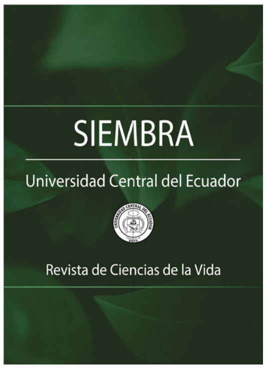
# *Sustainability in agroforestry systems: Case studies from the Santo Domingo canton*

## *Sostenibilidad en sistemas agroforestales: Casos de estudio del Cantón Santo Domingo*

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## Abstract

The study focuses on proposing agroforestry associations to characterize and evaluate the sustainability of farms in the Santo Domingo canton. This approach could promote the farm's long-term viability and contribute to the region's sustainable rural development, as agriculture and livestock are vital to the local economy. The non-experimental methodology employed included direct observation, documentary analysis, and surveys, that addressed the economic, environmental, and social dimensions of sustainability. The results showed that only 20% of the farms are fully sustainable, meeting all three sustainability indicators and achieving an overall index of at least two. Four farms were classified as sustainable: three in the Puerto Limón parish and one in Valle Hermoso. The remaining farms in the canton reflect a limited proportion of integral sustainability. In terms of income, farms primarily rely on the sale of cocoa and plantains. Expenditures are allocated to inputs, tools, transportation, and occasional labor. The most significant socioeconomic limitations identified were low education levels and economic risk, while the main challenges identified at the production level were limited crop diversity and soil nutrient depletion. These findings underscore the urgent need for strategies that strengthen the sustainability of agricultural and livestock production and enhance community resilience and social cohesion. Proposed agroforestry associations could optimize resource use, foster biodiversity, and ensure a more viable future for these rural communities.

**Keywords:** sustainability assessment, agroforestry systems, sustainable rural development.

## Resumen

El estudio se centra en proponer asociaciones agroforestales mediante la caracterización y evaluación de la sostenibilidad de fincas en el cantón Santo Domingo, que promuevan su viabilidad a largo plazo y contribuyan al desarrollo rural sostenible de la región, donde la agricultura y ganadería son vitales para la economía local. La metodología no experimental utilizada incluyó observación directa, análisis documental y encuestas, considerando las dimensiones económica, ambiental y social de la sostenibilidad. Los resultados indicaron que solo el 20% de las fincas son completamente sostenibles, cumpliendo con los tres indicadores de sostenibilidad y alcanzando un índice general igual o superior a dos. Cuatro fincas se clasificaron como sostenibles: tres en la parroquia Puerto Limón y una en Valle Hermoso, mientras que el resto del cantón refleja una proporción limitada de sostenibilidad integral en sus fincas. En términos de ingresos, las fincas dependen principalmente de la venta de cacao y plátano, mientras que los egresos se destinan a insumos, herramientas, transporte y capital humano ocasional. Entre las limitaciones socioeconómicas más destacadas se encuentran la baja escolaridad y el riesgo económico; a nivel productivo, los desafíos incluyen una diversidad limitada de cultivos y la pérdida de nutrientes del suelo. Estos hallazgos subrayan la necesidad urgente de estrategias que fortalezcan la sostenibilidad de la producción agrícola y ganadera, mejorando la resiliencia y la cohesión social en la comunidad. Las asociaciones agroforestales propuestas tienen el potencial de optimizar el uso de recursos, fomentar la biodiversidad y asegurar un futuro más viable para estas comunidades rurales.

**Palabras clave:** evaluación de sostenibilidad, sistemas agroforestales, desarrollo rural sostenible.

## 1. Introduction

Agriculture and livestock farming are fundamental pillars of Ecuador's rural economy, particularly in the province of Santo Domingo de los Tsáchilas, where approximately 60% of all Agricultural Production Units [APUs] cover between 20 and 50 hectares (Anzules et al., 2018). Despite their importance, however, these face serious challenges. The lack of a comprehensive assessment, encompassing economic, ecological, and social dimensions, hinders both informed decision-making and the implementation of appropriate practices, therefore putting their long-term sustainability at risk (Celi-Delgado & Aguirre-Mendoza, 2022; Corral Zambrano et al., 2021). This is exacerbated in a context of limited natural resources and increasing pressure on ecosystems. Therefore, it is critical to identify and promote sustainable agroforestry systems that can be implemented in order to contribute to rural development within the region.

These systems, which integrate trees with agricultural crops and/or livestock, offer multiple benefits, including improved biodiversity, soil conservation, and increased resilience to adverse weather events (Montagnini et al., 2015; Muñoz-Rengifo et al., 2021). In addition, agroforestry partnerships have been shown to optimize the use of natural resources, promoting practices that benefit both the economic well-being of agricultural producers and the state of health of the environment (Anzules et al., 2018). When well-managed, these production systems improve both the quality of life of farmers, and living conditions within the region. Nonetheless, in order to carry out adequate planning, it is essential to know their composition and current status.

There are various criteria for classifying agroforestry systems, such as those proposed by Alcívar-Torres et al. (2019), which can be classified into three types:

- Agroforestry: a combination of agricultural and woody crops, such as trees in agricultural crops, and crops in alleys between trees, among others.
- Silvopastoral: combination of forest crops or plantations with fodder and feed for animal husbandry. This includes practices such as timber, or fruit trees scattered in pastures, animal production under forest or fruit plantations, grasslands in tree alleys, living fences, living barriers, and windbreaks.
- Agroforestry: an integration of agricultural crops, forest plantations, and animal husbandry.

In addition, there are different proposals for classifying practices in agroforestry systems, such as those by Alcívar-Torres et al. (2019) or Celi-Delgado and Aguirre-Mendoza (2022). There are also several methodologies for assessing the sustainability of agroforestry systems, such as the Sustainability Assessment (Sarandón et al., 2014), the Sustainability Assessment Framework for Agriculture and the Environment [SAFE] (Van Cauwenbergh et al., 2007), and the Sustainability Assessment for Agriculture and Food [SAFA] (Organización de las Naciones unidad para la agricultura y Alimentación [FAO], 2014). Other tools include the Natural Resource Management Systems Assessment [MESMIS] (da Silveira Nicoloso et al., 2018), the Farm Sustainability Indicators [IDEA] (Zahm et al, 2008), the Monitoring Tool for Integrated Agricultural Sustainability [MOTIFS] (Meul et al., 2008; Van Passel & Meul, 2010), the Indicator-Based Sustainability Assessment Framework [FARMTOOLS] (Heredia-R et al., 2024), among other proposals by other authors such as Heredia-R et al. (2020).

The present study used methodologies based on the work of Celi-Delgado and Aguirre-Mendoza (2022) and Sarandón et al. (2014), which were selected both for their ability to ensure representativeness, and for their comprehensive approach, encompassing multiple dimensions of the production system. The application of these methodologies makes it possible to identify the strengths and weaknesses of each farm, therefore facilitating the formulation of specific recommendations to improve its sustainability. This approach not only benefits individual producers, but also presents important implications for rural development more in general.

One of the main drivers of this research is the recognition that agricultural sustainability is essential to ensuring food security and economic well-being in rural communities. The expansion of the agricultural frontier has led to the deterioration of natural resources (Heredia-R et al., 2021). The pressure on these resources, together with the effects of climate change and market fluctuations, requires agricultural producers to implement more sustainable practices. This, in order to mitigate environmental impact, as well as to promote ecosystem resilience and economic resilience in the current context of global economic and environmental uncertainty. (Muñoz-Rengifo, 2019).

The overall objective of this research was to propose agroforestry partnerships by characterizing and evaluating the sustainability of farms in the Santo Domingo canton, by promoting their long-term viability and contributing to sustainable rural development in the region. This objective was achieved through the following specific objectives: 1) Characterize the biophysical and socioeconomic components of farms in the Santo Domingo canton; 2) Determine the degree of sustainability of farms using the Sarandón methodology; and 3) Propose agroforestry partnerships adapted to the biophysical and socioeconomic characteristics of each farm in the Santo Domingo canton. These objectives are aligned with current trends in rural development, emphasizing the importance of a holistic approach that considers productive, social, and environmental aspects.

The comprehensive characterization of the farms, together with the application of a sustainability assessment methodology, enabled to develop proposals for agricultural producers that strengthen the sustainability of production systems, as well as their capacity to face environmental and social challenges.

## 2. Materials and Methods

### *2.1. Study area*

The study area is located in the parishes of Valle Hermoso, between coordinates -0.077256, -79.279767, and Puerto Limón, between coordinates -0.386552, -79.377283, in the canton of Santo Domingo, province of Santo Domingo de los Tsáchilas (Ecuador), where 10 agroforestry farms were selected (Figure 1).

### *2.2. Methodological approach and design*

This research is non-experimental, uses a mixed approach and presents an exploratory and descriptive scope, according to the classification of Hernández Sampieri et al. (2014), also known as exploratory documentary method (analysis and synthesis of documents, and direct observation (or field) method for obtaining information based on Morán Delgado and Alvarado Cervantes (2010).

### *2.3. Exploratory documentary method*

Through exploratory research, the authors conducted a documentary information search to compare the results obtained. To this end, a specific process (for searching for information) of the following steps was designed:

1) Selection of the academic search engine.
2) Development of search equations.
3) Execution of the information search.
4) Selection of studies.
5) Processing and analysis of the selected studies.

The authors used Google Scholar (Google LLC; USA) as the search engine of their choice. The following descriptors were chosen for the search equations: Agroforestry, Agroforestry systems, Agroecology; while the keywords were: Sustainability, Biodiversity, and Natural resource management; the operators used were Same, “”, *; and the study selection criteria were: primary and secondary sources of information, scientific rigor, relevance of variables.

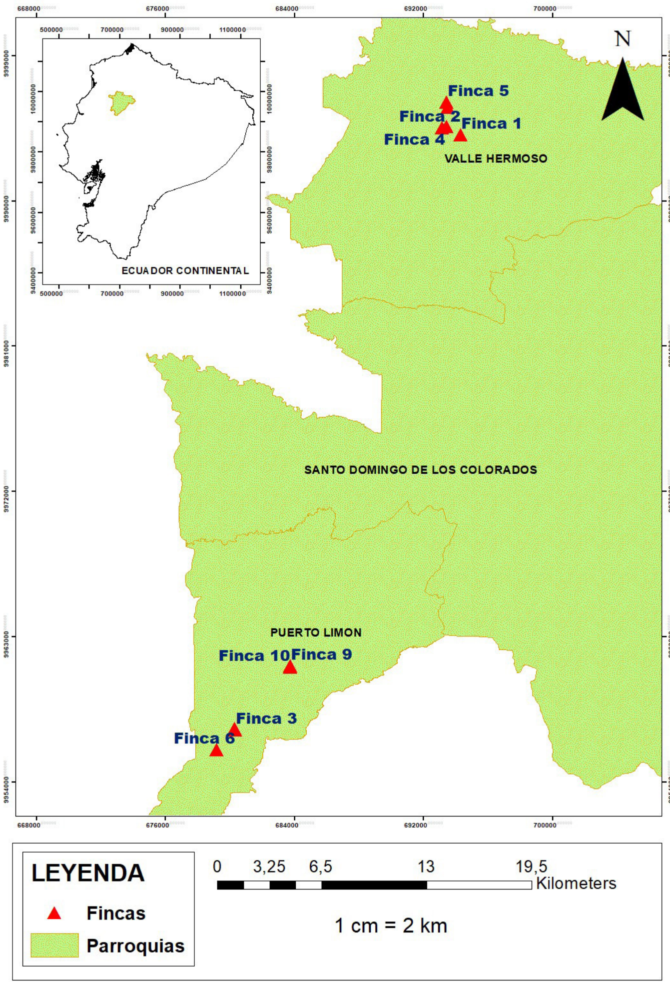


**Figure 1.** Location of the evaluated agroforestry farms.

*2.4. Direct observation method and data collection*

A snowball methodology (Goodman, 1961) was used to select farmers. The process began with the identification of the community leader, who recommended the following farmer, this step was then repeated until reaching a total of ten farms. Priority was given to farmers willing to participate in the research, provided they were actively engaged in agriculture and had agroforestry systems in their parish. Subsequently, field visits were conducted with the co-participants proceeding from the ten farms selected. During these tours, information on both biophysical and social aspects was collected, as well as on the types of agroforestry systems present on each farm. To complete the data, a survey was administered to each owner, gathering detailed information on land use and management, and on other key aspects in order to analyze the sustainability of the agroforestry systems detailed below.

2.4.1. Diagnosis of the biophysical and social aspects of farms

Information was collected as to the following biophysical and social aspects:

a) Cartography and land use. A cartographic survey was carried out on each farm, so that the name of each farmer, the total area of land owned, its topography, location, land use, including the crops grown in the area, and the total area of the farms could be specifically identified. In addition, the presence of water resources was evaluated, considering their importance for crop development and sustainability.
b) Identification of agroforestry systems. A tour of the farm was conducted, during which relevant data was

identified and collected, including the types of agroforestry systems present, and the total study area. Subsequently, a survey was administered to farm owners in order to obtain more detailed information about land characteristics. The data collected allowed for the classification of the site's agroforestry systems (Table 1), following the classification proposed by Celi-Delgado and Aguirre-Mendoza (2022).

c) Social aspects. A comprehensive analysis of the social aspects was conducted in relation to agroforestry systems, evaluating both the opportunities and the limitations associated with the means of production available on the farms. The study made it possible to identify the type of production implemented and its economic value, as well as to examine the situation of land tenure and access to basic services by producers. In addition, factors such as training and the level of association among farmers were analyzed, considering the support or restrictions on their access to resources, technology, and financing. These are key aspects to understand the social sustainability of agroforestry systems, and their impact on the quality of life of producer families, as well as to identifying areas where improvements can be implemented, in order to strengthen resilience and social development in the community.

**Table 1.** Categorization of the agroforestry systems found on the study farms.

| Sampling units | Types of agroforestry systems |
|---|---|
| AFS 1 | Hedgerows |
| AFS 2 | Agroforestry system |
| AFS 3 | Trees associated with short-cycle crops |
| AFS 4 | Special agroforestry system |

2.4.2. Diagnosis of the sustainability of existing agroforestry systems

The survey designed to assess sustainability was developed following the methodology of Sarandón et al. (2014), which considers indicators of economic, environmental, and social dimensions (Table 2). To facilitate the comparison of sustainability indicators, they were standardized on a scale ranging from zero (0) to four (4), where zero represents the least sustainable level and four the most sustainable. The values obtained were adjusted to this scale, taking into account the location and specific characteristics of each indicator, in order to ensure that the assessment adequately reflected its context.

Once calculated the indicators, they were interpreted on a scale of zero (0) to three (3), and the relationship between the three main indicators (economic, environmental, and social) was analyzed and compared with the organic agricultural production values for the area. Specific formulas were applied according to the analyzed indicator in order to weight the data.Then, the values were weighted by multiplying the scale score by a coefficient that reflects the relative importance of each indicator.

Equation [1] was used to calculate the economic impact value [*IK],* equation [2] was used for the environmental impact value *[IE],* and equation [3] was used for the social impact value [*ISC].* [3].

$$IK = \frac{2\frac{(A1+A2)}{2}+B+\frac{C1+C2+C3}{3}}{4} \quad [1]$$

where, *A1* = Diversification of production, *A2* = Area of production for self-consumption, *B* = Monthly income, *C1* = Diversification for sale, *C2* = Number of marketing channels, *C3* = Dependence on external inputs.

$$IE = \frac{\frac{A1+A2+A3}{3}+\frac{2B1+B2+2B3}{3}+\frac{C1+C2}{2}}{3} \quad [2]$$

where, *A1* = Crop rotation, *A2* = Crop diversification, *A3* = Agricultural residue management, *B1* = Use of machinery, *B2* = Plant cover, *B3* = Weed and insect management, *C1* = Temporal biodiversity, *C2* = Spatial biodiversity.

$$ISC = \frac{2\frac{A1+A2+A3+A4}{4}+B+C+D}{4} \quad [3]$$

where, *A1* = Housing, *A2* = Access to education, *A3* = Access to healthcare, *A4* = Services (water, electricity), *B* = Acceptability of the production system, *C* = Social integration (daily wages), *D* = Ecological knowledge and awareness (certification).

Once the values for each indicator were obtained, equation [4] was applied to calculate sustainability [*ISGen*].

$$ISGen = \frac{IK+IE+ISC}{3} \quad [4]$$

For a farm to be considered sustainable, the overall sustainability index must reach a value equal to, or greater than two (2), in each of the three dimensions evaluated, compared to the values for organic agricultural production in the area. The results obtained were presented using a spider web diagram, according to the methodology of Sarandón et al. (2014).

**Table 2.** Survey structure applied to farmers.

| Dimension | Indicator | Criterion |
|---|---|---|
| Economic | Food self-sufficiency | Diversification of production |
| | | Area of production for self-consumption |
| | Net monthly income | Income |
| | Economic risk | Diversification for sale |
| | | Number of marketing channels |
| | | Dependence on external inputs |
| Environmental | Soil conservation | Crop rotation |
| | | Crop diversification |
| | | Agricultural waste management |
| | Erosion risk | Use of machinery |
| | | Vegetation cover |
| | | Weed and insect management |
| | Biodiversity management | Temporal biodiversity |
| | | Spatial biodiversity |
| Social | Satisfaction of basic needs | Housing |
| | | Access to education |
| | | Access to healthcare |
| | | Services (water, electricity) |
| | Acceptability of the production system | Acceptability |
| | Social integration | Daily wages |
| | Ecological knowledge and awareness | Certification |

2.4.3. Proposal for profitable agroforestry associations for producers

A model proposal for agroforestry systems was designed, taking into account that these must include at least two species interacting with each other, at least one perennial woody species, and one species intended for agricultural purposes, as established by Somarriba (1992). By integrating this basic condition with the semi-forestry method proposed by Montagnini et al. (2015), it is hoped that modifications can be proposed that contribute to the sustainability of agroforestry systems.

### *2.5. Data processing*

Excel v.2019 (Microsoft Corporation; USA) software was used to correctly record and organize the data collected in the field. ArcGis v.10.8 software (Environmental Systems Research Institute; USA) was used to locate the study areas, and create the respective maps. Finally, the information on agroforestry systems was analyzed and interpreted to develop the sustainable management proposal. (Environmental Systems Research Institute; USA) was used to locate the study areas and create the respective maps. Finally, the information on agroforestry systems was analyzed, and interpreted to develop the sustainable management proposal.

## 3. Results and Discussion

### *3.1. Biophysical and socioeconomic characteristics of the farms evaluated*

#### 3.1.1. Land use

The collection of cartographic information on each of the farms, including land use and spatial distribution of species, revealed that 48% of the land is used for agriculture. Of this percentage, 55% corresponds to cocoa cultivation, 24% to bananas, 15% to cassava, 4% to balsa, and 2% to mixed crops including bananas, oranges, cassava, lemons, and avocados. On the other hand, 32% of the land is used for livestock and 20% for other uses. This distribution differs from the approach of the Municipal GAD Municipal de Santo Domingo (2015), indicating that, in general, 38% corresponds to livestock activity, 27% to agricultural activity, and 35% to a combination of both. This discrepancy is due to data obtained in specific areas where agriculture, especially cocoa cultivation, is predominant.

#### 3.1.2. Agroforestry systems

The farms evaluated exhibited a diversity of agroforestry systems, with most featuring living fences [AFS 1] (n = 8, 32%) and agrosilvopastoral systems [AFS 2] (n = 8, 32%). Conversely, trees associated with short-cycle crops [AFS 3] (n = 7, 28%), and special agroforestry systems [AFS 4] (n = 2, 8%) were observed less frequently. The climatic and edaphic characteristics and the biophysical potential of the area significantly influence the establishment of these systems (FAO, 1997). Within this context, Santo Domingo offers ideal conditions for the development of these production models.

The species most frequently observed on farms include, for hedges, caraca (*Erythrina glauca*) and cucarda (*Hibiscus rosa-sinensis*); for fruit trees, orange (*Citrus × sinensis*), mandarin (Citrus reticulata), and lemon (*Citrus limon*); for commercial species, cacao (*Theobroma cacao*), banana (*Musa × paradisiaca*), cassava *(Manihot esculenta*) and avocado (*Persea americana*); and, for timber species, balsa (*Ochroma pyramidale*) and teak (*Tectona grandis*) (Table 3). The farms evaluated are home to a total of 47 different species, of which 24 are the most common on six of the ten farms analyzed. These results are similar (49 species) to those reported by Celi-Delgado and Aguirre-Mendoza (2022) in the Zumba parish of Zamora Chinchipe, but higher when compared to the total number of species (11) and the number of most common species (5) reported by Verdezoto Vargas et al. (2024) on farms in the Milagro canton, Guayas province. They are also higher when compared to the total number of species (19) reported by Carvajal Benavides et al. (2024). The biodiversity found on the farms evaluated is important for ecological processes and for the conservation of biodiversity in the area (Ipinza et al., 2021), and its resilience.

**Table 3.** Agricultural species on the studied farms.

| Common name | Scientific name | N° | % |
|---|---|---|---|
| Achotillo | *Nephelium lappaceum* | 2 | 1,13 |
| Avocado | *Persea americana* | 5 | 2,82 |
| Ají ratón (hot pepper) | *Capsicum chinense Jacq.* | 2 | 1,13 |
| Garlic | *Allium sativum* | 3 | 1,69 |
| Almond tree | *Prunus dulcis* | 2 | 1,13 |
| Arazá (a type of apple) | *Eugenia stipitata* | 3 | 1,69 |
| Balsa Wood | *Ochroma pyramidale* | 6 | 3,38 |

| Common name | Scientific name | N° | % |
|---|---|---|---|
| Cacao | *Theobroma cacao* | 8 | 4,51 |
| Guadua cane | *Guadua angustifolia* | 6 | 3,38 |
| Caraca (a type of palm tree) | *Eritrina glauca* | 7 | 3,95 |
| White onion | *Allium fistulosum* | 3 | 1,69 |
| Chíparo (a type of palm tree) | *Zygia longifolia* | 4 | 2,25 |
| Cilantro (cilantro) | *Coriandrum sativum* | 3 | 1,69 |
| Coconut | *Cocos nucifera* | 2 | 1,13 |
| Cucarda (a type of palm tree) | *Hibiscus rosa-sinensis* | 3 | 1,69 |
| Ficus (a type of palm tree) | *Ficus benjamina* | 3 | 1,69 |
| Beans | *Phaseolus vulgaris* | 4 | 2,25 |
| Breadfruit | *Artocarpus altilis* | 5 | 2,82 |
| Guaba (a type of palm tree) | *Inga edulis* | 5 | 2,82 |
| Soursop | *Annona muricata* | 4 | 2,25 |
| Guava | *Psidium guajava* | 2 | 1,13 |
| Guayacán | *Guaiacum officinale* | 3 | 1,69 |
| Bean | *Vicia faba* | 3 | 1,69 |
| Lemon verbena | *Aloysia citrodora* | 5 | 2,82 |
| Laurel | *Laurus nobilis* | 3 | 1,69 |
| Lettuce | *Lactuca sativa* | 3 | 1,69 |
| Lemon | *Citrus limón* | 7 | 3,95 |
| Lemongrass | *Swinglea glutinosa* | 1 | 0,56 |
| Plantain | *Plantago major* | 2 | 1,13 |
| Corn | *Zea mays* | 3 | 1,69 |
| Mandarin | *Citrus reticulata* | 4 | 2,25 |
| Mango | *Mangifera indica* | 2 | 1,13 |
| Passion fruit | *Passiflora edulis* | 2 | 1,13 |
| Mate | *Crescentia cujete* | 3 | 1,69 |
| Orange | *Citrus × sinensis* | 6 | 3,38 |
| Oregano | *Origanum vulgare* | 4 | 2,25 |
| Toquilla Straw | *Carludovica palmata* | 1 | 0,56 |
| Grass | *Cynodon dactylon* | 8 | 4,51 |
| Cucumber | *Cucumis sativus* | 2 | 1,13 |
| Eyelashes | *Polyscias guilfoylei* | 1 | 0,56 |
| Pepper | *Capsicum annuum* | 2 | 1,13 |
| Samán | *Samanea* | 2 | 1,13 |
| Teak | *Tectona grandis* | 5 | 2,82 |
| Tomato | *Lycopersicon* | 2 | 1,13 |
| Banana | *Musa × paradisiaca* | 10 | 5,64 |
| Cassava | *Manihot esculenta* | 9 | 5,08 |
| Pumpkin | *Cucurbita moschata* | 2 | 1,13 |

Results indicate that Santo Domingo stands out as a highly productive canton, where 48% of its economic activity comes from the agricultural sector and 52% from the livestock sector and other uses. Among the animal species most commonly raised on farms are chickens, as well as cattle, buffalo, and pigs (Table 4). These findings are consistent with data reported by the GAD Municipal de Santo Domingo (2015), which indicates that the livestock sector represents 51.1% of the total area, while agriculture covers 25.6%.

**Table 4.** Animal species on the studied farms.

| Common name | Scientific name | N° | % |
|---|---|---|---|
| Pigs | *Sus scrofa domesticus* | 6 | 19.35 |
| Chickens | *Gallus gallus domesticus* | 10 | 32.25 |
| Ducks | *Anas platyrhynchos domesticus* | 4 | 12.90 |
| Tilapia | *Oreochromis niloticus* | 3 | 9.67 |
| Cattle | *Bos Taurus* | 8 | 25.80 |

Livestock farming is one of the most important sectors worldwide (Aguirre-Forero et al., 2021), and cattle are particularly relevant due to their contribution to greenhouse gas emissions. To address this problem, it is essential to adopt new habits and improve production technologies in this sector. In this context, agroforestry systems are a viable alternative for achieving cleaner and more sustainable livestock production (Caicedo-Vargas, 2020). One effective option is to implement mixed systems that integrate trees, forage shrubs, and short-cycle crops. This strategy not only increases biodiversity, but also helps to offset greenhouse gas emissions through storage or sequestration compared to monoculture (Jadán et al., 2012; Muchane et al., 2020), positioning these systems as a long-term production method that promotes environmental sustainability (Caicedo-Vargas, 2020).

*3.1.3. Socioeconomic characteristics*

As to what regards gender, a total of 58 people make up the families of the ten farms, of these 59% are men, and 41% are women (Table 5). According to the 2030 Land Use Plan “The Future of Chilachi To” (GAD Municipal de Santo Domingo, 2015), around 35,000 people work in the agricultural sector. Of these, 79% are men and 21% are women. These data correlate with the results obtained, as the number of men present in rural areas is higher than that of women.

**Table 5.** Number of family members on the studied farms.

| Farms | Women | Men | Total |
|---|---|---|---|
| María | 2 | 3 | 5 |
| Martha | 2 | 4 | 6 |
| Los Tres Hermanos | 1 | 3 | 4 |
| Alondra | 5 | 4 | 9 |
| Cristal | 2 | 4 | 6 |
| Familia Rivas | 3 | 5 | 8 |
| Familia Verdezoto | 2 | 5 | 7 |
| Rosita | 2 | 3 | 5 |
| La Fabita | 2 | 2 | 4 |
| Mis Dos Hijas | 3 | 1 | 4 |
| **Total** | **24** | **34** | **58** |
| **Average** | **2.4** | **3.4** | **5.8** |

In the parishes of Valle Hermoso and Puerto Limón, on farms, the distribution of schooling among families is as follows: 55% of the population has primary education, 21% has secondary education, 10% has higher education, and 14% has no education. These data differ when compared with those reported by Celi-Delgado and Aguirre-Mendoza (2022) in Zumba, Zamora Chinchipe province, where 66.7% of the population has primary education, 16.7% has secondary education, and 16.7% has higher education. However, the results are consistent with the findings of the 2030 Land Use Plan (GAD Provincial de Santo Domingo de los Tsáchilas, 2015), showing that 72.8% of the provincial population has only primary education, 22.6% has secondary education, and 5% has no education at all.

In the management and maintenance of agroforestry systems, owners use both their own and hired human capital. In harvesting and packaging activities, 40% of owners use only their own human capital, although they occasionally hire additional staff. Another 40% rely solely on their own human capital, while 20% choose to hire only external human capital. These results are consistent with the study by Celi-Delgado and Aguirre-Mendoza (2022) in the canton of Zumba, where it was found that 44.4% of landowners employ exclusively their own human capital, 44.5% use their own human capital and occasionally hire additional personnel, and 11.1% resort exclusively to external hiring.

The income generated by agroforestry systems (AFS) comes mainly from the sale of products such as plantains, cocoa, oranges, cassava, tangerines, achotillo (*Nephelium lappaceu*), avocados, and balsa wood. According to the survey, 40% of respondents earn income from the sale of plantains and cacao; 30% earn income from the sale of cacao, plantains, cassava, and occasionally balsa wood; 20% generate income from the sale of oranges, tangerines, avocados, cassava, and plantains; while 10% earn income from the sale of plantains, cocoa, oranges, tangerines, and occasionally achotillo (Figure 2).

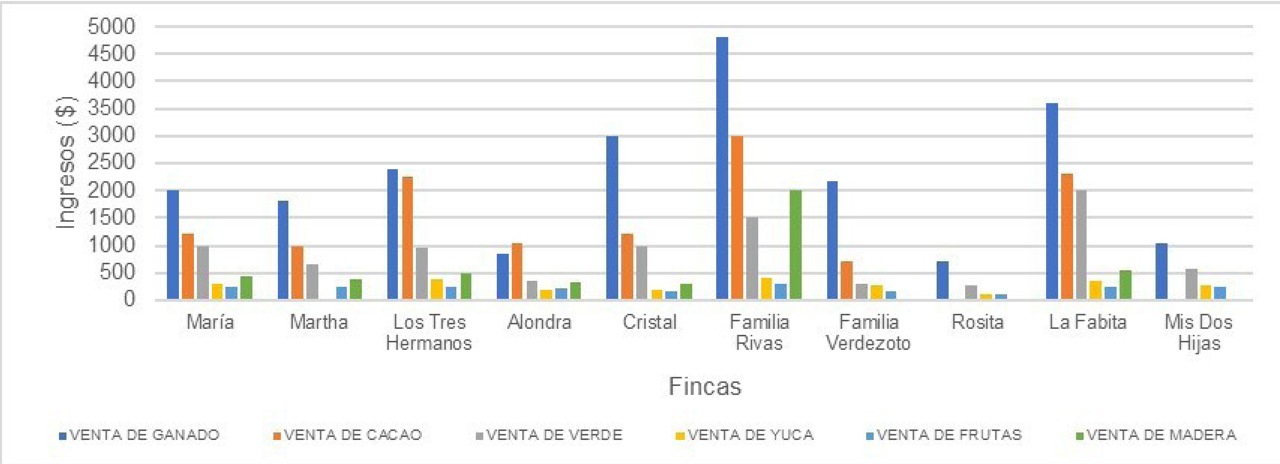


**Figure 2.** Annual income by activity.

Moreover, owners who raise and sell cattle and pigs earn additional income, making up for 30% of the total. In terms of expenses, AFS owners spend their money on supplies, tools, transportation, occasional human capital, and fuel. Jumbo (2017) reports similarities in expenditure factors, indicating that the main economic income from agroforestry systems comes from the sale of cocoa (33.3%), cattle (15.5%), and other crops (5.6%). These similarities provide a comprehensive overview of both income and expenditure flows within the country's agricultural sector.

### *3.2. Sustainability of the farms evaluated*

The "Familia Rivas" farm stands out for having the highest economic indicator, with a value of 2.75, while "Rosita" has the lowest economic value, with 0.92. In terms of the ecological indicator, "Familia Rivas" also leads with a value of 2.50, while the "Martha," "Familia Verdezoto," and "Rosita" farms occupy the lowest position, with a value of 1.66. Finally, in the social indicator, the "María" farm achieved a value of 2.38, while 'Alondra' and "Rosita" show the lowest values, reaching only 1.38. (Figure 3).

Variations in sustainability indicators are attributed to factors such as land area, access to basic services, educational level, and the use of technology, which has been shown to promote the sustainability of agricultural systems (Cayambe et al., 2023). It is clear that a better quality of life, including greater access to resources and education, translates into a higher degree of sustainability on farms. In this regard, Barrezueta-Unda and

Paz-González (2018) highlight that social aspects such as educational attainment, participation, and decision-making capacity have a significant impact on farmers' economies. When these factors are deficient, it is common for agricultural activities to be abandoned. This underscores the importance of strengthening educational and participatory capacities in rural communities to improve not only sustainability, but also the economic viability of farms (Heredia-R et al., 2020).

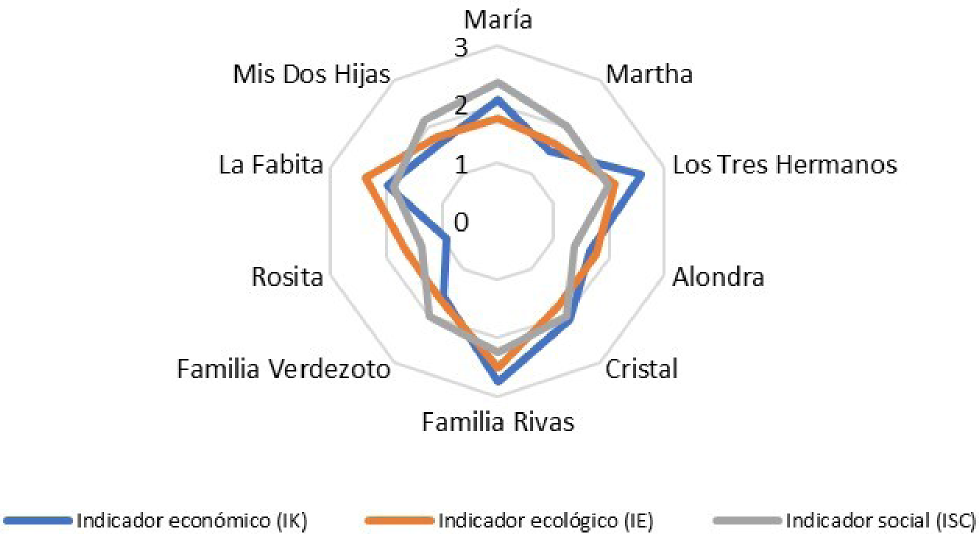


**Figure 3.** Sustainability polygon for the social, economic and environmental dimensions.

The sustainable farms identified in this study are: "Familia Rivas," with a Generational Sustainability Index [ISGen] of 2.50; "Los Tres Hermanos," with an ISGen of 2.23; and "La Fabita," with an ISGen of 2.09 (Figure 5). These farms meet the sustainability criteria established by Sarandón et al. (2014), as they all obtained scores equal to or greater than 2 in the three dimensions evaluated: economic, ecological, and social.

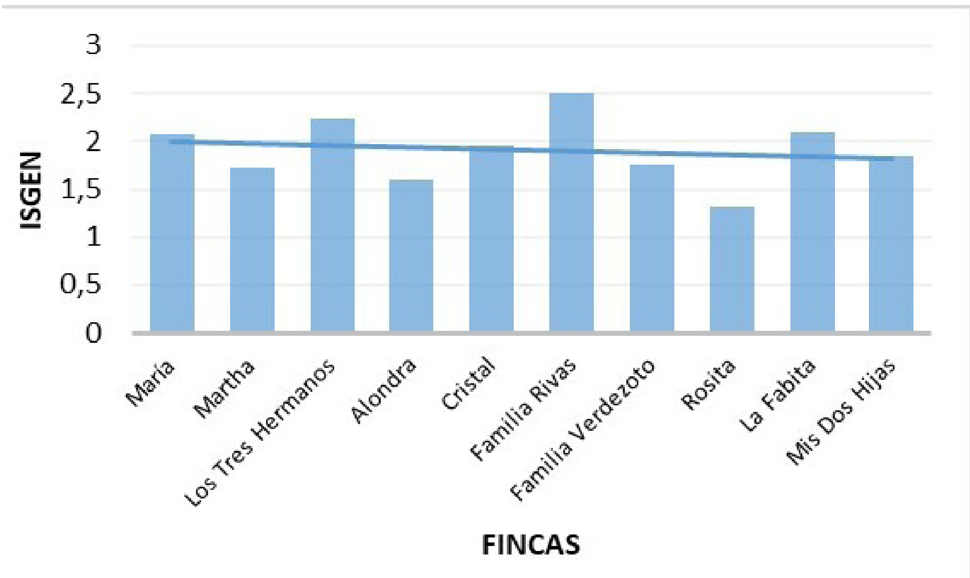


**Figure 4.** Overall sustainability of agroforestry systems.

Although the farm "María" has an ISGen score of 2.08, it cannot be considered sustainable according to Sarandón's criteria, since its ecological indicator has a score of approximately 1.75, which is below the minimum requirement of 2. This low score in the ecological dimension prevents the farm from being classified as sustainable, thus highlighting the importance of maintaining an adequate balance between all dimensions of sustainability. The other farms evaluated are considered unsustainable, as they did not achieve a value equal to or greater than 2 in the ISGen.

### *3.3. Proposal for agroforestry partnerships*

#### 3.3.1. Finca María

To improve productivity, diversify crops, optimize the use of space and time, and obtain better economic returns on the *Ochroma pyramidale* (balsa) plot, association 1 is proposed (Table 6; Figure 5). According to Contreras-Santos et al. (2021), this crop can be grown simultaneously with others, such as cassava, corn, or turmeric, which allows for income generation, while waiting for balsa wood production. In areas where cassava is currently grown, proposal 2 is suggested, while in the Phaseolus vulgaris (bean) plot, association 3 is recommended, as these crops do not compete for space, and the proliferation of corn pests and diseases is avoided, therefore improving the interactions between them and the yield, which is product of this, as pointed out by Altieri and Nicholls (2000).

**Table 6.** Proposed species for agroforestry Systems.

| N° | Existing crop, or farm site | Proposed type | Objectives of the proposal | Species covered by the proposal |
|---|---|---|---|---|
| 1 | *Ochroma pyramidale* (balsa) | Rotational agroforestry partner | Increase nitrogen fixation in the soil.<br>Diversify production. | *Manihot esculenta* (cassava) or *Zea mays* (corn). |
| 2 | Batch of cassava | Intercropping vegetable rows | Diversify and maximize production.<br>Provision of resources | Vegetables. |
| 3 | Batch of *Phaseolus vulgaris* (bean) | Agricultural partner | Take advantage of nitrogen fixation in the soil.<br>Diversify and maximize production. | *Zea mays* (corn). |
| 4 | *Theobroma cacao* (cacao) | Agroforestry partner | Improve productivity.<br>Diversify income.<br>Increase biodiversity.<br>Shade and climate.<br>Provision of food resources. | *Musa* spp. (banana) and *Musa × paradisiaca* (plantain). |
| 5 | *Musa × paradisiaca* (plantain) o *Musa spp* (banana) | | | *Persea americana* (avocado). |
| 6 | Pastoral system (pasture) | Silvopastoral | Diversify production.<br>Improvement of soil and microclimate.<br>Increase productivity.<br>Pest and disease control.<br>Diversify income. | Inga edulis (guava), *Annona muricata* (soursop), *Guaiacum officinale* (guayacan), *Citrus reticulata* (mandarin), *Citrus limon* (lemon), *Citrus × sinensis* (orange), *Crescentia cujete* (mate), *Laurus nobilis* (bay leaf), and *Ochroma pyramidale* (balsa). |
| 7 | Water source area | Silvicultural partner for preservation | Conserve water.<br>Stabilize soil and control erosion.<br>Promote diversity of flora and fauna.<br>Improve microclimate. | *Zygia longifolia* (chíparos) and *Guadua angustifolia* (guadúas). |
| 8 | Orchard | Intercropping or polyculture partner. | Increase productivity.<br>Control pests and diseases.<br>Improve biodiversity.<br>Improve soil structure, increase fertility, and promote water retention.<br>Diversify income and food and medicinal resources for the family. | *Allium sativum* (garlic), *Allium fistulosum* (onion), *Allium fistulosum* (chive), *Lycopersicon* (tomato), *Coriandrum sativum* (cilantro), *Capsicum annuum* (pepper), *Cucumis sativus* (cucumber), and some aromatic and medicinal plants such as *Origanum vulgare* (oregano) and *Aloysia citrodora* (lemon verbena). |
| 9 | Hedges | Agroforestry partner | Control erosion.<br>Improve biodiversity.<br>Provide shade and fodder.<br>Protect crops.<br>Recover soils. | *Eritrina glauca* (Caraca). |

| N° | Existing crop, or farm site | Proposed type | Objectives of the proposal | Species covered by the proposal |
|---|---|---|---|---|
| 10 | *Tectona grandis* (teak) | Crop integration | Increase productivity.<br>Control erosion and stabilize the soil.<br>Diversify income. | *Zea Mays* (corn). |
| 11 | Orchard | Intercropping partner | Control pests.<br>Increase productivity. | *Origanum vulgare* (oregano; medicinal resource) and *Cucumis sativu* (cucumber) as nutritious food. |
| 12 | Orchard | | Improve soil fertility.<br>Diversify income.<br>Provide food and medicinal resources. | *Phaseolus vulgaris* (bean) with *Lactuca sativa* (lettuce) and plants for pest control such as *Nasturtium officinale* (watercress), *Coriandrum sativum* (cilantro), *Allium sativum* (garlic), or *Origanum vulgare* (oregano). |
| 13 | *Erythrina glauca* (caraca) | Silvicultural partner in living fences. | Improve soil fertility.<br>Control erosion.<br>Provide shade and microclimate.<br>Diversify income.<br>Provide food and forage resources. | *Swinglea glutinosa* (lemongrass). |
| 14 | *Theobroma cacao* (cocoa) | Agroforestry partner | Increase biodiversity and productivity.<br>Improve soil.<br>Control erosion.<br>Diversify income.<br>Provide food and commercial resources. | *Musa paradisiaca* (banana) and *Zea mays* (corn). |
| 15 | Orchard | Intercropping or polyculture partner. | Pest and disease control.<br>Improve soil.<br>Diversify income.<br>Provide food and medicinal resources. | *Plantago major* (plantain), *Origanum vulgare* (oregano), and *Aloysia citrodora* (lemongrass). |
| 16 | Hedges | Improving living fences | Control erosion. Nitrogen fixation.<br>Provide forage resources.<br>Shade and protection.<br>Improve biodiversity.<br>Reduce wind speed. | *Leucaena leucocephala* (Leucaena). |
| 17 | *Manihot esculenta* (cassava) | Agroforestry partner | Nitrogen fixation.<br>Control erosion.<br>Increase productivity.<br>Diversify income.<br>Pest and disease control. | *Phaseolus vulgaris* (bean) and plants for pest control such as *Nasturtium officinale* (watercress), *Coriandrum sativum* (cilantro), *Allium sativum* (garlic) or *Origanum vulgare* (oregano). |
| 18 | Orchard | Intercropping or polyculture partner. | Pest and disease control.<br>Improve soil.<br>Increase productivity and profitability.<br>Diversify income.<br>Attract pollinators.<br>Provide food and medicinal resources. | *Lycopersicon* (tomato), *Allium fistulosum* (onion), *Coriandrum sativum* (cilantro), *Allium sativum* (garlic), *Capsicum annuum* (pepper), *Cucumis sativus* (cucumber), *Origanum vulgare* (oregano) and *Aloysia citrodora* (lemongrass). |

| N° | Existing crop, or farm site | Proposed type | Objectives of the proposal | Species covered by the proposal |
|---|---|---|---|---|
| 19 | New plot | | Diversify production.<br>Improve soil health.<br>Pest and disease control. | *Citrus × sinensis* (orange), *Citrus reticulata* (tangerine) y *Citrus limon* (lemon) plants for pest and disease control such as *Tagetes spp.* (marigold) and/or *Coriandrum sativum* (cilantro). |
| 20 | Pastoral system (pastures) | Agroforestry partner | Optimize space usage.<br>Improve soil health. | *Laurus nobilis* (laurel), *Guaiacum officinale* (guayacan), *Ochroma pyramidale* (balsa) and *Moringa oleífera* (moringa). |
| 21 | Pastoral system (pastures) | | Control erosion.<br>Provide medicinal and aromatic resources. | *Citrus × sinensis* (orange), *Mangifera indica* (mango), *Citrus limon* (lemon), *Guaiacum officinale* (guayacan) and *Laurus nobilis* (laurel). |
| 22 | Hedges | Barrier and protection | Diversify production.<br>Improve soil health.<br>Control erosion.<br>Provide medicinal and ornamental resources. | *Guaiacum officinale* (guayacan) and *Hibiscus rosa-sinensis* (Chinese hibiscus) |
| 23 | Nephelium lappaceum (mountain ash), Citrus × sinensis (orange), and Citrus reticulata (mandarin) | Agroforestry partner | Diversify production.<br>Improve soil health.<br>Control erosion.<br>Provide food resources. | *Cynodon dactylon* (Bermuda grass) and *Moringa oleifera* (moringa). |

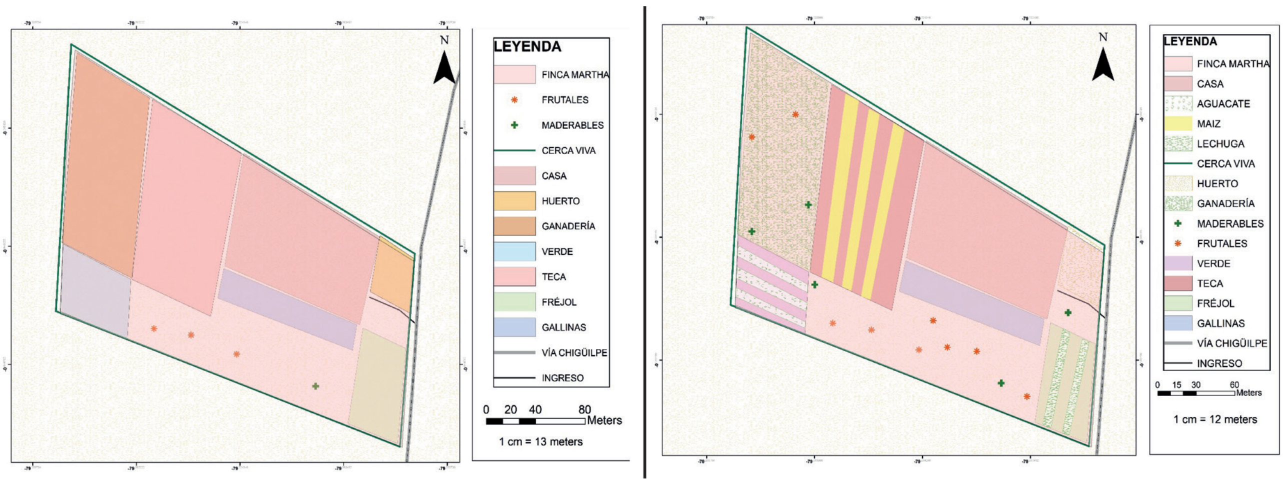


**Figure 5.** Initial (left) and proposed (right) land uses for Finca María.

Proposal 4 would allow two harvests before removing the banana and rotating the crop. According to Corven (1993), these crops are considered protective, because they improve ecological conditions, control weeds, reduce the need for fertilizers, and facilitate nitrogen fixation. By promoting a favorable microclimate and increasing biodiversity, these agroforestry systems promote more efficient and sustainable agricultural production. For the cultivation of Musa × paradisiaca (plantain), proposal 5 seeks to avoid monoculture, and prevent soil degradation by taking advantage of the complementarities and synergies that arise when combining crops, trees, and animals in different spatial and temporal arrangements, as indicated by Altieri and Nicholls (2000).

Proposal 6 is the implementation of an agroforestry system, as these contribute to carbon capture, lower nitrous oxide [$N_2O$] emissions, and the mitigation of methane [$CH_4$] emissions by ruminants. In addition, the system can be divided into sectors where livestock will graze in rotation to reduce soil deterioration due to animal load (Contreras-Santos et al., 2021).

In the water source sector, proposal 7 would preserve riverbanks, reduce the impact of water pollution, increase retention capacity in grasslands, and increase infiltration and protection of soil, springs, and streams, as reported by Auquilla-Cisneros (2005). A vegetable garden was proposed near the house, as well as improving hedges and boundaries by planting species to serve as a resistant barrier and provide shade for livestock once they reach their ideal height (proposals 8 and 9, respectively).

### 3.3.2. Finca Martha

To maintain soil quality and strengthen protective barriers against pests and diseases, proposal 5 was considered (Figure 6). The combination of perennial or semi-perennial crops, aimed at local and even international markets, is a traditional practice in smallholder farming systems in tropical areas (Tamayo Ortiz & Alegre Orihuela, 2022). Some examples of arrangements based on Theo*broma cacao* (cocoa), *Coffea arabica* (coffee), or *Musa* × *paradisiaca* (banana), in association with other crops, can be found on smallholder farms in Colombia, Ecuador, and Peru. The association of short-cycle crops that can continue producing multiple harvests while waiting for the timber crop to be ready for market is also proposed (proposal 10). This allows for greater profitability by associating two crops without affecting the well-being and productivity of the main crop, as noted Pilco et al. (2018).

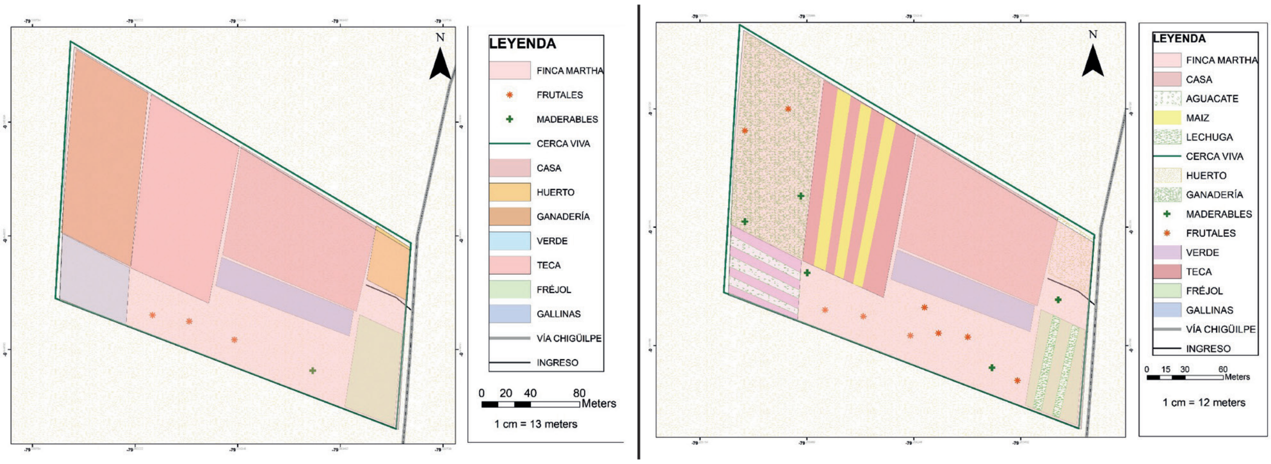


**Figure 6**. Initial (left) and proposed (right) land uses for Finca Martha.

In the pasture areas, the components of proposal 6 would serve as a buffer for greenhouse gas emissions and as shade for livestock. Animal manure would provide nutrients to the soil and, therefore, to the plants. For the orchard, proposal 11 would help increase medicinal plants, as well as serve as an ideal nutritious food for salads. In addition, to avoid competition for space and nutrients, and displaying a lower incidence of pests or diseases, proposal 12 would be applied. Finally, living fences can be enhanced to provide greater security and stability with proposals 9 and 13.

### 3.3.3. Finca Los Tres Hermanos

For this property in the pastoral system, implementing proposal 6 would provide shade for the livestock, strengthen the soil, and use the livestock manure as fertilizer. To avoid overloading the soil with the weight of the animals, rotation in the agroforestry-pastoral system is recommended; and in the cultivation of Theobroma cacao (cacao), through proposal 14, the short-cycle crop would produce until the cacao and banana reach their harvest stage (Figure 7). The banana cultivation would help with water and nutrient absorption, keeping the soil suitable for cacao and achieving better yields, as noted on the previous farms.

In the *Ochroma pyramidale* (balsa) plot, proposal 1 is suggested, taking into account that crops can be rotated, which would allow the soil to regenerate and rest from the usual nutritional demands of common crops. Along the banks of every water source, proposal 7 would be applied to preserve the water resource and obtain economic benefits by pruning the Guadua cane and selling these specimens for the manufacture of various objects or even for internal use on the farm. Lastly, the live fences present excessive space between plants (the planting distance is not correct), making it necessary to carry out regenerative pruning, and incorporate species from proposal 9 to strengthen the enclosure.

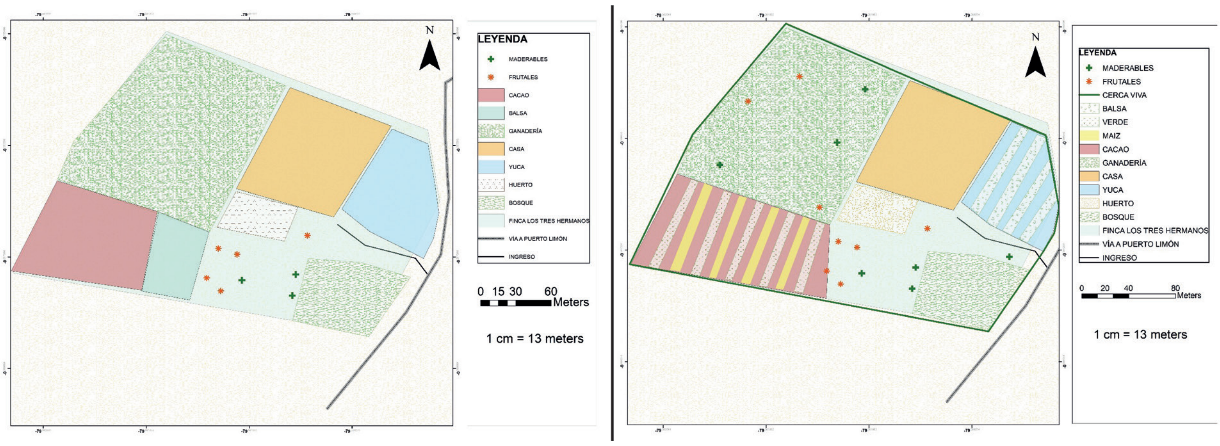


**Figure 7.** Initial (left) and proposed (right) land uses for Finca Los Tres Hermanos.

### 3.3.4. Finca Alondra

Being a small extension, it is recommended to implement proposal 6 in the pastoral system, so that the animals can graze without major problems, protected from the sun and without harming the soil with the animal load. Within this system there are fruit and timber trees that are not marketed. The main crop is Theobroma cacao (cocoa); within this context, proposal 13 can generate many benefits. According to Tamayo Ortiz and Alegre Orihuela (2022), in associations, the benefits of land use, compared to monoculture systems, are related to better efficiency in the use of natural resources (land and water), higher product yield, increased income, climate change mitigation (due to greater carbon storage capacity), reduction of pest and pathogen populations, promotion of biological control, increased population diversity of beneficial macro and microorganisms, as well as improved soil fertility (Figura 8).

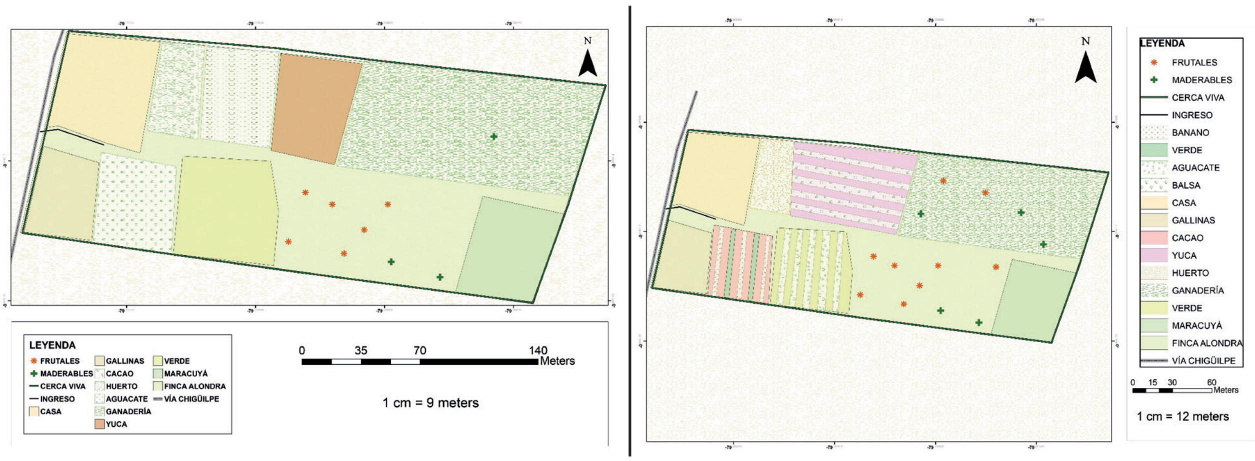


**Figure 8.** Initial (left) and proposed (right) land uses for Finca Alondra.

In the *Ochroma pyramidale* (balsa) plot, proposal 1 would allow economic returns in the short term, until the balsa reaches its harvest stage. To improve the orchard's substrate, it is recommended to incorporate aromatic and medicinal plants, and for its living fences, it is recommended to use windbreak trees that help protect the other nearby crops from the force of the wind and protect the soil from erosion (Proposals 15 and 16, respectively).

### 3.3.5. Finca Crista*l*

Being a large estate, improvements in its crops have been proposed through associations that generate higher income. This property is primarily dedicated to livestock farming, so it is important to pay special attention to the pastures. These can be divided so that the animal load does not affect the soil and, thus, can be rotated to different areas periodically. Additionally, proposal 6 can be incorporated to provide shade for the livestock and help facilitate the absorption of nutrients from the grass to improve the quality of feed for the animals (Figura 9A).


**Figure 9.** Proposed land use and arrangements of Cristal (A), Rivas Family (B), Verdezoto Family (C), Rosita (D), Fabita (E), and Mis dos hijas (F) farms.

The next stage of associations is proposal 5, as these are synergistic crops which help each other with the absorption of water and nutrients, and help the soil remain moist and nourished. According to Altieri and Nicholls

(2000), crop association requires exploiting complementarities and synergies. In this sense, the association between species in proposal 19 is suitable, as there is no competition for space, light, or nutrients, and they protect each other from pests and diseases. Balsa is a highly commercial wood but takes its time to grow, so it is recommended to associate it with another short-cycle crop to obtain economic benefits until reaching harvest age (Proposal 1), and to increase the soil's capacity to fix nitrogen. The orchard should be improved with the planting of vegetables and aromatic plants, as detailed in proposal 18. Finally, the living fences should be repaired, making it important to implement proposal 13.

3.3.6. Finca Familia Rivas

Proposal 1 is one of the alternatives for secure income, with the advantage that crops such as cassava and corn can be grown simultaneously, ensuring income while waiting for the timber production, as indicated by Méndez Salgado (2009). On the other hand, for Theobroma cacao (cacao), association 4, either at the same time or in rotation, would allow the commercialization of around 120 boxes of export bananas per month, being one of the important sources of income for the family (Figure 9B). A sector is established for planting citrus (Proposal 19), which are part of the paddocks and provide shade for the livestock. Likewise, timber trees are distributed (Proposal 20), thus forming an agroforestry-livestock system where the livestock rotates through the paddocks at set intervals, preventing soil compaction due to animal load. The riverbanks must be cleared and respect the 50 m protection strip established by law; and, thus, they should also be covered with trees that help conserve water resources (Proposal 7), which having a very extensive root system, adhere to the soil, and hold it so firmly that they prevent floods and landslides. The orchard near the main house should be readjusted where vegetables and garden produce can be planted for consumption (Proposal 8). Additionally, the remains of fruits, peels, and other organic waste obtained from the kitchen, should be used for fertilizer. An added benefit would be to improve the appearance of the tilapia pool, and offer sport fishing services to individuals as an agrotourism initiative. Living fences should also be implemented, since they are scarce; finally, the use of species from Proposal 13, that protect the soil, serve as economic and ecological enclosures, and also have an aesthetically pleasing appearance, is also recommended.

3.3.7. Finca Familia Verdezoto

In the pastures, an agroforestry-pastoral system with fruit and timber trees is proposed (Proposal 6); these help regulate livestock temperature and mitigate methane emissions (Figure 9C). In the planting of Musa × paradisiaca (banana), Proposal 5 was suggested. These two crops are synergistic, so there is no competition for space, light, or nutrients; on the contrary, they help each other obtain the necessary nutrients from the soil, grow, and sustain over time. For the cultivation of Manihot esculenta (cassava), Association 19 was established, as these two crops provide each other with the nutrients needed for their development. For the cultivation of Theobroma cacao (cocoa), Proposal 4 is suggested. These crops help regulate soil conditions, improving its nutrition and producing better fruits (Tamayo Ortiz & Alegre Orihuela, 2022). Based on the farmer's needs, a garden with certain vegetables for daily use is proposed, in addition to aromatic and medicinal plants (Proposal 15). Finally, the living fences should be arranged where necessary, and the implementation of beneficial tree species is advised (Proposals 9 and 13).

3.3.8. Finca Rosita

It is the smallest farm in the study, and the production on this property is mainly for personal/family consumption. However, it would be advisable to form associations in order to diversify the crops and make them profitable. The proposed associations are described below (Figure 9D). In the pasture area, it is suggested to incorporate fruit and timber trees (Proposal 24). This combination of trees with *Cynodon dactylon* (grass), called an agro-silvopastoral system, is one of the most suitable, as it helps protect the soil from erosion and compaction, while also providing shade and serving as a cushioning layer for gases produced by livestock.

Association 1 is proposed, as it consists of combinations that will provide immediate income while waiting for the harvest of the teak trees. This association generates ecological synergies, since corn contributes to nitrogen fixation in the soil, thereby enriching the substrate and promoting the growth of teak. As a result, higher quality logs are obtained for commercialization. Additionally, this combination reduces the likelihood of plants contracting pests or diseases, promoting a healthier and more productive agroecosystem. In the planting of Musa × paradisiaca (banana), proposal 5 is suggested, including two synergistic crops that mutually benefit each other's nutrition. On the other hand, association 1, being short-cycle, provides economic support until the balsa crop is ready. It is recommended to increase the number of laying hens for greater egg commercialization. The reorganization of the orchard was also proposed, where vegetables and garden crops of higher consumption should be planted (Proposal 18). This garden should be close to the main house so that they have access to the food when cooking. Finally, the living fences should include species that provide greater resilience (Proposal 21), and act as a wind barrier, preventing soil erosion and protecting nearby crops; and once they reach their harvest age, they can be marketed as an additional source of income.

3.3.9. Finca La Fabita

"La Fabita" is a complete farm with river access, a country house that also functions as a restaurant for visitors, a dance floor with a thatched toquilla palm roof, trails, and a tilapia pond. It also has a suitable house with guest rooms (Figure 9E). The proposal is an agro-tourism farm, to generate a new model in product development, focused on the traditions and customs that make communities unique, as highlighted by the Ministry of Tourism (MINTUR, 2020). This will help strengthen the work since it already offers this type of activity (Figure 9E). It is proposed that the restaurant area be adapted to include a garden in order to use the farm's own products. As to the pastures, trees are introduced (Proposal 6). This agro-silvo-pastoral system provides ideal conditions for the soil, the grass, and, consequently, the livestock.

The guayacan tree, in particular, should be introduced, as it blooms every year, giving a very striking yellow appearance. Around the dance floor, it is recommended to promote the planting of *Prunus dulcis* (almond trees), which provide a very relaxed atmosphere and shade for tourists, and even hammocks can be placed for resting. Also, along the riverbanks, tree planting should be implemented (Proposal 7), which helps preserve water resources and, at the same time, supports the soil walls, preventing overflows and providing shade for tourists to rest.

For the crops *Musa × paradisiaca* (banana) and *Ochroma pyramidale* (balsa), proposals 4 and 1, respectively, are recommended. On one hand, their interactions help the soil to become better nourished and retain moisture, as well as due to the economic importance of bananas. On the other hand, balsa, being a crop that takes time to harvest, should be associated with a short-cycle crop to generate income until the timber is ready for commercialization. These crops have been shown to have greater ecological synergism, as previously mentioned.

A plot with association 3 has significant ecological and economic benefits; that is, beans would help fix nitrogen [N] in the soil for maize, whose main requirement is N, allowing it to absorb these nutrients more easily. In addition, they are protected from pests and diseases that are very harmful in common maize crops. In the cultivation of *Persea americana* (avocado), the recommendation is the species from proposal 5, which are synergistic, and would help each other in the absorption of water and nutrients.

Finally, the main attraction of agrotourism is the tilapia pond for sport fishing, so it should have all the equipment to facilitate the use of the facilities. Additionally, for aesthetic reasons, it is recommended to improve the live fences with proposal 13, 16, or 22, and prune them so that they do not reach excessive heights and obstruct the view of the landscape.

3.3.10. Finca Mis Dos Hijas

For the fruit tree plot, proposal 22 would provide the paddocks with protection and soil support, greater nutrition for the grass, and at the same time, shade for the livestock (Figure 9F). Currently, around 100 to 120 boxes of export bananas (*Musa spp*) are sold, and an association with *Theobroma cacao* (cocoa), which is also a high-value crop, is proposed. This association benefits both crops in terms of nutrients and moisture, which are essential for their growth and production.

For *Ochroma pyramidale* (balsa), proposal 1 is considered suitable due to its significant ecological and economic benefits, as the short cycle would provide necessary income until the balsa harvest. It is proposed to increase the number of laying hens in the economic commercialization activity in order to generate additional income through egg sales. For river protection, proposal 7 is recommended. In the established orchard, it is recommended to plant more species (Proposal 21).

In addition, since the fence is very deteriorated and the stakes used do not provide significant ecosystem services, living fences are proposed (Proposal 7).

### *3.4. Analysis of agroforestry association proposals*

This research demonstrates the relevance of the methodologies employed in the sustainability of farms within the standardized understanding of agroforestry systems. However, other approaches are recognized that originate from socio-ecological systems, which question the paradigm of separating humans from nature, including domesticated plants, and which offer a better interrelationship between agroecosystems and biodiversity (González-Valdivia et al., 2016), or between agroforestry systems and the dynamics of rural landscape ecology. Although this is not the focus of this study, and these insights can serve as a starting point, they are insufficient for the standardized understanding of agroforestry systems at the rural level. The limitations of this approach include its individualized nature, which may not adequately address the broader dynamics of the landscape and the interactions between different productive systems (Plieninger et al., 2020).

Normalizing agroforestry systems which act as steps or a landscape mosaic in the connectivity of processes for the sustainability of forest landscapes in these rich life zones (composed of very Humid Tropical Forest, very Humid Piedmont Forest, lower Montane Very Humid Forest, and Montane Rain Forest) of the Santo Domingo Canton are justified on their own in the current context of climate change, and genetic and cultural erosion.

In this sense, research lines remain open aimed at understanding sociocultural relationships, crops, and biodiversity from an agroecological agroforestry perspective that incorporates analysis in a broader context, such as the landscape, watershed, or a regional system of natural areas.

## 4. Conclusions

Land use on farms is distributed as follows: 48% for agriculture, 32% for livestock, and 20% for other uses. The most common crops are cocoa, which accounts for 55%, and bananas, with 24%. The main agricultural species on the farms include cocoa, balsa, bananas, and cassava. Four types of agroforestry systems were identified: living fences, agrosilvopastoral, timber associations with short-cycle crops, and special agroforestry.

In terms of animal production, cattle and pigs are the most important. Additionally, the farms of the Rivas and Verdezoto families, together with “La Fabita”, have ponds for tilapia farming. “La Fabita” is also involved in agrotourism, which represents a significant additional income.

In the social sphere, 55% of the owners of the agroforestry systems studied have only completed primary education. The main sources of income come from the sale of cocoa and livestock, while other income is generated from the sale of wood and bananas. Expenditures are mainly used to purchase tools, fuel, transportation, and payment for temporary human capital.

The sustainability assessment revealed that the farms “Familia Rivas,” “Los Tres Hermanos,” and “La Fabita” meet sustainability criteria, achieving scores equal to, or greater than 2 in the economic, ecological, and social dimensions. Nevertheless, the farm “María” cannot be considered sustainable as its ecological indicator is 1.75, which is below the minimum threshold of 2 established by the Sarandón methodology. This analysis underscores the importance of maintaining a balance between the three dimensions to achieve sustainability in agroforestry systems.

For each farm, various combinations of timber species with short-cycle crops were proposed, as well as the integration of citrus and timber trees with pasture grass. Additionally, watershed management was included through the incorporation of G. angustifolia (guadua cane) and Z. longifolia (chíparos), and the implementation of living fences with species such as lemongrass, cucardas, and caraca on the boundaries was suggested, along with a vegetable garden. Livestock farming was also proposed, adjusted to the available space and capacity of each farm.

For the “Rivas”, “Fabita”, and “Verdezoto” farms, it is recommended to continue developing their agrotourism project, taking into account the adjustments suggested in this proposal. Finally, maps were designed to illustrate the proposed profitable agroforestry model for each property, thus facilitating a better understanding of the recommendations.

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## Contributor roles

- Julio César Muñoz-Rengifo: investigation, conceptualization, data curation, methodology, validation, supervision, writing – review & editing.
- Madelyn Nicol Moyano Zambrano: investigation, conceptualization, methodology, validation, project administration, writing – original draft, writing – review & editing.
- Marcelo Luna: methodology, validation, conceptualization, writing – original draft.
- Juan José Reyes-Pérez: conceptualization, methodology, validation, writing – review & editing.
- Marco Heredia-R: methodology, conceptualization, writing – review & editing.
- Segundo Bolier Torres Navarrete: methodology, validation, writing – review & editing.

## Ethical implications

The authors declare that they did not require approval from a Human Ethics Committee, as the study involved conducting surveys with farmers, who gave their free and voluntary consent to participate. The informed consent of each participating farmer was guaranteed, ensuring that they understood the purpose of the study, their voluntary participation, and their right not to respond or to withdraw at any time they deemed appropriate, without consequences. The bioethical principles of autonomy, beneficence, non-maleficence, and justice were strictly respected, protecting the confidentiality and privacy of the data collected. The research complied with applicable national legislation, the Statistics Law, and the Organic Health Law of Ecuador, which protect the dignity of participants and regulate the proper handling of personal information. Permission was obtained from the farming community to conduct interviews and surveys.

## Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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