# Bibliometric analysis of water resource quality conservation in agroecological structures

## Análisis bibliométrico de la conservación de la calidad del recurso hídrico en estructuras agroecológicas

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***Abstract*— Water conservation is essential for agricultural sustainability and adaptation to climate change. Agroforestry systems, which integrate trees and sometimes animals in the same production unit, offer hydrological benefits superior to those of conventional agricultural systems, positioning them as a key strategy for water resource management in agricultural areas. However, in Colombia, publications on the subject are limited. Understanding their dynamics is crucial to preserving water quality, especially in sectors such as fish farming, which is vital for biodiversity and ecosystem services. This study aimed to perform a bibliometric and systematic analysis of the Web of Science (WoS) database; the data were examined using graph theory and specialized tools such as VOSviewer and Tree of Science, investigating in diverse perspectives that explore the association between agroecological structures, water quality and conservation. The analysis was structured in three categories: roots (classic), trunk (structural) and branches-leaves (recent); inclusion and exclusion criteria were also applied, adopting certain guidelines of the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses); 61 relevant references were identified, highlighting Chen, Hung-Chih as the most cited author, and the United States and China as the leading countries in research on the subject. It was concluded that agroforestry systems are fundamental to conserve and improve water quality, promoting ecological agriculture and fish farming, welfare and sustainability, contributing to regional economic development; furthermore, there are knowledge gaps and it is necessary to have policies for the construction, research and implementation of these systems.**

***Index Terms*— Agroecological systems, ecosystem services, pollutants, water conservation, water quality.**

***Resumen*— La conservación del recurso hídrico es esencial para la sostenibilidad agrícola y la adaptación al cambio climático. Los sistemas agroforestales, que integran árboles y en ocasiones animales en una misma unidad de producción, ofrecen beneficios hidrológicos superiores a los de los sistemas agrícolas convencionales, posicionándolos como una estrategia clave para la gestión de recursos hídricos en áreas agrícolas. Sin embargo, en Colombia, las publicaciones sobre revisión del tema son limitadas. Comprender su dinámica es crucial para preservar la calidad del agua, especialmente en sectores como el piscícola, vital para la biodiversidad y los servicios ecosistémicos. Este estudio tuvo como objetivo realizar un análisis bibliométrico y sistemático de la base de datos Web of Science (WoS); los datos fueron examinados utilizando la teoría de grafos y herramientas especializadas como VOSviewer y Tree of Science, investigando en diversas perspectivas que exploran la asociación entre estructuras agroecológicas, calidad y conservación del agua. Se estructuró el análisis en tres categorías: raíces (clásicos), tronco (estructurales) y ramas-hojas (recientes) de igual forma se aplicó criterios de inclusión y excusión adoptando ciertas directrices del protocolo PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses); se identificaron 61 referencias relevantes, destacando a Chen, Hung-Chih como el autor más citado, y a Estados Unidos y China como los países líderes en investigaciones sobre el tema. Se concluyó que los sistemas agroforestales son fundamentales para conservar y mejorar la calidad del agua, promoviendo la agricultura y piscicultura ecológica, el bienestar y la sostenibilidad, aportando al desarrollo económico regional; además que existen brechas de conocimiento y es necesario que existan políticas para la construcción, investigación e implementación de estos sistemas.**

***Palabras claves*— Calidad del agua, conservación del agua, contaminantes, servicios ecosistémicos, sistemas agroecológicos.**

## I. Introduction

WATER is an essential resource for life and agricultural production, the quality of which is critical to the health of ecosystems and human communities. Without clean water, fundamental activities such as irrigation, livestock raising, fish farming and the maintenance of ecosystem services are seriously compromised.

However, water quality can deteriorate due to various human activities, especially those related to intensive agriculture. Excessive use of fertilizers, pesticides, and other agrochemicals leads to leaching of nutrients into groundwater, surface runoff that contaminates water bodies with sediments and chemicals, and soil erosion, which increases water turbidity and reduces sunlight penetration. In addition, the use of untreated wastewater for irrigation represents a significant risk to water security and public health.

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All of the above leads to the quest for water quality conservation, which is crucial to ensure agricultural

sustainability, protect the health of populations and preserve ecosystems. Aquatic systems require clean water to maintain biodiversity and provide essential services such as climate regulation and natural water filtration. In addition, the availability of quality water plays a key role in climate change adaptation, as healthy ecosystems are more resilient to extreme weather events.

To mitigate the negative impact of agricultural activities on water quality, several sustainable management strategies have been developed. These include agroforestry, integrated pest management, efficient fertilizer use, wastewater recycling, and riparian zone protection. The implementation of these practices is essential to ensure access to clean water in the future and to promote the sustainability of agricultural and natural systems.

In this context, bibliometric analysis is presented as a valuable tool to consolidate and evaluate scientific knowledge in this area. By means of statistical methods, it makes it possible to analyze academic production, identify research trends and evaluate the impact of published studies. According to Gómez, Gutiérrez and Pinzón (2005), cited in Gaitán Sánchez et al. [1], this approach facilitates obtaining relevant data on citations, authors, institutions and countries with the highest scientific production in a specific topic.

Bibliometric indicators fulfill two key functions: descriptive, which characterizes the state of knowledge in each area, and evaluative, which assesses this state from a specific perspective (Gómez, Gutiérrez & Pinzón, 2005, cited in Gaitán Sánchez et al., [1]).

To develop this research, a search was conducted in the Web of Science (WoS) database using the search terms: “Agroecological Structure*” OR “Main Agroecological Structure” OR “Agroecological Planning” OR “Agroecological System*” OR “Agroforestry System*” (Topic) and “water quality” OR “water conservation”. From this search, 61 references were obtained and analyzed using the WoS “Results Analyzer” tool, which made it possible to examine frequencies and generate relationship matrices, subsequently exported to Excel for detailed analysis. Additionally, the VOSviewer tool facilitated the graphical visualization of interaction networks between authors, countries and other key descriptors.

The search strategy was precisely designed to gather relevant scientific literature on the relationship between agroecological structures and water conservation and quality, to explore the next two research questions:

What has been the evolution of scientific knowledge on agroforestry systems and contributions to water quality and/or conservation?

What are the lines of research and future perspectives between agroforestry systems and water quality and/or conservation?

The objective of this research was to conduct a bibliometric and systematic analysis on water quality and/or conservation in agroecological structures, using the WoS database as the main source. To organize the documents obtained, the Tree of Science tool [2] was used, whose tree diagram categorizes the publications according to their relevance: the roots represent the classic documents, the trunk groups the structural studies, and the branches and leaves correspond to the most recent and emerging articles on the subject.

This study contributes to the understanding of the current state of research at the intersection between agroecology and water quality, providing a solid foundation for future lines of research and the development of sustainable management strategies in the agricultural sector.

Despite the increasing attention on agroecology and water management, the scientific literature still presents a significant gap in the detailed understanding of how agroecological structures can optimize water conservation at different spatial and temporal scales. In particular, there is a lack of studies that quantitatively and qualitatively integrate the impact of these structures on improving water quality and water efficiency in diverse agricultural systems. In addition, the interaction between agroecological practices and climate change in relation to water conservation is still a developing area of research.

This study is relevant both locally and globally, as challenges related to agricultural water conservation are common in multiple regions of the world. In a local context, the results can guide water management policies and sustainability strategies tailored to specific ecosystems, contributing to improve the resilience of agricultural communities. At the global level, bibliometric analysis has facilitated the exchange of knowledge between different regions and productive contexts.

## II. Type of Study and Analysis Material

### A. *Type of study and analysis material*

The bibliometric analysis was performed using data extracted from the Web of Science (WoS) database, chosen for being one of the most recognized sources for the evaluation of scientific production. This platform includes journals of great prestige and high visibility in multiple areas of knowledge, Archambault, (2009), cited in Gaitán Sánchez et al., [1]

The search was carried out using the following equation: “Agroecological Structure*” OR “Main Agroecological Structure” OR “Agroecological Planning” OR “Agroecological System*” OR “Agroforestry System*” (Topic) and “water quality ‘OR ’water conservation” (Topic) and Article or Review Article (Document Types), taking into account only articles and review articles, in addition to a window of observation between 2014 and 2023 to broaden the panorama and analyze research and innovations.

### B. *Bibliometric Variables*

In the initial phase, the following bibliometric indicators were defined: number of publications, countries, authors and their connections, academic institutions and total number of citations. Relationship and collaboration indicators were also considered, with the aim of creating thematic maps reflecting the interactions between authors and countries, as well as the co-occurrence of the selected keywords.

*C. Bibliometric Data Collection and Analysis*

Data collection was carried out using the established search equation, followed by downloading the records in plain text format from the Web of Science (WoS) database. To manage bibliometric indicators, the WoS "Analyze Results" and VOSviewer tools were used, while frequency calculations and visual representations were performed using tables and graphs in Microsoft Excel.

*D. Systematic Analysis of Collected Documents*

With the 61 records obtained in WoS, metrics related to the degree of input, degree of output, and intermediation were evaluated, which made it possible to classify the research using the metaphor of trees [3]. From this analogy, three key categories emerge. The first is the "Root" (high centrality), which refers to classic literature or research that possesses dominant theoretical importance within the field of study. These publications are frequently cited, although not necessarily referenced by other authors [4]. The second category corresponds to the "Main Body" (high intermediation), which includes those articles that are not only cited, but also serve as references in works cited by others [5], this section constitutes a structured work that combines fundamental classical theory with current research. Last are the "Branches and Leaves" (high out-degree), which represent recent articles focused on citing other studies and reflecting current trends within the field's research framework. These publications, also called "perspectives," delineate emerging research fronts and articles [4]. This methodology has been previously validated and applied in previous studies [6] [7]. Likewise, the results extracted from the WoS database were systematized in an Excel spreadsheet, analyzing key information such as titles, abstracts, keywords, main findings and number of citations. Finally, with the information collected and its analysis, the main challenges to advance in the application and conservation of water quality in agroecological structures were identified.

*E. Inclusion And Exclusion Criteria*

In order to ensure accuracy, transparency and reproducibility in the selection of studies, this research adopted certain guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol [8]. The inclusion and exclusion criteria applied in the process are detailed below:

1. Inclusion criteria

**Type of publication**

Only research and review articles published in peer-reviewed scientific journals were selected, thus ensuring the validity and reliability of the data analyzed. Other forms of publication, such as conference proceedings, book chapters and gray literature, were discarded due to the absence of a rigorous peer review process.

**Thematic relevance**

Only studies that explicitly addressed the relationship between agroecological structures and water quality conservation were included. This selection criterion ensured that the literature analyzed was aligned with the research objectives, allowing for a focused and relevant analysis.

**Language**

Initially, no language restrictions were established in the search process. However, the 61 studies finally selected were published in English, since this language predominates in the international scientific literature.

**Time frame**

The review addressed studies published between 2014 and 2023, to include the most recent developments in water quality conservation and the role of major agroecological structures.

2. Exclusion criteria

**Gray literature**

Gray literature, such as reports from non-governmental organizations and conference proceedings, was discarded in order to prioritize studies published in peer-reviewed journals, thus ensuring scientific rigor.

**Selection process**

Study selection was carried out following the phases established in the PRISMA protocol, with the complementary incorporation of a bibliometric analysis through the Tree of Science platform. This integration made it possible to structure the selection process in a systematic and chronological manner, optimizing identification.

**Identification**

A search was carried out in the Web of Science database, applying the search equation specified above. Initially, a set of studies directly linked to synergies between pollinators and floral stripes was identified. Subsequently, the selected articles were subjected to a detailed analysis using the Tree of Science algorithm, which made it possible to evaluate their impact and relevance.

**Detection**

Tree of Science analyzed the initially identified studies together with their citations, generating a structured selection of key articles. These were classified into three levels: roots (seminal publications), trunks (seminal studies) and leaves (recent research). Subsequently, an independent review of titles and abstracts was conducted to discard those that did not meet the predisposed criteria.

**Eligibility**

Studies that passed the screening phase were subjected to a rigorous evaluation to verify their relevance and scientific quality. Additional exclusion criteria were applied to ensure that only the most relevant and methodologically sound papers were included in the final analysis. This process involved a detailed review of the objectives, methodological approaches and findings of each study, as well as confirmation of its publication.

**Final inclusion**

Research that met all the inclusion criteria and satisfactorily passed the previous phases were incorporated into the systematic and bibliometric analysis.

**Minimum citation threshold**

No minimum citation threshold was established as a requirement for the inclusion of studies in the systematic review. We sought to integrate both seminal research with a high impact on the scientific literature and recent studies that, although they have not yet accumulated a significant number of citations, represent advances and emerging trends in the field. During the bibliometric analysis, citation metrics were used to identify the most influential papers, classifying them within the Tree of Science (ToS) categories: roots (seminal publications), trunks (structural studies) and leaves (recent research).

## III. RESULTS

A total of 61 documents were identified in this study, in which research articles predominated with 80.33% (49 articles) followed by subject reviews with 19.67% (12 articles). It is important to mention that the search period was from January 01, 2014, to December 31, 2023.

### *A. Production indicators.*

Fig 1 shows the scientific production in the defined period, where a growing trend is evident in the dissemination of research specifically from the year 2019 to 2020 and 2022 to 2023, but at the same time a decline could be observed in the years 2017 and 2021; the year 2023 illustrates the highest number of publications reaching 11 articles being 18.033% of the reported publications. The scientific community has interest in the field of knowledge with an annual growth rate of 10.65%, from the first year of review in 2014 to 2023. The citations in the year 2014 was 1 being the lowest in the range of time taken, reaching the maximum in 2023 with a total of 364.

When analyzing the scientific production by country, the United States leads the scientific production with 15 publications, representing 24.6%, followed by China with 18%, and finally England, Greece and Spain with 6.6% each, Table 1 shows the global impact of academic production on research associated with water quality and/or conservation in agroecological structures.

In relation to the authors, 10 most representative authors were found Table II, who are categorized by the number of documents published in the database, Chen, Hung-Chih from Kunming University, who has had the most publications, followed by Liu, Wenjie, and Nettles, Jami from China University and Weyerhaeuser Company respectively, in addition, their H-index (H-index), which is used to describe the scientific output of researchers, is correlated [9], where Liu,

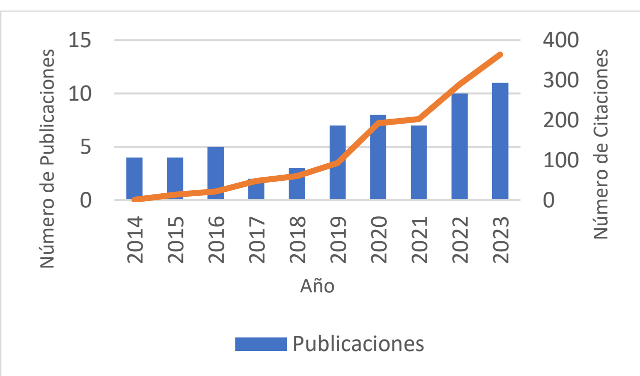


Fig. 1. Scientific production on water quality and/or conservation in agroecological structures and its products per year.

TABLE I
PRODUCTION OF ARTICLES BY COUNTRY

| *No* | *País* | *Publicaciones* | *%* |
|---|---|---|---|
| *1* | USA | 15 | 24.6% |
| *2* | CHINA | 11 | 18.0% |
| *3* | FRANCE | 8 | 13.1% |
| *4* | INDIA | 8 | 13.1% |
| *5* | GERMANY | 7 | 11.5% |
| *6* | BRAZIL | 6 | 9.8% |
| *7* | COSTA RICA | 4 | 6.6% |
| *8* | ENGLAND | 4 | 6.6% |
| *9* | GREECE | 4 | 6.6% |
| *10* | SPAIN | 4 | 6.6% |

TABLE II
MOST RELEVANT AUTHORS

| *No* | *Autor* | *Publicaciones* | *Citaciones* | *Indice H* | *Universidad* |
|---|---|---|---|---|---|
| *1* | Chen, Hung-Chih | 4 | 1810 | 25 | Kunming University |
| *2* | Liu, Wenjie | 4 | 2356 | 30 | University of Chinese Academy of Sciences |
| *3* | Nettles, Jami | 2 | 285 | 10 | Weyerhaeuser Company |
| *4* | Tian, Shiying | 2 | 649 | 11 | North Carolina State University |
| *5* | Chescheir, George M. | 2 | 1856 | 24 | North Carolina State University |
| *6* | Jiang, Xiao-Jin | 2 | 1277 | 20 | Northeast Forestry University - China |
| *7* | Cacho, Julian F. | 2 | 72 | 4 | North Carolina State University |
| *8* | Zhu, Xiai | 2 | 664 | 14 | University of Chinese Academy of Sciences |
| *9* | Wu, Junen | 2 | 844 | 15 | University of Chinese Academy of Sciences |
| *10* | Youssef, M. A. S. | 2 | 1344 | 19 | National Authority for Remote Sensing & Space Sciences (NARSS) |

Wenjie and Chen, Hung-Chih were found with an index of 30 and 25 respectively.

The journal with the highest impact in the search is SUSTAINABILITY, in second place AGROFORESTRY SYSTEMS and AGRICULTURAL SYSTEMS in third place, the journals in this review are indexed in the databases and all are part of quartile 1. Within the top 10 and with more importance are journals from Switzerland in first place, the Netherlands in second and third place, and the United Kingdom in second place (Table III).

TABLE III
UNITS FOR MAGNETIC PROPERTIES

| NO | REVISTAS | PUBLICACIONES | PORCENTAJE | CUARTIL | SJR | H-INDEX | PAÍS |
|---|---|---|---|---|---|---|---|
| 1 | SUSTAINABILITY | 4 | 6.6% | Q1 | 0.67 | 169 | Switzerland |
| 2 | AGROFORESTRY SYSTEMS | 3 | 4.9% | Q1 | 0.51 | 92 | Netherlands |
| 3 | AGRICULTURAL SYSTEMS | 2 | 3.3% | Q1 | 1.59 | 134 | United Kingdom |
| 4 | AGRICULTURE BASEL | 2 | 3.3% | Q1 | 0.61 | 66 | Switzerland |
| 5 | AGRICULTURE ECOSYSTEMS ENVIRONMENT | 2 | 3.3% | Q1 | 1.74 | 212 | Netherlands |
| 6 | ANIMALS | 2 | 3.3% | Q1 | 0.7 | 75 | Switzerland |
| 7 | CATENA | 2 | 3.3% | Q1 | 1.5 | 164 | Netherlands |
| 8 | GEODERMA | 2 | 3.3% | Q1 | 1.76 | 203 | Netherlands |
| 9 | LAND | 2 | 3.3% | Q1 | 0.73 | 54 | Switzerland |
| 10 | LAND DEGRADATION DEVELOPMENT | 2 | 3.3% | Q1 | 1.16 | 105 | United Kingdom |

Figure 2 illustrates the four elements of relevance that are part of the bibliographic analysis, in the first box Fig. 2A is the network of collaboration between authors, each node representing an author. In this case, the authors included in the network are Cacho, Julian F, Chescheir, George M., Tian, Shiying, Nettles, Jami E., and Youssef, Mohamed A. The size of the nodes reflects the number of publications or collaborations that each author has in this specific network. All authors appear to have similar node size, indicating an equal contribution in terms of collaborations.

Lines connect the nodes, representing collaborations between authors, the thickness of the lines could indicate the frequency or strength of collaborations between authors. In this graph, all authors are connected to each other, suggesting a very cohesive collaborative team.

There are no clear subgroups in this network, indicating that all authors collaborate closely with each other. The distribution of connections is even, which may indicate that there is no "lead author" in the network, but a more horizontal collaborative approach.

In this way, it can be indicated that this collaborative network is typical of a well-integrated research team, where all members collaborate directly with each other. The lack of subgroups or clusters indicates that this team probably works on highly interconnected projects or on a single common project.

In the second (Fig. 2B) is the co-citation network between authors; the lines connecting the nodes represent co-citations, i.e., how many times have two authors been cited together in other papers. The thickness and color of the lines can indicate the strength of the co-citation relationship. Thicker or more intensely colored lines usually represent more frequent co-citation. Authors Jose, S, Nair, Pkr and Lal, r appear to be related through co-citations, although not directly between Jose, S and Lal, r. This could indicate that Nair, pkr acts as a bridge between Jose, S and Lal, r. The intensity of the connections suggests that these authors have been cited together on several occasions, which could indicate a scholarly collaboration or that

They work on similar topics that are co-cited together.

The country collaboration network Fig. 2C highlights the United States, Brazil, India, China, Germany and France, the size of the nodes could indicate the number of publications or

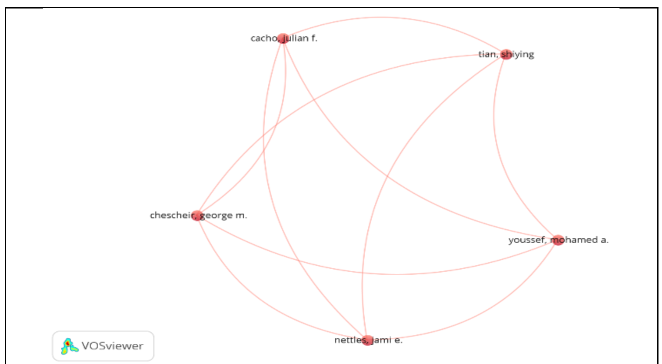


**Fig. 2A Network of collaboration between authors**

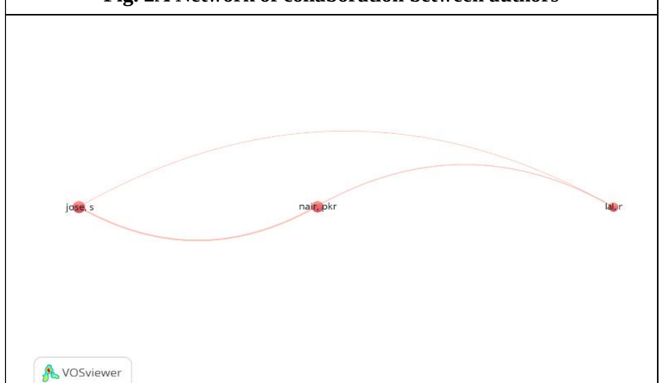


**Fig.2B Author cocitation network**

international collaborations in which each country is involved. In this case, the United States appears to be a central and largest node, suggesting a dominant role in collaborations.

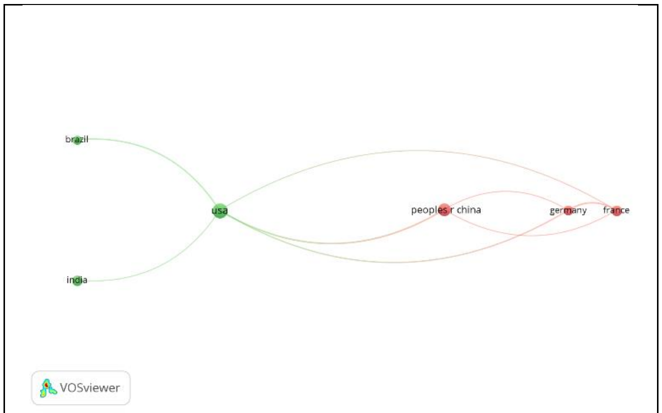


**Fig 2C. Country collaboration network**

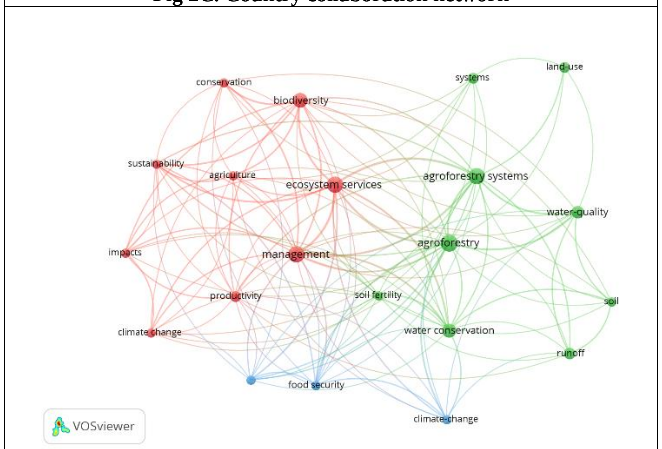


**Fig 2D. Keyword co-occurrence network**

Fig. 2: networks.

The lines connecting the nodes represent collaborations between countries, i.e., joint publications or projects. The United States is a central node collaborating with both countries such as Brazil and India on one side of the network, and China, Germany, and France on the other. This reflects the central role of the US in global scientific and academic collaboration. Brazil and India are more strongly connected to the U.S. but do not appear to have direct relationships with the other countries in the network. This could indicate that their international collaboration is mainly concentrated in the United States. China, Germany, and France are interconnected with each other, in addition to their connection to the U.S. This suggests an axis of collaboration between these countries, with China playing an important role within this sub-network. The absence of direct links between Brazil, India, and European countries or China could reflect that these countries' collaborations are mediated primarily through the United States. Finally, in the keyword co-occurrence network fig. 2D, the nodes and lines are colored to reflect different clusters or groups of keywords that are most closely related to each other, the red cluster focuses on themes of "biodiversity", "ecosystem services", "conservation", and "management". This suggests a group of keywords related to the management and conservation of biodiversity and ecosystem services. The green cluster groups words such as "agroforestry", "land-use", "soil fertility", and "water conservation". This cluster seems to be related to sustainable agriculture and land management, especially in the context of agroforestry. The blue cluster contains words such as "food security" and "climate change". This cluster seems to focus on food security and how it is affected by climate change.

The network shows a strong interaction between concepts related to ecosystem management, sustainable agricultural practices, and climate change impacts.

The "management" node acts as a central bridge, connecting several important themes. This suggests that management is a key concept linking diverse areas such as biodiversity conservation and land use sustainability. The presence of well-defined clusters indicates that although there is overlap between topics (e.g., the relationship between agroforestry and ecosystem services), there are also more specialized areas of research within the general field of environmental sustainability and management.

### *B. Network analysis*

Through this analysis, the most relevant documents on the topic can be identified, and the metaphor of a scientific tree was used to select documents with the highest metrics for review and organization [2]. Five classic (root), five structural (trunk) eleven (branches), and eight recent (leaves) [8].

### *C. Classic documents (Root)*

The research articles presented below, related to water quality and/or conservation and agroecological structures, are rooted in this literature review, standing out for their relevance in the field. In this sense, five (5) fundamental registers are analyzed which, as described above, present classic dispositions and dominances in the literature.

In this context, agroforestry systems constitute an innovative approach to achieve sustainable agriculture, allowing high crop yields and the protection of soil and water resources. In the present study, the efficiency of these systems in reducing contaminants in groundwater and surface water was determined. The results indicated an attenuation of nutrient leaching to groundwater of up to 97.7% and 90% for nitrogen and phosphorus, respectively, and up to 100% attenuation for both pollutants in surface runoff. In addition, several studies evidenced the capacity of agroforestry systems to reduce the presence of pesticides, with pollutant retention of up to 100% for various types of herbicides and fungicides, although only in runoff mitigation. However, insufficient research has yet been conducted to evaluate soil and groundwater protection against leaching of agrochemicals, especially pesticides. Therefore, further studies and policy implementation are required to maximize the practical benefits of these systems for agriculture, the environment, and ultimately human health and well-being [10].

According to Jose [11], in conventional farming systems, crops absorb less than half of the applied nitrogen and phosphorus. Therefore, excess fertilizer is removed through surface runoff or leached into the subsoil, thus contaminating water sources and decreasing their quality. In this context, agricultural surface runoff can lead to excess sediment, nutrients and pesticides in receiving water bodies, contributing to eutrophication in the Gulf of Mexico.

Based on this, agroforestry practices have proven to be an effective strategy for providing potable water. Among these, agroforestry systems include riparian buffers that contribute to the cleansing of runoff water by slowing its velocity, promoting infiltration, sediment deposition, and nutrient retention. A buffer of switchgrass (Panicum virgatum) and woody stem removed 20% more nutrients. In addition, trees with deep root systems can improve groundwater quality by acting as a “safety net”, recycling nutrients through root turnover and litterfall, which improves the efficiency of nutrient use in the system. Studies have reported this mechanism in both tropical and temperate regions, suggesting that agroforestry systems could play a substantial role in mitigating water quality problems generated by intensive agricultural practices [11].

On the other hand, in the Brazilian semi-arid region, inadequate soil management practices have exacerbated erosive processes. In this context, agroforestry systems have been identified as a viable alternative to reduce water erosion. The evaluation of the impact of two agroforestry systems (one traditional and one intensive) in comparison with natural vegetation and a conventional agricultural system, revealed that agroforestry systems were more efficient in reducing water erosion, reducing contamination and loss of water quality. Therefore, their adoption is recommended as a sustainable technical alternative for food production in the region [12].

Likewise, the integration of trees into pastures has proven to be an effective strategy to mitigate water pollution. Studies comparing three types of pastures - one without trees (Paspalum notatum), a pasture under 20-year-old pines (Pinus elliotti) and a pasture of native vegetation under pines - concluded that silvopastoral systems allow a more efficient uptake of nutrients, especially phosphorus, compared to pastures without trees. In addition, the capacity of soils under these systems to receive additional phosphorus is greater, thus reducing nutrient leaching to surface water and mitigating water pollution [13].

Finally, the adaptation of agricultural systems to climate change is crucial, given that this phenomenon can generate negative impacts on agricultural production. According to Lin [14], the resilience of agricultural systems can be improved through greater crop diversification. However, there are barriers such as economic incentives to produce specific crops, the focus on biotechnological strategies and the perception that monocultures are more productive. In this regard, crop and landscape simulation models can help farmers find optimal strategies to maintain production and profitability. Understanding the potential for greater diversity within agricultural systems is essential for coping with climate variability. By adopting practices that foster ecosystem services for pest control, disease and climate resilience, farmers can reduce the risk of production losses and strengthen their capacity to adapt to environmental changes.

In summary, this review has addressed, in the first instance, the definition of agroforestry systems, followed by the problems derived from conventional agriculture and, finally, the specific benefits of agroforestry practices, highlighting their relevance in climate change adaptation and water conservation.

### *D. Structural documents (Trunk)*

Within the structural documents of the knowledge tree, key trends in research development are identified, particularly in the following areas:

Agroforestry systems, which combine trees with crops or pastures, have been widely implemented in temperate and tropical regions due to their effectiveness in reducing water, soil and nutrient loss, as well as mitigating water pollution generated by agricultural activities. However, despite their widespread use, there are still few scientific reviews that comprehensively evaluate their efficiency and scope, considering factors such as soil type, management practices, climatic conditions and the hydrological processes involved. Therefore, it is essential to develop systematic studies that allow the generalization of agroforestry design and its adaptability in regions with similar climatic, geographic, ecological and socioeconomic characteristics worldwide [15].

The progressive deterioration of surface and groundwater quality in recent decades has increased interest in identifying sources of contamination. Agricultural intensification, driven by the need for high quality crops and high yields, has led to excessive use of fertilizers and pesticides, resulting in negative impacts on the environment, especially on soil and water bodies. A study conducted in experimental agricultural fields in the Mediterranean, in which N, P and K ions, as well as the herbicides pendimethalin, its metabolite M455H001 and s-metolachlor, together with the insecticide chlorpyrifos, were analyzed, showed that agroforestry systems, such as corn-poplar and potato-poplar associations, can significantly decrease water pollution. In particular, tree roots have the capacity to absorb excess agrochemicals, preventing them from leaching into groundwater by leaching or being transported to surface water by runoff [16].

On the other hand, multiple studies have shown that land use patterns significantly influence water infiltration capacity. Increasing infiltration and reducing runoff are fundamental aspects for soil and water resource conservation, especially in semi-arid environments. In this regard, research conducted on the Loess Plateau in China compared three planting systems over 11 years and concluded that agroforestry systems significantly improve soil infiltration and soil sustainability, particularly in semi-arid areas. These findings offer new insights into the applicability of agroforestry in regions with similar conditions around the world [17].

In recent decades, it has become evident that agroforestry not only contributes to the protection of natural resources, but also allows maintaining or increasing agricultural productivity. In a study developed in Xishuangbanna, southwest China, Wu JN [18], evaluated a rubber-based agroforestry system, finding that intercropping with legumes significantly improved water use efficiency and tree tolerance to adverse conditions. The rubber trees showed more stable physiological indices and higher water efficiency, suggesting that this strategy is highly beneficial for water conservation.

Finally, Panwar's [19], study examined the effectiveness of agroforestry systems for soil and water conservation on sloping land in the Shivalik region of India. By combining silvihortipastoral practices and the implementation of water harvesting structures, a significant reduction in soil loss was achieved, as well as an increase in runoff retention. These results underscore the potential of agroforestry as a viable strategy for resource conservation in sloping areas, and its integration into land-use planning is recommended as an effective alternative for the development of sustainable agriculture in challenging environments.

*E. Recent Perspectives (Branches)*

In the review conducted, three branches were identified that encompass specific sub-areas within the knowledge domain analyzed. These branches encapsulate articles focused on diverse topics derived from cluster analysis and allow the identification of relevant trends within the field of study [2]. One of these fundamental perspectives is the interconnection between water resources and energy and biomass production, a topic of growing relevance in the context of environmental sustainability and conservation.

*Perspective 1. Water and energy production.*

The relationship between water resources and energy generation is crucial for sustainable development. In this context, property rights over natural resources have been a key legislative tool to promote their responsible use and conservation globally. However, the incorporation of ecological property rights could significantly modify farmers' investment behavior in forests and water resources. This approach could strengthen forest protection, optimize water conservation and, consequently, improve water security in urban areas [20].

The progressive depletion of global land and groundwater reserves, resulting from prolonged overexploitation, underscores the need for effective management of these vital resources. The growing demand for water and soil due to accelerated population growth emphasizes the urgency of maintaining their integrity without compromising productivity. In this sense, agroforestry emerges as a promising strategy, since the integration of trees and shrubs into agricultural practices not only improves soil fertility and reduces erosion, but also optimizes water retention and conservation, favoring the soil's absorption capacity and hydraulic properties.

An emblematic example of the interdependence between water and energy is the Three Gorges Dam (TGD) in China, one of the largest hydropower infrastructures in the world. This dam has generated important benefits, such as drinking water supply, irrigation, power generation and flood control. However, it has also caused adverse environmental impacts, such as eutrophication in secondary rivers due to the accumulation of nutrients in the impounded water. This highlights the need for accurate and controlled water management to mitigate negative effects, such as algal blooms, which requires a detailed understanding of the interactions between main streams and their tributaries [21].

Also, large-scale bioenergy production significantly affects the hydrological cycle. According to Watkins et al. [22], it influences processes such as canopy interception, evapotranspiration, infiltration, runoff and aquifer recharge. These impacts vary according to the type of biomass, soil characteristics, agricultural practices and hydroclimatic conditions. In addition, the interaction between bioenergy and water management is intrinsically linked to land use, water availability and competing demands for this resource in watersheds. Therefore, policies related to water and bioenergy should be evaluated not only in terms of efficiency and effectiveness, but also considering their socioeconomic impacts and their effect on vulnerable communities.

Thus, an integrated and multidisciplinary approach is essential to ensure equitable and sustainable management of water resources in the context of energy and biomass production. Only through coordinated strategies will it be possible to avoid exacerbating water conflicts and ensure the long-term viability of these production systems.

*Perspective 2. Integration of ecosystem services and ecological modernization in agroforestry systems.*

Contemporary agriculture is facing increasing criticism due to its predominantly productivist approach, which often neglects the supporting and regulating services provided by ecosystems. In this context, agroforestry and ecological modernization strategies emerge as key alternatives to promote sustainability and improve human quality of life through the provision of multiple ecosystem services (ES) [23] [24].

Agroforestry systems can provide ecosystem benefits that contribute to both farm sustainability and human well-being. Notaro et al. [23], studied four ecosystem services in coffee agroforestry systems in Nicaragua: coffee production, water quality preservation, carbon sequestration, and biodiversity conservation. Their findings revealed that carbon sequestration depended more on the presence of large trees than on coffee yield, while tree biodiversity favored productivity up to a certain threshold, after which yield decreased. This underscores the importance of a moderate density of shade trees to optimize both production and SE provision.

Water quality and conservation are fundamental elements in agroforestry systems. The preservation of water sources and the optimization of water use guarantee not only the sustainability of the crop, but also the resilience of the ecosystem in the face of climatic changes. Agroforestry, by promoting vegetation cover and water infiltration into the soil, helps to regulate the hydrological cycle and reduce erosion, ensuring long-term water supply.

Additionally, Padovan et al. [25] addressed the impact of land pressure and the need to maximize income, which forces smallholders to cultivate in suboptimal areas. In a study in Nicaragua, they analyzed water use efficiency in agroforestry systems versus full-sun systems, demonstrating that agroforestry allows more efficient water use under adverse conditions. Most of the soil water was used for coffee transpiration rather than being lost to evaporation or consumed by shade trees. Two shade tree species, Tabebuia rosea and Simarouba glauca, were compared, providing valuable information for the selection of species that optimize water use and improve the resilience of the agroforestry system to water variability.

Therefore from an ecological modernization perspective, Duru [24] identifies two key approaches: (1) efficiency substitution agriculture, which seeks to optimize input use and minimize environmental impacts, and (2) biodiversity-based agriculture, which develops SE through biological diversification. To facilitate this transition, Duru proposes a transdisciplinary conceptual and methodological framework that involves agronomic innovations and coordination among actors in the supply chain and natural resource management. This approach requires technological, social, economic and institutional changes, enabling local actors to design adaptive action plans that foster the diversification and sustainability of agricultural systems.

In this way it can be emphasized that the integration of ecosystem services in coffee agroforestry systems not only improves agricultural productivity and sustainability but also contributes significantly to environmental conservation. Water quality and conservation play a crucial role in the stability of these systems, ensuring both productivity and ecosystem resilience. To maximize these benefits, it is essential to maintain an adequate density of shade trees and select species that optimize water use and biodiversity.

In addition, the transition to biodiversity-based agriculture requires a holistic approach involving innovations at multiple levels and close collaboration between the different stakeholders involved. Implementing these strategies can lead to agroecological intensification that balances agricultural production with the conservation of natural resources, thus ensuring the long-term sustainability of agroforestry systems.

*Perspective 3: Heavy metals and emerging contaminants in agroforestry systems.*

Mercury (Hg) is a highly toxic global pollutant that persists in aquatic ecosystems Li et al., [26] highlights how mercury, used in large quantities during the Manhattan project in Oak Ridge, Tennessee, still contaminates the surrounding watershed. Soil erosion and rainfall-runoff events contribute to mercury transport from nonpoint sources into aquatic ecosystems. Proper site management, such as improving vegetative cover and reducing slopes, is critical to reducing this mercury transport, where low plants play a crucial role in phytostabilizing the pollutant.

Agroforestry has been shown to be an effective strategy to control soil erosion and improve agricultural sustainability in semi-arid areas. Huang et al., [27] discusses how agroforestry systems influence soil water storage (SWS) and how the proximity of forest plantations can affect this storage, especially at the afforestation-cropland interface (ACI). In particular, species such as S. Japonica are recommended for their lower impact on soil water availability, making them a valuable option for improving the ecological environment and long-term sustainability in these regions.

Zhang et al., [28] stress the importance of “source-sink” landscape pattern analysis for nonpoint source pollution management. Remote sensing is presented as an effective technique to study these patterns and their relationship with water quality, despite technical challenges. Advances in this area have made it possible to optimize landscape management to reduce pollution, which is crucial for the protection of water resources and the construction of ecological security patterns.

Béliveau et al., [29] highlights the negative effects of soil erosion in the Amazon, where traditional agriculture has contributed significantly to soil degradation and the release of natural mercury into water bodies. Agroforestry practices in the Brazilian Amazon have proven to be effective in reducing both soil erosion and mercury mobility, making them a sustainable solution for agricultural management and environmental conservation. These practices not only conserve soil, but also reduce pollution, making agroforestry an essential tool for the protection of Amazonian ecosystems.

Finally, Pascual Aguilar et al., [30] addresses the emerging pollution problem in Mediterranean wetlands, such as L'Albufera de Valencia, where human impact and socioeconomic development have generated a high concentration of pollutants, including pharmaceuticals and pesticides. The research highlights the urgent need to implement measures to mitigate this pollution and protect these ecosystems of great ecological value, thus ensuring water sustainability and ecosystem health for future generations.

### *F. Leaves*

Agroforestry systems (AFS) are consolidated as a key strategy for agricultural sustainability and conservation of natural resources, especially in terms of water and soil quality. According to the review conducted by François et al. [31], the implementation of AFS contributes significantly to the reduction of nutrient losses, such as nitrogen (N) and phosphorus (P), whose accumulation derived from the intensive use of chemical fertilizers has generated serious water pollution problems. In addition, these systems favor the improvement of the physical, chemical and biological properties of the soil, promoting its water retention capacity and reducing erosion. Likewise, PBS have demonstrated a remarkable potential in the elimination of trace metals such as cadmium, aluminum and mercury in contaminated soils, strengthening their role as an integral agroecological tool. However, factors such as surface geology, slope gradient and topographic conditions can negatively influence water quality in watersheds, underscoring the need for strategic planning in their implementation.

In this context, Ntawuruhunga et al. [32] emphasize the importance of climate-smart agroforestry (CSAF) as a comprehensive solution for climate change mitigation and adaptation, particularly in rural areas. This approach combines trees, crops and livestock in sustainable production systems, optimizing water use and contributing to water security. However, the adoption of CSAF still faces significant challenges, especially among smallholder farmers, due to lack of knowledge and technical support. Therefore, the study highlights the need to strengthen evidence-based public policies, foster public-private partnerships and promote multidimensional initiatives that facilitate their effective implementation, thus ensuring their positive impact on food security, poverty reduction and the resilience of water ecosystems.

In Indonesia, Sudomo et al. [33] highlight agroforestry as a crucial mechanism for improving food security and access to water, especially among smallholder farmers. By adapting agroforestry practices to local conditions and market needs, sustainable incomes are generated that enable rural communities to strengthen their resilience to climate change. In addition, crop diversification in these systems improves water infiltration into the soil and reduces surface runoff, reducing pollution of water bodies and promoting the resilience of water ecosystems.

Srinivasarao et al. [34] address soil degradation in India as a critical problem that threatens water security and agricultural sustainability. The study highlights the need to adopt integrated soil and water conservation technologies aimed at minimizing erosion and fostering the development of resilient climate change communities. To this end, it proposes the strengthening of community capacities and the creation of local institutions to manage and maintain these conservation structures in the long term, thus ensuring the sustainability of water resources in vulnerable rural environments.

From an environmental governance perspective, Li [20] analyzes the impact of ecological property rights on the promotion of sustainable agroforestry practices in the Heihe Reservoir region, Shaanxi, China. The implementation of these rights has proven to be effective in reducing soil erosion and improving water management, in turn facilitating food security and increased income for local communities. However, the study points out that to maximize its impact, it is necessary to clarify the allocation of rights and strengthen government support through financial incentives and technical assistance.

In the livestock area, Pinheiro Machado Filho et al. [35] present the Voisin rational grazing system (VRG) as a sustainable agroecological alternative that optimizes animal productivity while improving soil and water quality. This model integrates multi-species grasslands with SAF, promoting ecosystem regeneration, carbon absorption and water retention in the soil, which contributes to the protection of water sources and biodiversity. Despite its high potential, the implementation of GBV requires a long-term vision and a comprehensive approach to overcome the associated technical and socioeconomic barriers.

On the other hand, Platis et al. [36] emphasize the need to reduce greenhouse gas emissions in agriculture, aligning agroforestry systems with the objectives of the Paris Agreement on climate change. These systems, in addition to minimizing the use of non-renewable energy, improve water use efficiency and significantly reduce the water and carbon footprint of agricultural production. The adoption of methodologies such as life cycle assessment is crucial to measure and mitigate the environmental impact of these systems, strengthening the long-term resilience of agroecosystems.

Finally, Bardule et al. [37] analyze the effectiveness of juvenile hybrid poplar plantations in agroforestry systems in reducing leaching of nutrients such as nitrogen, phosphorus, and potassium in the Baltic Sea region. Despite the use of fertilizers, a significant decrease in pollution of water bodies was evidenced, reaffirming the potential of PBS to improve water quality and promote sustainable agriculture.

Taken together, this research demonstrates that agroforestry systems represent a viable and effective alternative for water quality conservation in agroecological environments. However, their success depends on a strategic implementation that considers ecological, social and economic factors, as well as the strengthening of public policies and governance mechanisms that facilitate their adoption and long-term sustainability.

## IV. Discussion

A review of 61 records obtained in WoS was carried out using the metaphor of trees [3]. In agroecological systems, water quality and conservation are fundamental, given that these systems seek agricultural sustainability through the integration of practices that respect and preserve natural resources. Agroforestry systems, which combine trees with crops or pastures, stand out as a key strategy to mitigate the negative impacts of conventional agriculture, such as groundwater and surface water contamination due to the excessive use of fertilizers and pesticides.

A literature review shows that agroforestry systems can reduce nutrient leaching to groundwater by up to 97.7% for nitrogen and 90% for phosphorus and can remove up to 100% of these pollutants in surface runoff [10]. In addition, these systems offer a solution for pesticide depletion, protecting vulnerable water bodies, although more research is needed to fully address agrochemical leaching into the soil.

The adoption of agroforestry practices has also proven to be effective in semi-arid regions, as in the case of Brazil, where they have significantly reduced water erosion, a critical factor in water pollution and loss of water quality [12]. On the other hand, the integration of trees in pastures can prevent the loss of nutrients to water bodies, thus improving surface and groundwater quality [13].

It is also crucial to consider the adaptation of these systems to climate change. Crop diversification, a practice promoted within agroforestry, can increase the resilience of agricultural systems to climate variability, reducing the risk of contamination and deterioration of water resources [14].

In systems where water is a limited resource, fish farming can be integrated to make the most of available water, using the same resource for multiple purposes: fish farming, crop irrigation, and wetland maintenance. By integrating fish farming with other agricultural activities, environmental impacts, such as eutrophication of water bodies due to nutrient runoff, can be reduced, as well-designed systems can recycle these nutrients rather than allowing them to pollute rivers and lakes.

Thus, agroforestry systems have multiple benefits for water quality and conservation in agroecological systems, acting as a natural barrier that reduces pollution, improves water infiltration and reduces soil erosion.

While interest in the relationship between agroforestry systems and water quality has increased, knowledge gaps persist that require additional research. In particular, limitations have been identified in quantifying the long-term impacts of these systems on soil hydrodynamics and the composition of microbial communities involved in nutrient recycling [17]. Recent studies have pointed out the need to evaluate the capacity of agroforestry systems for biofiltration of emerging pollutants such as pesticides and heavy metals, as well as their impact on improving groundwater quality [27].

On the other hand, variability in the design and management of agroforestry systems poses a challenge for the generalization of their hydrological effects. There is a need to develop comprehensive models to more accurately predict the water efficiency of different agroforestry designs under climate change scenarios, especially in regions vulnerable to aridity [18].

The results of this study present significant implications for the design of public policies and sustainable water management strategies in agricultural contexts. The incorporation of agroforestry systems in territorial planning could improve water security and climate resilience of rural communities, reducing dependence on conventional water sources and mitigating the effects of climate variability [15]. It has been shown that these systems can reduce irrigation water demand by up to 30% by optimizing infiltration and soil moisture retention [13].

However, the transition to these systems requires the establishment of economic incentives, the strengthening of technical training and the development of regulatory frameworks that promote their large-scale implementation [19]. In this sense, payment for environmental services (PES) programs have shown to be an effective tool to incentivize the adoption of sustainable agroforestry practices in various regions of the world.

To strengthen the knowledge base on the relationship between agroforestry systems and water quality, the development of interdisciplinary studies that integrate ecohydrology, biogeochemistry and hydrological process modeling approaches is recommended [23]. In addition, the application of emerging technologies, such as satellite remote sensing and remote sensing water quality monitoring, would allow a more accurate assessment of the dynamics of these systems at different spatial and temporal scales [21]. Long-term studies that analyze the impact of ecological succession on the ecosystem services of agroforestry systems and their contribution to water resilience are required.

On the other hand, it is essential to foster international collaborations that allow the comparison of different geographical and socioeconomic contexts, facilitating the design of strategies adapted to local needs [24]. The integration of agroforestry systems into local and global water governance frameworks should be a priority approach to ensure their effective and sustainable implementation.

## V. Conclusions

The bibliometric and systematic study has identified key trends in scientific production on water conservation and quality in agroecological structures. A sustained growth in the amount of research published in the last decade was evidenced, with a predominance of studies coming from the United States and China, suggesting a strong interest in the application of agroforestry systems as a mitigation and adaptation strategy in the face of global environmental challenges.

Results confirm that agroforestry systems play a determining role in improving water quality, reducing pollution by nutrient and agrochemical leaching by up to 97.7% and favoring water retention in soils [10]. In addition, these systems contribute to the regulation of the hydrological cycle, decreasing erosion and improving water infiltration by up to 60% compared to conventional systems. These advantages are crucial in the context of climate change, where water conservation and ecosystem resilience are critical for agricultural sustainability.

Despite these findings, knowledge gaps persist in quantifying the long-term impacts of these systems in different soil types and climates, as well as their effectiveness in biofiltration of emerging pollutants [27]. The development of more accurate hydrological models and the strengthening of interdisciplinary research integrating ecohydrology, biogeochemistry, and remote sensing approaches are recommended to assess the water efficiency of these systems under different environmental scenarios [21].

Thus, it is crucial that policy makers recognize the potential of agroforestry systems in water conservation and encourage their adoption through economic incentives and payment for environmental services programs. The integration of these systems into water governance frameworks will contribute to long-term water security and sustainability of agricultural production in regions vulnerable to water stress.

This study reinforces the importance of agroforestry systems in sustainable water management, highlighting both their potential and the challenges that remain in their implementation. It calls on the scientific community and policy makers to promote applied research and the development of innovative strategies to maximize the benefits of these systems for water conservation. It is recommended to strengthen the generation of scientific evidence on the long-term effects of agroforestry systems on water quality, mitigation of diffuse pollution and water security in contexts of high climate vulnerability.

Finally, given that climate change will continue to exert increasing pressure on global water resources, agroforestry systems represent a viable alternative to improve ecosystem resilience and ensure the sustainability of agricultural production in the future.

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