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Article

Financial Analysis and Cost Implications of Implementing an Agroforestry System in Brazil

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Abstract: Agroforestry Systems (AFS) integrate agricultural and forest production, providing ecosystem environmental services. They are considered important tools for addressing problems caused by modern agricultural development. Despite their proven environmental and productive benefits, more studies are needed to support the viability and adoption of AFS by rural producers. This study accounts for the primary costs of implementing 1 hectare of a biodiverse AFS in Brazil. The results show that the acquisition of seedlings and propagules constitutes the highest costs, with avocado seedlings being the most expensive. Operational costs, particularly grading and the purchase of inputs, also represent significant expenses. Future research should focus on tracking the evolution of implementation costs, substituting expensive external supplies, and optimizing operational times for area preparation. These efforts will enhance the design and viability of AFS, addressing local producer needs and ensuring profitable maintenance.

Keywords: sustainable agriculture; financial viability; implementation costs; agricultural development; operational costs

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1. Introduction

The model of agricultural development adopted in Brazil through the Green Revolution, consisting of the use of technological packages linked to petrochemical and mining products, allowed the country to improve its position in the global scenario as an exporter of agricultural commodities and fostered internal industrial growth (Nehring, 2022). Since 1960, the technological revolution has led to significant transformations in almost every economic sector, including agriculture. This has resulted in profound changes in the social and territorial division of agricultural work, with the primary goal being to boost productivity and lower production costs through the utilization of machinery, chemical additives, and biotechnological inputs provided by the industry (Martinelli et al., 2010; Oyvat, 2016).

However, some consequences have emerged, such as social impacts on agrarian structure, environmental issues, and income concentration, exacerbating the agrarian and urban crises (Martinelli et al., 2010; Oyvat, 2016). The adoption of modern machinery in Brazilian farming reduced the need for labor, leading to an increase in rural exodus (Nehring, 2022). Large areas of natural vegetation were converted into agricultural land, leading to increased soil compaction, salinization, and desertification. Soil and water were also contaminated by agrochemicals (Pingali, 2012). There was a significant increase in pressure on areas suitable for this agriculture model, leading to social and environmental conflicts (Paulino, 2014).

Given the serious environmental and social impacts generated, there's hope to ensure that future generations continue to have access to natural resources vital to life and production (Nehring, 2022; Pingali, 2012; Srivastav, 2020). The Agroforestry Systems (AFS) adopt less aggressive production practices, playing an important role in this scenario (Angelotti et al., 2015; Gomez-Zavaglia et al., 2020; Ollinaho & Kröger, 2021; Sacramento et al., 2013). The AFS refers to a combination of land use systems and technologies that incorporate at least one perennial plant species into crop and/or animal husbandry within the same management unit, taking into account their spatial arrangement and chronology (Nair et al., 2021). AFS vary widely according to the purpose of establishment and in the spatial arrangement and they can use native plants, animals, and crops interleaved with trees (Rosa-Schleich et al., 2019). In this area, different species coexist and are planted and managed according to their specific requirements. The primary objective is to optimize biomass production, efficient use of space, light and nutrients, and produce agricultural and non-agricultural goods essential for human life and to ecosystem services (Haggar et al., 2019; Santos et al., 2019).

Comparing the performance of different systems requires an understanding of production costs. Technical coefficients for AFSs must consider labor, supply inputs, seedlings, and seeds necessary for implementation, as well as the management of the cultivation area for each species (Arco-Verde & Amaro, 2021). This allows for a cost projection specific to each species, leading to more accurate analyses, especially as AFSs consists of multiple plant species.

In order to promote AFSs as a replicable tool to distinct groups of producers, it is necessary to create management tools (Bowman & Zilberman, 2013). These might include cost estimates for area implementation, production forecasts and revenue projections, enabling efficient planting and management for achieving necessary profitability and socioeconomic improvements. Therefore, it is crucial to conduct studies that outline the costs of AFS implantation. The complexity of having multiple species within the reproductive system requires special attention to production dynamics. This is important not just for on-site management, but also for accurate financial projections, including initial expenditures such as supplies, seeds, seedlings, and labor costs. This data is fundamental to assist in the management of cultivated areas, as it takes into account the costs farmers will incur during implementation. Therefore, the purpose of this paper is to present and discuss the main costs of implementing one hectare of a biodiverse Agroforestry System in Brazil. To achieve this, we adhered to the steps outlined in Figure 1.

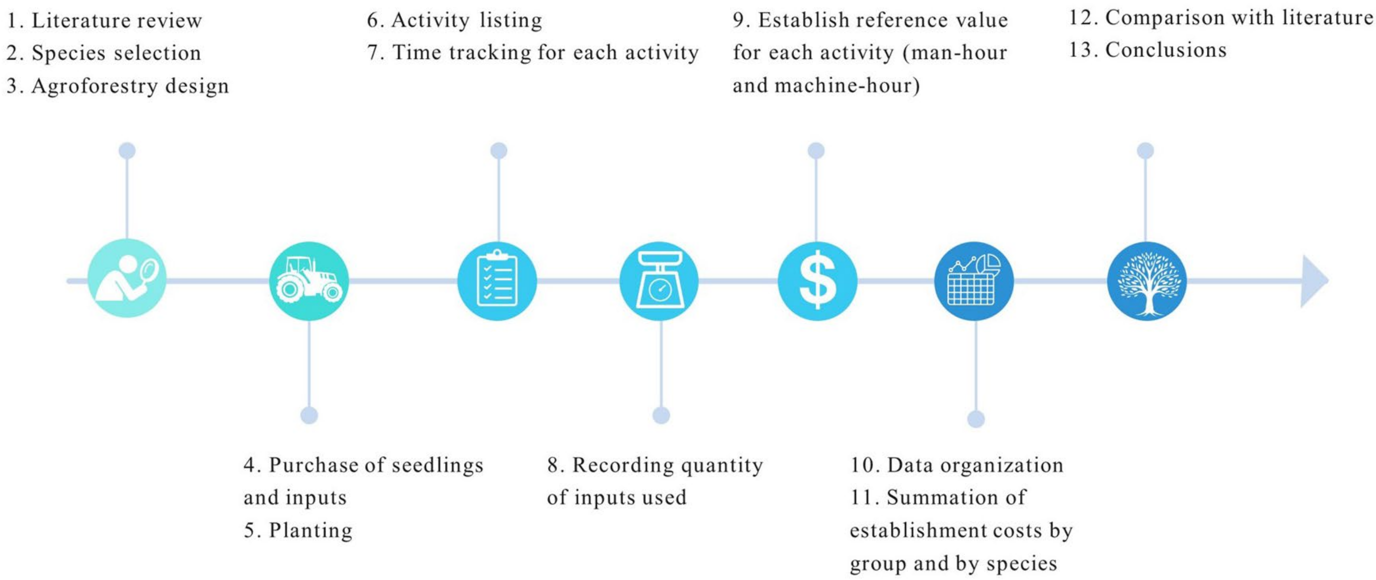

Figure 1. Key steps for evaluating the costs of implementing a biodiverse Agroforestry System in Brazil.

Literature Review

The adoption of AFS can bring a series of benefits and advantages to farmers, both economically and ecologically. Properties can experience economic advantages due to the diversity of production (Jezeer et al., 2018), increased productivity (Rezende et al., 2021) and the promotion of a green economy in which environmental services provided might be compensated. The soil will be protected as it benefits from reduced water and nutrient loss, as well as decreased erosion processes (Fahad et al., 2022). This also leads to an increase in fauna abundance, possibly attracting more predators to control herbivorous insects and more pollinators to aid in fruit formation (Marsden et al., 2020).

Ecologically, trees offer protection for vegetation, enhance biological pest control (Moura et al., 2021), reduce humidity loss, and mitigate wind impact (Anjos et al., 2022). The arrangement of the landscape surrounding cultivated areas has an impact on pollinator diversity. It offers new nesting possibilities and food resources throughout the year, subsequently, enhancing productivity, including fruits and seeds (Coutinho et al., 2020; Hipólito et al., 2018; Torezan-Silingardi et al., 2021). Furthermore, AFS demonstrated a more favorable assessment of environmental services compared to full-sun systems (de Melo Virginio Filho et al., 2021). Moreover, diversified practices like AFS offer significantly greater biodiversity and related ecosystem services, such as pest and weed control, soil health, nutrient and water management and carbon sequestration compared to non-diversified farming (Hübner et al., 2021). Multiple factors demonstrate the benefits of AFS in agriculture. AFSs offer significant environmental advantages by promoting the sustainable use of natural resources while reducing the need for external inputs (Froufe et al., 2020). This leads to increased food security and cost savings for producers. As a result, agroforest ecosystems tend to be more resilient in the face of economic and environmental challenges compared to conventional systems, particularly for small and medium-scale family farmers (Rosa-Schleich et al., 2019).

Despite studies showing that AFSs may be economically, socially, and ecologically viable (Rasmussen et al., 2024), they are not widely adopted (Do & Whitney, 2020). The increased biodiversity within AFS production complicates cultivation, requiring knowledge of the species, how to incorporate them into the production space, their growth habits, nutritional needs, and ecological factors (Sagastuy & Krause, 2019). It is important to have prior knowledge about the benefits and drawbacks that certain species may bring to financial gains and the cultivation area when grown in association with other plants. With this preliminary understanding, revenue can be generated by cultivating agricultural species that provide quick economic returns and intercropping them with timber species that yield financial returns in the long term (Sagastuy & Krause, 2019).

Farmers need to have a good understanding of the farming process and the design model for the areas to be cultivated and managed. This knowledge allows for making interventions that are beneficial in the long term and lead to profitable farming systems (Valencia et al., 2015; van der Wolf et al., 2019). Even though not just the concept and background are important, the role transition to achieve an established AFS must be taken into account (Ollinaho & Kröger, 2021). Associated with this knowledge are the financial aspects of the system. Not only crop yield, but also labor costs, price premiums for product quality, and additional income streams and costs of inputs are main factors that influence overall profitability (de Melo Virginio Filho et al., 2021). Diverse agricultural practices, such as AFSs, have been shown to potentially result in higher and more consistent yields, improved profitability, and reduced long-term risks. However, according to Rosa-Schleich et al. (2019), the ecological benefits for farmers were found to only partially outweigh the economic costs in the short term.

Sagastuy and Krause (2019) identified the three most commonly mentioned reasons why conventional agriculture farmers are hesitant to shift to agroforestry practices: uncertainty about whether the system will work, concerns about potential reduction in yield of the main agricultural crop, and a lack of models and knowledge in the region. This demonstrates the necessity of economic feasibility studies before implementing agroforest projects (Martinelli et al., 2019).

The absence of economic and financial indicators tailored to the needs of agroforestry production in agriculture can hinder adoption. Therefore, utilizing modeling tools and economic indicators can help identify the most suitable species configuration with the potential for both fast and long-term economic returns. This process can improve understanding of the market and help in accurately selecting crops. Studies have shown that diversified farming systems are just as profitable as simplified farming systems, with higher total costs, gross income and profits (net income or gross margin) in diversified systems compared to simplified ones. The benefit-cost ratio was found to be equivalent in both types of farming systems (Hübner et al., 2021).

There is strong evidence to suggest that AFSs are not only feasible but also economically advantageous compared to simplified farming systems in various situations (de Melo Virginio Filho et al., 2021). The benefit-cost ratio was found to be higher in diversified systems utilizing agroforestry (Hübner et al., 2021). Estimates show that household income generated from agroforestry was approximately three times higher than the income generated from conventional farming (Abbas et al., 2021).

The complexity of integrating multiple species into diverse systems also reflects in the complexity of evaluating positive financial indicators. Financial indicators in AFS do not always guarantee long-term success (Paul et al., 2017). Palma et al. (2020) conducted a study within an organic ADS and found that despite positive initial indicators during the evaluation period, the field results did not meet expectations. They discovered that high density of perennial species and improper allocation negatively affected production. Additionally, the high plant density and the number of trees in the system significantly increased overall costs and energy inputs (Tabal et al., 2021).

Costs in a diverse planting system can depend on a range of factors. From an overall perspective, it is possible to identify that labor availability and costs are concerns among researchers and practitioners. Before establishing an AFS, it is important to consider production cost and its economic feasibility (Martinelli et al., 2019). The choice of planting method, whether manual, semi-mechanized, or fully mechanized, labor availability (de Morais et al., 2023; Huang et al., 2023), input costs, and subsidies are all factors that impact the total cost. Studies conducted in various regions have shown that labor costs increased in diversified farming systems, but so did gross incomes, leading to farm profits equivalent to those in simplified systems (Hübner et al., 2021).

Those findings are similar as seen in other studies, such as Bentes-Gama et al. (2005) that discovered that labor represented over 50% of total costs, with the highest proportion occurring during land preparation. Armando et al. (2002) reported that the highest expenses were related to inputs, materials, and services (56.86%), followed by labor (43.14%). In a study by Pauletto et al. (2018), it was found that labor costs for cleaning and preparing the cultivation area accounted for 38 to 45% of the total resources invested in the crop. The labor demand in an AFS is influenced by several factors, including species composition and productive objective. AFSs designed for vegetable production, for example, require greater work intensity and more workers (Palma et al., 2020). Thus, the cost assessment of a complex production system depends on factors such as area size, plant quantity, technological level, labor availability, and crop focus (Grahmann et al., 2024; Tabal et al., 2021).

2. Methodology

2.1. Studied Area: Region and Rural Property Profiles

The study was conducted at the rural property "Sítio São Francisco" (23°09'53.50"S and 49°32'51.13"W) in the municipality of Timburi, São Paulo State, Brazil, from September 2021 to March 2022. We assessed the establishment of a one hectare diverse AFS using a variety of fruit and timber species. The area is predominantly covered by vegetation from the Atlantic Forest biome. Timburi town has a population of 2,647 people and a strong presence of family farming in its agricultural sector (Instituto Brasileiro de Geografia e Estatística, 2021). This has inspired the property owners to introduce agroforestry prototypes in the region. The rural property under analysis is actively working on projects aimed at developing and producing AFSs with the vision of setting a precedent for the region. It's worth noting that the municipality falls within the environmental preservation area of the state of São Paulo, designated by State Decree No. 20,960 dated June 8, 1983.

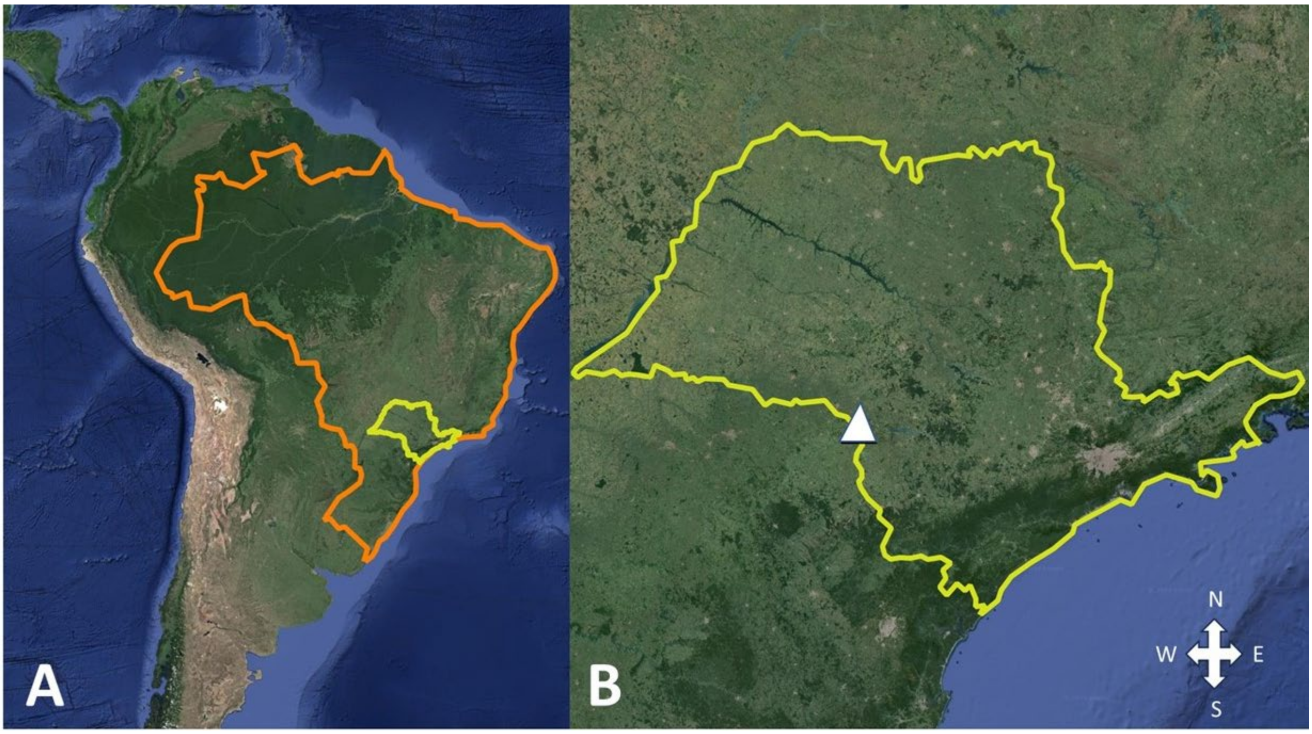

Figure 2. Study area. The São Paulo state (yellow) is located in the Southeastern part of Brazil (orange) (A). The Sítio São Francisco is situated in the city of Timburi (B), indicated by the white triangle.
Source: Google Earth.

2.2. Plant Species

The plant species used for the intercropped AFS were spaced in rows 4 meters apart from each other. The conventional avocado planting logic (8×6m) was used, with other species planted in between the free spaces. The exotic Avocado (*Persea americana*, Lauraceae) was the main crop on the property. Hass, Quintal, and Margarida were the three avocado varieties planted as a strategy for diversification and to synchronize pollen exchange among them (Gaurha et al., 2024). The dwarf banana (*Musa paradisiaca*, Musaceae) is an exotic invasive plant with medium to low stature (2.0 to 3.5 m) and was planted in all rows. This banana variety is considered cold-tolerant and moderately tolerant to nematodes, while also showing good potential for productivity (Quénéhervé et al., 2012). Pink pepper (*Schinus terebinthifolia*, Anacardiaceae) is a small-sized species native to the coastal restingas in Brazil. It was planted in rows interspersed between the rows of forestry species (African mahogany and pink jequitibá) for commercial purposes. This is because its seeds are used as a spice, and also serve as a species for pruning of its branches and leaves for fruit harvesting, which returns material to the soil after fruit separation (Wilkomm et al, 2024). Pink jequitibá (*Cariniana legalis*, Lecythidaceae) is a native tree species of the Atlantic Forest. It is being considered in this design for increasing diversity and producing long-cycle timber (Ribeiro et al., 2022). African mahogany (*Khaya grandifoliola*, Meliaceae) was chosen as a medium-cycle timber species. This exotic species has good wood quality and market value (Ferraz Filho et al., 2021), and it is more tolerant to tip borer than Brazilian mahogany. The species that had the highest number of planted seedlings in the area was the pink pepper, while the species with the lowest quantity was the pink jequitibá. As part of a strategy for biological nitrogen fixation and biomass production to cover the planting rows, four species were sown as cover crops: sunn hemp (*Crotalaria juncea*, Fabaceae), an exotic species, pigeon pea (*Cajanus cajan*, Fabaceae), jack bean (*Canavalia ensiformis*, Fabaceae), and forage radish (*Raphanus sativus*, Brassicaceae). The cover crop species were sown in the inter-row spaces only after planting the forestry and fruit species. Among the planted species, only sunn hemp is considered by the Horus Institute as an invasive species (Instituto Hórus, 2022).

2.3. Cost Calculations

This study accounts for the primary costs of implementing one hectare of a biodiverse AFS in Brazil, and the methodology used was based mainly on Araújo (2020). First, all the activities carried out to effectively characterize their operation and performance needed to be listed. For the application of the methodology, the establishment costs of the systems were divided into individual costs per species and collective costs. This separation resembles what happens at the field level, where some operations and supply inputs are used throughout, and others are specific to a given species. For example, the amount of hydrogel used per species or the time spent digging avocado planting holes is larger than the holes required for the forestry species.

The data was directly assigned to the activities performed by the producer based on the time spent and the cost generated for each activity. This process was applied to all system activities, including area preparation and planting. Reference values, taken as premises, accounted for the prices associated with establishing the studied AFS, as presented in Table 1. To determine costs, a base salary of R$1,200.00 per month in 2022 was established, with taxes set at 90% of this amount. The total is then divided by the average number of hours worked per month to calculate the hourly wage paid to each worker. The "hour/machine" figure represents the average regional rate for one hour of work with rented machinery, as provided by the owners.

Table 1. Individual costs on AFS implementation date expressed in Brazilian reais (R$), and after conversion to US dollars (US$) according to the exchange rate on the date of each publication.

Cost description	Individual cost (R$)	Exchange rate	Individual cost (US$)
Hour/person	12.7	4.73	2.68
Hour/machine	200.00	4.73	42.28
Hour/semi-mechanized labor	15.20	4.73	3.21
Salary	1,200.00	4.73	253.7
Taxes	0.90	4.73	0.19
Total labor costs/month	2,280.00	4.73	482.03

The resources used for carrying out the activities were documented in the field records. The costs associated with the activities and the total amount of resources used for specific tasks for each species were calculated periodically. For example, the quantity of hydrogel applied in plant holes varied for each plant species as shown in Table 2, as well as the amount of seedlings used per hectare, as shown in Table 3.

Table 2. Hydrogel amount (Kg) used per seedling of each species.

Species	Kg
Avocado (Plastic bag)	0.007
Pink pepper (Seedling tray)	0.003
Dwarf banana (Plastic bag)	0.003
African mahogany (Seedling tray)	0.003
Pink jequitiba (Seedling tray)	0.003

Table 3. Number of plants per species per hectare based on the proposed design.

Species	Plants/ Hectare
Pink pepper (*Schinus terebinthifolia*)	1,000
Dwarf banana (*Musa spp.)*	667
Avocado (*Persea americana*)	208
African mahogany (*Khaya senegalensis*)	156
Pink jequitiba (*Cariniana legalis*)	52

To calculate the identification costs for each species and the total cost of implementing the AFS, we categorized the inputs and activities into operational costs, supply costs, and seedlings and propagule costs. The total costs are the sum of these three categories. Each category has further subdivisions and descriptions of the items within it. For instance, in the operating costs we include the expenses related to cleaning and preparing the planting area. If the activity was not carried out in the entire area, the description includes the name of the species for which it was done. This approach was also used for the other groups, which allows for the allocation of costs for each species at the end.

2.4. Agroforest System Implementation Methodology

The label "semi-mechanized" is used because machinery and implements are used for site preparation and supply input distribution, while manual labor is used for the remaining operations. The sequence of operations for site preparation was determined based on the area's history, soil chemical and physical analysis, the experience of the technicians, and the availability of machinery and labor. Soil preparation was done using a Massey Ferguson tractor (4×4, 80hp) with a 16-disc drag harrow (Figure 3A). Then, lime and gypsum inputs were evenly distributed with new harrowing for better incorporation (Figure 3B). After that, our chosen organic fertilizer, the chicken manure, was spread in the planting rows using a lime spreader before row preparation (Figure 3C). Afterwards, a Forest Subsoiler SR with a fertilizer distribution box was used to prepare the planting rows (Figure 3D). Cover crop seeds were then sown in the spaces between the rows, and wood shavings were spread to cover the soil (Figure 3E). Then, holes were dug manually (Figure 3F), hydrogel was distributed, and seedlings were planted (Figure 3G).

Figure 3. Preparation of a biodiverse agroforestry system in Timburi city, Brazil. Soil tillage (A); soil amendment (B); distribution of chicken manure (C); subsoiling of planting rows (D); distribution of wood shavings to cover planting rows after sowing green manure seeds (E); manual digging of planting holes for the placement of seedlings rows (F); planting of seedlings (G).

3. Results

The total amount spent per hectare after totaling all product categories was R$28,164.60, equivalent to $5,954.46 (Table 4). The cost breakdown shows the percentage of each category relative to the total cost. It indicates that the purchase of supplies represents the lowest cost at 19%, followed by operation costs at 24%, and the most expensive being the acquisition and care of seedlings and propagules at 57%. The expenses for operations and the purchase of agricultural supplies (Table 5) were lower than the expenses incurred for the purchase of seedlings and propagules (Table 6).

Table 4. Total costs per component implanted in one hectare of biodiverse AFS in Timburi, SP, in Brazilian reais (R$), after conversion to US dollars (US$) according to the exchange rate on the date of each publication, and in percentage (%).

Group	Individual cost (R$)	Exchange rate	Individual cost (US$)	Percentage (%)
Supply Cost	5,350.49	4.73	1,131.18	19
Operational Cost	6,780.5	4.73	1,433.51	24
Seedling and Propagule Cost	16,033.60	4.73	3,389.77	57
TOTAL COST/HECTARE	28,164.60	4.73	5,954.46	100

Table 5. Operations performed during area preparation (AP) and planting (Pl), including required materials, unit considered as hour/machine (H/M) or hour/person (H/P), time spent during operation, and final cost of each process in Brazilian reais (R$) and US dollars ($), considering the exchange rate of 4.73.

	Performed Operation	Material	Unit	Time (hour)	Total Cost (R$)	Total Cost (US$)
AP	Area cleaning	Chainsaw	H/P	8.0	121.60	25.71
	Grading	80 hp Tractor (36" Disc Harrow)	H/M	8.0	1,600.00	338.27
	Liming operation	FertiMax DCA 5.8 Lime Spreader	H/M	4.0	800.00	169.13
	Assistance in liming operation	Marispan Front Bucket	H/M	0.6	120.00	25.37
	Row preparation	Forest Subsoiler SR	H/M	4.0	800.00	169.13
	Distribution of manure in the rows	FertiMax DCA 5.8 Lime Spreader	H/M	4.0	800.00	169.13
	Assistance in manure distribution	Marispan Front Bucket	H/M	0.6	120.00	25.37
	Distribution of wood shavings in the rows	FertiMax DCA 5.8 Lime Spreader	H/M	4.0	800.00	169.13
	Assistance in wood shaving distribution in the rows	Marispan Front Bucket	H/M	0.6	120.00	25.37
Pl	Opening of avocado planting holes (Plastic bag)	Manual Shovel	H/P	12.5	158.08	33.42
	Opening of pink pepper planting holes (Seedling tray)	Manual Shovel	H/P	16.0	202.67	42.85
	Opening of dwarf banana planting holes (Plastic bag)	Manual Shovel	H/P	10.7	135.18	28.58
	Opening of African mahogany planting holes (Seedling tray)	Manual Shovel	H/P	2.5	31.62	6.68
	Opening of Pink jequitiba planting holes (Seedling tray)	Manual Shovel	H/P	0.8	10.54	2.23
	Distribution of seedlings	Wheelbarrow	H/P	10.0	126.67	26.78
	Hydrogel distribution – Avocado planting hole	Bucket	H/P	2.1	26.35	5.57
	Hydrogel distribution – Pink pepper planting hole	Bucket	H/P	5.0	63.33	13.39
	Hydrogel distribution – Dwarf banana planting hole	Bucket	H/P	3.3	42.24	8.93
	Hydrogel distribution – African mahogany planting hole	Bucket	H/P	0.8	9.88	2.09
	Hydrogel distribution – Pink Jequitibá planting hole	Bucket	H/P	0.3	3.29	0.7
	Planting of avocado seedlings	-	H/P	10.4	131.73	27.85
	Planting of pink pepper seedlings	-	H/P	16.0	202.67	42.85
	Planting of dwarf banana seedlings	-	H/P	10.7	135.18	28.58
	Planting of African mahogany seedlings	-	H/P	2.5	31.62	6.68
	Planting of Pink Jequitibá seedlings	-	H/P	0.8	10.54	2.23
	Protection of avocado seedlings	Aluminum Protector	H/P	5.0	63.33	13.39
	Staking of seedlings	Bamboo	H/P	5.0	63.33	13.39
	Seeding of cover crops in the inter-rows	Raffia bags	H/P	4.0	50.67	10.71
		TOTAL			6,780.51	1,433.51

Table 6. Supply investments used, considering each quantity in kilograms (Kg), the price per unit and delivery cost in Brazilian reais, and final cost of each supply in Brazilian reais (R$) and US dollars ($), based on an exchange rate of 4.73.

Supply	**Unit**	**Quantity (Kg)**	**Price per unit + delivery (R$)**	**Total Cost (R$)**	**Total Cost (US$)**
Limestone	Ton	1.5	250.00	372.00	79.28
Gypsum	Ton	0.3	200.00	60.00	12.68
Reactive Natural Phosphate (29% P205)	Ton	0.4	780.00	312.00	65.96
Hydrogel for Avocado planting hole	Kg	1.4	33.00	45.30	9.58
Hydrogel for Pink Pepper planting hole	Kg	3.3	33.00	108.90	23.02
Hydrogel for Dwarf Banana planting hole	Kg	2.2	33.00	72.64	15.35
Hydrogel for African Mahogany planting hole	Kg	0.5	33.00	16.99	3.59
Hydrogel for Pink Jequitibá planting hole	Kg	0.2	33.00	5.66	1.2
Chicken Manure (1.2% Nitrogen)	Ton	5.0	150.00	750.00	158.56
Wood shavings	M^3	50.0	70.00	3,500.00	739.96
Aluminum Protector for Grafted Seedlings	Unit	208.0	0.50	104.00	21.99
			TOTAL	5,347.49	1,131.18

Table 7. Seedling and propagule cost breakdown per species, considering each quantity in kilograms (Kg), the price per unit, delivery cost and nursery cost in Brazilian reais, and final cost of each item in Brazilian reais (R$) and US dollars ($), based on an exchange rate of 4.73.

Seedling and Propagule	**Unit**	**Quantity (Kg)**	**Price per unit + delivery + nursery (R$)**	**Total Cost (R$)**	**Total Cost (US$)**
Pink pepper	Seedling	1,000	2.50	2,750.00	581.40
Dwarf banana	Seedling	667	4.00	2,934.80	620.47
Avocado	Seedling	208	35.00	8,008.00	1,693.02
African mahogany	Seedling	156	5.00	858.00	181.40
Pink Jequitibá	Seedling	52	3.00	171.60	36.28
Sun hemp	Kg	20	17.90	393.80	83.26
Pigeon pea	Kg	20	15.90	349.80	73.95
Jack bean	Kg	20	15.90	349.80	73.95
Forage radish	Kg	20	9.90	217.80	46.05
			TOTAL	16,033.60	3,389.77

The operational cost of each work stage varied, with grading being the most expensive, followed by liming, row preparation, and distribution of wood shavings in the rows (Figure 4). The highest costs for supply inputs were for wood shavings, followed by manure, limestone, and phosphate (Figure 5). The most expensive seedlings and propagules were grafted avocado seedlings, followed by dwarf banana and pink pepper seedlings (Figure 6). Avocado had the highest implementation cost in this AFS design, followed by pink pepper and dwarf banana (Figure 7).

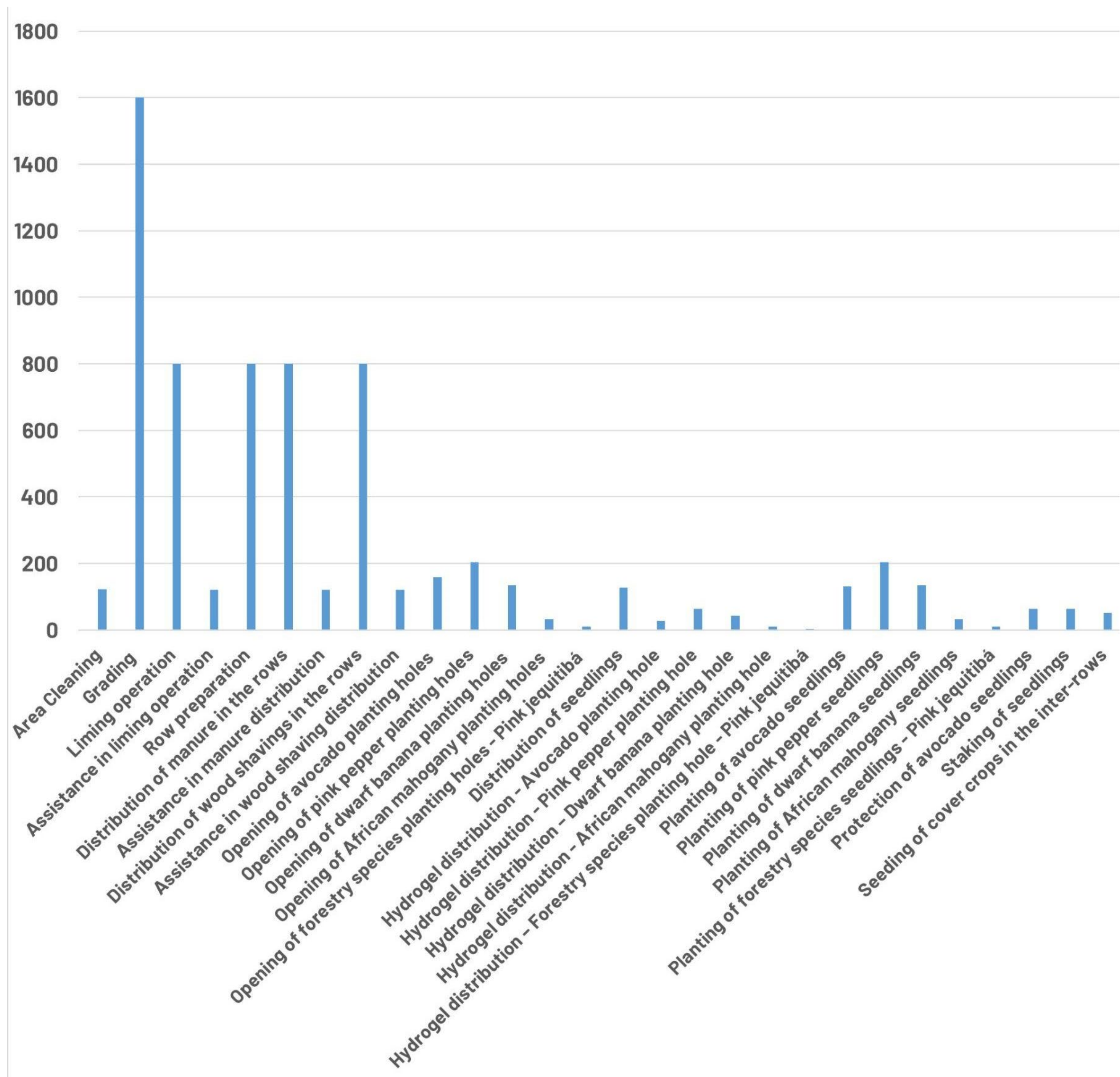

Figure 4. Investment (R$) within operating groups.

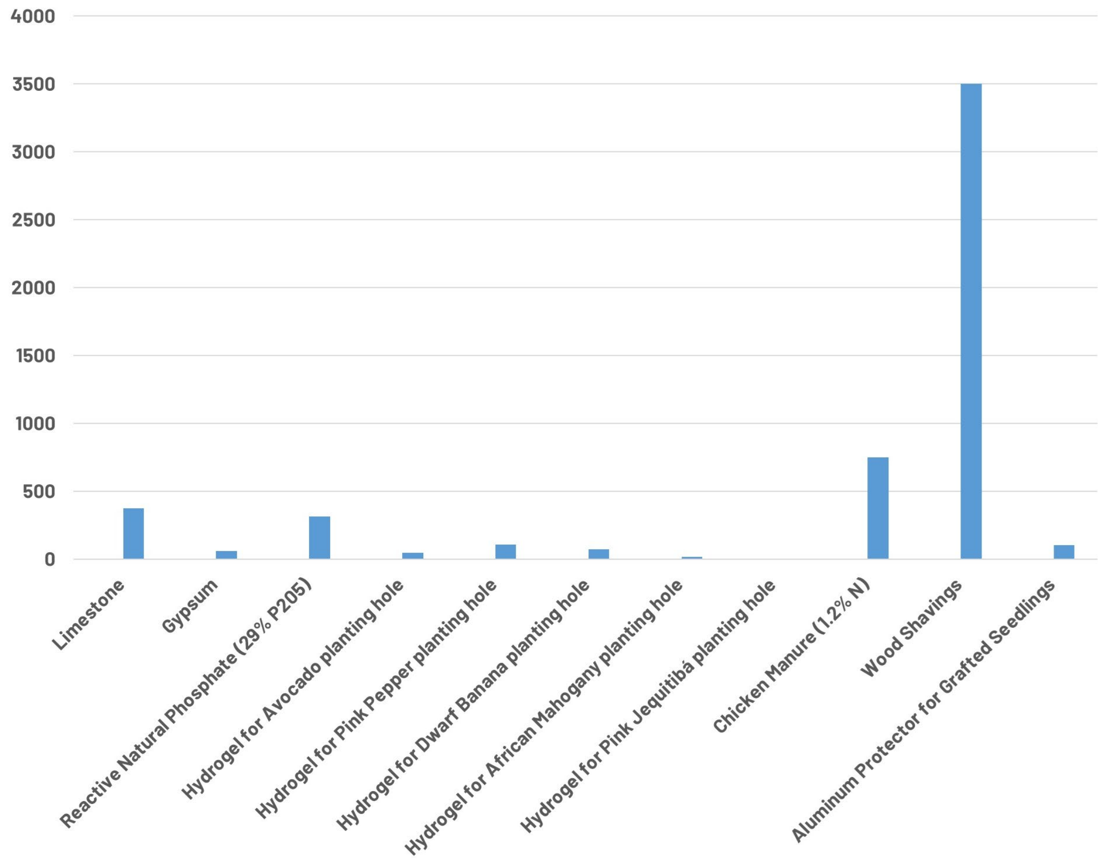

Figure 5. Investment (R$) within the supplies group.

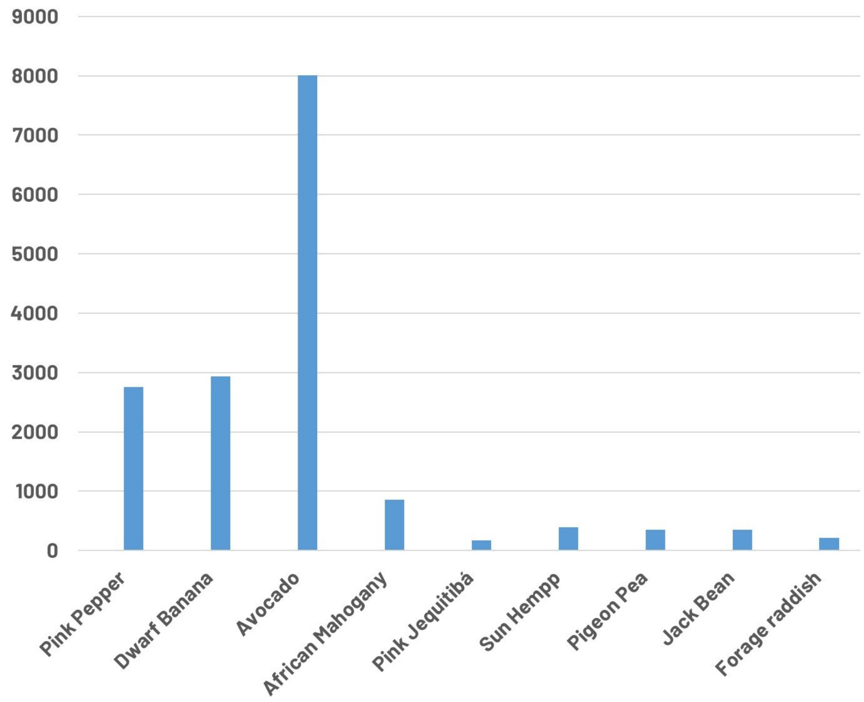

Figure 6. Investment (R$) in the purchase of seedlings and propagules.

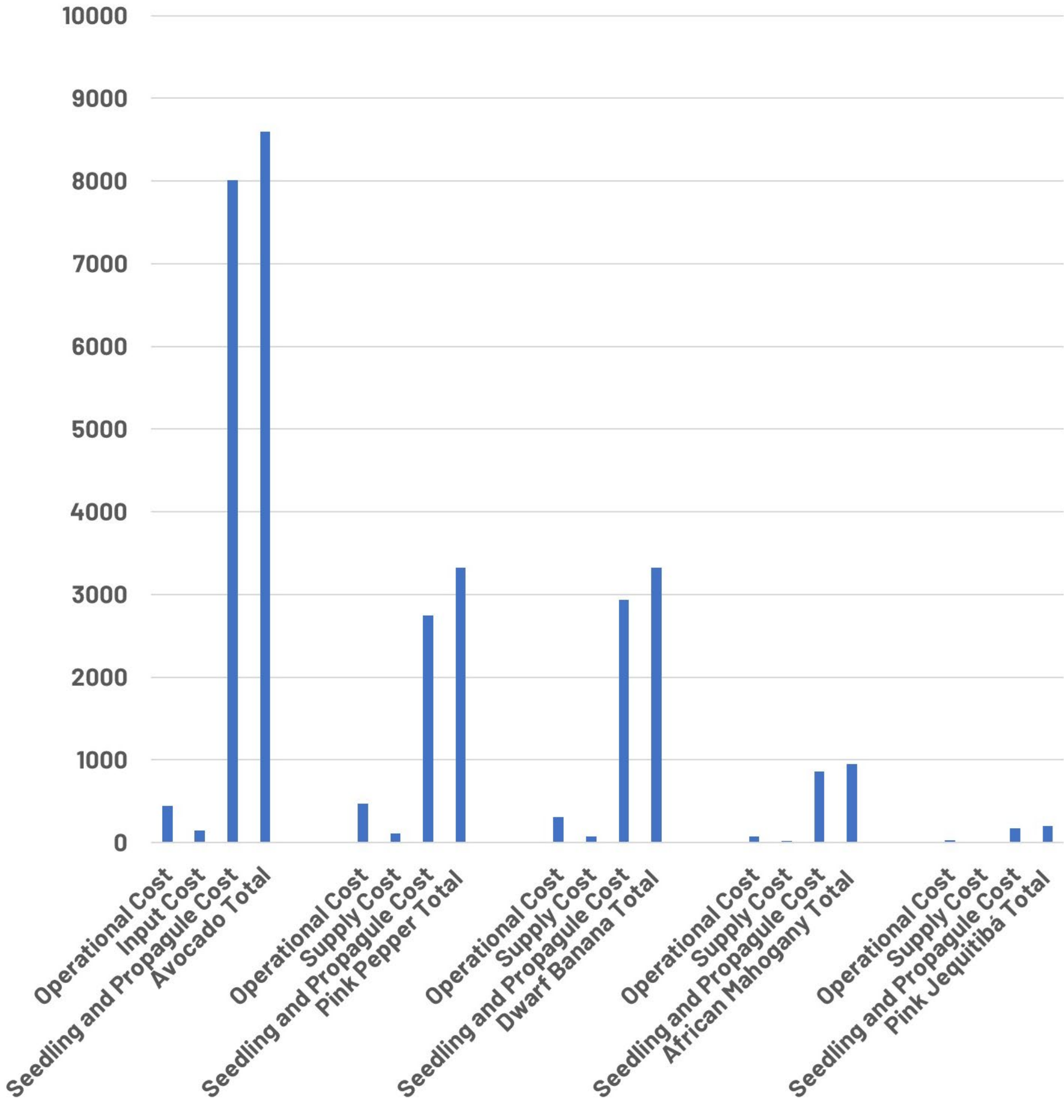

Figure 7. Total investment (R$) per species after the implementation of the agroforest system.

4. Discussion

The implementation costs for one hectare of a diverse AFS varied between the present study and those presented in the scientific literature. The costs observed at "Sítio São Francisco" in Brazil from September 2021 to March 2022 were significantly lower than the costs reported by Oliveira et al. (2017), as shown in Table 8. However, they were higher than the costs reported by Bentes-Gama et al. (2005), as well as the costs reported by Pauletto et al. (2018) for a semi-mechanized AFS and a mechanized AFS. However, when we convert the Brazilian reais to US dollars, the total investment required to implement one hectare of the diverse AFS we investigated was similar to the values found by Bentes-Gama et al. (2005), and the comparisons with the other studies were as previously. The implementation costs of an AFS reflect the complexity of these systems. They can be planned in different ways with varied species compositions and methods, in areas with very distinct original vegetation and characteristics. All these factors influence the overall implementation costs.

Table 8. Comparison of the total implementation costs for one hectare of AFS obtained by several authors in Brazilian reais (R$), and after conversion to US dollars (US$) according to the exchange rate on the date of each publication.

Reference	Total cost (R$)	Exchange rate	Total cost (US$)
Oliveira et al. (2017)	40,499.20	3,15	12,856.89
Oliveira et al. (2024)*	28,164.60	4,73	5,954.46
Bentes-Gama et al. (2005)	20,333.80	3,5	5,809.70
Pauletto et al. (2018): Semi-mechanized AFS	8,115.58	3,7	2,193.40
Pauletto et al. (2018): Mechanized AFS	6,191.48	3,7	1,673.37

* This present study

The cost study for implementing one hectare of diverse AFS showed that purchasing seedlings and propagules was the most expensive component, representing more than half of the total costs (57%) (Table 4). This finding is consistent with the results of Moraes et al. (2013), who allocated a very similar percentage (59.1%) of their costs to purchasing seedlings in the first year of implementing an AFS with coffee as the main crop. This occurred despite three distinct differences between these studies: the species of cultivated plants, the number of site preparation operations, and the types and quantities of inputs used, such as fertilizers, manure, and hydrogel. Consequently, the purchase of seedlings and propagules accounted for a very high percentage of the total expenses in our study, similar to the findings of Moraes et al. (2013). A comparable observation was made by Neves et al. (2014), where the purchase of seedlings and propagules represented 38.2% of the total costs for implementation. The decisive factor for seed costs assuming this importance in the evaluated studies, including the present one, was the high added value that fruit seedlings have in the market compared to forestry species. Therefore, the decision-making process to include species with high added value must consider that the investment in this group will be high at the time of implementation.

The purchase of avocado seedlings within this expense group represented 49.9% of the costs. This can be explained by the acquisition price of grafted seedlings, which require greater care to produce, and by a 10% increase in the final price of the seedling, reflecting the care in the waiting nursery. Our results are corroborated by Mouco et al. (2012), who analyzed the production costs of avocados and concluded that expenses with seedlings were the most significant among all the implantation costs analyzed. These significant seedling implementation costs can be reduced if farmers produce them themselves. However, it is worth noting that this process may be hindered by the need for technical knowledge, as exemplified by the production of grafted seedlings of clonal avocado varieties. The physiological and sanitary quality of the seedlings at the time of planting, among other factors, influences the future productive quality of these plants. Therefore, a technical and economic assessment should be made to determine whether in-house production is viable for reducing costs.

The second most expensive set of costs was the operational cost, which includes all mechanized, semi-mechanized, and manual operations, accounting for 24% of the total cost of implementing the diverse AFS. Of this, 18.68% corresponds to site preparation, while labor concentrated in planting operations accounted for only 5.32% of the total costs. Within the operational costs, site preparation was significantly more expensive than planting, despite requiring fewer hours of machinery used (34 hours in total) compared to planting hours (118 hours; Table 2). The cost of machinery per hour is substantially higher than the cost of labor per hour, resulting in 78% of operational costs being allocated to site preparation and 22% to planting. It is noteworthy that the cost of machinery per hour includes the costs of the machinery operator. Grading was the most expensive soil preparation operation, accounting for 30% of the total, which can be explained by the number of machinery hours required for this efficient preparation, as two gradings were performed, totaling 8 machine hours.

Similar values to ours were found by Palma et al. (2020), with 21% allocated to labor. However, higher values were reported by other authors, as cited below. Pauletto et al. (2018) compared the implementation costs of mechanized and semi-mechanized AFSs, finding that the amount spent on cleaning and preparing the cultivation area consumed between 38 to 45% of the total resources invested in the crop. Armando et al. (2002) found that the implementation of an AFS accounted for 43.14% of labor costs. Bentes-Gama et al. (2005) assessed the production and investment risk of AFSs and found that labor participation was higher in site preparation, corresponding to more than

50% of the total costs. Our results can be explained by the exclusive use of mechanized and semi-mechanized operations during our site preparation, consequently reducing the labor participation in terms of hours of work required. These data highlight the importance of considering that, due to the much higher cost of machinery per hour compared to labor per hour, mechanized AFSs can reduce the need for manual labor but not necessarily the overall costs.

However, costs will vary over time in the years following implementation. Neves et al. (2014) reported that labor costs constituted 80.1% in the first year of maintenance, decreasing to 63.5% by the fourth year. This variation indicates that the relative importance of input costs in implementation and their evolution over time will depend directly on the system type, desired production goals, and management intensity. The same considerations apply to labor, requiring early planning for management practices required by each cop to assess their suitability for the local context. This assessment is crucial for determining whether the system can achieve its intended objectives over time, whether they involve reducing external inputs or labor.

AFSs can be designed to reduce the need for labor over time. Palma et al. (2020) observed that in the first four years of their study on AFSs, labor was intense due to vegetable production. However, as the system matured and shading increased, which was less conductive to vegetable growth, labor requirements significantly decreased. Neves et al. (2014) noted that in the initial year of implementation, labor costs were lower compared to expenditures on inputs and seedlings. However, by the second year, labor costs become predominant due to tasks such as area cleaning, which decreased in the following years, thereby reducing labor needs. This reduction can be attributed to ground cover that minimizes weed growth and improves environmental balance.

The cost of inputs in our study represented the smallest proportion of total costs, accounting for only 19%. This percentage is lower than reported by Armando et al (2002), who found it to be 56.86%, and by Palma et al. (2020), who reported 79%. However, our values were higher than those found by Neves et al. (2014), who reported only about 10% for inputs. While comparing percentages among cost groups depends on their proportional relationship with other groups, it provides insight into how each cost group evolves over time.

Our most costly input was wood shavings, used for immediate soil cover in planting rows. However, the cost of acquiring these shavings combined with delivery fees proved to be financially burdensome, accounting for 65% of the total input costs. An alternative utilized by other AFSs involves using locally sourced vegetative cover, such as grasses, banana stems, pruning residues, and wood (Paula et al., 2015). Therefore, considering on-site production of vegetative material as an alternative to purchasing organic material for soil cover aligns with ecological management principles and can potentially reduce implementation costs.

Among the five species planted, our study found that avocado required the highest total investment per species for establishment. When considering costs in dollars, we observe similar expenditures across the three studies (Table 9), despite variations in study specifics: as our study planted 208 avocado seedlings per hectare, Partichelli et al. (2018) focused on monoculture with 100 avocado seedlings per hectare, and Mouco et al. (2012) planted 250 avocado seedlings per hectare. The slight cost variation between the cited authors and our study results from differences in seedling acquisition costs, labor rates per hour, machinery use per hour, and the number of avocado seedlings planted per hectare, all contributing to the overall cost structure.

Table 9. Comparison of the avocado total implementation costs for one hectare of AFS obtained by several authors in Brazilian reais (R$), and after conversion to US dollars (US$) according to the exchange rate on the date of each publication.

Reference	Total cost (R$)	Exchange rate	Total cost (US$)
Oliveira et al. (2024)*	8,600.13	4.73	1,818.21
Partichelli et al. (2018)	6,683.90	3.5	1,909.68
Mouco et al. (2012)	6,400.00	3.7	1,729.73

* This present study

Alves et al. (2020) investigated the economic viability of AFS focusing on fruit production and observed that commercial fruits are crucial for achieving financial viability. This underscores that, despite the high initial investment required to establish fruit trees within the system, they are strategically necessary for ensuring financial viability, enhancing food security, and bolstering economic and environmental resilience.

Biodiverse AFSs that integrate multiple species in diverse configurations demonstrate potential for financial viability by offering a variety of products, thereby enabling multiple income streams at different times (Oliveira et al., 2017). This supports our approach of maximizing species with commercial value. However, when planning such diversification, it is important to assess whether these species interact antagonistically or synergistically, necessitating ongoing monitoring of AFS evolution and potential management practices like pruning to ensure optimal plant growth.

Thus, it is important to note that despite our gross cost for implementing 1 hectare being higher than that found for monoculture crops, this cost per plant becomes more economical when divided by the number of individuals planted, regardless of the species. We planted a total of 2,083 individuals per hectare including fruit trees, service plants, and timber species, with a total cost of R$28.164,60, resulting in an average implementation cost of R$13.52 ($2.86) per plant. This average cost is significantly lower than that reported for each avocado seedling monoculture by Mouco et al. (2012): R$25.60 ($6.92), as well as by Partichelli et al. (2018): R$66.83 ($19.09).

Moreover, the perceived high implementation cost of an agroforestry system focused on avocado production, such as ours, might seem significant when not considering the quantity of individuals from other species. However, dividing our costs by all individuals planted in the system, as advocated by El Serafy's theory (1989, as cited in de Queiroz et al., 2020), results in a considerable cost reduction. This theory asserts that every available natural asset should be viewed as a permanent source of income. Therefore, even species with long cycles that may not yield immediate commercial returns provide valuable environmental benefits within the planting area. These include nutrient recycling, deeper water uptake that enhances moisture retention, reduced susceptibility to diseases through increased biodiversity, improved light capture, heightened photosynthesis rates, and enhanced soil fertility. These environmental services are essential components of a sustainable planting area.

Ultimately, AFSs should always be designed with a comprehensive approach that includes analyzing the implementation costs of the chosen design, as well as considering social and environmental aspects, local food security, input efficiency, and environmental enhancement (Arco-Verde & Amaro, 2014). Taking a systemic approach to these various aspects related to integrated production systems such as AFSs ensures multiple advantages and benefits. These can be optimized when aligned with a thorough study of implementation costs.

5. Conclusions

When investigating the primary implementation costs of a biodiverse agroforestry system in Brazil comprising five different main species, we found that the most substantial expense was for seedlings and propagules, followed by operational costs, and finally supply inputs. Avocado, chosen for its high economic value, incurred the highest implementation costs due to the expense of purchasing seedlings and the intensive care required for planting them. The significant market value of avocado fruits justifies these initial costs. Moreover, integrating seedling production on farms could potentially reduce acquisition costs, considering both technical and economic factors. Despite high machinery costs, this approach may be feasible in areas with limited labor availability. Contrary to current literature, labor costs in this study accounted for only 5.32% of total expenses. Tailoring the design to fit farmers' circumstances can lead to systems that demand different levels of labor and other management inputs. Furthermore, harrowing operations and the acquisition of wood shavings were identified as the most expensive within their respective categories. While input costs remained relatively low, optimizing the use of locally produced organic materials for row coverings could further reduce expenses. Overall, spreading total costs per unit across the total number of seedlings helps to dilute the expenses of establishing an agroforestry system. Each species planted in this study was selected for specific ecological or economic benefits, underscoring their crucial roles within the agroforestry system and facilitating this cost dilution.

The present investigation was limited to the period of the agroforestry system implementation. We suggest that further studies include the evolution of costs through ongoing monitoring, considering not only the initial implementation costs but also the costs incurred during the development of the agroforestry systems over the years, including the replacement of species. This approach could enhance the financial analysis with the new inputs and the production data from the mature, enabling more complex analyses and addressing many other questions related to agroforestry systems. Future studies can detail the implementation costs of AFSs in distinct countries, considering different species and other requirements. Such studies are essential for the successful application of these systems at the field level and for designing them more efficiently by practitioners according to the specific needs of each farmer. Ultimately, the potential social and environmental benefits of agroforestry systems make them an excellent alternative for sustainable food production, balancing conservation and productivity while supporting family farming. We also emphasize to policymakers the relevance of promoting greater adoption of agroforestry systems among farmers worldwide. Public subsidies and subsidized rural credit can facilitate the establishment of these systems.

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