



A Bibliometric and Thematic Approach to Digital Agriculture Research

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ABSTRACT

This study presents a bibliometric analysis aiming to identify research trends, main themes and strategic issues in the field of digital agriculture from 2019 to 2023. The number of publications, author productivity, citations and keyword trends were assessed by analyzing 508 publications obtained from the Scopus database with Bibliometrix software. The findings show a notable increase in academic output around the main themes of data governance, agricultural data and data access. This study contributes to the field by systematically mapping existing knowledge and research gaps and provides valuable insights for future research. Prominent findings include the integration of technological innovations in agriculture and their impact on productivity and sustainability. The study recommends the development of technological infrastructure and the provision of farmer training programs to promote the effective adoption of digital agricultural technologies.

Keywords: Digital agriculture, Bibliometric analysis, Thematic analysis

1. Introduction

Digital agriculture is a concept that signifies the integration of modern technologies into agricultural practices, leading to transformative changes in the agriculture sector. This concept encompasses subcategories such as smart farming, precision agriculture, and Agriculture 4.0, which leverage technologies like big data, the Internet of Things (IoT), artificial intelligence (AI), and cloud computing. Digital agriculture holds the potential to enhance agricultural productivity, ensure sustainability, and optimize resource use, yet realizing this potential requires comprehensive scientific research and practical implementation.

Digital agriculture is a rapidly expanding research field, but studies in this area are often fragmented and disconnected, making it challenging to understand the different dimensions of digital agriculture and to establish a framework for future research. Thus, examining digital agriculture research through bibliometric and thematic analyses is essential to understand the current state of the field, identify key trends, and define directions for future studies.

In existing literature, digital agriculture has been explored across various scientific disciplines. Klerkx, Jakku, and Labarthe (2019) emphasized the need for a social science perspective on digital agriculture and identified five main thematic clusters: adoption, use, and adaptation of digital technologies on farms; the impact of digitization on farmer identity and skills; power, ownership, privacy, and ethical issues within digitalized agricultural production systems; digitalization within agricultural knowledge and innovation systems; and the economy and governance of digitalized agricultural production systems and value chains. Sott et al. (2021) mapped the scientific landscape of digital agriculture, focusing on the adoption of precision techniques and breakthrough technologies to enhance productivity, quality, and sustainability. Using 4,694 publications from the Web of Science database, they conducted a bibliometric performance and network analysis with SciMAT software, identifying 22 strategic themes, including IoT, UAVs, and climate-smart agriculture. A thematic network structure analysis of the nine most significant clusters (motor themes) and a thematic evolution map from 1994 to 2020 were provided. Another

study by Zhou and Yin (2023) used Citespace to analyze 2,264 publications on digital agriculture from the WoS database (1997-2022). Findings revealed a gradual increase in annual digital agriculture publications across three phases, with six categorized research streams: Remote Sensing, Climate-Smart Agriculture, Artificial Intelligence, Internet of Things, Big Data, and Systems Integration. These studies focus primarily on the period up to 2022 and are limited to the Web of Science database.

This study is designed to conduct a bibliometric and thematic analysis of digital agriculture research. First, the digital agriculture literature was reviewed, and relevant studies were selected based on specific criteria. Subsequently, these studies were examined through bibliometric analyses, assessing metrics such as publication counts over time, citation counts, and the most prolific authors. Additionally, thematic analyses identified the main themes within digital agriculture research and highlighted the relationships among these themes.

The findings indicate a significant increase in scientific output in digital agriculture, with research in this field covering a broad spectrum of thematic topics. Particularly, themes such as data governance, agricultural data, and data accessibility stand out, reflecting their potential impact on the sustainability and productivity of digital agriculture. Future research should further investigate the integration of technologies like AI, IoT, big data, and cloud computing into agricultural applications.

2. Method

This study aims to characterize developments in digital agriculture from 2019 to 2023, guided by bibliometric analysis. Aria and Cuccurullo (2017) stated that bibliometric analysis serves to answer three critical questions: it defines the foundational knowledge and intellectual structure of a research field, explores its forefront or conceptual framework, and maps the social network structure of the relevant scientific community. In this context, bibliometric analysis will be employed to identify the fundamental knowledge, intellectual structure, and conceptual framework of studies conducted on digital agriculture. Additionally, by examining the social network structure of the scientific community active in this field, this study aims to provide a comprehensive understanding of the overall structure of this research domain.



Figure 1. Study Process

As illustrated in Figure 1, the selected methodology has facilitated the identification of key elements within the field: the most cited documents, prolific authors, emerging trend keywords, and the driving forces and directions influencing digital agriculture. The methodology is applied through five critical stages—research design, data collection, data analysis, data visualization, and interpretation—aligned with the bibliometric mapping standards set by Zupic and Čater (2015).

2.1. Research Design

The research design stage is crucial for shaping the research framework, as it involves formulating research questions that will guide the study and selecting appropriate methodologies to address these questions (Aria & Cuccurullo, 2017). This

stage also requires strategic decisions about various aspects of the research process. These decisions include determining the timeframe for the study, identifying the keywords guiding the literature review, selecting the databases to find relevant literature, and choosing software tools for data analysis. Each of these decisions aims to develop an approach that effectively meets the study's objectives.

2.2. Data Collection

Data collection for this research was conducted using the Scopus database, recognized for its extensive coverage and frequent adoption in bibliometric studies (Mongeon & Paul-Hus, 2016). While other databases such as PubMed, Web of Science, and Google Scholar offer unique advantages, Scopus was preferred for its comprehensiveness and its vast repository of peer-reviewed publications (Harzing & Alakangas, 2016). The literature search was conducted using the keyword “Digital agriculture,” focusing on publications’ titles, keywords, and abstracts. To capture recent developments effectively, the timeframe for the literature review was set from 2019 to 2023. Since journals typically publish the latest research findings and are more detailed than other types of publications (such as conference proceedings, which were more affected by delays and cancellations due to the COVID-19 pandemic), the study focused solely on journal articles to ensure data accuracy and rigor (Jin et al., 2018). The initial search yielded 1,132 documents, which were subsequently filtered by document type and year to a final dataset of 508 relevant articles.

2.3. Data Analysis

In bibliometric research, multiple software options are available for data analysis (Cobo et al., 2011). For this study, Biblioshiny, a user-friendly, web-based interface that requires no coding expertise, was used to perform a comprehensive analysis of the collected data. Biblioshiny, an extension of the Bibliometrix tool designed to make bibliometric analysis more accessible, was selected primarily for descriptive analysis (Aria & Cuccurullo, 2017). Biblioshiny supports data from major databases such as Scopus, Web of Science, Dimensions, PubMed, and Cochrane Library, making it ideal for processing and analyzing the descriptive aspects of bibliometric data (Moral-Muñoz et al., 2020).

2.4. Data Visualization and Interpretation

For collaborative network analysis and strategic mapping, we used Bibliometrix. Collaborative networks were created when two or more authors collaborated on an article, helping us understand the dynamics of knowledge production within the field. The strategic map was used to identify and visualize conceptual subdomains in a two-dimensional strategic diagram, leveraging co-word and h-index indicators (Aria, Misuraca, & Spano, 2020). Initially, keyword networks were created, where frequently co-occurring keywords formed high-density networks. The software then calculated relationships between these networks and grouped them into thematic clusters based on centrality and density. Centrality measures the interaction level of a keyword network with other networks, while density reflects the internal strength and cohesiveness of terms within the network. Themes are classified into four groups based on centrality and density (Cobo et al., 2015):

Motor Themes: These well-developed and important themes, found in the upper-right quadrant of the strategic map, structure the research field.

Niche Themes: Highly specialized and peripheral themes located in the upper-left quadrant.

Emerging or Declining Themes: Themes with low density and low centrality, representing emerging or declining research areas, located in the lower-left quadrant.

Basic Themes: These important but less developed themes are general and transversal for the research field and are found in the lower-right quadrant.

3. Findings

In this study, metadata analysis was conducted on 508 documents. The R Bibliometrix package, operating through the Biblioshiny interface on R Studio software, assisted in processing and performing a portion of the bibliometric analyses. The sample consisted of 443 research articles and 65 review articles published across 253 journals.

3.1. Bibliometric Analysis

Figure 2 illustrates the growth in the number of publications and the average annual citation rate over the years. The average citation count per article is calculated based on the number of years since publication, allowing for time compensation and enabling a more accurate comparison across years. A significant increase in scientific output has been observed in recent

years, showing a steady rise in the number of articles published in the field of digital agriculture. Notably, 2023 saw a marked increase in the number of articles, indicating that digital agriculture is attracting growing research interest.

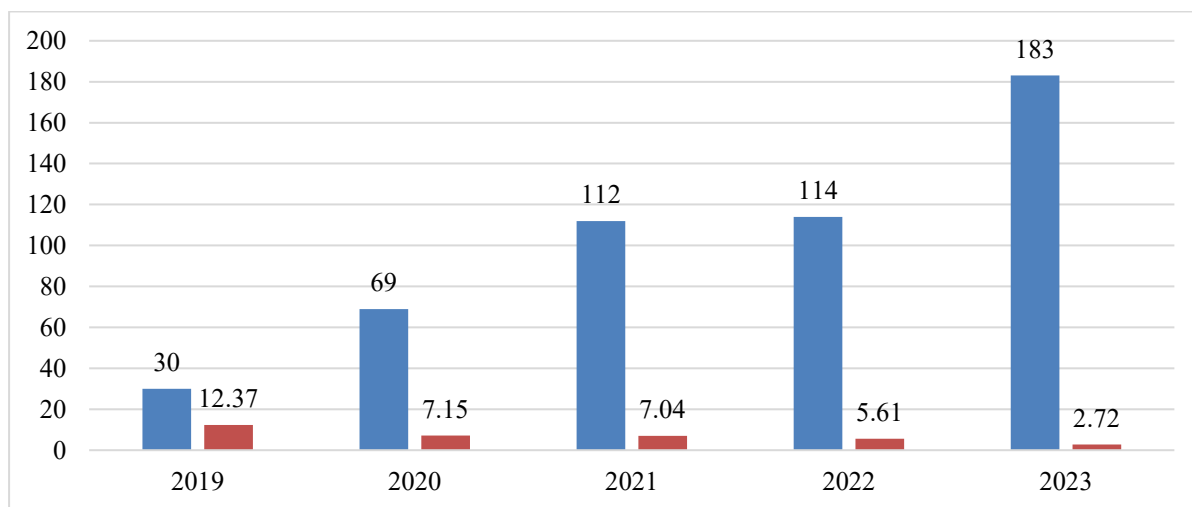


Figure 2. Article and Citation Counts

Despite the increase in publication numbers, a decline in the average annual citation rate has been observed. The highest average citation rate was recorded in 2019, with a gradual decrease in the following years, reaching its lowest level in 2023. This trend may indicate that newly published articles have not yet accumulated sufficient citations or suggest increased competition or a change in article quality within the field. To delve into the content of these studies, we focus on the three most impactful articles listed in Table 1.

Table 1. Most Cited Documents

Author(s)/Year	Article Title	Total Citation	Average Citation Per Year
Klerkx, Jakkub & Labarthe (2019)	A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda	658	109,67
Klerkx & Rose (2020)	Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways?	313	62,60
Mahmudul Hasan vd., (2021)	A survey of deep learning techniques for weed detection from images	258	64,50

Examining Table 1, the content of these articles provides a general and introductory perspective on the research field. The most cited article in this collection reviews studies on digital agriculture, smart farming, and Agriculture 4.0 from a social science perspective. The article aims to identify existing, emerging, and novel themes and topics in this area, contributing by introducing seventeen articles presented in this special issue. It reveals five main thematic clusters in the social sciences literature on digital agriculture: (1) Adoption, usage, and adaptation of digital technologies on farms; (2) The impact of digitization on farmer identity, skills, and farm work; (3) Power, ownership, privacy, and ethics in digital agriculture production systems and value chains; (4) Digitalization in agricultural knowledge and innovation systems; (5) Economy and governance of digitalized agricultural production systems and value chains (Klerkx et al., 2019).

The second most cited article, with 313 citations, is titled “Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways?” published in 2020. This perspective article argues for greater attention to the inclusive and exclusive impacts of Agriculture 4.0 technologies and evaluates how these technologies relate to various transition pathways toward sustainable agriculture and food systems (Klerkx & Rose, 2020). The third most cited article reviews current deep learning-based weed detection and classification techniques. The study found that most works applied supervised learning techniques, achieved high classification accuracy by fine-tuning pre-trained models on specific plant datasets, and obtained high accuracy levels when abundant labeled data were available (Hasan et al., 2021). The impact of an article can be observed through its citations, as high citation counts indicate recognition

by the academic community. On the other hand, some authors contribute significantly by the number of publications they produce. Figure 3 illustrates the most prolific authors over the years.

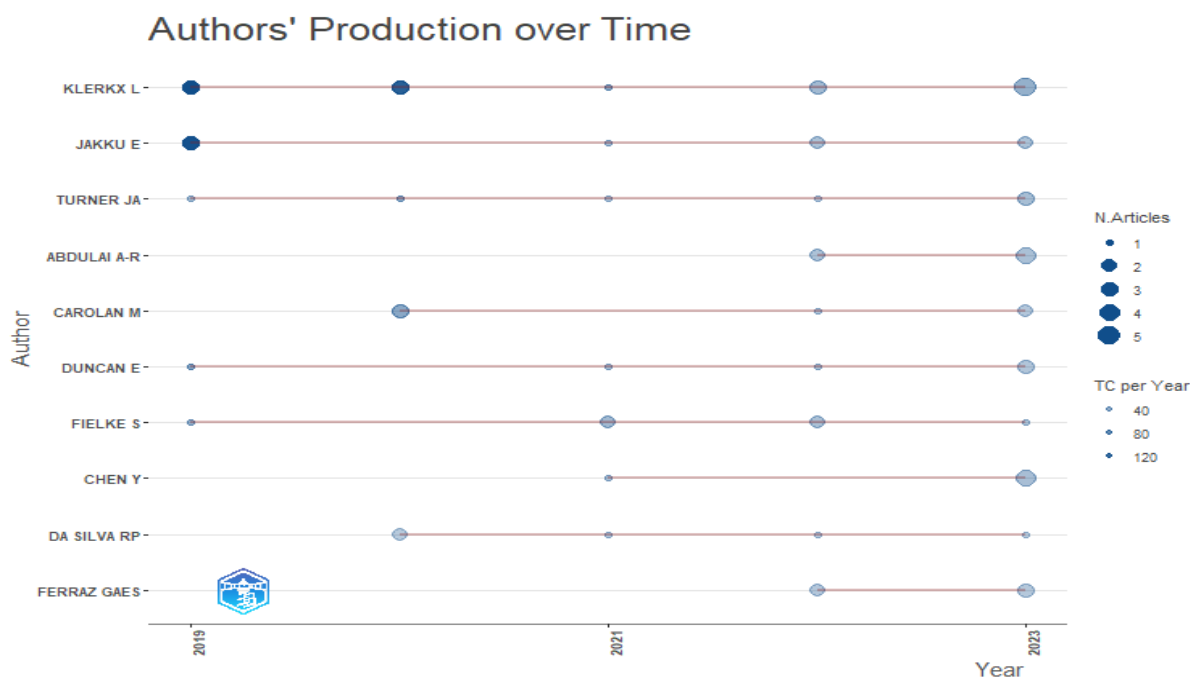


Figure 3. Most Prolific Authors

In Figure 3, the publication output of authors from 2019 to 2023 and the number of citations their articles received are presented. The horizontal axis represents the years, and the vertical axis represents the authors. Each point indicates an author's publication count in a given year and the total citations received by those publications. Authors like Klerkx L. and Jakku E. stand out for producing a high volume of publications and receiving substantial citations in certain years. Notably, Klerkx L. is prominent in both publication and citation counts in 2019 and 2021. Other authors, such as Turner JA, Abdulai AR, Carolan M, Fielke S, Chen Y, Da Silva RP, and Ferraz Gaes, have produced fewer but consistently regular publications over the years. Observing the size and color tones of the points, it is evident that the number of citations received in some years is significantly higher compared to others. For instance, the citation counts for Klerkx L. and Jakku E. are noticeably higher than those of other authors. Collaboration networks are formed as authors work together to produce articles. Figure 4 illustrates authors collaborating with each other.

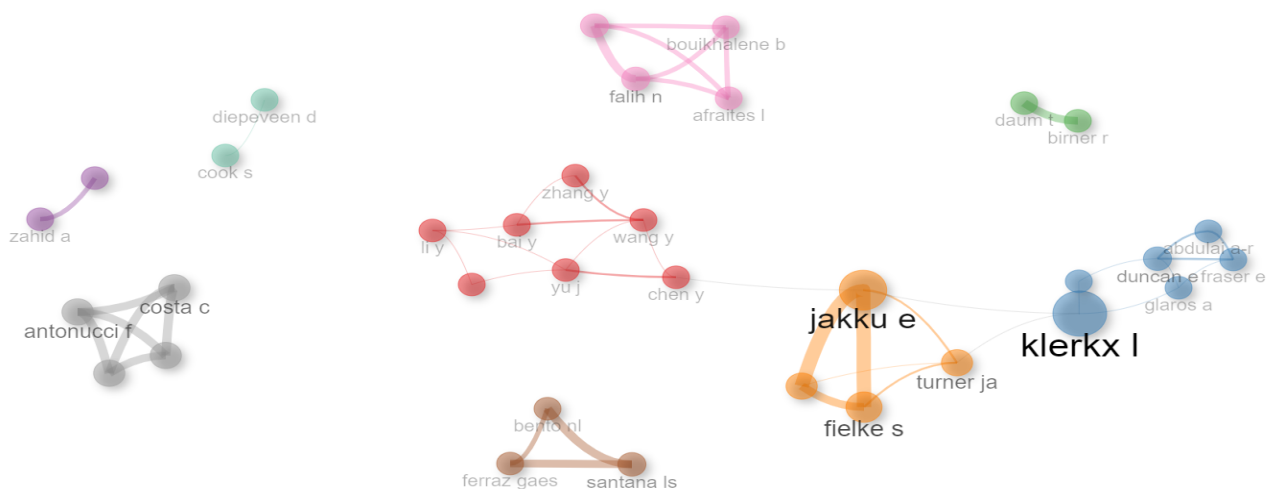


Figure 4. Most Prolific Authors

In Figure 4, as the number of co-authored publications increases, the line connecting two authors becomes thicker (Aria & Cuccurullo, 2017). In the network map, each node represents an author, and the lines between nodes illustrate collaborations between authors. Larger nodes, such as those for Jakku E. and Klerkx L., indicate that these authors have extensive collaboration with other authors, positioning them as central connection points in the network.

The map also displays smaller clusters of authors who work closely together but are relatively isolated from the rest of the network. For example, authors like Zahid A., Bouikhalene B., and Costa C. are located within their own smaller groups. Different colors represent distinct collaboration groups or topics, suggesting that authors of the same color are likely working on similar research themes. The density of connections reflects the frequency or strength of collaboration between authors; for instance, the link between Jakku E. and Fielke S. suggests frequent collaboration. Upon examining this author group's publications, it becomes apparent that they focus on topics such as digitalization in agriculture, smart farming, and the digitalization of agricultural innovation systems. As observed, authors establish collaborative networks, often influenced by shared research interests, institutional affiliations, or countries. To visualize the authors' affiliations by country, we included Figure 5.

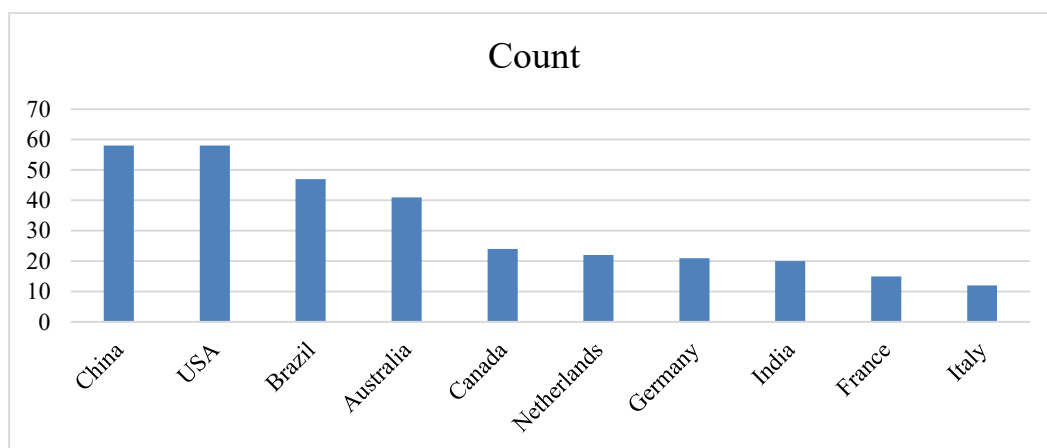


Figure 5. Most Prolific Countries

In Figure 5, data on the number of studies or publications by certain countries in the field of digitalization in agriculture or smart farming is presented. China and the USA lead with 58 publications, highlighting the significant importance they place on digitalization in agriculture. The institutions making the greatest contributions are shown in Figure 6.

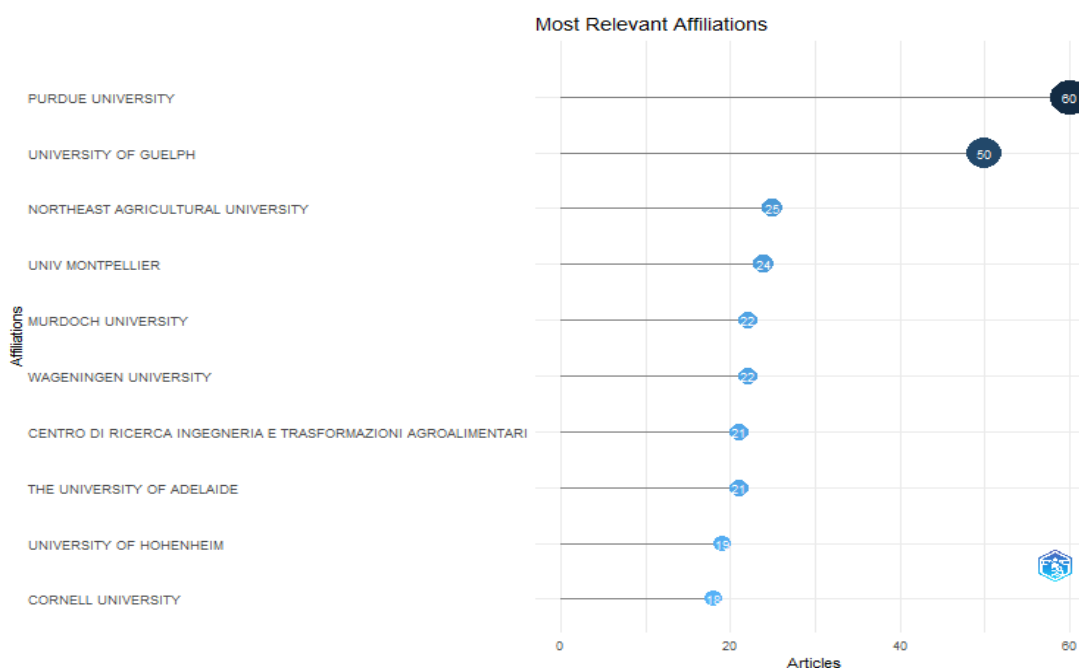


Figure 6. Most Prolific Affiliations

In Figure 6, Purdue University in the USA is identified as the university with the highest number of publications, followed by the University of Guelph. Over the years, publication dynamics, high-impact studies, prolific authors, author collaborations, and the institutions and countries to which authors are affiliated have been determined. From this point, digital agriculture topics have been examined in greater depth through thematic analysis.

3.2. Thematic Analysis

In Figure 7, a strategic map illustrates the research themes related to digitalization in agriculture and smart farming. This type of map displays both the centrality (relevance degree) and the development (density) of specific themes. The map is divided into four main quadrants:

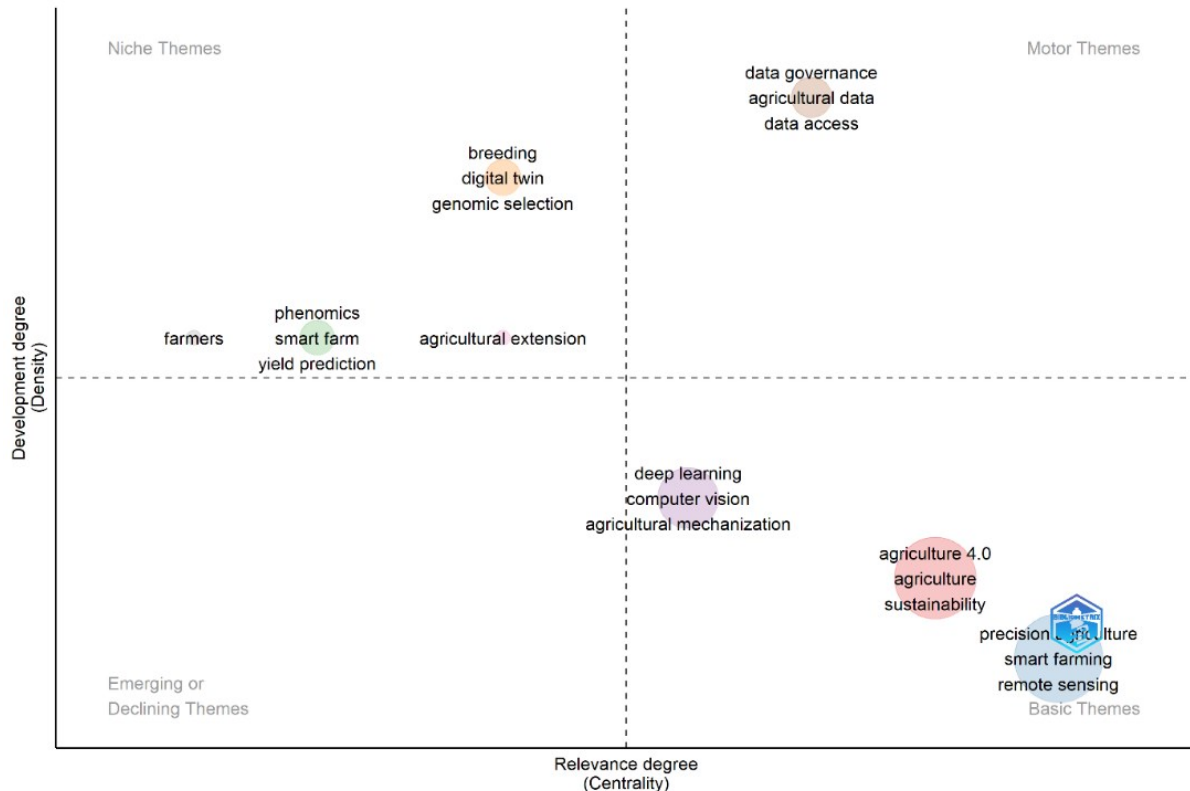


Figure 7. Thematic Map

In Figure 7, "data governance," "agricultural data," and "data access" are located in the motor themes quadrant. These themes have both high centrality and high development, indicating that they are critical and well-developed within the research field. In the niche themes quadrant, topics such as "breeding," "digital twin," and "genomic selection" are found. These topics have high development but low centrality, meaning they are specific and intensively researched but attract a narrower audience. The basic themes quadrant includes "precision agriculture," "smart farming," and "remote sensing." These topics have high centrality but low development, indicating that they are of broad interest but still hold significant potential for further advancement. Topics like "Agriculture 4.0" and "Agricultural Sustainability" are also located in the basic themes quadrant, suggesting that while these topics attract substantial interest, they require further development. In addition, trending topics by year, highlighted through keyword analysis, are displayed in Figure 8.

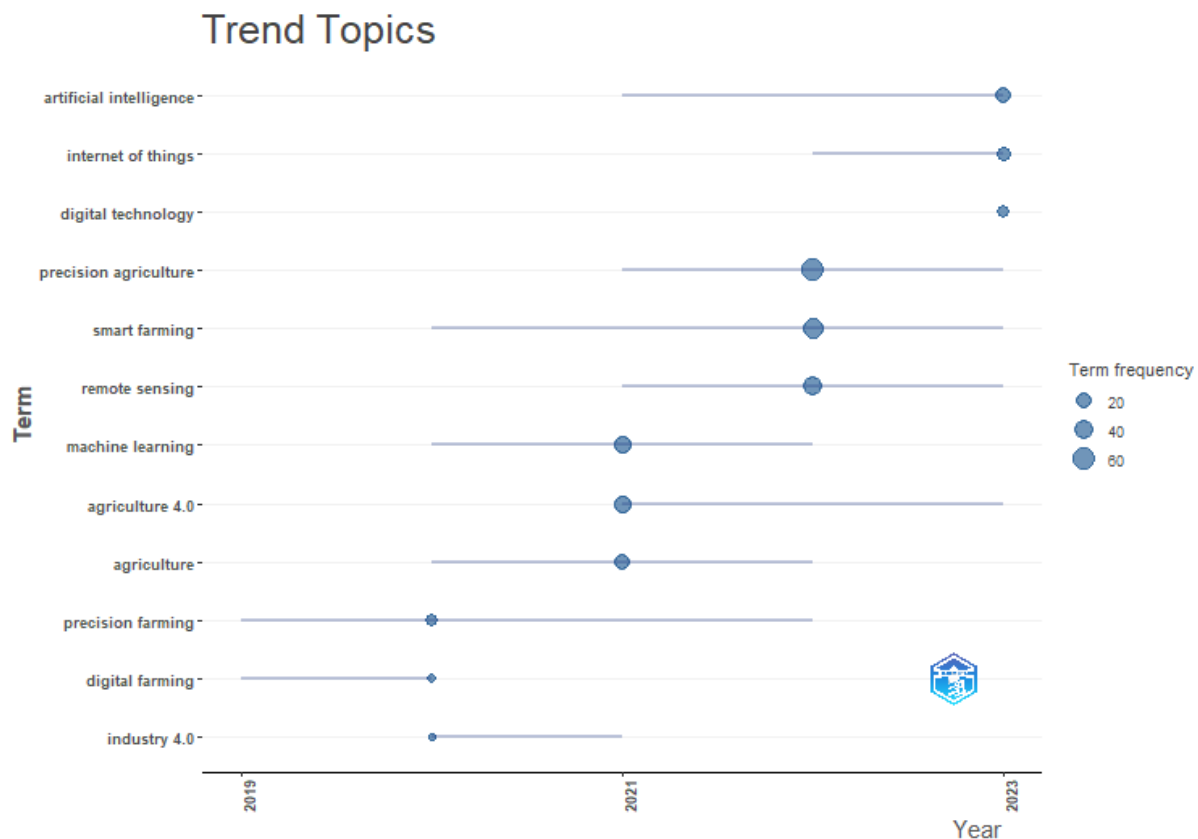


Figure 8. Trend Topic

In Figure 8, the evolution of trending topics in digital agriculture over the years and the frequency of these terms are shown. Term frequency indicates how often a specific term is used, and the graph allows us to compare the usage frequency of these terms over time. Artificial intelligence ranks at the top, showing steadily increasing interest, with the highest term frequency recorded in 2023. IoT began to gain popularity in agriculture from 2022 onwards. Precision agriculture saw a rise in popularity in 2021, which continued into 2022. Smart farming attracted increasing interest from 2020, with particularly high term frequency in 2021-2022. Remote sensing technologies have seen growing interest since 2021, peaking between 2021 and 2022.

Figure 8 illustrates how trending topics in digitalization in agriculture and smart farming have evolved over time, showing when specific terms became popular. Topics like artificial intelligence, IoT, digital technology, and precision agriculture stand out as key elements in the digital transformation of agriculture. These trends highlight the significance of digitalization and technological innovation in the agricultural sector, suggesting that more research and applications will likely focus on these areas in the future. The digitalization of agriculture has tremendous potential for enhancing productivity and ensuring sustainability, and these trends contribute to realizing this potential.

4. Discussion and Conclusion

This study aims to conduct a bibliometric analysis of academic publications on digital agriculture from 2019 to 2023, identifying research trends, main themes, and strategic topics within this field. The findings indicate a significant increase in research activities related to digital agriculture, driven by the rapid development and widespread adoption of digital agricultural technologies. However, a comprehensive bibliometric analysis is crucial for identifying current research trends and future research directions.

Among the most prominent themes are "data governance," "agricultural data," and "data access." Digital agriculture applications require the collection, processing, and analysis of large amounts of data. Data governance enables this process to be carried out effectively and efficiently. Specifically, the theme of "data governance" covers critical aspects such as data security, integrity, and accessibility (Tjhin & Riantini, 2022). The "agricultural data" theme involves collecting, analyzing,

and utilizing farm data in farm management decisions. Agricultural data have the potential to increase productivity, reduce costs, and support sustainable farming practices (Rachmawati, 2021). The "data access" theme covers policies and practices regarding access to and sharing of agricultural data, promoting information exchange and collaboration among researchers, farmers, and agricultural stakeholders to foster innovations in the sector (Soheyb, Abdelmoutia, & Labib, 2021).

Analyses reveal a significant rise in research on digital agriculture. Artificial intelligence and machine learning have great potential in areas such as productivity enhancement, disease detection, crop management, and resource optimization. These technologies will contribute to developing decision support systems by providing more complex methods for analyzing agricultural data (Singh et al., 2022). IoT enables real-time data collection and analysis through the use of sensors and devices in agriculture, which is especially useful in precision farming applications (Soheyb et al., 2021). The collection, storage, and processing of large agricultural data volumes will be supported by big data analytics and cloud computing technologies, facilitating the analysis of agricultural data and deriving meaningful insights (Rachmawati, 2021). In the future, there will be a greater focus on sustainability and environmental impact in agriculture. Digital agriculture applications will support sustainable farming practices, such as reducing environmental footprints and conserving water and energy (Singh et al., 2022).

Despite the benefits of digital agriculture, there are challenges and limitations in implementing these technologies. In regions with inadequate technological infrastructure, it may be challenging to effectively adopt digital agriculture practices. Additionally, the adaptation process for farmers to these new technologies remains a significant issue. In this context, it is essential to develop training and support programs to facilitate the adoption and effective use of digital agriculture technologies (Bertoglio et al., 2021).

The theoretical contributions of this study reveal the thematic structure of research in digital agriculture and the evolution of these themes over time, enriching the knowledge base in this field. Practically, it emphasizes the potential of digital agriculture technologies to enhance productivity and sustainability in agricultural production. To implement these technologies effectively, appropriate policies and strategies should be developed. In particular, improving technological infrastructure, organizing training programs for farmers, and promoting digital agriculture practices are essential.

Future research should examine the impacts of digital agriculture technologies on different agricultural production systems in more detail. Additionally, the socio-economic impacts of these technologies should be investigated. To encourage the adoption of digital agriculture technologies, training and support programs for farmers should be developed. Furthermore, suitable policies and strategies should be designed to improve technological infrastructure and promote the widespread use of digital agriculture applications.

This study presents a comprehensive bibliometric analysis of research in the digital agriculture field, identifying the existing knowledge base, research gaps, and providing valuable insights for future studies.

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