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Review

Adoption and Diversity of Agroforestry Systems in the Amazon Biome: A Bibliometric Overview

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Abstract: Agroforestry systems (AFSs) exhibit varied composition and dynamics as intrinsic characteristics of their specificities. In this context, a review of the adoption, composition, and dynamics of AFSs in the Amazon biome was conducted to identify the origin, institutions, and researchers of published studies with results on this scientific topic, focused on trends and characteristics of AFSs diversity in the Amazon. The methodology adopted was a scoping review, based on searches in the Scopus and Web of Science databases, using specific keywords to ensure that the articles addressed topics related to the adoption, composition, and dynamics of AFSs in the Amazon. Following the selection of subtopics, 66 articles were selected and analyzed. The analysis revealed that research on AFSs in the Amazon highlights interactions among traditional knowledge, innovations, and sustainability. The analysis of research published between 1996 and 2023 indicated growth in studies with an interdisciplinary focus, primarily from Brazil. However, internationalization, collaborative networks, and funding factors contribute to the prominence of foreign institutions. Research studies often address topics such as species diversity, agrobiodiversity, and tree growth in agroforestry intercrops. In this context, homegarden agroforestry (HAF) emerges as one of the main subjects of study, encompassing multifunctional environments, richness diversity, and ongoing experimentation with plant species. The choice of species for AFSs is influenced by factors such as labor, personal preferences, and market demands, although loggers and commercial forestry systems tend to have lower diversity, contrasting with HAF. AFSs implementation methods vary according to financing, management, and the farmer's education and gender. Environmental conservation, food security, ecosystem services, and production flexibility are highlighted as benefits of AFSs, while challenges include technical and economic limitations. This research highlights the strengthening and consolidation of AFSs by addressing scientific gaps and demonstrating the need for studies on the adoption, consolidation, and management of these systems, as well as the relationship between diversity and yield. Future research should be concentrated on deepening studies on the relationship between diversity and yield in AFSs, as well as on management

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strategies that support the consolidation of these systems in the Amazon biome, integrating innovation, public policy support, and traditional knowledge of farmers.

Keywords: bibliometrics; homegarden; agrobiodiversity; forest plantation; polyculture; thematic analysis

1. Introduction

Agroforestry systems (AFSs) are a land use alternative that enhances biodiversity, helps mitigate species loss in natural forests, and supports the maintenance of refuges for native species [1]. Additionally, this practice promotes microbial, floristic, faunal, and soil diversity [2] and plays a crucial role in biodiversity conservation and enhancement [3]. When its inherent complexity is considered in public policies, agroforestry can become an effective strategy for rural planning [4]. It is one of the most efficient production strategies, as it not only contributes to food security but also mitigates environmental degradation [5,6].

The use of fertilizing trees in AFSs increases the value of food crops [7], making agroforestry a promising approach for climate-smart agriculture due to its positive impact on food security [8]. The evolving scientific research in this topic is significant, including the exploration of crop and land use alternatives aligned with environmental conservation principles [9,10] emphasizing that AFSs offer sustainable production models.

In this context, a scoping review was conducted to identify and analyze scientific approaches in the literature on key topics, including the adoption, composition, and dynamics of various AFSs in the Amazon biome. Several terms were used to locate published studies on AFSs in the Amazon, including crop forestry, alley cropping, multicropping, and succession systems. Other terms included homegarden agroforestry (HAF) or equivalent terms, such as household garden or peri-domestic garden, which are common practices in the region, serving diverse purposes, and located surrounding households.

The Amazon biome plays a crucial role in regulating the global climate, hosting significant biodiversity and carbon reserves, and contributing to mitigating the effects of climate change [11,12]. However, it is under constant anthropogenic pressure from the expansion of livestock farming, shifting agriculture, mining, and illegal gold prospecting, which accelerate deforestation and increase degraded areas [13,14]. In this context, the adoption of AFSs is considered a viable and sustainable alternative solution for food and raw material production, promoting income generation for farmers and agricultural practices with the potential to improve biophysical parameters in the rehabilitation of degraded areas [15,16].

The conduction of bibliographic reviews has been widely used to examine various aspects of AFSs in different regions of the world. For example, a study conducted in Europe and North America analyzed the economic performance of these systems and identified knowledge gaps in this field [17]. Similarly, an evaluation carried out in Germany examined changes in crop management and modern agroforestry practices [18]. A comprehensive analysis in tropical, temperate, and arid regions highlighted the multifunctionality of agroforestry in improving soil health and fertility [19], while another study explored the effects of agroforestry on biodiversity [4]. In the United States, agroforestry patterns and their relationship with regenerative agriculture were assessed [20]. A systematic review focused on Latin America investigated the role of agroforestry in strengthening food security [6]. Furthermore, other studies of this nature aim to systematize evidence on ecosystem services in arid lands [21] and evaluate the potential of agroforestry for carbon sequestration in aboveground biomass [22].

Scientific research on AFSs in the Amazon has expanded, mainly focusing on adoption, composition, and dynamics. The diversity of AFSs reflects the richness and complexity of agroforestry practices in the Amazon. The adoption of these practices is crucial for conserving biodiversity and strengthening food security for local communities [23] and is supported by technical training, integration of public policies, strengthening of marketing chains, and continuous technical assistance [24]. The integration of different production systems, such as AFSs and HAF, offers economic and environmental benefits, promoting the sustainability and resilience of production areas when associated with family-based agriculture in the Amazon [25]. However, the reasons that motivate producers to adopt or maintain crops with agroforestry practices in the Amazon are still poorly systematized.

Considering these aspects, the following guiding questions were established for this research: (a) What are the main researched locations, scientific journals, and institutions and researchers involved in the topic? (b) What are the trends and main characteristics of scientific research addressing the composition and diversity of AFSs in the Amazon biome? (c) How are plant species dynamics in different AFSs depicted in research? (d) How do scientific studies discuss the adoption, promotion, and motivation of farmers or maintainers of these production systems? Thus, the objective of this study was to conduct a scoping review of the specialized scientific literature, addressing the determinants related to the adoption, composition, and dynamics of AFSs in the Amazon biome.

In this context, the bibliometric analysis of the literature has a significant contribution to elucidating qualitative data regarding, for example, the main investigated locations, scientific journals publishing studies on the topic, and the institutions and researchers involved in agroforestry in the region. Furthermore, the qualitative analysis of the literature aimed to identify relevant topics and understand what is being described in studies on AFSs. For this purpose, a scoping review was adopted as a strategy, an effective tool for systematizing and identifying research gaps [26]. This approach has proven to be powerful in transparently exposing the frameworks of primary studies [27], providing a comprehensive overview of existing methods and techniques that have been proposed or applied in research articles [28]. This perspective constitutes the main motivation of this study concerning AFSs.

2. Material and Methods

A scoping review was conducted to comprehensively identify relevant literature, including qualitative and quantitative studies, experimental and observational analyses, and case studies on AFSs in the Amazon. This type of review is commonly used to map broad research topics, providing an overview of key findings and knowledge gaps. A systematic approach was employed to map evidence on AFSs, identifying the main concepts, theories, sources, and information gaps [26,29,30]. This type of review was chosen because it is commonly used to map key concepts that underpin a research area and to clarify definitions, information gaps, and concepts, or investigate research methodologies [31,32].

Thus, for the development of this analysis, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol [33] was employed. This method proposes the adoption of clear and objective steps for the selection of articles in a literature review. The first step, called identification, involves searching for all studies related to the keywords defined by the authors. At this initial stage, a set of articles are generated, serving as the basis for the second step, in which the studies are selected. For this purpose, the authors establish qualitative criteria for analyzing the identified works, in accordance with the review's objective. Finally, the studies included in the review are thoroughly examined, and the relevant information is synthesized. The final step involves indicating the main findings of the studies, the timeframe of the results, and the methods adopted.

Therefore, this review was conducted using keywords associated with AFSs and HAF to facilitate the discussion on the approach of the studies. The searched terms were required to appear in the title, abstract, or keywords of the selected articles. Therefore, the advanced search function with Boolean operators (OR and AND) was utilized (Table 1).

Table 1. Search parameters used for screening articles in the Scopus and Web of Science databases, selected for a scoping review focused on the adoption, composition, and dynamics of agroforestry systems in the Amazon biome.

Search key
((“Agroforestry syste*” OR agroforest* OR agro-forest OR “alley crop*” OR “successional agroforest* syste*” OR “biodiverse agroforest* syste*” OR “Agroforest* practic*” OR “multistrat agroforestry syste*” OR agrossilvicult* OR “commercial plantation agroforestry” OR “backyard garden” OR “domestic garden*” OR homegarden* OR “home garden*”) AND (adoption OR composition OR “floristic analysis” OR dynamics OR decision OR perception OR diversity OR choice OR “socio-cultural aspect*” OR “social acceptability” OR evolution Or promotion OR “social influence”) AND (Amazon* OR “Amazon biome” OR “tropical amazon” OR “Pan Amazon”)).

The search for scientific articles to compose the corpus of this review was conducted in the Scopus and Web of Science databases, accessed through the portal of the Brazilian Coordination for the Improvement of Higher Education Personnel (Periódicos CAPES), using the following filters: language (English) and search type (articles), considering 2023 as the cut-off year. The research was conducted from 4 to 6 April 2024. The Web of Science (WoS) and Scopus platforms were chosen for being the most internationally recognized databases, providing relevant information across various research fields [34–36].

The article inclusion criteria were as follows: (a) research conducted on the Amazon biome; (b) articles published in English and indexed in the two pre-selected databases; (c) articles reporting research directly associated with AFSs or HAF; and (d) articles presenting original research (case or experimental studies with primary data). The exclusion criteria, after reviewing the title and abstract of each article, were as follows: (a) articles reporting research on other biomes; (b) duplicate articles; (c) articles that do not address AFSs or HAF, or address them without focusing on the topics of interest (adoption and perception, composition, dynamics, evolution, diversity, and promotion associated with these production systems); (d) review articles; and (e) articles published in languages other than English. Additional details on the key information considered in the topics analyzed regarding AFSs, which served as objective criteria for selecting the articles included in the review, are available in Table 2.

The search yielded 337 articles in the Web of Science and 227 in the Scopus database. The records were exported in full using the Bib Tex (.bib) format. Duplicates were then automatically removed using the Bibliometrix package in the R program (www.bibliometrix.org, accessed on 13 January 2025), resulting in the elimination of 130 duplicates. As a result, 434 articles were manually screened in an Excel spreadsheet using the “classify” tool. This procedure excluded 55 additional duplicates, leaving 379 articles for further screening.

After reviewing titles and abstracts, articles that did not address the pre-established topics of interest as their main objective were excluded. Articles addressing AFSs but with primary objectives focused on other topics were also excluded. These objectives included specific management or monitoring of plant species; soil attributes and fertility; soil biota; nutrient dynamics and cycling; wood quality and properties; entomology;

phytopathology; plant growth; biomass; carbon stocks; avifauna; and AFSs in biomes outside the Amazon. This selection step yielded 66 articles which, after thorough reading, were deemed pertinent to the scoping review. For a more comprehensive analysis of these articles, we recommend referring to the supplementary material (Table S1), which provides detailed information such as authorship, keywords, abstract, document identifier, journal of publication, language, total page count, year of publication, citation count, and other relevant data.

Table 2. Main information considered in the analyzed topics on agroforestry systems (adoption and perception; support and promotion; dynamics; diversity and composition), which served as criteria for selecting the articles included in the review.

Researched Topic	Criteria and Information That Should Be Included in the Article About Agroforestry Systems to Be Selected for the Research
Adoption and perception	Individual circumstances and personal preferences; motivation related to the local economic and cultural context; adoption linked to land ownership or perception of economic benefits; partnerships for implementing AFSs; actors inclined to adopt AFSs; local initiatives for implementation; social role of crops; obstacles and expansion of AFSs; farmers' preferences.
Support and promotion	Market impact on AFSs; promotion and economic incentives for AFSs cultivation; benefits and influence of market forces on system simplification; impact assessment of incentive actions for AFSs; performance and commercialization; influences on productivity.
Dynamics	Rotation periods in land use; intensification and emphasis on specific species in agroforestry systems; management dynamics over time, introduction or replacement of species, temporal evolution of crops, cultivation duration.
Diversity	Social reasons, environmental factors, and management techniques affecting species diversity in AFSs; relationship between area and species diversity in AFSs; influence of AFSs types or environments on diversity in AFSs; differences between systems.
Composition	Recommended use for species; number of species and families in AFSs; cultural influence on AFSs composition; origin of species cultivated in AFSs; predominant or most frequent species.

A flow diagram was developed to clarify the methodological process, from the obtaining to the selection of the articles (Figure 1).

After selecting 66 articles, a detailed review was conducted based on the full reading of the studies, allowing the extraction of essential data for the research. Information was collected on the type of AFSs studied, the research objectives, the methodologies applied, and the locations where the studies were conducted. Additionally, key findings were synthesized regarding the botanical composition, diversity indicators, temporal dynamics of plant species, and social aspects such as farmers' perceptions and motivations for adopting AFSs. The effects of support actions and incentives for AFSs were also analyzed, as well as the advantages and challenges identified in the studies regarding the adoption and management of AFSs in the Amazon biome. Further details on this stage of the study are available in the Supplementary Material (Table S2).

The following parameters were identified using the Bibliometrix package in the R program: (a) year of publication; (b) institutional affiliation of authors; (c) trend topics; (d) thematic word map; (e) article journal; (f) most prolific authors; (g) most cited articles in the databases; and (h) productivity by country. In item c, the trend topics function identifies research tendencies (more common terms) in a study field based on the analysis of keyword occurrences across different time intervals. The Bibliometrix package also extracts words plus, which identifies and classifies research areas by analyzing the co-occurrence of these words.

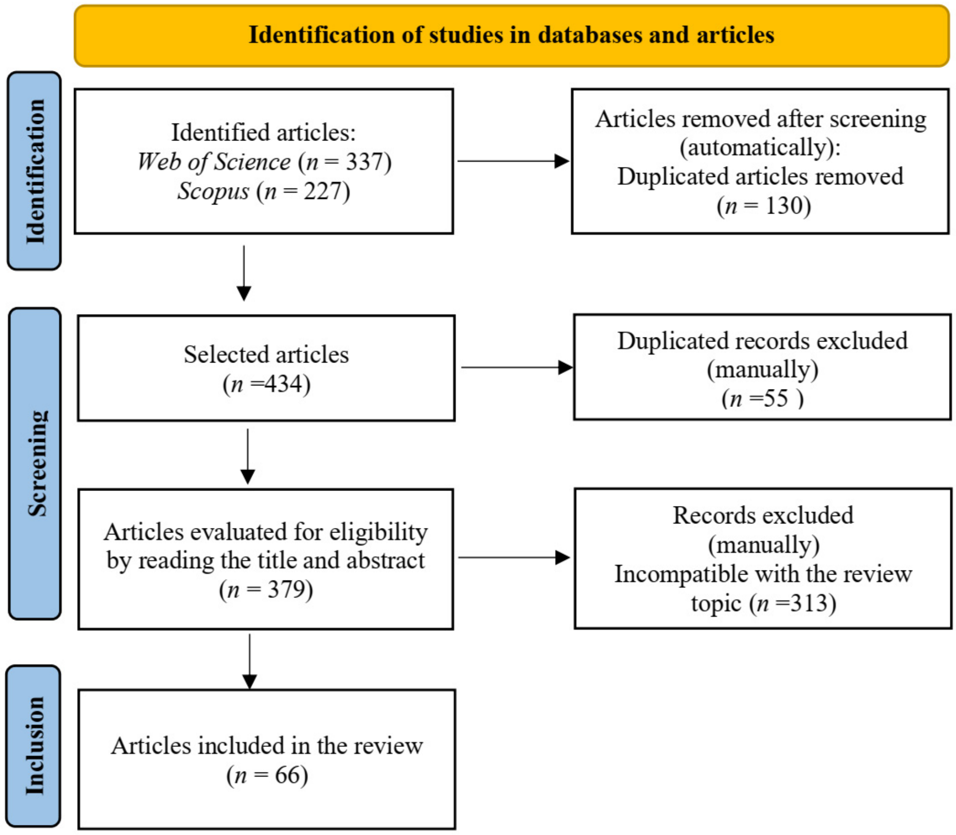

Figure 1. PRISMA flow diagram summarizing the methodology used for selecting articles for the review on agroforestry systems in the Amazon biome. Adapted from Ref. [33].

A cluster network was developed using VOSviewer 1.6.20 to connect predominant keywords found in the titles and abstracts of articles with a minimum frequency of four occurrences. This threshold was chosen after testing the software and balancing graph clarity: increasing the threshold reduced the number of displayed terms, while lowering it led to an excess of words, hindering visualization.

3. Results and Discussion

3.1. Characteristics of the Articles

The 10 most cited articles [37–46] stood out among the 66 selected articles, predominating in the homegarden agroforestry (HAF) or household garden topic. These articles address the composition, diversity, and richness of plants, the medicinal use of plant resources, and agrobiodiversity. The 66 selected articles were published between 1996 and 2023, across 42 journals, with an annual growth rate of 1.5% and a mean citation count of 19.5 per article. The articles were authored by 230 researchers, with an average of 3.8 co-authors per article; only three articles had a single author, and 38.0% featured international co-authorship. A total of 254 unique keywords were identified in the articles, with 215 words classified as the most frequent in titles and abstracts (words plus).

The number of published articles exhibited annual fluctuations (Figure 2). Production peaks were identified in 2016, 2019, 2021, and 2022, with six or seven articles published per year, and significantly low production between 2008 and 2012. This suggests the occurrence of catalyzing events that either stimulated or discouraged research, including the emergence of new areas, climatic events, global discussions, financing availability, and social or policy issues influencing research. Therefore, the scientific production surveyed in this review does not seem to follow a growth or decline pattern, suggesting that other factors are influencing the number of published studies.

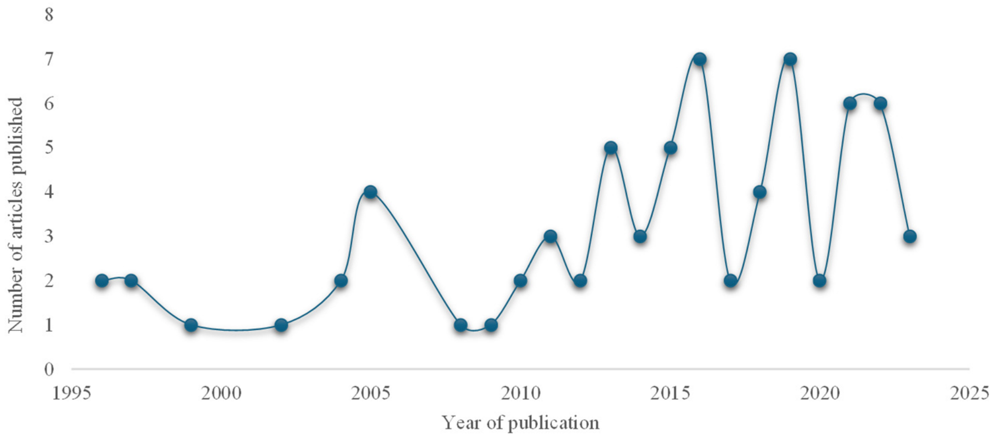

Figure 2. Quantity of articles published per year, in the Scopus and Web of Science databases, selected for the review on agroforestry systems in the Amazon biome.

The 19 research institutions with the highest number of articles associated with them (ranging from 3 to 14 articles) include Brazil with 6, Canada and Germany with 3, the United States and Ecuador with 2, and Colombia, Spain, and the Netherlands with 1 article each. The institutions with the highest number of published studies are Wageningen University and Research (14 articles) and the National Institute for Amazon Research (12 articles).

In addition, the Federal Rural University of the Amazon in Brazil and the University of Saskatchewan in Canada published nine articles each; McGill University, also in Canada, published six articles; and the University of Florida, in the United States, published five articles. McGill University was the institution with the oldest published study (since 1996) but had no new publications after 2008. The universities of Koblenz and Landau in Bonn and Hamburg, Germany, the Maranhão and São Paulo State Universities (São Paulo, Brazil), and the National University of Colombia (Bogotá, Colombia) published four articles each. The other institutions recorded three published articles each, namely the Mamirauá Sustainable Development Institute and Federal University of Western Pará (Santarém, Brazil), National Institute for Agricultural Investigations and Central University of Ecuador (Quito, Ecuador), University of Miami (Coral Gables, FL, USA), Autonomous University of Barcelona (Barcelona, Spain), and the University of British Columbia (Vancouver, BC, Canada).

The most productive institutions in Brazil were the National Institute for Amazon Research, the Federal Rural University of the Amazon, Maranhão State University, Mamirauá Sustainable Development Institute, and the Federal University of Western Pará, all located in the Brazilian Amazon, as well as the University of São Paulo in São Paulo.

The general analysis of published studies and their origins indicates a prominence of institutions headquartered outside the Amazon, a reduced participation of institutions from countries within this biome, including Brazil, Ecuador, and Colombia, and an absence of institutions from other Latin American countries. The prominence of foreign institutions in research on the Amazon biome is primarily attributed to factors related to research internationalization, broad contribution networks, available financing, and research promotion.

3.2. Frequent Terms in the Published Studies

Regarding the trend topics, 215 expressions or words were identified as the most frequent in titles and abstracts of articles published from 2004 to 2020. This indicates that there were insufficient mentions in articles published outside this period to reach the minimum frequency of five mentions required for inclusion in this group. The most frequently mentioned trend topics in the more recent studies (from 2013 onwards) include conservation (15 occurrences), biodiversity, diversity, management, and forest (12.5 occurrences). This indicates a growing trend in studies emphasizing management and environmental indicators of AFSs. Other prominent terms include systems, agroforestry, and agroforestry systems, which together have the highest frequency (above 15). Similarly, homegardens and home gardens together account for 12 occurrences. In contrast, agriculture, with fewer occurrences (five mentions), is spread over a longer period (2004 to 2018), indicating constancy.

A thematic map was created based on the standout keywords in the articles (words plus). The map included the most consistent terms from the articles, forming six clusters with the 16 most frequent words (Figure 3), distributed across two axes: density and centrality. These axes illustrate the importance of highlighted topics within the scope studied. The two clusters inserted in Motor Themes showed high density and centrality, suggesting that the articles with these topics align most closely with the focus of the scoping review. The largest group, containing the terms conservation, biodiversity, and diversity, was in this quadrant. This cluster highlights the connection between AFSs and discussions on cultivation, landscape, and richness. The second cluster, also located in the same quadrant, included the terms in-home gardens, knowledge, and dynamics, representing other keywords linked to shade plant diversity, composition, and agrobiodiversity. These terms demonstrated higher centrality in the review, highlighting areas that require further research and suggesting a possible information gap.

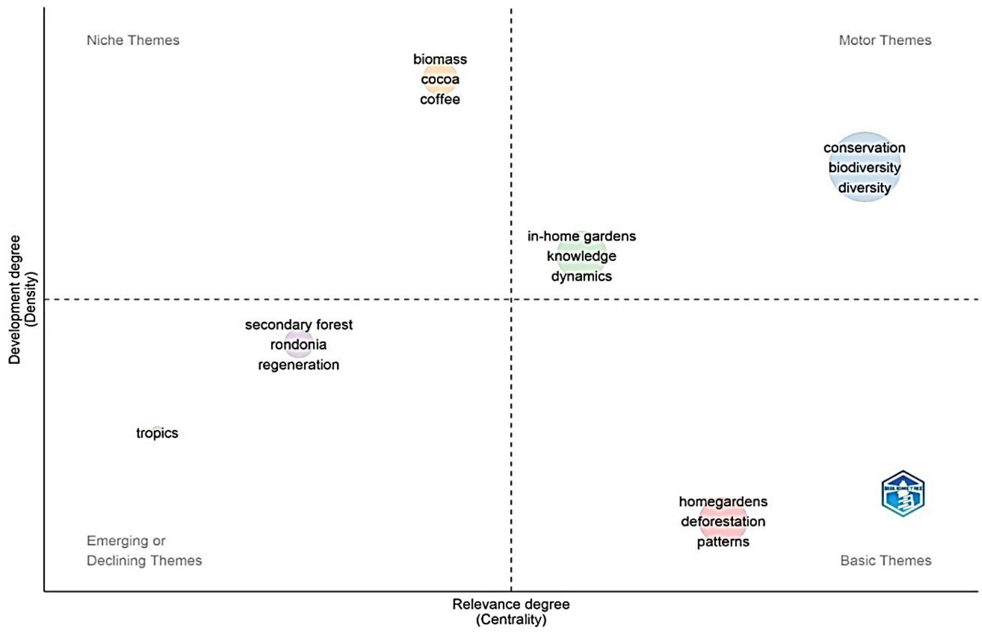

Figure 3. Thematic map of prominent keywords (most frequent words) from articles in the Scopus and Web of Science databases, selected for the review on agroforestry systems in the Amazon biome. Themes are organized by relevance (centrality) and degree of development (density). The quadrants highlight motor themes (consolidated and central), basic themes (fundamental but less developed), niche themes (specialized), and emerging or declining themes.

Homegardens, another term referring to HAF, is in the lower-right quadrant under *Basic Themes*, forming a cluster with *deforestation* and *patterns*. This cluster indicates that these terms have low density but high centrality, suggesting that they are essential to the study area but may be not fully investigated or are broad concepts.

The terms biomass, cocoa, and coffee formed a cluster located in the upper-left quadrant under Niche Themes, representing topics with high density but low centrality. This indicates that, while well researched, these terms are not central to the research focus, as they are specialized topics within the review scoping. Studies in this quadrant focus on the composition or diversity of AFSs but are more focused on explaining other parameters, such as assessing the ecological relationship between floristic composition and soil properties within a cacao AFSs with a short fallow period [47].

Emerging or Declining Themes, located in the lower-left quadrant, included the terms secondary forest, Rondônia, and regeneration, forming a cluster, and tropics, forming another (Figure 3). These groups exhibit low density and centrality in the research, suggesting that they may be emerging terms and thus infrequently used, or they could be becoming less prominent in research.

The distribution of terms in the articles' co-occurrence network is illustrated in a cartographic map (Figure 4), depicting the interrelation between words, indicated by circles, and lines indicating the frequency with which two terms appear together in the articles. The search identified a total of 2.452 words and 132 expressions of high importance in the 66 selected articles.

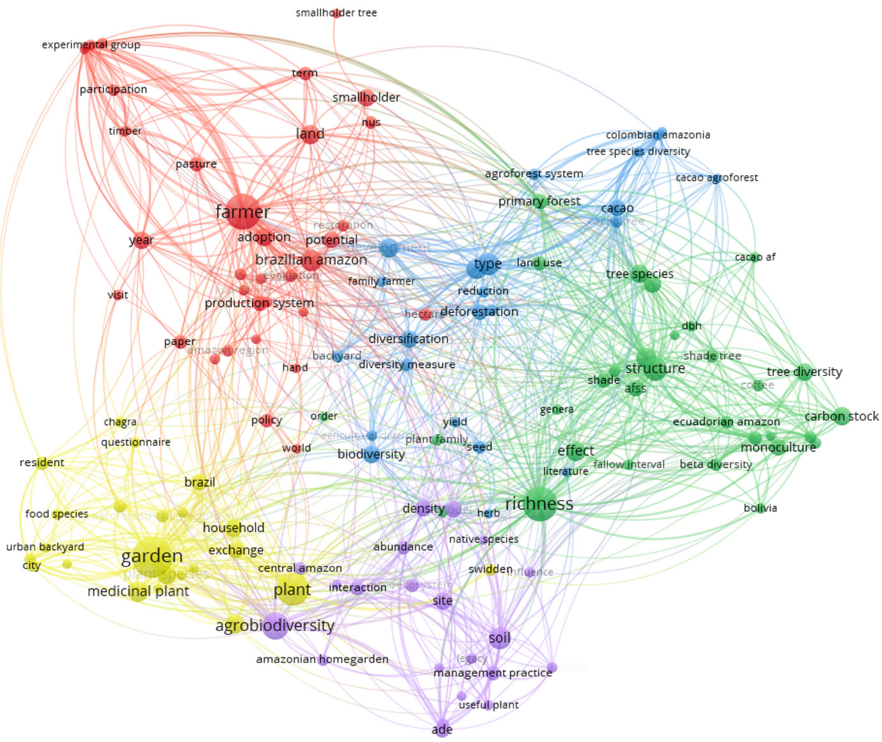

Figure 4. Diagram illustrating the co-occurrence network of keywords identified in the systematic review from the Scopus and Web of Science databases, selected for the review on agroforestry systems in the Amazon biome. The nodes (points) represent keywords (with size proportional to their frequency), the edges indicate co-occurrences (relationships between keywords), and the colors highlight thematic clusters, such as farmer, Brazilian Amazon, and production (red cluster); crop, type, development, and cocoa (blue cluster); structure, richness, and tree species (green cluster); agrodiversity, diversity, and soil (purple cluster); and plant, garden, and medicinal plant (yellow cluster).

This selection identified five clusters (groups of different colors), formed by the terms with the highest frequency (Figure 4). The prominent terms were: farmer, Brazilian Amazon, and production (red cluster); crop, type, development, and cocoa (blue cluster); structure, richness, and tree species (green cluster); agrodiversity, diversity, and soil (purple cluster); and plant, garden, and medicinal plant (yellow cluster).

The red cluster contained the highest number of terms (34 items), indicating research focused on socioeconomic aspects of the Brazilian Amazon, specifically on production and management, with emphasis on land use dynamics and the agricultural practices of smallholders. This group shows a strong association between farmer and experimental group, as indicated by the large thickness of the line connecting them. Examples of articles included in this cluster are a study evaluating the trend of polyculture crops with perennial plants in the Amazon [46]; a study evaluating diversity measures in different types of soil cover, including AFSs [48]; and a study identifying factors related to access to financing, management, education, and decision-making in the adoption of commercial AFSs by smallholder farmers in the state of Pará [49].

The blue cluster contained the second-highest number of terms (31 items), which included agroforest system, cacao and tree species, indicating a focus on technical approaches to AFSs that incorporate cacao crops, primarily because it also included the terms shade, structure, and effect. This group emphasizes studies related to cacao cultivation in AFSs in Latin America, focusing on aspects such as shading, small-scale agricultural diversity, and the diversity of cacao-based systems [50–52].

The green cluster contained 23 terms representing central topics related to richness and structure, indicating that the studies are broadly connected to several topics, including homegardens, soils, and agrobiodiversity. This group highlights research on cacao crops related to shade trees, structure, and carbon stocks [53,54].

The yellow cluster contained 23 items indicating a concentration of research on HAF, primarily focused on urban evaluations. However, like the purple cluster, it also presented a strong connection with agrobiodiversity and medicinal plants. The studies listed in this group primarily focus on investigating factors related to species diversity and richness in agroforestry homegardens in urban areas, with an emphasis on usage relationships and social factors [55–57].

This yellow cluster includes studies on agrobiodiversity in HAF, highlighting fruit and medicinal species in the Amazon estuary (Amapá) and plant management in Bolivia [58,59]. It also features research on food species cultivated in urban HAF in Acre [60]. The term chagra is also present in the yellow cluster, highlighting a study that addressed the knowledge, perception, and commerce in an indigenous community in Colombia [61], and a study that compared plant diversity used between chagras and homegardens in Peru [62]. Other authors use this term, described as crakra, in studies in Ecuador [54,63,64].

The purple cluster contained the lowest number of terms (21), indicating research centered on agrobiodiversity. The terms garden, exchange, and ADE (referring to Amazon dark earths) indicated the prominence of studies on the diversity of cultivated plants, including medicinal plants, and management in HAF, as well as research focused on Amazon dark earths, also known as Terra Preta or Indian black earth. Several studies demonstrate the function of these lands (fertile anthropogenic soils) in the conservation of native and exotic agrobiodiversity, and how their characteristics influence the structure, diversity, and composition in homegardens in the Amazon biome, along the Madeira and Urubu Rivers, in the state of Amazonas, Brazil.

The purple cluster also contained the terms site, interaction, management practice, and soil, indicating specific studies on the influence of locations on agrobiodiversity, as well as management practices and plant use, reflecting the human dimension of environments. This cluster includes studies among the most cited, including those of Oliver T. Coomes on agrobiodiversity in household gardens [37,39,45], and a study highlighting the high diversity in homegardens with minimal focus on the market [65].

The distribution of terms and the thickness of the lines that connect them (Figure 4) indicated trends and research gaps. Fine lines represented a less frequent or weaker correlation between concepts in the articles. For example, the connection between adoption and establishment, which was distant and connected by a fine line, indicates an area within the AFSs topic that requires further investigation. Similarly, management practice is not connected with adoption or establishment, suggesting areas that could be better addressed, as management practices influence adoption and are linked to the labor of family farmers, who predominantly adopt AFSs. Therefore, an article highlights the recognition of local agroforestry practices and the understanding of the changes in farmers' subsistence means that the adoption of AFSs can demand [66]. Studies addressing these links are lacking, representing an important gap in the evaluation of AFSs implementation. In this regard, a systematic review on the challenges hindering the adoption of agroforestry practices revealed that the main barriers are related to technical agronomic, socioeconomic, and political legislative aspects [24].

The term diversification was connected to biodiversity, deforestation, restoration, model, and native species (Figure 4). However, studies addressing the diversification of different AFSs and its impact on production were limited. In addition, studies on the effect of increasing plant species or abundance of individuals on the management, labor activities, and farmers' perception of these changes are scarce. The main objectives of studies discussing the production aspects of AFSs were cacao yield, decreases in production costs, shading and coffee production, promotion of non-wood products, and logistics for marketing AFSs products [53,67–70].

Based on the results and gaps identified in published articles, approaches to fruit and food production in AFSs can be recommended as potential subjects for new research, as two related terms were identified: food species and useful plant, which are not connected (Figure 4). In general, studies addressing plant use and composition show results of surveys on HAF [60,65,71–73].

Similarly, terms such as seed, development, production system, and diversification showed no co-occurrence with terms related to food production in AFSs, highlighting an information gap that can be explored in new research. For example, studies conducted in Tomé-Açu, Pará, Brazil, featuring the terms development and co-production in their title primarily focus on integrating collective knowledge and strategies for disseminating and consolidating the Tomé-Açu Agroforestry Systems (SAFTA) [74,75].

The terms from Figure 4 are distributed by year of publication (Figure 5). Terms more recently used (2019 to 2020) form the red and orange clusters, including tree species diversity, type, family farmer, restoration, underutilized tree species, traditional knowledge, chagra, diversity measure, biodiversity conservation, fallow interval, and collective action, and synonym for AFSs or HAF, such as backyard. The recent use of these terms reflects the growing inclusion of small-scale research, indicating an increasing trend of studies in this scope.

The central words from 2017 to 2018 were structure, richness, and cacao. This period highlights the concentration of studies on cacao, carbon, and biodiversity, focusing on practices of smallholder farmers, primarily in Colombia and Ecuador. Examples of articles from this period include a study evaluating a cacao AFSs with innovative approaches, estimating canopy shading and understory light availability [76], and a study on rural homegardens in the Eastern Amazon [77], which demonstrated that the farmers' origin influenced the diversity of plant species.

Older terms (2012 to 2015) were primarily distributed into two clusters, including garden, Brazilian Amazon, plant and farmer, household, village, adoption, pasture, year, secondary forest succession, density, development, swidden, production system, site, and resident. These clusters concentrated terms related to AFSs, production analysis, and experiments. Examples of articles from this period include two studies conducted in the Tapajós River region [78,79], focusing on the use of AFSs as an economic alternative to cut-and-burn practices in small-scale agriculture, and the ethnobotanical use and knowledge of forest plant diversity in various vegetation areas, including HAF.

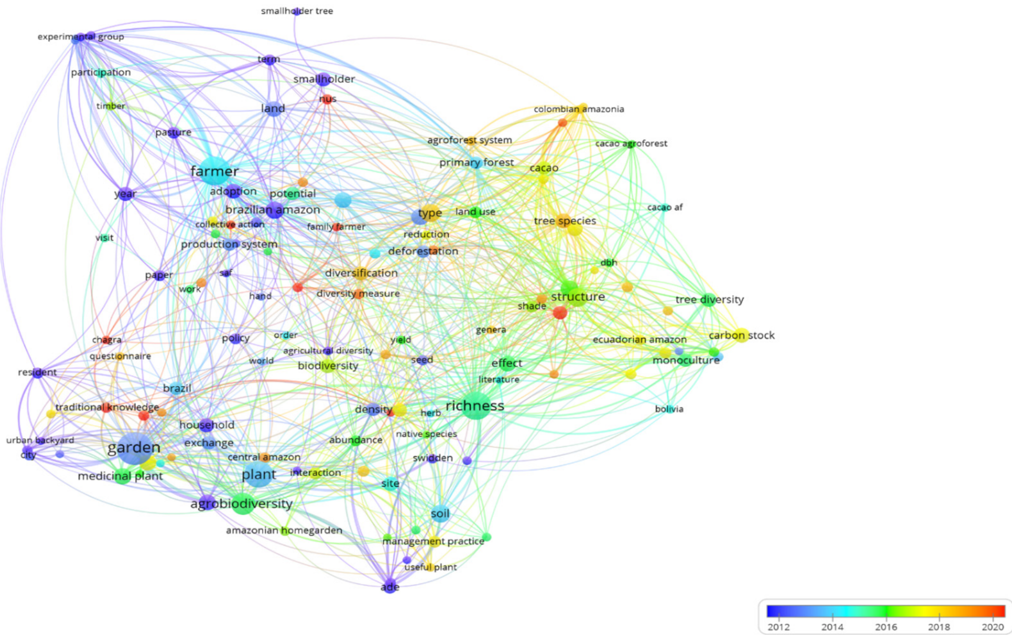

Figure 5. Diagram of the keyword network with distribution by year identified in the Scopus and Web of Science databases, selected for the review on agroforestry systems in the Amazon biome.

Studies published in 2016 primarily focused on diversity, richness, agrobiodiversity, abundance, and land use. Several terms related to cacao crops appeared in the studies from this year, including cacao agroforest, cacao AF, cacao, cocoa, cacao tree, shade, and tree diversity.

Four articles with older studies (1996 to 1999) relevant to the research scope were identified [40,45,46,80]. These studies exhibited certain peculiarities not observed in subsequent research. For example, a study evaluating AFSs in Peru [80] did not use the term chagra (chakra or chacra) with the same emphasis found in more current studies, despite being conducted in an environment with fallow management characteristics typical of this type of system. This article refers to polyculture areas such as *forest gardens* or agroforestry fields, terms that were also not identified in the other selected articles.

A pioneering study [40] focused on understanding agroforestry fallow cycles, emphasizing the dimension of the available area and its effect on diversity and marketing. In addition, a survey conducted across several states of the Brazilian Amazon [46] focused on understanding crop patterns, agroforestry dynamics, and developmental constraints in polyculture fields. Moreover, the oldest published article on the HAF topic evaluated plants in the Peruvian Amazon focusing on the influence of tourism and the distance from urban markets [45].

3.3. Main Authors and Studies

In terms of accumulated production, the scientific journal Agroforestry Systems had the highest number of published articles (17), and demonstrated consistent growth over the analyzed period, indicating a specialization in this research area. The journal Economic Botany published a total of five articles, though no new studies related to the scope have been published after 2011. The journals Agriculture Ecosystems & Environment, Science Forest, Development and Environment, and Plos One published three articles each; however, their publication frequency varied starting from 2013 onwards. The journals Sustainability, Acta Amazon, Acta Botanica Brasilica, and Agricultural Economics published one or two studies connected to the research scope.

The authors with the highest number of published articles included Charles R. Clement, with six articles, followed by Oliver T. Coomes and André B. Junqueira, each with four articles. Jorge H. Cota-Sánchez, Izildinha S. Miranda, and Thiago A. Vieira each published three articles, and Javier Amigo, Natalie C. Ban, John O. Browder, and Verônica Caballero-Serrano each published two. These results indicate that Charles R. Clement is a central figure in this field, while authors with fewer published studies may be emerging or less active in the AFSs field.

The 15 articles with the highest number of citations were published by various journals, except 4 articles, which appeared in Economic Botany and Agroforestry Systems. The citation analysis identified the three most cited articles [39,44,45], which contributed to the understanding of species domestication dynamics and agrobiodiversity in household gardens or HAF. Moreover, most studies (nine) were conducted between 1996 and 2009, while only six were published more recently (2014 to 2019). This suggests that the theoretical and methodological foundations established in these studies remain relevant to current research and continue to be cited.

The interdisciplinary spectrum demonstrated by several journals through the most cited articles highlights the multifaceted nature of AFSs, where dialogs between diverse knowledge areas are essential for advancing research. These studies include research on household gardens or HAF that encompass agrobiodiversity, floristic diversity, composition, and ecosystem services [37,43,45,81]; traditional knowledge and its influence on the diversity of medicinal plants in household gardens [38,41]; characteristics and dynamics of domestication of species [44]; agroforestry adoption and practices [40]; and diversity of plants grown in fields and homegardens and its relation to geographical isolation [57].

Studies focused on evaluating AFSs of small-scale farms included an assessment of crop patterns and agroforestry dynamics in Brazil [46], and an analysis of production efficiency and marketing [68], primarily of forest products, in four countries in the Amazon biome (Brazil, Peru, Bolivia, and Ecuador). Studies emphasizing market aspects included an investigation of product destinations and the diversity of homegardens in the Amazonas [65], and an analysis of the AFSs of Tomé-Açu (Pará) to demonstrate the actions required for AFSs to serve as an economic alternative to livestock [82].

This list of articles also includes studies addressing species diversity and carbon stocks [42], as well as factors affecting the adoption of cacao AFSs as a strategy for reforesting [83]. The theme with higher visibility, based on the number of citations, is HAF or household garden.

3.4. International Collaboration in Research

Collaboration among 24 countries was identified based on the scientific contributions of all authors and co-authors. Brazil stands out with 98 authors, followed by Canada (27), the United States (24), Germany (22), the Netherlands (16), Peru (15), Ecuador (13), and Spain (12), while the number of authors from the other 16 countries listed is fewer than 8.

Regarding the country location of the researched areas, 55.4% were in Brazil (36 articles), 24.6% in Peru (16 articles), 10.8% in Ecuador (7 articles), 6.2% in Bolivia (4 articles), and 3.1% in Colombia (2 articles). Only one article was not included in this list, as it involved four countries in its database [68]. However, no studies meeting the criteria of this review were found from other countries and territories through which the

Amazon biome extends (Guyana, French Guiana, Suriname, and Venezuela), highlighting an information gap in these locations.

Publications are often made in local or regional journals, conference proceedings, and books that are not indexed in higher-visibility databases, such as those used in this study, and are sometimes published in other languages, which hinders their cataloging and visibility. It is essential to promote policies that encourage the publication of research conducted by the academic community in high-impact scientific journals [84]. In addition to logistical and infrastructure challenges in the Amazon [85], other limitations may be related to scientific dissemination, including low investment in science, insufficient research funding, and limited participation in academic cooperation networks. Furthermore, the emphasis on solutions to social or political problems may contribute to a reduction in scientific advancement in certain areas.

3.5. Types of AFSs Researched

Figure 6 illustrates the distribution of various types of AFSs that were the focus of research in the selected articles. The most researched AFSs type was HAF, or household gardens, representing 39.4% of studies (26 articles). Crop forest AFSs, or commercial AFSs, were addressed in 13 articles (19.7%), cacao production (AFSs cacao) in 7 articles (15.2%), while improved fallow, coffee AFSs, and chagra AFSs were less frequently studied. Among the 66 selected studies, 7 (10.6%) evaluated two to five AFSs types within the same article, additionally addressing soil enrichment crops, regeneration conduction, forest livestock systems, and pasture enrichment. Four studies were not listed as they did not specify the type of AFSs researched, instead focusing on topics related to the adoption and impact of projects and policies, work relationships, and the domestication and use of agricultural species.

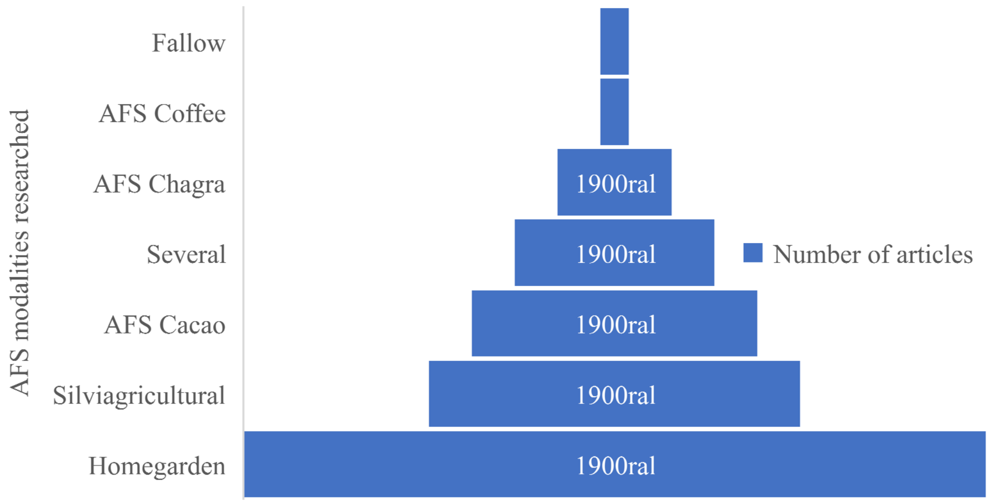

Figure 6. Number of articles and AFSs types identified in the review on agroforestry systems in the Amazon biome.

3.6. Area Size, Methodology, and Sample Effort

Only 28 articles (42.4%) out of the 66 selected provided information on the size of the area (rural property or AFSs area). Only 1 of the 11 articles focusing on HAF research provided information on the total mean size of the property [55], whereas the others reported the area occupied by homegardens, which ranged from 0.023 to 1.2 hectares (ha). One exception was identified, where homegardens occupied 2 ha, as the study considered the agroforestry surrounding the houses as an extension of the homegarden, resulting in large dimensions [72]. The areas of cacao AFSs ranged from 1 to 4 ha in Peru, Brazil, and

Colombia [50,69,76]. The size of areas with crop forest, crop livestock, improved fallow, and chagras AFSs ranged from 0.25 to 20 ha, as reported in 14 articles. The sizes of properties with commercial AFSs were described in seven articles (10.6%) and ranged from 1.5 to 100 ha.

Regarding the methodologies employed in the selected articles, interviews were the predominant single tool for data collection in 34 articles (51.5%); inventory practices, involving the implementation of plots, were used in 17 articles (25.74%). Only two articles (3.0%) relied on secondary data, such as satellite images and production statistics. Additionally, combined approaches, such as interviews with questionnaires and inventory, were employed in nine articles (13.6%). The remaining four studies were conducted utilizing a combination of methods, including interviews, plot inventories, participant observations, soil sampling, and transect collection.

The collection effort showed no consistency in the sampled units, likely due to factors such as logistics, accessibility, size of areas, social characteristics, and nature of case studies in the published research. Sample sizes (plots, properties, or interviews) ranged from 10 to 50 for cacao and coffee AFSs and from 12 to 70 for other crop forest systems. HAF exhibited the most diverse sampling, with sample sizes ranging from six to 334 research units. Other studies examining various types of AFSs within the same article utilized 6 to 181 collection points. One study on improved fallow utilized 32 interviews, while another on chagras AFSs used 6 to 61 sampling units.

3.7. Choice of Species in AFSs

The choice of species for cultivation or maintenance in AFSs is influenced by numerous factors. Individual circumstances and personal preferences determine the crops to be grown and the effort they warrant [80]. Available labor was a significant factor in the adoption of AFSs, since groups with mixed or non-logger systems have higher regular labor requirements [86]. However, evidence suggests that crop intensification and a focus on a single plant species tend to homogenize floristic composition [80]. Studies on cacao crops suggest that system composition is influenced by fallow intervals, as observed in Ecuador [47], and by shade tree diversity and management strategies, as observed in Brazil [50].

Crops guided by donors predominantly involve the planting of seedlings from nurseries, whereas crops managed by smallholder farmers rely on transplanting seedlings and protecting specimens of natural regeneration [68]. Additionally, farmers use ecological information to introduce a wide diversity of tree species [87]. However, the inclusion of native fruit tree species with commercial potential in AFSs is constrained by technical, social, environmental, and economic factors, particularly the lack of information and operational challenges related to harvest [88].

In this context, a study conducted in São Félix do Xingu, Pará, Brazil, found that cacao crops are influenced by labor, market value, reforestation, and soil suitability, although not specifically during the AFSs implantation stage [83]. Furthermore, a study reported that the primary potential products of shade trees for cacao crops are fruits, wood, charcoal, and medicinal products [50]. In Peru, the maintenance of original tree vegetation that is practiced in cacao AFSs is strongly affected by its production value or service functions [52], with a preference for timber species or fruit trees to be grown with cacao [89].

Plant species in HAF are selected for food security, household consumption, personal satisfaction, and well-being associated with shading, and minimally for product sales [90] to complement family income. Plants cultivated in these environments have important food value, whereas spontaneously occurring plants are primarily valued for their medicinal properties [59].

Regarding the number of plant species identified in the research, 44 articles (66.6%) provided quantitative data, often including the number of botanical families composing the studied production systems. Twenty-two of these articles were focused on HAF, sixteen on other AFSs, and three addressed two or more categories of production systems.

Information on the floristic composition of homegardens varied in the number of species and botanical families. However, some studies restricted the inventory scope based on the purpose of collections, such as medicinal, food, condiment, or specific plant groups. Similarly, not all studies reported the number of botanical families. The number of species in homegardens ranged from 41 to 484, with a mean of 147.2 ± 102.6 species. Homegardens with the highest species richness (more than 200 species) were found in three Brazilian states: Amazonas (ADE), Mato Grosso (urban areas), and Pará (urban and rural areas). The number of botanical families in homegardens was 28 to 97. The frequency distribution showed that most articles (59.1%) reported homegardens with 41 to 129 species, whereas 22.7% reported 130 to 218 species. Homegardens with more than 218 species were recorded in 18.1% of the articles (four studies).

Studies on commercial AFSs (cacao, coffee, crop forest, and chagra) reported 16 to 127 plant species (mean 53.7 ± 31.9) and 12 to 40 botanical families, indicating lower species richness compared to HAF. However, some studies focused exclusively on specific plant groups, such as species planted for projects, arboreal and fruit tree species, or palms, wood trees, and banana trees [52,63,67,76].

Species richness in studies on commercial AFSs varied widely, with 38.9% of articles reporting 16 to 38 species, 44.4% reporting 39 to 82 species, and 16.7% reporting more than 83 species. The highest species richness was recorded in studies on cacao AFSs in Colombia and Bolivia [42,76], which reported 127 and 105 species, respectively.

3.8. Diversity and Richness in AFSs

Studies on diversity and richness in AFSs within the Amazon biome primarily focused on comparing these systems with other environments, such as primary forest, secondary forest, and fallow areas. For example, one study evaluated arboreal species in cacao AFSs, secondary forests, and primary forests [52] and found that although AFSs cannot fully replicate the higher diversity indices of primary forests, they have crucial functions in conserving agricultural landscapes, where forests are intensely fragmented.

Diversity tends to increase linearly with the sizes of properties and AFSs [40,62]. In agroforestry crops, few species show a high number of individuals [50]; however, properties smaller than 10 ha exhibit greater diversification [63]. The reviewed articles indicated that AFSs integrated with natural regeneration can balance agricultural production with species richness and diversity [91]. However, managing natural regeneration may be more effective for promoting species diversity than tree cropping [68]. Historically, management practices have transformed the abundance of useful plant species and altered floristic composition [44]. Additionally, agricultural diversity primarily reflects household asset endowments [51].

In Peru, cacao AFSs with mid-age crops (16–29 years) exhibited lower diversity compared to young AFSs [89]. However, species richness increased significantly as the crops aged [69]. Moreover, the diversity across various soil cover types, including AFSs, revealed limitations in measures used to differentiate soil cover types in all strata [48].

HAF exhibits the highest plant diversity among the crop models of farmers [39]. Despite extensive knowledge of useful forest species diversity, most plants utilized originate from modified areas such as homegardens, fallow lands, and secondary forests [78]. Household garden maintainers diversify these spaces by cultivating crops previously grown in annual fields as a strategy to partially offset agrobiodiversity loss [58].

HAF with greater plant diversity offers enhanced ecosystem services [81], while plant species in gardens reflect traces of human history [92]. This is evidenced by the high diversity of species found in homegardens established in TPA, highlighting the legacy of previous human occupations [72]. The successive occupation by different cultural groups over time may have contributed to the higher diversity of useful species observed today [93].

The studies indicated that HAF structure, diversity, and agricultural species richness are influenced by several factors, including the origin of farmers and the management of these environments [77]; soil fertility, natural and anthropogenic variations in soil properties, and homegarden size [94,95]; family income, homegarden size, and topography [60,96]; farmers' centrality within exchange networks and proximity to their residence [41]; distance from urban centers, level of external information exchange, and household garden size [37,57]; and the propensity to interact and receive plant donations [45].

3.9. Functions of Agroforestry Systems

The AFSs identified in this review highlight HAF as a multifunctional central system with a wide range of species, serving as areas for testing and conserving plant specimens. However, few studies have addressed the age of homegardens: one study in Peru and one in Ecuador, which reported means of 7.6 and 13 years, respectively [38,39,45].

These environments are recognized as centers for cultivating useful plants, points for the flow of materials for subsequent crops, and areas for experimenting with new species [39,58,94]. They also serve as sites for establishing seedling nurseries [87], receiving plants grown in fields [37], and functioning as open laboratories for plant selection [92]. These locations acquire new uses through continuous experimentation, facilitated by increased contact [59]. In commercial AFSs, farmers also foster continuous experimentation, creating dynamic systems [40,46], with management practices that alter the forest composition [44].

The exchanges of plant species in HAF reveal a social network strengthened by the sharing of traditional knowledge [56], leading HAF to be considered the most dynamic of all ecosystems [93]. Families with higher diversity in their household garden tend to exchange more plant materials compared to those with limited diversity [37]. More biodiverse systems enable farmers to participate in cycles of donation and expansion within social networks [45], while kinship ties and gender influence the exchange patterns of medicinal plants [41]. Following this implementation logic, some improved fallow areas near houses can become permanent household gardens over time, dominated by fruit trees [87]. Homegardens in TPA have more fertile soils and are often used for exotic crop species, as farmers take advantage of this high fertility to grow nutrient-demanding species [94,95].

In different AFSs, fruit tree species are emphasized as central due to their frequency and abundance [39,41,43,58,63,73,77,79]. Beyond the cultivation and maintenance of fruit trees, studies report at least one additional category of use, including vegetables, medicinal plants, or non-fruit food plants [45,57,60]. Several studies also discuss the destination of food plants in AFSs without specifying distinct plant groups [56,61,71,81].

HAF is reported to predominantly contain arboreal individuals that are food plants and herbaceous plants with therapeutic value [59]. Other AFSs are characterized by the predominance of native trees that produce forest products other than logs [68]. Several studies on HAF report the dominance of exotic crop species [46,60,65,77], whereas research on the Madeira River identified a predominance of native species [94].

The cultivation of medicinal plants in HAF not only reinforces their therapeutic purposes, but also reflects their cultural heritage [97]. These locations are identified as sources of food, essential for subsistence in rural zones, whereas in urban areas, they are primarily valued for ornamental and shading purposes [81]. In general, the functional convergence of HAF is emphasized, as despite differences in number of species, the relative number per category of use is comparable [45].

3.10. Social and Production Aspects of Agroforestry Systems

HAF is described as an extension of houses, with practical and economic values in meeting domestic needs [58], as senior women predominantly manage these environments [45,56,60,71]. This context highlights the importance of women in conserving agrobiodiversity in household gardens. They are identified as the primary transmitters of traditional knowledge on medicinal plants [38] and are responsible for introducing new species [71] and increasing plant diversity in the gardens [45]. In contrast, commercial AFSs are predominantly managed by men [49,61].

Studies addressing production and economic advantages report divergent results. Intercropped AFSs improved cacao crop yield and quality due to high diversity [69] while also reducing costs and increasing income and profitability, primarily in non-monetary terms [98]. A coffee AFSs in Peru showed increased yields as shade cover decreased [70], whereas in Ecuador, cacao grown in single-crop systems produced the highest yields [54]. Studies also reported that market forces tend to simplify AFSs configurations [46], and families with large landholdings utilize AFSs in a way that is potentially more sustainable and profitable [40].

The low marketing rate of agroforestry products has been attributed to inadequate market access and a lack of facilities for processing, storage, and sales [67]. The initiatives for the cultivation of trees and marketing of products found in four countries (Brazil, Bolivia, Peru, and Ecuador) indicate that AFSs should prioritize non-log products for successful reforesting, given the limited marketing options [68].

3.11. Motivation and Adoption of Agroforestry Systems

The adoption of AFSs is associated with various reasons and motivations, primarily related to potential capital accumulation, with land ownership being a crucial factor for the implementation of perennial agricultural systems [79]. A study conducted in the Brazilian Northeast, outside the Amazon Biome, revealed that the participation of producers in institutional food purchase programs is essential to encourage the adoption of AFSs [23]. In addition, the recognition of agroforestry practices [66] and the widespread use of traditional knowledge [78] are crucial to this process. Owners of large landholdings, with a higher number of farm residents, demonstrated a greater propensity to adopt innovative AFSs [86].

Agricultural diversity reflects the allocation and distribution of resources and family assets, which is a key element for conservation production but can also be a limitation for the adoption of AFSs [51]. The limitations of rural extension services and the use of information on AFSs are also identified as obstacles to adoption [99]. A study conducted in Bragança, Pará, Brazil, identified access to financing, AFS management (including objectives, cultural practices, and land preparation), education level, and decision-making (influenced by farmers' gender), as the main determinants for adopting this production system [49].

The agroforestry status was shown to be dynamic in the evaluated articles concerning the adoption of intercropping systems. The articles indicated that AFSs implementations are not expanding in Bolivia [42], and wood plantations have been less successful in various countries within the Amazon biome [68]. However, farmers in Rondônia and Pará expressed the intention to expand the size of agroforestry sites [67,100]. The adoption of an innovative model of agricultural systems by farmers in Tomé-Açu created new opportunities, resulting in greater flexibility in the choice of their arrangements, the development of new techniques, and expanded marketing options, which inspired local smallholder farmers to adopt AFSs [74,75].

These motivations and opportunities for adopting agroforestry also include the environmental and ecosystem services provided by arboreous environments, which are connected to water quality and food security [54,91,100]; consumption of fruits, medicinal resources, improvements in other crops, and product sales [88]; higher satisfaction related to itinerant pasture and agriculture [98]; shade for perennial crops, better working conditions, soil protection and improvement [68]; shade and thermal comfort [86,101]; and production diversification [42].

A study on farmers under the Program for Socio-Environmental Development of Rural Family Production (Proambiente) also confirmed that AFSs production resulted in higher food availability, increased acquisition of goods, promotion of environmental services, and the inclusion of farmers in the consumer market due to the diversity of products in agroforestry arrangements [101]. Thus, a trend of spontaneous diffusion of agroforestry is expected in areas with demonstration plots of agroforestry practices [67].

Studies on environmental aspects of AFSs reported that including wood production was a catalyst for forest restoration [67]. These systems enable the conservation and rehabilitation of land use in areas where tropical forests have been degraded and fragmented [52,86]. In addition, their potential for biodiversity conservation in agroforest programs is significant [59], and this conservation, enabled by the shade of trees, may be a target of policies encouraging their maintenance [50]. AFSs can enrich the soil, improving its fertility by reproducing mechanisms of forest conservation [44], and can be used to restore protected reserves and mitigate environmental liabilities [83]. Studies also reported that increases in AFSs areas are an attempt to restore the functions and benefits lost to environmental degradation [100].

An analysis of the potential of AFSs in Tomé-Açu indicated that they represent a complex social technological system encompassing a distinct philosophy of Amazonian land use and agriculture, as well as innovative agricultural techniques, processing, and value-added chains, pointing towards a path for sustainable rural development in the Amazon [75]. Thus, public financing could be justified by numerous positive externalities of AFSs for families and communities [79] or incentivized through remuneration for avoided deforestation [54]. Future efforts for food security and poverty reduction need to focus more on species-rich AFSs [98].

3.12. Incentives and Promotion of Agroforestry Systems

Although there is evidence that small farmers need support to shift their cultivation practices toward optimal land use, including AFSs, efforts to disseminate technical knowledge and demonstrate the economic and ecological benefits are crucial [102]. Studies addressing the impact of financing or other incentives on the implementation and development of AFSs in the Amazon were scarce among the articles selected for this review. The financing source showed a strong correlation with the AFSs composition in Bragança, Pará, where the selected species were adopted by farmers due to interest in the crop, despite delays in the delivery and development of the project [49]. The recommendation is that financing projects should complement those focused on the use of products from fallow areas, open fields, and household gardens [78] to avoid overloading the people involved and altering the main production mode.

Research conducted by the Agroforestry Tree Domestication Program, after 20 years of implementation, indicated that the objectives were not achieved and, according to farmers, the program was financially unviable [103]. Another evaluation emphasized that (a) there was no difference between the sizes of plantations guided by donors and those implemented by farmers; (b) donors promote tree plantations with limited success, neglecting management limitations and underestimating the potential of local independent tree plantations; and (c) smallholder farmers seldom continued the regular maintenance of plantations guided by donors after the project ended [68]. In this context, a study in Peru on agroforestry use grants, where farmers maintain forest remnants and establish or maintain AFSs, found that most farmers indicated a need for economic incentives, particularly for tree plantations [66]. In this context, another review on AFSs highlighted that, in addition to economic incentives to reduce initial costs, it is essential to integrate AFSs into national policies aligned with global discussions to ensure the recognition of their functionalities [102].

A study showed that the official technical assistance agency was active only during the initial years of establishment of AFSs, leading to implementation failure [49]. In addition, most agroforestry arrangements were established based on farmers' initiatives rather than external agents [46]. A study conducted in Rondônia showed that the average area allocated to AFSs decreased after the agency leading the project closed [99]. This project, conducted by an association financed by an international organization from 1996 to 2009, successfully promoted the adoption of AFSs while the organization was active, although it did not result in significant improvements in the farmers' financial yield.

Several studies addressed weaknesses of or threats to the adoption and continuity of AFSs [42,46,62,68,76,79,88] identifying limitations such as (a) insufficient agro-industries; (b) limited access to quality seeds and seedlings; (c) operational challenges in harvesting wood within intercropping systems; (d) lack of information on specific agricultural practices; (e) insufficient labor and equipment for pruning; (f) high initial implementation costs; (g) unfamiliarity with the cultivation of certain species; (h) difficulties in maintaining diversity and conservation; and (i) challenges in integrating with market and influencing biocultural relations that sustain in situ conservation.

However, some promising results were reported, including a study in Rondônia, which found that most farmers retained at least one or more wood-producing species in their agroforestry plots after 10 years [67]. Additionally, most farmers expressed interest in expanding planted areas with valuable timber species or enriching fallow areas [66]. The prominent function of farmers in Tomé-Açu led to the adoption of AFSs by petrol companies, which initially did not consider the group for financing *Elaeis guineensis* Jacq. crops [74,75].

Therefore, despite scientific advances, the expansion of AFSs faces challenges related to technical knowledge, financial incentives, and the need for programs involving education, research, and rural extension institutions to enhance understanding and promote the adoption of these systems. Similarly, another review highlighted that among the challenges for the adoption and acceptance of AFSs in Europe are high implementation costs, the lack of financial incentives, and limited marketing of AFSs products, as well as a lack of education, awareness, and practical field demonstrations [104]. In addition, information gaps limiting the expansion of AFSs extend beyond the diversity of available perennial species to include issues related to management and lack of economic data, such as production costs and profitability, which could assist in shifting the paradigm of traditional monoculture.

The completion of this review highlighted that future research on AFSs, focusing on the themes addressed in this study, could involve and provide greater visibility to the Amazonian countries not covered, such as Guyana, French Guiana, Suriname, and Venezuela. Such an approach would enable the integration of regional data into a broader understanding of the Amazon, aiming to support the development of more effective and collaborative public policies among Amazonian countries.

As proposals for future studies, it is suggested to conduct systematic reviews on the most deficient topics, such as diversity and productivity, in addition to proposing long-term studies involving financial and economic feasibility analyses. These approaches would allow for a deeper evaluation of the relationship between implementation, profitability, crop diversity, and the consolidation of AFSs. Another relevant aspect would be the integration of geoprocessing and remote sensing tools which, combined with in loco validations, could reveal trends and patterns of adoption and promotion of AFSs in the Amazon. Despite advances in agroforestry research, there is still a clear need for multidisciplinary approaches and expanded experimental studies to promote specific AFSs models adapted to the particularities of each locality.

Finally, it is stated that this study's main limitations are a restricted geographical focus, the exclusion of keywords related to economic aspects, environmental and ecosystem services, public policies, and dissemination strategies, as well as the absence of research in languages other than English and in databases other than those selected. Possible strategies to address these limitations include considering an expansion of the scope of analysis in future studies. This would enable complementary investigations and discussions in light of the findings of this research, emphasizing more specific approaches. Thus, studies with a narrower focus could identify additional gaps, taking into account the particularities of each environment.

4. Conclusions

The scope of this review on the adoption, diversity, and evolution of AFSs in the Amazon leads to the following conclusions:

Brazilian evolution and leadership: Brazil has experienced dynamic and interdisciplinary growth, emerging as a leader in research and author affiliations.

Diversity of approaches: The reviewed evaluated articles highlight diverse approaches across different countries, with a focus on specific crops, such as cacao in Colombia and Ecuador, and traditional management practices in Peru. This diversity reflects the adaptation of AFSs to local conditions and cultural contexts.

Emphasis on fruit tree species: Regardless of the predominant type, AFSs commonly include fruit tree species, highlighting the importance of this system as an alternative to meet family needs. Evidence shows that farmers require external support to consolidate resilient systems in the Amazon biome.

Scientific gaps: Further studies should explore the connection between AFSs adoption, consolidation, and management, as well as the relationship between diversity and yield. The scarcity of data on AFSs composition and dynamics, except for homegardens, reinforces the need for further research on this topic, primarily considering different contexts and management practices, with an emphasis on including the perspective of family farmers.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land14030524/s1, Table S1: Complete list of articles assessed in the bibliometric review; Table S2: Description of the information extracted from the analyzed articles, organized into categories including identification, objectives, methodology, location, botanical composition, diversity indicators, temporal dynamics, social aspects, perceptions, incentives, challenges, advantages, and key conclusions of studies on agroforestry systems in the Amazon biome.

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References

1. Demie, G.; Negash, M.; Asrat, Z.; Bohdan, L. Perennial plant species composition and diversity in relation to socioecological variables and agroforestry practices in central Ethiopia. *Agrofor. Syst.* **2024**, *98*, 461–476. [CrossRef]
2. Udawatta, R.P.; Rankoth, L.M.; Jose, S. Agroforestry for biodiversity conservation. *Agrofor. Ecosyst. Serv.* **2021**, *11*, 245–274.
3. Nair, P.R.; Kumar, B.M.; Nair, V.D.; Nair, P.R.; Kumar, B.M.; Nair, V.D. Agroforestry for Biodiversity Conservation. *Introd. Agrofor. Four Decades Sci. Dev.* **2021**, 539–562.
4. Torralba, M.; Fagerholm, N.; Burgess, P.J.; More, G.; Plieninger, T. Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agric. Ecosyst. Environ.* **2016**, *230*, 150–161. [CrossRef]
5. Wilson, M.; Lovell, E.S. Agroforestry—The Next Step in Sustainable and Resilient Agriculture. *Sustainability* **2016**, *8*, 574. [CrossRef]
6. Villanueva-González, C.E.; Pérez-Olmos, K.N.; Mollinedo, M.S.; Lojka, B. Exploring agroforestry and food security in Latin America: A systematic review. *Environ. Dev. Sustain.* **2024**, 1–17. [CrossRef]
7. Coulibaly, J.Y.; Chiputwa, B.; Nakelse, T.; Kundhlande, G. Adoption of agroforestry and the impact on household food security among farmers in Malawi. *Agric. Syst.* **2017**, *155*, 52–69. [CrossRef]
8. Singh, P.; Choudhary, B.B.; Dwivedi, R.P.; Arunachalam, A.; Kumar, S.; Dev, I. Agroforestry improves food security and reduces income variability in semi-arid tropics of central India. *Agrofor. Syst.* **2023**, *97*, 509–518. [CrossRef]
9. Nair, P.R. Agroforestry systems and environmental quality: Introduction. *J. Environ. Qual.* **2011**, *40*, 784–790. [CrossRef]
10. Miccolis, A.; Peneireiro, F.M.; Marques, H.R.; Vieira, D.L.M.; Arco-Verde, M.F.; Hoffmann, M.; Rehder, T.; Pereira, A.V.B. *Restauração Ecológica Com Sistemas Agroflorestais: Como Conciliar Conservação Com Produção: Opções Para Cerrado e Caatinga*; Agriculture Applications Service: Tokyo, Japan, 2016.
11. Fearnside, P.M. Valoração do estoque de serviços ambientais como estratégia de desenvolvimentoEstado do Amazonas. *Inclusão Soc.* **2018**, *12*, 141–151.
12. Lapola, D.M.; Pinho, P.; Barlow, J.; Aragão, L.; Berenguer, E.; Carmenta, R.; Liddy, H.; Seixas, H.; Silva, C.; Silva-Junior, C.; et al. The drivers and impacts of Amazon forest degradation. *Science* **2023**, *379*, eabp8622. [CrossRef] [PubMed]
13. Peres, C.A.; Campos-Silva, J.; Ritter, C.D. Environmental policy at a critical junction in the Brazilian Amazon. *Trends Ecol. Evol.* **2023**, *38*, 113–116. [CrossRef] [PubMed]
14. Cabral, B.F.; Yanai, A.M.; de Alencastro Graça, P.M.L.; Escada, M.I.S.; de Almeida, C.M.; Fearnside, P.M. Amazon deforestation: A dangerous future indicated by patterns and trajectories in a hotspot of forest destruction in Brazil. *J. Environ. Manag.* **2024**, *354*, 120354. [CrossRef] [PubMed]
15. Villa, P.M.; Martins, S.V.; de Oliveira Neto, S.N.; Rodrigues, A.C.; Hernández, E.P.; Kim, D.-G. Policy forum: Shifting cultivation and agroforestry in the Amazon: Premises for REDD+. *For. Policy Econ.* **2020**, *118*, 102217. [CrossRef]
16. Martins, W.B.R.; de Matos Rodrigues, J.I.; de Oliveira, V.P.; Ribeiro, S.S.; Barros, W.D.S.; Schwartz, G. Mining in the Amazon: Importance, impacts, and challenges to restore degraded ecosystems. Are we on the right way? *Ecol. Eng.* **2022**, *174*, 106468. [CrossRef]
17. Thiesmeier, A.; Zander, P. Can agroforestry compete? A scoping review of the ecomic performance of agroforestry practices in Europe and rth America. *For. Policy Ecomics* **2023**, *150*, 102939. [CrossRef]
18. Nerlich, K.; Graeff-Hönninger, S.; Claupein, W. Agroforestry in Europe: A review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. *Agrofor. Syst.* **2013**, *2*, 475–492. [CrossRef]
19. Fahad, S.; Chavan, S.B.; Chichaghare, A.R.; Uthappa, A.R.; Kumar, M.; Kakade, V.; Pradhan, A.; Jinger, D.; Rawale, G.B.; Yadav, D.K.; et al. Agroforestry systems for soil health improvement and maintenance. *Sustainability* **2022**, *14*, 14877. [CrossRef]
20. Elevitch, C.R.; Mazaroli, D.N.; Ragone, D. Agroforestry standards for regenerative agriculture. *Sustainability* **2018**, *10*, 3337. [CrossRef]
21. Farinaccio, F.M.; Ceccon, E.; Pérez, D.R. Could agroforestry restore ecosystem services in arid lands? An analysis through the weight of the evidence approach. *Agrofor. Syst.* **2024**, *98*, 507–521. [CrossRef]

22. Abbas, F.; Hammad, H.M.; Fahad, S.; Cerdà, A.; Rizwan, M.; Farhad, W.; Ehsan, S.; Bakhat, H.F. Agroforestry: A sustainable environmental practice for carbon sequestration under the climate change scenarios—A review. *Environ. Sci. Pollut. Res.* **2017**, *24*, 11177–11191. [CrossRef] [PubMed]
23. Sagastuy, M.; Krause, T. Agroforestry as a biodiversity conservation tool in the atlantic forest? Motivations and limitations for small-scale farmers to implement agroforestry systems in rth-eastern Brazil. *Sustainability* **2019**, *11*, 6932. [CrossRef]
24. Tranchina, M.; Reubens, B.; Frey, M.; Mele, M.; Manti, A. What challenges impede the adoption of agroforestry practices? A global perspective through a systematic literature review. *Agrofor. Syst.* **2024**, *98*, 1–21. [CrossRef]
25. Agroflorestal, R.B. *Manual Agroflorestal Para a Amazônia*; Rebraf, Ed.; Embrapa: Brasília, DF, Brazil, 1996; Volume 1.
26. Arksey, H.; O'Malley, L. Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 19–32. [CrossRef]
27. Cordeiro, L.; Soares, C.B. Revisão de escopo: Potencialidades para a síntese de metodologias utilizadas em pesquisa primária qualitativa. *Bol. Do Inst. Saúde-BIS* **2019**, *20*, 37–43. [CrossRef]
28. Martin, G.P.; Jenkins, D.A.; Bull, L.; Sisk, R.; Lin, L.; Hulme, W.; Wilson, A.; Wang, W.; Barrowman, M.; Sammut-Powell, C.; et al. Toward a framework for the design, implementation, and reporting of methodology scoping reviews. *J. Clin. Epidemiol.* **2020**, *127*, 191–197. [CrossRef]
29. Pham, M.T.; Rajić, A.; Greig, J.D.; Sargeant, J.M.; Papadopoulos, A.; McEwen, S.A. A scoping review of scoping reviews: Advancing the approach and enhancing the consistency. *Res. Synth. Methods* **2014**, *5*, 371–385. [CrossRef]
30. Tricco, A.C.; Lillie, E.; Zarin, W.; O'Brien, K.K.; Colquhoun, H.; Levac, D.; Moher, D.; Peters, M.D.J.; Horsley, T.; Weeks, L.; et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Ann. Intern. Med.* **2018**, *169*, 467–473. [CrossRef]
31. Peters, M.D.; Godfrey, C.M.; Khalil, H.; McInerney, P.; Parker, D.; Soares, C.B. Guidance for conducting systematic scoping reviews. *JBI Evid. Implement.* **2015**, *13*, 141–146. [CrossRef]
32. Munn, Z.; Peters, M.D.; Stern, C.; Tufanaru, C.; McArthur, A.; Aromataris, E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med. Res. Methodol.* **2018**, *18*, 1–7. [CrossRef]
33. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, 71. [CrossRef] [PubMed]
34. de Sousa, W.L.; Zacardi, D.M.; Vieira, T.A. Traditional ecological kwledge of fishermen: People contributing towards environmental preservation. *Sustainability* **2022**, *14*, 4899. [CrossRef]
35. Martín-Martín, A.; Orduna-Malea, E.; Thelwall, M.; López-Cózar, E.D. Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *J. Informetr.* **2018**, *12*, 1160–1177. [CrossRef]
36. Zhu, J.; Liu, W. A tale of two databases: The use of Web of Science and Scopus in academic papers. *Scientometrics* **2020**, *123*, 321–335. [CrossRef]
37. Levis, C.; Flores, B.M.; Moreira, P.A.; Luize, B.G.; Alves, R.P.; Franco-Moraes, J.; Lins, J.; Konings, E.; Peña-Claros, M.; Bongers, F.; et al. How people domesticated Amazonian forests. *Front. Ecol. Evol.* **2018**, *5*, 171. [CrossRef]
38. Coomes, O.T.; Ban, N. Cultivated plant species diversity in home gardens of an Amazonian peasant village in rtheastern Peru. *Ecomic Bot.* **2004**, *58*, 420–434. [CrossRef]
39. Lamont, S.R.; Eshbaugh, W.H.; Greenberg, A.M. Species composition, diversity, and use of homegardens among three Amazonian villages. *Ecomic Bot.* **1999**, *53*, 312–326. [CrossRef]
40. Jacobi, J.; Andres, C.; Schneider, M.; Pillco, M.; Calizaya, P.; Rist, S. Carbon stocks, tree diversity, and the role of organic certification in different cocoa production systems in Alto Beni, Bolivia. *Agrofor. Syst.* **2014**, *88*, 1117–1132. [CrossRef]
41. Caballero-Serra, V.; McLaren, B.; Carrasco, J.C.; Alday, J.G.; Fiallos, L.; Amigo, J.; Onaindia, M. Traditional ecological kwledge and medicinal plant diversity in Ecuadorian Amazon home gardens. *Glob. Ecol. Conserv.* **2019**, *17*, e00524.
42. Ban, N.; Coomes, O.T. Home gardens in Amazonian Peru: Diversity and exchange of planting material. *Geogr. Rev.* **2004**, *94*, 348–367. [CrossRef]
43. Díaz-Reviriego, I.; González-Segura, L.; Fernández-Llamazares, Á.; Howard, P.L.; Molina, J.L.; Reyes-García, V. Social organization influences the exchange and species richness of medicinal plants in Amazonian homegardens. *Ecol. Soc.* **2016**, *21*, 1. [CrossRef] [PubMed]
44. Perrault-Archambault, M.; Coomes, O.T. Distribution of agrobiodiversity in home gardens along the Corrientes River, Peruvian Amazon. *Econ. Bot.* **2008**, *62*, 109–126. [CrossRef]
45. Smith, N.J.; Falesi, I.C.; de Alvim, T.P.; Serrão, E.A.S. Agroforestry trajectories among smallholders in the Brazilian Amazon: Invation and resiliency in pioneer and older settled areas. *Ecol. Ecomics* **1996**, *18*, 15–27. [CrossRef]
46. Coomes, O.T.; Burt, G.J. Indigeus market-oriented agroforestry: Dissecting local diversity in western Amazonia. *Agrofor. Syst.* **1997**, *37*, 27–44. [CrossRef]

47. Vera-Vélez, R.; Cota-Sánchez, J.H.; Grijalva-Olmedo, J. Beta diversity and fallow length regulate soil fertility in cocoa agroforestry in the rthern Ecuadorian Amazon. *Agric. Syst.* **2021**, *187*, 103020. [CrossRef]
48. Dias, C.H.S.; Miranda, I.S.; Vale, I.D.O.; Santos, G.G.A.; Neto, S.V.C.O.T.; Costa, L.G.S. Differentiating diversity among different land cover types in the eastern Amazon. *Acta Amaz.* **2023**, *53*, 271–280. [CrossRef]
49. Pompeu, G.D.S.S.; Rosa, L.S.; Modesto, R.S.; Vieira, T.A. Adoption of agroforestry systems by smallholders in Brazilian Amazon. *Trop. Subtrop. Agroecosystems* **2012**, *15*, 165–172. [CrossRef]
50. Braga, D.P.; Domene, F.; Gandara, F.B. Shade trees composition and diversity in cacao agroforestry systems of southern Pará, Brazilian Amazon. *Agrofor. Syst.* **2019**, *93*, 1409–1421. [CrossRef]
51. Perz, S.G. The effects of household asset endowments on agricultural diversity among frontier colonists in the Amazon. *Agrofor. Syst.* **2005**, *63*, 263–279. [CrossRef]
52. Vebrova, H.; Lojka, B.; Husband, T.P.; Zans ME, C.; Van Damme, P.; Rollo, A.; Kalousova, M. Tree diversity in cacao agroforests in San Alejandro, Peruvian Amazon. *Agrofor. Syst.* **2014**, *88*, 1101–1115. [CrossRef]
53. Cardozo, E.G.; Rousseau, G.X.; Celenta, D.; Salazar, H.F.; Gehring, C. Effect of species richness and vegetation structure on carbon storage in agroforestry systems in the Southern Amazon of Bolivia. *Rev. Biol. Trop.* **2018**, *66*, 1481–1495.
54. Jadán, O.; Jara, M.C.; Torres, B.; Selesi, D.; Ramos, D.A.V.; Günter, S. Influence of tree cover on diversity, carbon sequestration and productivity of cocoa systems in the Ecuadorian Amazon. *Programa Cambio Climático Cuencas (PCCC)* **2015**, *3*, 35–47. [CrossRef]
55. Wezel, A.; Ohl, J. Does remoteness from urban centres influence plant diversity in homegardens and swidden fields?: A case study from the Matsiguenka in the Amazonian rain forest of Peru. *Agrofor. Syst.* **2005**, *65*, 241–251. [CrossRef]
56. Gervazio, W.; Yamashita, O.M.; Roboredo, D.; Bergamasco, S.M.P.P.; Felito, R.A. Urban agroforestry home gardens in southern Amazon: The agrobiodiversity guardians? *Ciência Florest.* **2022**, *32*, 163–186. [CrossRef]
57. Siviero, A.; Delunardo, T.A.; Haverroth, M.; Oliveira, L.C.; Mendonça, A.M.S. Medicinal plants in urban backyards in Rio Branco, Acre. *Rev. Bras. Plantas Med.* **2012**, *14*, 598–610. [CrossRef]
58. Steward, A. Reconfiguring agrobiodiversity in the Amazon estuary: Market integration, the Açaí trade and smallholders' management practices in Amapá, Brazil. *Hum. Ecol.* **2013**, *41*, 827–840. [CrossRef]
59. Thomas, E.; Van Damme, P. Plant use and management in homegardens and swiddens: Evidence from the Bolivian Amazon. *Agrofor. Syst.* **2010**, *80*, 131–152. [CrossRef]
60. Siviero, A.; Delunardo, T.A.; Haverroth, M.; de Oliveira, L.C.; Mendonça, Â.M.S. Cultivation of food species in urban gardens in Rio Branco, Acre, Brazil. *Acta Bot. Bras.* **2011**, *25*, 549–556. [CrossRef]
61. Garavito, G.; Clavijo, R.; Luengas, P.; Palacios, P.; Arias, M.H. Assessment of biodiversity goods for the sustainable development of the chagra in an indigeus community of the Colombian Amazon: Local values of crops. *J. Ethbiol. Ethmed.* **2021**, *17*, 23.
62. Iverson, A.L.; Iverson, L.R. Contrasting Indigeus Urarina and Mestizo Farms in the Peruvian Amazon: Plant Diversity and Farming Practices. *J. Ethbiol.* **2021**, *41*, 517–534.
63. Vera, V.R.R.; Cota-Sánchez, J.H.; Olmedo, J.E.G. Biodiversity, dynamics, and impact of chakras on the Ecuadorian Amazon. *J. Plant Ecol.* **2019**, *12*, 34–44. [CrossRef]
64. Vargas-Tierras, Y.B.; Prado-Beltrán, J.K.; Nicolalde-Cruz, J.R.; Casaves, F.; de Virginio-Filho, E.M.; Viera-Arroyo, W.F. Characterization and role of Amazonian fruit crops in family farms in the provinces of Sucumbíos and Orellana (Ecuador). *Cienc. Y Teclogía Agropecu.* **2018**, *19*, 501–515.
65. de Souza, N.B.; Junqueira, A.B.; Struik, P.C.; Stomph, T.; Clement, C.R. The role of fertile anthropogenic soils in the conservation of native and exotic agrobiodiversity in Amazonian homegardens. *Agrofor. Syst.* **2019**, *93*, 471–482. [CrossRef]
66. Leitão-Barboza, M.S.; Kawa, N.C.; Junqueira, A.B.; Oyuela-Caycedo, A. Open air laboratories: Amazonian home gardens as sites of experimentation, collaboration, and negotiation across time. *J. Anthropol. Archaeol.* **2021**, *62*, 101302. [CrossRef]
67. Junqueira, A.B.; Souza, N.B.; Stomph, T.J.; Almekinders, C.J.; Clement, C.R.; Struik, P.C. Soil fertility gradients shape the agrobiodiversity of Amazonian homegardens. *Agric. Ecosyst. Environ.* **2016**, *221*, 270–281. [CrossRef]
68. Lins, J.; Lima, H.P.; Baccaro, F.B.; Kinupp, V.F.; Shepard, G.H., Jr.; Clement, C.R. Pre-Columbian floristic legacies in modern homegardens of Central Amazonia. *PLoS ONE* **2015**, *10*, e0127067. [CrossRef]
69. Fraser, J.A.; Junqueira, A.B.; Clement, C.R. Homegardens on Amazonian dark earths, n-anthropogenic upland, and floodplain soils along the Brazilian middle Madeira river exhibit diverging agrobiodiversity. *Econ. Bot.* **2011**, *65*, 1–12. [CrossRef]
70. Major, J.; Clement, C.R.; DiTommaso, A. Influence of market orientation on food plant diversity of farms located on Amazonian dark earth in the region of Manaus, Amazonas, Brazil. *Econ. Bot.* **2005**, *59*, 77–86. [CrossRef]
71. Robiglio, V.; Reyes, M. Restoration through formalization? Assessing the potential of Peru's Agroforestry Concessions scheme to contribute to restoration in agricultural frontiers in the Amazon region. *World Dev. Perspect.* **2016**, *3*, 42–46. [CrossRef]
72. Solis, R.; Vallejos-Torres, G.; Arévalo, L.; Marín-Díaz, J.; Ñique-Alvarez, M.; Engedal, T.; Bruun, T.B. Carbon stocks and the use of shade trees in different coffee growing systems in the Peruvian Amazon. *J. Agric. Sci.* **2020**, *158*, 450–460. [CrossRef]
73. Kieck, J.S.; Zug, K.L.; Yupanqui, H.H.; Aliaga, R.G.; Cierjacks, A. Plant diversity effects on crop yield, pathogen incidence, and secondary metabolism on cacao farms in Peruvian Amazonia. *Agric. Ecosyst. Environ.* **2016**, *222*, 223–234. [CrossRef]

74. Hoch, L.; Pokorny, B.; De Jong, W. How successful is tree growing for smallholders in the Amazon? *Int. For. Rev.* **2009**, *11*, 299–310. [CrossRef]
75. Browder, J.O.; Wynne, R.H.; Pedlowski, M.A. Agroforestry diffusion and secondary forest regeneration in the Brazilian Amazon: Further findings from the Rondônia Agroforestry Pilot Project (1992–2002). *Agrofor. Syst.* **2005**, *65*, 99–111. [CrossRef]
76. Pauletto, D.; Guerreiro Martorano, L.; Lopes, L.S.S.; de Matos Bentes, M.P.; Vieira, T.A.; de Sousa Oliveira, G.; Sousa, V.; da Silva, Á.F.; da Silva Ferreira de Lima, P.; Tribuzy, A.S.; et al. Plant composition and species use in agroforestry homegardens in the Eastern Amazon, Brazil. *Sustainability* **2023**, *15*, 11269. [CrossRef]
77. de Almeida, L.S.; Gama, J.R.V. Quintais agroflorestais: Estrutura, composição florística e aspectos socioambientais em área de assentamento rural na Amazônia brasileira. *Ciênc. Florest* **2014**, *24*, 1041–1053. [CrossRef]
78. de Castro, F.; Futemma, C. Farm Kwledge Co-Production at an Old Amazonian Frontier: Case of the Agroforestry System in Tomé-Açu, Brazil. *Rural Landsc. Soc. Environ. Hist* **2021**, *8*, 3. [CrossRef]
79. Futemma, C.; De Castro, F.; Brondizio, E.S. Farmers and social invations in rural development: Collaborative arrangements in eastern Brazilian Amazon. *Land Use Policy* **2020**, *99*, 104999. [CrossRef]
80. Salazar, J.C.S.; Bieng, M.A.N.; Melgarejo, L.M.; Di Rienzo, J.A.; Casaves, F. First typology of cacao (*Theobroma cacao* L.) systems in Colombian Amazonia, based on tree species richness, capy structure and light availability. *PLoS ONE* **2018**, *13*, e0191003.
81. Garcia, B.N.R.; Vieira, T.A.; de Oliveira, A.F. Tree and shrub diversity in agroforestry homegardens in rural community in eastern amazon. *Floresta* **2017**, *47*, 543. [CrossRef]
82. Tremblay, S.; Lucotte, M.; Revéret, J.-P.; Davidson, R.; Mertens, F.; Passos, C.J.S.; Romaña, C.A. Agroforestry systems as a profitable alternative to slash and burn practices in small-scale agriculture of the Brazilian Amazon. *Agrofor. Syst.* **2015**, *89*, 193–204. [CrossRef]
83. Couly, C.; Sist, P. Use and kwledge of forest plants among the Ribeirinhos, a traditional Amazonian population. *Agrofor. Syst.* **2013**, *87*, 543–554. [CrossRef]
84. De Jong, W. Swidden-fallow agroforestry in Amazonia: Diversity at close distance. *Agrofor. Syst.* **1996**, *34*, 277–290. [CrossRef]
85. Caballero-Serra, V.; Onaindia, M.; Alday, J.G.; Caballero, D.; Carrasco, J.C.; McLaren, B.; Amigo, J. Plant diversity and ecosystem services in Amazonian homegardens of Ecuador. *Agric. Ecosyst. Environ.* **2016**, *225*, 116–125. [CrossRef]
86. Yamada, M.; Gholz, H.L. An evaluation of agroforestry systems as a rural development option for the Brazilian Amazon. *Agrofor. Syst.* **2002**, *55*, 81–87. [CrossRef]
87. Schroth, G.; Garcia, E.; Griscom, B.W.; Teixeira, W.G.; Barros, L.P. Commodity production as restoration driver in the Brazilian Amazon? Pasture re-agro-forestation with cocoa (*Theobroma cacao*) in southern Pará. *Sustain. Sci.* **2016**, *11*, 277–293. [CrossRef]
88. Araoz, E.G.E.; Giersch, L.V.; Martínez, J.C.V.; Latorre, M.F.; Condori, W.G.L.; Peralta, J.N.P. Scientific production in the Scopus database of a public university in the Peruvian Amazon. *Arch. Venezolas Farmacol. Y Ter.* **2022**, *41*, 437–442.
89. Théry, H. Situações da AmazôniaBrasil econtinente. *Estud. Avançados* **2005**, *19*, 37–49. [CrossRef]
90. Blinn, C.E.; Browder, J.O.; Pedlowski, M.A.; Wynne, R.H. Rebuilding the Brazilian rainforest: Agroforestry strategies for secondary forest succession. *Appl. Geogr.* **2013**, *43*, 171–181. [CrossRef]
91. Marquardt, K.; Milestad, R.; Salomonsson, L. Improved fallows: A case study of an adaptive response in Amazonian swidden farming systems. *Agric. Hum. Values* **2013**, *30*, 417–428. [CrossRef]
92. Lagneaux, E.; Jansen, M.; Quaedvlieg, J.; Zuidema, P.A.; Anten, N.P.; Garcia, M.; García Roca, M.R.; Kettle, C.J. Diversity bears fruit: Evaluating the ecomic potential of undervalued fruits for an agroecological restoration approach in the Peruvian Amazon. *Sustainability* **2021**, *13*, 4582. [CrossRef]
93. Goñas, M.; Rubio, K.B.; Briceño, N.B.R.; Pariente-Mondragón, E.; Oliva-Cruz, M. Tree diversity in agroforestry systems of native fine-aroma cacao, Amazonas, Peru. *PLoS ONE* **2022**, *17*, e0275994. [CrossRef] [PubMed]
94. Rayol, B.P.; de Miranda, S.I. Homegardens in the Central Amazon: Characterization, social importance and agrobiodiversity. *Cienc. Florest.* **2019**, *29*, 1614–1629. [CrossRef]
95. Neto, M.M.O.; de Navegantes Alves, F.L.; Schwartz, G. Agroforestry systems associated with natural regeneration: Alternatives practiced by family-farmers of Tomé-Açu, Pará. *Sustain. Debate/Sustentabilidade Debate* **2022**, *13*, 2022.
96. Rayol, B.P.; Vale, I.D.; Miranda, I.S. Tree and palm diversity in homegardens in the Central Amazon. *Agrofor. Syst.* **2019**, *93*, 515–529. [CrossRef]
97. Palheta, I.C.; Tavares-Martins, A.C.C.; Lucas, F.C.A.; Jardim, M.A.G. Ethbotanical study of medicinal plants in urban home gardens in the city of Abaetetuba, Pará state, Brazil. *Boletín Latiamerica Y Caribe Plantas Med. Y Aromáticas* **2017**, *16*, 206–262.
98. Cardozo, E.G.; Muchavisoy, H.M.; Silva, H.R.; Zelarayán ML, C.; Leite MF, A.; Rousseau, G.X.; Gehring, C. Species richness increases income in agroforestry systems of eastern Amazonia. *Agrofor. Syst.* **2015**, *89*, 901–916. [CrossRef]
99. Sills, E.O.; Caviglia-Harris, J.L. Evaluating the long-term impacts of promoting 'green' agriculture in the Amazon. *Agric. Ecomics* **2015**, *46*, 83–102. [CrossRef]
100. Almeida, A.; Ferreira, J.N.; Coudel, E. Perception of ecosystem services by family farmers in the municipality of Irituia/PA, Eastern Amazon: Subsidies for forest restoration. *Desenvolv. Meio Ambiente* **2023**, *62*, 1423–1438.

101. Oliveira, J.S.R.; Kato, O.R.; Oliveira, T.F.; Queiroz, J.C.B. Evaluation of sustainability in Eastern Amazon under proambiente program. *Agrofor. Syst.* **2010**, *78*, 185–191. [CrossRef]
102. Ntawuruhunga, D.; Ngowi, E.E.; Mangi, H.O.; Salanga, R.J.; Shikuku, K.M. Climate-smart agroforestry systems and practices: A systematic review of what works, what doesn't work, and why. *For. Policy Econ.* **2023**, *150*, 102937. [CrossRef]
103. Wiersberg, T.; Callo-Concha, D.; Ewert, F. Pitfall or priority drift? Participatory tree domestication programs: The case of agroforestry in the Peruvian Amazon. *J. Sustain. For.* **2016**, *35*, 486–499. [CrossRef]
104. Sollen-rrlin, M.; Ghaley, B.B.; Rintoul, N.L.J. Agroforestry benefits and challenges for adoption in Europe and beyond. *Sustainability* **2020**, *12*, 7001. [CrossRef]