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Bibliometric Analysis of the Role of Artificial Intelligence in Enhancing Agricultural Extension Services

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HIGHLIGHT

- Research output increased rapidly after 2016, peaking in 2022 with significant global scholarly attention.
- Recent keyword trends reveal growing emphasis on IoT, deep learning, and agricultural robotics in digital extension models.
- The literature demonstrates strong global collaboration, averaging 11.5 co-authors per publication with significant international partnerships.
- International co-authorship rate of 22.85% highlights strong global collaboration in AI-driven agricultural research.

ARTICLE INFO

Keywords: Artificial intelligence, Extension service, Sustainable agriculture, Internet of things, Machine learning.

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ABSTRACT

Agricultural extension services are still crucial to rural development and global food security; traditional methods frequently have issues with scalability, cost and farmer-specific customisation. Artificial intelligence (AI) offers a new solution to overcome these issues by offering predictive, data-driven and context-specific advisory systems. 337 papers on AI in agricultural extension that were indexed in Scopus between 2010 and 2025 were examined in this study using bibliometric analysis. Biblioshiny and VOS viewer were used in the analysis to map authorship patterns, country-level contributions, publishing trends and theme clusters. It is evident that the research activity grew after 2016 and reached a peak in 2022 at an annual growth rate of 2.33%. The area is extremely collaborative and interdisciplinary, with the United States, China and India providing the most work globally, with an average of 11.5 co-authors per manuscript. Keyword and thematic analysis show that more advanced applications like machine learning, deep learning, IoT, and agricultural robotics have replaced earlier efforts on digital infrastructure. The results indicate that hybrid systems, in which AI supplements human knowledge to provide inclusive, moral, and sustainable advisory services, will be the most successful extension models in the future.

INTRODUCTION

The diffusion of innovations theory, which describes how new practices and technologies spread among communities, has historically served as the foundation for agricultural extension. The Diffusion of Innovations Theory remains relevant in the AI era, as the adoption of AI-based advisory systems continues to depend on communication channels, farmer characteristics, and institutional support. Thus, AI-driven extension represents an evolution of diffusion processes rather than a departure from them (Chen & Li, 2022). Almost half of the world's workforce is employed in agriculture, which continues to be the main source of income for billions of people and the foundation of rural economies worldwide. In addition to being essential for food security, ensuring sustainable agricultural productivity and resilience is also critical for rural development and poverty alleviation (Sahoo et al., 2025). In order

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to ensure that scientific discoveries, technological advancements and best practices actually reach the farmers who need them most, extension serves as a liaison between research institutions and farming communities. For many years, in order to fulfil their mandate, extension services relied on printed materials, farmer field schools, farm visits, demonstration plots and interpersonal communication (Bernet et al., 2001; Nain et al., 2015; Inutan et al., 2025).

Through the use of radio, television, mobile phones and eventually internet-based platforms, information and communication technologies (ICTs) have made it possible to distribute knowledge across geographic borders (Hassan & Mirza, 2020). However, AI, which has started to change the entire essence of extension services has emerged as the true disruptive force (Pavaloaia & Necula, 2023; Haleem et al., 2022). The traditional extension methods which frequently give general suggestions AI systems are able to evaluate massive datasets such as weather forecasts, soil quality, insect occurrence and market trends and provide context-specific guidance that is customised for specific farmers or communities (Jayasingh et al., 2024). Farmers' basic photos can be used by mobile applications using AI-driven image recognition to diagnosis crop problems. Chatbots can communicate with farmers in their native tongues via natural language processing technology, which breaks down literacy hurdles and provides 24/7 consulting services (Asthana & Bhujade, 2025). The digital divide is still evident since many farmers lack mobile phones with dependable internet access or the literacy to utilise AI-enabled platforms (Atapattu et al., 2024). Extension organisations may strategically deploy resources, prioritise treatments, and identify areas at high risk of crop failure with the use of predictive models (Rane et al., 2024). AI systems can discover new concerns and knowledge gaps by analysing farmer questions and behavioural patterns. These qualities are a significant departure from typical extension's reactive, one-size-fits-all approach (Meshram et al., 2025).

Ethical considerations around data security, ownership and trust are especially important when farmers are forced to reveal sensitive information. Additional reasons to be concerned include algorithmic biases, which occur when models trained on global or non-representative datasets fail to reflect local reality (Bahangulu & Owusu-Berko, 2025). The most effective hybrid systems in the future will likely be those that employ AI to complement human extension workers rather than to replace them (Huang et al., 2025; Schubert & Barrett, 2024).

METHODOLOGY

This study employed a bibliometric research approach to systematically evaluate and map the scholarly literature concerning the application of Artificial Intelligence (AI) in improving agricultural extension services. A quantitative technique called bibliometrics enables academics to assess cooperation patterns, publishing trends, citation effect and the intellectual framework of an area of study. Bibliometric analysis offers a suitable way to identify important players, emerging topics and knowledge gaps that guide future research and policy orientations. This study evaluates the application of AI in agricultural extension services from 2010 to 2025 using bibliometric analysis. The primary data source was Scopus, a well-known database of reputable scientific publications, because of its extensive indexing of peer-reviewed journal articles and conference sessions. Using the terms "Artificial Intelligence," "Extension" and "Services," a thorough search produced an initial dataset of 629 articles. Following the application of inclusion criteria, which included eliminating duplicates, keeping only English-language journal articles, conference papers and book chapters and eliminating irrelevant items, the dataset was reduced to 337 articles, which were then exported in CSV format for analysis. Bibliometric analysis was performed using the Biblioshiny package in RStudio with Vosviewer, which made it possible to evaluate publishing trends, frequently used terms and research contributions by country (Linnenluecke et al., 2020). Key researches included tree map visualisation for hierarchical keyword representation, trend analysis to see annual publication patterns and co-occurrence network analysis to find study subjects. Scopus results were used to evaluate the regional distribution of research output. Visualisations and statistical findings demonstrated the evolution and key areas of research in AI-driven sustainable agriculture. Strict parameters were adhered to ensuring the validity and reproducibility of the findings. The analysis was interpreted through the lens of the Diffusion of Innovations Theory, linking publication trends, collaboration patterns and thematic evolution with stages of innovation diffusion.

RESULTS

Table 1 shows that the bibliometric dataset on artificial intelligence in agricultural extension services, which spans the years 2010 to 2025, provides a comprehensive picture of the state of the subject. Over the course of these 15 years, 337 documents from 152 sources have been published, demonstrating a steady but low annual growth rate of 2.33%. The literature is very new and has garnered significant scholarly attention with an average document age of 6.22 years, 10.99 citations per document and a total of 3053 references cited. 3337 Keywords Plus (ID) and 3953 Author's Keywords (DE) highlight the field's broad subject scope, which ranges from technical AI techniques to agricultural and extension applications. Authorship patterns reveal a highly collaborative research culture with 2419 authors contributing to the dataset and no single-authored documents identified. The fact that each paper usually has 11.5 co-authors and that over a quarter (22.85%) of publications are the product of transnational cooperation demonstrates the global and networked nature of this field of study. While journal articles (110, 32.6%) provide more coherent contributions, conference papers (193, 57.3%) make up the bulk of document categories, demonstrating the quickly evolving nature of AI-related extension research. Smaller but noteworthy percentages that offer contextual perspectives and syntheses include book chapters (16, 4.7%) and review papers (18, 5.3%). These patterns indicate that AI in agricultural extension is still an emerging but rapidly consolidating field, where high collaboration reflects the interdisciplinary nature of the domain and the need for integrating technological, agricultural and socio-economic expertise for effective advisory systems.

Table 1. Bibliometric Data Set

Description	Results
Main information about data	
Timespan	2010:2025
Sources (Journals, Books, etc)	152
Documents	337
Annual Growth Rate %	2.33
Document Average Age	6.22
Average citations per doc	10.99
References	3053
Document contents	
Keywords Plus (ID)	3337
Author's Keywords (DE)	3953
Authors	
Authors	2419
Authors of single-authored docs	0
Authors collaboration	
Single-authored docs	0
Co-Authors per Doc	11.5
International co-authorships %	22.85
Document types	
Article	110
Book chapter	16
Conference paper	193
Review	18

Word cloud of keyword

The field's prevailing topics and intellectual framework may be seen in the keyword treemap of publications on artificial intelligence in agricultural extension services. Fundamentally "artificial intelligence" is by far the most common term, occurring 239 times (27%), highlighting its significance as the unifying idea across investigations. This is surrounded by strong theme clusters such as "decision support systems" (42; 5%), "decision making" (35; 4%) and "learning systems" (34; 4%) that emphasise the application of AI to enhance extension results and farmer-level advising procedures. The technological basis of research is highlighted by terms like "internet of things" (30; 3%), "web services" (24; 3%), "big data" (14; 2%) and "cloud computing" (12; 1%), which denote the integration of linked devices, data analytics and cloud infrastructure into AI-driven extension models. The most popular computational tools are suggested by keywords that indicate particular methodological approaches such as "machine learning" (16; 2%), "deep learning" (11; 1%) and "data mining" (9; 1%). Application-oriented terms like "agriculture" (8; 1%), "ecosystems" (9; 1%) and "virtual reality" (12; 1%) emphasise the contextual emphasis on agricultural systems, sustainability, and immersive extension platforms. Cross-domain terms such as "sales" (9; 1%), "health care" (10; 1%) and "e-learning" (10; 1%) show interdisciplinary borrowing and the application of AI concepts to agricultural settings. Even though AI itself acts as the discourse's anchor, the figure illustrates how research momentum is distributed across clusters of decision-making support, IoT integration, big data analytics and immersive technologies, indicating a shift from theoretical exploration to practical technologically enabled extension solutions. This progression reflects the diffusion of increasingly complex innovations, consistent with the Diffusion of Innovations Theory. This suggests a shift from conceptual research toward practical decision-oriented AI applications in extension systems.

Keywords analysis

The keyword trend analysis graphic clearly illustrates the evolution of artificial intelligence research emphasis in agricultural extension services between 2010 and 2025. In the early years (2010–2014), terms like "database systems," "uncertainty analysis," "communication" and "service-oriented architecture (SOA)" were frequently used to indicate basic work on creating reliable information systems and computational frameworks to support digital agriculture. During the mid-phase (2015–2018), as the focus shifted to apply digital solutions, terms like "cloud computing," "web services," "decision support systems," "learning systems" and "semantics" were commonly utilised. This implies that AI research has focused on decision-making models and service-oriented guidance platforms for agricultural settings. During the consolidation

Figure 1. Tree map of keywords

era (2018–2020), high-frequency terms including “artificial intelligence,” “decision making,” “machine learning” and “big data” were frequently utilised. This points to a tendency towards intelligent advising systems, data-driven extensions, and predictive analytics. Complex and specialised applications like “deep learning,” “artificial neural networks,” “internet of things (IoT),” “virtual reality” and “agricultural robots,” which demonstrate how cutting-edge AI technologies are integrated into precision farming and immersive extension techniques, were developed during the most recent period (2020–2024). While terminology like “5G mobile communication systems” have evolved to show how next-generation connection enables real-time advising services, terms like “artificial intelligence” and “decision support systems” have persisted for some years, emphasising their critical role in creating the sector. The temporal evolution of keywords indicates a transition from early-stage digital innovations to advanced AI applications aligning with stages of innovation diffusion. This trend reflects the progression from early experimentation to advanced, field-level AI adoption in agricultural advisory services.

Co-occurrence keywords analysis

The co-occurrence keyword network map depicts the interconnected thematic structure of research on artificial intelligence in agricultural extension services, with “artificial intelligence” at the centre and closely linked to “machine learning,” “decision making,” “decision support systems,” “learning systems,” and “data mining,” all of which form the backbone of AI-driven extension research. Using terms like “decision support systems,” “knowledge-based systems,” “agricultural robots,” “technology adoption,” and “sustainable development,” the green cluster highlights decision-making and support systems and shows how AI is used to automate services, optimise advisory processes, and connect extension with robotics and sustainability objectives. The blue cluster which includes “information systems,” “computer science,” “databases,” “simulation,” “uncertainty analysis,” “risk assessment” and “forecasting,” highlights the significance of accurate data and predictive modelling while illuminating the computational and infrastructure underpinnings of the field. While the red cluster highlights the digital transformation of agriculture, terms like “digital technologies,” “Industry 4.0,” “supply chains,” “extension services,” “5G mobile communication systems” and “optimisation” show how AI is integrated into modern agricultural and communication frameworks. Human-centered and transdisciplinary applications are included in the purple cluster, which connects “deep learning,” “virtual reality,” “healthcare,” “social networking” and “COVID-19.” These uses highlight the expansion of immersive technology and cross-sectoral effects. The orange cluster emphasises efforts to make AI-driven systems more user-friendly and flexible for extension delivery by concentrating on accessibility and interoperability through “web services,” “semantic web,” “ontology,” “user interfaces,” and “benchmarking.” The figure as a whole shows that although the term “artificial intelligence” serves as the discourse’s focal point, the field splits into five interrelated streams: computational infrastructure, decision-support applications, agricultural digital transformation, cross-disciplinary innovations, and semantic-web-based user systems. These streams reflect a developing, multidisciplinary, and farmer-centred research landscape. The clustering of technologies and systems suggests interconnected innovation networks that facilitate faster diffusion across agricultural systems. The presence of multiple interconnected clusters indicates that AI-driven extension is not a standalone innovation but part of a broader digital ecosystem, where technological, institutional and socio-economic components interact to shape advisory effectiveness.

Thematic map

The thematic map of research on Artificial Intelligence in agricultural extension services provides a structured overview of

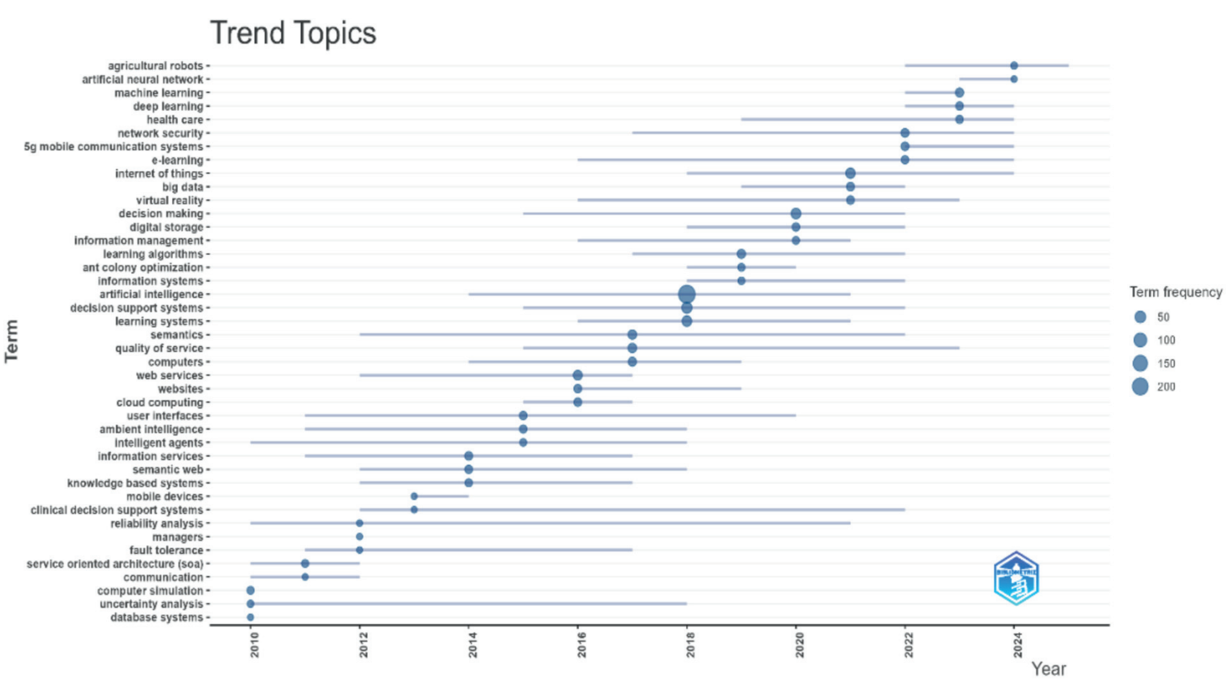
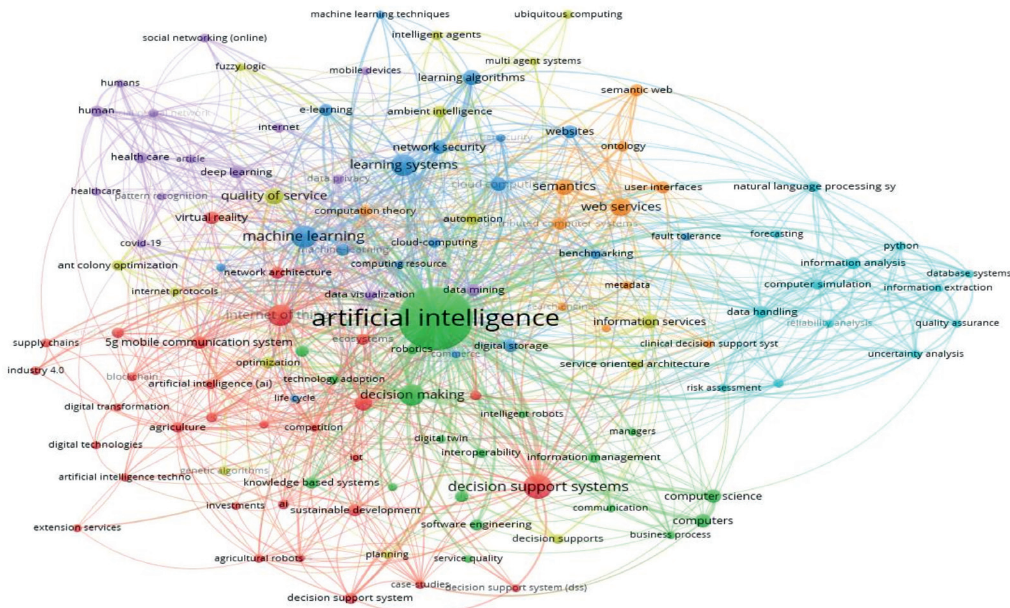


Figure 2. Trend analysis of keywords

Figure 3. Co-occurrence Network diagram of keywords



how different concepts are positioned in terms of centrality (relevance to the field) and density (degree of development). "Artificial intelligence," "learning systems" and "decision making" stand out as the most fundamental and key ideas in the Basic Themes quadrant (bottom right), acting as the fundamental building blocks that link the whole field of study. The tools and frameworks that support advisory models, farmer decision assistance, and adaptive learning systems are the fundamental core of artificial intelligence in extension. Topics like "ecosystems," "decision support systems," and "sustainable development" seem to be highly developed and important in the Motor Themes quadrant (upper right). Their positioning suggests that they are leading forces in the field, demonstrating how AI is increasingly being used for environmental management, systemic decision-support frameworks that support the UN's sustainability agenda, and more general agricultural sustainability goals in addition to individual advisory tasks. Specialised but less important subjects like "data handling," "information analysis," and "computer simulation" are grouped together in the Niche Themes quadrant (upper left). These are sophisticated, highly developed research fields that provide methodological complexity (e.g., high-resolution data processing and modelling), but their incorporation into mainstream agricultural extension studies is still marginal. "Bayesian networks," "budget control," and "test environment" are included in the Emerging or Declining Themes quadrant (bottom left). Their placement indicates that they are either less well-known than more recent AI-driven techniques or understudied research areas with room to expand (like Bayesian networks in probabilistic modelling). Transitional topics including "deep learning," "healthcare," and "human" are positioned in the middle of the map. Overall, the image shows a clear hierarchy: fundamental AI and decision-making tools serve as the basis, decision-support and sustainability topics propel the field ahead,

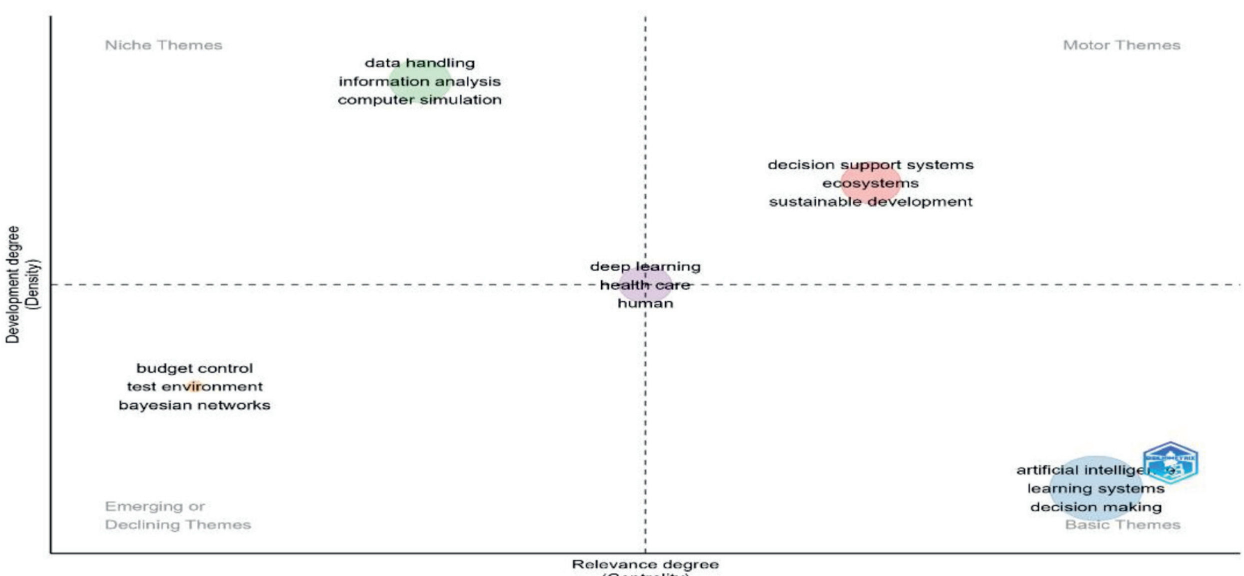


Figure 4. Thematic map

specialised fields enhance the technique and emergent themes suggest future opportunities. This development demonstrates how the discipline is moving from fundamental AI principles to useful, farmer-centered and sustainable applications. The dominance of motor themes such as decision support systems and sustainability indicates that the field is moving toward impact-oriented research, where AI applications are increasingly aligned with global agricultural challenges and policy priorities.

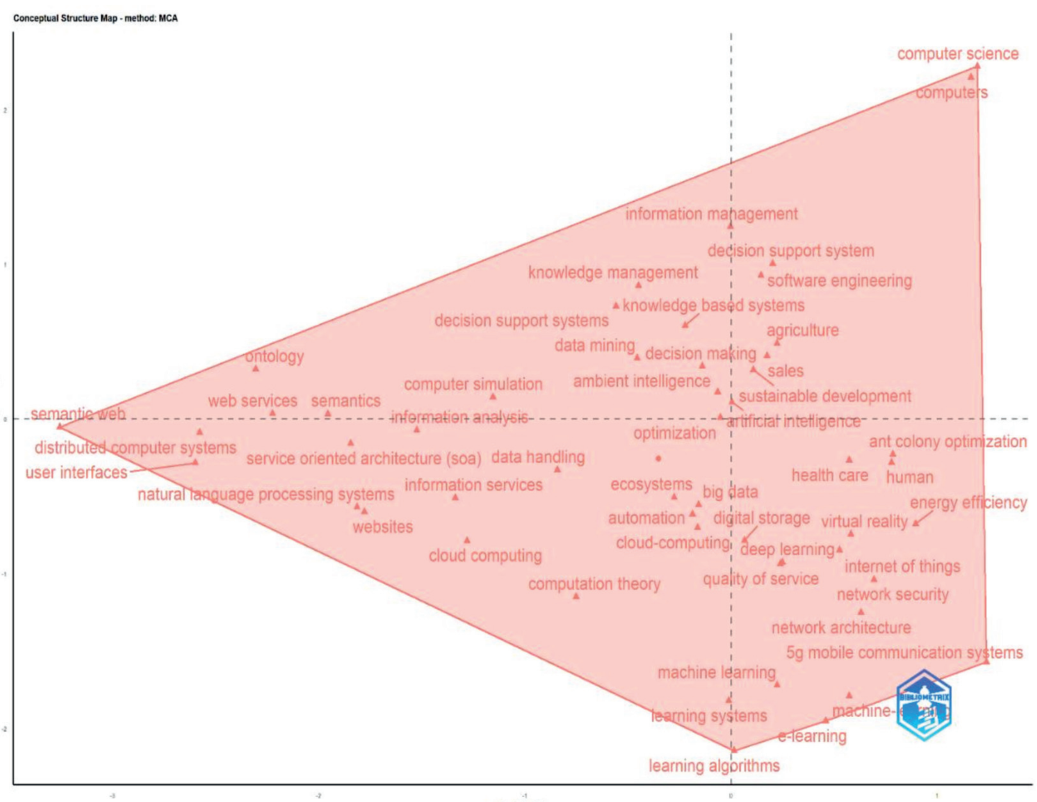
Conceptual structure

The conceptual structure map derived from Multiple Correspondence Analysis (MCA) which explained the thematic organization of the literature on the role of artificial intelligence in enhancing agricultural extension services. The map positioned keywords across two dimensions (Dim 1 and Dim 2) according to their co-occurrence patterns, thereby indicating the conceptual relationships among major research themes. Keywords located closer together represented stronger conceptual associations, whereas those positioned farther apart indicated relatively independent or emerging research directions within the field. The right quadrant of the map was dominated by advanced technological themes such as artificial intelligence, machine learning, deep learning, Internet of Things (IoT), big data and 5G mobile communication systems. The close clustering of these terms suggested that recent studies had largely focused on the integration of intelligent digital technologies into agricultural systems. These technologies were strongly associated with application-oriented concepts such as decision support systems, knowledge-based systems, optimization and sustainable development, indicating that AI-driven analytical tools had been widely explored to improve predictive capabilities, farm-level decision-making, and real-time advisory services delivered through agricultural extension. The central portion of the map included keywords such as knowledge management, data mining, ambient intelligence and decision-making, which functioned as linking domains between technological innovations and extension service outcomes. These themes highlighted the growing importance of managing agricultural knowledge and extracting meaningful insights from large datasets to support evidence-based extension strategies. In contrast, the left side of the map represented foundational information technologies, including the semantic web, distributed computer systems, service-oriented architecture and cloud computing. Overall, the conceptual structure suggested a progressive transition from basic digital infrastructure toward advanced AI-enabled systems designed to enhance the efficiency, accuracy and sustainability of agricultural extension services. This conceptual alignment demonstrates that the field is transitioning from foundational information systems toward advanced AI-enabled knowledge frameworks, emphasizing predictive analytics and data-driven decision-making in extension services.

DISCUSSION

Research on artificial intelligence (AI) in agricultural extension services is a relatively new but quickly developing topic as shown by the bibliometric study of 337 articles from 2010 to 2025. Although average growth has been low (2.33% per year), the sharp increase in production after 2016 suggests a period of significant development, with peaks in 2022 and 2024. Four main topic clusters are identified by the co-occurrence network analysis: institutional and policy frameworks, agricultural systems and innovations, human and environmental factors and adaptive solutions (Roy et

Figure 5. Conceptual Structure Map



al., 2024). According to the bibliometric results, research on AI in agricultural extension has grown consistently since 2010 peaking in 2022 and accelerating significantly after 2016. This path is similar to the global expansion of digital agriculture, where robots, IoT, and machine learning became commonplace topics (Bronson & Knezevic, 2016; Wolfert et al., 2017). Similar multidisciplinary dynamics have been documented in research on ICT4D and precision agriculture where technical complexity necessitates cooperation between domain scientists, policy players and technical specialists (Lioutas & Charatsar, 2019). Large-scale investments in AI infrastructure benefit the US and China, while India's agrarian economy with millions of smallholders makes it an ideal testbed for AI-enabled extension. Despite their smaller amount European donations demonstrate a strong commitment to sustainability and precision farming which is consistent with EU policy aims (Klerkx & Rose, 2024; Barman et al., 2026). A North-South split is shown by the data with many low-income, agriculturally reliant regions particularly in Southeast Asia and Sub-Saharan Africa remaining under-represented while having the greatest need for inclusive extension ideas. Analyses of keyword trends and co-occurrences show a distinct thematic evolution. Infrastructure (database systems, SOA) was the emphasis of early research (2010–2014), which progressively moved to applied digital solutions (learning systems, decision support systems) in the mid-2010s and culminated in frontier applications (virtual reality, deep learning and agricultural robotics) beyond 2020. However, issues like Bayesian networks, budget control, and test environments remain specialist or declining. These trends imply that the two axes of technological sophistication (AI models, IoT integration) and systemic importance (sustainability, ecosystems, farmer decision-making) are stabilising the intellectual structure of AI in extension. Important gaps in our understanding of farmer behaviour, inclusion, and institutional governance are also shown by the bibliometric evidence. Technological tools may not be widely adopted if these socio-institutional factors are not addressed, which is reminiscent of previous experiences when ICTs failed to overcome obstacles related to trust, digital inequality, and local relevance (Aker, 2011). The report draws attention to enduring issues with algorithmic bias, data privacy and digital inequality. AI solutions run the danger of excluding smallholders without cell phones, reliable internet, or digital literacy, even as they offer personalisation at scale. In order to contextualise guidance, foster trust and ensure that technology serves inclusive and location-specific needs, the role of human extension agents remains central, as consistently emphasized in agricultural extension literature. The bibliometric findings further support this perspective, as the co-occurrence network and thematic analysis reveal a strong integration between technological components (machine learning, decision support systems) and extension-related elements such as communication systems, knowledge management and user interfaces. This indicates that AI-driven tools are being developed within existing extension frameworks rather than as independent systems. Therefore, the concept of hybrid extension models is not merely a theoretical assumption but is supported by the observed convergence of technological and human-centred themes, suggesting that effective extension in the AI era will depend on the complementary interaction between digital tools and field-level advisory services (Omotayo et al., 2025).

CONCLUSION

The consistent increase in academic production, especially after 2016 is indicative of a growing understanding of AI's capacity to move extension away from traditional, generalised methods and towards more flexible, data-driven and farmer-specific advising systems. Drawing from computer science, engineering, decision sciences, and the social sciences, the research demonstrates that AI in extension is intrinsically multidisciplinary. The United States, China and India have made significant contributions to the highly collaborative research, but the under-representation of Africa and Latin America reveals a critical imbalance in areas where extension services are most important for rural development and food security. The field's thematic evolution shows a clear trajectory: sophisticated applications like machine learning, deep learning, the Internet of Things (IoT) and immersive technologies have supplanted the early emphasis on digital infrastructure. This suggests that future extension models will rely on the complementary interaction between AI-driven tools and human extension services to ensure effective, inclusive and context-specific advisory delivery.

DECLARATIONS

Ethics approval and informed consent: As the research was carried out with bibliometric analysis, the Scopus database was used for the study, with inclusion and exclusion criteria.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The author declares that they have thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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REFERENCES

Aker, J. C. (2011). Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics, 42*(6), 631–647. https://doi.org/10.1111/j.1574-0862.2011.00545.x

Asthana, S., & Bhujade, R. K. (2025). AI-Driven predictive modeling for crop disease detection. *International Journal of Environmental Sciences*, *11*(1), 54-64.

Atapattu, A. J., Perera, L. K., Nuwarapaksha, T. D., Udumann, S. S., & Dissanayaka, N. S. (2024). Challenges in achieving artificial intelligence in agriculture. In *Artificial intelligence techniques in smart agriculture* (pp. 7-34). Singapore: Springer Nature Singapore.

Bahangulu, N. J. K., & Owusu-Berko, N. L. (2025). Algorithmic bias, data ethics, and governance: Ensuring fairness, transparency and compliance in AI-powered business analytics applications. *World*

Journal of Advanced Research and Reviews, 25(2), 1746–1763. https://doi.org/10.30574/wjarr.2025.25.2.0571

Barman Bikram, Singh Rashmi, Padaria, R. N., Nain, M. S., Quader, S. W., & Praveen, K. V. (2026). A qualitative synthesis of barriers to agriculture 4.0 adoption: evidence from a systematic literature review. *Discover Agriculture, 4*, 34 https://doi.org/10.1007/s44279-026-00505-7

Bernet, T., Ortiz, O., Estrada, R. D., Quiroz, R., & Swinton, S. M. (2001). Tailoring agricultural extension to different production contexts: a user-friendly farm-household model to improve decision-making for participatory research. *Agricultural Systems*, *69*(3), 183-198. 10.1016/S0308-521X(01)00024-5

Bronson, K., & Knezevic, I. (2016). Big Data in food and agriculture. *Big Data & Society, 3*(1). https://doi.org/10.1177/2053951716648174

Chen, X., & Li, T. (2022). Diffusion of agricultural technology innovation: Research progress of innovation diffusion in Chinese agricultural science and technology parks. *Sustainability*, *14*(22), 15008. https://doi.org/10.3390/su142215008

Haleem, A., Javaid, M., Qadri, M. A., Singh, R. P., & Suman, R. (2022). Artificial intelligence (AI) applications for marketing: A literature-based study. *International Journal of Intelligent Networks*, *3*, 119-132. https://doi.org/10.1016/j.ijin.2022.08.005

Hassan, M. M., & Mirza, T. (2020). Information and communication technology (ICT) in the distance education system: An overview. *IOSR Journal of Research & Method in Education (IOSR-JRME)*, *10*(6), 38-42.

Huang, L., Duan, Q., Liu, Y., Wu, Y., Li, Z., Guo, Z., Liu, M., Lu, X., Wang, P., Liu, F., Ren, F., Li, C., Wang, J., Huang, Y., Yan, B., Kioumourtzoglou, M., & Kinney, P. L. (2025). Artificial intelligence: A key fulcrum for addressing complex environmental health issues. *Environment International*, 109389. https://doi.org/10.1016/j.envint.2025.109389

Inutan, S. M. B., Dujali, I. L., Bacus, M. S., Quijano-Pagutayao, A. S., & Sarita, V. B. (2025). The role of Agricultural Extension in farmers' Technology adoption for sustainable agricultural practices in Davao Oriental, Philippines. *International Journal of Research and Innovation in Applied Science, X*(IV), 342–354. https://doi.org/10.51584/ijrias.2025.10040028

Jayasingh, D. K., Anand, A., & Das, K. S. (2024). Artificial intelligence in agricultural extension. *In* Jyotishree A. & Malik B. (Eds) Innovative Agriculture: Strategies and Concepts, *115*. Akinik Publications New Delhi

Klerkx, L., & Rose, D. (2019). Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? *Global Food Security, 24*, 100347. https://doi.org/10.1016/j.gfs.2019.100347

Linnenluecke, M. K., Marrone, M., & Singh, A. K. (2020). Conducting systematic literature reviews and bibliometric analyses. *Australian Journal of Management 45*(2), 175-194.

Lioutas, E. D., & Charatsari, C. (2019). Big data in agriculture: Does the new oil lead to sustainability? *Geoforum, 109*, 1–3. https://doi.org/10.1016/j.geoforum.2019.12.019

Meshram, K., Mishra, U., & Rathnayake, U. (2025). Application of artificial intelligence in agri-tech, environmental and biodiversity conservation. *Array*, 100412.

Nain, M. S., Singh, R., Mishra, J. R., & Sharma, J. P. (2015). Utilization and linkage with agricultural information sources: a study of Palwal district of Haryana state. *Journal of Community Mobilization and Sustainable Development, 10*(2), 152-156.

Omotayo, A. O., Adediran, S. A., Omotoso, A. B., Olagunju, K. O., & Omotayo, O. P. (2025). Artificial intelligence in agriculture: ethics, impact possibilities, and pathways for policy. *Computers and Electronics in Agriculture, 239*, 110927. https://doi.org/10.1016/j.compag.2025.110927

Pavaloaia, V. D., & Necula, S. C. (2023). Artificial intelligence as a disruptive technology—a systematic literature review. *Electronics*, *12*(5), 1102. https://doi.org/10.3390/electronics12051102

Rane, J., Kaya, O., Mallick, S. K., & Rane, N. L. (2024). Smart farming using artificial intelligence, machine learning, deep learning, and ChatGPT: Applications, opportunities, challenges, and future directions. *Generative Artificial Intelligence in Agriculture, Education, and Business*, 218-272. https://doi.org/10.70593/978-81-981271-7-4_6

Roy, P., Maji S., Jirli B., Singh P., & Nain, M. S. (2024). Scopus-Indexed Indian Journal of Extension Education: Crafting improvement strategy through altmetric and bibliometric analysis. *Indian Journal of Extension Education, 60*(2), 1-10. https://doi.org/10.48165/IJEE.2024.60201

Sahoo, S., Singha, C., Govind, A., & Moghimi, A. (2025). Review of climate-resilient agriculture for ensuring food security: Sustainability opportunities and challenges of India. *Environmental and Sustainability Indicators*, *25*, 100544. https://doi.org/10.1016/j.indic.2024.100544

Schubert, K. D., & Barrett, D. (2024). Data governance, privacy, and Ethics. In Technology, Work and globalization (pp. 87–110). https://doi.org/10.1007/978-3-031-51063-2_5

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. (2017). Big data in smart farming – A review. *Agricultural Systems*, 153, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023