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Mapping Global Research on Precision Agriculture with a Bibliometric Approach Analysis Period 2010–2025

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ABSTRACT

Precision Agriculture (PA) has emerged as a transformative approach in modern farming, integrating advanced digital technologies to enhance productivity, resource efficiency, and sustainability. This study aims to map global research trends in Precision Agriculture using a bibliometric analysis covering the period 2010–2025. Bibliographic data were retrieved from the Scopus database and analyzed using VOSviewer to examine publication growth, citation patterns, authorship collaboration, institutional networks, country contributions, and keyword co-occurrence structures. The results indicate a significant and continuous increase in scholarly output, reflecting the growing strategic importance of PA in addressing global food security and climate challenges. China, the United States, and India emerge as leading contributors, supported by strong institutional collaborations and expanding international research networks. Thematic analysis reveals that artificial intelligence, machine learning, deep learning, UAV-based remote sensing, IoT systems, and sustainability-related topics dominate the research landscape. The findings highlight a clear shift toward data-driven agricultural systems and integrated smart farming ecosystems. This study provides a comprehensive overview of the intellectual, social, and conceptual structure of Precision Agriculture research and offers insights for future research directions, technological innovation, and policy development to support sustainable agricultural transformation

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1. INTRODUCTION

Precision Agriculture (PA) has evolved into a core approach within "smart farming" and broader agricultural automation. At its heart, PA is a management strategy that collects, processes, and analyzes spatial and temporal field data to manage variability and support more precise decisions and machine actions in agricultural production [1]. This framing emphasizes that PA is not a single tool, but an integrated decision system: sensing variability, translating it into actionable prescriptions, and executing operations with higher accuracy than conventional uniform field management. As global agriculture faces intertwined pressures PA becomes increasingly central because it promises "more with less": higher productivity and quality while improving resource-use efficiency [2].

Technological progress has accelerated PA from early yield mapping and GNSS-guided machinery into data-rich, multi-layered systems that include remote sensing, proximal sensors, IoT networks, decision-support analytics, and variable-rate application. High-resolution satellite imagery, drones, and sensor platforms now support near-real-time crop and soil monitoring, enabling timely interventions for irrigation, nutrient management, and pest or disease detection [2]. Remote sensing, in particular, has become a major engine of PA research because it scales field observation across space and time, with vegetation indices and multi-sensor datasets enabling yield prediction and stress diagnostics across diverse agroecosystems. These advances also deepen PA's connection to sustainability goals by supporting targeted input use and reducing waste [3].

Parallel to technological momentum, the empirical evidence base on PA's performance has grown. Studies increasingly examine PA outcomes not only in agronomic terms (yield, quality) but also economic and environmental dimensions (profitability, nitrogen-use efficiency, reduced chemical load) [4]. This shift matters because adoption decisions depend on clear value propositions, investment feasibility, and local compatibility. Recent synthesis work indicates that PA and related digital agricultural technologies can deliver measurable efficiency gains and environmental co-benefits, while also highlighting heterogeneity by farm size, region, and technology type. These patterns reinforce the need to understand where and how PA research is expanding globally, and which themes are becoming dominant across the literature [5].

Given the rapid expansion and diversification of PA studies, bibliometric analysis is increasingly used to map scientific landscapes. Bibliometrics helps quantify publication growth, identify influential sources and authors, reveal collaboration networks, and detect thematic structures through keyword co-occurrence and co-citation patterns. Methodological guidance in the bibliometric literature emphasizes combining performance analysis (e.g., outputs, citations, leading journals) with science mapping (e.g., networks and clusters) to understand how a field develops intellectually and socially. As research becomes more interdisciplinary bibliometrics offers a systematic way to capture the "big picture" and reduce fragmentation in how evidence is interpreted.

Among bibliometric mapping tools, VOSviewer has become widely used because it supports large-scale visualization of networks (authors, institutions, countries) and conceptual structures (keyword clusters) in an interpretable format. Its mapping approach is commonly applied to identify cluster formation, emerging topics, and shifts in research attention over time, making it well-suited for a field like PA that has experienced successive waves (GNSS and yield mapping → remote sensing and variable-rate technologies → IoT, AI, robotics, and integrated decision platforms). A bibliometric study focused on global PA research from 2010–2025 is therefore timely to consolidate what is known, clarify how the knowledge base is organized, and provide an evidence-driven agenda for future inquiry and policy support. This study aims to map global research on Precision Agriculture using a bibliometric analysis approach for the period 2010–2025.

2. METHOD

This study employs a quantitative bibliometric approach to map the global development of research on Precision Agriculture during the period 2010–2025. Bibliographic data will be retrieved from the Scopus database, selected for its extensive international journal coverage and comprehensive metadata, including titles, abstracts, keywords, author names, institutional affiliations, and citation information. A structured search strategy will be developed using key terms such as "precision agriculture," "precision farming," "smart farming," "variable rate technology," and related concepts in digital and data-driven agriculture. The search will be limited to publications between 2010 and 2025 and restricted to peer-reviewed journal articles and review papers to ensure academic rigor and consistency. The retrieved records will be exported in CSV and BibTeX formats for further processing.

To perform science mapping and network visualization, this study utilizes VOSviewer, a widely adopted software tool for bibliometric analysis and knowledge structure mapping. VOSviewer will be used to conduct co-authorship analysis (to identify collaboration networks among authors, institutions, and countries), co-occurrence analysis of keywords (to uncover thematic structures and research trends), and citation and co-citation analysis (to detect influential publications and intellectual linkages within the field). In the visualization maps, nodes will represent bibliographic elements (e.g., authors or keywords), while link strength will indicate the intensity of relationships between them. Cluster analysis generated by VOSviewer will help identify dominant research themes and emerging topics within Precision Agriculture research. The findings will be presented through visual network maps, tables, and trend graphs, providing a comprehensive overview of the intellectual, social, and conceptual structure of global Precision Agriculture research from 2010 to 2025.

3. RESULT AND DISCUSSION

Co-Authorship Analysis

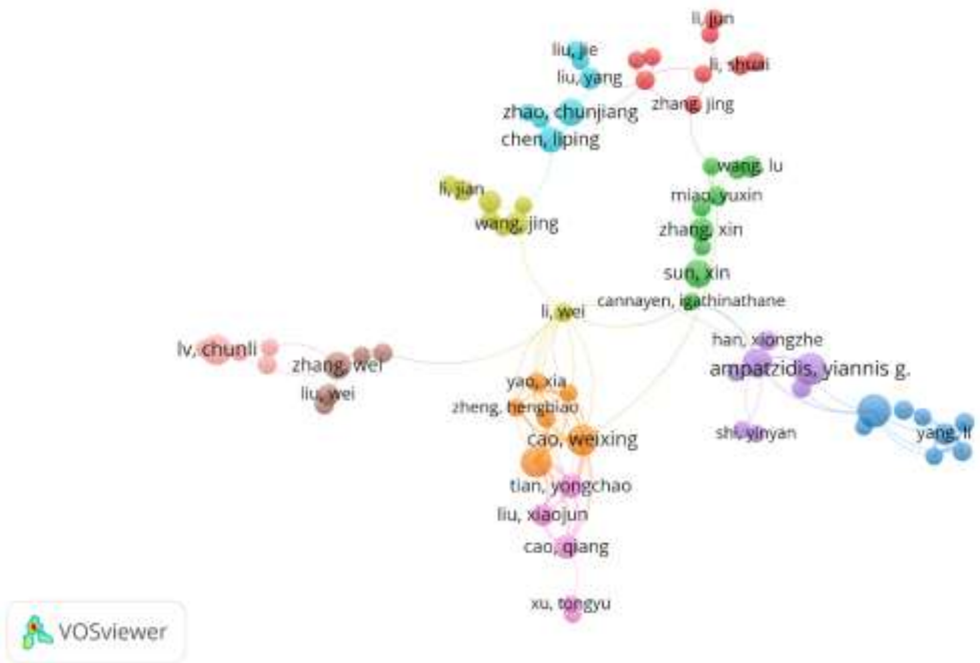

Figure 1. Author Visualizaton
Source: Data Analysis

Figure 1 illustrates the collaboration structure among authors in Precision Agriculture research, revealing several distinct yet interconnected clusters. The size of the nodes indicates author productivity or influence (based on publications or citations), while the links represent collaboration intensity. A prominent central cluster appears around Cao, Weixing and Li, Wei, suggesting they play a bridging role connecting multiple research groups. Several tightly connected clusters—primarily composed of Chinese authors such as Liu, Wang, Zhang, and Chen—indicate strong regional collaboration networks, reflecting China's significant contribution to Precision Agriculture research. Additionally, smaller but cohesive clusters, such as the group around Ampatzidis, Yiannis G., suggest international or interdisciplinary collaboration hubs. The network structure shows both dense intra-cluster collaboration and selective inter-cluster linkages, indicating that while research groups tend to collaborate closely within their regional or institutional networks, certain key authors act as connectors across clusters.

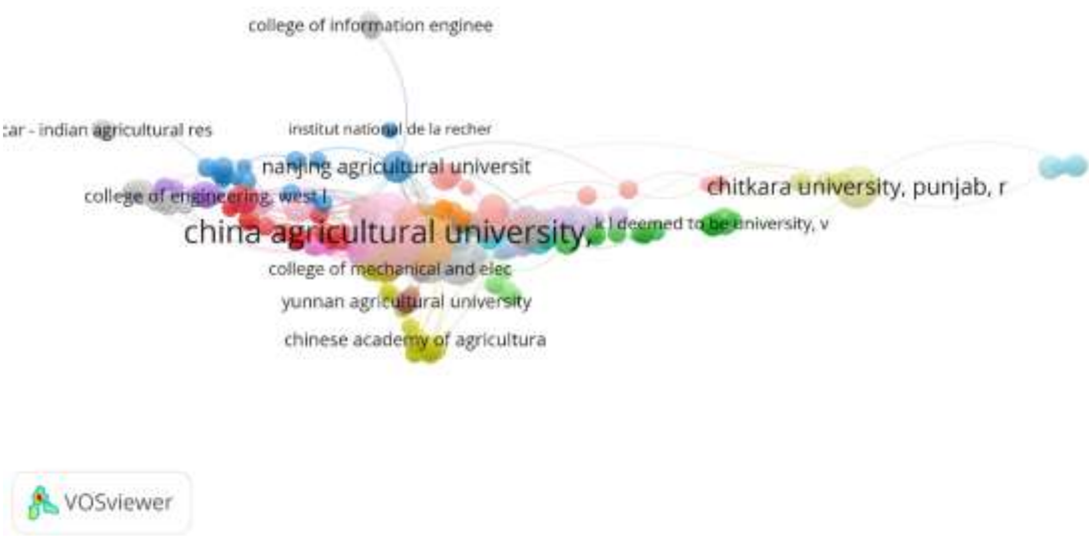

Figure 2. Institution Visualization
Source: Data Analysis

Figure 2 above highlights the dominant role of China Agricultural University as the central hub in global Precision Agriculture research. Its large node size indicates high productivity and strong citation impact, while the dense web of links connecting it to other institutions—such as Nanjing Agricultural University, Yunnan Agricultural University, the Chinese Academy of Agricultural Sciences, and various engineering colleges—reflects intensive domestic collaboration within China. The clustering pattern suggests that Chinese institutions form the core of the research landscape, with strong intra-national partnerships driving much of the publication output. Beyond China, institutions such as Chitkara University (Punjab, India) and other international partners appear as smaller but connected nodes, indicating growing cross-country collaboration, though less centralized than the Chinese network.

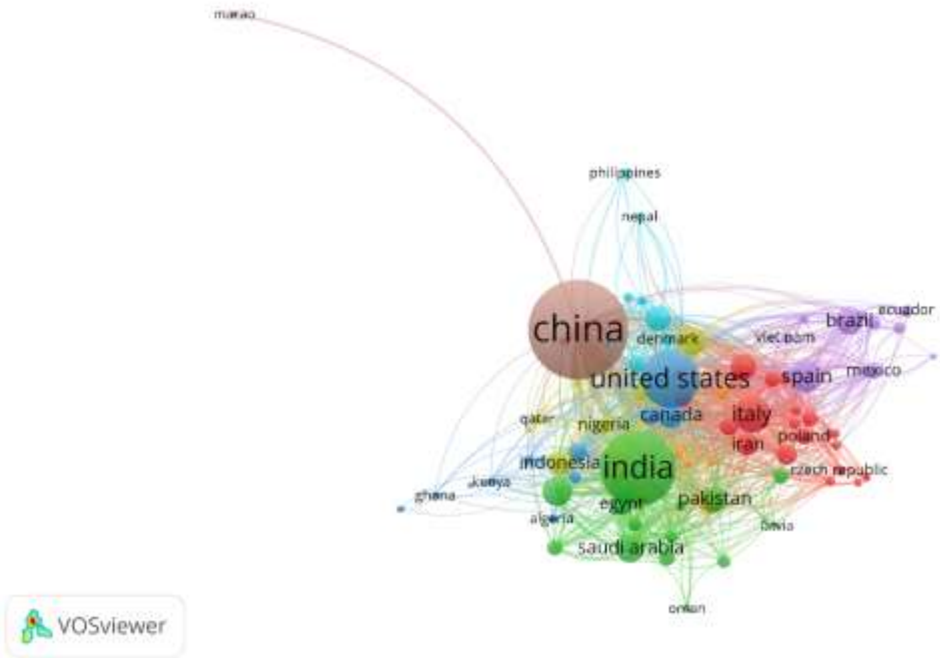

Figure 3. Country Visualization
Source: Data Analysis

Figure 3 illustrates the global distribution and partnership patterns in Precision Agriculture research. China emerges as the most dominant contributor, indicated by the largest node size and extensive link connections, signifying both high publication output and strong international collaboration. The United States and India also appear as major hubs, forming a dense collaborative core alongside European countries such as Italy, Spain, and Poland. The clustering pattern suggests regional collaboration blocs: a strong Asian cluster centered on China and India, a European cluster around Italy and Spain, and a Latin American cluster including Brazil and Mexico. Countries such as Pakistan, Saudi Arabia, Egypt, and Indonesia are actively connected within emerging research networks, indicating expanding participation from developing economies. The interconnected structure demonstrates that while research production is concentrated in a few leading countries, international collaboration is increasingly widespread, reflecting the global and multidisciplinary nature of Precision Agriculture research.

Citation Analysis

Table 1. Top Cited Literature

Citations	Authors and Year	Title
2,441	[6]	Managing nitrogen for sustainable development
2,404	[7]	Machine learning in agriculture: A review
2,018	[8]	Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges
1,664	[9]	The application of small unmanned aerial systems for precision agriculture: A review
1,594	[10]	Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps
1,538	[11]	Remote sensing for agricultural applications: A meta-review
1,316	[12]	CRISPR/Cas Genome Editing and Precision Plant Breeding in Agriculture

1,245	[13]	Precision agriculture and food security
1,225	[14]	Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: A review
1,143	[15]	Applications of remote sensing in precision agriculture: A review

Source: Scopus

Keyword Co-Occurrence Analysis

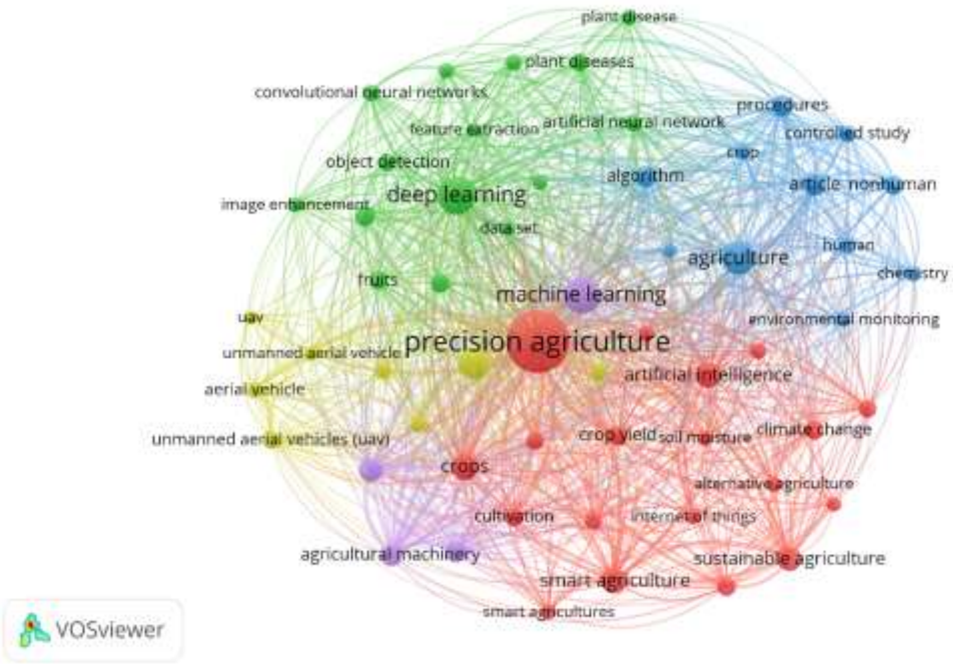

Figure 4. Network Visualization
Source: Data Analysis

Figure 4 reveals the intellectual structure of Precision Agriculture research, with "precision agriculture" positioned at the center as the dominant and most frequently occurring term. Its large node size indicates high prominence within the literature, while the dense interconnections show that it serves as a conceptual anchor linking multiple technological and thematic domains. Surrounding this central term are clusters that reflect the interdisciplinary nature of the field, integrating agricultural sciences, data analytics, artificial intelligence, environmental monitoring, and engineering systems. One major cluster (green) emphasizes deep learning, convolutional neural networks, image enhancement, object detection, feature extraction, and plant disease detection. This cluster highlights the rapid integration of computer vision and machine learning techniques into agricultural applications. The presence of terms such as "fruits," "plant disease," and "dataset" indicates that image-based crop monitoring and disease classification have become a significant research focus. This suggests that recent advances in artificial intelligence are strongly shaping the methodological direction of Precision Agriculture research.

Another prominent cluster (red) connects smart agriculture, artificial intelligence, crop yield, soil moisture, climate change, sustainable agriculture, and internet of things (IoT). This thematic grouping reflects the transition from traditional precision input management toward broader digital ecosystem approaches. It demonstrates how PA research increasingly addresses sustainability and climate adaptation, integrating IoT-based sensing systems with predictive analytics to optimize productivity while reducing environmental impact. The interlinkages between sustainability and AI-related terms suggest that environmental resilience has become a central concern within the field. A distinct cluster (yellow) centers on UAVs (unmanned aerial vehicles), aerial vehicles, and remote sensing technologies, indicating the strong relevance of drone-based monitoring systems. These technologies enable high-resolution spatial data acquisition for crop assessment and field variability analysis. The strong connections between UAV-related terms and machine learning keywords reflect the growing use of drone imagery combined with AI-based analytics for yield prediction and crop health monitoring.

A blue cluster associated with broader scientific descriptors such as agriculture, environmental monitoring, controlled study, and chemistry indicates foundational and interdisciplinary contributions that link agronomic experimentation with technological applications. This cluster suggests that while technological innovation dominates the research landscape, empirical agricultural experimentation and environmental assessment remain essential components.

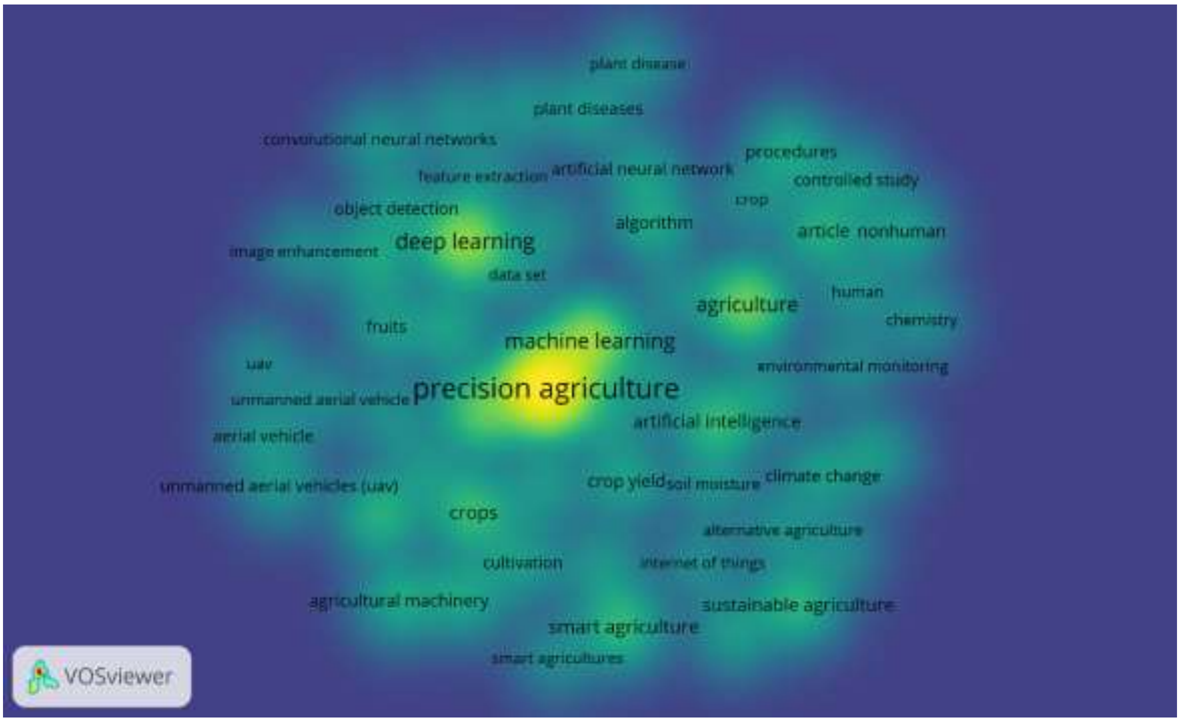

Figure 5. Density Visualization
Source: Data Analysis

Figure 5 highlights the most intensively researched themes in Precision Agriculture by using color gradients, where yellow indicates high frequency and strong co-occurrence, and blue represents less dominant topics. The brightest and most concentrated area centers on "precision agriculture", confirming its position as the core concept in the research landscape. Closely surrounding it are "machine learning" and "deep learning," which appear in high-density zones, indicating that artificial intelligence techniques are central drivers of current scholarly activity. This suggests that the evolution of Precision Agriculture over the past decade has been strongly shaped by data-driven modeling, predictive analytics, and computer vision applications. In addition to AI-related terms, moderately dense areas include "agriculture," "smart agriculture," "artificial intelligence," "crops," "internet of things," "sustainable agriculture," and "climate change." These keywords reflect the integration of digital technologies with sustainability and environmental monitoring objectives. Meanwhile, UAV-related terms and plant disease detection appear in medium-density regions, indicating important but more specialized research streams.

Discussion

The findings of this bibliometric study reveal a substantial and continuous expansion of global research on Precision Agriculture (PA) between 2010 and 2025. The steady growth in publications reflects the increasing strategic importance of digital technologies in addressing global food security, resource efficiency, and climate adaptation challenges. The dominance of key terms such as precision agriculture, machine learning, and deep learning in the keyword co-occurrence and density visualizations indicates that the field has undergone a clear technological shift. Earlier PA studies were primarily centered on variable-rate technology and GNSS-based field management, whereas recent research is increasingly characterized by artificial intelligence–driven analytics, computer vision, and predictive modeling. This transformation suggests that PA is no longer limited to input optimization but has evolved into a data-intensive, decision-support ecosystem integrating sensing, automation, and algorithmic intelligence.

The author and institutional collaboration networks further demonstrate that research production is geographically concentrated yet globally interconnected. China emerges as the leading contributor, both in terms of publication output and collaborative link strength, supported by strong institutional hubs such as China Agricultural University and other agricultural research institutes. The United States and India also play prominent roles, forming a dense collaborative core alongside European countries such as Italy and Spain. The clustering patterns indicate that while domestic collaborations remain strong within leading countries, international partnerships are expanding, particularly between Asia, Europe, and emerging economies. This reflects the global relevance of PA technologies and the shared need to modernize agricultural systems under varying agroecological and socio-economic conditions.

The thematic structure identified through keyword clustering highlights four dominant research streams. First, the integration of deep learning and convolutional neural networks for plant disease detection and crop monitoring underscores the centrality of computer vision in agricultural innovation. Second, UAV-based remote sensing forms a significant technological pillar, enabling high-resolution spatial data collection for yield prediction and field variability analysis. Third, IoT and smart agriculture systems represent a shift toward interconnected digital farming infrastructures. Fourth, sustainability-oriented themes—such as climate change, soil moisture management, and sustainable agriculture—demonstrate the increasing alignment of PA research with environmental resilience and resource conservation objectives. Together, these clusters suggest that the field is moving toward holistic digital ecosystems rather than isolated technological solutions.

Importantly, the density visualization shows that artificial intelligence–related keywords dominate the research landscape, indicating that AI has become the primary methodological engine of PA research. However, foundational agronomic concepts such as crops, cultivation, and environmental monitoring remain interconnected with technological themes. This balance highlights that while PA research is technology-driven, it remains grounded in practical agricultural applications. The continued presence of empirical and experimental terms suggests that field validation and agronomic performance assessment remain critical components of scientific inquiry in this domain.

Despite the strong growth and diversification of PA research, the network structure also reveals areas for further development. Collaboration intensity is still concentrated among a limited number of leading countries, suggesting the need for greater inclusion of underrepresented regions, particularly in Africa and parts of Southeast Asia. Moreover, while AI and sensing technologies are heavily studied, research addressing socio-economic adoption barriers, cost-effectiveness for smallholder farmers, and policy integration appears less visible in the dominant clusters. Future research should therefore move beyond technological advancement toward inclusive implementation models that ensure equitable access and long-term sustainability.

4. CONCLUSION

This bibliometric study provides a comprehensive mapping of global research on Precision Agriculture from 2010 to 2025, revealing a rapidly expanding and increasingly interdisciplinary field. The findings demonstrate that research has shifted from traditional precision input management toward data-driven systems dominated by artificial intelligence, machine learning, UAV-based sensing, and IoT-enabled smart farming technologies. China, the United States, and India emerge as leading contributors, supported by strong institutional networks and growing international collaboration. The thematic structure highlights the convergence of technological innovation with sustainability goals, particularly in crop monitoring, climate adaptation, and resource efficiency. Precision Agriculture research reflects a transformative digital evolution in agricultural science, while future studies should emphasize broader global inclusion, socio-economic feasibility, and practical implementation strategies to ensure sustainable and equitable agricultural modernization.

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