

## Article

# An Economic Evaluation of an Intensive Silvo-Pastoral System in San Martín, Peru

John Jairo Junca Paredes <sup>1</sup>, Sandra Guisela Durango Morales <sup>2</sup>  and Stefan Burkart <sup>1,\*</sup> 

<sup>1</sup> Tropical Forages Program, International Center for Tropical Agriculture (CIAT), km 17 recta Cali-Palmira, Cali 6713, Colombia; j.junca@cgiar.org

<sup>2</sup> Multifunctional Landscapes, International Center for Tropical Agriculture (CIAT), km 17 recta Cali-Palmira, Cali 6713, Colombia; s.durango@cgiar.org

\* Correspondence: s.burkart@cgiar.org

**Abstract:** The cattle sector plays a critical role in Peru's agricultural economy, yet it faces challenges related to low productivity and environmental degradation. Sustainable alternatives like silvo-pastoral systems (SPSs) offer promising solutions to enhance both economic returns and ecological outcomes in cattle farming. This study examines the economic viability of an intensive SPS (SPSi) compared to traditional monoculture grass systems in San Martín, Peru. The SPSi under study is in the evaluation phase, integrates grasses, legumes, shrubs, and trees, and has the potential to enhance cattle farming profitability while simultaneously offering environmental benefits such as improved soil health and reduced greenhouse gas emissions. Through a discounted cash flow model over an eight-year period, key profitability indicators—Net Present Value (NPV), Internal Rate of Return (IRR), Benefit–Cost Ratio (BC), and payback period—were estimated for four dual-purpose cattle production scenarios: a traditional system and three SPSi scenarios (pessimistic, moderate, and optimistic). Monte Carlo simulations were conducted to assess risk, ensuring robust results. The results show that the NPV for the traditional system was a modest USD 61, while SPSi scenarios ranged from USD 9564 to USD 20,465. The IRR improved from 8.17% in the traditional system to between 26.63% and 30.33% in SPSi scenarios, with a shorter payback period of 4.5 to 5.8 years, compared to 7.98 years in the traditional system. Additionally, the SPSi demonstrated a 30% increase in milk production and a 50% to 250% rise in stocking rates per hectare. The study recommends, subject to pending validations through field trials, promoting SPSi adoption through improved access to credit, technical assistance, and policy frameworks that compensate farmers for ecosystem services. Policymakers should also implement monitoring mechanisms to mitigate unintended consequences, such as deforestation, ensuring that SPSi expansion aligns with sustainable land management practices. Overall, the SPSi presents a viable solution for achieving economic resilience and environmental sustainability in Peru's cattle sector.

**Keywords:** agroforestry system; sustainable cattle farming; profitability indicators; Monte Carlo simulation; dual-purpose cattle



Academic Editor: Fabio Gresta

Received: 11 March 2025

Revised: 5 May 2025

Accepted: 16 May 2025

Published: 20 May 2025

**Citation:** Junca Paredes, J.J.; Durango Morales, S.G.; Burkart, S. An Economic Evaluation of an Intensive Silvo-Pastoral System in San Martín, Peru. *Grasses* **2025**, *4*, 21. <https://doi.org/10.3390/grasses4020021>

**Copyright:** © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

The agricultural sector contributes 6.4% to Peru's Gross Domestic Product (GDP) [1], with livestock accounting for 36.5% of this share. Within the livestock sector, the poultry industry (including poultry, chickens, and eggs) dominates at 42.5%, while cattle and raw milk represent 4% and 4.5%, respectively [2]. Nearly half of the country's dairy production operates within a context of business and technical informality, which negatively impacts

both product quality and profitability in the livestock industry [3]. Peru also has the lowest per capita beef consumption in South America at 5.9 kg per person per year, a figure that is well below the national consumption rates for chicken (51.5 kg per person per year) and fish (18.7 kg per person per year) and closely aligned with pork consumption at 5.8 kg per person per year [2,4].

The San Martín province, located in northeastern Peru, has a relatively small cattle sector compared to its dominant poultry industry. Livestock contributes 14.8% to the province's agricultural GDP, with beef and milk accounting for 2.4% and 1.3%, respectively, while poultry represents a significant 8.5% share [5]. In San Martín, cattle farming predominantly relies on dual-purpose systems. However, the widespread use of extensive farming practices results in poor animal nutrition, which in turn leads to low productivity and quality levels [6]. Environmentally, the region has been heavily impacted by deforestation [7]. Despite these challenges, the growing market potential presents a significant opportunity for economic development within the cattle sector but also a threat to sustainability. Implementing more productive and efficient systems could revitalize cattle farming in the region but if not well managed lead to more deforestation and environmental degradation.

One promising alternative for sustainable growth is the adoption of silvo-pastoral systems (SPSs). These systems not only enhance productivity and income but also offer environmental benefits, such as reduced per area greenhouse gas emissions, increased biodiversity, and microclimatic regulation, among others [8–12]. As a result, SPSs have emerged as a cornerstone of agrarian policy aimed at fostering sustainable cattle farming systems [13]. Among the different types of SPS, the intensive SPS (SPSi) combines grasses, legumes, shrubs, and trees for animal nutrition, allowing for intensified production while mitigating the environmental impact of cattle farming [14]. The additional components to grasses offer a series of advantages. Perennial legumes fix their nitrogen, contributing to greater meat or milk production [15]. Likewise, they reduce the environmental impact since they depend less on synthetic fertilizers [16]. With the inclusion of trees, the SPSi can provide microclimatic regulation, reduce wind speed, solar radiation, and thermal stress during periods of high temperature [17].

For the region, several analyses and evaluations have highlighted the technical advantages of SPSi [7,18,19]. However, a deeper investigation into the economic performance of these systems is needed as this is a critical factor for producers when considering the adoption of new technologies. Implementing an SPSi requires new investments, making it essential to determine whether the resulting income compensates for and exceeds these additional expenses. In Peru, particularly in the San Martín province, such economic analyses remain scarce. Given this context, the objective of this study is to carry out an economic evaluation of an SPSi in the Tarapoto municipality, located in the San Martín province, which is in the evaluation phase. The system under analysis is a dual-purpose cattle system with Girolando cattle and was established on an area of 2.5 hectares. Its components include the grass *Urochloa brizantha* cv. Marandú, which covers 7200 m<sup>2</sup> (72%) per hectare, the legume *Centrosema macrocarpum* covering 800 m<sup>2</sup> (8%) per hectare, the shrub *Tithonia diversifolia* covering 1500 m<sup>2</sup> (15%) per hectare, and a range of timber trees occupying 500 m<sup>2</sup> (5%) per hectare. The trial was designed to reflect regional production conditions. The selection of system components and the projections of data on productivity, costs, and expected income are based on expert opinions, the scientific literature, commercial market information, and official statistical data [2,20–25].

The economic evaluation includes four scenarios. The first is the baseline technology, which is the traditional system, a monoculture of the grass *Urochloa brizantha* cv. Marandú. The other three are the described SPSi under pessimistic, moderate, and optimistic scenarios. The definition of the scenarios corresponds to expectations of improvements in milk

and beef productivity. Through a discounted cash flow model over 8 years, profitability indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit–Cost Ratio (BC), and payback period (PR) were estimated for each of the scenarios. Monte Carlo simulations were conducted to incorporate probability elements into the analysis, providing a greater robustness to the results.

Apart from this introduction, the document is structured as follows: Section 2 provides an overview of cattle farming in the Peruvian Amazon region, with a particular focus on San Martín, and explores the motivations behind promoting the adoption of the SPS in the region. Section 3 outlines the materials and methods used for the economic evaluation and describes the scenarios studied. Section 4 presents the results, which are then compared with findings from the literature in the discussion in Section 5. Finally, the study's conclusions and recommendations are presented in Section 6.

## 2. Cattle Farming in San Martín Province

The national cattle population in 2022 was estimated at 5,862,308 animals, with 945,553 milking cows [2]. The San Martín province accounts for 213,453 cattle, representing 3.64% of the national total. In terms of milking cows, the region has 20,406, which corresponds to 2.16% of the national total. In Peru's milk market, the demand for raw milk is driven by industrial companies such as Leche Gloria, Laive, and Nestlé Peru, followed by several medium and small-scale companies. These industries collectively process 48% of the national production. Another 42% is handled by approximately 6500 artisanal plants throughout the country, of which only about one-tenth are considered formal. The remaining 10% of production is used for calf feeding and family consumption [26].

### 2.1. Motivation to Encourage the Adoption of SPS in San Martín Province

In the provinces of Amazonas and San Martín, production units are typically small, generally covering less than 10 hectares [27,28]. Regarding pasture performance, over 70% of the secondary forests in the Peruvian Amazon ecoregion consist of low-productivity native pastures, degraded improved pastures, and areas at various stages of recovery. The absence of technical management, animal overstocking, and overgrazing has led to nutrient depletion, negatively impacting soil quality. Deforestation for the creation of pastureland is a recurring issue. Currently, extensive grazing remains the dominant practice in these regions. SPSs offer a sustainable solution by promoting more efficient land management [7,29].

Some experiences in San Martín, evaluating *Urochloa brizantha* and leguminous shrub species in living fences, shading, and protein banks, have demonstrated acceptable performance results [19]. Additionally, other studies in the region have analyzed silvo-pastoral systems (SPSs) incorporating *Urochloa decumbens*, *Inga edulis* (Guaba trees), and *Eucalyptus* species in both dispersed arrangements and as living fences. The dispersed trees were remnants of those previously used for timber, firewood, and construction materials. Living fences have been established with a focus on cattle farming, serving to delimit pastures and provide shade for animals [7,30]. Despite these positive examples, such SPS arrangements remain underutilized, and there is limited technical training available for producers in the region. As a result, these systems are often implemented spontaneously, without institutional support or follow-up, and their benefits have yet to be fully quantified [7].

Although SPSs are not widely known, local producers in San Martín implement some of their techniques, such as living fences to manage cattle and as a source of feed and protection [27]. In the context of extensive cattle farming and limited diversity in feeding systems, there are significant opportunities to further develop these technologies. One positive externality is the environmental impact of these transformations. Works highlights

the role of trees in mitigating greenhouse gases [31]. For example, *Eucalyptus viminalis* has shown potential for carbon capture in an SPS in northern Peru. Providing empirical evidence on the economic and environmental viability of SPSs is crucial to promoting wider adoption [28,32–35].

## 2.2. Intensive Silvo-Pastoral Systems

SPSs combine tree cultivation with cattle farming, providing shade for animals, complementing their diet, and improving their overall living conditions [36]. The primary goal of SPSs is to enhance efficiency while minimizing the environmental footprint of cattle farming [37]. Among the various SPS configurations, notable arrangements include living fences, dispersed trees and shrubs within pastures, protein banks, intensive silvo-pastoral systems (SPSis), and windbreaks [38].

The particular focus of this study is on the economic evaluation of the SPSi. The SPSi enhances the production of high-quality forage, reduces production costs, increases productivity per hectare, and promotes biodiversity [39,40]. The SPSi is an agroecological system composed of three layers, strata, or levels [38]. The upper layer consists of native, fruit, or timber trees, which contribute by reducing cattle heat stress through shading, providing protection against strong winds, and lessening the impact of raindrops, thus mitigating soil erosion. These trees also serve as refuges for wildlife, facilitating biological pest control, and offer additional income opportunities, such as through the sale of timber or fruit. The second layer comprises leguminous shrubs, known for their high protein content. These shrubs often have flexible stems to prevent breakage during grazing. In the lowest layer, grasses are used for grazing, often mixed with legumes, which enrich the diet and contribute nitrogen and organic matter to the soil. The environmental impact of adopting an SPSi is substantial. The additional plant matter and the increased root density in the system improve water retention, carbon content, and overall soil quality [37].

Intensive silvo-pastoral systems stand out within the range of silvo-pastoral arrangements due to their higher intensification and sustainability. This is reflected in the diversity and density of their components. The diversification contributes to both the quantity and nutritional quality of feed for livestock. On the other hand, the high density of system components enhances both environmental and productive benefits. In some cases, green forage production in SPSis has doubled compared to semi-intensive SPSs [41]. SPSis optimize edaphic conditions due to the higher number of trees, which, in combination with legumes, result in significant savings on nitrogen fertilizers, improve pasture quality, and provide ample shade coverage for livestock [41–44]. While density may depend on environmental characteristics, an SPSi can include shrubs with densities ranging from 10,000 to 40,000 plants per hectare. As for the trees, these tend to be of different species and are typically located along the perimeter, delimiting paddocks, or planted in lines. Tree density can vary from 25 to 200 trees per hectare [45].

## 3. Materials and Methods

This section outlines the methods applied for the economic analysis conducted for both the traditional system and the SPSi. First, the characteristics of each technology and the assumptions used for their evaluation are presented. Following this, the discounted cash flow model and the probabilistic techniques applied to assess different productivity scenarios are explained.

### 3.1. Description of Evaluated Technologies

The system analyzed is based on a 2.5-hectare trial in the San Martín province. The trial was designed to be representative of the region, reflecting its specific environmental

and productive conditions. It is important to note that this region faces agroclimatic risks, such as increasingly prolonged droughts, which particularly affect the dominant sandy soils [46]. These soil conditions typically require additional irrigation and inorganic fertilizers, which increase the environmental impact of cattle farming [47,48]. Therefore, the SPSi, as proposed in this study, is a plausible alternative to mitigate these challenges.

Two production systems are evaluated in this study. The first is a traditional system, representative of the San Martín province, consisting of a monoculture of *Urochloa brizantha* cv. Marandú as forage grass. The second system is an SPSi, which includes *Urochloa brizantha* cv. Marandú as the primary pasture, the legume *Centrosema macrocarpum*, the shrub *Tithonia diversifolia*, commonly known as Botón de Oro (Mexican sunflower), and a set of timber trees. The main characteristics of these system components are described below.

The grass *Urochloa brizantha* cv. Marandú serves as the baseline technology for this evaluation. Originating from a volcanic region in Africa, where soils have favorable fertility levels, this cultivar was introduced and released in Brazil [49]. It has since been widely adopted across the American tropics. Key characteristics of *Urochloa brizantha* cv. Marandú include its resistance to spittlebug, a requirement for soils with intermediate to high fertility, and its poor tolerance to waterlogging [50]. In Peru, experiences have shown that this cultivar associates well with legumes and is highly palatable to cattle due to its leaf content, making it well accepted by livestock. Currently, it is the second most widely planted forage and ranks first in sales within the country [51]. *Urochloa brizantha* cv. Marandú has demonstrated strong performance in the soils of Alto Mayo, located in San Martín [52]. Its superior qualities compared to other materials, such as *Urochloa decumbens*, have made it the most widely used forage in this region. In the evaluated SPSi, an area of 7200 m<sup>2</sup> (72%) per hectare was established with *Urochloa brizantha* cv. Marandú.

The legume used in the SPSi is *Centrosema macrocarpum*, which is well suited to highly acidic and low-fertility soils. It demonstrates drought tolerance, high nutritional value, and resistance to major diseases affecting *Centrosema* species [50]. Legumes are valuable for providing cattle with essential micronutrients, plant-based proteins, and minerals [53]. One of their most significant contributions is their ability to fix atmospheric nitrogen into the soil, enhancing the agroecosystem's nitrogen levels. This natural nitrogen fixation reduces the need for excessive chemical fertilizers, which can lead to water and atmospheric contamination. Consequently, legumes help to significantly mitigate the environmental impact of cattle farming [53]. In the Peruvian Amazon, *Centrosema macrocarpum* has proven effective in restoring overgrazed soils. Experiments using degraded pastures of *Urochloa brizantha* to establish agroforestry systems have validated the effectiveness of this legume [29]. In the evaluated SPSi, an area of 800 m<sup>2</sup> (8%) per hectare was established with *Centrosema macrocarpum*. The spatial distribution of the legume was in alleyways.

The shrub used in the SPSi is *Tithonia diversifolia* (commonly known as Botón de Oro), a perennial shrub that can grow between 2 and 5 m in height [50]. It is notable for its high potential for dry matter production, its adaptability to a range of climatic and soil conditions, and its high nutritional value, even though it is not a legume [50]. Empirical evidence has shown that the inclusion of this shrub species is effective for productive cattle management [23,54]. Additionally, studies conducted in tropical conditions with low humidity confirm that supplementing cow diets with small amounts of *Tithonia diversifolia* not only increases milk productivity but also helps mitigate methane (CH<sub>4</sub>) emissions [23]. In the evaluated SPSi, an area of 1500 m<sup>2</sup> (15%) per hectare was established with *Tithonia diversifolia*. This area was arranged in a hedge design consisting of three rows, with a planting distance of 1 × 1 m.

The final component of the SPSi consists of timber seedlings. *Erythrina edulis* was used for living fences, planted with a spacing of 5 m, resulting in 80 plants per hectare.

Other species include *Cordia gerascanthus* (Black Laurel, 8–15 years), *Cedrelinga catenaeformis* (Tornillo, 30 years), *Brosimum alicastrum* (Machinga, 8 years), *Vitex pseudolea* (Paliperro, 30 years), *Sauvagesia erecta* (Goma Huayo, 8 years), and *Guazuma crinita* (Bolaina, 5–8 years). These trees are expected to provide 15% to 20% shade per hectare. The microclimate regulation for livestock is the main objective of this component, although they also serve as a source of income in the long term. The native timber seedlings were planted in an area of 500 m<sup>2</sup> (5%) per hectare, following a design of one row per strip, with a spacing of 20 × 15 m and 100 plants per hectare. Many of these species are anticipated to generate income after four to eight years.

The cattle in the system is Girolando, a cross between Holstein (5/8) and Gir (3/8), which has good performance and adaptability in tropical dairy farming and dual-purpose systems, with a weight standard of 450 kg [55,56]. The weight of the calf at weaning is 150 kg, and the annual lactation period is 305 days. Between the traditional system and the SPSi, productivity per cow can vary from 5 to 6.5 L per day, the calving interval ranges from two to one year, and the carrying capacity is 1 to 2 or 3 tropical livestock units (TLUs; 1 TLU = 450 kg) with their respective calf per hectare [2,20–25]. Therefore, the implementation of good practices such as rotational grazing and access to the consumption of cv. Marandú, *Centrosema macrocarpum*, and *Tithonia diversifolia* are crucial for increasing the productivity of the SPSi.

### 3.2. Assumptions for the Discounted Cash Flow Model

As the established trial is still in the evaluation phase, projections of animal response indicators, productivity, costs, and income were made for the economic evaluation—based on expert opinions, scientific literature, commercial data, and official statistics [2,21–23,25]. The analysis period is set for 8 years, from 2023 to 2030, which corresponds to the productive lifespan of the dual-purpose Girolando cattle used in this evaluation. The discount rate is set at 8% [57]. This analysis uses current prices, meaning the cash flow incorporates an adjustment for inflation. This indexation is applied to the entire cost and income structure, using the Consumer Price Index (CPI) as a reference [58]. The analysis is conducted in U.S. dollars (USD), with a conversion from Peruvian Soles (PEN) based on the exchange rate at the time of the investment, which was 3.83 PEN per USD (BCRP, 2023c). Table 1 synthesizes the technical parameters of the production system.

**Table 1.** Productive assumptions for building the cash flow per hectare.

Information of the Production System	Scenarios			
	Traditional	SPSi PS	SPSi MS	SPSi OS
Milk productivity (1 cow <sup>-1</sup> day <sup>-1</sup> )	5	6.5	6.5	6.5
Annual lactation period (days)	305	305	305	305
Stocking rate (animals ha <sup>-1</sup> )	1	1	2	3
Weight of 1 TLU (kg)	450	450	450	450
Weight of calf at weaning (kg) *	150	150	150	150
Productive lifespan of the system (years)	8	8	8	8

\* In the traditional scenario, there is approximately one calf every two years and in the SPSi one every year, respectively. Note: The three scenarios for SPSi are PS: pessimistic scenario, MS: moderate scenario, and OS: optimistic scenario.

It is important to note that, since there is no significant demand from the dairy industry, quality aspects do not influence the product's value. The economic benefits of implementing an SPSi will stem from higher animal stocking rates (SRs), improvements in productivity, increased efficiency in the cost structure, and the sale of timber. Additionally, the analysis accounts for the salvage value of the animals at the end of the evaluation period.

Furthermore, scientific literature evaluating the productive potential of *Urochloa brizantha* and *Tithonia diversifolia* for improving dairy production systems was consulted [20–23,25]. Based on

this, it is anticipated that with the SPSi, the stocking rate (SR) will increase from 1 to 2 TLUs per hectare, or even, in a more optimistic scenario, to 3 TLUs per hectare. Milk productivity is expected to rise from 5 L per day per cow in the monoculture system to 6.5 L per day per cow in the SPSi. Finally, regarding beef production, the monoculture system produces one calf at weaning per cow of 150 kg, approximately every two years, whereas in the SPSi, the frequency is projected to increase to one calf per year with the same liveweight.

During the analysis period, no renewal for productive maintenance is assumed for *Urochloa brizantha* in the traditional system, consistent with local management practices, as cost constraints prevent producers from engaging in this practice. Similarly, no renewal is assumed in the SPSi; however, this is due to the efficient land management that makes renewal unnecessary. Additionally, it is important to highlight that only organic fertilizers will be used in the SPSi, which results in cost savings and reduces the burden of fertilizer expenses in the cost structure [59].

### 3.3. The Discounted Cash Flow Model

The cash flow organizes the income and expenses for the evaluated investment alternatives, resulting in a net benefit for each analyzed period. This enables the calculation of various profitability measures, which take into account the time value of money by applying a discount rate [60]. As defined by [61], the profitability indicators used in this evaluation include the following:

The first indicator is the Net Present Value (*NPV*). The *NPV* is calculated by summing the net benefits derived from the cash flow and discounting them to their present value using the discount rate. If the *NPV*, as shown in Equation (1), is greater than zero, the investment alternative is deemed profitable.

$$NPV = \sum_{t=1}^T \frac{NCF_t}{(1+r)^t} - I_0 \quad (1)$$

where

$I_0$  is the initial investment;  $NCF_t$  is the net cash flow (difference between income and costs) for each period, and  $r$  is the discount rate.

The Internal Rate of Return (*IRR*) is a specific discount rate ( $r^*$ ) that makes the *NPV* of Equation (1) equal to zero, as shown in Equation (2). If the *IRR* is greater than the discount rate, it indicates profitability.

$$NPV = 0 \quad (2)$$

The third indicator is the Benefit–Cost Ratio (*BC*). It is calculated as the ratio between the present value of benefits (*PVB*) and the present value of costs (*PVC*), as shown in Equation (3). The discount rate is applied to both the *PVB* and *PVC* in this calculation. If the *PVB* exceeds the *PVC*, the investment is considered profitable. In other words, for profitability to be indicated, the *BC* from Equation (3) must be greater than one.

$$BC = \frac{PVB}{PVC} \quad (3)$$

The fourth indicator is the payback period (*PB*). This indicator reflects the time it takes to recover the initial investment ( $I_0$ ) in the productive project. It indicates the moment when the cumulative net cash flows equal the initial outlay. When comparing various investment alternatives, the preferred option is the one with the highest *NPV*, *IRR*, and *BC*, while also having the lowest *PB*, as it implies faster recovery of the investment.

### 3.4. Risk Analysis

Agricultural ventures, like any other productive projects, are subject to various elements of risk and uncertainty. Climatic factors, fluctuations in input prices, or changes in market prices for end products can all affect profitability and are typically beyond the control of the producer. A comprehensive economic evaluation should incorporate these potential risks to provide a more realistic perspective on the expected outcomes. Studies that account for these factors allow for a more accurate estimation of benefits [62].

In line with this approach, and to complement the analysis, after verifying the relevance of the Pert distribution, Monte Carlo simulations were conducted to generate probability distributions for key profitability indicators such as NPV and IRR [63–65]. This approach allows for the calculation of expected values for these indicators. According to the law of large numbers, this is the most accurate estimator. Additionally, variability measures, such as the coefficient of variation, can be used to obtain probability values [66]. The simulations were performed using @Risk software, with a 90% confidence level and 5000 iterations.

Based on scientific literature minimum, most likely, and maximum values were identified for the variables of interest, enabling the use of the Pert distribution [20–23,25,66]. The details of the values for the moderate scenario are shown in Table 2. The pessimistic and optimistic scenarios have the same variability applied here.

**Table 2.** Parameters for Pert distribution, moderate case, per hectare.

Variable	Minimum	Most Likely	Maximum
Milk price (USD L <sup>-1</sup> )	0.32	0.34	0.36
Milk productivity (L cow <sup>-1</sup> )	6.2	6.5	6.8
Stocking rate (cows ha <sup>-1</sup> )	1	2	3
Discount rate (%)	7.6	8.0	8.4

This analysis was carried out for four different scenarios. The first scenario represents the traditional monoculture system using *Urochloa brizantha* cv. Marandú (traditional system). The second scenario represents the SPSi with all its productive benefits but assumes a pessimistic expectation of only 1.2 TLUs per hectare (SPSi PS). The third scenario represents a moderate outcome, assuming 2 TLUs per hectare (SPSi MS). Finally, the fourth scenario assumes an optimistic outcome with 3 TLUs per hectare (SPSi OS). Milk productivity is also expected to rise, with an average increase from 5 L per day in the traditional system to 6 L per day in the SPSi.

## 4. Results

### 4.1. Cost and Revenue Structure

Commercial information on the costs of productive systems per hectare is available. Although the data are not broken down in extensive detail, it is sufficient to consolidate the total costs for both establishment (CE) and operational expenses (CO). The CE of the traditional system refers to the initial investments required to set up the productive system, amounting to USD 2804 per hectare on average. Of this total, cattle acquisition and other costs accounted for 44.69%, equivalent to USD 1253. The remaining 55.31%, or USD 1551, was allocated to land preparation, which includes clearing and burning (USD 522), fencing (USD 783), planting (USD 183), and chemical fertilizers (USD 63). The two systems—traditional and SPSi—have differences in CE for two reasons: higher costs in the traditional system due to its reliance on chemical fertilizers and burning and other infrastructure items that make it more costly. On the other hand, the SPSi has higher costs due to the additional materials required and, in general, because it has a higher stocking

rate, which drives the cost for animal acquisition and the other costs item. Table 3 provides more detail on the cost and income structure.

**Table 3.** Financial assumptions for building the cash flow per hectare \*.

Variables	Traditional	SPSi PS	SPSi MS	SPSi OS
Milk price (USD L <sup>-1</sup> )	0.34	0.34	0.34	0.34
Beef price (USD kg liveweight <sup>-1</sup> ) **	1.54	1.54	1.54	1.54
Animal acquisition (USD animal <sup>-1</sup> ) and other establishment costs	1253	3133	3133	3133
Clearing, burning, and others ***	522			
Chemical fertilizers ***	63	-	-	-
Fencing	783	783	783	783
Planting	183	183	183	183
Management cost (USD cow <sup>-1</sup> y <sup>-1</sup> )	261	418	418	418
Annual income from milk sales (USD TLU <sup>-1</sup> )	518	673	673	673
Annual income from beef sales (USD calf <sup>-1</sup> ) **	232	232	232	232

\* Establishment cost items in average values \*\* In the traditional scenario, sales occur every two years.  
\*\*\* Does not apply to SPsi.

On the other hand, CO refers to the annual expenses necessary to maintain the system, including inputs and animal health care. These operational costs are USD 418 for the SPsi and USD 261 for the traditional system. Labor costs are implicitly included within these figures. Neither the traditional nor the SPsi systems incur costs related to pasture renewal.

Regarding market conditions, the price of beef is USD 1.54 per kg liveweight [67], which reflects the value for selling a weaned calf weighing approximately 150 kg at USD 231. The price of milk in the region is USD 0.34 per liter. As a result, revenues in the first year of operation could reach up to USD 1028 for the traditional system, while in the SPsi scenarios, they could range from USD 2714 to USD 6333, depending on varying projections of milk productivity and stocking rates.

#### 4.2. Profitability Indicators

The profitability indicators presented in Table 4 clearly demonstrate that all analyzed scenarios are profitable as the NPV is greater than zero and the IRR exceeds the market discount rate across all cases. However, there is a significant difference between the traditional system and the SPsi scenarios. The NPV increases from a modest US\$61 in the traditional system to values ranging from USD 9564 to USD 20,465 in the SPsi scenarios. Similarly, the IRR shows a substantial improvement, rising from 8.17% in the traditional system to 26.63%, 29.02%, and 30.33% in the various SPsi scenarios. These results underscore the economic advantages of adopting the proposed SPsi over the traditional monoculture system.

**Table 4.** Profitability indicators.

Indicator	Traditional	SPSi PS	SPSi MS	SPSi OS
NPV (USD)	61	9564	15,014	20,465
IRR (%)	8.17	26.63	29.02	30.33
BC	1.006	1.628	1.632	1.634
PB (years)	7.98	5.78	4.91	4.55

Notes: The discount rate is 8% and the evaluation is for 2.5 hectares.

The BC ratio follows the same trend, consistently exceeding a value of 1 and increasing according to the expectations of each scenario. The payback period is approximately 7.98 years for the traditional system, while in the SPsi scenarios, it ranges from 5.8 to 4.5 years, demonstrating a quicker recovery of the initial investment in the silvo-pastoral systems.

To account for the inherent risk and uncertainty, a probabilistic analysis using Monte Carlo simulation was applied. This approach allows for more robust estimates by associating probability distributions with key indicators. Given the productive context of this evaluation, the stocking rate (SR) and milk productivity (MP) were selected as the primary determinants of profitability. Then, for the chosen variables, minimum, most probable, and maximum values were obtained, which enabled the use of the Pert distribution [66,68]. The analyzed indicators—NPV and IRR—confirmed profitability across all scenarios.

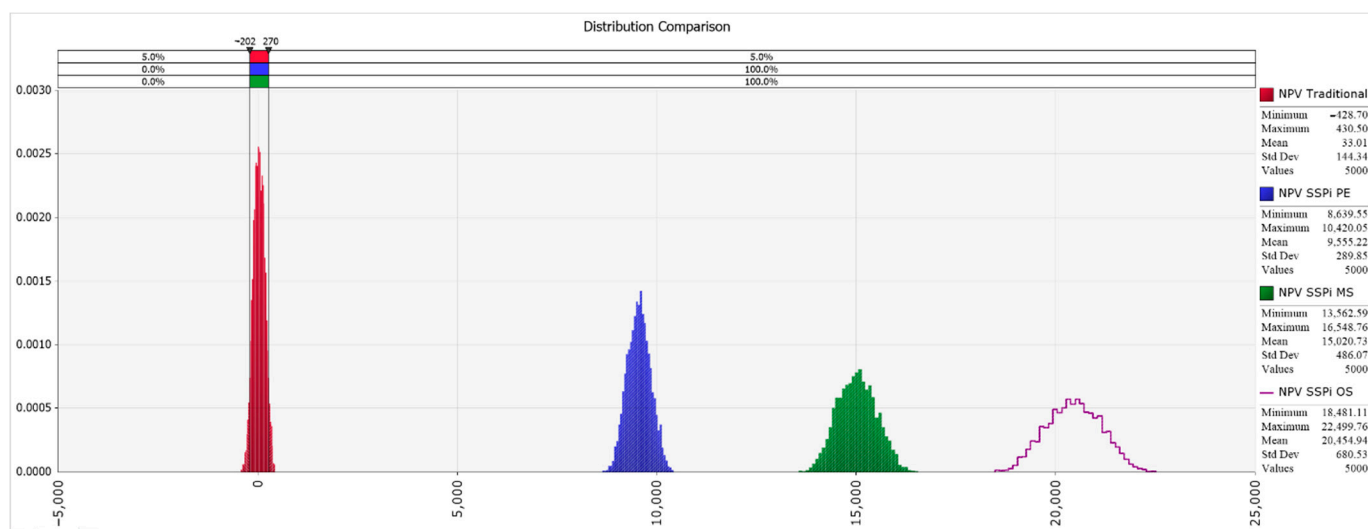
As indicated in Table 5, the highest average NPV was observed in the optimistic scenario, with a value of USD 20,455, followed by the moderate scenario with USD 15,021. The average IRR in these systems was 30.33% and 29.03%, respectively. In contrast, the traditional system displayed a coefficient of variation (CV) of 4.4. The three SPSi scenarios exhibited improved precision in the estimations, with a lower CV ranging from 0.0303 to 0.0333, indicating more reliable profitability predictions under the SPSi models.

**Table 5.** Quantitative risk analysis.

Indicator	Measure	Traditional	SPSi PS	SPSi MS	SPSi OS
NPV	Mean (USD)	33	9555	15,021	20,455
	SD *	144.34	289.85	486.07	680.53
	CV **	4.3726	0.0303	0.0324	0.0333
	Prob(NPV < 0) ***	0.41	0.00	0.00	0.00
IRR	Mean (%)	8.09	26.62	29.03	30.33

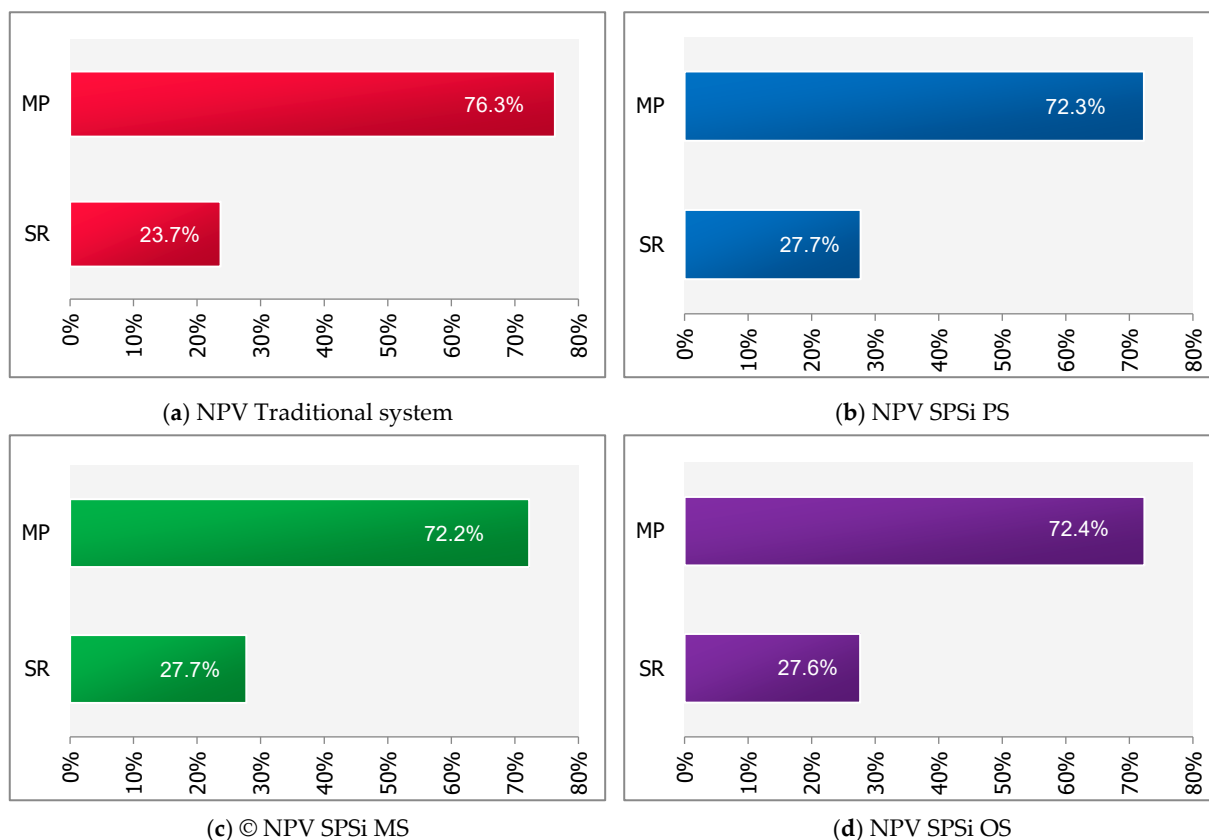
\*SD: standard deviation; \*\* CV: confidence interval; \*\*\* Prob: probability.

In Figure 1, the differences among the four technologies can be better observed. The probability distribution for the traditional system (red) is profitable; however, it is the one positioned furthest to the left. The SPSi shifts the NPV curves to the right, in line with increases in MP and SR, across the pessimistic (blue), moderate (green), and optimistic (purple) scenarios. As a result, the average NPV value increases from USD 33 to values between USD 9555 and USD 20,455.



**Figure 1.** NPV probability distributions by analyzed scenarios. Note: estimated with @risk software.

To verify and explore the influence of factors underlying profitability, a sensitivity analysis was conducted. Specifically, the contribution to variance quantifies the impact of certain variables on the Net Present Value (NPV). The results of this analysis are visualized in the form of tornado charts, which are presented in Figure 2.



**Figure 2.** NPV sensitivity analysis—contribution to variance. Note: estimated with @risk software.

The variable with the greatest influence on profitability is milk production. In the traditional system, MP accounts for 76.3% of the variation in NPV, while in the SPSi scenarios, it accounts for 72.3%, 72.2%, and 72.4% in the pessimistic, moderate, and optimistic scenarios, respectively. This result was derived from a sensitivity analysis conducted using Monte Carlo simulation with a 90% confidence level. Since market prices cannot be influenced directly by producers, MP becomes the most important determinant for enhancing economic benefits across all systems. The second most significant variable is stocking rate, which explains 23.7% of the variation in NPV in the traditional system. In the SPSi scenarios, SR contributes an average of 27.7% to the variation in NPV. It is important to highlight the relevance of having a greater number of calves for profitability as their increase is correlated with the rise in SR. This indicates that SR plays a crucial role in the financial performance of the SPSi, alongside MP. Thus, optimizing both MP and SR is key to maximizing profitability in these systems.

## 5. Discussion

### 5.1. Economic Evaluation of SPSi in San Martín Province

SPSs are increasingly recognized by policy and the beef and dairy value chains as effective alternatives for improving the technical, economic, and environmental aspects of cattle farming [69–73]. The findings of this study strongly underscore the financial and environmental benefits of implementing intensive silvo-pastoral systems (SPSis) in the San Martín region of Peru over traditional grass monoculture systems. Across various scenarios, SPSis consistently outperformed the traditional systems, showing marked improvements in key financial metrics such as NPV, IRR, and BC ratios. The results not only validate the economic potential of SPSi but also align with global evidence from other regions where SPSs have significantly enhanced agricultural profitability and sustainability.

The projections in our study show a 30% increase in milk production and a 50% to 250% rise in animal stocking rates per hectare in the SPSi compared to the traditional grass monoculture system. These improvements translate into significant economic benefits. In the evaluated traditional system, the NPV was a modest USD 61, barely above zero, signaling limiting profitability. In contrast, the SPSi scenarios showed strong improvements in NPV, ranging from USD 9564 in the pessimistic scenario to USD 20,465 in the optimistic scenario. This represents an increase of more than 150-fold compared to the traditional system, highlighting the substantial economic advantages of adopting the SPSi. Similarly, the IRR increased from 8.17% in the traditional system to between 26.63% and 30.33% in the SPSi scenarios, reflecting significantly higher returns on investment. The BC ratio also increased from 1.006 in the traditional system to values between 1.628 and 1.634 in the SPSi scenarios, signaling a more efficient allocation of resources and a higher return on every dollar invested. The payback period for the traditional system was nearly 8 years, a considerable recovery time for initial investments. However, the SPSi shortened this payback period to between 4.5 and 5.8 years, underscoring the quicker return on investment associated with SPS.

Although SPSs are not yet widely known in the study area, another recent analysis in the Peruvian Amazon suggests their profitability: a profitability analysis using the Land Expectation Value (LEV) method for a 10-hectare farm with *Eucalyptus globulus* trees and Holstein cattle [74]. The LEV per hectare was USD 9272, USD 4737, and USD 3230 at discount rates of 4%, 8%, and 12%, respectively. Our results contribute to these findings and help in amplifying the portfolio of economically viable SPS options for this region in Peru.

Our results are also consistent with empirical evidence from other regions around the world, where SPSs have demonstrated similar economic benefits. For example, in India, a study in the Himalayas, which examined the establishment of a SPS on 184 hectares, aimed at reducing reliance on forest forage [75]. Through surveys of 222 households across five villages, the study calculated economic indicators for an agroforestry strategy using multipurpose species such as *Amorpha fruticosa*, *Andropogon virginicus*, *Avena sativa*, and *Cytisus scoparius*. The results showed an exceptionally high IRR of 155.73% over a 12-year horizon, driven by improved livestock productivity and sustainable land use practices. While the IRR in our study did not reach this level, the increase to over 30% in the optimistic SPSi scenario still reflects the significant financial advantages of the SPSi, especially when compared to the 8.17% observed in the traditional system.

In Brazil, a global leader in cattle production, similar successes with SPSs have been documented. It was reported that an SPS on 120 hectares, featuring *Urochloa brizantha* cv. Marandú and *Eucalyptus* trees, achieved returns of 12% to 120% over three years, compared to returns ranging from −10% to 44% in traditional systems [76]. The high variability in returns across traditional systems was due to factors such as poor soil management, climate variability, and the high costs of chemical inputs—issues that SPSs help mitigate. Our study shows that in the San Martín region, the SPSi similarly outperformed traditional systems by reducing reliance on chemical fertilizers and improving soil health through the integration of legumes and trees. Another study in Rio Grande do Sul, Brazil, analyzed a 2-hectare SPS with ryegrass and *Eucalyptus grandis* trees. With trees planted at a density of 166 per hectare and four years old, the system showed profitability with an IRR of 19.79% [77].

In Costa Rica, a study evaluated an SPS with *Erythrina poeppigiana* shrubs and dairy cows, yielding positive net margins in milk production [78]. In Mexico, an evaluation of an SPSi with 60 Gyr cattle on 58 hectares showed a positive net margin per cow of USD 109.4 [79].

Further comparisons can be drawn from studies in Colombia. A financial analysis compared two SPSs—*Urochloa brizantha* cv. Toledo + *Leucaena leucocephala* and *Urochloa* hybrid cv. Cayman + *Leucaena leucocephala*—with two monoculture grass systems [80].

Their analysis revealed that although SPS establishment costs were higher, the systems showed superior animal performance, with 33% higher stocking rates, 51% greater daily liveweight gains, and a 34% increase in annual beef sales income. These results align closely with our findings, where the stocking rates in SPSi scenarios were projected to increase by up to 250%, and milk productivity was expected to rise from 5 L per cow per day in the traditional system to 6.5 L in the SPSi scenarios. This increased productivity directly translates into greater revenues, with the first-year revenues for the SPSi ranging from USD 2714 to USD 6333, compared to just USD 1028 in the traditional system.

Moreover, an economic analysis in Colombia compared a grass monoculture system—*Urochloa* hybrid cv. Cayman—with a silvopastoral system that integrated *Urochloa* hybrid cv. Cayman and *Leucaena diversifolia* [81]. Despite the SPS having 60% higher establishment costs, it delivered a 66% increase in gross income per hectare and a 119% increase in net income. In our study, the establishment costs for the SPSi were estimated at USD 4099 per hectare on average and are thus higher than in the traditional system. The operational costs for the SPSi were slightly higher at USD 418 per hectare per year, compared to USD 261 for the traditional system. This is being influenced by the increase in SR in the SPSi, which causes stronger cost increases for acquiring additional cattle than in the traditional system. These additional costs were offset by the higher revenues from milk and beef production, as well as the long-term cost savings from reduced reliance on chemical fertilizers and enhanced land productivity. It was also found that the evaluated SPS reduced the minimum land area required to generate two Colombian basic salaries from 6.54 hectares to 3.76 hectares and shortened the payback period from 6 years to 4 years [81]. Their risk analysis highlighted a 72% probability of economic loss for the monoculture system, whereas the SPS reduced this risk to 0%. Sensitivity analysis identified that the sale price per kilogram of live weight and animal production were the main drivers of profitability, accounting for 64.2% of the variance in the monoculture and 55.2% in the SPS. Stress tests revealed that negative changes in these factors could reduce the NPV of the monoculture by 335%, compared to only a 57% reduction for the SPS, underscoring the SPS's financial viability and greater resilience compared to the monoculture system. These results are also consistent with our evaluation, i.e., with the estimated reduction in the payback period from 8 to 4.5–5.8 years, the reduction in the risk of economic loss from 41% to 0%, and the dependence on the end product prices (in our case milk) on economic viability.

In a case study, the implementation of an SPS on four dairy farms in Colombia was evaluated [82]. Their findings showed that the introduction of improved pasture management and SPS helped mitigate the losses that the traditional system was incurring, though it did not immediately lead to profitability. Improved pasture management, rotational grazing, and optimized fertilization resulted in higher milk production, but these gains were insufficient to fully cover costs in the initial phases. However, as stocking rates increased and the areas of improved pastures expanded in subsequent scenarios, economic indicators such as the NPV, IRR, and BC ratio showed improvement, suggesting the potential for profitability with sustained investment and enhanced management practices—similar to our results for the different SPSi scenarios.

One of the primary advantages of SPS is their ability to diversify income streams, particularly through timber production. In our study, timber production was projected to increase profitability by 2.06% to 4.64%. In Ecuador, it was shown that integrating *Jatropha curcas* into a livestock system as a living fence for biofuel production resulted in an 18% return on investment [83]. The inclusion of timber and other agroforestry components in the SPS not only provides additional revenue sources but also contributes to environmental sustainability, a critical consideration in regions facing deforestation and soil degradation.

Before continuing, it is important to highlight that profitability rates above 100%, which are abnormally high, should be viewed in light of their large scale, where economies of scale operate on production costs. In the production systems under analysis, the common denominator is small farms, where efficiency gains due to the scale of production are not feasible. On the other hand, although the profitability in this study does not reach these atypical levels, it can be considered significantly higher compared to some of the cases mentioned, which are close to 10%. These differences can be examined in relation to two main assumptions about the traditional technology and SPSi. First, although local information was used to approach the actual characteristics of livestock farming in this area, there may be a bias since an extensive field trial is not available. As a result, a traditional system is characterized by very low levels of dairy productivity and stocking rates, which allows for significant potential improvements in profitability indicators when transforming to the proposed SPSi. For example, in the traditional system, only one calf is sold every two years, while in the SPSi, it is one each year. Second, it is implicitly assumed that producers have the technical capacities or will receive institutional support that will not represent additional costs. The above is crucial for ensuring that productivity assumptions hold throughout the time frame of the silvo-pastoral project.

Another key benefit and potential income stream of SPSs, though not factored into this study's financial analysis, is the potential for payments for ecosystem services (PESs), particularly for carbon sequestration. Studies have shown that SPSs significantly reduce greenhouse gas emissions. For instance, it was found that SPSs reduced methane emissions by 0.03 g per gram of liveweight gain, translating to an annual reduction of 145 tons of CO<sub>2eq</sub> for a herd of 1000 cattle [80]. This reduction in emissions has the potential to generate substantial income through carbon credits. In their study, it was calculated that these reductions could be valued at USD 6122 per year based on an average price of USD 42.25 per ton of CO<sub>2eq</sub> [80]. Similarly, another study found that SPSs could mitigate up to 163 tons of CO<sub>2eq</sub>, valued at USD 27,716, while also improving financial metrics such as the NPV, IRR, and BC ratio [84]. Furthermore, the SPS treatments provided substantial microclimatic benefits, with over 60% shade coverage. Replacing this natural shade with synthetic structures would cost USD 12,158 over three years, but natural shade saves USD 4053 annually, translating to an economic value of over USD 2 million per year if applied to a 1000-hectare system. They also found that including the environmental benefits of CH<sub>4</sub> reduction in the financial analysis significantly enhanced the financial indicators of the SPS. Similarly, in their case study on enhancing dairy systems in Colombia, the researchers demonstrated that improved pasture management and the implementation of an SPS can mitigate up to 163 tons of CO<sub>2eq</sub>, valued at USD 27,716, while also improving financial metrics such as the NPV, IRR, and BC ratio [84].

SPSis offer a range of environmental and animal welfare benefits. By incorporating legumes, shrubs, and trees, they help reduce greenhouse gas emissions, addressing climate change challenges [85,86]. Specifically, SPSis aid in soil recovery, protect water sources, and can curb the expansion of the agricultural frontier. Additionally, the tree canopy provides shade for animals while also functioning as windbreaks [85,87,88]. Environmental valuation exercises attempt to monetize some of these benefits, such as carbon capture and storage and the thermal comfort of animals provided by the tree canopy's shade [80,85]. A limitation of the present document is that such an analysis was not carried out as the relevant environmental information was not available. Additionally, due to the socioeconomic context of the region, the analysis focused on a conventional economic evaluation. It is a first attempt to show the advantages of an SPSi in a scenario where the most common practice is monoculture and there are no institutional incentives in the environmental sphere. This is because, despite the diversity of species in this region of Peru, SPSis have

not been significantly developed yet [32]. Thus, to address these information constraints and the local socioeconomic realities, the exercise was limited to the cost and revenue aspects of a conventional analysis.

In summary, empirical evidence from both large- and small-scale trials supports the profitability of SPSs, with returns ranging from 12% to 156%. In many cases, these returns exceed those calculated in this study, which range from 26.62% to 30.33%. Variations in investment returns can be attributed to cattle farming's sensitivity to environmental, market, and institutional factors across different regions [89]. Nonetheless, profitability in SPSs has consistently been demonstrated, and the results of this analysis, combined with the regional context, indicate a favorable environment for adopting an SPSi in the San Martín province in Peru. However, on this last point, it must be noted that completed local field trials are needed to validate these results. This is an essential condition for making evidence-based policy recommendations. A completed on-site trial could identify other implementation challenges, such as the system's response to climatic conditions, the proper management of different species, and potential hidden costs that may arise. While small producers may have an informal approach to the SPSi, shifting from monoculture to a food system with species diversity could conflict with cultural and traditional aspects [7,33,34]. Therefore, the installation and scaling of the SPSi would face risks such as high initial costs while achieving producer awareness [24,28]. The factors limiting the development of the SPSi are multidimensional, encompassing financial, market, and technical, as well as socio-cultural, aspects. The next section will elaborate on these obstacles.

### *5.2. Obstacles and Chances for Scaling the Adoption of SPS*

The adoption of the SPS faces a range of significant barriers that must be addressed to facilitate widespread uptake. These challenges include (i) financial constraints, such as limited access to credit and lengthy payback periods, which can deter farmers from making long-term investments; (ii) knowledge and information gaps, including insufficient technical assistance and extension services, and the need for specialized skills to implement SPS practices; (iii) socio-cultural factors, such as entrenched gender roles and the prevalence of traditional cattle practices like extensive grazing on natural pastures, which may hinder the shift to more sustainable systems; (iv) labor shortages, exacerbated by competition with more lucrative (and sometimes illegal) sectors, which reduce the available workforce for agricultural activities; (v) unclear land tenure, which discourages long-term investments in land improvements; (vi) market dynamics, such as fluctuating prices for inputs and end products; (vii) legal restrictions, which may limit the ability of farmers to fully utilize these systems; and (viii) farmers' inherent risk aversion, which leads to reluctance in adopting new technologies due to fear of potential losses [35,80,90–99].

To overcome these multifaceted obstacles, a comprehensive and integrated approach is necessary. This includes targeted interventions, such as providing access to favorable agricultural credit with flexible terms and designing government programs that specifically focus on reducing emissions in cattle farming. It is equally important to ensure that the environmental benefits, such as the mitigation of greenhouse gas emissions achieved through the SPS, are financially recognized. This can be accomplished by enabling producers to participate in PES schemes or carbon markets, which would reward their contributions to climate change mitigation [100].

While the benefits of scaling up the SPS are considerable, it is essential to recognize potential unintended consequences that may arise from widespread adoption. There is emphasis that the SPS should be implemented primarily in areas unsuitable for crop production to prevent competition with other agricultural systems [101]. However, this approach

may result in unintended negative outcomes, such as increased deforestation, particularly when cattle intensification occurs on marginal lands and land tenure is unclear [102].

One concern is that improved cattle birth rates within the SPS can lead to surplus calves, which are often sold to unsustainable fattening operations located at deforestation frontiers. In fact, cattle farming is one of the leading drivers of deforestation in Colombia and Latin America [98,99,102]. Additionally, the productivity gains associated with the SPS could encourage farmers to expand operations into forests and other ecosystems, a phenomenon known as the Jevons paradox [103].

In the context of San Martín, the low adoption rate is primarily due to a series of limitations tied to technical and socioeconomic factors [32]. The first barrier is the insufficient investment in research, which hampers the development of appropriate technologies for implementing these production systems. The second barrier is the lack of financial instruments to incentivize adoption. The third barrier is the limited technical and administrative training, leaving farmers without the necessary skills to efficiently manage silvo-pastoral projects. The fourth barrier is the limited access to competitive markets for high-quality seed and seedlings [33,34].

In summary, these limitations result in a general lack of awareness regarding the potential economic and environmental benefits of the SPS in the Amazon and San Martín regions of Peru. While SPS initiatives have emerged spontaneously in these areas, they lack the institutional and scientific support necessary to positively influence farmers' willingness to adopt [33,34]. However, the informal nature of SPS adoption can be seen as an advantage compared to other regions where there may be greater resistance to incorporating trees into livestock systems [35]. Based on these insights, public policy should prioritize the promotion of the sector by providing extension services for capacity building, improving information systems, and facilitating competitive access to plant material markets [28,33–35].

To address these risks, a combination of incentives and robust monitoring mechanisms is necessary to ensure that the SPS promotes sustainability rather than contributes to deforestation. Effective strategies may include deforestation monitoring, traceability systems, and taxes on conventional pasture use. By implementing these measures, the expansion of the SPS can be aligned with sustainable cattle farming goals, mitigating potential environmental harm [92,99].

## 6. Conclusions and Recommendations

Our study demonstrates that the SPSi provides clear economic advantages and to some extent environmental advantages over traditional monoculture grass systems in San Martín, Peru. These systems significantly improve farm profitability by enhancing milk production and increasing animal stocking rates while also shortening the time required to recover initial investments. In addition to financial benefits, the SPSi offers notable environmental gains, such as improved soil health and reduced greenhouse gas emissions, positioning them as a sustainable solution for cattle farming in the region. These findings align with global evidence, reinforcing the potential of the SPSi to increase agricultural productivity and sustainability.

In terms of determinants of profitability, it is important to note that the number of calves is also a determining factor in improving the system's income. However, in the traditional system, calves are only sold every two years, whereas in the SPSi, the increased SR ends up capturing a higher weight according to the simulations.

Despite the evident advantages, the adoption of the SPSi faces several barriers, including financial constraints, knowledge gaps, and socio-cultural challenges. Addressing these obstacles through targeted interventions, such as improved access to credit and technical support, will be essential to facilitate broader adoption.

This document provides important guidelines for promoting the SPSi. Of course, field trials are necessary to validate the results, which could also include the issue of ecosystem services not monetized here. The latter responds to the fact that in accordance with the analysis and research of the local context, in practice, small producers cannot benefit from these services (yet). Similarly, no progress was made in a social evaluation as the information collected was limited to productive and economic aspects.

Overall, the SPSi presents a compelling model for sustainable cattle farming, offering both economic resilience and environmental benefits. However, ensuring long-term success will require coordinated efforts to overcome adoption barriers and implement supportive policies.

Based on our study, we provide the following recommendations:

**Wider adoption of the SPS should be encouraged:** The economic and environmental benefits of the SPS demonstrated in this study provide a strong case for promoting these systems across San Martín and other regions, but more evidence is needed with local trials to validate such projections. Governmental and non-governmental organizations should prioritize extending the SPS to cattle farmers to improve farm profitability and sustainability. Policymakers can leverage the existing empirical and informal knowledge about the SPSi in San Martín. For instance, remaining trees from logging operations are part of the livestock landscape and, in some cases, are used to demarcate paddocks or serve as windbreaks. This means that while monocultures predominate and farmers may be unaware of the benefits of the SPSi, they are already sensitized to the advantages of incorporating other plant species on their farms. Therefore, efforts can be made to formalize these practices and integrate additional ones.

**Financial and knowledge barriers need to be addressed for encouraging wider adoption:** To accelerate adoption of the SPS, access to favorable credit terms and financial incentives should be provided. Additionally, capacity-building initiatives, technical assistance, and extension services are necessary to bridge knowledge gaps and equip farmers with the skills required to implement and manage these systems.

**PES schemes should be implemented:** Governments should create frameworks to compensate farmers for the environmental benefits provided by the SPS, such as carbon sequestration. Establishing participation in carbon markets or PES programs would generate an additional income stream, encouraging farmers to adopt and sustain these systems. Green bonds or credit lines for the silvo-pastoral sector could support its growth, as such, financial instruments are currently unavailable in the study area.

**Unintended consequences of adoption need to be mitigated:** While the SPS offers numerous advantages, it is essential to prevent potential unintended consequences like deforestation, particularly in regions with unclear land tenure. Policymakers should implement robust monitoring systems, traceability protocols, and deforestation prevention measures to ensure that the expansion of the SPS aligns with sustainable land management practices and existing policy frameworks. Given that monoculture of cv. Marandú predominates and trees are not used efficiently, extension services should promote technical farm management, as well as the incorporation of the legume *Centrosema macrocarpum*, the shrub species Botón de Oro, and the defined tree species. These elements have shown good results in agronomic trials for the region. Proper management of these components will ensure the sustainability and scalability of the SPSi.

**Sustainable land management should be fostered through policy interventions:** A combination of regulatory mechanisms, including taxes on conventional monoculture pasture use and incentives for sustainable practices, will be crucial to ensuring that the SPS contributes to long-term environmental and economic sustainability in Peru's cattle sector. Finally, it is important to continue the economic evaluation of silvo-pastoral alternatives as this helps foster interest in these technologies. Additionally, environmental valuation elements can be incorporated by

measuring carbon capture and storage in tree biomass. This can also be achieved by monetizing the avoided costs associated with the shade provided by tree canopies, compared to a grey infrastructure that would offer the same service.

**Author Contributions:** J.J.J.P., S.G.D.M. and S.B. contributed to the conceptualization. J.J.J.P., S.G.D.M. and S.B. developed the methodology. J.J.J.P. conducted the formal analysis. J.J.J.P., S.G.D.M. and S.B. were involved in writing, reviewing, and editing. J.J.J.P., S.G.D.M. and S.B. contributed to resources. S.G.D.M. and S.B. handled supervision and funding acquisition. S.G.D.M. and S.B. were responsible for project administration. All authors contributed to the article and approved the submitted version. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by the CGIAR Initiative on Livestock and Climate (L&C) and the CGIAR Science Program on Sustainable Animal and Aquatic Foods (SAAF). The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data analyzed in this study is subject to the following licenses/restrictions: Requests to access these datasets should be directed to the corresponding author.

**Acknowledgments:** This work was carried out as part of the CGIAR Initiative on Livestock and Climate (L&C) and the CGIAR Science Program on Sustainable Animal and Aquatic Foods (SAAF). We thank all donors who globally support our work through their contributions to the CGIAR System. The views expressed in this document may not be taken as the official views of these organizations.

**Conflicts of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## References

1. BCRP. Actividad económica: Enero 2021 resumen. In *Notas de Estudios del BCRP no. 21–18 de Marzo de 2022*; Banco Central de Reserva del Perú: Lima, Peru, 2021; pp. 1–21.
2. MIDAGRI. Anuario Estadístico. In *Producción Ganadera y Avícola 2022*; Ministerio de Desarrollo Agrario y Riego: Lima, Peru, 2023; pp. 1–165.
3. Zavala Pope, M. Análisis del sector lácteo peruano. In *Cadena de la Leche*; Ministerio de Agricultura: Lima, Peru, 2010.
4. MIDAGRI. Midagri Impulsa Producción y Consumo de Carne Para Luchar Contra la Anemia Infantil. Nota de Prensa. 2019. Available online: <https://www.gob.pe/institucion/midagri/noticias/52971-minagri-impulsa-produccion-y-consumo-de-carne-para-luchar-contra-la-anemia-infantil> (accessed on 10 March 2025).
5. BCRP. *San Martín: Síntesis de Actividad Económica, Marzo 2023*; Banco Central de Reserva del Perú, Sucursal Iquitos: Iquitos, Peru, 2023.
6. DRASAM. *Plan De Desarrollo Ganadero Para La Región San Martín 2007–2016*; Dirección Regional Agraria San Martín (DRASAM) Gobierno Regional De San Martín: San Martin, Peru, 2007; pp. 1–45.
7. Echevarría, M.; Pizarro, D.; Gómez, C. *Alimentación de Ganadería en Sistemas Silvopastoriles de la Amazonia Peruana*; Programa Nacional de Innovación Agraria (PNIA); Universidad Nacional Agraria La Molina (UNALM): La Molina, Peru, 2019; pp. 1–17.
8. Cuevas-Reyes, V.; Jiménez, J.E.R.; Bravo, M.B.; Meza, A.L.; Sánchez-Toledano, B.I.; Gallegos, T.M.; Nieto, C.R. Evaluación financiera y económica de un sistema silvopastoril intensivo bajo riego. *Rev. Mex. Cienc. For.* **2020**, *11*, 89–110. [[CrossRef](#)]
9. Gomes da Silva, I.A.; Dubeux, J.C.B.; Melo, A.C.L.; da Cunha, M.V.; dos Santos, M.V.F.; Apolinário, V.X.O.; Freitas, E.V. Tree legume enhances livestock performance in a silvopasture system. *Agron. J.* **2021**, *113*, 358–369. [[CrossRef](#)]
10. Jose, S.; Dollinger, J. Silvopasture: A sustainable livestock production system. *Agrofor. Syst.* **2019**, *93*, 1–9. [[CrossRef](#)]
11. Lemes, A.P.; Garcia, A.R.; Pezzopane, J.R.M.; Brandão, F.Z.; Watanabe, Y.F.; Cooke, R.F.; Sponchiado, M.; de Paz, C.C.P.; Camplesi, A.C.; Binelli, M. Silvopastoral system is an alternative to improve animal welfare and productive performance in meat production systems. *Sci. Rep.* **2021**, *11*, 14092. [[CrossRef](#)]
12. Peri, P.L.; Dube, F.; Varella, A.C. Silvopastoral Systems in the Subtropical and Temperate Zones of South America: An Overview. In *Silvopastoral Systems in Southern South America*; Springer: Berlin/Heidelberg, Germany, 2016; Volume 11.
13. MIDAGRI. *Consideraciones Técnicas Para la Consolidación de un Modelo de Ganadería Tropical Sostenible en el Peru*; MIDAGRI (Ministerio de Desarrollo Agrario y Riego): Lima, Peru, 2023.

14. Chará, J.; Reyes, E.; Peri, P.; Otte, J.; Arce, E.; Schneider, F. *Sistemas Silvopastoriles y su Contribución al uso Eficiente de los Recursos y los Objetivos de Desarrollo Sostenible: Evidencia Desde América Latina*; FAO, CIPAV and Agri Benchmark: Rome, Italy, 2018; pp. 1–60.
15. Lagrange, S.P.; MacAdam, J.W.; Villalba, J.J. The Use of Temperate Tannin Containing Forage Legumes to Improve Sustainability in Forage–Livestock Production. *Agronomy* **2021**, *11*, 2264. [[CrossRef](#)]
16. Thilakarathna, M.S.; Papadopoulos, Y.A.; Rodd, A.V.; Grimmett, M.; Fillmore, S.A.E.; Crouse, M.; Prithiviraj, B. Nitrogen fixation and transfer of red clover genotypes under legume–grass forage based production systems. *Nutr. Cycl. Agroecosyst.* **2016**, *106*, 233–247. [[CrossRef](#)]
17. Schinato, F.; Munka, M.C.; Olmos, V.M.; Bussoni, A.T. Microclimate, forage production and carbon storage in a eucalypt-based silvopastoral system. *Agric. Ecosyst. Environ.* **2023**, *344*, 108290. [[CrossRef](#)]
18. Erazo, M. *La Importancia de los Sistemas Silvopastoriles para la Recuperación de los Bosques y Suelos de la Amazonía Peruana*; UNALM (Universidad Nacional Agraria La Molina): La Molina, Peru, 2023.
19. Roque Alcarraz, R.E.; Silva Del Águila, J.G.; Barrera Lozano, M. Sistemas silvopastoriles para la producción ganadera en el Centro de Producción Limón Rocío de la UNSM-T. *Rev. Vet. Zootec. Amaz.* **2022**, *2*, e398. [[CrossRef](#)]
20. Durango, S.G.; Barahona, R.; Bolívar, D.; Chirinda, N.; Arango, J. Feeding Strategies to Increase Nitrogen Retention and Improve Rumen Fermentation and Rumen Microbial Population in Beef Steers Fed with Tropical Forages. *Sustainability* **2021**, *13*, 10312. [[CrossRef](#)]
21. Mahecha, L.; Escobar, J.; Suárez, J.; Restrepo, L. *Tithonia diversifolia* (hemsl.) Gray (botón de oro) como suplemento forrajero de vacas F1 (Holstein por Cebú). *Livest. Res. Rural. Dev.* **2007**, *19*, 1–7.
22. Herrera, J.E.R.; Cuartas, C.A.; Naranjo, J.F.; Tafur, O.; Hurtado, E.A.; Arenas, F.A.; Chará, J.; Murgueitio, E. Efecto de la oferta y el consumo de *Tithonia diversifolia* en un sistema silvopastoril intensivo (SSPi), en la calidad y productividad de leche bovina en el piedemonte Amazónico colombiano. *Livest. Res. Rural. Dev.* **2015**, *27*, 1–9.
23. Rivera, J.E.; Villegas, G.; Chará, J.; Durango, S.G.; Romero, M.A.; Verchot, L. Effect of *Tithonia diversifolia* (Hemsl.) A. Gray intake on in vivo methane (CH<sub>4</sub>) emission and milk production in dual-purpose cows in the Colombian Amazonian piedmont. *Transl. Anim. Sci.* **2022**, *6*, txac139. [[CrossRef](#)] [[PubMed](#)]
24. Rivera, J.E.; Villegas, G.O.; Serna, L.; Chará, J.; Murgueitio, E. Potencial de los sistemas silvopastoriles con *Leucaena leucocephala* para incrementar la producción bovina y mitigar las emisiones de gases de efecto invernadero en el caribe colombiano. In *Sistemas Silvopastoriles: Hacia Una Diversificación Sostenible*; Rivera, J., Chará, J., Murgueitio, E., Rosales, R.B., Eds.; CIPAV: Cali, Colombia, 2023; pp. 1–1349.
25. Mauricio, R.M.; Calsavara, L.H.F.; Ribeiro, R.S.; Pereira, L.G.R.; de Freitas, D.S.; Paciullo, D.S.; Barahona, R.; Rivera, J.E.; Chara, J.; Murgueitio, E. Feeding ruminants using *Tithonia diversifolia* as forage. *J. Dairy Vet. Anim. Res.* **2017**, *5*, 117–120. [[CrossRef](#)]
26. INDECOPI. *Informe Preliminar. Estudio de Mercado Sobre el Sector Lácteo en el Perú*; Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual (INDECOPI): Lima, Peru, 2022.
27. Alegre, J.; Sánchez, Y.; Pizarro, D.; Gómez, C. *Manejo de los Suelos Con Sistemas Silvopastoriles en Las Regiones de Amazonas y San Martín*; Programa Nacional de Innovación Agraria (PNIA); Universidad Nacional Agraria La Molina (UNALM): La Molina, Peru, 2019; pp. 1–23.
28. Pizarro, D.; Vásquez, H.; Bernal, W.; Fuentes, E.; Alegre, J.; Castillo, M.S. Assessment of silvopasture systems in the northern Peruvian Amazon. *Agrofor. Syst.* **2020**, *94*, 173–183. [[CrossRef](#)]
29. Alegre, J.; Lao, C.; Silva, C.; Schrevels, E. Recovering degraded lands in the Peruvian Amazon by cover crops and sustainable agroforestry systems. *Peruv. J. Agron.* **2017**, *1*, 1–7. [[CrossRef](#)]
30. Valencia, F.; Cronkleton, P.; Bustamante, M. *Cadenas de Valor Forestal en Moyobamba, San Martín. Oportunidades Para Pequeños Productores*; Documentos de Trabajo 272; CIFOR-CGIAR: Bogor Barat, Indonesia, 2021; pp. 1–41.
31. Bazán, F.E.M.; Chávez, W.M.; Villanueva, J.R.B.; Aldave, J.C.V.; Gallardo, U.P. Uso potencial de *Eucalyptus viminalis* Labill. para la captura de carbono en un sistema silvopastoril, Perú. *Colomb. For.* **2022**, *26*, 64–78. [[CrossRef](#)]
32. Uriarte, J.S.; Diaz-Quevedo, C.; Pino, M.E.M.; Chávez, L.M.D.; Rivera, J.L.L.; Vásquez, H.; Ccasa, H.A.Q. Sustentabilidad productiva de la instalación de sistemas silvopastoriles: Una revisión sistemática basada en la realidad de Perú y Colombia. *Cienc. Y Tecnol. Agropecu.* **2023**, *24*, e3048.
33. Fuentes, E.; Gómez, C.; Pizarro, D.; Alegre, J.; Castillo, M.; Vela, J.; Huaman, E.; Vásquez, H. A review of silvopastoral systems in the Peruvian Amazon region. *Trop. Grassl. Forrajes Trop.* **2022**, *10*, 78–88. [[CrossRef](#)]
34. Navarro, E.F.; Gómez, C.; Pizarro, D.; Alegre, J.; Castillo, M.S.; Vela, J.; Huaman, E. Development of Silvopastoral Systems in the Peruvian Amazon. In *Silvopastoral systems of Meso America and Northern South America*; Springer International Publishing: Cham, Switzerland, 2023; pp. 135–154. [[CrossRef](#)]
35. Lee, S.; Bonatti, M.; Loehr, K.; Palacios, V.; Lana, M.A.; Sieber, S. Adoption potentials and barriers of silvopastoral system in Colombia: Case of Cundinamarca region. *Cogent Environ. Sci.* **2020**, *6*, 1823632. [[CrossRef](#)]
36. Grebner, D.L.; Bettinger, P.; Siry, J.P.; Boston, K. *Introduction to Forestry and Natural Resources*; Elsevier: Amsterdam, The Netherlands, 2021. [[CrossRef](#)]

37. Campanhola, C.; Pandey, S. Sustainable Livestock and Animal-Sourced Food. In *Sustainable Food and Agriculture*; Campanhola, C., Pandey, S., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 225–232. [CrossRef]
38. Libreros, H.F. *Experiencias Locales. Sistemas Silvopastoriles: Opción para la Mitigación y Adecuación al Cambio Climático en Bosque Seco Tropical*; Revista Semillas: Bogotá, Colombia, 2015. Available online: <https://www.semillas.org.co/es/sistemas-silvopastoriles-opci> (accessed on 10 March 2025).
39. COFUPRO. *Sistemas Silvopastoriles Intensivos, Base de la Productividad, Creación de Valor y Sostenibilidad de la Ganadería del Trópico de México*; Premio Innovagro 2014 El fruto del ingenio; Coordinadora Nacional de las Fundaciones Produce, A.C. (COFUPRO); COFUPRO: Distrito Federal, México, 2014; pp. 1–108.
40. IICA; Ministerio de Agricultura (MA); United States Department of Agriculture, Washington, D.C. (United States of America); Ministerio de Economía, Planificación y Desarrollo, Santo Domingo (República Dominicana). *Establecimiento y uso de Sistemas Silvopastoriles en República Dominicana*; Programa de Préstamos al Sector Agropecuario Agroindustrial y Comercial (PRESAAC): Santo Domingo, Dominican Republic, 2016; pp. 1–35.
41. Bacab, H.M.; Madera, N.B.; Solorio, F.J.; Vera, F.; Marrufo, D.F. Los sistemas silvopastoriles intensivos con *Leucaena leucocephala*: Una opción para la ganadería tropical. *Av. Investig. Agropecu.* **2013**, *17*, 67–81.
42. Broom, D.M.; Galindo, F.A.; Murgueitio, E. Sustainable, efficient livestock production with high biodiversity and good welfare for animals. *Proc. R. Soc. B Biol. Sci.* **2013**, *280*, 20132025. [CrossRef] [PubMed]
43. Broom, D.M. Components of sustainable animal production and the use of silvopastoral systems. *Rev. Bras. De Zootec.* **2017**, *46*, 683–688. [CrossRef]
44. Murgueitio, E.; Cuartas, C.; Naranjo, J. *Ganadería Del Futuro: Investigación Para El Desarrollo*; CIPAV: Cali, Colombia, 2008.
45. Murgueitio, E.; Uribe, F.; Molina, C.H.; Galindo, W.; Chará, J.; Flores, M.X.; Giraldo, C.; Cuartas, C.A.; Solarte, L.H.; González, J.G.; et al. *Establecimiento y Manejo de Sistemas Silvopastoriles Intensivos Con Leucaena*; CIPAV: Cali, Colombia, 2016.
46. Barrios-Pérez, C.; Rahn, E.; Sulca, S.; Alvarez Toro, P. Fortaleciendo el Sector Agrícola en San Martín, Perú a partir de nuevos Servicios Agroclimáticos. *Sustain. Sci. Technol.* **2023**. [CrossRef]
47. Huang, J.; Hartemink, A.E. Soil and environmental issues in sandy soils. *Earth Sci. Rev.* **2020**, *208*, 103295. [CrossRef]
48. Osman, K.T. Sandy Soils. In *Management of Soil Problem*; Springer International Publishing: Cham, Switzerland, 2018; pp. 37–65. [CrossRef]
49. EMBRAPA. *Brachiaria brizantha cv. Marandu*; Empresa Brasileira de Pesquisa Agropecuária—EMBRAPA: Brasília, Brazil; Centro Nacional de Pesquisa de Gado de Corte—CNPGC Campo Grande: Campo Grande, Brazil, 1984; pp. 1–32.
50. Cook, B.; Pengelly, B.; Schultze-Kraft, R.; Taylor, M.; Burkart, S.; Cardoso Arango, J.A.; González Guzmán, J.J.; Cox, K.; Jones, C.; Peters, M. *Tropical Forages: An Interactive Selection Tool*; International Center for Tropical Agriculture (CIAT): Cali, Colombia; International Livestock Research Institute (ILRI): Nairobi, Kenya, 2020.
51. MIDAGRI. *Pastos Naturales*; Ministerio de Desarrollo Agrario y Riego—MIDAGRI: Lima, Peru, 2023. Available online: <https://datosabiertos.gob.pe/dataset/pastos-cultivados-para-el-desarrollo-ganadero-ministerio-de-desarrollo-agrario-y-riego> (accessed on 10 March 2025).
52. Perulactea. El Pasto Brachiaria: Sus híbridos e Introducción al Perú—Segunda Parte. *Perulactea. Edwin Palacios* **2015**. Available online: <https://perulactea.com/el-pasto-brachiaria-sus-hibridos-e-introduccion-al-peru-segunda-parte/> (accessed on 10 March 2025).
53. Raza, A.; Zahra, N.; Hafeez, M.B.; Ahmad, M.; Iqbal, S.; Shaukat, K.; Ahmad, G. Nitrogen Fixation of Legumes: Biology and Physiology. In *The Plant Family Fabaceae*; Springer: Singapore, 2020; pp. 43–74. [CrossRef]
54. Sotelo, M.E.; Castañeda, N.; Sánchez, M.A.R.; Quintero, M.; Arango, J. *Especies Vegetales Útiles Para Sistemas Silvopastoriles del Caquetá, Colombia*; Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH: Bonn, Germany; Centro Internacional de Agricultura Tropical (CIAT): Cali, Colombia, 2016; pp. 1–84.
55. Perulactea. Girolando: Una Raza para Producir Leche en el Trópico. 2014. Available online: <https://perulactea.com/girolando-una-raza-para-producir-leche-en-el-tropico/?amp-wp-skip-redirect=1> (accessed on 10 March 2025).
56. Perulactea. Girolando: Una Mirada al Ganado Lechero Tropical. *Not. Int.* **2012**. Available online: <https://perulactea.com/girolando-una-mirada-al-ganado-lechero-tropical/#:~:text=La%20Girolando%20es%20considerada%20la,un%20rendimiento%20muy%20satisfactorio%20econ%C3%B3micamente> (accessed on 10 March 2025).
57. MEF. *Guía General Para la Identificación, Formulación y Evaluación de Proyectos de Inversión. Módulo 3: Evaluación*, Dirección de Política y Estrategias de la Inversión Pública. Dirección General de Programación Multianual de Inversiones; Ministerio de Economía y Finanzas—MEF: Miraflores, Peru, 2021; pp. 1–45.
58. BCRP; IPC. Bcrpdata. Banco Central de Reserva del Perú. Gerencia Central de Estudios Económicos. 2023. Available online: <https://estadisticas.bcrp.gob.pe/estadisticas/series/anuales/resultados/PM05217PA/html> (accessed on 10 March 2025).
59. Contexto Ganadero. Perú Promoverá el Uso de Fertilizantes Orgánicos. *Contexto Ganad.* **2023**. Available online: <https://www.contextoganadero.com/internacional/peru-promovera-el-uso-de-fertilizantes-organicos> (accessed on 10 March 2025).
60. Miranda, J.J. *Gestión de Proyectos*; Universidad Del Azuay: Cuenca, Ecuador, 2022.

61. CEPEP. Indicadores de Rentabilidad. Centro de Estudios para la Preparación y Evaluación Socioeconómica de Proyectos (CEPEP) Boletín Número V 1–10. 2017. Available online: [https://www.cepep.gob.mx/work/models/CEPEP/metodologias/boletines/indicadores\\_rentabilidad.pdf](https://www.cepep.gob.mx/work/models/CEPEP/metodologias/boletines/indicadores_rentabilidad.pdf) (accessed on 10 March 2025).
62. Vilani, L.; Zanin, A.; Lizot, M.; Trentin, M.G.; Afonso, P.; Lima, J.D.d. A Framework for Investment and Risk Assessment of Agricultural Projects. *J. Risk Financ. Manag.* **2024**, *17*, 378. [CrossRef]
63. Clayman, M.R.; Fridson, M.S.; Troughton, G.H. *Corporate Finance. A Practical Approach*; John Wiley & Sons: Hoboken, NJ, USA, 2012.
64. Morris, J.R.; Daley, J.P. *Introduction to Financial Models for Management and Planning*; Taylor & Francis: London, UK, 2009.
65. Platon, V.; Constantinescu, A. Monte Carlo Method in Risk Analysis for Investment Projects. *Procedia Econ. Financ.* **2014**, *15*, 393–400. [CrossRef]
66. Park, C.S. *Contemporary Engineering Economics*; Pearson: London, UK, 2007.
67. INEGI. Perú. Compendio estadístico 2023. Instituto Nacional de Estadística e Informática. Sistema Estadístico Nacional 1063–2041. 2023. Available online: [https://www.inei.gob.pe/media/MenuRecursivo/publicaciones\\_digitales/Est/Compendio2023/COMPENDIO023.html](https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Compendio2023/COMPENDIO023.html) (accessed on 10 March 2025).
68. Enciso, K.; Charry, A.; Castillo, Á.R.; Burkart, S. Ex-Ante Evaluation of Economic Impacts of Adopting Improved Forages in the Colombian Orinoquía. *Front. Environ. Sci.* **2021**, *9*, 673481. [CrossRef]
69. Mavisoy, H.; Vallejos, A.R.R.; Narváez-Herrera, J.P.; Sánchez, Á.; de Almeida, A.M. Using silvopastoral systems for the mitigation of greenhouse gas emissions from livestock in the Colombian Amazon. *Agrofor. Syst.* **2024**, *98*, 337–352. [CrossRef]
70. Lerma, L.M.; Baca, M.F.D.; Burkart, S. Sustainable beef labeling in Latin America and the Caribbean: Initiatives, developments, and bottlenecks. *Front. Sustain. Food Syst.* **2023**, *7*, 1148973. [CrossRef]
71. Moreno Lerma, L.; Díaz Baca, M.F.; Burkart, S. Public Policies for the Development of a Sustainable Cattle Sector in Colombia, Argentina, and Costa Rica: A Comparative Analysis (2010–2020). *Front. Sustain. Food Syst.* **2022**, *6*, 722522.
72. Baca, M.F.D.; Lerma, L.M.; Burkart, S. How do sustainability policies emerge in the Colombian political system? A Kaleidoscope Model Analysis of the Policy for Sustainable Cattle 2022–2050. *Clean. Circ. Bioeconomy* **2024**, *7*, 100075. [CrossRef]
73. Cubbage, F.; Balmelli, G.; Bussoni, A.; Noellemeyer, E.; Pachas, A.N.; Fassola, H.; Colcombet, L.; Rossner, B.; Frey, G.; Dube, F.; et al. Comparing silvopastoral systems and prospects in eight regions of the world. *Agrofor. Syst.* **2012**, *86*, 303–314. [CrossRef]
74. Chizmar, S.; Castillo, M.; Pizarro, D.; Vasquez, H.; Bernal, W.; Rivera, R.; Sills, E.; Abt, R.; Parajuli, R.; Cubbage, F. A Discounted Cash Flow and Capital Budgeting Analysis of Silvopastoral Systems in the Amazonas Region of Peru. *Land* **2020**, *9*, 353. [CrossRef]
75. Islam, M.A.; Mugloo, J.A.; Raj, A.; Bhat, G.M.; Wani, A.A.; Gatoo, A.A.; Malik, A.R.; Pala, N.A.; Shah, M. Agroforestry Strategy for Revitalizing Fodder Security in Kashmir Himalaya, India. *Agric. Res.* **2022**, *11*, 528–538. [CrossRef]
76. Filho, W.C.M.; Barbosa, G.F.; Cardoso, D.L.; Ferreira, A.D.; Pedrinho, D.R.; Bono, J.A.M.; de Souza, C.C.; Frainer, D. Productive sustainability in a silvopastoral system. *Biosci. J.* **2017**, *33*, 10–18. [CrossRef]
77. Bernardy, D.; Jesus, L.C.; Ziembowicz, M.M.; Weiler, E.B.; de Farias, J.A. Production and financial feasibility in silvopastoral system in small rural property. *Rev. Árvore* **2022**, *46*, 1–7. [CrossRef]
78. Jiménez-Ferrer, G.; Mendoza-Martínez, G.; Soto-Pinto, L.; Alayón-Gamboa, A. Evaluation of local energy sources in milk production in a tropical silvopastoral system with *Erythrina poeppigiana*. *Trop. Anim. Health Prod.* **2015**, *47*, 903–908. [CrossRef]
79. García-Martínez, A.; López, I.E.; Jiménez, S.E.; Albarran-Portillo, B.; Yong, G.; Rayas amor, A.A. Evaluación productiva y económica de un sistema silvopastoril intensivo en bovinos doble propósito en Michoacán, México. *CIENCIA ergo sum* **2018**, *25*, 8.
80. Sandoval, D.F.; Florez, J.F.; Valencia, K.J.E.; Cabrera, M.E.S.; Stefan, B. Economic-environmental assessment of silvo-pastoral systems in Colombia: An ecosystem service perspective. *Heliyon* **2023**, *9*, e19082. [CrossRef]
81. Enciso, K.; Sotelo, M.; Peters, M.; Burkart, S. The inclusion of *Leucaena diversifolia* in a Colombian beef cattle production system: An economic perspective. *Trop. Grassl. Forrajes Trop.* **2019**, *7*, 359–369. [CrossRef]
82. Quintero, R.G.; García, E.H.; Florez, F.; Burkart, S.; Arango, J. A case study on enhancing dairy cattle sustainability: The impact of silvopastoral systems and improved pastures on milk carbon footprint and farm economics in Cauca department, Colombia. *Agrofor. Syst.* **2024**, *98*, 3001–3018. [CrossRef]
83. Rade L, D.Y.; Cañadas, A.; Zambrano, C.; Molina, C.; Ormaza, A.; Wehenkel, C. Viabilidad económica y financiera de sistemas silvopastoriles con *Jatropha curcas* L. en Manabí, Ecuador. *Rev. MVZ Córdoba* **2017**, *22*, 6241–6255. [CrossRef]
84. González-Quintero, R.; van Wijk, M.T.; Ruden, A.; Gómez, M.; Pantevez, H.; Castro-Llanos, F.; Notenbaert, A.; Arango, J. Yield gap analysis to identify attainable milk and meat productivities and the potential for greenhouse gas emissions mitigation in cattle systems of Colombia. *Agric. Syst.* **2022**, *195*, 103303. [CrossRef]
85. Huertas, S.M.; Bobadilla, P.E.; Alcántara, I.; Akkermans, E.; van Eerdenburg, F.J.C.M. Benefits of Silvopastoral Systems for Keeping Beef Cattle. *Animals* **2021**, *11*, 992. [CrossRef] [PubMed]
86. Ibrahim, M.A.; Guerra, L.; Casasola Coto, F.; Neely, C. *Importance of Silvopastoral Systems for Mitigation of Climate Change and Harnessing of Environmental Benefits*; Programa Agroambiental Mesoamericano (MAP). Fase I; Food and Agriculture Organization: Rome, Italy, 2013; Chapter X; pp. 1–8.

87. Bosi, C.; Pezzopane, J.R.M.; Sentelhas, P.C. Silvopastoral system with Eucalyptus as a strategy for mitigating the effects of climate change on Brazilian pasturelands. *An. Acad. Bras. Ciências* **2020**, *92*, e20180425. [[CrossRef](#)]
88. Sales-Baptista, E.; Ferraz-De-Oliveira, M.I. Grazing in silvopastoral systems: Multiple solutions for diversified benefits. *Agrofor. Syst.* **2021**, *95*, 1–6. [[CrossRef](#)]
89. Helguera Pereda, L.; Lanfranco Crespo, B. *Riesgo y Rentabilidad en Empresas Ganaderas*; Serie Técnica N° 157; Instituto Nacional de Investigación Agropecuaria (INIA): Singapore, 2006; pp. 2–74.
90. Enciso, K.; Triana, N.; Díaz, M.; Burkart, S. On (Dis)Connections and Transformations: The Role of the Agricultural Innovation System in the Adoption of Improved Forages in Colombia. *Front. Sustain. Food Syst.* **2022**, *5*, 741057. [[CrossRef](#)]
91. Tschopp, M.; Ceddia, M.G.; Inguaggiato, C. Adoption of sustainable silvopastoral practices in Argentina’s Gran Chaco: A multilevel approach. *J. Arid. Environ.* **2022**, *197*, 104657. [[CrossRef](#)]
92. Tschopp, M.; Ceddia, M.G.; Inguaggiato, C.; Bardsley, N.O.; Hernández, H. Understanding the adoption of sustainable silvopastoral practices in Northern Argentina: What is the role of land tenure? *Land Use Policy* **2020**, *99*, 105092. [[CrossRef](#)]
93. Jara-Rojas, R.; Russy, S.; Roco, L.; Fleming-Muñoz, D.; Engler, A. Factors Affecting the Adoption of Agroforestry Practices: Insights from Silvopastoral Systems of Colombia. *Forests* **2020**, *11*, 648. [[CrossRef](#)]
94. Charry, A.; Narjes, M.; Enciso, K.; Peters, M.; Burkart, S. Sustainable intensification of beef production in Colombia—Chances for product differentiation and price premiums. *Agric. Food Econ.* **2019**, *7*, 1–18. [[CrossRef](#)]
95. Puppo, L.; Aguerre, M.; Camio, G.; Hayashi, R.; Morales, P. Evaluación del riego por melgas en los suelos del sur del Uruguay. Uso del modelo WinSRFR, resultados preliminares. *Agrociencia Urug.* **2018**, *22*, 79–92. [[CrossRef](#)]
96. Raes, L.; Speelman, S.; Aguirre, N. Farmers’ Preferences for PES Contracts to Adopt Silvopastoral Systems in Southern Ecuador, Revealed Through a Choice Experiment. *Environ. Manag.* **2017**, *60*, 200–215. [[CrossRef](#)]
97. Cancino, R.M.Z.; Zebadúa, M.E.V.; Toral, J.N.; Garay, A.H.; Tinajero, J.J.M. Adopción de sistemas silvopastoriles y contexto sociocultural de los productores: Apoyos y limitantes. *Rev. Mex. Cienc. Pecu.* **2016**, *7*, 471–488. [[CrossRef](#)]
98. Zapata, C.; Robalino, J.; Solarte, A. Influencia del pago por servicios ambientales y otras variables biofísicas y socioeconómicas en la adopción de sistemas silvopastoriles a nivel de finca. *Livest. Res. Rural. Dev.* **2015**, *27*, 63.
99. Calle, Z.; Murgueitio, E.; Chará, J.; Molina, C.H.; Zuluaga, A.F.; Calle, A. A Strategy for Scaling-Up Intensive Silvopastoral Systems in Colombia. *J. Sustain. For.* **2013**, *32*, 677–693. [[CrossRef](#)]
100. Díaz, M.F.; Enciso, K.; Triana Ángel, N.; Muriel, J.; Burkart, S. *Pagos por Servicios Ambientales para Sistemas Silvopastoriles en Colombia*; CIAT 1–54; Centro Internacional de Agricultura Tropical (CIAT): Cali, Colombia, 2019.
101. Parodi, A.; Valencia-Salazar, S.; Loboguerrero, A.M.; Martínez-Barón, D.; Murgueitio, E.; Vázquez-Rowe, I. The sustainable transformation of the Colombian cattle sector: Assessing its circularity. *PLOS Climate* **2022**, *1*, e0000074. [[CrossRef](#)]
102. Castro-Nunez, A.; Buriticá, A.; Gonzalez, C.; Villarino, E.; Holmann, F.; Perez, L.; Del Río, M.; Sandoval, D.; Eufemia, L.; Löhr, K.; et al. The risk of unintended deforestation from scaling sustainable livestock production systems. *Conserv. Sci. Pr.* **2021**, *3*, e495. [[CrossRef](#)]
103. Alcott, B. Jevons’ paradox. *Ecol. Econ.* **2005**, *54*, 9–21. [[CrossRef](#)]

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.