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Review

Sustainable Production Systems in the Brazilian Amazon: A Systematic Review

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Abstract: The integration of the Amazon into the global commodities market requires ensuring the rational use of resources to meet market and socio-political demands, such as the UN's 2030 Agenda. Responsible production practices are essential to address the current demand for sustainable land use and resource management. This study reviewed the literature (2004–2024) on the opportunities and challenges of implementing and consolidating sustainable production systems in the Amazon. It found a low distribution of studies across Brazilian Amazon states and a surge in publications since 2015, focusing on agroforestry systems and forest management. Challenges include socio-political limitations that hinder public decision-making, leading to inefficient policies, as well as economic issues, lack of know-how, inadequate infrastructure, poor logistics, and cultural resistance. Nevertheless, these systems offer opportunities such as intensified and diversified production, carbon sequestration, and soil and forest conservation. Finally, future research should consider political, social, and economic aspects to facilitate the transition from traditional to sustainable models, supporting strategies for consolidating these systems in the Amazon.

Keywords: agroforestry systems; forest management; pasture management; sustainable agriculture

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1. Introduction

Tropical ecosystems host much of the planet's biodiversity on a global scale, providing raw materials and ecosystem services that benefit not only local communities but society as a whole [1–3]. The Amazon rainforest represents about 40% of the remaining tropical forests, contributing to the dynamic balance of climate and water systems, offering socioeconomic alternatives to local communities, and meeting societal demands for its products [4–8].

However, many tropical ecosystems, including the Amazon, have faced intensive and large-scale resource use. This has led to a regional geoeconomic shift, transitioning from an extractivist economy to one based on agriculture and livestock, and in some sub-regions, agribusiness—integrating the Amazon into the global commodities market as a frontier for agribusiness expansion [1,9,10].

The historical occupation and integration of the Brazilian Amazon, one of the world's most important tropical biomes and a last agricultural frontier, have been influenced by global events such as the Green Revolution and national programs like Operação Amazonia and the National Integration Program. These initiatives imposed a development logic often at odds with the natural ecosystem [11–13].

Initially, activities were centered on extractive resource exploitation and subsistence farming [13]. With the introduction of conventional agricultural practices driven by these events, the region's agricultural production shifted, driving the expansion of agricultural frontiers [1,13,14]. While this brought socioeconomic gains, it also caused significant social and environmental damage due to unsustainable agricultural practices [1,15]. The relationship between agriculture and the Amazon's occupation remains paradoxical: though aggressive exploitation prevails, well-managed practices can benefit various stakeholders [16].

Thus, addressing problems like deforestation, fires, and conflicts—rooted in land use practices and linked to agriculture and livestock—through sustainable land-based solutions is important for modern agriculture's sustainability, especially in complex biomes like the Amazon [11].

Ensuring the efficient and responsible use of natural resources, increasing sustainable productivity, and meeting societal demands should be a constant concern for all agricultural stakeholders. Aligning production models with the Sustainable Development Goals (e.g., SDG 12—Responsible Consumption and Production, and SDG 13—Climate Action) under the United Nations' 2030 Agenda is essential to establish sustainable consumption and production patterns across supply chains [1,17].

Climate change, population growth, and the continuous pursuit of improved living standards intensify the pressure on natural resources, especially in agriculture. Balancing production and consumption to ensure livelihoods is a major challenge, particularly in the Amazon, where economic exploitation of natural resources transforms production and market structures [1,9,11,12,17,18].

In these production systems, many farmers face challenges such as poor infrastructure and logistics, limited access to agricultural inputs, specialized labor shortages, inadequate technical assistance, lack of credit financing, and product certification. These factors drive the search for alternatives to the ensure long-term sustainability of production [2,17].

In this context, the need for sustainable production systems and responsible practices in the Amazon is clear, given the growing demand for resource-optimized processes. Furthermore, there is increasing market pressure to avoid products derived from environmentally harmful production processes [18].

In that sense, identifying factors that hinder the consolidation of sustainable practices in the region is fundamental for optimizing techniques that address local needs and limitations. Additionally, assessing potential opportunities can help resolve challenges related to implementing these systems. A comprehensive literature review on this topic aims to provide a broader and more cohesive understanding of the current state of sustainable production in the Amazon, supporting decision-making and guiding future scientific research.

2. Materials and Methods

2.1. Protocol for Article Retrieval

Before conducting the systematic literature review, a review protocol was developed. To achieve this, the systematic review applied the recommendations and checklist of The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). The articles were selected using the following bibliographic databases: ScienceDirect, SpringerLink, Scopus and Wiley. The period covered was from 2004 to 2024.

The search protocol consisted of selected terms to retrieve articles on sustainable production in the Brazilian Amazon. For this purpose, the keywords Amazon, "Amazon Rainforest", and "Brazilian Amazon" were applied. Similarly, to obtain articles contributing to the discussion of sustainable production techniques in this Brazilian biome, the following terms were used: Sustainable, "Sustainable production systems", "Sustainable agriculture", and "Sustainable intensification". Finally, based on previous research and the authors' prior knowledge of the most relevant productive models implemented in the region, the following terms were selected to retrieve articles discussing sustainable management of the specified production systems in the Brazilian Amazon: Agroforestry, Agroecological, Organic, "Direct Planting", "Forest Management", Silvopastoral, "Fish Farming", Pisciculture, Intercropping, "Integrated Crop-Livestock", "Integrated Crop-Forestry", "Integrated Crop-Livestock-Forestry", "Integrated Livestock-Forestry", "Degraded Pastures", and "Integrated Fruit Systems".

Thus, this protocol generated a comprehensive and efficient Boolean search operator for selecting relevant articles for this review. The following combination of keywords and operators was applied in the bibliographic databases, with minor adjustments based on each platform's search requirements: (Amazon OR "Amazon Rainforest" OR "Brazilian Amazon") AND (Sustainable OR "Sustainable Production Systems" OR "Sustainable agriculture" OR "Sustainable intensification") AND (Agroforestry OR Agroecological OR Organic OR "Direct Planting" OR "Forest Management" OR Silvopastoral OR "Fish Farming" OR Pisciculture OR Intercropping OR "Integrated Crop-Livestock" OR "Integrated Crop-Forestry" OR "Integrated Crop-Livestock-Forestry" OR "Integrated Livestock-Forestry" OR "Degraded Pastures" OR "Integrated Fruit Systems").

After retrieving the articles, duplicate entries were excluded. No restrictions were imposed on the type of research included. For the selection process, the articles obtained with each combination of words in the search using Boolean operators were evaluated for the adequacy of the information contained in the title and abstract to the scope of the review. The selected articles were then analyzed in depth, and those addressing one or more research questions were included.

The evaluation process was carried out independently by two authors and, in case of disagreement, the article was evaluated again until consensus was reached. The Parsifal platform was used to support the article selection process.

2.2. Research Questions

In order to guide the selection of articles, the following research questions were formulated:

1. What are the main sustainable production models implemented in the Amazon?
   Precepts: Identification and description of the most commonly used sustainable production models in the Amazon region, analysis of the principles, practices, and key characteristics of each sustainable production model.
2. What are the main challenges encountered in applying these models?
   Precepts: Identification and analysis of the main barriers and challenges to implementing sustainable production models in the Amazon, including legal issues, lack of financial incentives, cultural resistance, limited access to resources, and inadequate infrastructure. Assessment of the impact of government policies, regulations, and external pressures on the development and adoption of sustainable production models.
3. What are the opportunities observed in the Amazon region for consolidating the use of these production systems?
   Precepts: Identification and analysis of emerging opportunities to promote and consolidate the use of sustainable production systems in the Amazon region, such as incentive programs, specific financing, public-private partnerships, and development of sustainable value chains. Assessment of the role of local communities, non-governmental organizations, research institutions, and companies in the promotion and implementation of sustainable agricultural practices.

2.3. Article Selection and Exclusion Criteria

Although there were no restrictions on the type of research, documents considered as gray literature, such as books, book chapters, and conference abstracts, were not included in the review. Given the geographical focus of this study (Brazilian Amazon), only articles written in English and Portuguese were considered, corresponding to publications in international and national journals, respectively. Duplicate articles were excluded. After reading the title and abstract, articles that did not address the scope of the review were excluded.

During the full reading, fifty articles were excluded for the following reasons: (1) They addressed the topic, but did not mention in the abstract that the research was conducted outside the Amazon or in another country with the same biome. As a result, they were excluded upon identifying the research location during the full-text review; (2) They addressed the roles of actors in sustainable production in the Amazon, but not specifically the production systems.

Articles that were appropriate to the scope of the work but did not answer at least one of the research questions were eliminated from the review.

2.4. Research Limitations

This review did not consider books, book chapters, and conference abstracts, which may omit important information not covered in more depth in journals.

The diversity of terms used to name the different types of sustainable production systems could not be applied in the research. For example, the production system that integrates Crop-Livestock-Forestry is referred to by various terms, such as "agrosilvopastoral system" and "ICLF System", which were summarized in "Integrated Crop-Livestock-Forestry", which may have omitted important articles.

The review covered a 20-year period (2004–2024), selected based on the observed increase in publications on the topic during this timeframe. As a result, relevant articles published before 2004 were not included, which may have led to the omission of important information.

3. Results

3.1. Quantitative Analysis

Of the 5385 articles identified in the four research databases, 93 met the inclusion criteria and were deemed eligible for full-text review (Figure 1). Of these, only 39 studies were selected for inclusion in this review, as they addressed at least one of the research questions (Appendix A).

The analyzed articles were published in a total of 26 different journals. During the period evaluated, there was an increase in the frequency of publications from 2015 onwards in the databases evaluated, reflecting a growing interest in promoting sustainable production in the Amazon biome (Figure 2).

This interest may be associated with the UN 2030 Agenda, which comprises the 17 Sustainable Development Goals, three of which are at the core of sustainable production in the Amazon: Zero Hunger and Sustainable Agriculture (Goal 2), Responsible Consumption and Production (Goal 12), and Action Against Global Climate Change (Goal 13). These objectives are closely linked to sustainable agricultural production. In this context, the Amazon, as a threatened biome and a food producer, represents a strategic environment for research aimed at deepening the discussion on sustainability in food production. Thus, achieving these objectives marks progress toward more sustainable and safer agricultural practices, aligning with global strategies to enhance sustainability and food security in agriculture. Thus, the Amazon is at the center of interest for research that aims to promote environmentally friendly production processes.

There was no significant concentration of articles in a single journal, which may be attributed to the interdisciplinary nature of sustainable production. This allows various fields to work on different aspects (political, legislative, environmental, economic, social) of the same production system (Figure 3). The journals with the most articles included in the review were Agriculture, Ecosystems & Environment (n = 4), followed by Agroforestry

Systems (n = 3), Forest Ecology and Management (n = 3), Grass and Forest Science (n = 3), and Land Use Policy (n = 3). This indicates that, despite the interdisciplinary nature of the issue, topics related to soil conservation and production in agroforestry systems and timber production predominate. This is attributed to the economic importance and tradition of diversified family farming in the Amazon, as well as the role of agroforestry systems in maintaining soil structure and fertility. Moreover, timber exploitation is a longstanding practice in the region, which justifies the interest.

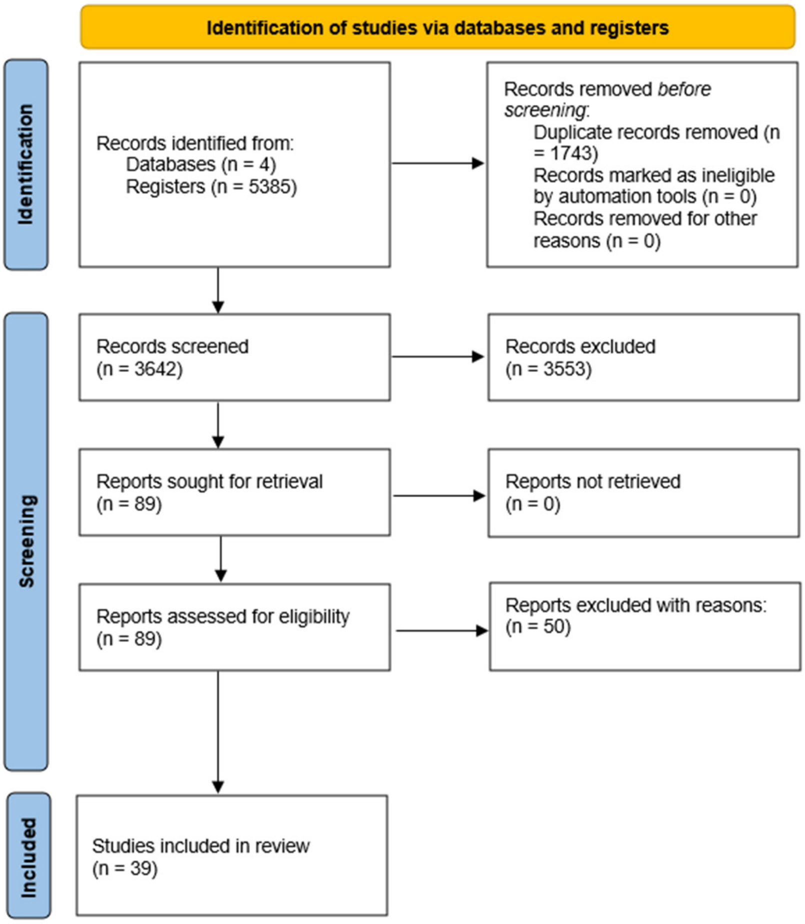

Figure 1. PRISMA flow diagram for systematic review.

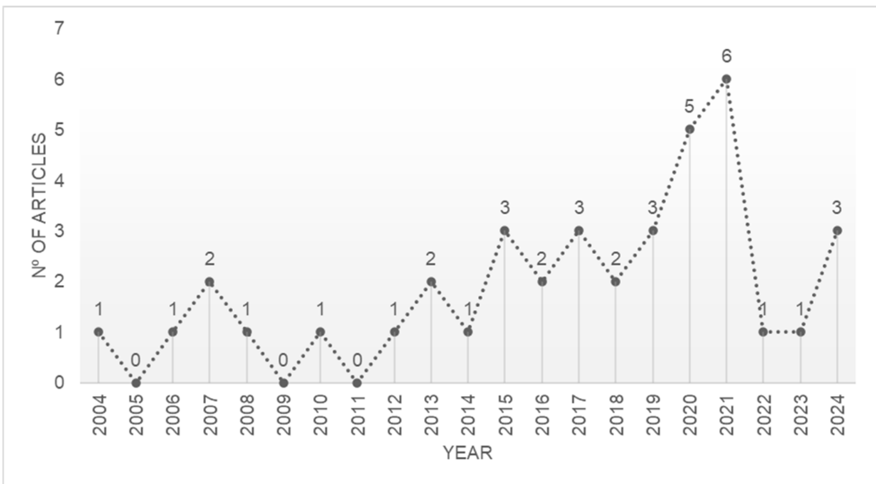

Figure 2. Number of publications addressing challenges and opportunities for implementing sustainable production systems in the Amazon between 2004 and 2024.

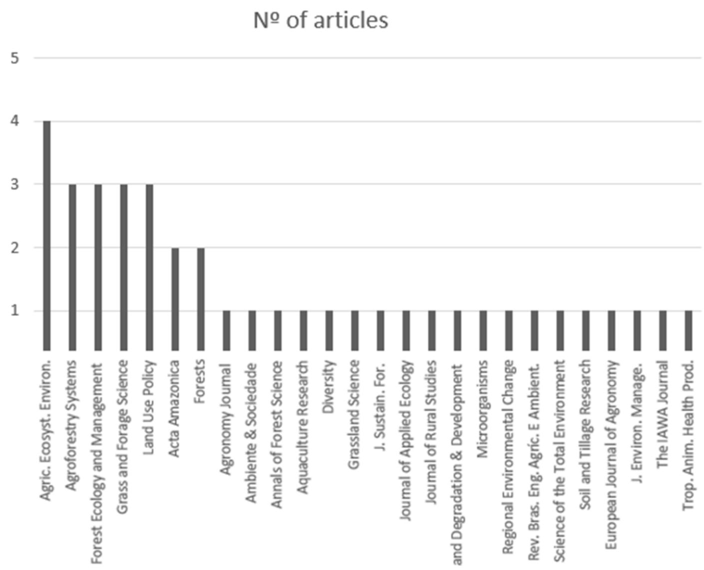

Figure 3. Number of articles per journal.

While research often focuses on specific systems, most of the topics covered primarily address the technical aspects of agricultural production. Future studies should explore the social, economic, political, and legislative dimensions of these systems, acknowledging their complexity not only as a means of production but also as sources of livelihood, social interaction, and political significance for local communities and within the global agricultural context.

3.2. Qualitative Analysis

Among the selected articles, agroforestry systems (n = 18), pasture management (n = 2), aquaculture (n = 1), forest management (n = 10), silvopastoral (n = 5), agropastoral (n = 1), and conservation systems (n = 2) comprised the scope of the review (Figure 4). As previously mentioned, this trend can be explained by the importance of integrated production in the Amazon for income diversification through family farming. Systems such as agroforestry, silvopastoral, and agropastoral represent progress toward more sustainable and secure agricultural practices, aligning with global strategies to enhance sustainability and food security in Amazonian agriculture. The role of the Brazilian Agricultural Research Corporation (EMBRAPA) in developing research on the management and feasibility of agroforestry systems in the region also contributes to the promotion of these systems.

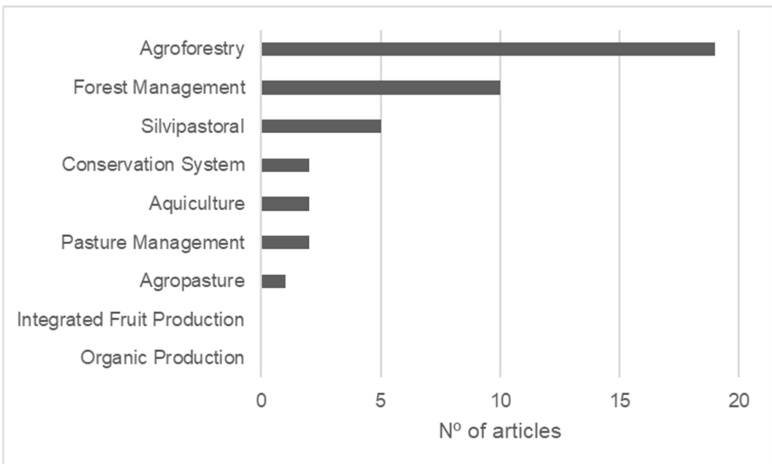

Figure 4. Number of publications by production system.

However, systems like integrated fruit production and organic farming are still uncommon research topics in the Amazon, with no articles in this review addressing these subjects. These systems, which are less prevalent in the region due to logistical and infrastructural challenges, hold potential for income generation through the commercialization of high-value-added products.

The experimental studies included in the review were concentrated in the states of Pará (n = 15), Mato Grosso (n = 12), Rondônia (n = 4), Amazonas (n = 4), Maranhão (n = 1), Amapá (n = 1), and Acre (n = 1); these states are part of the Legal Amazon, a region in Brazil that encompasses the nine states of the Amazon basin. The concentration of studies in these states is associated with the development and consolidation of agricultural production in these areas, particularly in the states of Pará and Mato Grosso.

No studies that met the research criteria of this review were found in the states of Tocantins and Roraima, which are also part of the Legal Amazon.

Agroforestry systems presented the highest number of publications. For this system, most of the studies are concentrated in the states of Pará (n = 6) and Mato Grosso (n = 6). Regarding forest management, the fieldwork found was predominantly conducted in the state of Pará (n = 5). These results indicate a low volume of research in states affected by the loss of vegetation cover such as Acre, Roraima, Rondônia, Maranhão, and Tocantins (Figure 5), which have areas where deforestation is spreading and could benefit from technical information that balances sustainability with timber and non-timber production.

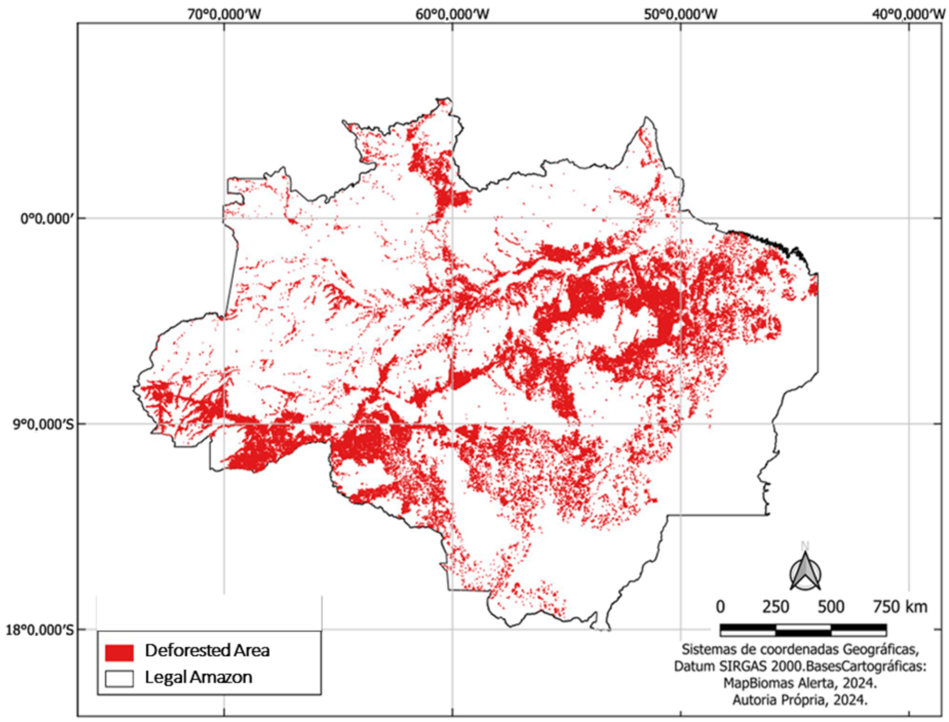

Figure 5. Deforested area in the Legal Amazon region [19].

In this literature review, we expected to find publications on sustainable systems and practices adapted to the Amazonian environment. However, despite their importance for sustainable agricultural production, systems such as aquaculture (n = 1), conservationist systems (n = 2), organic production (n = 0), and integrated fruit production (n = 0) had few or no studies on the subject.

Furthermore, although there are economic and fiscal incentives, the Amazon biome still needs more support and research to promote sustainable intensification of agricultural production and thus contribute to the achievement of the United Nations Sustainable Development Goals related to population growth, climate change, and food security.

4. Discussion

4.1. Challenges for Implementing and Consolidating Sustainable Production Systems in the Amazon

From a broader perspective, authors such as [20] highlight the ambiguity of the concept of "agroforestry", which makes it difficult to formulate policies that support the transition from the agribusiness-based model (monoculture) to forest production models. Agroforestry is seen as a solution to environmental and social problems [21,22], but it is often an ambiguous and poorly defined concept, with a wide variety of agroforestry practices in different parts of the world. The authors recommend studies that address the broader political and economic aspects of these systems rather than biotechnical studies at the property level. Furthermore, it is important to consider agroforestry transitions as a system-level issue; thus, research that includes political as well as social equity and justice issues should be carried out [20].

In a study evaluating the challenges to implementing agroforestry systems in the Amazon, ref. [23] identified labor, implementation costs, and know-how as the challenges most emphasized by producers in Mato Grosso. Regarding the forestry element, the most important challenges were implementation costs and marketing. Other factors such as farm size, farmer resources, and cultural preferences were also cited as influencing the adoption of integrated systems. In addition, the same study highlights the importance of policies to encourage low-carbon agricultural production, such as the ABC plan. In a study focused on the perception of rural producers in the states of Rondônia, Acre, Mato Grosso, and Pará, ref. [24] analyzed the challenges of adopting integrated crop-livestock systems and identified several obstacles, such as the lack of qualified labor, few marketing options, inadequate infrastructure, unfavorable regulatory environment, and, in some areas, poorly drained soils. Furthermore, non-income-related reasons, such as maintaining quality of life and preserving traditions, have led producers to prioritize factors other than profit maximization. A broader range of policies, beyond credit subsidies, is needed to encourage the adoption of sustainable intensification strategies. These include educational programs, compensation for ecosystem services, and improvements in transport and logistics infrastructure, which can support intensification and foster an environment conducive to innovation. Agroforestry systems have proven to be an effective option for increasing pasture productivity. Public policies should, in particular, prioritize the dissemination of sustainable agroforestry practices in the Amazon biome, where the growth of cattle herds and pastures has been most significant in recent decades [25]. Regarding SAF as a strategy for restoring vegetation cover and ecosystem services, these systems have not proven to be efficient in short periods of time and in sandy soils. Furthermore, previous degradation has resulted in high variability in plant development and carbon stocks [26].

The promotion of sustainable systems in the Amazon motivated by government benefits for associations and cooperatives does not significantly impact the adoption intensity of these practices by organizations. Conditions such as particularities of the producer, the associate, financial and management characteristics, attributes of sustainable practice, and psychological attributes are preponderant factors in the adoption of sustainable practices. Furthermore, agricultural policies should go beyond economic support and incorporate continuous training in new technologies for the sustainable natural resources market [27].

However, despite the conceptual benefits of integrated systems, for ref. [28], in the Amazon conditions in the state of Mato Grosso, the use of a silvopastoral system with eucalyptus did not reduce significantly the thermal stress of animals, despite the better conditions under the tree canopy. According to ref. [25], in the Amazon biome, no significant impacts were identified on livestock stocking rates or the total value of agricultural production in agroforestry, thus not qualifying the intensification of land use.

In intensive fish farming in the Amazon, low water renewal and high fish density compromise water quality. These conditions negatively impact zootechnical performance and animal welfare, ultimately reducing production yields [29].

Regarding sustainable forest management, there is interest in its adoption by small farmers, but in the study by ref. [30], none of them systematically manage the forest. According to farmers, the recovery of degraded areas on their properties is hindered by the lack of economic incentives and high initial costs (seeds and seedlings). Additionally, around 40% of farmers rely on the collection of non-timber forest products (such as Brazil nuts and hearts of palm) for subsistence; however, policies supporting non-timber product extraction remain limited for this population.

According to ref. [31], community forestry is largely influenced by external decisions, which promote industrial-scale forestry practices at the community level or prioritize the interests of external agents. The study highlights that timber is just one of several sources of livelihood for producers. Therefore, broader and more inclusive goals should be considered. Implementing "bottom-up" approaches enables beneficiaries to define priorities that are most relevant to them, increasing the likelihood of success in forest management projects.

Regarding sustainable forestry in the Amazon, the competition between timber from sustainable sources and areas of agricultural expansion is uneven. The domestic market for non-certified timber is more accessible to sawmills, which often operate with small profit margins and follow the advancing agricultural frontier. In this sense, fostering sustainable community-based timber production is essential for establishing a foundation for responsible forestry. In addition, decentralizing and democratizing forest land ownership—through the creation of extractive reserves and granting states and municipalities greater autonomy in land demarcation—is necessary for ensuring timber exploitation occurs without harming the environment [32].

However, sustainable timber production on public lands is highly dependent on low-impact logging, which often overlooks factors such as sustainable harvest cycles for forest stands and individual species, and planting and regeneration of seedlings for high-value species that occur at low densities. Furthermore, low-impact logging, when not combined with forestry, leads to volume reduction and the imminent risk of extirpation of high-value timber. Moreover, the current regulatory and technical capacity to implement low-impact logging in new areas is insufficient, and there is a disparity between demand and human resources in government agencies [33]. This situation hampers the ability to monitor and control illegal logging activities.

Forest management of natural populations, such as açaí, can lead to gradual impoverishment of the flora over decades due to thinning practices that favor the target species. Therefore, multi-taxonomic studies are needed to support management plans for economic-ecological zoning in Amazonian floodplain forests managed for açaí in order to prevent large-scale loss of cryptic biodiversity [34]. In addition, the use of integrated pollination, incorporating both wild and managed pollinators, can reduce pollination by wild bees, and this can mean increased environmental and socioeconomic risks associated with the activity. Therefore, it is recommended that producers prioritize the conservation of forest areas on their properties to safeguard pollination services and the sustainability of açaí production in the Amazon [35].

The currently available biomass prediction models for the exploitation of endangered species, such as rosewood (*Aniba rosaeodora* Ducke), are inadequate for accurately measuring productivity, representing a serious obstacle to subsidizing the activity [36].

4.2. Opportunities for Implementing and Consolidating Sustainable Production Systems in the Amazon

Agroforestry systems show great potential for above-ground carbon sequestration and reestablishing nutrient cycling when compared to natural succession [26]. According to ref. [37], agroforestry systems with oil palm are as effective as secondary forests in nitrogen immobilization within soil microbial biomass. Ref. [38] suggests that microbial community composition may differ among agroforestry systems (açaí and cocoa), cocoa monoculture, and adjacent forests, which may allow greater ecological diversity and nutrient richness in the soil. However, further studies are needed to understand the diversity, interactions, and functions of the microbial community in the system addressed.

Agroforestry systems can contribute to biodiversity conservation by preserving native species; however, even with restoration planting, some biodiversity loss may still occur. Re-agroforestry of degraded areas with tree and understory crops can also enhance food security for producers. However, it is important to prevent encroachment on native forests and to promote system intensification [27].

Soil protection provided by AFS vegetation cover contributed to reducing soil vulnerability to erosion and mercury leaching processes, comparable to mature forests; however, this vegetation protection does not completely prevent leaching. The transition to this cultivation system is challenging, highlighting the need to prioritize initiatives to support them in the implementation of this agricultural model [39].

The adoption of integrated crop-livestock-forestry systems can be stimulated by public/private partnerships to strengthen the flow of information and allow investment in infrastructure; despite growing interest, it is still a challenge to encourage them to adopt this system in the country [40].

The implementation of this production model enhances macroaggregate formation and increases carbon and nitrogen stocks in soils [40,41]. However, further research is needed to better understand the driving forces and impediments to the accumulation of organic carbon in the soil in integrated systems, including studies on organic matter stability [40].

Considering the ecological recovery capacity of integrated systems and their relevance in the Amazon, ref. [42] suggests that agropastoral systems can be agroecological models. These systems promote self-sufficiency, resilience to market fluctuations, and reduced environmental impact when the links between system elements (soil, crops, and animals) follow agroecological principles (diversity of land use and biotic and abiotic resources, maximization of ecological and production interactions, among others), improving its performance.

Livestock farming in the Amazon is a highly debated and controversial practice, which is why the adoption of technologies and management supported by incentive policies for more intensive and sustainable livestock farming in the Amazon is a viable alternative for increasing productive and economic yields and consequently reducing pressure on forests. However, this adoption by livestock farmers, especially small farmers, will require strong political will through government subsidies, such as the ABC program [41].

Studies on AFS benefits, particularly in animal production, highlight the synergy between system components. The production of beef cattle in integrated systems allows for performance as advantageous as the monoculture of grasses when managed correctly; in addition, the synergy between the components of the crop-livestock-forest integration indicates that this system has an even greater potential to increase cattle production in the Amazon [43,44]; however, further long-term studies are recommended to confirm these benefits [43].

According to ref. [45], the shading caused by eucalyptus on Marandu grass (*Urochloa brizantha*) at a distance of three meters, where the shading was longer, significantly altered the composition and characteristics of the canopy; however, the grass is resilient at greater distances from the tree rows. In silvopastoral systems, Marandu grass pastures exposed to up to a 30% reduction in PAR maintain leaf productivity comparable to monocultures. In the long term, pruning, thinning, and east-west woodland reduce the shading effect on forage [46]. According to ref. [47], when properly managed, cropping systems can sequester carbon, resulting in benefits such as increased meat production and improved soil quality. Additionally, the inclusion of plantations and forests in these livestock systems enhances these benefits, reinforcing the potential of integrated systems to offset greenhouse gas emissions.

Integrated crop-livestock systems can act as pathways for carbon accumulation and release, depending on the management and level of pasture degradation. When succession involves soybean as the primary crop without soil disturbance, carbon accumulation occurs, contingent upon factors such as the chosen crop, soil conditions, climate, and the duration of system use [48].

The application of nutritional management strategies for conventional pasture fertilization (urea and ammonium sulfate) can contribute to mitigating greenhouse gas emissions, enhancing forage accumulation and animal production. Furthermore, it supports the sustainable intensification of forage, thereby preventing the expansion of agricultural areas. Microorganisms such as *Azospirillum brasilense* may be beneficial for supplying nutrients to pastures in the Amazon, but further studies to evaluate this technique are needed [49]. Although only one study on animal supplementation in silvopastoral systems in the Amazon was observed in the databases evaluated, the study by ref. [50] observed that supplementation reduces the emission of methane and volatile fatty acids in vitro, which are the primary energy sources for ruminants.

The use of spontaneous capoeira grass pastures by small farmers in the Bragantina region of the state of Pará is a strategy for producers aiming to maintain the recovery capacity of their lands, especially those with a tradition of utilizing fallow areas following human impact and fires. However, this system yields lower performance than grass monocultures. These results should be considered with caution, since the study period for drawing such conclusions is relatively short (3 years). Furthermore, these systems are not suitable for intensive livestock farming, but they offer an alternative for small producers who cannot afford the management costs and high initial investment required for legume pastures [51,52].

Agricultural production in the Amazon offers alternative models for areas replacing traditional slash-and-burn practices, focusing on improving soil quality. In the northeastern region of Pará, ref. [53] observed improvements in the physicochemical properties of soils after the application of the SHIFT-Tipitamba cultivation system (cutting and shredding of cover vegetation) when compared to the slash-and-burn method. For ref. [54], slash-and-shred results in intermediate and variable values for most physical and hydraulic soil properties, contributing to a certain extent to enhanced soil quality. Thus, these techniques can enable the viable intensification of agriculture in the Amazon. Likewise, sustainable animal production in the region can adopt configurations tailored to the biome, considering the historical evolution of regional agricultural and livestock production [51].

The forest component in silvopastoral systems in the Amazon is a key factor for the adaptation of these systems in the region. Agroforestry systems offer the advantage of integrating timber sales alongside agricultural and livestock production within the same area. According to ref. [55], Paricá (*Schizolobium amazonicum*) production in AFS is enhanced when soil management practices are avoided. However, when intercropped with soybeans (for one year) and corn (for two years), subsoiling, fertilization, and inoculation with growth-promoting microorganisms are recommended. The quality of freijó (*Cordia goeldiana*) wood produced in AFS is comparable to that obtained in monoculture or native forest [56]. The cultivation of *Ficus insipida*, either in monoculture or within AFS in floodplain areas, can help alleviate pressure on the few remaining intact floodplain forests. Additionally, this practice offers the added benefit of improving the economic conditions of the local riverside population within a relatively short period [57].

Sustainable aquaculture in the Amazon, through multitrophic integration, serves as a key provider of ecosystem services by mitigating eutrophication in receiving water bodies and sequestering atmospheric carbon dioxide. This approach demonstrates significant potential for system intensification compared to conventional aquaculture. It can be implemented using the biofloc system, offering an alternative for optimal conditions in intensive tambaqui cultivation. With minimal water exchange relative to clear-water farming, this method maintains favorable zootechnical performance and animal welfare indicators [29].

The commercial and sequential management of biomass through the pruning of endangered forest species, such as rosewood (*A. rosaeodora*), significantly reduces the export of macro- and micronutrients compared to the complete felling of trees, presenting a viable alternative for sustainable forest management [36].

Predictive equation models for estimating mass and volume offer a viable alternative for forest management in productive plantations under various conditions and management approaches, with potential application under the legal frameworks regulating the activity [58]. The Weibull growth estimation model demonstrates strong performance in predicting the annual increment and diameter of *Manilkara elata*, supporting its use in forest production planning, as well as in growth and yield forecasting for short-term remediation plantations or species lacking annual growth rings for dendrochronological studies [59]. Additionally, measures to enhance the monitoring of commercialized timber, such as wood anatomy analysis and its integration into databases, provide valuable tools for government agencies to combat illegal trade [60].

Forest management for non-timber forest products enables integrated crop pollination (ICP), i.e., the use of wild and managed pollinators, which contributes to conserving pollinator diversity while simultaneously ensuring effective pollination services and increasing crop yields [35].

5. Conclusions

This review shows that studies addressing agroforestry and forest management systems prioritize the problems and opportunities faced by producers. Studies are concentrated in a few states in the Amazon, which can be an obstacle to identifying regional problems.

Research highlights the effects of agroforestry systems on the environment (technical studies) to the detriment of research that explores their impact on the socio-economic realities of the population and the interactions between stakeholders (communities, businesses, and governments), as well as the principles and conditions for the adoption or transfer of these systems. Therefore, there is a need for studies that address the complexity of agroforestry transitions and their regional particularities, considering social, infrastructure, and legislative aspects. In this way, it is possible to support agents promoting assertive and efficient public policies.

Studies on common systems in family farming in the region, such as aquaculture, conservation systems, productive backyards, organic production, and integrated fruit species production, were not found. These systems are important for optimizing and improving income in a sustainable manner in the Amazon.

Forest management in the Amazon faces challenges such as associated costs, lack of economic incentives, and decision-making processes external to the community. Measures such as the decentralization and democratization of forest land ownership, the creation of extractive reserves, municipal autonomy in land demarcation, efficient low-impact management techniques, and technical monitoring and regulation are necessary steps for the sustainable use of forests.

In terms of scientific research, it is important that future studies analyze political, environmental, and socioeconomic issues associated with the implementation of sustainable systems in order to understand stakeholders' motivations for adoption. In addition, the introduction of new emerging technologies to integrate production systems should be addressed to support the transition process. These studies can serve as a basis for the intensification of agricultural production in the region. Policies for credit provision, infrastructure development, and regulatory enforcement should be more widespread and effective, as these factors represent obstacles to the transition to a sustainable model.

The growing global demand for products and services with a lower environmental impact encourages the adoption of sustainable techniques in agricultural production. Thus, the productive systems of the Amazon can benefit from and contribute to the region's environmental conservation and food security. In this context, future studies should address the obstacles to implementation, propose strategies, and identify opportunities for establishing these systems to guide decision-making and ensure income generation and quality of life in the Amazon.

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Appendix A

Table A1. Description of studies included in the review.

Title	Author	Year	Production System	Database	Reference
Agroforestry transitions: The good, the bad and the ugly	Ollinaho, O.I.; Kröger, M.	2021	Agroforestry	Science Direct	[20]
The economic impacts of the diffusion of agroforestry in Brazil	Maia et al.	2021	Agroforestry	Science Direct	[25]
Crop-livestock-forestry systems as a strategy for mitigating greenhouse gas emissions and enhancing the sustainability of forage-based livestock systems in the Amazon biome	Monteiro et al.	2024	Agroforestry	Science Direct	[47]
Reduction of Soil Erosion and Mercury Losses in Agroforestry Systems Compared to Forests and Cultivated Fields in the Brazilian Amazon.	Béliveau et al.	2017	Agroforestry	Science Direct	[39]
The Microbial Community Structure in the Rhizosphere of *Theobroma cacao* L. and *Euterpe oleracea* Mart. Is Influenced by Agriculture System in the Brazilian Amazon	Sousa et al.	2024	Agroforestry	Science Direct	[38]

Table A1. *Cont.*

Title	Author	Year	Production System	Database	Reference
Modelling biodiversity responses to land use in areas of cocoa cultivation	Maney, C.; Sassen, M.; Hill, S.L.L.	2022	Agroforestry	Science Direct	[27]
Impact of Pasture, Agriculture and Crop-Livestock Systems on Soil C Stocks in Brazil.	Carvalho, J.L.N.	2010	Agroforestry	Science Direct	[48]
Adoption and development of integrated crop–livestock–forestry systems in Mato Grosso, Brazil	Gil, J.; Siebold, M.; Berger, T.	2015	Agroforestry	Science Direct	[23]
Soil mineral and microbial nitrogen in oil palm-based agroforestry systems in eastern Amazon	Santiago et al.	2013	Agroforestry	Scopus	[37]
Growth and Yield of *Schizolobium parahyba* var. amazonicum According to Soil Management in Agroforestry Systems: A Case Study in the Brazilian Amazon	Sales et al.	2021	Agroforestry	Scopus	[55]
Physico-mechanical properties of the wood of freijó, *Cordia goeldiana* (Boraginacea), produced in a multi-stratified agroforestry system in the southwestern Amazon	Mascarenhas et al.	2021	Agroforestry	Scopus	[56]
Aggregation, carbon, and total soil nitrogen in crop-livestock-forest integration in the Eastern Amazon	Silva et al.	2018	Agroforestry	Scopus	[41]
Management Criteria for *Ficus insipida* Willd. (Moraceae) in Amazonian White-Water Floodplain Forests Defined by Tree-Ring Analysis	Schöngart et al.	2007	Agroforestry	Scopus	[57]
Agroforestry systems: an alternative to intensify forage-based livestock in the Brazilian Amazon	Domiciano et al.	2020	Agroforestry	Springer	[43]
Carbon sequestration and nutrient cycling in agroforestry systems on degraded soils of Eastern Amazon, Brazil	Celentano et al.	2020	Agroforestry	Springer	[26]
Integrated Farming Systems for Improving Soil Carbon Balance in the Southern Amazon of Brazil.	Oliveira, J.D.M.	2018	Agroforestry	Springer	[40]
Intensive cattle browsing did not prevent fallow recuperation on smallholder grass-capoeira pastures in the NE-Amazon	Hohnwald et al.	2015	Agroforestry	Springer	[51]
Forage and animal production on palisadegrass pastures growing in monoculture or as a component of integrated crop–livestock–forestry systems	Carvalho et al.	2019	Agroforestry	Wiley	[44]
Perceptions of integrated crop-livestock systems for sustainable intensification in the Brazilian Amazon	Cortner et al.	2019	Silvopastoral	Science Direct	[24]
The influence of trees on the thermal environment and behavior of grazing heifers in Brazilian Midwest	Lopes et al.	2016	Silvopastoral	Springer	[28]
Shading Effects on Marandu Palisadegrass in a Silvopastoral System: Plant Morphological and Physiological Responses	Gomes et al.	2019	Silvopastoral	Wiley	[45]
In vitro ruminal fermentation parameters and methane production of Marandu palisadegrass (*Urochloa brizantha*) in a silvopastoral system associated with levels of protein supplementation	Santos et al.	2020	Silvopastoral	Wiley	[50]
Shading effects on canopy and tillering characteristics of continuously stocked palisadegrass in a silvopastoral system in the Amazon biome	Gomes et al.	2020	Silvopastoral	Wiley	[46]
Agroecological principles for the redesign of integrated crop–livestock systems	Bonaudo et al.	2014	Agropastoral	Science Direct	[42]

Table A1. *Cont.*

Title	Author	Year	Production System	Database	Reference
Integrating cattle into the slash-and-burn cycle on smallholdings in the Eastern Amazon, using grass-capoeira or grass-legume pastures	Hohnwald et al.	2006	Pasture Management	Science Direct	[52]
Nitrous oxide emissions and forage accumulation in the Brazilian Amazon forage-livestock systems submitted to Ninput strategies	Nascimento et al.	2021	Pasture Management	Wiley	[49]
Growth performance and health of juvenile tambaqui, *Colossoma macropomum*, in a biofloc system at different stocking densities	Santos et al.	2021	Aquaculture	Wiley	[29]
Floristic impoverishment of Amazonian floodplain forests managed for açaí fruit production	Freitas et al.	2015	Forest Management	Science Direct	[34]
How long does the Amazon rainforest take to grow commercially sized trees? An estimation methodology for *Manilkara elata* (Allemão ex Miq.) Monach	Ferreira et al.	2020	Forest Management	Science Direct	[59]
Forestry control in the brazilian amazon III: anatomy of wood and charcoal of tree species from sustainable forest management	Silva et al.	2024	Forest Management	Science Direct	[60]
Tropical Forest Management and Silvicultural Practices by Small Farmers in the Brazilian Amazon: Recent Farm-Level Evidence from Rondônia	Summers, P.M.; Browder, J.O.; Pedlowski, M.A.	2004	Forest Management	Science Direct	[30]
Community Forests for Forest Communities: Integrating Community-Defined Goals and Practices in the Design of Forestry Initiatives	Hajjar, R.; Kozak, R.A.; El-Lakany, H.; Innes, J.L.	2013	Forest Management	Science Direct	[31]
New Allometric Equations to Support Sustainable Plantation Management of Rosewood (*Aniba rosaeodora* Ducke) in the Central Amazon	Krainovic; Almeida; Sampaio	2017	Forest Management	Scopus	[58]
Sequential management of commercial rosewood (*Aniba rosaeodora* Ducke) plantations in central amazonia: seeking sustainable models for essential oil production	Krainovic et al.	2017	Forest Management	Scopus	[36]
Novas Perspectivas Para a Gestão Sustentável Da Floresta Amazônica: Explorando Novos Caminhos.	Ros-Tonen, M.	2007	Forest Management	Scopus	[32]
Technical Challenges to Sustainable Forest Management in Concessions on Public Lands in the Brazilian Amazon.	Schulze, M.; Grogan, J.; Vidal, E.	2008	Forest Management	Scopus	[33]
Forest Conservation Maximises Açaí Palm Pollination Services and Yield in the Brazilian Amazon.	Campbell, A.J.	2023	Forest Management	Wiley	[35]
Fire-Free Fallow Management by Mechanized Chopping of Biomass for Sustainable Agriculture in Eastern Amazon: Effects on Soil Compactness, Porosity, and Water Retention and Availability	Reichert, J.M.	2006	Conservation System	Wiley	[54]
Physicochemical Properties of Soils in the Brazilian Amazon Following Fire-Free Land Preparation and Slash-and-Burn Practices	Comte, I.	2012	Conservation System	Science Direct	[53]

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