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Bibliometric Analysis on Precision Agriculture Technology

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ABSTRACT

This study employs a bibliometric analysis using VOSviewer to visualize the authorship network within the domain of precision agriculture, identifying key researchers and their collaborative relationships. By mapping the connections based on publications from a specified time period, the analysis highlights the central figures like Erickson, B, who play pivotal roles in the network and reveals the interlinkages among various contributors. The study provides insights into the structural dynamics of research collaborations and elucidates the influence patterns among the scholars. Despite the inherent limitations such as database selection bias and the static nature of the bibliometric snapshot, the results offer valuable implications for enhancing research collaboration, academic planning, and strategic positioning within the scholarly community. This approach not only aids in recognizing influential entities and emerging talents but also assists institutions and funders in making informed decisions that could drive impactful research in precision agriculture.

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1. INTRODUCTION

Precision agriculture has emerged as a transformative approach in the farming sector, integrating advanced technologies to enhance crop productivity and environmental sustainability [1], [2]. This innovative method leverages data-driven insights to tailor farming practices to the precise needs of individual plots of land. Over the years, the adoption of precision agriculture has been propelled by the proliferation of technologies such as GPS, sensors, and data analytics, which collectively improve decision-making processes and optimize resource usage [3]. As the global population continues to rise, the demand for agricultural output intensifies, placing a premium on techniques that can boost yield without compromising ecological balance [4].

The scholarly landscape reflects a growing interest in precision agriculture, evidenced by an increasing volume of research that explores its diverse applications and impacts [5]–[7]. These studies often focus on the efficacy of specific technologies like drone-based monitoring systems, soil sensors, and satellite imagery in enhancing various aspects of agricultural production. Moreover, research has also delved into the socioeconomic implications of these technologies, examining how they affect the profitability and labor dynamics within the agricultural sector. Despite the advancements, the integration of precision agriculture varies significantly across different regions, influenced by economic, technical, and policy-related factors [8].

A bibliometric analysis of the existing literature on precision agriculture technology offers a comprehensive overview of how the field has evolved [9]. Such an analysis can identify pivotal studies, emerging trends, and pivotal technologies that have shaped the trajectory of precision agriculture research [10]. This approach also helps in understanding the collaboration networks among researchers and institutions, highlighting the interdisciplinary nature of precision agriculture studies. By mapping the intellectual landscape, researchers can pinpoint areas that have been well-explored and those that still require further investigation [11].

Despite its promise and the extensive research conducted so far, precision agriculture faces several challenges that impede its widespread adoption. These include high initial costs, the complexity of technologies, and the need for specialized skills among agricultural workers. Moreover, there is a notable gap in research regarding the long-term environmental impacts of these technologies, such as soil health and biodiversity. The variability in research focus and quality, geographical biases, and the rapid pace of technological change further complicate the comprehensive assessment of precision agriculture's benefits and drawbacks.

While there is abundant research on precision agriculture, there remains a lack of synthesis in the literature that addresses the comprehensive scope of technologies and their practical impacts. Many studies are fragmented, focusing narrowly on specific aspects or technologies within precision agriculture. This makes it difficult to draw generalizable conclusions about the effectiveness and scalability of these technologies across different agricultural contexts. Moreover, the rapid evolution of technology outpaces the scholarly literature, creating a lag in academic responses to new advancements. A bibliometric analysis is needed to consolidate existing research, assess its breadth and depth, and identify gaps and future directions in the field.

The objective of this research is to perform a bibliometric analysis on the existing body of literature concerning precision agriculture technology. This analysis aims to map the development of the field over time, identify the most influential works, discern prevailing trends, and uncover the network of collaborations that foster advancements in this area. By achieving these goals, the study will provide a structured and comprehensive overview of the state of precision agriculture technology research, facilitating a better understanding of its trajectory and potential areas for further exploration.

2. LITERATURE REVIEW

2.1 Thematic Evolution in Precision Agriculture

The foundational premise of precision agriculture is the application of exact and controlled farming techniques that cater to the unique requirements of individual plots. Early research in the 1990s focused on the use of Geographic Information Systems (GIS) and Remote Sensing (RS) as tools for soil mapping and crop monitoring [12]. These technologies enabled farmers to apply variable-rate technology (VRT) in fertilization, seeding, and pesticide application, optimizing inputs and reducing environmental impact. Over time, the focus expanded to include yield monitoring and control systems, which are critical for understanding and improving production efficiencies [13].

As technology advanced, the integration of Internet of Things (IoT) devices and sensors provided a real-time data stream that significantly enhanced the precision and adaptability of farming operations. Studies by [14] and [15] have demonstrated how IoT applications in PA can lead to more responsive and data-driven decisions, enhancing yields and reducing waste. Furthermore, artificial intelligence and machine learning algorithms have been applied to this data to predict crop health, yield outcomes, and optimize resource allocation, as detailed in the work by [16].

2.2 Technological Integration in Precision Agriculture

The integration of technology in PA has been extensively reviewed, with particular emphasis on the role of sensors, drones, and satellite imagery. According to [17], the deployment of soil and crop sensors provides critical data that can be used to enhance the precision of irrigation, fertilization, and pest management strategies. Drones, on the other hand, offer a unique advantage in their ability to rapidly and regularly monitor large and inaccessible areas, capturing high-resolution images that are vital for crop health assessments and management [18].

Satellite imagery has been another cornerstone of PA, providing broad-scale temporal data essential for long-term trend analysis and seasonal planning. [4] have highlighted the cost-effectiveness and extensive reach of satellite technologies, making them invaluable for precision agriculture applications, especially in developing regions where other technologies may be cost-prohibitive.

2.3 Impact Assessment of Precision Agriculture Technologies

The impacts of PA technologies have been studied across various dimensions, including economic, environmental, and social aspects. Economically, the adoption of PA has been linked to increased profitability due to higher yields and reduced input costs. [19] provided a comprehensive review of economic benefits, reporting that the adoption of precision technologies could lead to a 10-20% increase in profitability. Environmentally, precision agriculture practices have been associated with significant reductions in the use of water, fertilizers, and pesticides, thereby mitigating the adverse effects on the surrounding ecosystem [20].

Socially, the adoption of PA technologies has reshaped rural labor markets and required new skill sets from farmers. While some studies like those by [21] suggest that PA may lead to job displacement due to automation, others argue that it creates higher-skilled positions that could attract younger generations back to agriculture [22].

2.4 Integration Challenges and Future Directions

Despite the apparent benefits, the integration of PA technologies faces several challenges. High initial costs, lack of technical expertise, and data management issues are prominent barriers that hinder the widespread adoption of PA technologies, particularly in less developed countries. Furthermore, concerns about data privacy and the digital divide could exacerbate existing inequalities in agricultural productivity between developed and developing regions [23]. Future research needs to address these barriers while exploring innovative models for technology transfer and education in precision agriculture. Additionally, there is a need for longitudinal studies to better understand the long-term impacts of PA on soil health, biodiversity, and rural communities.

3. METHODS

This research employs a bibliometric analysis to systematically review and evaluate the body of literature pertaining to precision agriculture technology, specifically utilizing data extracted from the Google Scholar database. We identified relevant publications by searching keywords such as "precision agriculture," "smart farming," "IoT in agriculture," and other related technological terms, capturing articles, conference papers, and reviews from the inception of precision agriculture to the present. For data analysis, we used VOSviewer software, which facilitated the creation of co-citation, bibliographic coupling, and co-authorship networks, allowing for the identification of influential authors, seminal papers, and emerging trends within the field. Additionally, the geographical distribution of the studies was reviewed to understand regional focuses and gaps in the research. This methodology enables a thorough exploration of the evolution and current landscape of precision agriculture technology, providing insights into its development trajectories and potential future directions.

4. RESULTS AND DISCUSSION

4.1 Metrics Data of Literature

Table 1. Citation Metrics

Publication years:	1996-2024
Citation years:	28 (1996-2024)
Papers:	980
Citations:	86825
Cites/year:	3100.89
Cites/paper:	88.60
Cites/author:	38580.71
Papers/author:	412.83
Author/paper:	3.13
h-index:	142
g-index:	265
hI,norm:	85
hI,annual	3.04
hA-index	52
Papers with ACC >= 1,2,5,10,20: 916,808,545,322,179	

Source: Publish or Perish, 2024

Table 1 presents a comprehensive set of citation metrics for publications on precision agriculture from 1996 to 2024. Over these 28 years, 980 papers have been published, amassing a total of 86,825 citations, averaging 3,100.89 citations per year and 88.60 citations per paper. The high citation rate per author, at 38,580.71, along with 412.83 papers per author, reflects a robust collaborative network in this field, evidenced by an average of 3.13 authors per paper. The h-index of 142 and g-index of 265 signify a significant impact and influence of this body of work, indicating that many papers have been highly cited, showing substantial depth and breadth in the research. The normalized and annualized h-indices (hI,norm at 85 and hI,annual at 3.04) further highlight the consistent quality and influence of the research over time. The hA-index at 52 underscores the sustained impact of the authors in this domain. The distribution of papers with at least 1, 2, 5, 10, and 20 citations showcases the wide recognition and application of the research findings, affirming the field's vitality and ongoing relevance.

4.2 Citation Analysis

Table 2. Top Cited Literature

Citation	Author and Year	Title	Findings
2202	[24]	The application of small unmanned aerial systems for precision agriculture: a review	This paper reviews the application of small unmanned aerial systems (UAS) in precision agriculture, highlighting their effectiveness in crop monitoring and data collection. It emphasizes the advantages of UAS in enhancing crop yield predictions, detecting plant diseases, and optimizing resource allocation.
2166	[17]	Twenty-five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps	Mulla discusses the significant advances in remote sensing technologies over 25 years and their applications in precision agriculture. The paper identifies the progress made in yield estimation, soil property mapping, and disease detection, while also highlighting the unresolved issues related to data integration and interpretation.
2102	[25]	Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture	Cassman's work explores ecological intensification in cereal production, advocating for the integration of precision agriculture techniques to enhance yield potentials and improve soil quality. The paper argues that precision agriculture is crucial for sustainable intensification, which can meet growing food demands without adverse environmental impacts.
1764	[26]	Precision agriculture—a worldwide overview	This comprehensive overview addresses the global adoption of precision agriculture, discussing its technological advancements and regional adaptations. The authors provide insights into the economic benefits and scalability challenges faced by various countries implementing precision agricultural practices.
1591	[27]	Precision agriculture and food security	Gebbers and Adamchuk analyze the role of precision agriculture in enhancing food security. The paper

			details how precision technologies can reduce waste, increase efficiency, and thereby contribute significantly to feeding the growing global population.
1203	[12]	Future directions of precision agriculture	This paper discusses future trends and potential advancements in precision agriculture. It focuses on the development of more sophisticated sensor technologies and the integration of big data analytics to further refine agricultural practices and decision-making processes.
1198	[28]vv	On-the-go soil sensors for precision agriculture	The study introduces and evaluates the effectiveness of on-the-go soil sensors, which allow for real-time soil property measurements. These sensors are shown to improve the precision of soil management practices, enhancing nutrient application and reducing environmental impact.
1126	[29]	Plant disease detection by imaging sensors–parallels and specific demands for precision agriculture and plant phenotyping	Mahlein's research focuses on the use of imaging sensors for the detection of plant diseases. The paper highlights the potential of these technologies in precision agriculture and plant phenotyping, emphasizing their role in early detection and management of crop diseases.
1117	[13]	Aspects of precision agriculture	Pierce and Nowak explore various aspects of precision agriculture, including technological components, implementation challenges, and economic impacts. The paper provides a broad overview of how precision agriculture can be tailored to fit different agricultural environments.
1013	[4]	Precision agriculture and sustainability	This article examines the relationship between precision agriculture and sustainability. It argues that precision agriculture practices can lead to sustainable agricultural methods by optimizing input use and reducing environmental footprints.

Source: Publish or Perish, 2024

4.3 Co-Word Network Analysis

1. Network Visualization

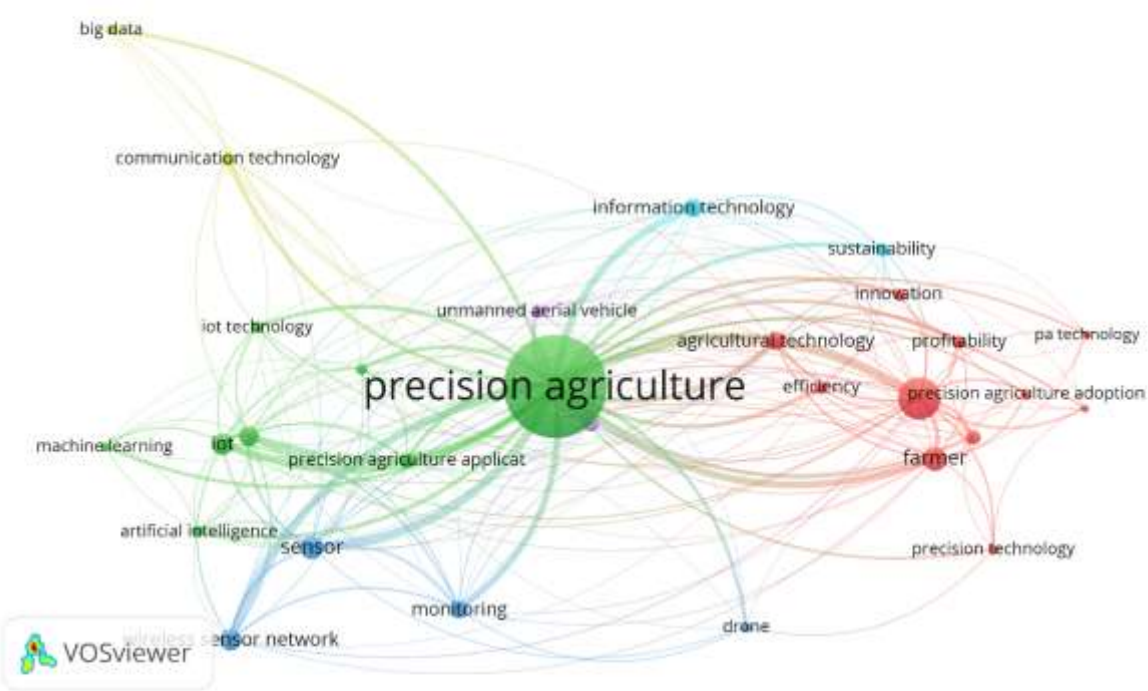

Figure 1. Network Visualization
Source: Data Analysis, 2024

Table 3. Clusters Composition

Cluster	Items	Description
Green Cluster	"Precision Agriculture", "IoT", "Machine Learning", "Artificial Intelligence"	This cluster focuses on the integration of advanced technologies in agriculture, emphasizing the use of IoT and artificial intelligence to enhance precision agriculture practices. It explores how machine learning algorithms can analyze vast amounts of data to optimize crop health, yield, and resource usage, leading to smarter, more efficient farming techniques.
Red Cluster	"Agricultural Technology", "Innovation", "PA Technology", "Profitability", "Efficiency", "Farmer", "Precision Technology"	The red cluster revolves around the impact of innovative agricultural technologies on farming efficiency and profitability. It covers various aspects of precision agriculture (PA) technologies that help farmers make informed decisions to boost productivity and economic returns while minimizing waste and environmental impact.
Blue Cluster	"Wireless Sensor Network", "Sensor", "Monitoring", "Drone", "Information Technology", "Sustainability"	This cluster examines the role of sensor-based technologies and drones in monitoring agricultural environments, facilitated by wireless sensor networks and IT solutions. It highlights how these

		technologies contribute to sustainable farming by enabling real-time monitoring and management of agricultural resources and conditions.
Yellow Cluster	"Communication Technology", "Big Data"	The yellow cluster addresses the critical role of communication technologies and big data in agriculture. It discusses how the ability to transmit, process, and analyze large datasets through advanced communication infrastructures can lead to more informed decision-making and improved agricultural outcomes.
Purple Cluster	"Unmanned Aerial Vehicle"	This cluster is dedicated to exploring the specific applications of unmanned aerial vehicles (UAVs) or drones in agriculture. It focuses on their use for crop monitoring, aerial imaging, and precision spraying, providing farmers with detailed insights into crop health and environmental conditions, thereby enhancing the precision and effectiveness of agricultural practices.

Source: Data Analysis, 2024

Table 3 categorizes the composition of various clusters based on their focus and utilization in agriculture, as delineated by specific technologies and methods. The Green Cluster highlights the integration of IoT and artificial intelligence in precision agriculture, using machine learning to optimize farm outputs efficiently. In contrast, the Red Cluster emphasizes the broader scope of agricultural technology and innovation, focusing on enhancing profitability and efficiency through precision agriculture techniques that support informed decision-making. The Blue Cluster delves into the deployment of sensor-based technologies and drones, supported by wireless networks and information technology, to facilitate sustainable farming via real-time monitoring. The Yellow Cluster explores the pivotal roles of communication technology and big data in improving agricultural decisions and outcomes through enhanced data processing capabilities. Lastly, the Purple Cluster specifically focuses on the applications of unmanned aerial vehicles in agriculture, demonstrating their effectiveness in crop monitoring and precision spraying to boost crop health and farm management efficiency. Collectively, these clusters showcase a diverse array of technological advancements shaping modern agricultural practices towards more sustainable, efficient, and data-driven approaches.

2. Overlay Visualization

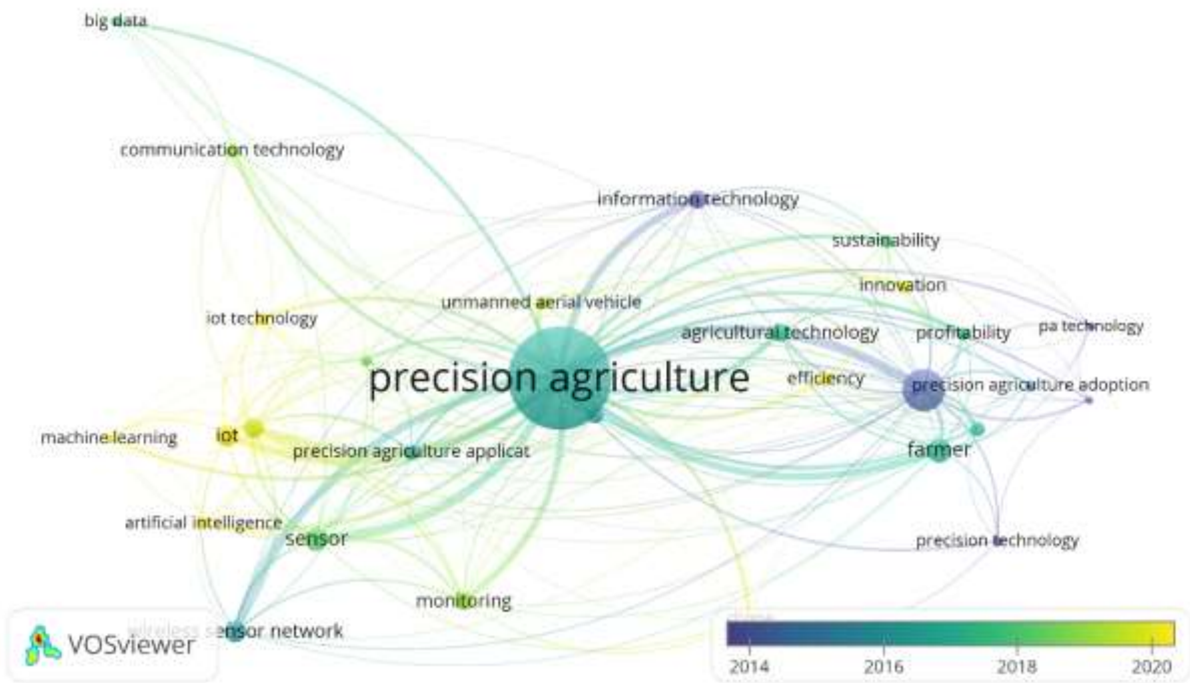

Figure 2. Overlay Visualization
Source: Data Analysis, 2024

The visualization above showcases the interconnected themes within the domain of precision agriculture from 2014 to 2020. Each node represents a key concept, and the lines indicate relationships between them based on co-occurrence in the literature.

Table 4 Trend of Research

Year	Research Focus
2014	The focus includes 'Information Technology,' 'Precision Agriculture Adoption,' 'PA Technology,' and 'Precision Technology.' This suggests that during this period, there was significant discussion around integrating advanced IT solutions into precision agriculture, primarily aiming to adopt and refine precision agriculture technologies.
2016	Keywords like 'Precision Agriculture,' 'Wireless Sensor Network,' 'Big Data,' and 'Farmer' indicate a shift towards implementing practical IoT applications in farming. The emphasis on 'Wireless Sensor Network' and 'Big Data' highlights a growing interest in data-driven farming solutions that directly involve the end-users, namely farmers.
2018	The terms 'Sustainability,' 'Sensor,' 'Communication Technology,' and 'Monitoring' reflect an increased awareness of sustainable practices and the role of continuous monitoring in agriculture. The focus is on sustainability and efficiency, using sensors and communication technologies to achieve these goals.
2019	Concepts such as 'IoT,' 'Machine Learning,' and 'Artificial Intelligence' start to gain prominence. This phase marks a sophisticated integration of AI and machine learning with IoT devices in agriculture, emphasizing smart, autonomous systems capable of enhancing farm management and productivity through advanced analytics.

Source: Data Analysis, 2024

3. Density Visualization

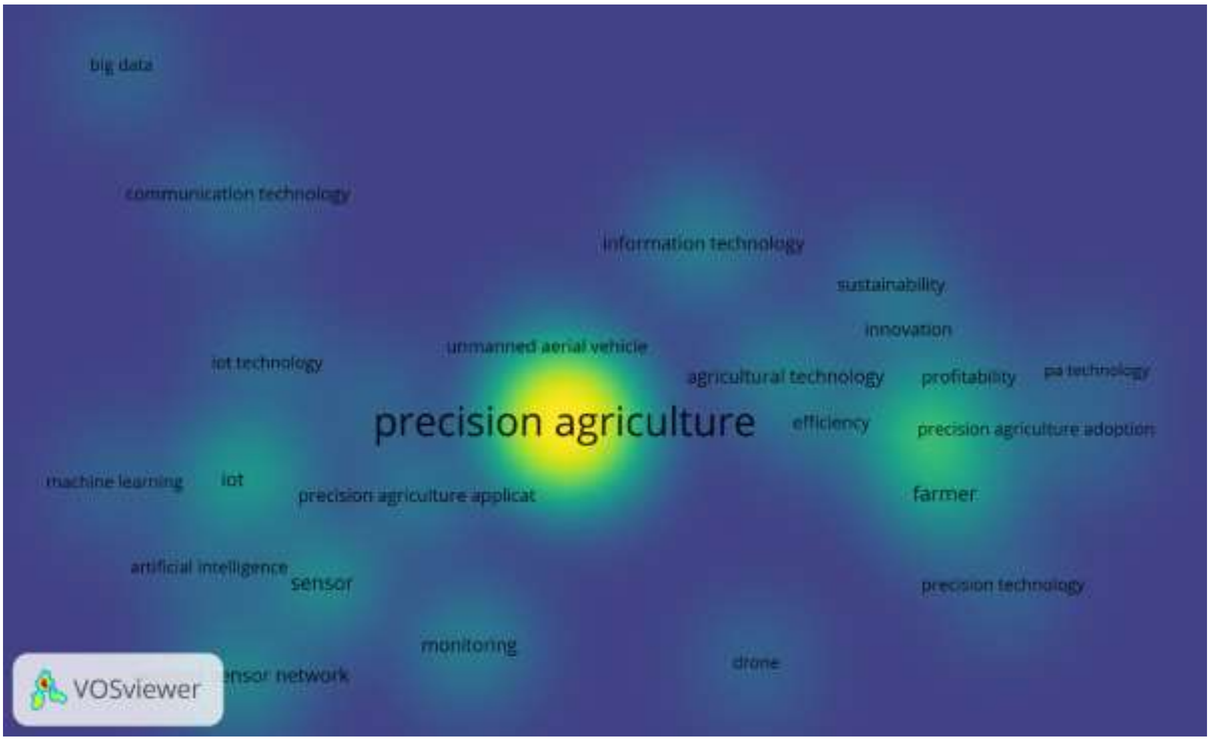

Figure 3. Density Visualization
Source: Data Analysis, 2024

The figure illustrates a bibliometric analysis of various concepts related to precision agriculture, depicted as nodes in different colors representing distinct clusters of interrelated themes. The central node, "precision agriculture," signifies the focal point of this study, highlighting its paramount importance in the analyzed literature. Around this node, other significant concepts like "IoT," "machine learning," "artificial intelligence," "sensor," and "unmanned aerial vehicle" are positioned, suggesting these technologies are integral to the development and implementation of precision agriculture practices. Their proximity to the central node indicates strong associations, likely reflecting their combined application in enhancing agricultural processes through automation and data-driven decision-making.

The distribution of nodes across the map, such as "big data," "communication technology," and "information technology" near the periphery, while still linked to the central theme, suggests these are supportive technologies critical to the infrastructure of precision agriculture. They facilitate the collection, transmission, and processing of data essential for the operation of more directly involved technologies like sensors and drones. The presence of "sustainability," "profitability," and "efficiency" on the map indicates the desired outcomes or key motivations behind adopting precision agriculture techniques, which aim to make farming practices more sustainable, cost-effective, and efficient.

4.4 Co-Authorship Network Analysis

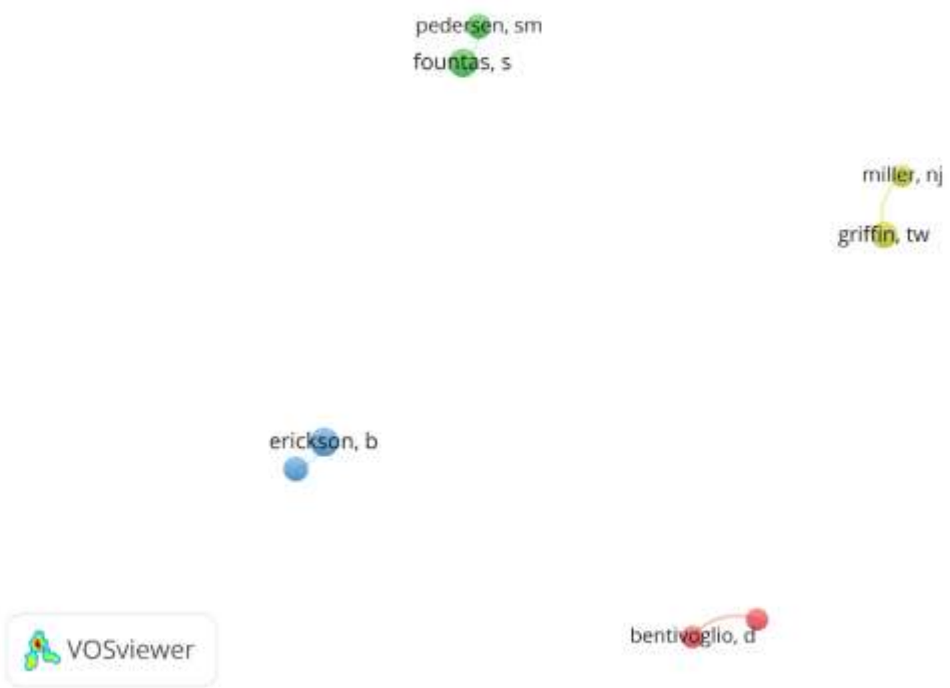

Figure 4. Authorship Network Visualization
Source: Data Analysis, 2024

In the diagram, Erickson, B appears as a central figure, possibly indicating a higher degree of connectivity or influence within this network, which could be due to this author's prolific nature or central involvement in collaborative research. Other authors, such as Pedersen, SM, Fountas, S, Miller, NJ, Griffin, TW, and Bentivoglio, D, are positioned around Erickson, B, suggesting they may have either co-authored papers with Erickson or have worked in closely related research areas. The absence of visible lines connecting these authors directly might imply that the connections are not as strong or direct as between others, or they may represent emerging relationships within the field. The placement and distribution of these nodes can help in understanding the structure of collaborations and the flow of information within this particular academic domain, highlighting key contributors and potential influencers in the field.

4.5 Practical Application

1. **For Researchers**

The central placement of certain authors like Erickson, B suggests they are key nodes in this network, likely due to their extensive collaboration and citation. Researchers can use this information to identify potential collaborators who are central to a network or explore emerging scholars (like those more peripherally placed) for fresh perspectives or new collaborative ventures.

2. **For Institutions**

Academic institutions can use these insights to foster partnerships by organizing conferences, workshops, or joint research projects that encourage collaboration among these key researchers. Recognizing prolific authors helps institutions in pinpointing thought leaders who can attract research funding and elevate project outcomes.

3. **For Funding Agencies**

Funding bodies looking to maximize the impact of their grants can use these maps to identify which researchers have significant influence and collaboration networks. Supporting projects led by such individuals or teams might increase the likelihood of groundbreaking research and higher citation impacts, promoting innovation in specific research areas like precision agriculture.

4. **For Universities**

University research offices can leverage this information to strengthen support for researchers who are central to important networks, provide necessary resources for those looking to expand their research impact, or improve networking opportunities for researchers who are less connected.

5. **For Professional Development**

Institutions can develop targeted professional development programs for researchers based on the network's structure. Those at the periphery might benefit from workshops on collaborative research and grant writing, while central figures might be trained in leadership and mentorship to manage large, interdisciplinary projects effectively.

Limitation

The bibliometric analysis presented, while informative, carries several limitations inherent to such studies. Firstly, the reliance on specific databases may introduce a selection bias, as publications not indexed in the chosen databases are excluded, potentially overlooking significant contributions from other sources. Additionally, the analysis depends heavily on the accuracy and completeness of the metadata provided by the database, such as correct author affiliations and citation details, which if incorrect, could skew the results. The network visualization primarily reflects quantitative relationships like co-authorships or citations, potentially missing qualitative aspects of collaboration such as the influence of mentorship, informal collaborations, or interdisciplinary impacts beyond the scope of indexed publications. Furthermore, the static snapshot provided by the analysis may not accurately capture the evolving dynamics of research networks, as new collaborations form and older ones may dissolve over time. This temporal limitation means the analysis might not fully represent the current state of the research landscape, reducing the applicability of the findings for future-oriented decision-making.

5. CONCLUSION

The bibliometric analysis utilizing VOSviewer to map the network of authors in the field of precision agriculture provides valuable insights into the collaborative dynamics and influential researchers shaping this rapidly evolving domain. By identifying central figures such as Erickson, B, and outlining the broader network of contributors, this study highlights key nodes of collaboration and potential areas for further scholarly interaction. Despite its limitations related to database selection biases and the static nature of the data, the findings offer practical implications for enhancing research collaboration, strategic academic planning, and targeted recruitment. Institutions, funding agencies, and researchers can leverage this information to forge stronger partnerships, optimize resource allocation, and strategically position their contributions for greater impact. As precision agriculture continues to integrate advanced technologies like IoT and AI, understanding the network of intellectual contributions becomes crucial in steering future innovations and addressing the complex challenges of sustainable agriculture.

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