Mapping Global Research Trends on Smart Farming Using Bibliometric Analysis 2010–2025

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Article Info

Article history:

Received February, 2026
Revised February, 2026
Accepted February, 2026

Keywords:

Smart farming; Precision agriculture; Digital agriculture; Internet of Things

ABSTRACT

This study maps global research trends on smart farming through a bibliometric analysis of Scopus-indexed publications published between 2010 and 2025. Using VOSviewer as the primary analytical tool, the study examines publication growth, co-authorship networks, institutional and country collaborations, keyword co-occurrence structures, overlay visualization, and thematic density patterns. The results indicate a significant increase in scholarly output over the study period, reflecting the rapid expansion of digital and intelligent technologies in agriculture. India emerges as a central hub in international collaboration networks, while technology-oriented universities and computer science departments play a dominant role in knowledge production. The keyword analysis reveals that smart agriculture and precision agriculture form the intellectual core of the field, strongly connected to Internet of Things, machine learning, deep learning, remote sensing, and agricultural machinery. Overlay visualization demonstrates a temporal shift from infrastructure-focused research toward AI-driven analytics and sustainability-oriented applications, particularly in relation to climate change and food security. The study highlights the transition of smart farming research toward an integrated Agriculture 4.0 paradigm and identifies future directions related to interoperability, data governance, inclusive adoption, and measurable sustainability impacts.

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1. INTRODUCTION

The agricultural sector is undergoing a profound transformation driven by technological innovation, data integration, and the increasing urgency to achieve sustainable food production systems. Rapid population growth, climate change, land degradation, and resource scarcity have intensified the need for more efficient and resilient farming practices [1], [2]. In response, smart farming has emerged as a promising paradigm that integrates digital technologies such as the Internet of Things, artificial intelligence, big data analytics, robotics, remote sensing, and precision agriculture tools to optimize agricultural productivity and sustainability. Unlike conventional farming approaches, smart farming emphasizes real-time monitoring, data-driven decision-making, and automation to enhance crop yield, reduce input waste, and mitigate environmental impacts [3], [4]. This technological shift reflects a broader movement toward digital agriculture, where information systems and intelligent technologies become central to farm management and value chain coordination [5].

Since 2010, global research on smart farming has expanded significantly, reflecting growing academic, industrial, and governmental interest in digital transformation within agriculture. Advances in sensor technologies, unmanned aerial vehicles, satellite imagery, and cloud computing have provided researchers with new tools to monitor soil conditions, crop health, irrigation efficiency, and livestock management [6], [7]. The convergence of these technologies has accelerated interdisciplinary collaboration among agronomists, engineers, computer scientists, environmental scientists, and economists. Consequently, smart farming research has evolved beyond technical experimentation toward integrated systems that consider sustainability, economic feasibility, and socio-environmental impacts [6], [7]. The increasing publication output over the past decade indicates that smart farming has become a strategic research area aligned with global agendas such as sustainable development, climate adaptation, and food security enhancement.

Furthermore, smart farming research demonstrates strong connections with emerging concepts such as precision agriculture, climate-smart agriculture, sustainable intensification, and agricultural resilience. Scholars have explored how digital tools can improve resource-use efficiency, reduce greenhouse gas emissions, and enhance farm-level decision-making under uncertain climatic conditions. The adoption of artificial intelligence and machine learning algorithms has enabled predictive analytics for yield forecasting, pest detection, disease identification, and irrigation scheduling. These technological advancements have reshaped the structure of agricultural innovation ecosystems, encouraging partnerships among universities, research institutions, technology companies, and policymakers. As a result, smart farming is not merely a technological upgrade but represents a systemic transformation of agricultural production models.

In addition to technological advancements, the geographic distribution of smart farming research has evolved considerably. Developed countries initially dominated the research landscape due to stronger technological infrastructure and research funding capacity. However, emerging economies have increasingly contributed to the field, particularly in regions where agricultural modernization is essential for economic development and poverty reduction. This global diffusion of research activity highlights the importance of understanding collaboration networks, institutional productivity, and cross-country partnerships in shaping the direction of smart farming innovation. Mapping these networks provides insights into how knowledge flows across regions and how research capacity influences the development and adoption of smart agricultural technologies.

Despite the rapid expansion of publications, the intellectual structure and thematic evolution of smart farming research remain complex and multifaceted. The field encompasses diverse topics such as sensor development, machine learning applications, sustainable water management, smart irrigation systems, blockchain-based supply chains, and farm automation. As the volume of literature grows, it becomes increasingly challenging to synthesize trends, identify dominant research clusters, and detect emerging themes. Traditional narrative reviews may not adequately capture the structural dynamics and quantitative patterns within large bibliographic datasets. Therefore, a systematic bibliometric analysis becomes essential to objectively map the scientific landscape, reveal research hotspots, identify influential authors and institutions, and trace the evolution of key themes over time.

Although smart farming research has grown substantially between 2010 and 2025, there is still limited comprehensive mapping of its global scientific development, collaboration patterns, thematic clusters, and temporal evolution using quantitative bibliometric approaches. Existing studies often focus on specific technologies or regional contexts without providing an integrated overview of the entire research ecosystem. Consequently, scholars and policymakers lack a clear understanding of how research trends have shifted, which countries and institutions dominate the field, what thematic areas are emerging, and where potential research gaps remain. This absence of a structured and data-driven mapping limits strategic decision-making for future research directions and policy formulation in smart agriculture. This study aims to map global research trends on smart farming from 2010 to 2025 using a bibliometric analysis approach.

2. METHOD

This study employs a quantitative bibliometric analysis approach to systematically map and evaluate global research trends on smart farming from 2010 to 2025. The bibliographic data were collected from the Scopus database, which is widely recognized for its comprehensive coverage of peer-reviewed international publications across multidisciplinary fields. Scopus was selected due to its extensive indexing of high-impact journals, conference proceedings, and review articles relevant to agriculture, engineering, environmental science, and information technology. The data retrieval process was conducted using a structured search query containing keywords such as "smart farming," "digital agriculture," "precision agriculture," "smart agriculture," and related terms. The search was limited to publications within the period 2010–2025 and restricted to articles, conference papers, and reviews written in English to ensure consistency and relevance. After applying inclusion and exclusion criteria, the final dataset was exported in CSV format for bibliometric processing.

The bibliometric analysis was performed using VOSviewer, a specialized software tool designed for constructing and visualizing bibliometric networks. VOSviewer enables the analysis of co-authorship, co-occurrence of keywords, citation, bibliographic coupling, and co-citation relationships. In this study, several types of network analyses were conducted. First, co-authorship analysis was used to identify collaboration patterns among authors, institutions, and countries. Second, citation and co-citation analyses were applied to determine influential authors, journals, and documents within the smart farming research landscape. Third, keyword co-occurrence analysis was conducted to reveal major thematic clusters and research hotspots. The minimum occurrence threshold for keywords and authors was adjusted to ensure meaningful visualization while maintaining analytical clarity.

To examine the temporal evolution of research themes, overlay visualization in VOSviewer was employed to detect emerging topics and shifting research focus over time. Density visualization was also used to identify highly concentrated research areas and dominant thematic structures within the field. The bibliometric indicators analyzed in this study include publication growth trends, citation counts, total link strength, and cluster formation.

3. RESULT AND DISCUSSION

Co-Authorship Analysis

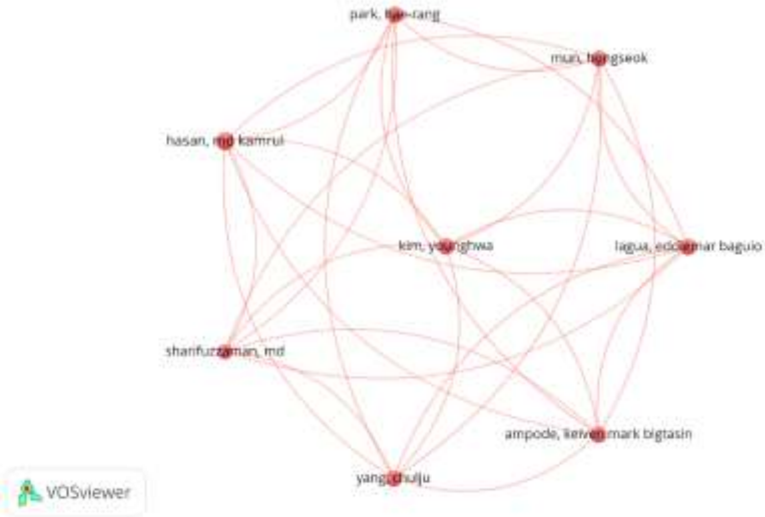

Figure 1. Author Visualization
Source: Data Analysis

Figure 1 shows a relatively compact and highly interconnected group of researchers in the smart farming field. All authors appear within a single cluster (indicated by the same color), suggesting that they belong to a closely collaborating research community rather than fragmented sub-groups. Nodes such as Kim, Younghwa, Mun, Hongseok, Ampode, Keivenmark Bigtasin, and Lagua, Eddiemar Baguio are positioned centrally, indicating stronger collaborative ties and possibly higher co-authorship frequency with other members of the network. The dense web of connecting lines reflects frequent collaboration among these authors, suggesting active joint research and shared thematic focus. Meanwhile, authors located slightly toward the periphery, such as Hasan, Md Kamrul and Sharifuzzaman, Md, remain connected but may have comparatively fewer collaborative links within this specific group.

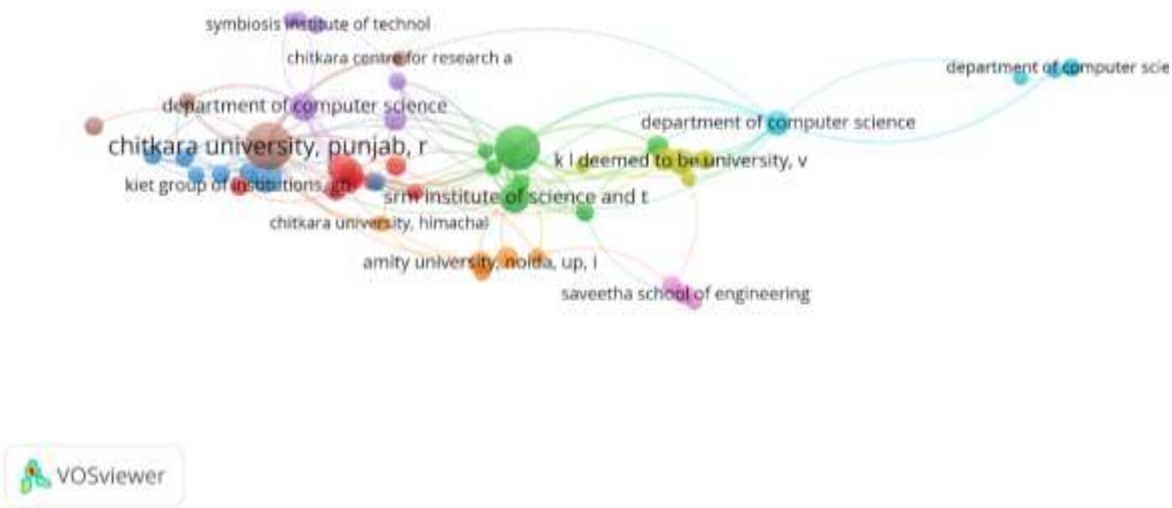

Figure 2. Institution Visualization
Source: Data Analysis

Figure 2 illustrates several interconnected clusters centered around key universities contributing to smart farming research. Chitkara University, Punjab appears as one of the most prominent and influential nodes, indicated by its larger size and multiple linkages with other institutions such as Chitkara University Himachal, KIET Group of Institutions, and Symbiosis Institute of Technology. Another significant hub is KL Deemed to Be University, which connects strongly with departments of computer science and other engineering-focused institutions, reflecting the technological orientation of smart farming studies. The presence of multiple "Department of Computer Science" nodes highlights the strong integration of computing disciplines—such as IoT, AI, and data analytics—within agricultural innovation research. Smaller nodes like Saveetha School of Engineering and Amity University are connected but positioned more peripherally, suggesting participation within specific collaborative projects rather than acting as central drivers.

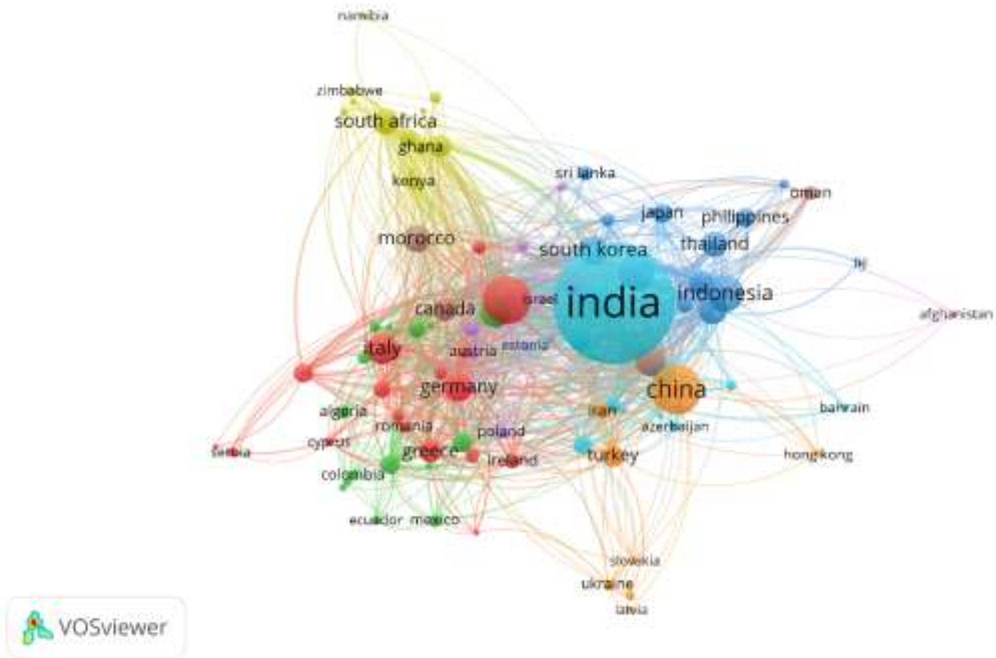

Figure 3. Country Visualization
Source: Data Analysis

Figure 3 reveals a highly interconnected global research landscape in smart farming, with India emerging as the most dominant and central contributor, indicated by its large node size and extensive linkages with numerous countries. India acts as a key collaboration hub, particularly connecting with China, Indonesia, South Korea, and several European countries such as Germany, Italy, and Greece. China also appears as a major player, forming strong ties within the Asian research cluster and linking to Middle Eastern and Eastern European countries. The European cluster—featuring Germany, Italy, Poland, Greece, and Austria—demonstrates dense intra-regional collaboration, while African countries such as South Africa, Ghana, Kenya, Namibia, and Zimbabwe form another visible collaborative group connected to both India and European partners. Southeast Asian countries, including Indonesia, Thailand, and the Philippines, are closely tied to India and China, reflecting regional cooperation in digital agriculture initiatives.

Citation Analysis

Table 1. Top Cited Literature

Citations	Authors and Year	Title
3,663	[8]	Deep learning in agriculture: A survey
2,373	[6]	Big Data in Smart Farming – A review
1,189	[9]	A review on the plant microbiome: Ecology, functions, and emerging trends in microbial application
1,059	[1]	A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda
1,023	[10]	Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk
1,007	[11]	A review on UAV-based applications for precision agriculture
891	[12]	Nanotechnology in agri-food production: An overview
890	[13]	A review on the practice of big data analysis in agriculture
888	[14]	Machine Learning Applications for Precision Agriculture: A Comprehensive Review
773	[15]	From smart farming towards agriculture 5.0: A review on crop data management

Source: Scopus, 2025

Keyword Co-Occurrence Analysis

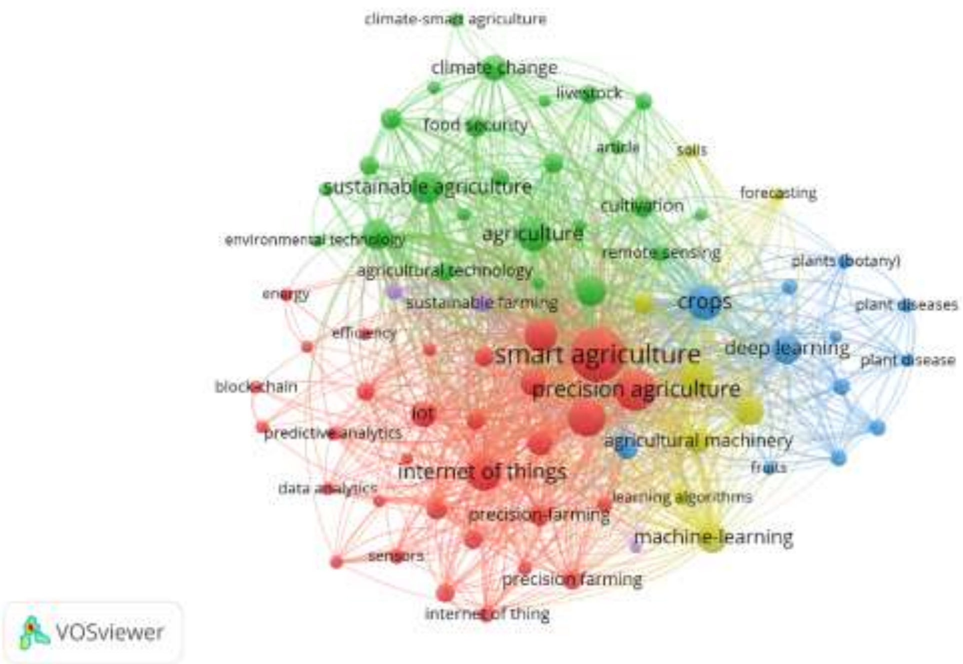

Figure 4. Network Visualization
Source: Data Analysis

Figure 4 reveals a well-structured and multidisciplinary landscape of smart farming research organized into several major thematic clusters. At the center of the map, "smart agriculture" and "precision agriculture" appear as dominant core terms, indicating their foundational role in structuring the field. These central nodes are strongly connected to a wide range of technological and agricultural concepts, demonstrating that smart farming research is highly integrated rather than fragmented. The dense interlinkages suggest that technological innovation and agricultural sustainability are not studied in isolation but are deeply intertwined across the literature. The red cluster primarily represents the technological backbone of smart farming, highlighting terms such as Internet of Things (IoT), sensors, predictive analytics, data analytics, blockchain, and precision farming. This cluster reflects research focused on digital infrastructure, connectivity, and data-driven decision systems. IoT appears as a particularly strong node, emphasizing the importance of real-time monitoring and smart sensor networks in optimizing farm operations. The presence of blockchain and predictive analytics indicates growing attention to secure data management, traceability, and intelligent forecasting within agricultural systems.

The green cluster emphasizes sustainability-oriented themes, including sustainable agriculture, climate change, food security, livestock, and climate-smart agriculture. This indicates that smart farming research increasingly aligns with global sustainability agendas. Rather than focusing solely on productivity gains, the literature connects digital agriculture to broader environmental and social objectives such as resilience, resource efficiency, and adaptation to climate variability. The strong linkage between sustainable agriculture and agriculture-related keywords suggests that sustainability has become a central narrative within smart farming discourse. The blue cluster centers around crop-focused and AI-driven applications, featuring keywords such as crops, deep learning, plant disease, plants (botany), and forecasting. This cluster reflects the application of machine learning and computer vision techniques for crop monitoring, disease detection, yield estimation, and plant phenotyping. The integration of deep learning and plant disease detection shows how artificial intelligence has become a dominant research direction, particularly in image-based crop diagnostics and predictive modeling. The yellow cluster highlights advanced analytics and automation themes, including machine learning, agricultural machinery, learning algorithms, soils, and remote sensing. This cluster bridges hardware-based agricultural systems with computational intelligence. The linkage between machine learning and remote sensing suggests the increasing use of satellite imagery and UAV data combined with AI algorithms for large-scale monitoring.

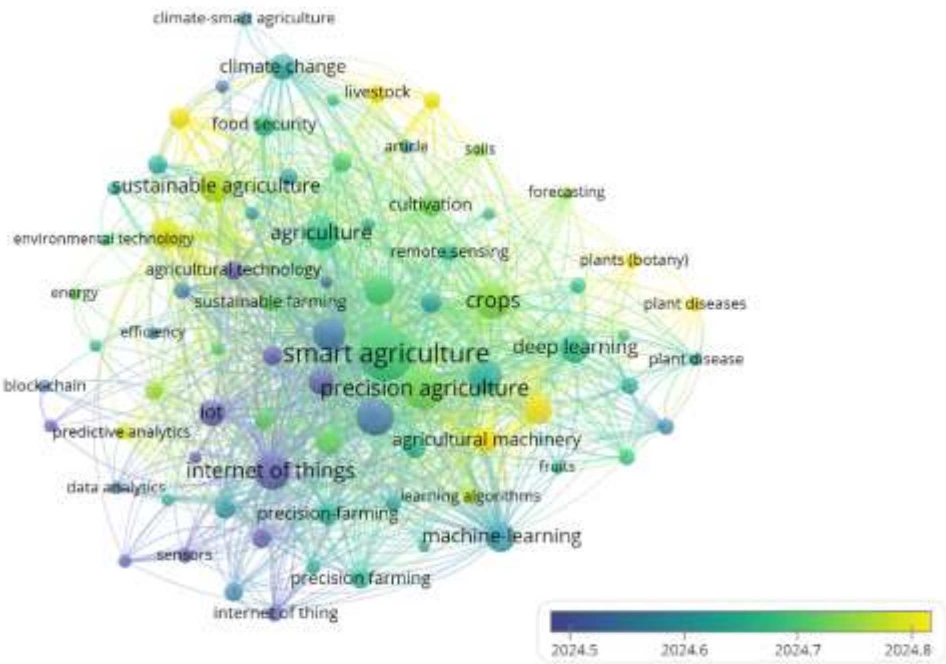

Figure 5. Overlay Visualization
Source: Data Analysis

Figure 5 illustrates the temporal evolution of smart farming research, where node colors represent the average publication year. Keywords displayed in darker blue tones reflect earlier research emphasis, while green to yellow tones indicate more recent and emerging topics. Foundational terms such as internet of things, sensors, precision farming, and data analytics appear in relatively earlier shades, suggesting that initial smart farming research concentrated on establishing digital infrastructure, sensor networks, and connectivity frameworks as the technological backbone of the field. More recent developments are reflected in green to yellow nodes, particularly around themes such as crops, sustainable agriculture, climate change, livestock, food security, and plant diseases. This shift suggests that research has progressively moved beyond purely technological experimentation toward application-driven and sustainability-oriented objectives. The stronger presence of crop-focused analytics and environmental themes indicates that smart farming is increasingly aligned with climate adaptation strategies and resource efficiency goals. Additionally, keywords such as deep learning, machine learning, remote sensing, and agricultural machinery appear in transitional green-yellow tones, highlighting the growing integration of artificial intelligence and automation into agricultural systems. This pattern reflects the transition from basic IoT-enabled monitoring to advanced AI-powered decision support and predictive systems.

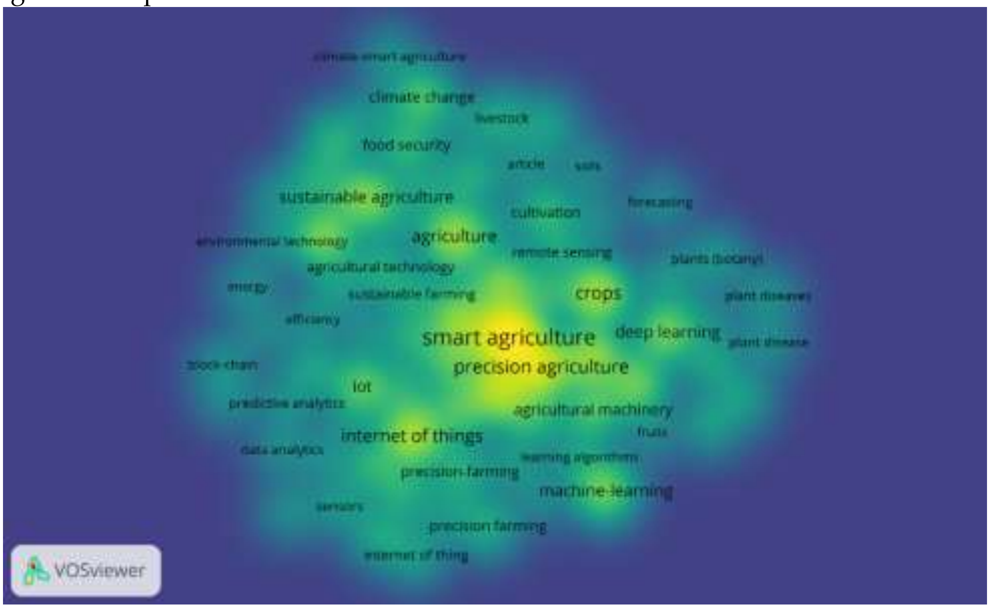

Figure 6. Density Visualization
Source: Data Analysis

Figure 6 highlights the most intensively researched themes within the smart farming literature. The brightest and most concentrated area is centered around smart agriculture and precision agriculture, indicating that these concepts form the intellectual core of the field. Closely surrounding this hotspot are related terms such as internet of things, crops, machine learning, and agricultural machinery, suggesting that technological integration and data-driven crop management are the dominant research priorities. The high density in this central zone reflects both the frequency of these keywords and their strong interconnections across publications. Moderate-density areas extend toward themes such as sustainable agriculture, climate change, food security, deep learning, plant disease, and remote sensing. This pattern shows that sustainability and AI-based crop analytics are also highly active research domains, though slightly less concentrated than the core smart agriculture–IoT nexus. In contrast, terms such as blockchain, predictive analytics, and environmental technology appear in lower-density zones, indicating emerging but comparatively less mature research areas.

Discussion

The bibliometric findings reveal a strong and accelerating expansion of smart farming research between 2010 and 2025, confirming the growing scientific and technological importance of digital transformation in agriculture. The publication growth trajectory reflects broader global drivers, including Industry 4.0 adoption, climate change pressures, food security concerns, and the rapid advancement of IoT and artificial intelligence technologies. The dense interconnections observed in the co-authorship and keyword networks suggest that smart farming is not an isolated technological niche but rather a multidisciplinary domain integrating computer science, agricultural engineering, environmental science, and sustainability studies.

From the author collaboration analysis, the presence of tightly connected researcher clusters indicates concentrated research groups working collaboratively on technological innovation in agriculture. The relatively compact network structure suggests that smart farming research is often conducted within strong team-based or institutional partnerships, particularly in engineering and computer science domains. This reflects the complexity of developing integrated systems such as IoT-based monitoring platforms, AI-driven crop diagnostics, and automation solutions, which require interdisciplinary expertise. However, the network structure also suggests that collaboration may still be regionally concentrated rather than evenly globalized.

The institutional collaboration map highlights the dominance of technology-oriented universities, particularly those with strong computer science and engineering departments. Institutions such as Chitkara University and KL Deemed to Be University serve as central nodes, reinforcing the observation that smart farming research is largely driven by computational and technological innovation. The repeated appearance of "Department of Computer Science" in the network further confirms that the field is increasingly shaped by data science, machine learning, and systems engineering approaches rather than purely agronomic frameworks. This technological orientation aligns with the strong presence of IoT, machine learning, and deep learning in the keyword analysis.

At the country level, India emerges as the most influential and central contributor in the global collaboration network. India functions as a major knowledge hub linking Asian, European, and African countries, indicating both high research productivity and strong international engagement. China also appears as a significant contributor, particularly within the Asian cluster, reflecting national investments in digital agriculture and AI innovation. European countries such as Germany and Italy form a dense collaborative group, while African nations such as South Africa, Ghana, and Kenya are visibly connected, suggesting growing participation in smart farming research aimed at climate resilience and food security. The network structure demonstrates that smart farming is increasingly a globally interconnected research domain, though with certain regional leaders shaping its direction.

The keyword co-occurrence analysis provides deeper insight into the intellectual structure of the field. The red cluster, centered on IoT, sensors, data analytics, and blockchain, represents the technological infrastructure foundation of smart farming. This indicates that connectivity, data acquisition, and digital monitoring systems are central to the literature. The green cluster emphasizes sustainability themes, including climate change, food security, and sustainable agriculture, demonstrating that digital farming research is strongly aligned with environmental and resilience objectives. The blue and yellow clusters highlight AI-driven applications, crop monitoring, machine learning algorithms, and agricultural machinery, reflecting the integration of computational intelligence with mechanized agricultural systems. The overlay visualization reveals a clear temporal evolution in research priorities. Earlier studies focused more heavily on IoT, sensors, and precision farming infrastructure. More recent publications emphasize deep learning, crop analytics, sustainability, and climate-related applications. This shift suggests that the field has matured from establishing digital connectivity frameworks toward developing intelligent, predictive, and sustainability-oriented systems. Smart farming research is therefore transitioning from infrastructure deployment to value optimization, where AI-driven analytics and sustainability outcomes are central.

The density map further confirms that smart agriculture, precision agriculture, IoT, and machine learning form the intellectual core of the field. High-density areas reflect mature and frequently studied topics, while lower-density areas such as blockchain and predictive analytics indicate emerging but less consolidated themes. This suggests that while AI and IoT applications are already well-established, research on secure data governance, interoperability standards, and decentralized agricultural systems remains underdeveloped. Despite the strong technological orientation, several research gaps emerge. First, much of the literature emphasizes technical feasibility rather than socio-economic adoption, especially among smallholder farmers in developing countries. Second, issues of data privacy, cyber-security, explainable AI, and ethical deployment receive comparatively limited attention. Third, while sustainability appears prominently in keyword clusters, empirical measurement of environmental impact reduction and cost-benefit validation remains insufficient. Addressing these gaps will be critical for translating smart farming innovation into scalable and inclusive agricultural transformation.

4. CONCLUSION

This bibliometric mapping of global smart farming research from 2010 to 2025 demonstrates a significant and sustained expansion of scientific attention toward digitally enabled agricultural systems. The findings reveal that the field is structurally centered on smart agriculture and precision agriculture, with strong integration of Internet of Things infrastructure, machine learning, deep learning, remote sensing, and agricultural machinery. Collaboration networks highlight the prominent role of India and other technologically active countries in shaping the research landscape, while institutional patterns confirm the dominance of computer science and engineering disciplines in driving innovation. The temporal evolution of keywords indicates a clear shift from foundational connectivity and sensor-based systems toward AI-driven analytics and sustainability-oriented applications, particularly in relation to climate change and food security.

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