West Science Nature and Technology
Vol. 4, No. 01, March 2026, pp. 66~73

Sustainable Agriculture Research 2000–2026 Core Themes Growth Trajectories and Knowledge Networks: A Bibliometric Review

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Article Info

Article history:

Received March, 2026
Revised March, 2026
Accepted March, 2026

Keywords:

Sustainable Agriculture; Bibliometric Analysis; Research Trends; VOSviewer

ABSTRACT

This study aims to map the intellectual structure, thematic evolution, and collaboration patterns of sustainable agriculture research from 2000 to 2026 using a bibliometric approach. Data were collected from the Scopus database and analyzed using VOSviewer to identify core themes, research trajectories, and knowledge networks. The results indicate a significant growth in publications, particularly after 2015, reflecting increasing global attention to sustainability challenges in agriculture. Co-occurrence analysis reveals several dominant thematic clusters, including environmental sustainability, soil and nutrient management, technological innovation (e.g., precision agriculture and machine learning), and biological aspects of crop production. Density visualization highlights that while core topics such as sustainable agriculture and resource management are well-established, emerging areas such as circular economy, carbon management, and AI-driven agriculture remain relatively underexplored. In addition, collaboration network analysis suggests that research is largely dominated by developed countries, although contributions from developing regions are gradually increasing. This study contributes by providing a comprehensive overview of research trends and identifying future research directions to support the development of sustainable and resilient agricultural systems.

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1. INTRODUCTION

Sustainable agriculture has emerged as a critical response to the pressing challenges of global food security, environmental degradation, and climate change. The rapid growth of human populations and the intensification of conventional agricultural practices have placed unprecedented pressure on natural resources, including soil, water, and biodiversity [1]. In response, sustainable agriculture emphasizes practices that balance productivity with ecological stewardship, social responsibility, and economic viability. Over the last two decades, research in this field has expanded significantly, addressing issues ranging from agroecology and integrated pest management to organic farming, conservation tillage, and climate-resilient cropping systems [2], [3]. This growth reflects a broader scientific and policy recognition of the need to harmonize

agricultural production with environmental sustainability.

The scientific landscape of sustainable agriculture is characterized by interdisciplinary approaches that integrate agronomy, ecology, economics, and social sciences. Researchers have increasingly recognized that isolated technological interventions are insufficient without consideration of socio-economic and cultural contexts [3]. For instance, studies on soil health management, water-efficient irrigation, and precision agriculture highlight the importance of technology, whereas community-based initiatives emphasize participatory approaches, local knowledge, and farmer networks. Such integration has facilitated the development of holistic frameworks that guide sustainable practices while also informing policy decisions. Consequently, sustainable agriculture research has become not only a technical domain but also a platform for broader discussions on sustainability transitions, resilience, and global food systems governance [4].

Over the period from 2000 to 2026, bibliometric analyses reveal a notable increase in scientific publications, citation networks, and collaborative research on sustainable agriculture. The rise of digital databases, open-access journals, and international research consortia has accelerated knowledge dissemination and cross-disciplinary collaboration [5]. Mapping these developments through bibliometric methods provides critical insights into research trends, emerging topics, and influential scholars or institutions. Core themes such as organic farming, agroforestry, climate-smart agriculture, and biodiversity conservation have consistently attracted scholarly attention, reflecting both environmental priorities and societal concerns about sustainable food systems. Furthermore, knowledge networks have expanded beyond regional boundaries, enabling the diffusion of innovations and best practices globally [6].

The dynamics of knowledge production in sustainable agriculture are closely linked to global environmental and policy shifts. International initiatives, including the Millennium Development Goals (MDGs), Sustainable Development Goals (SDGs), and national-level strategies for climate adaptation and food security, have driven funding and research priorities. For instance, SDG 2 emphasizes "zero hunger" while promoting sustainable agricultural practices, incentivizing both academic research and applied interventions. Similarly, global concerns about carbon emissions, water scarcity, and land degradation have encouraged research that integrates ecological modeling, life-cycle assessment, and socio-economic evaluation. This alignment between policy objectives and scientific inquiry has contributed to the emergence of sustainability-oriented research clusters, demonstrating the interconnectedness of science, governance, and practice.

Another significant trend in sustainable agriculture research is the increasing attention to knowledge networks and collaboration patterns. Co-authorship networks, institutional partnerships, and thematic clusters reveal how research communities evolve over time, identifying central actors, influential publications, and emerging topics [7]. The growth trajectories of these networks indicate both the expansion of research capacity and the specialization of subfields. For example, studies on organic soil management often intersect with biodiversity conservation, while climate-smart agriculture research may link to policy analysis and socio-economic modeling. Such interconnectedness illustrates that the development of sustainable agriculture knowledge is not linear but rather characterized by complex interdependencies across disciplines, institutions, and geographic regions.

Finally, the methodological rigor of sustainable agriculture research has evolved alongside thematic growth. Bibliometric studies, meta-analyses, and systematic reviews increasingly complement field-based experiments and case studies, providing robust evidence for policy and practice [8]. Bibliometrics, in particular, enables

researchers to quantify the growth, impact, and structure of the scientific landscape, offering insights into thematic concentration, influential authors, and institutional contributions. By tracing research outputs from 2000 to 2026, it is possible to identify both persistent themes and emerging priorities, as well as gaps where further investigation is warranted. This methodological evolution underscores the importance of evidence-based approaches in shaping the future of sustainable agriculture research and practice.

Despite substantial growth in publications and collaborative networks, sustainable agriculture research faces several challenges. First, the fragmentation of knowledge across disciplines and regions can hinder the consolidation of best practices. Second, emerging issues such as climate change adaptation, soil degradation, and socio-economic inequities demand integrative research that spans both biophysical and social sciences. Finally, while bibliometric analyses have grown in popularity, there remains a lack of comprehensive reviews that map the evolution of core themes, growth trajectories, and knowledge networks over an extended period, limiting our understanding of the field's historical development and future directions.

The objective of this study is to conduct a bibliometric review of sustainable agriculture research from 2000 to 2026, with a focus on identifying core themes, analyzing growth trajectories, and mapping knowledge networks.

2. METHODS

This study employed a bibliometric approach to systematically analyze research on sustainable agriculture published between 2000 and 2026. Bibliometrics is a quantitative method that enables the mapping of scientific knowledge, trends, and collaborations through publication and citation data [8]. The primary data source for this analysis was the Web of Science Core Collection database, selected for its comprehensive coverage of high-quality, peer-reviewed journals and its suitability for advanced citation and co-authorship analyses. Publications were retrieved using a structured search strategy combining keywords such as "sustainable agriculture," "organic farming," "agroecology," "climate-smart agriculture," and "biodiversity in agriculture," applied to titles, abstracts, and author keywords. To ensure the relevance and quality of the dataset, only research articles and reviews published in English were included, while conference proceedings, book chapters, and editorial materials were excluded.

The data cleaning and preprocessing steps involved standardizing author names, institutional affiliations, and keywords to reduce duplication and inconsistency in the network analysis. Core bibliometric indicators were computed, including publication counts, citation counts, h-index, and journal impact metrics. Growth trajectories of sustainable agriculture research were examined through annual publication trends and cumulative citation analysis. Thematic mapping was conducted using keyword co-occurrence networks, enabling the identification of core research themes and emerging topics over the 26-year period. Co-authorship and institutional collaboration networks were analyzed to reveal knowledge structures, influential researchers, and inter-institutional partnerships. All bibliometric analyses were performed using specialized software tools such as VOSviewer, which facilitate the visualization and clustering of networks, as well as the detection of trends and research hotspots.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network Visualization

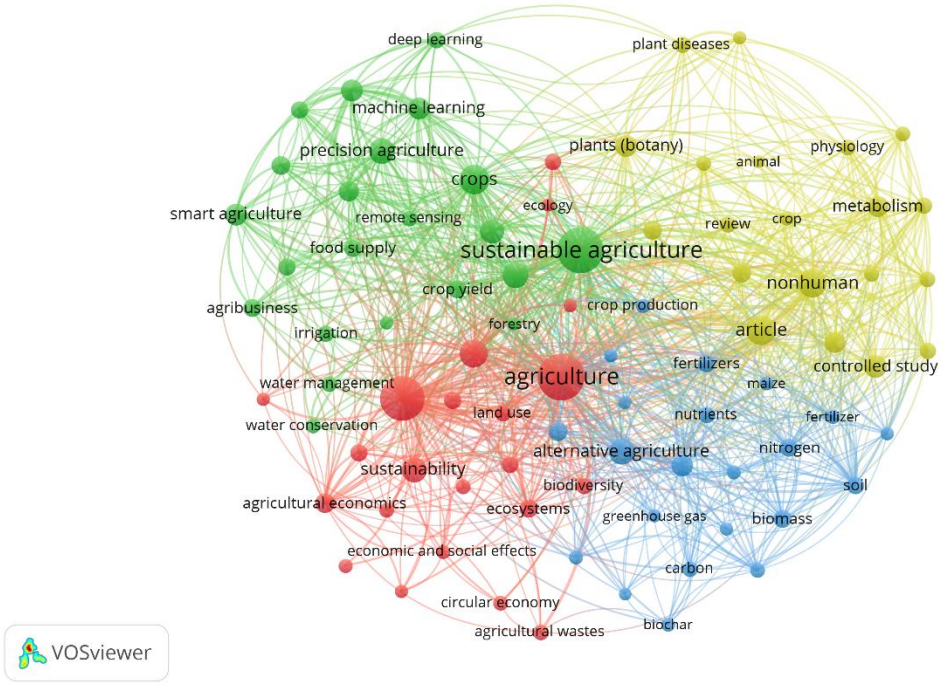

Figure 1. Network Visualization
Source: Data Analysis, 2026

Figure 1 reveals the intellectual structure of sustainable agriculture research through the clustering of keywords into several interconnected thematic groups. At the center of the network, the term "sustainable agriculture" appears as the dominant node, indicating its role as the core concept linking multiple research streams. Closely connected to it is the term "agriculture," which acts as a foundational domain, bridging traditional agricultural studies with emerging sustainability-oriented approaches. The density and centrality of these nodes suggest that the field is highly integrated, with sustainability acting as the primary lens through which agricultural research is currently framed.

The green cluster highlights the growing importance of technological innovation in sustainable agriculture. Keywords such as machine learning, deep learning, precision agriculture, remote sensing, and smart agriculture indicate a strong shift toward digital and data-driven farming practices. This cluster reflects the increasing integration of artificial intelligence and advanced analytics to improve crop productivity, optimize resource use, and enhance decision-making processes. The presence of terms like food supply and crop yield further suggests that these technologies are being applied to address global food security challenges, marking a transition toward Agriculture 4.0.

The red cluster represents environmental sustainability and resource management perspectives. Key terms such as sustainability, ecosystems, biodiversity, water management, irrigation, and land use emphasize ecological balance and conservation strategies. This cluster indicates that a substantial portion of research is dedicated to understanding how agricultural practices impact natural ecosystems and how sustainable methods can mitigate environmental degradation. Additionally, the

inclusion of economic and social effects and circular economy suggests an interdisciplinary approach that integrates environmental, social, and economic dimensions of sustainability.

The blue cluster focuses on soil science, nutrient management, and climate-related aspects. Keywords such as soil, nitrogen, fertilizer, carbon, greenhouse gas, and biochar reflect research aimed at improving soil fertility while reducing environmental impacts such as emissions and nutrient runoff. This cluster highlights the critical role of soil health and carbon management in achieving sustainable agricultural systems. The presence of terms like biomass and carbon sequestration indicates increasing attention to agriculture's role in climate change mitigation.

The yellow cluster captures biological and physiological dimensions of agriculture, including plant diseases, metabolism, physiology, and crop science. This cluster reflects traditional agricultural and biological research that continues to underpin sustainable practices. The inclusion of controlled study and review suggests a strong foundation of experimental and evidence-based research in this domain.

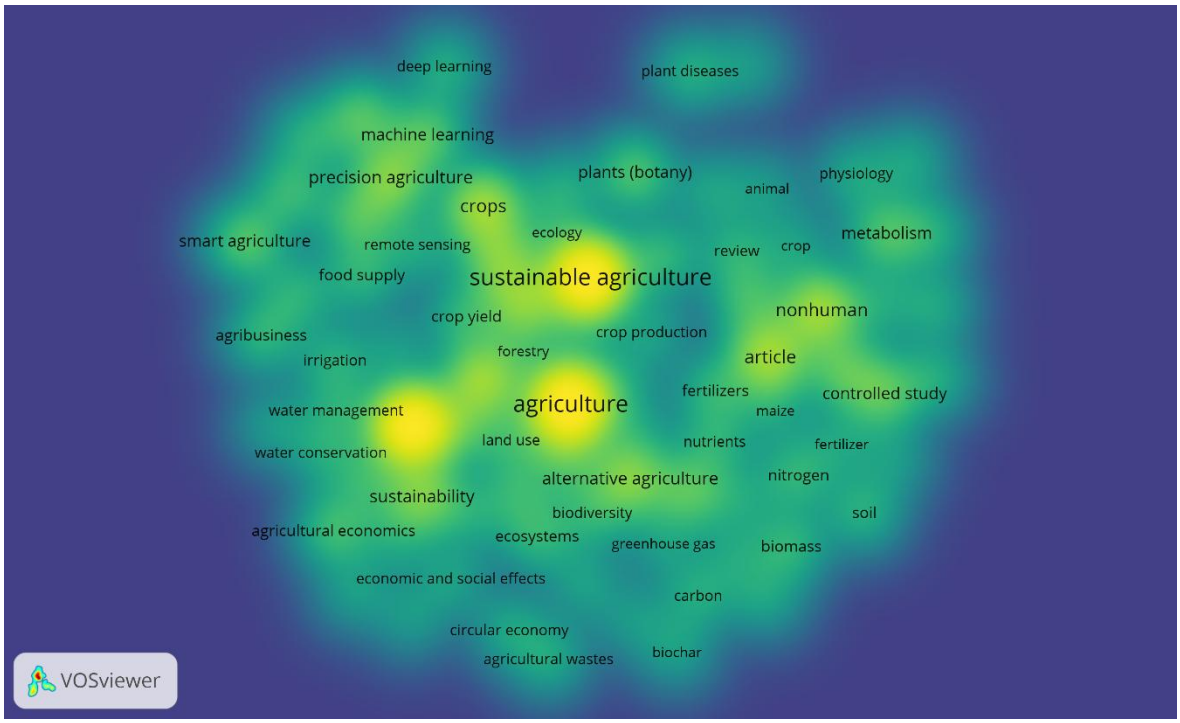

Figure 2. Density Visualization

Source: Data Analysis, 2026

Figure 2 highlights the concentration and intensity of research topics within the field of sustainable agriculture. The brightest (yellow) areas are centered around the keywords "sustainable agriculture" and "agriculture," indicating that these are the most frequently studied and highly interconnected themes in the literature. Surrounding these core concepts are moderately dense areas (green), including topics such as crop production, land use, water management, irrigation, and sustainability, which suggest well-established but still actively evolving research domains. This pattern reflects a strong foundational focus on optimizing agricultural systems while balancing environmental and resource management concerns. In contrast, the peripheral areas (blue to darker shades) represent less dense and relatively underexplored topics, such as biochar, carbon, circular economy, agricultural wastes,

and some aspects of machine learning and deep learning. Although these themes appear less central, their presence indicates emerging directions in sustainable agriculture research, particularly in the integration of climate mitigation strategies and digital technologies.

3.2 Citation Analysis

Table 1. Top Cited Documents

Citations	Authors and year	Title	Source
9,484	[9]	Food security: The challenge of feeding 9 billion people	Science, 327(5967), pp. 812–818
8,384	[10]	Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems	Lancet, 393(10170), pp. 447–492
6,668	[11]	Solutions for a cultivated planet	Nature, 478(7369), pp. 337–342
6,335	[12]v	Agricultural sustainability and intensive production practices	Nature, 418(6898), pp. 671–677
6,284	[13]	Global food demand and the sustainable intensification of agriculture	Proceedings of the National Academy of Sciences of the United States of America, 108(50), pp. 20260–20264
4,926	[14]	Microalgae for biodiesel production and other applications: A review	Renewable and Sustainable Energy Reviews, 14(1), pp. 217–232
3,047	[15]	Going back to the roots: The microbial ecology of the rhizosphere	Nature Reviews Microbiology, 11(11), pp. 789–799
2,921	[16]	The NCEP climate forecast system version 2	Journal of Climate, 27(6), pp. 2185–2208
2,803	[17]	Knowledge systems for sustainable development	Proceedings of the National Academy of Sciences of the United States of America, 100(14), pp. 8086–8091
2,629	[18]	Worldwide decline of the entomofauna: A review of its drivers	Biological Conservation, 232, pp. 8–27

Source: Scopus, 2026

Discussion

The findings of this bibliometric analysis demonstrate that sustainable agriculture research has evolved into a highly interdisciplinary and rapidly expanding field. The centrality of "sustainable agriculture" and "agriculture" in both the network and density visualizations confirms that the literature is strongly anchored in integrating productivity goals with environmental sustainability. This aligns with the broader global agenda, including sustainable development and climate action, where agriculture plays a pivotal role. The increasing volume of publications, particularly in recent years, reflects heightened academic and policy interest in addressing food security challenges while maintaining ecological balance.

One of the most significant insights from the co-occurrence analysis is the emergence of technology-driven agriculture

as a dominant research stream. The prominence of keywords such as machine learning, precision agriculture, and remote sensing indicates a paradigm shift toward digital transformation in agricultural practices. This trend suggests that sustainable agriculture is no longer solely associated with traditional ecological approaches but is increasingly supported by data-driven decision-making and advanced technologies. Such developments are critical in enhancing efficiency, reducing resource waste, and improving yield prediction, thereby contributing to more resilient agricultural systems.

At the same time, the environmental dimension remains a foundational pillar of the field. The clustering of terms related to ecosystems, biodiversity, water management, and land use highlights the continued importance of ecological sustainability in agricultural research. These findings suggest that scholars are actively exploring strategies to minimize environmental degradation while maintaining productivity. The integration of concepts such as circular economy and sustainability further indicates a shift toward holistic approaches that consider long-term environmental and socio-economic impacts rather than short-term gains.

The analysis also reveals the growing importance of soil health, nutrient management, and climate-related research. Keywords such as nitrogen, carbon, greenhouse gases, and biochar reflect increasing attention to the role of agriculture in climate change mitigation and adaptation. This indicates that sustainable agriculture research is expanding beyond farm-level practices to address global environmental challenges. The inclusion of carbon-related topics suggests a strong research interest in carbon sequestration and emission reduction, positioning agriculture as both a contributor to and a solution for climate change.

The presence of emerging but less dense topics in the visualization points to future research opportunities. Areas such as AI-driven agriculture, circular resource management, and advanced climate mitigation strategies remain relatively underdeveloped compared to core themes. This suggests that while the field has matured in its foundational areas, there is still substantial potential for innovation and exploration. Future studies should focus on integrating technological advancements with ecological principles and expanding research in underrepresented regions to ensure a more inclusive and globally relevant development of sustainable agriculture knowledge.

4. CONCLUSION

This study provides a comprehensive bibliometric overview of sustainable agriculture research from 2000 to 2026, revealing a dynamic and increasingly interdisciplinary field shaped by the convergence of environmental, technological, and socio-economic perspectives. The findings indicate that while core themes such as sustainability, resource management, and crop production remain central, there is a clear shift toward emerging areas including digital agriculture, climate change mitigation, and circular economy practices. The analysis also highlights the growing role of advanced technologies, such as machine learning and precision agriculture, in transforming traditional farming systems into more efficient and resilient models. Despite the maturity of several research domains, the presence of less-developed themes suggests significant opportunities for future exploration, particularly in integrating innovation with sustainability goals.

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