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EMERGING TRENDS IN GREEN AGRICULTURE RESEARCH: A BIBLIOMETRIC ANALYSIS

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Abstract. Green agriculture has gained significant attention in recent years, as evidenced by a growing number of publications. However, comprehensive analyses of the field's structure and development remain scarce. This study addresses this gap by conducting a bibliometric analysis using the Citespace tool, based on 295 articles indexed in the Scopus database from 2004 to October 2024. The analysis identifies trends in annual publications, leading journals, and key research areas. Keyword co-occurrence analysis further reveals three primary themes: the application of high-tech solutions to transform traditional agricultural models, the alignment of agriculture with sustainable development, and the promotion of green practices through advanced technologies. The findings also highlight gaps in the literature, offering insightful directions for future green agriculture research.

Keywords: agriculture, green agriculture, bibliometric analysis, Citespace.

1. Introduction

In the context of climate change and global environmental degradation, traditional agricultural practices, heavily reliant on natural resource exploitation and greenhouse gas emissions, have posed significant challenges to both society and the environment. These challenges necessitate rethinking conventional agricultural practices and proposing a shift towards green agriculture (GA), a sustainable farming approach that integrates environmental protection measures, minimizes emissions, and promotes ecological balance to enable agriculture to adapt to adverse conditions [1, 2]. By safeguarding and improving natural resources, GA emphasizes productivity, human health, and ecosystem preservation. Developing green agriculture is not merely an option but an inevitable trend to ensure sustainable ecosystems, meet the increasing demand for food, and safeguard the health and safety of future generations.

As of October 2024, the number of publications related to GA indexed in the Scopus database has increased more than 60-fold compared to a decade ago, demonstrating a surge in academic interest. Research in this field spans macro and micro levels. At the macro level, studies focus on building sustainable agricultural systems to address climate change [3], adopting high-tech applications to mitigate the environmental impacts of agricultural chemicals [4,5], and integrating agriculture with green production strategies [6,7,8]. At the micro level, researchers develop specific technologies and methods to reduce agriculture's environmental impact, protect biodiversity, and improve ecosystem health. These efforts lay the foundation for sustainable green agriculture that balances production needs with environmental preservation [9,10,11].

Bibliometric studies on GA primarily review specific topics using different approaches, such as analyzing literature on new technology applications and identifying their potential in GA [12], conducting systematic reviews on integrated pest management [13], and examining trends in the application of organic fertilizers to support sustainable agricultural [14]. These studies continue to propel the development of GA research.

Despite these advancements, new conceptual frameworks and ideas continuously emerge. Therefore, quantitative bibliometric analysis is an appropriate method for researchers to track the development of this trend, identify research gaps, and explore emerging areas. This study aims to employ CiteSpace for bibliometric analysis on GA research to answer the following research questions:

(i) What are the current research findings on GA?

(ii) What gaps remain to be explored further?

2. Content

2.1. Data and Research Tools

This study utilizes data from the Scopus database, a reputable and globally recognized indexing system widely used in scientific research. Scopus ensures that the selected studies are representative and of high academic quality [15]. To enhance the accuracy and reliability of the analysis, the search process adhered to the PRISMA guidelines. The search employed the keyword "green agriculture," restricted to articles in English, yielding an initial dataset of 295 publications. These were subsequently screened based on titles and abstracts to ensure relevance, resulting in a refined dataset for bibliometric analysis.

CiteSpace is a powerful bibliometric analysis tool, particularly renowned for identifying and visualizing trends and patterns in scientific research [16]. Unlike other analytical tools, CiteSpace not only aggregates data but also focuses on uncovering critical "breakthrough points" and "research clusters" within a field [17]. One of its standout features is the ability to detect critical nodes and edges within citation networks, facilitating the identification of influential authors, articles, and concepts over time [18]. Additionally, CiteSpace enables users to pinpoint emerging trends and potential "research gaps," supporting the development of new research directions [19]. Through its visualizations and time-based analyses, CiteSpace provides researchers with quick access to critical information, fostering a deeper understanding of the dynamic evolution of research fields [18].

2.2. Research Findings

2.2.1. Annual Publications

Figure 1 illustrates the annual publication trends in GA research from January 2004 to October 2024, with keywords related to GA first appearing in 2004. Overall, the development of GA research can be categorized into three distinct phases:

(i) Initial Phase (2004–2017): This period marks the infancy of GA research, with an average of only 1–3 publications per year. The limited output reflects the low awareness of GA concepts and the absence of advanced relevant technologies. However, these early studies laid the groundwork for future development;

(ii) Early Development Phase (2018–2020): During this phase, the number of publications increased slightly and stabilized at over ten articles per year. This growth signifies the beginning of intensified GA research, driven by increasing awareness of the impact of agriculture on climate change and a growing global interest in sustainable agricultural practices;

(iii) Rapid Growth Phase (2021–2024): A notable surge in publications occurred during this period, with the number of articles increasing from 30 in 2021 to 89 in 2023, representing a threefold increase. By October 2024, 65 articles had been published, surpassing 54 articles in 2022, despite covering only part of the year. This growth highlights the global recognition of GA's critical role in mitigating climate change, conserving soil resources, and ensuring food security.

These trends underscore GA's emergence as a dynamic and rapidly expanding field of research over the past decade, attracting increasing attention from researchers worldwide. As such, contemporary scholars should continue to invest in and expand research in this promising domain.

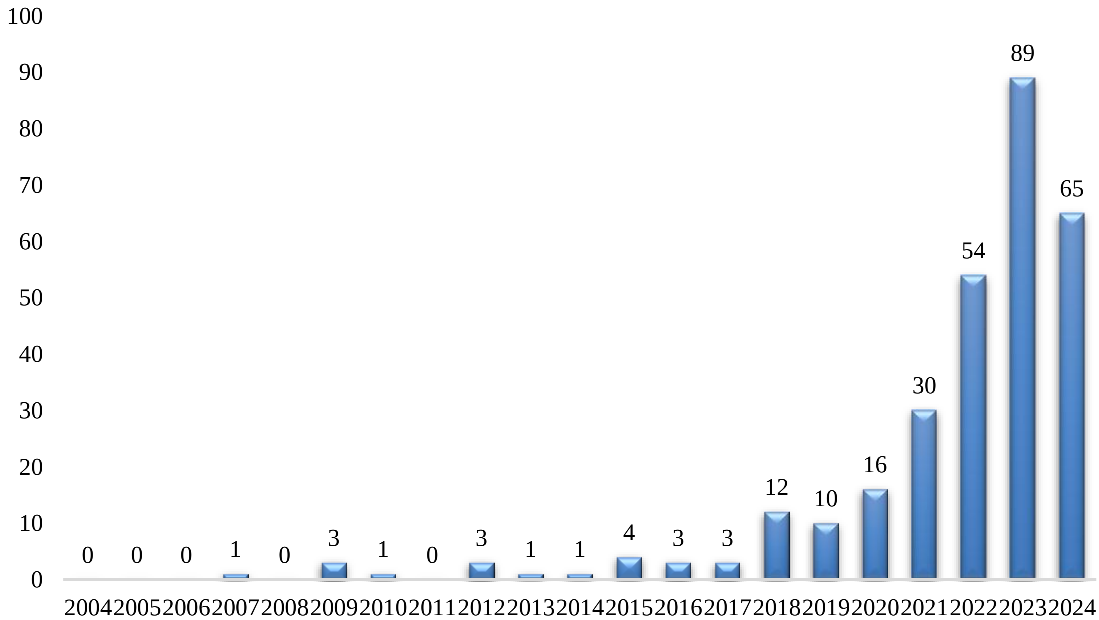

Figure 1. Annual number of published studies on GA

2.2.2. Journal Analysis

Table 1. Publication journal statistics

Rank	Journal	5-Year IF	Count
1	Sustainability (Switzerland)	3.9	29
2	Journal of Cleaner Production	11.1	14
3	Environmental Science and Pollution Research	5.4	11
4	Agriculture (Switzerland)	2.8	8
5	International Journal of Environmental Research and Public Health	4.5	8
6	Science of the Total Environment	8.2	8
7	Environment, Development and Sustainability	4.7	7
8	PLOS ONE	3.5	5
9	Scientific Reports	4.0	5
10	Frontiers in Microbiology	5.2	4

Table 1 presents the top 10 journals with the highest number of GA publications, highlighting their significant contributions to this research field. The journals with the most publications directly related to environmental science and sustainable development. Specifically, *Sustainability* leads with 29 articles, followed by the *Journal of Cleaner Production* with 14 articles. While *Sustainability* is a multidisciplinary, open-access journal, the *Journal of Cleaner Production* is a specialized subscription-based journal. Given their focus on environmental issues and sustainability, it is unsurprising that these journals account for many articles in this field. The two leading journals (*Sustainability* and *Journal of Cleaner Production*) represent over 14.6% of total articles, while the remaining eight collectively contribute approximately 14.2%. Notably, journals with high publication volumes typically exhibit high impact factors, with four journals surpassing an impact factor of 5. The *Journal of Cleaner Production* stands out with an impact factor exceeding 10, underscoring its significant influence in this domain.

These findings encourage researchers to improve their manuscripts' quality and provide guidance on selecting appropriate journals for future submissions.

2.2.3. Research areas related to green agriculture

Table 2 presents the top 10 fields contributing to research on GA which spans various disciplines, including agriculture, environmental science, business, and social sciences. The most prominent fields in GA research are environmental science (48.5%), agricultural and biological sciences (26.8%), energy (18.6%), and social sciences (16.6%). Additionally, areas such as computer science, chemistry, business and management, economics, pharmacology, and earth sciences are also relevant. This highlights the interdisciplinary nature of GA research.

Table 2. Publication category statistics

Rank	Category	Count	Percent
1	Environmental Science	143	48,5
2	Agricultural and Biological Sciences	79	26,8
3	Energy	55	18,6
4	Social Sciences	49	16,6
5	Engineering	41	13,9
6	Computer Science	37	12,5
7	Chemistry	34	11,5
8	Business, Management and Accounting	25	8,5
9	Materials Science	24	8,1
10	Economics, Econometrics and Finance	21	7,1

2.2.4. Co-occurrence keyword analysis

Table 3 presents the ten most frequently co-occurring keywords in GA research: frequency, centrality, and first appearance year. Overall, keywords such as "Green agriculture," "Agriculture," and "Sustainable development" are the most frequently co-occurring, with frequencies of 98, 85, and 30, respectively. These keywords strongly connect to green agriculture, reflecting its focus on sustainability and agricultural practices.

Table 3. Top 10 co-occurring keywords

Ranking	Count	Centrality	Year	Keyword
1	98	0.11	2015	green agriculture
2	85	0.33	2015	agriculture
3	30	0.09	2010	sustainable development
4	26	0.12	2020	nonhuman

5	24	0.06	2018	fertilizers
6	22	0.05	2017	agriculture development
7	21	0.24	2012	alternative agriculture
8	19	0.08	2018	agriculture production
9	19	0.14	2019	chemistry
10	18	0.12	2021	soil

Figure 2 illustrates the temporal evolution of research keywords, tracing the development of themes related to GA over time. The analysis reveals that research on green agriculture originated from studies on general environmental protection, with “environmental protection” being the prominent keyword before 2000 (The study expanded the search scope to identify keywords that serve as the foundation for research on green agriculture, highlighting “environmental protection” as a pivotal term and phrase first mentioned in the literature in 1990). During the 2000–2010 period, keywords such as “alternative agriculture” and “sustainable development” began to emerge, marking a shift in focus towards sustainable development strategies and alternative agricultural models. During the 2010–2020 period, more specific concepts, including “green agriculture” and “agricultural development,” gained prominence, emphasizing sustainable farming practices and the application of technology in agriculture. From 2020 to 2024, keywords such as “green agricultures,” “chemistry,” and “alternative agriculture” became prominent, accompanied by increasingly complex citation networks, reflecting the growing interdisciplinarity in green agriculture research.

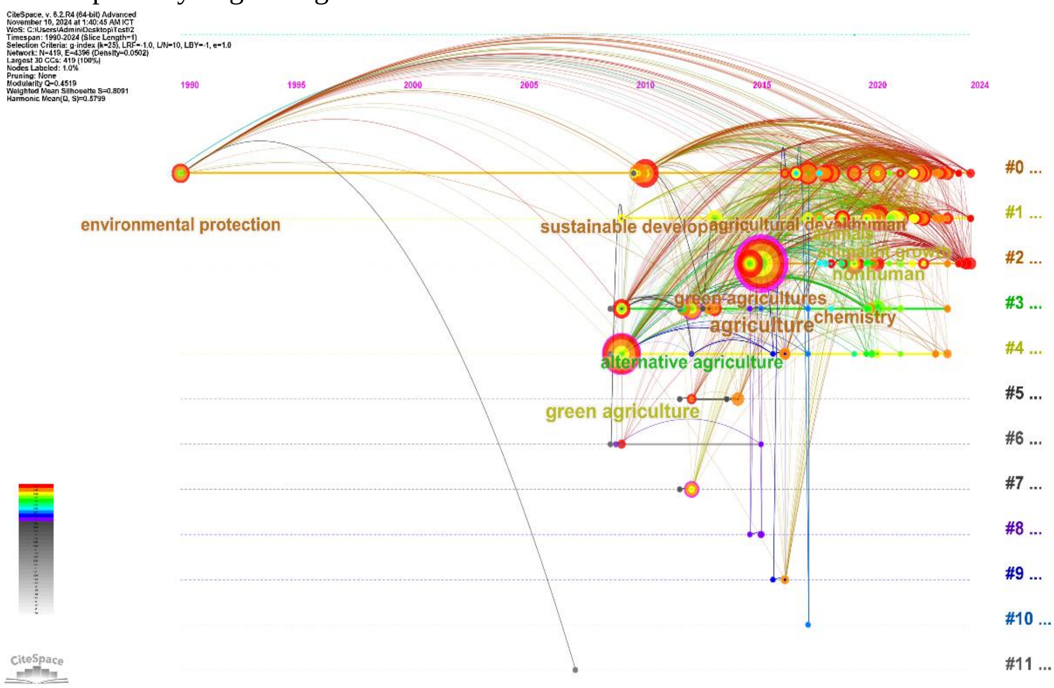

Figure. 2. Evolution of research keywords

Figure 3 illustrates the co-occurrence keyword clusters, encompassing 4396 nodes and 419 connections, covering a wide range of topics. This visualization reflects the diversity in approaches and sustainable solutions within green agriculture and can be classified into three primary research directions:

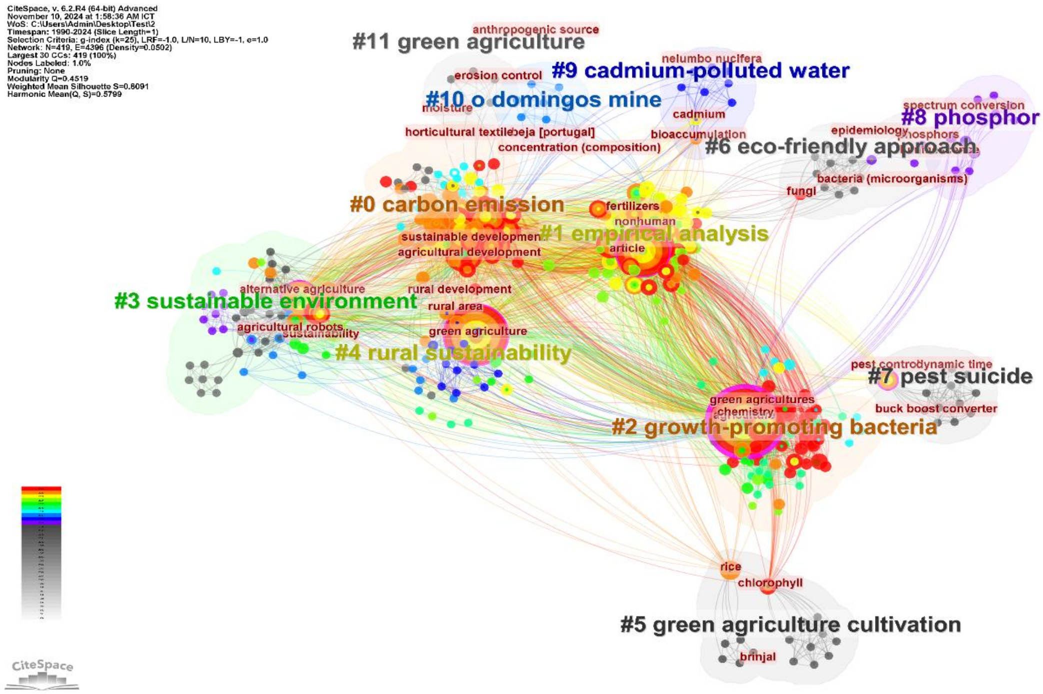

Figure 3. Keyword co-occurrence network

(i) Application of Advanced Technologies in Agriculture: This research direction focuses on clusters 0 (Carbon Emission), 1 (Empirical Analysis), and 2 (Growth-Promoting Bacteria), highlighting the transformative role of high-tech solutions in reducing chemical impacts on the environment, enhancing agricultural productivity [6, 20, 21]. Cluster 0 centers on reducing greenhouse gas emissions through innovative practices such as nano-biochar for carbon sequestration, slow-release fertilizers to lower nitrous oxide emissions, and resource-efficient techniques for sustainable farming. Cluster 1 emphasizes empirical evaluations of modern agricultural methods across diverse geographic and climatic conditions, integrating artificial intelligence (AI) and the Internet of Things (IoT) to optimize production processes. Cluster 2 explores the use of beneficial microorganisms, including nitrogen-fixing and growth-promoting bacteria, to enhance crop yields, soil health, and plant resilience under extreme conditions, reducing reliance on chemical fertilizers and preserving natural resources.

(ii) Sustainable Agriculture and Ecosystem Conservation: This direction encompasses clusters 3 (Sustainable Environment), 4 (Rural Sustainability), and 6 (Eco-Friendly Approach), emphasizing the efficient use of resources and ecosystem preservation [22-24]. Cluster 3 investigates the nexus between agriculture and environmental health, focusing on strategies for managing land and water resources to mitigate ecological degradation and adapt to climate change. Cluster 4 expands into rural sustainability, promoting environmentally friendly farming practices such as organic agriculture and efficient fertilizer management while fostering community education and participation. Cluster 6 advances the development of eco-friendly solutions, such as biofertilizers and beneficial microorganisms, to reduce dependency on chemical inputs and safeguard ecosystems. Collectively, these studies contribute to improving agricultural efficiency, environmental conservation, and the broader goal of sustainable global agriculture.

(iii) Innovative Materials, Beneficial Microorganisms, and Advanced Pest Control: This direction incorporates clusters 2 (Growth-Promoting Bacteria), 7 (Solar Pest Control Devices), and 8 (Phosphorus Materials for Photosynthesis Enhancement), showcasing the integration of novel technologies to promote green agriculture [25-28]. Cluster 2 emphasizes microbial

solutions to boost nutrient availability, nitrogen fixation, and phosphorus solubilization while improving plant resistance to environmental stresses, thus reducing chemical fertilizer dependence. Cluster 7 focuses on solar-powered pest control devices employing "pest suicide" mechanisms to minimize pesticide usage, protect ecosystems, and reduce costs for farmers. Cluster 8 targets the application of phosphorus-based materials to optimize light-to-energy conversion during photosynthesis, improving crop productivity while mitigating environmental impacts. These advancements enhance agricultural output and align with sustainability principles, supporting the transition to modern, eco-friendly farming systems.

2.3. Research gaps and future directions

Amidst the pressing challenges of climate change and the growing demand for sustainable agricultural practices, research on GA has achieved remarkable progress, from advanced technological applications to sustainable production strategies. However, several critical gaps persist, requiring future research efforts as outlined below:

(i) Greenhouse gas reduction and ecological performance measurement: Clusters like Carbon Emission (Cluster 0) and Empirical Analysis (Cluster 1) have highlighted the need for greenhouse gas reduction and ecological performance measurement. However, comprehensive long-term databases, particularly in developing countries, remain inadequate. Developing global data repositories and advanced metrics to track emissions and assess ecological outcomes will be critical in advancing predictive models and policy integration.

(ii) Evaluation of advanced technologies in diverse contexts: Clusters such as Sustainable Environment (Cluster 3) emphasize the importance of advanced technologies like IoT, renewable energy, and big data for sustainable agriculture. However, large-scale empirical studies evaluating these technologies in diverse geographic and climatic conditions are scarce. Future research should focus on assessing these innovations' feasibility and long-term effectiveness in regions with harsh natural conditions or limited resources.

(iii) Addressing socio-economic dimensions of GA: Current studies predominantly address the technical and environmental dimensions of GA, while socio-economic factors such as the cost of technology adoption, labor structure transitions, and community acceptance are underexplored (cluster 4 Rural Sustainability and cluster 6 Eco-Friendly Approach). Future research should evaluate the cost-benefit trade-offs of GA models, investigate effective farmer training programs, and explore socio-cultural factors influencing the adoption of green practices.

(iv) Biodiversity and ecosystem integration: Green Agriculture (Cluster 11) has underscored the significance of biodiversity and ecosystem conservation within GA. However, there is a lack of integrated models combining conservation efforts with agricultural productivity. Future studies should delve into the interactions between green agriculture and both micro (soil microbiota) and macro (flora and fauna) ecosystems to provide holistic, sustainable solutions.

(v) Renewable energy and green materials innovation: Clusters such as Cluster 7 Pest Suicide and Cluster 8 Phosphor reveal the potential of renewable energy and green materials to mitigate environmental impacts. However, there is a need to expand alternative energy sources and innovate in green materials. Research should prioritize the development of renewable energy solutions like biomass, wind, and geothermal and enhance materials like innovative fertilizers and bio-nanoparticles to optimize resource efficiency and reduce chemical usage.

3. Conclusions

Over the past two decades, research on green agriculture has witnessed exponential growth, expanding into diverse interdisciplinary domains. The findings highlight the conceptual foundations, associated dimensions, and critical role of GA in sustainable development strategies.

However, addressing existing research gaps, such as the empirical evaluation of technologies, the creation of long-term databases, the integration of conservation with productivity, and the socio-economic dimensions of GA, remains essential. These challenges represent opportunities for innovative research, reinforcing the importance of integrating technology, science, and policy to promote sustainable and climate-resilient agriculture for the future.

Nonetheless, this study is limited by its exclusive reliance on the Scopus database and English-language publications. Future research could broaden its scope by incorporating data from the Web of Science database and exploring literature in other languages to achieve a more comprehensive and nuanced perspective.

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