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Original article

Ecological rehabilitation and floristic structure in the Amazonian chakra agroforestry system

Rehabilitación ecológica y estructura florística en sistema agroforestal chakra amazónico

Reabilitação ecológica e estrutura florística no sistema agroflorestal chakra da Amazônia

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ABSTRACT

Amazonian agroforestry systems integrate agricultural and forestry components that contribute to productive sustainability and biodiversity conservation. The objective of this study was to propose an ecological rehabilitation strategy for the Yana Rumi farm by characterizing the chakra agroforestry system and structurally evaluating the associated secondary forest. The research was conducted in the Madre Tierra parish, Mera canton, Pastaza province (Ecuador). A descriptive approach based on participatory production diagnosis and floristic evaluation was applied. For the analysis of the secondary forest, four 10 × 10 m plots were established using stratified sampling, where tree species, abundance, and diameter at 1.30 m. The Shannon and Simpson diversity indices and the Importance Value Index (IVI) were calculated. The chakra system showed edaphic limitations associated with poor drainage and acidification processes that affected traditional crops. The secondary forest exhibited low diversity (average H' = 0.280) and structural dominance of *Apeiba membranacea* and *Piptocoma discolor*. The proposed rehabilitation strategy included agricultural diversification with *Carica papaya L.*, *Ananas comosus* (L.) Merr, and *Hibiscus sabdariffa L.*, incorporation of organic fertilization, and forest enrichment with multipurpose species. The results indicate that integrating agroecological practices and forest enrichment can improve the ecological resilience and productive functionality of the agroforestry system.

Keywords: Agroforestry, Amazonian chakra, floristic diversity, ecological rehabilitation, agroforestry systems.

RESUMEN

Los sistemas agroforestales amazónicos integran componentes agrícolas y forestales que contribuyen a la sostenibilidad productiva y a la conservación de la biodiversidad. El objetivo del estudio fue proponer una estrategia de rehabilitación ecológica para la finca Yana Rumi mediante la caracterización del sistema agroforestal chakra y la evaluación estructural del bosque secundario asociado. La investigación se desarrolló en la parroquia Madre Tierra, cantón Mera, provincia de Pastaza (Ecuador). Se aplicó un enfoque descriptivo basado en diagnóstico productivo participativo y evaluación florística. Para el análisis del bosque secundario se establecieron cuatro parcelas de 10 × 10 m bajo muestreo estratificado, donde se registraron especies arbóreas, abundancia y diámetro a 1.30 m. Se calcularon los índices de diversidad de Shannon, Simpson y el Índice de Valor de Importancia (IVI). El sistema chakra evidenció limitaciones edáficas asociadas a drenaje deficiente y procesos de acidificación que afectaron cultivos tradicionales. El bosque secundario presentó baja diversidad (H’ promedio = 0,280) y dominancia estructural de *Apeiba membranacea y Piptocoma discolor*. La estrategia de rehabilitación propuesta incluyó diversificación agrícola con *Carica papaya L.*, *Ananas comosus* (L.) Merr e *Hibiscus sabdariffa L.*, incorporación de fertilización orgánica y enriquecimiento forestal con especies multipropósito. Los resultados indican que la integración de prácticas agroecológicas y enriquecimiento forestal puede mejorar la resiliencia ecológica y la funcionalidad productiva del sistema agroforestal.

Palabras clave: Agroforestería, chakra amazónico, diversidad florística, restauración ecológica, sistemas agroforestales.

RESUMO

Os sistemas agroflorestais amazônicos integram componentes agrícolas e florestais que contribuem para a sustentabilidade produtiva e a conservação da biodiversidade. O objetivo deste estudo foi propor uma estratégia de reabilitação ecológica para a fazenda Yana Rumi, caracterizando o sistema agroflorestal chakra e avaliando estruturalmente a mata secundária associada. A pesquisa foi realizada na paróquia de Madre Tierra, cantão de Mera, província de Pastaza (Equador). Foi aplicada uma abordagem descritiva baseada em diagnóstico participativo da produção e avaliação florística. Para a análise da mata secundária, foram estabelecidas quatro parcelas de 10 × 10 m utilizando amostragem estratificada, onde foram registradas as espécies arbóreas, a abundância e o diâmetro a 1,30 m. Os índices de diversidade de Shannon e Simpson e o Índice de Valor de Importância (IVI) foram calculados. O sistema chakra apresentou limitações edáficas associadas à drenagem deficiente e processos de acidificação que afetaram as culturas tradicionais. A mata secundária apresentou baixa diversidade (H′ médio = 0,280) e dominância estrutural de Apeiba membranacea e Piptocoma discolor. A estratégia de reabilitação proposta incluiu a diversificação agrícola com Carica papaya L., Ananas comosus (L.) Merr. e Hibiscus sabdariffa L., a incorporação de fertilização orgânica e o enriquecimento florestal com espécies multiuso. Os resultados indicam que a integração de práticas agroecológicas e enriquecimento florestal pode melhorar a resiliência ecológica e a funcionalidade produtiva do sistema agroflorestal.

Palavras-chave: Agrofloresta, chakra amazônico, diversidade florística, restauração ecológica, sistemas agroflorestais.

INTRODUCTION

Agroforestry systems (AFS) represent production models that integrate tree species with agricultural crops and, in some cases, livestock, replicating ecological processes of the natural forest. This approach contributes to maintaining soil structure, increasing organic matter, promoting nutrient cycling, and improving the ecological resilience of agroecosystems (Manono and Mwami 2026). Furthermore, AFS constitute important biocultural reservoirs for Indigenous and peasant communities, conserving native species and management practices linked to ancestral knowledge.

Several studies show that agroforestry systems (AFS) reduce dependence on external inputs, improve agricultural yields, diversify income, and decrease the environmental impacts of conventional agriculture (Pérez-Abadia, Medina-Arroyo, and Navarro-Hevia 2024) . However, their implementation remains limited in Ecuador due to institutional barriers, scarce technical assistance, and cultural resistance to change in traditional production systems.

In the Amazon, agroforestry systems (AFS) and indigenous systems such as chakras fulfill critical functions in biodiversity conservation, the maintenance of ecosystem services, and climate change mitigation. Ecological rehabilitation in these contexts seeks to recover ecosystem functionality, restore productivity, and reduce the effects of land-use change, without necessarily aiming to fully restore the original and natural conditions of the ecosystem (Flores-Garnica, Flores-Rodríguez, Rivera-Leyva *et al*., 2024)

In the Ecuadorian Amazon, traditional systems known as chakras represent an ancestral form of agroforestry management developed by Indigenous communities, combining food crops, forest species, and medicinal plants. These systems play a fundamental role in food security and the preservation of biocultural knowledge.

However, various land-use transformation processes, loss of soil fertility, and technical limitations in production management have affected the sustainability of these systems. In this context, ecological rehabilitation is proposed as a strategy aimed at restoring the ecological functionality of the ecosystem and improving its productive capacity through agroecological practices and forest enrichment.

The Yana Rumi agroforestry farm faces problems related to poor drainage, loss of soil fertility, and low productive diversification, which limits the yield of traditional crops. Given these issues, the structural assessment of the secondary forest and the characterization of the chakra system are fundamental for designing sustainable management strategies. The objective of this study was to propose an ecological rehabilitation strategy for the Yana Rumi agroforestry farm by characterizing the chakra system and evaluating the floristic structure of the associated secondary forest.

MATERIALS AND METHODS

The study was conducted on the Yana Rumi farm, located in the Puerto Santa Ana community, Madre Tierra parish, Mera canton, Pastaza province, Ecuador. The property covers approximately 34 hectares and is located in UTM zone 18M, within a humid megathermal climate characterized by average annual temperatures between 21 and 22 °C and annual rainfall ranging from 5000 to 5500 mm (GAD-MERA 2020). The soils are classified as Inceptisols, with a sandy loam texture, low natural fertility, and drainage limitations. The ecological zoning of the farm was developed using geographic information systems (GIS), integrating biotic variables and anthropogenic pressures to delineate the units of analysis of the production system.

Productive diagnosis of the chakra system

The diagnosis of the chakra agroforestry system was carried out through a semi-structured interview with the owner, following the methodological criteria proposed for participatory rural diagnoses (Mantino, Burbi, Re *et al.*, 2026). Variables such as the following were recorded: agricultural floristic composition; spatial and temporal distribution of crops, production cycles, planting distance; as well as the agronomic management and fertilization practices implemented in the agroforestry system.

The use of organic fertilizers and sustainable management practices within the production system was also evaluated. Based on the information obtained, an agricultural diversification proposal was designed incorporating species of productive interest such as *Carica papaya* L., *Solanum lycopersicum* L., *Ananas comosus* (L.) Merr. and *Hibiscus sabdariffa* L. (Rojas-Pardo, Beltrán-Vargas and Zafra-Mejía 2022) . Furthermore, for the improvement of the chakra system Basic practices were considered for the farm, including the preparation of the area, the establishment of adequate planting distances and the application of organic fertilizers, based on the life cycle, the harvest stage and the dynamics of the species' output within the production system.

The spatial redesign of the production system was represented by a three-dimensional model developed in SketchUp Pro and subsequently visualized in Twinmotion, which allowed the simulation of the organization of the agroforestry landscape.

Ecological backup forest assessment

For the analysis of the secondary forest structure (3.67 ha), four 10 × 10 m plots (100 m² each) were established using stratified sampling and systematic distribution, in order to capture the structural heterogeneity of the site. In each plot, tree species, number of individuals, and diameter at breast height (DBH) at 1.30 m were recorded. The choice of 100 m² plots was based on their efficiency in assessing composition and diversity in tropical ecosystems, as they allow for greater sampling intensity and reduce error in contexts of high spatial variability; furthermore, their replication favors robust estimates of forest structure in secondary forests (Berernardes-da-silveira, Chaves-e-Carvalho, Nicoletti et al. 2022).

For the analysis of the structure and floristic diversity of the secondary forest, the following ecological indices were calculated: Shannon–Wiener index (H'), Simpson's dominance index (1−D), and Pielou 's evenness index (J') based on the abundance and distribution of the species recorded in the plots. In addition, the Importance Value Index (IVI) was determined by summing relative density, relative frequency, and relative dominance for each species and was interpreted according to the ranks (Bulega, Maliando Salim, Katani *et al* . 2023).

Statistical analysis

Differences in diversity between plots were assessed using the non-parametric Kruskal-Wallis test. Floristic similarity between plots was estimated using the Sørensen index. Spearman's rank correlation coefficient was also applied to analyze the relationship between dominance and floristic diversity. Statistical and graphical analyses were performed using PAST version 4.03 and R version 4.3.1.

RESULTS AND DISCUSSION

The results of the farm zoning showed that the production system has a spatial configuration typical of Amazonian family agroforestry systems, where productive areas and remnants of secondary forest coexist, contributing to the ecological stability of the landscape.

The area designated for the chakra system was 0.37 ha, while the secondary forest occupied 3.67 ha of the property. This land use pattern coincides with that reported for traditional Amazonian agroforestry systems oriented towards self-sufficiency and productive diversification (Figure 1).

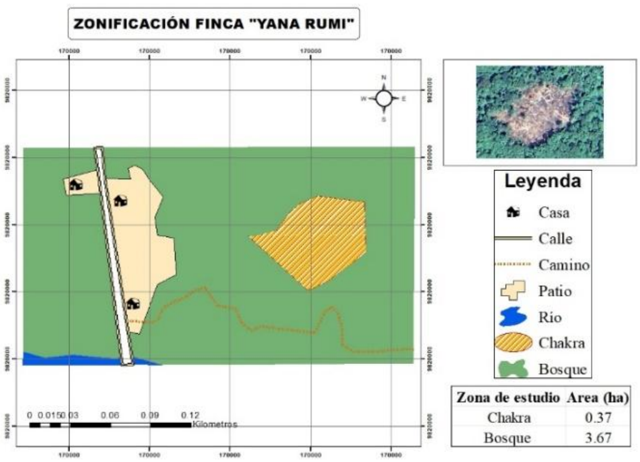

Figure 1. *- Conceptual map of the evaluated chakra agroforestry system*

The information obtained through the interview with the owner allowed us to corroborate that the productive management system is based on empirical knowledge of ancestral origin, transmitted intergenerationally within the Kichwa family, which coincided with what was stated by (Ramírez-Contreras, Castro-Ramírez, Yumbo *et al*., 2023).

This process of cultural transmission is a central element in the preservation of traditional agroecological practices characteristic of the chakra system. Furthermore, it was identified that family labor represents the main operational support for these production units, which are predominantly oriented towards food self-sufficiency and the socioeconomic sustainability of the family unit.

Main problems in the chakra system

The soil analysis revealed uneven terrain that led to waterlogging and the formation of muddy soils, affecting aeration, soil structure, and nutrient distribution. In these areas, reddish tones were observed on the soil surface, related to iron accumulation, a characteristic associated with acidification processes. This condition limited the growth of key crops such as *Manihot esculenta* Crantz, *Zea mays* L., and *Musa paradisiaca L.*, and favored weed proliferation (Figure 2).

Figure 2. - *Chakra areas under flood conditions*

This behavior was correlated with the high rainfall of the Mera canton, where precipitation exceeds 5000 mm annually, generating water saturation in soils of low permeability, in correspondence with that reported by (Urdiales-Flores, Célleri, Mariéthoz *et al*., 2025) who also proposes that intense rainfall and hydrological dynamics in the Ecuadorian Andes have described similar mechanisms of runoff, soil saturation, iron accumulation in regions of high rainfall and mountainous geomorphology, especially in tropical basins and Andean moorlands.

Agricultural characterization of the chakra

Nine species of agricultural interest were recorded, mostly belonging to the families Euphorbiaceae , Poaceae , and Musaceae (Table 1). *M. esculenta* (cassava), *Z. mays* (corn) and *Musa paradisiaca* (banana) showed the greatest representation, corroborating their importance as base crops in Amazonian chakra systems.

Table 1. - Species of the *chakra agroforestry system evaluated*

Cluster	Common name	Scientific name	Family	Number of individuals
Cereal	Corn	*Zea mays*	Poaceae	200
Fruit trees tropical	Banana	*Paradise Muse*	Musaceae	90
	Silk banana	*Musa acuminata* Colla	Musaceae	30
Tubers and roots	Yucca	*Manihot esculenta*	Euphorbiaceae	500
	Papachina	*Colocasia esculenta* (L) Scott	Araceae	30
	Sweet potato	*Ipomoea batatas* (L) Lam.	Convulvulaceae	10
	Jibaro potato	*Dioscorea trifida* LF.	Dioscoreaceae	5
	Taro	*Xanthosoma sagittifolium (L.) Schott.*	Araceae	1
Palm	Pambil	*Iriartea deltoidea* Ruiz & Pav.	Arecaceae	8

Mixed species associations were identified, integrated in a traditional manner, without defined spacing patterns or contemporary agronomic criteria, although they provide basic foods for family consumption. This organization coincided with that described for indigenous systems that prioritize ancestral knowledge over the technical design of the agroecosystem (Vera-Velez and Ramos-Veintimilla 2025).

perennial crops were identified in the field, with cycles ranging from 5 to 24 months. *I. batatas* had an approximate cycle of 150 days, while *M. esculenta, C. esculenta, X. sagittifolium,* and *D. trifida* showed cycles of 8 to 12 months. Perennial crops, such as *M. paradisiaca* and *M. acuminata,* reached cycles close to 12 months, mainly influenced by the empirical management practices applied.

The spatial organization of the production system responded primarily to the producer's cultural criteria rather than a planned technical design. This configuration coincides with that reported by (Heras, Moreno Lopez, Quevedo *et al*. 2024), who point out that the absence of spatial planning in traditional agroforestry systems can reduce productive efficiency and favor competition between species, which highlights the need to integrate agroecological and conservation strategies to strengthen the resilience of chakra systems (Figure 3).

Figure 3. - *Distribution of agricultural species under chakra conditions*

The absence of mineral or organic fertilization was noted, with only the ashes generated by burning the undergrowth and forest plant residues being used as the traditional source of soil nutrients (Figure 4). This management practice coincided with that reported by Ramos-Rodríguez, Alcíval-Cobeña, Cedeño-Luna *et al*. (2022), who described similar practices in chakra systems oriented towards self-sufficiency. It was also observed that species such as *Dioscorea trifida* (wild potato), *Musa paradisiaca* (plantain), *Manihot esculenta* (cassava), and *Xanthosoma sagittifolium* (malanga), were planted directly on the ashes, in accordance with traditional practices. These practices have been identified as a relevant factor for the conservation of plant diversity, associated with the active cycle of shifting cultivation, which culminates in the temporary abandonment of the field.

Figure 4. **-** *Use of ash as a nutritional input in agricultural crops under chakra conditions*

Chakra system improvement

The need to incorporate new agricultural species was determined based on the owner's interests, and planting distances were modified to promote growth and reduce interspecific competition. The proposal included *Carica papaya* and *Solanum. lycopersicum, Ananas comosus* and *Hibiscus Sabdariffa,* under criteria of ecological compatibility and productive diversification to guarantee efficient management of time and resources. In addition, the system's outputs, such as harvested products and their derivatives.

Bokashi (manure) was also recommended, which influences the soil quality index and the expansion of the cultivated area to 1.5 ha to improve productive capacity and food security. The establishment of a formal composting area would reduce waste and promote sustainable agroecological practices (Choque-Tarqui and Ticona-Quispe 2024)

Rehabilitation proposal

The proposal integrated species with different production cycles and ecological functions (Figure 5). *Carica papaya* was selected as a living fence due to its ability to reduce erosion, act as a physical barrier, and adapt to soils with varied textures. Furthermore, the use of processed organic matter in papaya cultivation increases the availability of nitrogen and other mineral nutrients in the soil (Bindu and Renjan 2025) .

S. lycopersicum was integrated with a spacing of 0.40 × 0.50 m and fertilization with compost, mycorrhizae and ash (Bernados, Espineli, A. *et al.,* 2024) (Alonso-López, Collado-Catalino, Barois-Boullard *et al*., 2015). *Ananas comosus* was established with distances of 0.30–0.50 m and organic fertilization (Martínez-Conde, Palacios-Torres, Ramírez-Seañez *et al* . 2024), while *H. sabdariffa* required distances of 0.70 × 0.90 m which may be influenced by the red color and separation of bracts, as well as by the development of the calyx in relation to the diameter and dry weight (Aguiar-Luna, Loeza-Corte and Alcántara-Jiménez 2023).

Figure 5. *- Ecological rehabilitation of the chakra system*

The inclusion of new species aimed to optimize crop rotation, restore soil fertility, and promote greater biodiversity—fundamental aspects for the recovery of the production system. This also strengthened food security and the resilience of the system. From a socioeconomic perspective, there was a willingness to invest in diversifying and improving the farm to increase productivity, which aligns with the findings of Carvajal-Benavides, Mugmal-Farinango, Rosales-Enríquez *et al.* (2024) , who highlighted the need to organize productive areas in Amazonian chakras, emphasizing the association between short-cycle and perennial crops as a strategy to promote family food security.

To strengthen the organic fertilization of the chakra, a 2 × 3 m composting module was implemented. It was installed under a roof and constructed with local materials, such as toquilla straw and chonta wood bases, thus ensuring the infrastructure's sustainability. Likewise, the traditional crops present in the chakra were maintained, including *Manihot esculenta* (cassava), *Colocasia esculenta (potato*), *Dioscorea trifida* (wild potato), *Zea mays* (maize), *Ipomoea batatas* (sweet potato), *Musa acuminata* (silk banana), *Musa paradisiaca* (plantain), and *Xanthosoma sagittifolium)* (malanga).

Analysis of the Importance Value Index (IVI), floristic diversity and rehabilitation proposal

The structural analysis of the secondary forest showed a marked dominance of pioneer species, mainly *Apeiba membranacea* and *Piptocoma discolor,* indicating an intermediate successional stage characteristic of ecosystems previously subjected to disturbances. This pattern is common in tropical secondary forests, where pioneer species exhibit high colonization capacity and rapid regeneration after land use changes or anthropogenic disturbances (Huera-Lucero, Lopez-Piñeiro, Torres *et al*., 2024).

Table 2. *- Importance Value Index (IVI) in secondary forest on the "Yana rumi" farm*

Scientific name	Relative abundance	Relative frequency	Dominance Relative	IVI
Lacmellea oblongata Markgr	5	7	3.93	5.12
Mouriri Oligantha Pilg	5	7	4.52	5.32
Chimarrhis glabriflora Ducke	5	7	5.80	5.74
Grias neuberthii JF Macbr.	14	13	2.99	10.20
Pourouma cecropiifolia Mart.	24	20	3.78	15.86
Piptocoma discolor (Kunt) Pruski	33	27	9.65	23,22
Apeiba membranous Spruce ex Benth.	14	20	69.34	34.54

This pattern coincides with that described for tropical secondary forests where fast-growing species with high colonizing potential tend to dominate the initial canopy structure, temporarily limiting the incorporation of later-arriving species. In contrast, species such as *Lacmellea oblongata, Mouriri Oligantha and Chimarrhis Glabriflora* showed low IVI values, suggesting a marginal structural role within the evaluated ecosystem. Likewise, the abundant but not dominant presence of *Pourouma cecropiifolia* suggests a transitional successional stage where competition for light and space limits the development of larger individuals, a phenomenon documented in disturbed Amazonian secondary forests (Solano- notes and Belezaca- Pinargote 2022).

Diversity indices showed low values, with an average Shannon index of 0.280, reflecting a simplified floristic structure and high dominance of a few species and low functional redundancy of the ecosystem. This condition can reduce ecological resilience to climatic or anthropogenic disturbances.

Table 3. *- Alpha diversity indices and descriptive statistics per plot*

Index/Plot	P1	P2	P3	P4	Average	OF	CV (%)
Shannon (H')	0.145	0.277	0.366	0.333	0.280	0.097	34.7
Simpson (D)	0.022	0.020	0.056	0.111	0.052	0.043	81.3
Simpson (1 − D)	0.978	0.980	0.944	0.889	0.948	0.043	4.7
Simpson (1/D)	45.45	50.00	17.86	9.01	30.58	20,22	66.1
Equity (J')	0.076	0.145	0.191	0.174	0.147	0.051	34.6

Legend: *SD: Standard deviation. CV: Coefficient of variation.*

These results are consistent with studies conducted in tropical secondary forests, where pioneer species typically dominate the early stages of regeneration after anthropogenic disturbances.

The Kruskal-Wallis test did not detect significant differences between plots ($H = 3.21$; $p = 0.22$), although ecological trends showed relevant contrasts in structure and dominance.

Additionally, the floristic similarity matrix based on the Sørensen index (Figure 6) revealed that plots P3 and P4 shared the greatest compositional similarity (0.78), while P1 showed the least similarity with respect to the rest (0.40), which confirms the existence of differentiated microenvironments within the forest system.

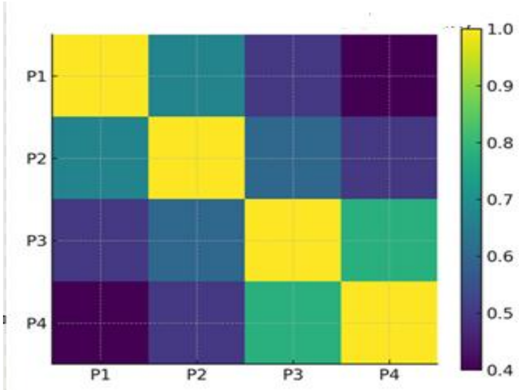

Figure 6. *- Similarity matrix between plots according to the Sørensen Index*

In functional terms, the dominance of *P. discolor,* which represented approximately 33% of the recorded individuals, along with the significant presence of *A. membranacea* and *P. cecropiifolia,* is indicative of a secondary forest in an intermediate successional phase, where colonization by pioneer species conditions the structural dynamics and temporarily limits the incorporation of late species.

Recent ecological studies have indicated that low levels of diversity and evenness in secondary forests are associated with reduced ecological resilience to disturbances, due to the system's limited functional redundancy (Guerra-Martínez, García-Romero, and Martínez-Morales 2021). Consequently, these results support the relevance of implementing active forest rehabilitation strategies aimed at increasing the ecosystem's structural and functional complexity.

Under this approach, the proposed rehabilitation was based on an integrated model of assisted natural regeneration and forest enrichment, prioritizing forest clearings and edges for the introduction of species of ecological and economic interest. Scientific evidence has shown that enriching secondary forests is an effective strategy to accelerate successional processes, improve seedling survival, and increase carbon sequestration potential in degraded tropical landscapes (Oluwajuwon, Chazdon, Ota *et al*. 2024).

successional processes and increase the structural complexity of the system. Species such as *Bactris Gasipaes, Ilex guayusa, Bixa orellana and Inga edulis*, fulfill key ecological functions, including biological nitrogen fixation, microclimate regulation and provision of non-timber forest products (Baker, Adami, Silva-Junior *et al*., 2025).

In a medium-term horizon (3–8 years), forest enrichment was oriented towards fast-growing and high-value timber species, such as *Cordia alliodor* (Ruiz & Pav.) Oken (laurel), *Ochroma pyramidale* (Cav. ex Lam.) Urb. (raft) *and Schizolobium parahyba* (Vell.) Blake (pachaco), simultaneously maintaining remnant individuals of secondary forest with ecological and structural value. This approach coincides with recent studies that highlight the role of Amazonian chakra -type systems in biodiversity conservation, carbon sequestration, and the productive sustainability of Amazonian rural landscapes (Huera-Lucero, Lopez-Piñeiro, Torres, and Bravo-Medina 2024). The integration of food, non-timber, and timber species generates a stratified production system that promotes ecological stability and reduces the risks associated with dependence on a single crop.

However, the implementation of these strategies faces significant biophysical limitations. The soil conditions identified in the study area, particularly water saturation and soil acidification, can restrict the growth of agricultural and forestry species by reducing the availability of essential nutrients and promoting leaching processes, a common phenomenon in tropical soils subjected to high rainfall. Furthermore, the lack of spatial planning in planting distances and the random distribution pattern of crops increase interspecific competition for light and nutrients, hinder management practices, and reduce the productive efficiency of the system, as has been noted in recent studies on the sustainability of Amazonian agroforestry systems (Heras, Moreno Lopez, Quevedo, and Cuichan Paucar 2024).

Overall, the results suggest that the evaluated secondary forest exhibits an ecological structure typical of early-stage recovery systems, with low diversity, high dominance of pioneer species, and moderate spatial heterogeneity among plots. In this context, integrating rehabilitation, production diversification, and forest enrichment strategies represents a viable approach to increasing the ecological resilience of the system, improving landscape functionality, and strengthening the socioeconomic sustainability of Amazonian production units.

From an adaptive management perspective, the combination of assisted natural regeneration with selective enrichment and agroforestry diversification can accelerate the transition from an impoverished secondary forest to a more complex, resilient, and productive system within the Amazonian socio-ecological mosaic.

CONCLUSIONS

Chakra agroforestry system of the Yana Rumi farm maintains a productive organization based on traditional knowledge that contributes to family food security, although it presents soil and management limitations that affect agricultural productivity. The evaluated secondary forest showed low floristic diversity and dominance of pioneer species such as *Apeiba membranacea* and *Piptocoma.* The discoloration indicates an ecosystem in an intermediate successional stage. The ecological rehabilitation strategy based on agricultural diversification, organic fertilization, and forest enrichment constitutes a viable alternative for improving the ecological resilience and productive sustainability of the Amazonian agroforestry system.

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