GMR
The Original

INFLUENCE OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) ON FARMERS' PARTICIPATION AND AGRICULTURAL PERFORMANCE: A SYSTEMATIC LITERATURE REVIEW

Siddharth B L [1], M. Asokhan[2*], S. R. Padma [3], S. Kokilavani [4], R. Gangai Selvi[5]

[1] Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[2] Principal, Institute of Agriculture, Kumulur, Tiruchirappalli - 621712, India
[3] Assistant Professor, (Agricultural Extension) ICAR KVK, Pongalur,Tiruppur - 641667, India
[4] Assistant Professor, (Agricultural Meteorology) Department of Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore-641003, India
[5] Professor, (Statistics) Department of Physical sciences & IT, Tamil Nadu Agricultural University, Coimbatore- 641003, India
*Corresponding Author Email - *masokhan@tnau.ac.in*

ABSTRACT
Agriculture has been revolutionized by the fast development of Information and Communication Technology (ICT), which has led to increased accessibility to information, more participation of farmers, and improved performance of farms. The goal of this systematic literature review is to investigate the impact of ICTs on farmer participation and agricultural performance. An SLR was done using the PRISMA protocol to guide the selection process of appropriate research papers. Scopus served as the primary database, from which 225 relevant papers between the years 2015 and 2026 were collected. Out of these, 185 papers were included in the final analysis after employing the set inclusion and exclusion criteria. Results show that ICT plays an integral part in promoting farmer participation through extension services, communication, and knowledge sharing through the use of ICTs. Participating farmers are able to adopt modern agricultural practices easily, which enhances their productivity and overall farm management. The study highlights the fact that the influence of ICT on the performance of agriculture is very much related to the degree of involvement of farmers as well as the presence of enabling factors. The study concludes that in order to take full advantage of ICT in agriculture, a comprehensive approach that is inclusive and facilitated by proper policy support is needed.

KEYWORDS: Agricultural Performance; Digital Agriculture; Farmer Participation; Farm Income; Information and Communication Technology (ICT); Technology Adoption.

1.INTRODUCTION

In developing countries, agriculture continues to play a crucial role in rural lifestyles and economic growth, especially in India, where a sizable section of the population depends on farming for both food security and revenue. Despite its significance, the industry still has structural inefficiencies, such as poor market integration, insufficient extension services, risks associated with climate change, and limited access to accurate and timely information. These limitations frequently lead to farmers making worse-than-ideal decisions, being less productive, and having unstable incomes. Overcoming these obstacles and converting conventional agricultural systems into more knowledge-driven and effective systems has been made possible in recent decades by the quick development of information and communication technology (ICT) [1, 2]. ICT in agriculture encompasses a broad spectrum of digital breakthroughs, including decision-support systems, internet-based platforms, mobile communication, and remote sensing technologies. These solutions improve farmers' access to vital information by facilitating the real-time broadcast of information about weather, pest control, input management, and market dynamics. Farmers may make more informed decisions about production and marketing when they have better access to information, which lowers uncertainty and transaction costs [3, 4]. The change to digital agriculture and smart farming techniques, which emphasize productivity, accuracy, and sustainability in agricultural production systems, has been expedited by the growing ubiquity of smartphones and digital infrastructure in rural regions [5, 6]. Enhancing farmer engagement in agriculture and market systems is one of ICT's most important contributions. Farmers may obtain advisory services, participate in knowledge-sharing networks, and communicate with extension agents more successfully thanks to digital platforms. Farmers' involvement and participation in decision-making processes have been shown to be significantly increased by ICT-based extension models, such as e-extension platforms and mobile advisory services [7, 8].

ICT also promotes social learning by facilitating contact amongst farmers, which strengthens collective action within farming communities and encourages the spread of innovations [9]. Increased involvement is especially crucial for increasing the uptake of contemporary farming methods and technology, which eventually improves farm-level results.

ICT significantly affects agricultural performance, including productivity, revenue generation, and technical efficiency, in addition to involvement. Farmers can maximize input utilization, lower production risks, and allocate resources more effectively when they have access to fast and accurate information. ICT interventions, especially mobile-based market information systems, have been shown to improve market efficiency, lessen information asymmetry, and increase price realization, all of which can raise farm incomes [10, 11]. Additionally, site-specific crop management is supported by cutting-edge digital tools like data analytics and precision agricultural technology, which boost yields while reducing environmental effects [12].

Nonetheless, there is still disparity in the adoption and use of ICT among farmers, especially among smallholder farmers in rural areas. The efficient use of ICT technologies is nevertheless hampered by obstacles such insufficient digital literacy, poor infrastructure, problems with affordability, and socioeconomic inequality [13, 14].

This digital divide highlights the need for focused actions to guarantee fair access to digital resources and raises questions about how inclusive the digital agricultural transformation will be. To fully utilize ICT to improve farmer engagement and agricultural performance, these issues must be resolved. The significance of ICT in agriculture has been the subject of an increasing amount of research, although these studies frequently take a disjointed approach, concentrating either on technology adoption or on performance results separately. A thorough synthesis that incorporates these aspects to offer a full knowledge of how ICT concurrently affects farmer engagement and agricultural production is lacking. In order to guide investment in digital agriculture, influence policy design, and advance sustainable agricultural growth, an integrated viewpoint is essential.

2.PROBLEM FOCUS

Information and communication technology (ICT) in agriculture has grown quickly, but little is known about how it affects farmers' involvement and agricultural productivity. The majority of current research looks at ICT adoption, farmer behavior, or agricultural results separately, failing to sufficiently incorporate these aspects into a cohesive analytical framework. Because of this, it is unclear how ICT concurrently affects agricultural performance (production, revenue, and efficiency) and farmer involvement (engagement, decision-making, and information sharing). Additionally, actual data from different locations shows conflicting results; some studies show substantial increases in income and productivity, while others show negligible or context-specific effects. Digital literacy, the availability of infrastructure, institutional support, and socioeconomic circumstances are some of the variables that frequently affect these differences. However, the lack of a systematic synthesis of these determinants makes it difficult to draw generalized conclusions or inform effective policy interventions. The incomplete knowledge of the relationship between ICT-enabled engagement and performance results is another significant gap. Although more access to digital technologies is thought to promote farmer participation, it's not always evident if this results in quantifiable increases in agricultural revenue and production. This disparity emphasizes the necessity of a thorough investigation that looks at both procedures at the same time.

Furthermore, the continued existence of the digital divide, especially among rural smallholder farmers, raises questions about how inclusive ICT-driven agricultural revolution would be. The advantages of digital agriculture could continue to be concentrated within comparatively privileged people if access, skill, and cost inequities are not addressed. A thorough literature review that summarizes previous studies, pinpoints important topics, and critically assesses the connection between ICT, farmer engagement, and agricultural performance is obviously necessary in light of these difficulties. By delivering a thorough and integrated synthesis of the literature, this study seeks to close this knowledge gap and provide policymakers, academics, and practitioners with insights on the role of ICT in agricultural growth.

3.METHODOLOGY

The impact of information and communication technology (ICT) on farmers' engagement and agricultural performance is investigated in this study using a systematic literature review (SLR) methodology. The review adheres to the PRISMA framework, which guarantees an open, methodical, and repeatable procedure for locating, vetting, and choosing pertinent papers. Because of its comprehensive coverage of excellent, peer-reviewed journal papers, the Scopus database was chosen as the main source of literature. The research focuses on current advancements in digital agriculture, namely how ICT may improve agricultural production and increase farmer engagement. The search was limited to the years 2015–2026 in order to catch current research trends.

The study was limited to English-language peer-reviewed academic articles and review papers. Conference papers, book chapters, novels, editorials, and conference reviews were among the other document kinds that were not included. In a similar vein, in order to preserve uniformity and quality, non-English publications, trade journals, book series, conference proceedings, and articles in press were omitted. Additionally, only final published publications with open access were taken into account. Table 1 presents the specific inclusion and exclusion criteria. Using Boolean operators, a thorough search method was created to find pertinent studies. Key phrases including "Digital Technology," "Mobile Technology," "Information and Communication Technology (ICT)," "Farmer Participation," "Farmer Engagement," "Agricultural Performance," "Farm Productivity," "Farm Income," "Digital Agriculture," and "Smart Farming" were included in the search string. This strategy made sure that outcome variables (output, revenue, and efficiency) and behavioral aspects (farmer involvement and engagement) were sufficiently recorded. Table 2 displays the whole keyword combinations and search approach. 225 articles were found in the Scopus database after the initial search. Following the PRISMA approach, these records underwent a methodical screening procedure. All 225 items were gathered from the database during the identification phase. The inclusion and exclusion criteria were used throughout the screening phase, and studies that weren't relevant were eliminated. Consequently, forty items were eliminated, mostly because they were irrelevant, redundant, or did not fit the predetermined standards. The remaining 185 papers were then assessed in the eligibility stage based on their titles, abstracts, and keywords to make sure they matched the goals of the study. Only studies with enough quality and relevance were kept for additional analysis thanks to this step. At this point, articles that didn't fit the requirements were eliminated. Ultimately, 185 papers were chosen and added to the systematic review at the inclusion stage. The qualitative synthesis and analysis offered in this study are based on these investigations. The PRISMA flow diagram (Figure 1) shows the number of studies found, screened, eliminated, and included at each stage of the selection process.

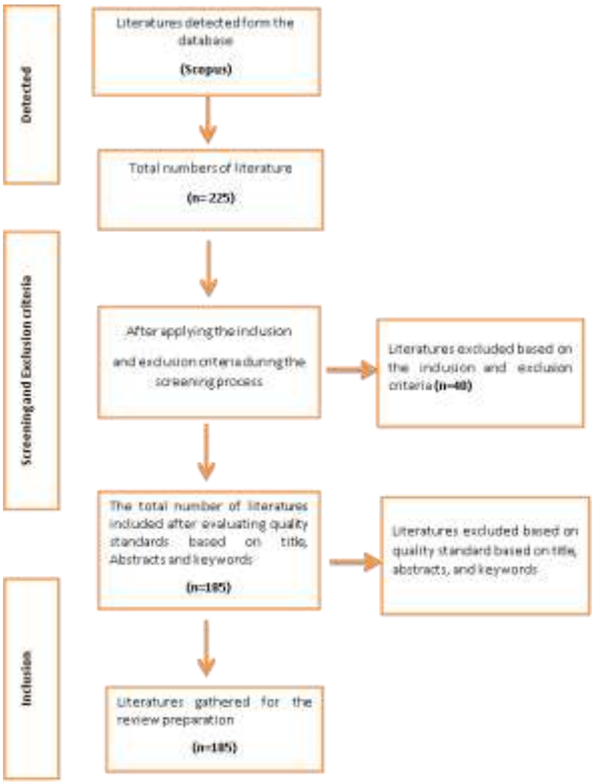

Fig. 1. The PRISMA flowchart

Table 1. Inclusion and exclusion criteria

Databases	**Inclusion**	**Exclusion**
Time span	2015 – 2026	<2015
Document type	Articles, Review	Conference papers, Book chapters, Books, Editorials, Conference reviews
Languages	English	Non- English And others all
Source type	Journal	Trade journal Book series Book Conference proceeding
Publication stage	Final	Article in press
Open access	All open access	Others

Table 2. The list of keywords employed during the database literature searches

DATABASES	KEYWORDS	TOTAL NUMBER OF ARTICLE
Scopus	"("Information and Communication Technology" OR ICT OR "Digital Technology" OR "Mobile Technology") AND ("Farmer Participation" OR "Farmer Engagement" OR "Farmer Involvement") AND ("Agricultural Performance" OR "Farm Productivity" OR "Farm Income" OR "Agricultural Efficiency") AND (Agriculture OR "Digital Agriculture" OR "Smart Farming") AND (Farmers OR "Smallholder Farmers" OR "Rural Farmers")	225

4.RESULT AND DISCUSSION

4.1.CO-AUTHORSHIP NETWORK ANALYSIS (AUTHORS)

The collaboration structure among writers contributing to the literature on information and communication technology (ICT) in agriculture is revealed by the co-authorship network, which was created using VOSviewer. Different clusters can be seen in the image, each of which represents a group of writers who commonly work together. The underlying research groups and patterns of academic engagement within the area are highlighted by these groupings (Figure 2).The two main clusters that make up the network are denoted by the colors red and green. Authors like Twumasi Martinson Ankrah, Ansah Stephen, Asante Dennis, Addai Bismark, and other collaborators are included in the red cluster. This cluster's extensive linkages show a high degree of internal cooperation, indicating that the authors are a part of a closely related research group that regularly contributes to the field. The strong linkages among these authors reflect repeated co-authorship and shared research interests. Authors like Siaw Anthony, Agbenyo Wonder, Jiang Yuansheng, and Ntim-Amo Gideon are part of the green cluster. Strong internal connection, a sign of an active cooperative network, is also present in this group, much like in the red cluster. This cluster's numerous linkages indicate regular collaborative publications and well-coordinated research initiatives. Furthermore, relationships between authors in the green and red clusters show that there is inter-cluster cooperation, proving that information sharing happens amongst various research teams rather than being limited to discrete clusters.

Some authors hold more prominent roles in the network, demonstrating their significance in promoting cooperation. Agbenyo Wonder and Siaw Anthony in particular show up as notable nodes with more connections, indicating that they are important in connecting many writers and making a substantial contribution to the field of study. In a similar vein, Twumasi Martinson Ankrah's significance inside that cooperative group is shown by his significant connectedness within the red cluster. The number of publications or relative contribution of each author is represented by the size of the nodes in this network, and the strength of co-authorship ties is indicated by the thickness of the links. Because they retain extensive collaborative linkages and actively contribute to the literature, authors with larger nodes and thicker connections are more influential. Overall, the co-authorship analysis shows that there are significant collaboration patterns in agricultural ICT research, with key authors serving as essential connections and clearly defined research clusters. This framework reflects a dynamic and interconnected research environment where cooperation is essential to expanding knowledge and stimulating innovation in digital agriculture.

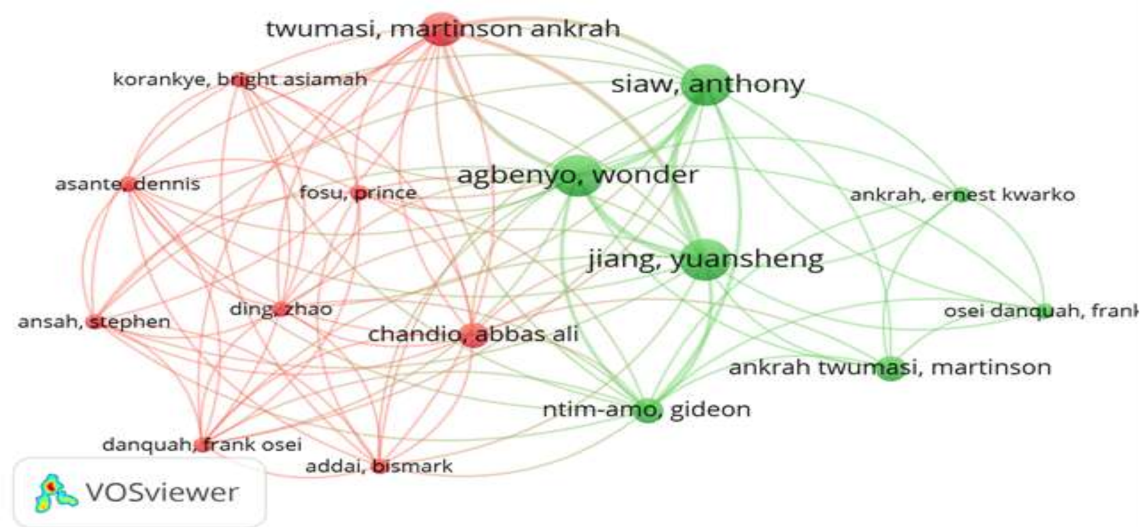

Fig. 2.

Co-authorship Network Analysis (Authors)

4.2.CO-AUTHORSHIP NETWORK OF COUNTRIES

The country-level co-authorship network created with VOSviewer is shown in Figure 3, which highlights global research cooperation in the field of information and communication technology (ICT) in agriculture. Each node in this network symbolizes a nation, and the size of the node indicates how many articles that nation has contributed. The strength of cooperation between nations is indicated by the thickness of the linkages between nodes, which show cooperative partnerships. China is the biggest contributor, according to the network, as seen by the size of its nodes and the number of links it has with other nations. This implies that China is at the forefront of international cooperation and research output in ICT-enabled agriculture. Similarly, the United States also demonstrates strong collaborative linkages with several countries, including the United Kingdom, Australia, and New Zealand, indicating its central role in global research networks.

Another significant cluster is made up of nations like Ghana, South Africa, and Nigeria, who are active contributors to African research. Strong ties between these nations demonstrate regional cooperation and rising involvement in ICT-based agriculture research. Ethiopia also shows up as a node that is comparatively less connected, suggesting that there is little but growing network cooperation. Although they have relatively smaller node sizes, which indicate lesser publication output or collaboration intensity, other nations like Kenya, Thailand, Germany, Pakistan, and Saudi Arabia also contribute to the network. The clustering pattern indicates that both shared research interests and geographic proximity have an impact on international research collaboration. Global information sharing is reflected in inter-cluster interconnections, whilst strong intra-cluster connections show regional cooperation. Overall, the network shows how ICT research in agriculture is becoming more globalized, with important nations serving as hubs that promote cross-border cooperation and knowledge sharing

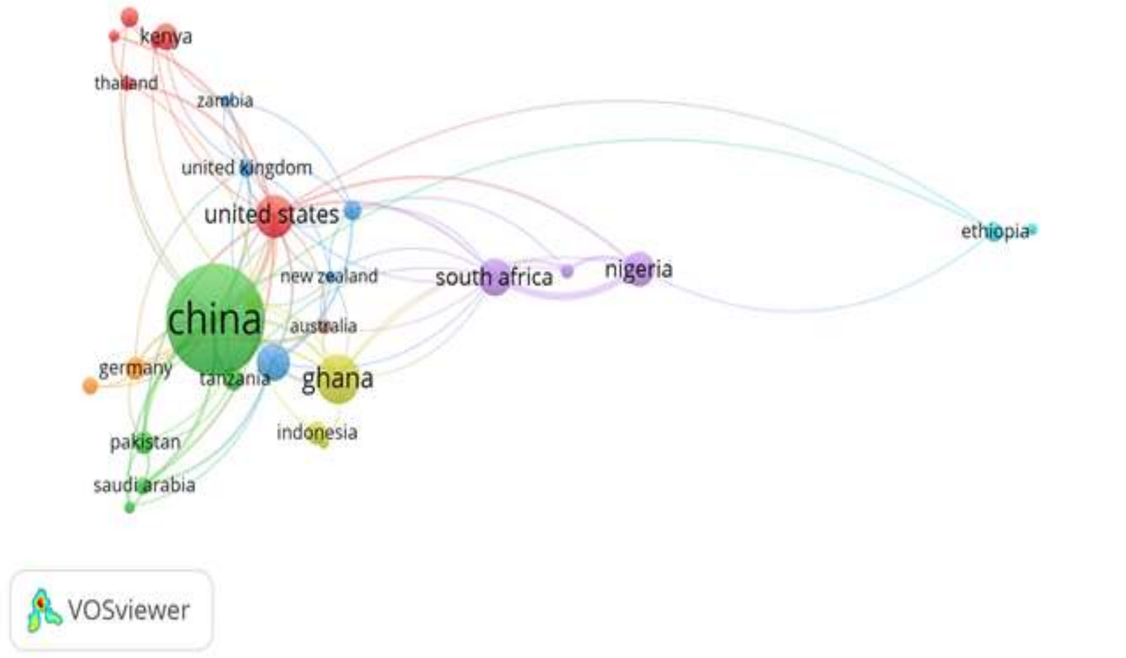

Fig. 3. Co-authorship network of countries

.

4.3.CO-OCCURRENCE NETWORK OF AUTHOR KEYWORDS

The conceptual framework and prevalent research themes in ICT and agriculture are shown by the co-occurrence network of author keywords created with VOSviewer (Figure 4). Each node in this network represents a term; the linkages show the co-occurrence relationships between keywords, and the size of the node reflects how frequently it occurs. As seen in Figure 4, "agriculture" stands out as the most common term, demonstrating its pivotal function and robust correlation with several study subjects. The importance of ICT acceptance and innovation dissemination within agricultural systems is shown by closely related words like "adoption," "technology adoption," and "digital agriculture." Several theme groups are also shown by the network. Research on farmer behavior, income results, and information availability is the focus of the "adoption" cluster. Keywords like "income," "crop farmers," and "China" show a heavy emphasis on empirical research looking at how ICT adoption affects the economy. Furthermore, the existence of a "treatment effect model" implies the use of sophisticated econometric techniques for examining adoption effects. "Technology adoption" and "agricultural extension" constitute another significant cluster, emphasizing the part extension services play in promoting ICT use. The inclusion of "gender" in this cluster is indicative of the increasing focus on sociodemographic aspects of technology adoption.

Additionally, terms like "Ghana" and "attitude" are included in the cluster linked to "rural development," indicating study on behavioral factors and the impact of ICT in rural transformation. Sustainability-related terms like "sustainability" and "technical efficiency" indicate a growing focus on ICT-enabled, ecologically friendly, and productive farming methods. Overall, the keyword co-occurrence analysis (Figure 4) shows that ICT and agriculture research is interdisciplinary, incorporating topics of rural development, technology adoption, farmer engagement, and agricultural performance. A well-established and developing field of study is shown in the strong links between terms.

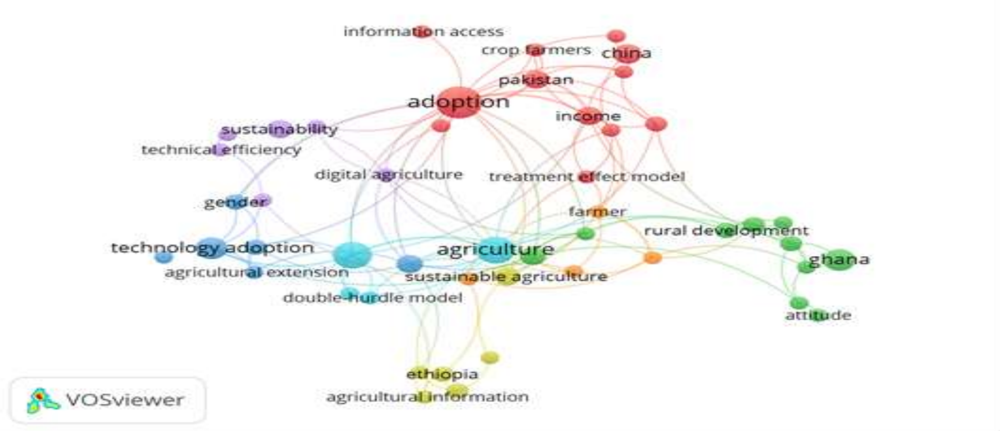

Fig. 4. Co-occurrence network of author keywords

4.4.BIBLIOGRAPHIC COUPLING OF AUTHORS

The study field's intellectual structure and thematic links are depicted in the bibliographic coupling network of authors created with VOSviewer (Figure 5). Each node in this network represents an author, and the size of the node indicates how many articles or citations the person has produced. Authors that mention comparable works are positioned closer together and create different clusters that highlight linked research interests because the linkages between nodes show the intensity of common references. The network displays a number of notable clusters, as seen in Figure 5, suggesting the existence of distinct study groups. The red cluster, which is focused on Kassem, Hazem S., and Kehinde, Ayodeji Damilola, is a strongly linked collection of writers who have made substantial contributions to the area. Strong connections within this cluster point to a common conceptual base, perhaps with an emphasis on rural development, agricultural performance, and ICT adoption. Another significant research group is the green cluster, which is headed by Agbenyo Wonder. The authors in this cluster are near to one another, which suggests that they have similar research interests, especially when it comes to topics like rural livelihoods, socioeconomic determinants, and farmer engagement. In a similar vein, Dokmaithes and Rapee are part of the yellow cluster, which is a smaller but coherent group with closely related study concerns. The blue cluster, which is led by Adgo and Enyew, seems to serve as a link between several clusters. This implies a more comprehensive and multidisciplinary approach to study, enabling the integration of knowledge across several subject areas. Furthermore, Li, Fuduo retains significant connections with the blue cluster while being positioned slightly outside of the core clusters, suggesting a specialized but related research contribution. Lu, Qian, on the other hand, seems to be somewhat removed from the center network, indicating a more autonomous study path or a specialized area with little overlap in cited references when compared to other writers.

Such placement can be a reflection of new fields of study or unique approaches to methodology. Overall, the bibliographic coupling analysis (Figure 5) shows that the field of study is somewhat interrelated, with different subject clusters and degrees of cooperation. While peripheral writers represent specialized or developing research directions, bridge authors emphasize the integration of knowledge across subfields. In addition to showcasing the research domain's maturity and variety, this structure also highlights areas for improved interdisciplinary integration and cooperation.

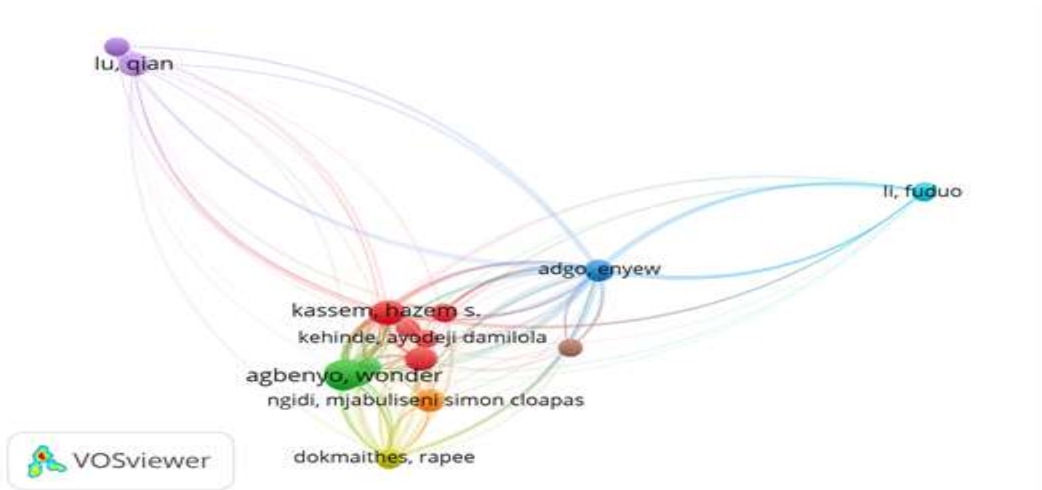

Fig. 5. Bibliographic Coupling of Authors

ROLE OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN FARMERS' PARTICIPATION AND AGRICULTURAL PERFORMANCE

Information and Communication Technology (ICT) plays a transformative role in modern agriculture by enhancing farmers' access to information, improving decision-making processes, and strengthening linkages across agricultural value chains. In recent years, ICT has emerged as a critical enabler in bridging information gaps and facilitating knowledge dissemination, particularly in developing countries such as India. By providing timely and location-specific information, ICT empowers farmers to make informed decisions regarding crop selection, input use, and market participation, thereby improving both engagement and performance outcomes [15,16]. Increasing farmer engagement through better communication and access to extension services is one of ICT's main functions. Farmers may communicate with agricultural professionals and organizations more efficiently thanks to digital solutions including online advisory platforms, interactive voice response systems, and mobile applications. By enabling farmers to actively seek information, exchange comments, and participate in cooperative learning processes, these platforms encourage inclusive involvement. ICT-based extension services dramatically raise farmers' awareness and promote their participation in agricultural innovation systems, according to studies [17]. Additionally, peer-to-peer learning has been reinforced by the use of social media and digital networks, allowing farmers to share experiences and information, which in turn increases their ability to adopt better agricultural methods [18].

Additionally, ICT is essential in helping farmers accept new technologies and alter their behavior. ICT lowers the uncertainty around new technologies and promotes their adoption by giving people access to trustworthy and pertinent information. Digital platforms are more relevant and successful since they frequently provide personalized recommendations based on local circumstances. Therefore, when ICT-enabled consulting services are provided, farmers are more likely to adopt better seeds, fertilizers, and sustainable agricultural techniques [19]. Additionally, by combining real-time data and predictive analytics, ICT improves farmers' decision-making skills and increases farm management effectiveness. ICT greatly enhances production, revenue, and resource-use efficiency in agriculture. Farmers may find better selling possibilities, lessen their reliance on middlemen, and negotiate favorable rates when they have access to market information via digital channels. Improved income levels and lower transaction costs result from this greater market openness [1]. Additionally, ICT-based instruments like remote sensing systems and precision farming technologies allow for the effective use of inputs, reducing waste and raising crop yields. Sustainable agricultural output requires site-specific management techniques, which these technologies assist [20]. ICT also plays a significant role in improving market integration and agricultural value chains. By connecting farmers with buyers, financial institutions, and input suppliers, digital platforms enhance value chain efficiency and coordination. By giving farmers direct access to customers and wider markets, e-commerce platforms and digital marketplaces lower market barriers and boost profitability [21].

Furthermore, ICT makes it easier for farmers to access financial services like lending, insurance, and digital payments, all of which are essential for boosting their capacity for investment and economic resilience. Despite these benefits, digital literacy, the availability of infrastructure, and institutional support are some of the enabling elements that determine how successful ICT is in agriculture. The potential advantages of ICT and its influence on farmer engagement and performance may be limited in the absence of these elements. Therefore, enhancing digital access, increasing farmers' capacity, and guaranteeing the inclusivity of digital interventions must be the main goals of policies intended to promote ICT in agriculture.

CHALLENGES OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN FARMERS’ PARTICIPATION AND AGRICULTURAL PERFORMANCE

Information and communication technology (ICT) has the potential to revolutionize agriculture, but a number of institutional, socioeconomic, and technological obstacles prevent its widespread acceptance and efficient use. These obstacles make it more difficult for ICT to completely increase farmer involvement and boost agricultural output, especially in emerging nations like India. The digital divide, which describes differences in access to ICT infrastructure and services between various geographical areas and socioeconomic levels, is one of the biggest obstacles. Farmers' access to ICT-based services is sometimes hampered by low network coverage, poor internet connectivity, and restricted digital device availability in rural locations [22]. This inequality is further exacerbated by income disparities, as smallholder farmers may not be able to afford smartphones, data services, or advanced digital tools.

Farmers' lack of technological expertise and digital literacy is another significant obstacle. Many farmers lack the skills needed to utilize ICT tools and platforms efficiently, especially those who are older and have less formal education. This restricts their capacity to obtain, analyze, and utilize digital data while making agricultural decisions [23]. ICT adoption stays surface-level and does not result in significant increases in participation or performance in the absence of sufficient training and capacity-building programs. Another significant obstacle to ICT adoption in agriculture is infrastructure constraints. Consistent usage of ICT tools is hampered in many rural areas by unstable electrical supplies and inadequate digital infrastructure. These limitations reduce the efficacy and dependability of digital platforms, internet services, and mobile devices [24]. Additionally, the lack of localized digital content tailored to specific agro-climatic conditions further reduces the relevance of ICT-based information for farmers.

The lack of understanding and confidence in ICT services is another significant problem. Concerns regarding the dependability and correctness of the information offered by digital platforms may make farmers reluctant to embrace digital technology. Low adoption rates are also a result of a lack of knowledge about the possible advantages of the ICT services that are accessible [25]. Therefore, encouraging the efficient use of ICT in agriculture requires building confidence through reliable and user-friendly platforms. ICT integration into agricultural systems is further hampered by institutional and policy-related issues. ICT projects may become disjointed and ineffective as a result of poor coordination between government organizations, businesses, and extension services. The scalability and durability of ICT interventions are further constrained by a lack of investment in rural digital infrastructure and insufficient legislative support [26].

Furthermore, inconsistent information quality and accessibility may result from the lack of established frameworks for data management and digital service delivery.

In digital agriculture, data security and privacy are becoming more and more of a problem. The potential of data abuse and cyber threats increases as farmers depend more and more on digital platforms to get information and complete transactions. Farmers' trust in ICT systems may be damaged and their adoption discouraged by unclear legislation and data protection measures [6]. Lastly, the adoption and use of ICT are also influenced by sociocultural factors. For certain groups, especially women farmers, access to digital technology may be limited by social norms, cultural hurdles, and gender inequities. The overall efficacy of ICT initiatives in fostering equitable agricultural development is diminished by these disparities, which also restrict inclusive participation [27].

CONCLUSION

To enable to investigate the impact of information and communication technology (ICT) on farmers' engagement and agricultural performance, this research thoroughly examines the body of current literature. The results show that via improving information availability, bolstering communication networks, and facilitating data-driven decision-making, ICT has emerged as a key force behind agricultural change. Farmers are now much better able to interact with agricultural knowledge systems and take part in production and market-related activities because to the integration of digital tools including mobile-based advisory services, e-extension platforms, and precision agriculture technology. The review also shows that ICT improves agricultural performance by boosting technical efficiency, raising farm revenue, and increasing production. Farmers may maximize resource utilization and lower production risks by having access to real-time weather, input, and market pricing information. Additionally, by lowering transaction costs and information asymmetry, ICT promotes improved market integration, which enhances price realization and farmers' overall financial results.

However, the study also identifies several structural and operational challenges that constrain the effective utilization of ICT in agriculture. The persistence of the digital divide, limited digital literacy, inadequate infrastructure, and affordability constraints continue to restrict access to ICT tools, particularly among smallholder farmers in rural areas. In addition, institutional gaps, lack of coordination among stakeholders, and concerns related to data privacy and trust further limit the scalability and sustainability of ICT interventions. A key contribution of this review lies in its integrated approach, which simultaneously examines farmer participation and agricultural performance two dimensions that have often been analyzed independently in previous studies. The findings suggest that while ICT enhances farmer engagement and knowledge exchange, its impact on performance outcomes is contingent upon enabling factors such as infrastructure, skills, and institutional support. This highlights the need for a holistic and inclusive approach to digital agricultural development. In conclusion, ICT holds substantial potential to transform agricultural systems; however, its effectiveness depends on the creation of an enabling environment that ensures equitable access, capacity development, and supportive policy frameworks. Policymakers should focus on strengthening rural digital infrastructure, promoting digital literacy, and designing inclusive ICT-based interventions tailored to the needs of smallholder farmers. Future research should emphasize empirical validation of integrated models and explore context-specific strategies to enhance the synergy between farmer participation and agricultural performance. Such efforts will be essential for achieving sustainable, inclusive, and technology-driven agricultural development.

REFERENCES

1. Aker JC. Information from markets near and far: Mobile phones and agricultural markets in Niger. American Economic Journal: Applied Economics. 2010 Jul 1;2(3):46-59. https://doi.org/10.1257/app.2.3.46
2. Qiang CZ, Kuek SC, Dymond A, Esselaar S, Unit IS. Mobile applications for agriculture and rural development. Washington, DC: World Bank; 2012 May. https://doi.org/10.1596/21892
3. Mittal S. Modern ICT for agricultural development and risk management in smallholder agriculture in India. CIMMYT; 2012 Apr 20.
4. Nakasone E, Torero M, Minten B. The power of information: The ICT revolution in agricultural development. Annu. Rev. Resour. Econ.. 2014 Oct 5;6(1):533-50. https://doi.org/10.1146/annurev-resource-100913-012714
5. Trendov NM, Varas S, Zeng M. Digital technologies in agriculture and rural areas. FAO;; 2019.
6. Wolfert S, Ge L, Verdouw C, Bogaardt MJ. Big data in smart farming–a review. Agricultural systems. 2017 May 1;153:69-80. https://doi.org/10.1016/j.agsy.2017.01.023
7. Davis KE, Joseph J, Barry T, von Maltitz L, Van Niekerk J, Ngomane T, Rasoanindrainy A. Global agricultural extension staff functional competencies. Intl Food Policy Res Inst; 2021 Dec 9. https://doi.org/10.2499/p15738coll2.134857
8. Spielman D, Lecoutere E, Makhija S, Van Campenhout B. Information and communications technology (ICT) and agricultural extension in developing countries. Annual review of resource economics. 2021 Oct 5;13(1):177-201. https://doi.org/10.1146/annurev-resource-101520-080657
9. Bandiera O, Rasul I. Social networks and technology adoption in northern Mozambique. The economic journal. 2006 Oct 1;116(514):869-902. https://doi.org/10.1111/j.1468-0297.2006.01115.x
10. Jensen R. The digital provide: Information (technology), market performance, and welfare in the South Indian fisheries sector. The quarterly journal of economics. 2007 Aug 1;122(3):879-924. https://doi.org/10.1162/qjec.122.3.879
11. Fafchamps M, Minten B. Impact of SMS-based agricultural information on Indian farmers. The World Bank Economic Review. 2012 Jan 1;26(3):383-414. https://doi.org/10.1093/wber/lhr056

12. Lee CL, Strong R, Dooley KE. Analyzing precision agriculture adoption across the globe: A systematic review of scholarship from 1999–2020. Sustainability. 2021 Sep 15;13(18):10295. https://doi.org/10.3390/su131810295
13. Arif M. ICTs and development in Pakistan: a review. Journal of Innovations and Sustainability. 2018;4(3):7-25. https://doi.org/10.51599/is.2018.04.03.07
14. Donner J. Research approaches to mobile use in the developing world: A review of the literature. The information society. 2008 May 6;24(3):140-59. https://doi.org/10.1080/01972240802019970
15. Bank W. ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions. Updated Edition. Washington, DC: World Bank. doi: 10.1596.
16. Tossou SH, Okou FA, Kpanou SB. A systematic review of policy enforcement as a catalyst for digitalizing agriculture in West and East Africa. Journal of African Development. 2020 Dec 1;21(1):68-95. https://doi.org/10.5325/jafrideve.21.1.0068
17. Asenso-Okyere K, Mekonnen DA. The importance of ICTs in the provision of information for improving agricultural productivity and rural incomes in Africa. African Human Development Report. UNDP Sponsored research Series. 2012 Jan;43.
18. Heeks R. Information and communication technology for development (ICT4D). Routledge; 2017 Nov 8. https://doi.org/10.4324/9781315652603
19. Ali J, Kumar S. Information and communication technologies (ICTs) and farmers' decision-making across the agricultural supply chain. International Journal of Information Management. 2011 Apr 1;31(2):149-59. https://doi.org/10.1016/j.ijinfomgt.2010.07.008
20. Zhang N, Wang M, Wang N. Precision agriculture—a worldwide overview. Computers and electronics in agriculture. 2002 Nov 1;36(2-3):113-32. https://doi.org/10.1016/S0168-1699(02)00096-0
21. Jia X, Bijman J, Silva C, Ranking M. Contract farming: Synthetic themes for linking farmers to demanding markets. Contract farming for inclusive market access. 2014:21-35.
22. Hilbert M. The end justifies the definition: The manifold outlooks on the digital divide and their practical usefulness for policy-making. Telecommunications Policy. 2011 Sep 1;35(8):715-36. https://doi.org/10.1016/j.telpol.2011.06.012
23. Park S. Digital inequalities in rural Australia: A double jeopardy of remoteness and social exclusion. Journal of Rural Studies. 2017 Aug 1;54:399-407. https://doi.org/10.1016/j.jrurstud.2015.12.018
24. Palvia P, Baqir N, Nemati H. ICT for socio-economic development: A citizens' perspective. Information & Management. 2018 Mar 1;55(2):160-76. https://doi.org/10.1016/j.im.2017.05.003
25. Rogers EM. Diffusion of innovations. 4th. New York. 1995;4.
26. Lahiri B, Anurag TS, Borah S, Marak NR, Pavan Kumar ST, Sangma SM, Sangma AK, Marak BR. Designing a user-centric mobile-based agro advisory system for sustainable development of smallholder farming systems in the eastern Himalayas, India. Information Technology for Development. 2024 Oct 1;30(4):665-95. https://doi.org/10.1080/02681102.2024.2327860
27. Women C. The mobile gender gap report 2019. GSMA, London Retrieved from https://www. gsmaintelligence. com/research. 2019.