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Evolution of Agroforestry Research: A Bibliometric Study

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ABSTRACT

This bibliometric study examines the evolution of agroforestry research over several decades, analyzing publication patterns, citation trends, and collaboration networks. Utilizing data from a comprehensive database, we identified major thematic areas including sustainability, carbon management, and the socioeconomic impacts on smallholder farmers. The analysis reveals a significant growth in the focus on environmental benefits such as carbon sequestration and biodiversity conservation within agroforestry systems. Additionally, the study highlights the key roles of influential researchers and outlines the dynamic collaboration networks that drive the field. By mapping the intellectual landscape of agroforestry research, this study provides both theoretical insights and practical implications, emphasizing the contribution of agroforestry to sustainable land management and climate change mitigation. This research not only charts past and current trends but also identifies under-researched areas, suggesting directions for future investigation.

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1. INTRODUCTION

Agroforestry, the integrated approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock, has gained significant traction over the decades as a sustainable land management practice [1], [2]. This multifaceted system not only enhances biodiversity and reduces erosion but also increases soil fertility and water retention, thereby improving overall agricultural productivity [3]. Historically, agroforestry practices have been indigenous to tropical regions but have expanded globally due to their ecological and economic benefits [4].

The scientific investigation into agroforestry began to formalize in the late 20th century as researchers started to quantify the benefits and challenges associated with these systems [3]. The initial studies focused on understanding the ecological interactions within agroforestry setups and gradually expanded to socio-economic aspects, policy frameworks, and technological innovations [5], [6]. This evolution reflects a growing recognition of agroforestry's potential to address critical issues like food security, climate change mitigation, and economic development, especially in vulnerable rural communities [7].

In recent years, the scope of agroforestry research has broadened significantly, integrating modern technologies such as remote sensing and genetic engineering to enhance tree-crop interactions and optimize resource allocation [8], [9]. Moreover, the role of agroforestry in achieving the United Nations Sustainable Development Goals has catalyzed a new wave of interdisciplinary research, connecting agroforestry with larger environmental and social policy contexts [10], [11]. Despite these advancements, a comprehensive analysis of the research trends and shifts in thematic focus over time is lacking.

A bibliometric analysis offers a powerful tool to map the intellectual landscape of a field, providing insights into the dynamics of research activity, collaboration networks, and emerging trends [12]. For agroforestry, such an analysis could elucidate how research priorities have shifted in response to global environmental changes and policy developments [13]. It can reveal the impact of technological advancements on research focus and collaboration patterns, potentially guiding future research directions [14].

Despite the significant growth in agroforestry research, there is a discernible gap in comprehensive bibliometric studies that aggregate and analyze the vast body of literature to identify prevailing trends, key themes, and pivotal changes in the field over time. Current literature reviews often focus on specific aspects of agroforestry or are limited in scope, thus not providing a holistic view of the research evolution. A bibliometric study is essential to synthesize these disparate strands of research and offer a structured and quantifiable overview of the field's development, influential studies, and future directions.

The objective of this research is to conduct a comprehensive bibliometric analysis of agroforestry literature from its inception to the present day. This study aims to map the evolution of research themes, analyze collaboration patterns, and identify the most influential works and authors in the field. By doing so, it seeks to provide a detailed understanding of the trajectory of agroforestry research, contributing to strategic planning and policy-making in sustainable land management.

2. LITERATURE REVIEW

2.1 Agroforestry Systems and Practices

Agroforestry as a practice has been a part of traditional farming systems for centuries but has only gained substantial scientific attention in the past few decades. According to Nair [15], agroforestry is defined as a sustainable land use system that increases the overall yield of the land, combining the production of crops (including forest tree products) and livestock with benefits derived from ecological interactions. Early studies by Young [16] highlighted the potential of agroforestry systems to enhance

soil fertility through nitrogen-fixing trees, control erosion, and optimize the usage of sunlight and water. Moreover, research by Jose [17] emphasized the role of agroforestry in carbon sequestration, crucial for mitigating climate change impacts.

2.2 Evolution of Agroforestry Research Themes

Initial agroforestry research primarily focused on understanding biophysical interactions within the system. Over time, the research expanded into more diverse areas, including economic viability, social acceptability, and environmental impact. Sinclair [18] provided an early overview of the role of agroforestry in sustainable rural development, while recent studies have explored its economic dimensions, such as market access and profitability [19]. The integration of social sciences within agroforestry research marked a significant evolution, as noted by Plieninger et al. [20], who investigated community engagement and stakeholder perceptions in agroforestry projects.

2.3 Technological Advancements in Agroforestry Research

The application of advanced technologies has dramatically shaped agroforestry research over the last two decades. Geographic Information Systems (GIS) and remote sensing technologies have been particularly transformative, enabling the analysis of land use changes and the spatial distribution of agroforestry practices on a large scale [21]. Genetic engineering and biotechnology have also been explored to improve crop yields and resistance against pests and diseases within agroforestry systems, as discussed by [22].

2.4 Bibliometric Studies in Agroforestry

Despite the extensive body of research on various aspects of agroforestry, bibliometric analyses remain scarce. These studies are crucial for mapping the research landscape, identifying core themes, and understanding the impact of different research contributions. Adebayo & Oladele [23] conducted one of the few bibliometric reviews on agroforestry, which analyzed publication patterns but did not delve into thematic evolutions or citation networks. More comprehensive bibliometric studies are required to fill this gap and provide insights into the developmental trajectory and influence patterns within the field.

2.5 Collaboration and Influence in Agroforestry Research

Collaborative networks in agroforestry research have been pivotal in advancing the field. Studies by (1) highlight how international collaborations have facilitated knowledge exchange across different agroecological zones, leading to innovations tailored to local contexts. The role of influential institutions and researchers has also been documented, with major contributions coming from organizations like the World Agroforestry Centre (ICRAF) and various agricultural universities globally.

3. METHODS

This bibliometric study utilized data sourced from the Google Scholar database to analyze the development of agroforestry research up to the year 2024. The search strategy employed keywords such as "agroforestry," "sustainable land management," and related terminologies. Criteria for inclusion were set based on publication type, date, and relevance to agroforestry topics to ensure a comprehensive dataset. Essential data points collected included publication trends, citation counts, authorship details, and thematic focus areas. For the analysis of co-authorship and thematic trends, we used VOSviewer, a tool designed for constructing and visualizing bibliometric networks. This facilitated the examination of collaboration patterns and the prevalence of research themes over time.

4. RESULTS AND DISCUSSION

4.1 Metrics Data of Citation

Table 1. Citation Metrics

Publication years:	1979-2024
Citation years:	45 (1979-2024)
Papers:	980
Citations:	142182
Cites/year:	3159.60
Cites/paper:	145.08
Cites/author:	69481.69
Papers/author:	428.33
Author/paper:	3.11
h-index:	194
g-index:	311
hI,norm:	120
hI,annual	2.67
hA-index	38
Papers with ACC >= 1,2,5,10,20:	976,934,717,402,163

Source: Data Processed by Publish or Perish, 2024

Table 1 presents a comprehensive bibliometric analysis of agroforestry research published between 1979 and 2024. Over these 45 years, a total of 980 papers have been published, accumulating an impressive 142,182 citations, which averages to 3,159.60 citations per year. The average citation per paper stands at 145.08, indicating significant impact and relevance in the field. The data reveals a high level of collaboration with an average of 3.11 authors per paper and an average of 428.33 papers per author, suggesting that the agroforestry research community is both active and collaborative. The h-index, a metric that measures both the productivity and citation impact of the publications, is remarkably high at 194, underscoring the influential nature of the work in this domain. The g-index is even higher at 311, which further highlights that a substantial number of papers have received a high citation count. Additionally, the hI,norm of 120 and an annual hI of 2.67 reflect the consistency and longevity of citation impact over the years. The hA-index of 38 suggests that there are at least 38 authors with a square number of citations equal to or exceeding their square number of papers. The distribution of papers with accumulative citations (ACC) shows that nearly all papers have been cited at least once, with a significant number achieving citations in higher brackets, illustrating the depth and breadth of influence these publications have had within and possibly beyond the agroforestry research community.

4.2 Descriptive Analysis

4.2.1 Citation Analysis

Table 2. Top Cited Literature

Citation	Author and Year	Title	Findings
3115	[24]	An introduction to agroforestry: four decades of scientific developments	This foundational text offers a comprehensive overview of the evolution of agroforestry over forty years, discussing major scientific developments and the establishment of agroforestry as a recognized field of study. It likely serves as a critical resource for both historical insight and foundational knowledge in agroforestry education and research.

Citation	Author and Year	Title	Findings
2190	[17]	Agroforestry for ecosystem services and environmental benefits: an overview	Jose's work synthesizes the ecosystem services provided by agroforestry systems, including biodiversity conservation, carbon sequestration, and soil and water conservation. It emphasizes the role of agroforestry in enhancing environmental health and offering sustainable agricultural solutions.
1626	[16]	Agroforestry for soil conservation	This piece focuses on the benefits of agroforestry in preventing soil erosion and maintaining soil health, crucial for sustainable agriculture. It likely provides evidence and methodologies for using trees and shrubs to stabilize soil and improve fertility.
1572	[25]	Plantation forestry in the tropics: tree planting for industrial, social, environmental, and agroforestry purposes	Evans discusses the multifunctional role of plantation forestry in tropical regions, covering its applications in industry, social settings, environmental conservation, and as part of integrated agroforestry practices, highlighting the versatility and economic benefits of plantations.
1569	[26]	Carbon sequestration in tropical agroforestry systems	This research examines the potential of tropical agroforestry systems to act as carbon sinks, an important aspect in the context of climate change mitigation. It provides quantitative analyses of carbon stocks and sequestration rates associated with different agroforestry practices.
1504	[27]	Agroforestry as a strategy for carbon sequestration	Similar to Albrecht and Kandji's work, this paper explores how agroforestry can contribute to carbon sequestration efforts globally. It likely offers strategic insights into how agroforestry can be optimized for better carbon uptake and storage.
1405	[28]	Carbon sequestration: an underexploited environmental benefit of agroforestry systems	This publication argues that the capacity of agroforestry systems to sequester carbon is not fully utilized and provides recommendations on how to enhance this environmental

Citation	Author and Year	Title	Findings
			benefit, potentially influencing policy and practice in land management.
1205	[29]	A guide to monitoring carbon storage in forestry and agroforestry projects	MacDicken's guide offers methodologies for effectively monitoring and quantifying carbon storage in forestry and agroforestry projects, an essential tool for researchers and practitioners involved in carbon accounting and environmental impact assessments.
1072	[30]	Agroforestry for soil management.	This publication likely expands upon Young's earlier work, providing more detailed strategies and findings on how agroforestry can be used to manage soil health and fertility in sustainable farming systems.
1028	[31]	Agroforestry: a refuge for tropical biodiversity?	This research explores agroforestry's role in biodiversity conservation in tropical regions, assessing its effectiveness as a habitat for various flora and fauna compared to traditional agricultural and forest landscapes.

Source: Data Processed by Publish or Perish, 2024

4.2.3 Co-Word Network Analysis

1. Network Visualization

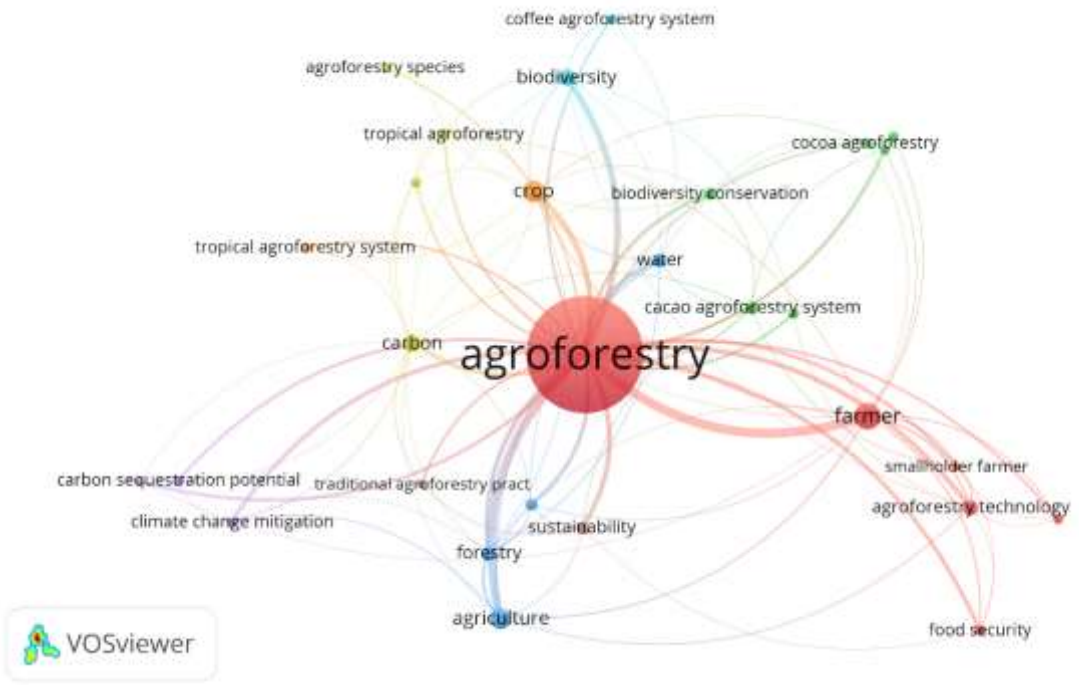

Figure 1. Visualization Network

The figure above illustrates the interconnectedness of various research themes within the field of agroforestry. At the center, "agroforestry" itself is the most prominent node, indicating that it is the central topic around which other themes revolve. This central positioning underscores the multidisciplinary nature of agroforestry research, bridging aspects of biodiversity, carbon management, sustainability, and agriculture. Key thematic nodes such as "carbon," "sustainability," "biodiversity conservation," and "agriculture" are closely linked to agroforestry, highlighting the major areas of focus within the field. These connections suggest active research intersections that explore how agroforestry practices impact and benefit ecological health, carbon sequestration, and agricultural productivity.

Peripheral nodes like "coffee agroforestry system," "cocoa agroforestry," and "tropical agroforestry" denote specific systems within agroforestry, each linked to broader themes like "crop" and "water," indicating specialized research areas that focus on the integration of agroforestry practices within specific crop systems and environmental conditions. The links between "farmer" and "smallholder farmer" with the central agroforestry node emphasize the socio-economic dimension of agroforestry research, focusing on the role of farmers in implementing and benefiting from agroforestry practices.

Table 3. Cluster Composition

Cluster	Items	Description
Red Cluster (Include brown and orange small cluster)	"agroforestry", "farmer", "smallholder farmer", "agroforestry technology", "food security", "crop", "tropical agroforestry system", "sustainability"	This cluster focuses on the practical and socio-economic aspects of agroforestry, emphasizing the role of farmers, particularly smallholders, in implementing agroforestry systems. It highlights the use of agroforestry technology to enhance food security and crop production within tropical and sustainable agroforestry frameworks. The cluster suggests a strong focus on how agroforestry practices can be adapted to local conditions to improve sustainability and livelihoods.
Blue Cluster (Include light blue cluster)	"forestry", "agriculture", "water", "biodiversity", "coffee agroforestry system"	The blue cluster revolves around the ecological and environmental foundation of agroforestry, linking it closely with broader forestry and agricultural practices. Key themes include water management, biodiversity, and specific agroforestry systems like coffee agroforestry. This cluster likely examines the interactions between agroforestry and traditional forestry/agricultural practices to enhance ecosystem services and biodiversity.
Green Cluster	"cacao agroforestry system", "biodiversity conservation", "cocoa agroforestry"	Centered on cacao-based agroforestry systems, this cluster delves into biodiversity conservation within these specific systems. It explores the nuances of integrating cocoa cultivation with agroforestry practices to promote ecological benefits, demonstrating a focused study on the environmental impacts and conservation potentials of agroforestry in cocoa production areas.
Yellow Cluster	"Carbon", "Tropical	This cluster addresses the environmental impacts of agroforestry, particularly focusing on

	Agroforestry", "Agroforestry Species"	carbon dynamics within tropical agroforestry settings. It covers topics related to carbon storage capabilities of various agroforestry species, underscoring the role of agroforestry in carbon management and its potential contribution to climate change mitigation strategies.
Purple Cluster	"Carbon Sequestration Potential", "Climate Change Mitigation", "Traditional agroforestry practice"	The purple cluster is deeply rooted in the environmental science aspects of agroforestry, specifically its potential for carbon sequestration and climate change mitigation. It also reflects on traditional agroforestry practices, suggesting a historical and potentially culturally ingrained approach to maximizing the environmental benefits of agroforestry, aiming to align traditional knowledge with modern sustainability challenges.

2. Overlay Visualization

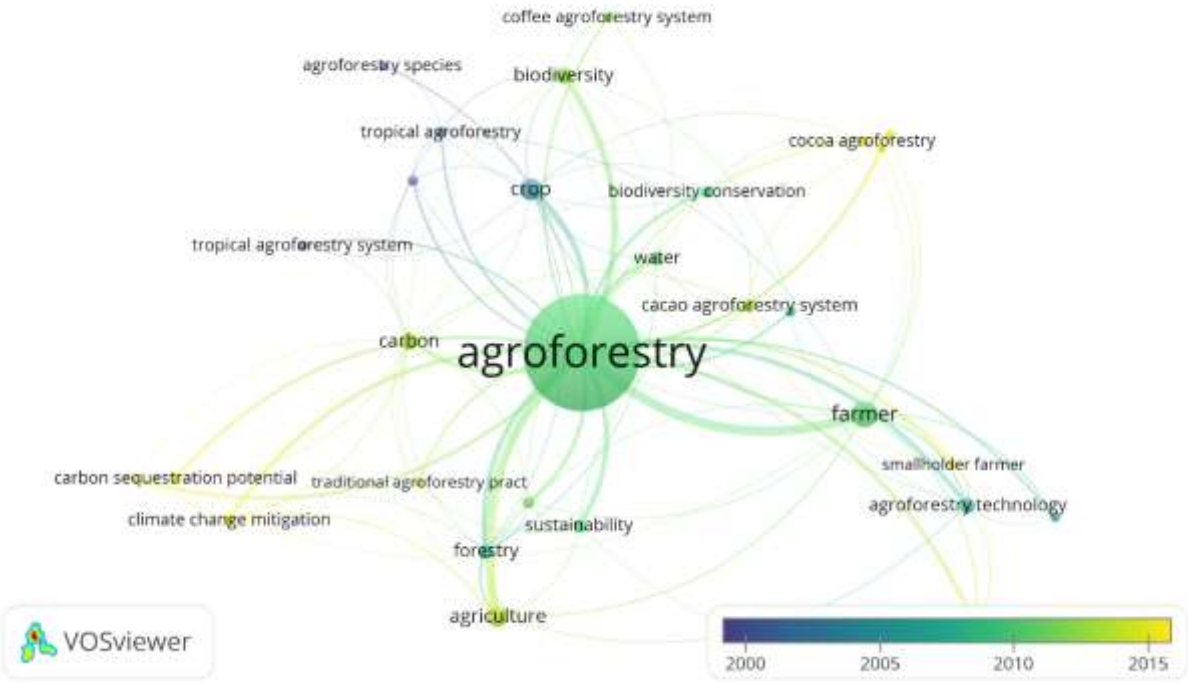

Figure 2. Overlay Visualization

The focus in the early 2000s appears to be foundational, with core concepts like "agroforestry," "crop," and "tropical agroforestry system" gaining prominence. Research during this period likely centered on establishing and defining agroforestry practices within the context of tropical regions, emphasizing basic ecological and agricultural interactions. During Mid-2000s to Early 2010s period, there is a noticeable shift toward more integrated topics such as "sustainability," "agroforestry technology," and "smallholder farmer." This indicates a growing concern for the practical implementation of agroforestry systems, focusing on technological advances and the socio-economic impact on small-scale farmers. The research seems to be expanding to include discussions on how agroforestry can be used as a tool for sustainable development and poverty alleviation.

In the more recent years leading up to 2015, the emphasis shifts towards environmental impact topics such as "carbon," "climate change mitigation," and "carbon sequestration potential." This trend suggests that the agroforestry research community was increasingly concerned with the role of agroforestry in environmental conservation efforts, particularly in carbon management and climate action. Studies during this time likely explored the effectiveness of agroforestry practices in sequestering carbon and contributing to global mitigation strategies against climate change.

Overall, the progression from basic agroforestry systems and agricultural integration to a focused emphasis on sustainability and environmental impacts reflects the evolving nature of agroforestry research. Each period marks a shift in priorities and expands the scope of agroforestry from merely a farming practice to a significant component of environmental sustainability and climate resilience strategies.

3. Density Visualization

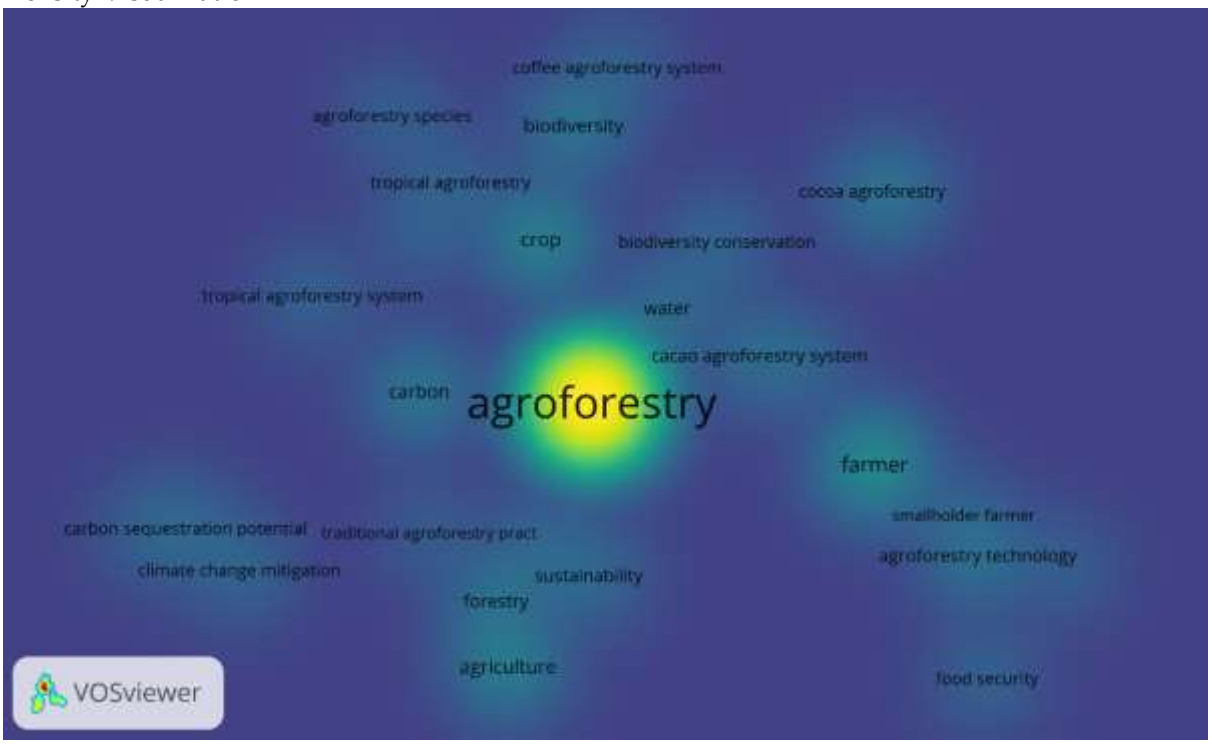

Figure 3. Density Visualization

This visualization highlights several less bright areas that could represent potential research topics needing further exploration:

1. Coffee Agroforestry System

This area, despite its significant role in sustainable agriculture, especially in tropical regions, appears less emphasized. Potential research could explore the economic benefits, biodiversity impacts, and scalability of coffee agroforestry systems in different environmental settings.

2. Biodiversity Conservation

While closely related to broader agroforestry practices, biodiversity conservation within specific agroforestry systems seems to be a less saturated research area. Studies could focus on quantifying the benefits of biodiversity in these systems and developing methods to enhance species diversity and ecosystem services.

3. Traditional Agroforestry Practices

The node related to traditional agroforestry practices is less prominent, suggesting room for research into how indigenous knowledge and traditional methods can be integrated with modern agroforestry techniques to improve sustainability and resilience against climate change.

4. Agroforestry Species

Specific research on agroforestry species, particularly those less common or underutilized, could provide valuable insights into their roles and benefits within agroforestry systems. This could include studies on species adaptability, inter-species interactions, and their economic potentials.

Each of these areas presents a unique opportunity to delve into under-researched aspects of agroforestry, potentially contributing to the field's depth and breadth while addressing global challenges such as climate change, food security, and ecological degradation.

4.3 Author Collaboration Network Analysis

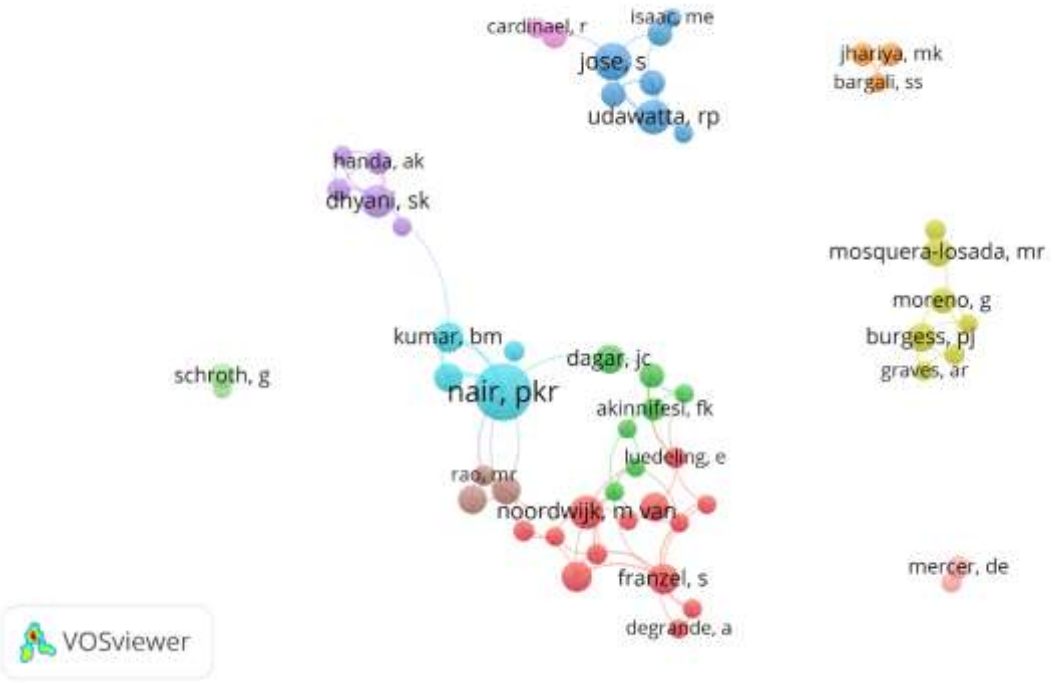

Figure 4. Author Visualization

The VOSviewer network map displayed illustrates the co-authorship relationships among researchers in the field of agroforestry, with nodes representing individual researchers and lines indicating collaborations between them. The various colors of the nodes denote distinct clusters of researchers who frequently collaborate with each other, suggesting specialized subgroups within the broader agroforestry research community.

The central and most connected nodes, such as PKR Nair and BM Kumar, highlight influential researchers who serve as key connectors in the network, suggesting their significant contributions and central roles in agroforestry research collaborations. These central figures likely have a broad range of co-authored works, underlining their

pivotal roles in shaping the research landscape. Smaller nodes, such as Moreno and Burgess, while less connected, indicate specialized contributions or emerging researchers in the field. The varying distances between nodes can imply the strength or frequency of collaborations, with closely positioned nodes suggesting stronger or more frequent collaborations. This network provides insights into the structure and dynamics of the academic community in agroforestry, identifying both leading and emerging scholars in the field.

4.4 Practical Implications

The practical implications of this bibliometric analysis in agroforestry research are substantial for policymakers, practitioners, and stakeholders involved in sustainable land management. Firstly, the identification of key themes such as carbon sequestration, biodiversity conservation, and the integration of traditional practices provides a clear direction for developing targeted interventions and support mechanisms that enhance the ecological and economic benefits of agroforestry systems. For instance, understanding the prominence of carbon management within agroforestry research can help in designing programs that leverage agroforestry as a strategy for climate change mitigation. Additionally, the focus on technologies and practices that aid smallholder farmers underscores the need for accessible, scalable agroforestry models that can be adopted across diverse geographical and socio-economic contexts to improve food security and livelihoods.

4.5 Theoretical Contributions

Theoretically, this study contributes to the literature by mapping the evolution of agroforestry research and highlighting its multidisciplinary nature. It showcases the dynamic interplay between ecological, economic, and social factors within agroforestry systems. The analysis not only reaffirms the role of agroforestry in addressing global challenges like climate change and food security but also enhances our understanding of how research collaborations and thematic focuses have shifted over time. Furthermore, by identifying less-explored areas such as coffee agroforestry systems or the role of biodiversity in these settings, this study opens up new avenues for research and theory development in sustainable agriculture and environmental management.

5. CONCLUSION

This bibliometric study has illuminated the comprehensive landscape of agroforestry research from its foundational concepts to its implications for sustainability and climate resilience. By analyzing citation patterns, collaboration networks, and thematic trends, the study highlights how agroforestry has evolved to become a critical component of sustainable land use discussions globally. The identification of core researchers and their collaborative networks provides insights into the intellectual structure of the field, indicating both robust academic contributions and potential gaps in the current knowledge base. Ultimately, this study underscores the importance of continued research and collaboration in agroforestry to enhance its theoretical foundations and practical applications, ensuring it can effectively contribute to the global sustainability agenda.

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