], who used a cost estimation method based on inputs such as fertilizer, machinery, fuel, and labor, as well as sensitivity analysis to evaluate pasture maintenance, stocking rates, and grazing costs. It emphasizes the importance of forage utilization rates and compares grazing days to winter feeding days, considering scenarios like fall fertilization and annual crops for cost efficiency (Table 6). For example, dividing grazing areas into units involves the cost of fencing and maintenance, which can be a financial burden for both private ranchers and national agencies [56,70]. Recent estimates indicate that fencing costs range from $1.18/ha for mobile electric fencing to $18.27/ha for high-tensile electric fencing [71]. A study by Sanqiang [72] used a questionnaire survey method, collecting data from 121 randomly sampled households in Maqu County on the Qinghai–Tibet Plateau, and compared the economic viability of rotational grazing systems (RGS) and continuous grazing systems (CGS) among herder households in Maqu County on the Qinghai–Tibet Plateau. Although RGS offered ecological benefits, its higher production costs per sheep unit hindered its adoption. Additionally, herders encountered difficulties in adapting to the new practices required for RGS, such as managing native grass availability and implementing supplementary feeding.

Table 6. Expected average costs of grazing per day.

		Estimated Pasture Maintenance Costs/ha				
		$50/ha	**$75/ha**	**$100/ha**	**$125/ha**	**$150/ha**
Estimated Stocking Rate	2 ha per head	$0.40	$0.60	$0.80	$1.00	$1.30
	3 ha per head	$0.6	$0.90	$1.30	$1.60	$2.0
	4 ha per head	$0.80	$1.30	$1.70	$2.10	$3.0

Source: Burdine [45].

The long-term benefits of improved land health and more efficient grazing systems can significantly offset costs in beef production. According to ref. [65], beef cattle finished on high-quality pasture can achieve average daily gains of 1 kg or more and reach market weight within 20 months, costing only $27 per hundred-weight of gain, compared to $60 in confinement systems. Additionally, Parker [73] found that cows grazing on pasture consumed more forage while relying less on stored feed, making grazing systems more profitable, as each cow on a grazing farm generated $121 more in gross margin than those in confinement. These findings align with ref. [74], which emphasizes the economic benefits of forage improvement in the USA. For instance, the alfalfa industry contributes an estimated $8.1 billion annually, while forage and livestock systems in the southeastern USA generate around $11.4 billion per year. Together, these findings underscore the importance of sustainable forage practices, which not only enhance land health but also yield significant economic benefits in livestock production. In a study by [75], an economic analysis of different grazing systems, namely, seasonal long grazing, four-camp rotational grazing, and holistic planned grazing, found varying net profits in the first two years. In year one, the net profits per hectare for these systems were $112.50, $4.74, and $5.97, respectively, while in year two, the profits increased to $116.50, $8.32, and $10. The total capital costs for these systems were $41.90, $23.92, and $30.40 in year one and $37.90, $20.34, and $26.40 in year two, respectively.

Over time, investing in sustainable grazing systems, including fencing and infrastructure, can lead to significant financial returns [45]. While there is an initial cost for fencing and infrastructure, these expenses are quickly recovered through increased productivity. For example, this study predicted that, over 10 years, a well-managed grazing system can generate an average net profit of $1000 per hectare each year. Additionally, by improving forage quality and increasing animal weight gain, farmers can boost their gross margin by $121 per cow per year. For a 10-cow farm, this means an extra $1210 annually, leading to total gross margin gains of over $12,100 over a decade. When combined with the added benefits of healthier land and lower feed costs, these long-term financial gains show how sustainable grazing practices can both restore ecosystems and increase profitability in livestock farming.

4. Financial Framework for Sustainable Pasture and Rangeland Production

Sustainable pasture and rangeland management requires strategic approaches to address the shortage of feed for livestock caused by climate change, land degradation, and the increasing human population [76,77]. Recent global environmental changes, such as the sudden onset of droughts, extreme storm events, land fragmentation, and the introduction of non-native species, have further exacerbated these challenges. Additionally, rising livestock feed prices have led to decreased livestock production worldwide [78–80]. Furthermore, Hruska [81] highlighted that rangelands and pastures are sensitive to socio-economic changes that affect operation costs, commodity prices, consumer preferences, energy development, and environmental policy. Given these complex interdependencies, it is crucial to develop effective approaches and systems (frameworks) that can enhance the resilience of pastures and rangelands.

While several studies have proposed frameworks focused solely on rangeland utilization and management, such as the Science Framework by Chambers [82], which connects the Department of the Interior's Integrated Rangeland Fire Management Strategy with targeted conservation actions for the sagebrush biome, there is growing recognition of the need for comprehensive approaches. This framework strategically identifies priority management areas by analyzing ecosystem resilience and resistance to invasive species, alongside habitat requirements for species like the greater sage-grouse. By employing geospatial tools and a resilience-resistance habitat matrix, this framework provides essential guidance on risk assessment and adaptive management strategies, ultimately enabling the protection and sustainability of sagebrush ecosystems and their biodiversity. Moreover, the decision framework developed by [83] emphasizes the importance of integrating fire regime characteristics with plant traits to enhance the management of rangeland plant communities. This approach highlights how factors such as fire intensity, seasonality, and frequency influence plant responses, particularly regarding species dominance and community composition. By combining fire regime components with plant life forms and survival attributes, practitioners are provided with a strategic guide to effectively manage rangeland ecosystems. Furthermore, ref. [79] underscored the necessity of adaptive management frameworks in pastoral systems to enhance resilience against climate variability and ensure sustainable livestock productivity. Their findings, linked with the observed impacts of changing precipitation patterns on forage production and herd dynamics, further emphasized the critical importance of integrating climate data and adaptive strategies into rangeland management practices. Similarly, Misiuk [84] proposed a model that accounts for the balance between livestock product production and consumption, which can help to implement measures to manage food security.

On the other hand, there is limited literature on a financial framework for both sustainable pasture and rangeland productivity. In this context, a close study conducted by [85] developed a socio-ecological system (SES) framework to evaluate the impacts of climate and land use changes on these systems. A key observation of their research was the selection of critical indicators, such as evaporative demand, land cover extent, and aboveground plant biomass, which assessed the resilience and vulnerability of rangeland ecosystems. Additionally, the framework emphasized the importance of evaluating the economic value of cattle products relative to the total agricultural value.

This approach provides valuable insights for sustainable livestock production and guides policy decisions aimed at enhancing the viability of rangeland and pasture systems amidst changing environmental conditions. However, there is currently no study on the economic viability of sustainability for both rangelands and planted pastures.

Building on these insights and observations about the input and output costs for sustainable rangeland and pasture management from several studies [33,47,48,56,70–75] and those highlighted in Table 4, the current study proposes a comprehensive framework for sustainable pasture production and rangeland management, as shown in Figure 1. This framework seeks to balance both cultivated/planted pastures and natural rangelands by considering key factors such as the cost of input resources (e.g., land preparation, fertilizers, seeds, irrigation, herbicides, fencing materials, and storage), the expected resource outputs (e.g., improved biodiversity, increased vegetation cover, high-quality forage, enhanced animal production, and greater income), and with the target of addressing (targeted interventions) issues such as the reduction of land degradation and increased livestock production. By integrating these elements, the framework aims to optimize productivity while ensuring ecological and economic sustainability.

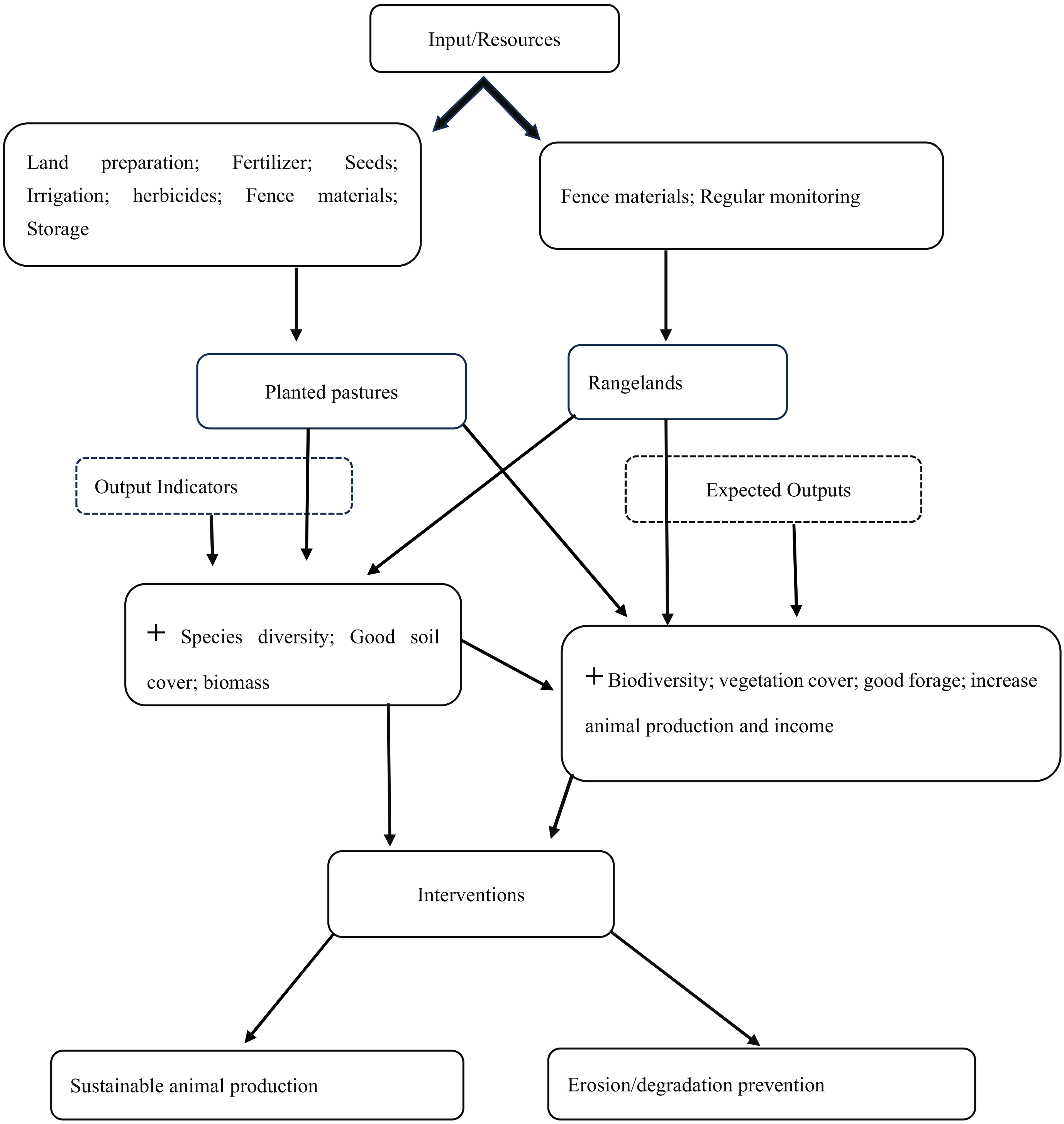

Figure 1. Conceptual framework for sustainable pasture production and rangeland management practices. (+) Indicates positive effects. Solid arrows indicate causal relationships, and small arrows indicate causal effect.

5. Limitations in Adopting Sustainable Pasture Management Systems

Despite the ecological and financial benefits of sustainable pasture and livestock systems, their adoption in communal areas remains challenging due to financial and logistical barriers. Land ownership is a major issue for smallholder farmers, as communal lands are not privately owned. This results in the absence of clear grazing management plans and unrestricted livestock movement, often leading to overgrazing [86]. The lack of ownership discourages individual farmers from investing in long-term improvements, such as fencing and infrastructure. Additionally, the initial investment required for sustainable practices, such as managed grazing or establishing planted pastures, is often unaffordable due to limited financial resources [87,88]. Smallholder farmers also face difficulties in securing the necessary resources for feed collection, storage, and transportation [89]. Without adequate access to credit, technical assistance, and policy interventions, transitioning to more sustainable and cost-effective systems remains a challenge. Furthermore, one critical issue is the excessive or improper use of nitrogen fertilizers, which, while enhancing pasture productivity, can contribute to soil degradation, water pollution through nitrate leaching, and greenhouse gas emissions, particularly nitrous oxide. The high costs associated with nitrogen-fertilized pastures further burden resource-limited farmers [90]. To overcome these barriers, comprehensive policy frameworks and financial mechanisms are essential. Interventions should include targeted financial support, improved access to credit, enhanced transportation infrastructure, and training and technical assistance to help farmers implement sustainable practices effectively. Addressing these challenges will not only cut costs and improve the economic viability of livestock farming but also contribute to broader ecological sustainability goals.

6. Conclusions

This review of the literature emphasizes the importance of sustainable pasture and rangeland management practices for improving livestock production and farmers' livelihoods. The findings reveal that certain strategies can greatly reduce costs. For example, extending outdoor grazing periods can cut winter feed costs by up to 40%. Effective use of nitrogen fertilizers also plays a crucial role in increasing pasture productivity. One study demonstrated that applying 180 kg of nitrogen per hectare led to a substantial internal rate of return (IRR) of 35.79% and a net present value (NPV) of $5926.03 at a 6% tax rate.

Additionally, grazing on Leucaena-grass pastures in Australia resulted in animal production increases of up to four times, while in Kenya, selling hay was found to be more profitable than selling fresh forage. This illustrates the need to identify the most effective practices based on local conditions, as different areas may require different strategies. While the literature highlights promising profitability rates from these sustainable practices, there is a need for a clearer summary of which practices are most effective and under what circumstances. This review shows that certain methods like using nitrogen-fixing plants in Brazil or improving forage varieties in Kenya have demonstrated strong economic returns. However, to encourage the adoption of these sustainable practices, specific recommendations arise from this review. Policymakers should develop financial programs that help smallholder farmers to cover the initial costs associated with transitioning to sustainable practices. Improving transportation infrastructure would also assist farmers in managing feed logistics more effectively. Furthermore, targeted training programs should be established to educate farmers about sustainable practices tailored to their specific contexts. Despite these findings, it is important to note the limitations of this literature review. The results are based on the existing body of research, which may not fully capture all regional or agricultural variations. Therefore, more empirical studies are necessary to confirm these insights and examine market dynamics and environmental impacts in real-world conditions. By adopting these recommendations and addressing the identified limitations, stakeholders can promote better sustainable pasture and rangeland management practices, ultimately enhancing the resilience of livestock systems amid increasing environmental challenges.

Author Contributions: M.R. took the lead in writing the article. All authors provided significant feedback and contributed to structuring the study. M.M., W.T. and A.R. made substantial contributions to the conceptual development of the article. All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

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