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Map of Sustainable Agriculture Research Development: Global Bibliometric Analysis (2000–2025)

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ABSTRACT

This study maps the global development of sustainable agriculture research through a bibliometric analysis of publications indexed in Scopus from 2000 to 2025. Using VOSviewer for network visualization, the study examines publication trends, keyword co-occurrence patterns, and collaboration networks among authors, institutions, and countries. The findings reveal a substantial increase in research output over time, indicating growing scholarly and policy attention to sustainability in agriculture. Core research themes are strongly centered on sustainable development, climate change, food security, soil health, and environmental impact. The keyword network demonstrates a multidimensional structure in which environmental sustainability forms the conceptual backbone, supported by soil nutrient management and carbon-related studies. In addition, emerging clusters highlight increasing integration of biotechnology, microbial research, and digital technologies such as machine learning and smart agriculture. Country collaboration analysis identifies China as a dominant global hub, with strong linkages to Europe, North America, and other Asian regions, reflecting expanding international cooperation. Institutional networks further show the presence of key research centers that act as bridges in knowledge production. Overall, the study indicates that sustainable agriculture research is transitioning toward an integrated paradigm combining ecological resilience, technological innovation, and socio-economic sustainability. The results provide a comprehensive overview of the field's evolution and offer insights into future research directions emphasizing interdisciplinary integration and global collaboration.

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1. INTRODUCTION

Sustainable agriculture has become one of the most critical research and policy agendas of the twenty first century. The growing global population, projected to reach nearly 10 billion by 2050, has intensified pressure on agricultural systems to produce more food while preserving environmental integrity [1], [2]. Conventional agricultural practices, characterized by heavy reliance on chemical inputs, monoculture systems, and intensive land use, have contributed to soil degradation, biodiversity loss, water scarcity, and greenhouse gas emissions. These environmental challenges have prompted scholars, policymakers, and practitioners to rethink agricultural paradigms and shift toward more sustainable approaches that balance productivity, environmental protection, and social equity [3], [4]. As a result, sustainable agriculture has evolved into a multidisciplinary field that integrates ecological principles, economic viability, and social responsibility [3].

Over the past two decades, research on sustainable agriculture has expanded rapidly across continents. Scholars have explored diverse themes, including agroecology, organic farming, climate smart agriculture, conservation agriculture, precision agriculture, circular bioeconomy, and regenerative farming systems [5], [6]. Technological advancements, such as digital agriculture, remote sensing, artificial intelligence, and Internet of Things applications, have further enriched the discourse by offering innovative solutions for resource efficiency and environmental monitoring. Simultaneously, policy frameworks such as the Sustainable Development Goals, particularly Goal 2 on Zero Hunger and Goal 13 on Climate Action, have strengthened the global commitment to transforming agricultural systems. The integration of sustainability principles into agricultural research has thus become both a scientific necessity and a global development priority [7], [8].

The globalization of agricultural research has also encouraged cross national collaboration and interdisciplinary integration. Developed and developing countries alike contribute to the body of literature, although research capacity and thematic priorities may differ significantly [9], [10]. For instance, European and North American studies often emphasize technological innovation and policy reform, while research in Asia, Africa, and Latin America frequently focuses on smallholder resilience, food security, and climate adaptation. The increasing interconnection of research networks has facilitated knowledge exchange, yet it has also generated a complex and fragmented body of literature. With thousands of publications emerging annually, it becomes increasingly challenging to systematically understand the intellectual structure, dominant themes, and collaborative patterns that shape the evolution of sustainable agriculture research.

In response to this complexity, bibliometric analysis has emerged as a powerful methodological approach to map scientific knowledge. By quantitatively analyzing large scale publication data, bibliometric methods allow researchers to identify publication trends, influential authors, leading institutions, collaboration networks, thematic clusters, and emerging research fronts. Tools such as VOSviewer and databases such as Scopus enable the visualization of co authorship networks, keyword co occurrence patterns, citation structures, and thematic evolution over time. Bibliometric analysis does not merely summarize existing literature; it reveals hidden structures and dynamics within a research field, providing a macro level perspective that complements traditional systematic reviews [11]. In the context of sustainable agriculture, a comprehensive bibliometric mapping can illuminate how the field has evolved over a quarter century and where future research directions may lie.

Between 2000 and 2025, the global research landscape has undergone significant transformations influenced by technological innovation, climate crises, geopolitical shifts, and sustainability transitions. The early 2000s were marked by foundational debates on organic farming and ecological intensification. The 2010s saw a surge in climate change adaptation strategies, resilience frameworks, and sustainable supply chain management. More recently, the 2020s have been characterized by digital transformation, data driven agriculture, and regenerative approaches aligned with carbon neutrality goals. Despite the richness of these developments, a comprehensive and updated global mapping covering the entire 2000 to 2025 period remains limited. Existing studies often focus on specific subtopics, shorter time frames, or regional perspectives, leaving a gap in understanding the holistic progression of sustainable agriculture research at the global scale.

Although sustainable agriculture has become a central theme in global scientific discourse, there is still insufficient comprehensive bibliometric mapping that systematically captures its global development over a twenty five year period from 2000 to 2025. The rapid expansion of publications has created a fragmented knowledge landscape in which thematic evolution, collaborative dynamics, influential contributors, and emerging research frontiers are not fully understood. Without an integrated bibliometric analysis, it is difficult to identify dominant research clusters, shifting priorities, regional contributions, and potential gaps that require further exploration. This limitation hampers the ability of scholars and policymakers to design informed research agendas and strategic collaborations for advancing sustainable agricultural systems worldwide. This study aims to map the global development of sustainable agriculture research from 2000 to 2025 using a bibliometric approach

2. METHOD

This study employed a quantitative bibliometric approach to map the global development of sustainable agriculture research from 2000 to 2025. The data source used in this study was the Scopus database, selected due to its extensive coverage of peer reviewed international publications across disciplines. A comprehensive search strategy was developed using relevant keywords such as "sustainable agriculture," "agricultural sustainability," "sustainable farming," "agroecology," and related terms. The search was limited to publications published between 2000 and 2025 and restricted to articles, reviews, and conference papers written in English to ensure consistency and comparability. The retrieved records included bibliographic information such as title, authors, affiliations, abstract, keywords, publication year, source title, and citation data. After the initial extraction, the data were exported in CSV format for further analysis and screened to remove duplicates or irrelevant records.

The bibliometric analysis was conducted using VOSviewer, a widely used software tool for constructing and visualizing bibliometric networks. Several types of analyses were performed, including co authorship analysis to identify collaboration patterns among authors, institutions, and countries; keyword co occurrence analysis to detect major research themes and emerging topics; and citation analysis to explore influential publications and intellectual structures within the field. Threshold criteria were applied in VOSviewer to ensure meaningful visualization, such as setting minimum numbers of documents or citations for authors and keywords to be included in the network maps. The software generated network visualization, overlay visualization, and density visualization maps, which facilitated the interpretation of relationships and research evolution over time.

To ensure analytical rigor, the study adopted a systematic procedure in data cleaning, normalization, and interpretation. Variations in author names, institutional affiliations, and keywords were standardized to reduce bias caused by inconsistencies in indexing. The analysis was conducted at multiple levels, including global publication trends by year, leading countries and institutions based on productivity and citations, and thematic clustering based on keyword networks. The results from VOSviewer visualizations were interpreted descriptively to identify dominant research clusters, shifts in thematic focus across periods, and patterns of international collaboration.

3. RESULT AND DISCUSSION

Co-Authorship Analysis

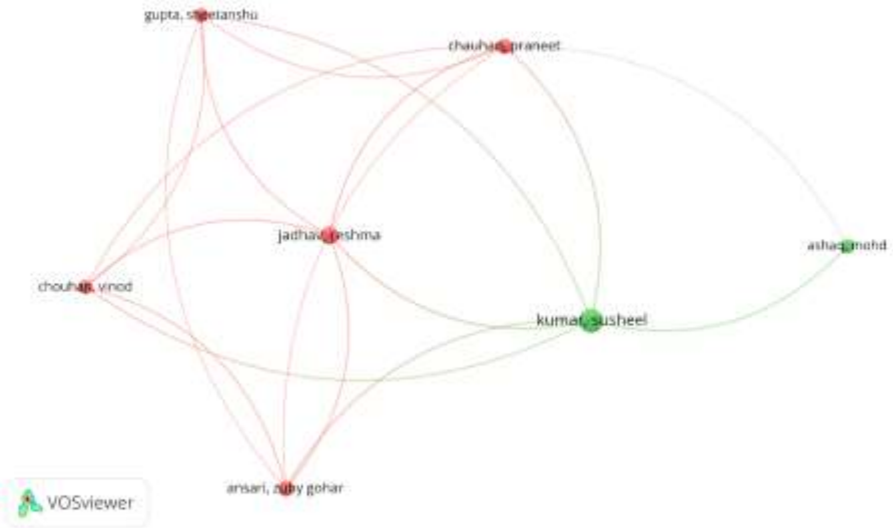

Figure 1. Author Visualization
Soruce: Data Analysis

Figure 1 reveals a relatively small but clearly structured collaboration pattern within sustainable agriculture research. Two main clusters are visible: a red cluster composed of authors such as Gupta Sneetanshu, Chauhan Praneet, Jadhav Reshma, Chouhan Vinod, and Ansari Zuby Gohar, and a green cluster centered around Kumar Susheel and Ashaq Mohd. The red cluster appears denser, indicating strong internal collaboration among its members, with Jadhav Reshma acting as an important connecting node within this group. Meanwhile, Kumar Susheel stands out as the most prominent and central author in the green cluster, with direct collaborative ties extending toward both his cluster member (Ashaq Mohd) and authors in the red cluster. This bridging role suggests that Kumar Susheel functions as a key connector between otherwise distinct collaboration groups.

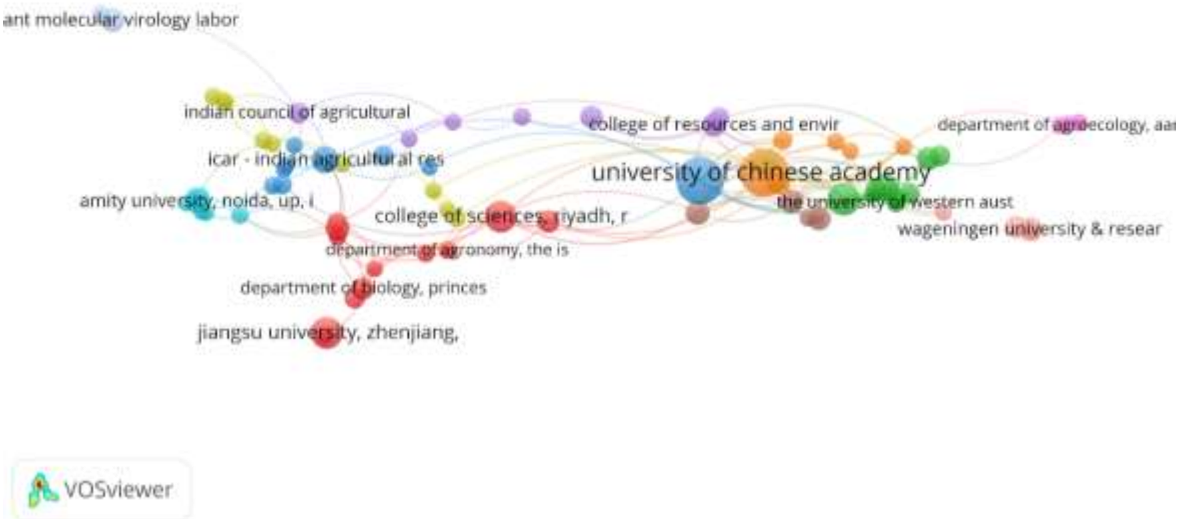

Figure 2. Institution Visualization
Source: Data Analysis

Figure 2 shows a multi-cluster global structure centered strongly around the University of Chinese Academy of Sciences, which appears as the largest and most connected node, indicating its dominant role in sustainable agriculture research collaborations. Several regional clusters are visible. On the left side, Indian institutions such as ICAR–Indian Agricultural Research Institute, Indian Council of Agricultural Research, and Amity University form a tightly connected group, suggesting strong domestic collaboration within India. Another cluster includes Jiangsu University and departments of agronomy and biology, reflecting institutional collaboration within China and linked academic departments. In the Middle Eastern region, the College of Sciences in Riyadh connects into the broader network, indicating cross-regional cooperation. On the right side, institutions such as Wageningen University & Research and The University of Western Australia form part of a more internationally connected cluster, highlighting engagement from leading agricultural research centers in Europe and Australia.

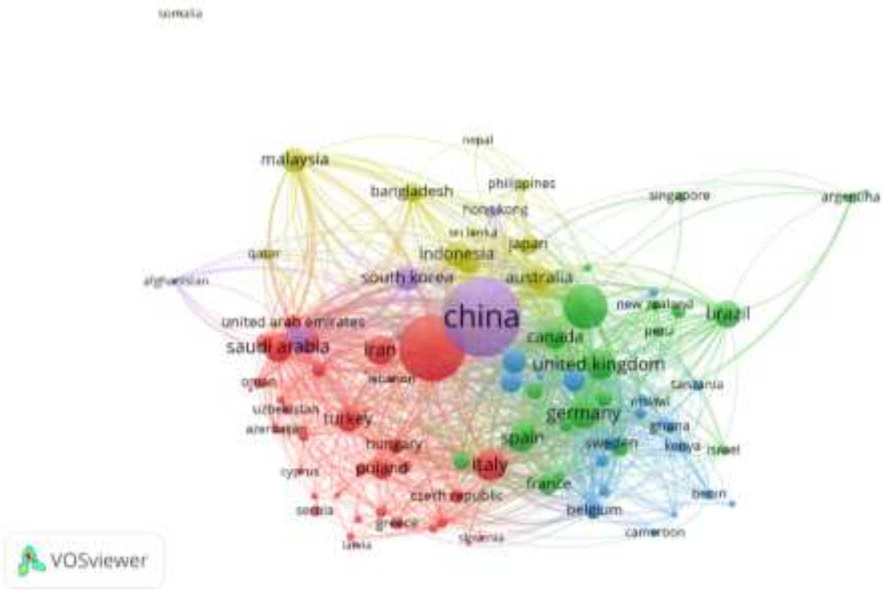

Figure 3. Country Visualization
Source: Data Analysis

Figure 3 reveals a dense and highly interconnected global structure, with China emerging as the most dominant and central actor in sustainable agriculture research. Its large node size and extensive links indicate high publication output and strong international collaboration. China is closely connected with countries such as the United Kingdom, Germany, Canada, Australia, and Brazil, forming a core collaboration hub. The red cluster highlights strong activity from Middle Eastern and Southern European countries, including Iran, Saudi Arabia, Turkey, Italy, and Poland, reflecting regional research partnerships. The green and blue clusters show active participation from Western Europe, North America, and parts of Latin America and Africa, with Germany, the United Kingdom, France, Belgium, and Brazil acting as important connectors. Meanwhile, the yellow cluster reflects Southeast and East Asian collaborations involving Malaysia, Indonesia, Japan, South Korea, Bangladesh, and the Philippines.

Citation Analysis

Table 1. Top Cited Literature

Citations	Authors and Year	Title
9,439	[12]	Food security: The challenge of feeding 9 billion people
8,284	[13]	Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems
6,635	[14]	Solutions for a cultivated planet

6,316	[15]	Agricultural sustainability and intensive production practices
6,243	[16]	Global food demand and the sustainable intensification of agriculture
4,909	[17]	Microalgae for biodiesel production and other applications: A review
3,029	[18]	Going back to the roots: The microbial ecology of the rhizosphere
2,915	[19]	The NCEP climate forecast system version 2
2,793	[20]	Knowledge systems for sustainable development
2,608	[21]	Worldwide decline of the entomofauna: A review of its drivers

Source: Scopus, 2026

Keyword Co-Occurrence Analysis

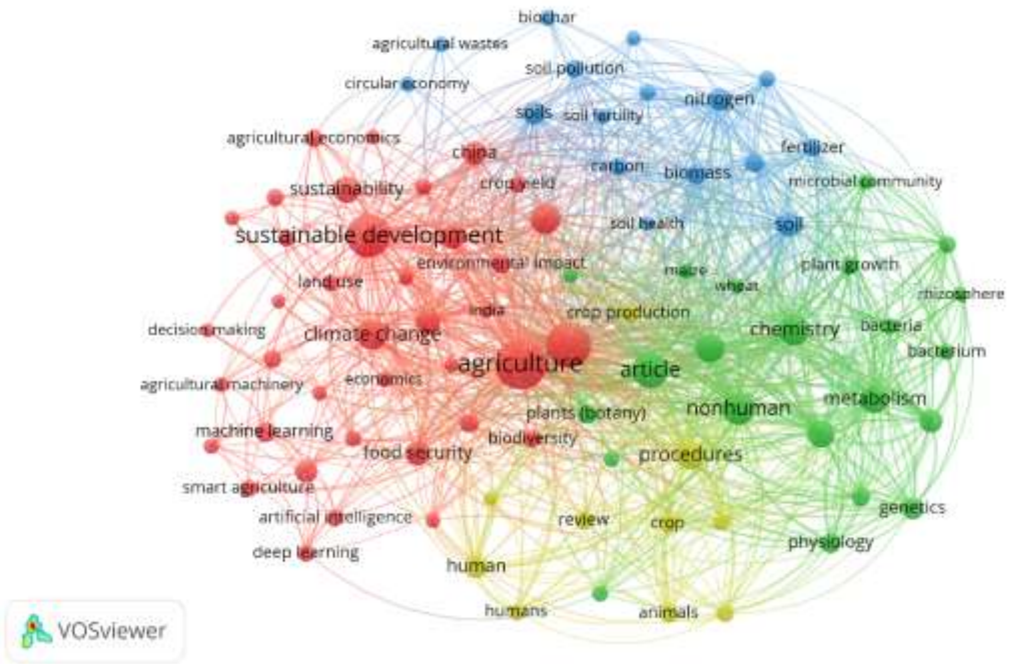

Figure 4. Network Visualization
Source: Data Analysis

Figure 4 illustrates a well-structured and multidisciplinary landscape of sustainable agriculture research. The visualization is dominated by several large and highly connected nodes, particularly agriculture, sustainable development, and climate change, indicating that these themes form the conceptual core of the field. The density of links suggests strong interconnections between environmental, economic, and production-related issues. Sustainable agriculture research is therefore positioned not only as a production system concern but also as a broader sustainability and climate resilience agenda. The red cluster primarily reflects macro-level and socio-environmental themes. Keywords such as sustainable development, climate change, food security, environmental impact, economics, and machine learning indicate the integration of sustainability discourse with technological innovation and policy considerations. The presence of terms like artificial intelligence, deep learning, and smart agriculture suggests a growing emphasis on digital transformation within sustainable farming systems, highlighting a shift toward precision and data-driven agriculture.

The blue cluster is strongly centered on soil-related research themes. Terms such as soil, nitrogen, soil fertility, carbon, biochar, soil pollution, and biomass reveal a major research focus on soil health, nutrient management, and carbon cycling. This cluster emphasizes biophysical processes and resource efficiency, reflecting the importance of soil management as a foundation of sustainable agricultural systems. The strong connectivity among these terms indicates that nutrient cycling and soil restoration remain central scientific pillars of sustainability research. The green cluster represents a more biological and microbiological dimension of sustainable agriculture. Keywords such as chemistry, bacteria, microbial community, rhizosphere, metabolism, genetics, and physiology show the integration of plant science, microbiology, and biotechnology into agricultural sustainability studies. This suggests that recent research increasingly explores microbial interactions, plant–soil systems, and genetic factors to enhance productivity while reducing environmental impacts. The yellow cluster appears to integrate applied and cross-cutting themes, including crop, review, humans, animals, and biodiversity. This cluster bridges ecological, agronomic, and socio-economic dimensions, indicating interdisciplinary expansion.

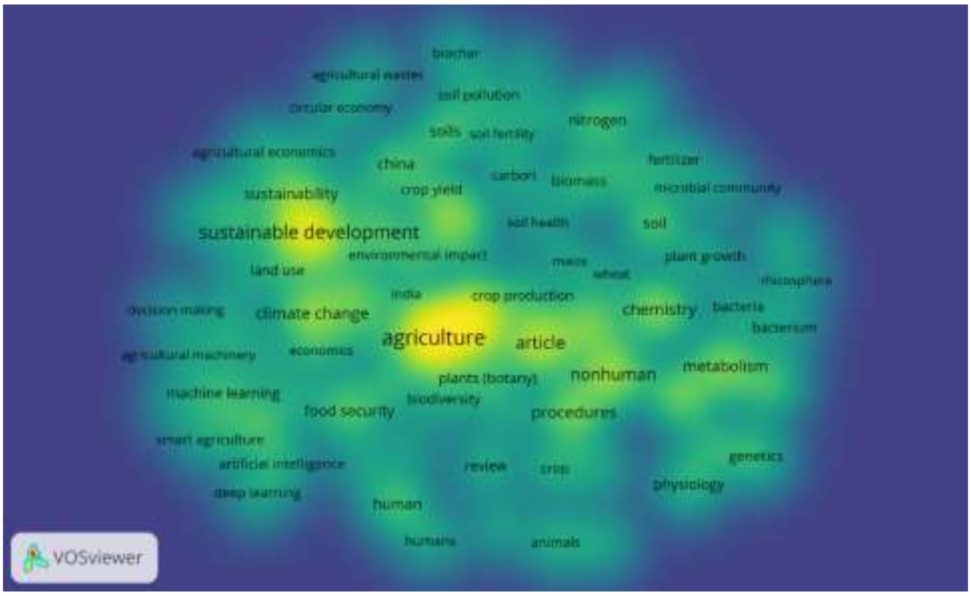

Figure 5. Density Visualization
Source: Data Analysis

Figure 5 highlights the most intensively researched themes in sustainable agriculture studies. The brightest and most concentrated areas are centered around keywords such as agriculture, article, sustainable development, and climate change, indicating that these topics form the conceptual and analytical core of the field. High-density zones also extend toward food security, crop production, and environmental impact, suggesting strong scholarly attention to the relationship between agricultural productivity and sustainability challenges. This confirms that global research is strongly anchored in balancing production demands with climate and environmental concerns. Moderate-density areas appear around soil-related and biological themes such as soil, nitrogen, soil fertility, microbial community, chemistry, metabolism, and genetics, reflecting sustained but slightly more specialized scientific engagement. Emerging technological themes including machine learning, artificial intelligence, and smart agriculture are present but less dense, indicating growing yet still developing research streams.

Discussion

This bibliometric analysis reveals that sustainable agriculture research has evolved into a highly integrated and multidisciplinary field between 2000 and 2025. The steady growth of publications and the density of international collaborations indicate that sustainability in agriculture is no longer a peripheral topic but a central scientific and policy priority. The prominence of keywords such as sustainable development, climate change, and food security confirms that research is strongly aligned with global sustainability agendas and climate resilience frameworks. The field increasingly reflects a systems perspective, connecting environmental, economic, and social dimensions rather than treating agricultural productivity as an isolated objective. The keyword network demonstrates that environmental sustainability remains the conceptual backbone of the literature. Soil health, nutrient management, carbon dynamics, and biomass recycling are consistently interconnected, suggesting that resource efficiency and ecosystem restoration are enduring priorities. The strong presence of soil-related themes highlights the recognition that long-term agricultural sustainability depends fundamentally on soil conservation and nutrient cycling. This reinforces the argument that regenerative and climate-smart practices are becoming structural components of contemporary agricultural research rather than niche subfields.

At the same time, the analysis identifies a significant expansion toward biological and microbiological approaches. The clustering of terms such as microbial community, rhizosphere, genetics, and metabolism indicates growing attention to plant–soil–microbe interactions as mechanisms for improving productivity while reducing chemical inputs. This suggests a shift from purely input-intensive models toward biologically informed strategies, including biofertilizers, microbial management, and biotechnology-driven innovations. Such developments reflect a deeper scientific exploration of sustainable intensification grounded in ecological processes. Another important finding is the increasing integration of digital technologies within sustainable agriculture research. Although still less dense compared to environmental themes, keywords such as machine learning, artificial intelligence, and smart agriculture demonstrate a clear emerging trajectory. This signals a transformation toward precision-based and data-driven sustainability strategies. The coexistence of digital innovation with environmental and biological themes suggests that future research may converge around technologically enhanced sustainability solutions, combining AI-driven decision support with soil and ecosystem management.

The country collaboration network highlights China as the most central and dominant contributor, functioning as a global hub that connects Asian, European, and transcontinental research networks. Strong participation from European countries, North America, and parts of Southeast Asia further illustrates the global integration of the field. However, collaboration patterns also reveal regional clustering, indicating that research partnerships are still partially shaped by geographic proximity and regional priorities. Expanding more inclusive global collaborations, particularly involving underrepresented regions, may enhance knowledge exchange and contextual adaptation of sustainable practices. Institutional collaboration patterns reinforce the presence of major research hubs, particularly large universities and agricultural research institutes. These institutions serve as bridges between national and international research communities. The dominance of specific institutions suggests concentrated expertise, but it also highlights the importance of fostering broader institutional networks to diversify perspectives and innovation pathways.

4. CONCLUSION

In conclusion, this bibliometric study demonstrates that global research on sustainable agriculture from 2000 to 2025 has expanded significantly and evolved into a highly interconnected, multidisciplinary field. The literature is strongly anchored in themes of sustainable development, climate change, soil health, and food security, while increasingly integrating biological innovations and digital technologies such as artificial intelligence and smart agriculture. International collaboration networks, with China and several European countries acting as key hubs, reflect the global importance of sustainability challenges in agriculture. The field is moving toward an integrated paradigm that combines environmental stewardship, technological advancement, and socio-economic resilience, suggesting that future research should prioritize cross-disciplinary integration and inclusive global partnerships to strengthen sustainable agricultural systems worldwide.

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