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Towards Smart Agriculture: Analysis of Agricultural Digitalization and Social Engagement in Indonesia

Salya Elva Corinna[1], Aldi Hardianto[2], Ganjar Ndaru Aji[3], Salsabila Gunawijaya[4], Shania Alya Hisna[5]
[1,2,3,4,5] Master of Communication Studies, Faculty of Social and Political Sciences, University of Indonesia

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ABSTRACT

Agricultural digitalization is a strategic solution for increasing productivity and efficiency in the agricultural sector in the Industrial Revolution 4.0 era. Agricultural digitalization represents a fundamental transformation that is transforming food production, distribution, and consumption systems. The main advantage of digitalization lies in its ability to effectively collect, process, and analyze data ranging from weather information and soil characteristics to crop yield estimates. This study used a scoping review method to examine the literature related to the implementation of digital technology in Indonesian agriculture, focusing on the benefits, challenges, and the role of agricultural extension workers. The study results show that technologies such as IoT, AI, and GIS can drive increased agricultural yields, although their adoption is still limited to groups of farmers with high digital literacy. Age, education, infrastructure, and socio-cultural dynamics also influence technology acceptance. The Social Shaping of Technology approach emphasizes that the success of digitalization is influenced by the social context and the active participation of various parties. Challenges such as resistance to change, lack of training, and infrastructure gaps need to be addressed through inclusive cross-sector collaboration. Further research is recommended to explore technology implementation in non-Java regions and encourage active farmer involvement in innovation.

Corresponding Author:

Name: Salya Elva Corinna
Institution: Master of Communication Science, Faculty of Social and Political Sciences, University of Indonesia
E-mail: salyaelvacorinna@gmail.com

1. INTRODUCTION

In the era of globalization and the Industrial Revolution 4.0, digital innovation plays a crucial role in increasing efficiency, productivity, and national food security. In Indonesia, the agricultural sector contributes significantly to Gross Domestic Product (GDP) and serves as the primary source of livelihood for a large rural population [1]. Agricultural digitalization represents a fundamental transformation that is transforming food production, distribution, and consumption systems. The primary advantage of digitalization lies in its ability to effectively collect, process, and analyze data ranging from weather information and soil characteristics to crop yield estimates [2].

However, technology adoption remains hampered by limited infrastructure, low digital literacy, and resistance to change. Therefore, strategies are needed that are not only technology-based but also consider the social context and farmer capacity.

Practices in agricultural digitalization encompass various technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and geographic information systems (GIS). These technologies enable real-time monitoring of land conditions, more accurate weather predictions, and more efficient resource management [3]. However, the adoption of digital technology among farmers still faces various obstacles, including limited infrastructure, high investment costs, and low digital literacy among farmers. One example of the application of agricultural digitalization is the e-Reporting Polygon, developed by the Indonesian Ministry of Agriculture as a tool to digitize agricultural land mapping and increase transparency in the distribution of fertilizer subsidies [4]. While not the only technology used, this example illustrates how digitalization can contribute to more accurate and efficient agricultural governance [1]. Digitalization in Indonesia's agricultural sector still faces major challenges, with limited digital literacy among farmers a major obstacle that creates a gap between technological potential and its utilization in the field [2].

Uneven technological infrastructure, particularly in rural areas, and limited human resource capacity to assist farmers are the reasons for the slow digital transformation process [5]. In this context, agricultural extension workers play a crucial role as facilitators and intermediaries between technology and farmers. Their role extends beyond providing information, including technical assistance, digital literacy education, and strengthening farmers' institutional capacity to prepare them for the digital agriculture era [6]. This scoping review aims to comprehensively review the literature related to the implementation of digital innovation in the agricultural sector. The primary focus is on identifying factors influencing farmers' adoption of digital technology and highlighting the crucial role of extension workers in strengthening digital literacy at the grassroots level. By referencing various innovation examples, such as smart farming and Polygon e-Reporting, this study is expected to provide a comprehensive overview of the challenges and opportunities for digital transformation in Indonesia's agricultural system.

2. LITERATURE REVIEW

2.1 Digitalization of Agriculture in Indonesia

In Indonesia, digitalization not only involves the application of technological tools but also requires collaboration between various actors such as farmers, extension workers, the government, the private sector, and research institutions to create an inclusive and sustainable digital agricultural ecosystem [7]. Digital transformation in agriculture in Indonesia is still in its early stages, marked by various initiatives such as agricultural e-commerce platforms, digital land reporting systems (e-Reporting Polygon), and the use of drones and IoT sensors for crop monitoring. However, its distribution is uneven and tends to be concentrated in areas with adequate infrastructure. Digitalization has also brought a paradigm shift in agricultural development, from being manual and experiential to being data-driven and analytical. This has prompted the need to strengthen the digital capacity of key actors in the agricultural sector, particularly smallholder farmers and extension workers in remote areas [8]. The application of digital technology in agriculture brings significant benefits. Technologies such as

the Internet of Things (IoT), artificial intelligence (AI), and geographic information systems (GIS) enable more accurate and efficient data-driven decision-making. Data obtained from soil sensors, drones, or weather monitoring applications allows farmers to precisely manage planting times, fertilizer application, and pest control [3]. At a macro level, digitalization can increase agricultural productivity, reduce post-harvest losses, and strengthen national food security. Furthermore, digital systems also promote transparency in the distribution of aid or subsidies, as demonstrated by the e-Reporting Polygon system developed by the Ministry of Agriculture [4]. Digitalization also opens up broader market access for farmers through digital agricultural platforms, enabling them to sell their crops directly to consumers or industry without intermediaries. Thus, digitalization strengthens the bargaining position of smallholder farmers and accelerates their integration into the digital economy.

2.2 Social Challenges of Agricultural Digitalization Implementation (SST Approach)

Digitalization in the agricultural sector offers various benefits, including streamlining cultivation and marketing activities. However, this transformation also brings significant implications, such as the weakening of community values of mutual cooperation and the risk of unemployment due to automation. In Indonesia, the potential for developing digital agriculture is enormous. The main challenge lies in optimizing the benefits of this technology while minimizing its negative consequences. Therefore, the use of the digital era must be directed wisely to create a more efficient and sustainable agricultural system [9]. Despite its promise, the implementation of agricultural digitalization in Indonesia still faces various social challenges. One of the main challenges is low digital literacy among farmers. Many farmers, especially older ones, are not yet familiar with using digital devices or understanding the benefits of technology for their agricultural practices [2].

The Social Shaping of Technology (SST) approach emerged as a critical response to the view that technological development is linear, neutral, and uninfluenced by social context. SST rejects this view by emphasizing that technology does not develop in isolation, but rather through a complex process of interaction with social actors, organizational culture, government policies, and political-economic dynamics [10]. In the context of agricultural digitalization in Indonesia, SST serves as an important framework for understanding how technology adoption is influenced by social factors, such as farmer resistance to change, the role of extension workers in mediating technology, and limitations in infrastructure and digital literacy. Thus, low digital literacy among farmers, resistance to change, and unequal access to digital infrastructure are not merely technical barriers, but reflect social structures that are also

intertwined in the digitalization process.

For example, many farmers, especially older ones, are not yet accustomed to using digital devices or understanding the benefits of technology for their agricultural practices [2]. This suggests that the success of technology implementation depends not only on the sophistication of digital systems, but also on the extent to which they are relevant, understandable, and accepted within the local social context. Furthermore, unequal access to digital infrastructure such as the internet and electricity in rural areas is a major obstacle. Remote areas often lack a stable internet connection, a key prerequisite for the operation of cloud-based digital systems or online applications [5]. Digital transformation in agriculture also requires a shift in mindset among agricultural sector actors, including extension workers. Resistance to adopting new technologies often arises because they are perceived as complicated, expensive, or irrelevant to local needs.

Farmers' human resources are synonymous with their decision-making process in selecting the information/technology to be implemented [11]. Therefore, the SST approach underscores the crucial role of agricultural extension workers as agents of socio-technological relations. Strengthening the capacity of extension workers is key to bridging the gap between technology and farmers. Improving agricultural competencies and information systems is essential to enhancing the professionalism of agricultural human resources. Therefore, improving the resources of both farmers and extension workers is essential for the success of agricultural development programs [9]. The role of extension workers is not merely as information providers, but also as facilitators, trainers, and liaisons between technological innovation and local farmer needs. With a participatory and contextual approach, extension workers can increase farmers' readiness to adopt digital technology sustainably [6].

3. METHODS

This study aims to examine the impact of agricultural digitalization on farmers in Indonesia over the past five years, focusing on both positive and negative changes. The scoping review method was chosen because of its ability to provide a comprehensive overview of the existing literature without being tied to strict criteria such as systematic reviews [12]. The research focused on case studies in Indonesia, utilizing search results from Google Scholar and the SINTA database (levels 1-3) for the past five years. [13] examined the impact of agricultural digitalization on the economic well-being of farming communities in Adiluwih and Gadingrejo Pringsewu Districts, demonstrating that the application of digital technology can increase farmer incomes through efficient resource use and improved market access. Furthermore, [14] discussed how e-commerce in the agricultural sector contributes to the digital economy in Indonesia, highlighting the importance of technology adoption for the sustainability of farming businesses.

This scoping review method involves several important steps: first, a literature search using keywords related to "agricultural digitalization" and "information technology" through academic databases such as SINTA

and Google Scholar; second, a selection of articles based on inclusion criteria; third, data extraction from selected articles on the impacts and benefits of digitalization; and fourth, a descriptive analysis of the findings to identify general trends and existing knowledge gaps. Through this method, this study not only seeks to summarize the main results but also to identify areas requiring further research. Thus, the scoping review is an effective tool for understanding the digitalization landscape in agriculture, as well as providing valuable insights for researchers, practitioners, and policymakers in developing better strategies for technology implementation in the agricultural sector.

4. RESULTS AND DISCUSSION

Digitalization in agriculture is a key strategy for increasing productivity and efficiency in agricultural systems. This study of digital technology research in agricultural practices in Indonesia is considered capable of providing a more comprehensive picture of the dynamics of implementation, distribution, and challenges faced. The results and discussion section presents 10 articles curated according to discussions related to digitalization in agriculture, both inclusive and exclusive. In Indonesia, although the number of studies on agricultural digitalization is not as high as in some other countries, the trend is increasing, especially in recent years. This is driven by several factors, including government encouragement through precision agriculture programs, the emergence of various agritech startups, and the need to increase smallholder farm productivity. The COVID-19 pandemic has also played a significant role in accelerating the adoption of digital technology in this sector.

The study results show that the agricultural digitalization process in East Java remains uneven and tends to be sporadic. The implementation of digital technology is largely concentrated in areas with more advanced information technology infrastructure, such as Malang, Kediri, and Pasuruan. In these areas, digital technology is widely used for non-cultivation activities such as agricultural marketing, product distribution, and communication between farmers. Meanwhile, the use of technology in the cultivation process or on-farm activities is still limited to certain farming communities, particularly those belonging to the younger generation or millennial farmers. This suggests that the level of technology adoption is not only determined by the availability of equipment, but also influenced by factors such as age, education level, and access to digital information.

The literature review shows that agricultural digitalization in Indonesia encompasses a variety of technologies, from the Internet of Things (IoT), artificial intelligence (AI), geographic information systems (GIS), to national programs such as smart farming and e-Reporting Polygon. The implementation of these technologies aims to increase productivity, land management efficiency, and transparency in agricultural governance. Although adoption is uneven, the application of digital technology is already visible in several regions, especially those with adequate infrastructure. This technology has proven to have positive impacts in the form of increased crop yields, efficient fertilizer use, and broader market access. However, there are also negative impacts, such as reduced social interaction among farmers due to the shift to digital systems, and the risk of increasing the gap between digitally literate and non-digital farmers.

Technology & Study Location	Implementation Example	Positive impact	Negative impact
IoT (soil sensors, drones, monitoring applications) East Java, West Java	Agri Drone Sprayer, soil moisture sensor	Water & fertilizer efficiency, real-time field monitoring	High costs, need digital literacy

Artificial Intelligence (AI) Central Java	Weather prediction, fertilizer recommendation application	More accurate cultivation decisions	Dependence on digital systems
GIS. Sleman, Berau	Polygon e-Reporting	Accurate land data, transparent subsidy distribution	Requires a stable internet connection
Smart Farming. Malang, Bogor	Agriculture War Room, Liniku.id	Increased productivity, digital marketing	Only accessible to young/educated farmers
Digital Applications. Java, Sumatra	TaniHub, iTani, iGrow, Desa Apps	Wide market access, fast information	Limited rural infrastructure

The rate of digital technology adoption by farmers is influenced by a number of social, economic, and infrastructure factors. The main drivers are the growing need for efficiency, government policy support, and encouragement from a younger generation who are more familiar with technology. However, Adoption is also hampered by low digital literacy, the relatively old age of farmers, limited access to infrastructure (internet and electricity), and high investment costs.

Factor	Driver	Inhibitor
Digital Literacy	Young farmers adapt quickly	Elderly farmers have difficulty using the application
Education	Formal education supports understanding of technology	Low basic education limits access to informants
Infrastructure	The existence of an internet network in urban areas	Remote areas with minimal internet and electricity access)
Cost	Government subsidy assistance & agritech programs	High initial investment costs (drone, sensors, app)
Socio-cultural	Support from extension workers & millennial farmer communities	Resistance to change from traditional methods

Research conducted by Prastiwi et al. (2025) revealed that Indonesia's agricultural sector is undergoing a transition due to digitalization, which has the potential to increase efficiency, productivity, and appeal to the younger generation. Although technologies such as sensors, drones, and real-time agricultural applications have been adopted in several regions and shown positive results, particularly in water efficiency, fertilizer efficiency, and harvest time, adoption remains generally limited (Sudaryanto et al., 2022). The government, private sector, and educational institutions are encouraged to collaborate in providing training, building rural digital infrastructure, and creating inclusive policies (Amelia & Munim, 2023). Digital business models are also crucial in leveraging technology for long-term benefits. With policy support and increased digital literacy, technology-based smart farming is believed to drive a comprehensive and sustainable transformation of Indonesian agriculture. A review of several articles shows that the use of technology in agricultural digitalization is quite diverse. The benefits of agricultural digitalization can be seen in Table 1.

Table 1. Utilization of Agricultural Digitalization

Technology	Tool	Reference
Digital marketing (app and website based)	Liniku.id, portalsayur.com, e-Fishery, Village Apps	Rafli et al., (2020); Wibowo, 2020; Amelia & Munim (2023)
Land management (Smart Farming)	Blockchain technology, Drone, Agriculture War Room, Agri Drone Sprayer	Rachmawati, 2020; Prastiwi et al., 2025

Digital outreach activities	Utilization of technologies such as virtual and augmented reality, 3D modeling, artificial intelligence, edge computing, digital twin, blockchain	Tapi et al., (2024)
Dissemination of agricultural information	iTani, iGrow, TaniHub, Desa Apps	Mayasari et al., (2020); Amelia & Munim (2023); Nasir (2021)

Source: (Author's Documentation, 2025)

Discussion/Analysis

The review results indicate that the agricultural digitalization process is taking place in stages, starting from the use of simple technologies such as mobile phones for information access, to advanced technologies such as drones and automation systems. The agricultural digitalization process, as demonstrated in the literature review, shows that technology adoption by farmers is not only determined by the availability of technology, but also by the implementation of various social factors that can shape how the technology is used (Sirajuddin, 2021). Research conducted by [15] shows the results of the use of the liniku.id application as a platform for digital marketing of agricultural products and also agrotourism. The development of Liniku.id as an intelligent agribusiness information system is a concrete example of the use of digital technology, where digital technology is not only available but also actively used by various actors (farmers, the private sector, and the government) to manage the agricultural process comprehensively, from production planning to post-harvest handling.

A different study by [16] concerns the iTani application, developed by the Center for Agricultural Library and Technology Dissemination. iTani supports the dissemination of agricultural information in the form of ebooks and interactive social features. This technology is not only intended for farmers but is also used by various stakeholders, such as agricultural extension workers, researchers, academics, students, and policymakers, thus creating a knowledge-based agricultural ecosystem. The presence of iTani reflects that technology does not develop linearly but is shaped by the social need for fast, inclusive, and easy-to-understand access to agricultural information. iTani not only provides information but also encourages collaboration and knowledge exchange across actors in the agricultural system. Research by [17] and [18] shows that various digital technologies have been adopted in the agricultural sector in Indonesia, particularly in East Java and Java. Farmers utilize applications such as iGrow, TaniHub, and e-Fishery for farm management, financing, and crop marketing. Social media such as WhatsApp, Facebook, and Instagram are also utilized for communication and promotion. Furthermore, e-commerce platforms like Tokopedia and Shopee are helping to expand market reach directly to consumers. In areas with greater access to technology, geographic information systems, digital climate data, and tools like drones and Internet of Things (IoT)-based sensors are being used to monitor crops, soil moisture, and irrigation and fertilizer efficiency [19].

Desa Apps is an example of digital agricultural extension, providing online discussion and consultation spaces between farmers and experts, as well as sharing information on crop diseases, market prices, and credit recommendations [18]. Other technologies include applications that provide weather information, cultivation techniques, price predictions, and the use of drones, soil sensors, and automatic irrigation systems. Programs such as the Farmer Card (Kartu Tani) also support the digitalization of subsidized fertilizer distribution and access to financing. However, limited funding, technical access, and low digital literacy remain major barriers, especially for older farmers. Smart farming technologies that are beginning to be implemented include the use of AI, big data, cloud computing, weather and soil sensors, and mobile/web-based applications that assist with crop planning,

fertilization, and satellite imagery-based monitoring. Overall, although technology adoption remains uneven, its potential for increasing agricultural efficiency and productivity is enormous.

Technology Distribution

To achieve adequate technology, information distribution is necessary. In agriculture, information distribution is generally carried out through agricultural extension services (Indraningsih, 2018). As explained by [20], agricultural extension activities have now been transformed by utilizing digital technology. This includes the use of online platforms and social media to reach farmers more widely and efficiently, allowing them to access information in real time and tailored to their needs and preferences. Information distribution can also occur without an extension process, with the existence of online information providers such as ebooks. [16] This article discusses the iTani application as a digital platform for distributing agricultural information and technology to stakeholders, including farmers, extension workers, and policymakers. This application is equipped with digital library and e-Reader features, as well as social features that enable interaction between users. iTani facilitates broad access to agricultural innovation and knowledge and serves as a platform for building virtual farmer group networks.

The distribution of digital technology in Indonesia's agricultural sector is carried out through various channels and collaborative approaches, including government programs such as "Millennial Farmers" and "Go Digital Farmers," training from agricultural offices, field extension workers, universities, and collaborations with agritech startups and non-governmental organizations [21]. Local governments also play a role through smart farming initiatives, although implementation is not yet evenly distributed across regions. Millennial farmer communities, farmer cooperatives, and horizontal relationships between farmers are important agents in participatory and bottom-up technology dissemination. Educational institutions such as Gadjah Mada University (UGM) have contributed to the dissemination of applications such as Desa Apps, which adhere to open access principles. In addition to training and mentoring, partnerships between the public and private sectors are a key strategy for expanding access to digital technology. However, the distribution of this technology still faces significant challenges, particularly in remote areas and areas outside Java, which have limited infrastructure such as internet networks and electricity access. The lack of long-term technical support and the availability of digital devices also hinder the equitable distribution of technology. Therefore, technology distribution efforts require inclusive infrastructure development and cross-sector support to ensure optimal digital transformation in agriculture across Indonesia.

Challenges of Using Digital Technology

In today's digital era, the use of technology in various sectors, including agriculture, has become crucial for increasing efficiency and productivity. However, despite the immense potential offered by technology, the challenges in its implementation cannot be ignored. Various obstacles, such as low levels of digital literacy among users, limited access to adequate infrastructure, and adaptation to constantly evolving innovations, create barriers to the effective use of technology in the field. [3] identified several challenges faced by farmers in adopting digital technology for Smart Farming 4.0. The main challenges include low adoption rates due to a lack of understanding and distrust of technology, high investment costs, and difficulties in changing perceptions about modern agricultural machinery. Limited internet access in some areas and the need to input large amounts of data into software also hinder adoption. Furthermore, the complexity of the technology and the low qualifications of the rural workforce are additional factors that complicate it. These challenges highlight the need for appropriate training, support, and policies to increase technology adoption in agriculture.

The implementation of digital technology in Indonesia's agricultural sector faces various structural, cultural, and economic challenges. Key challenges include low digital literacy, particularly among older and traditional farmers, and limited internet network infrastructure in rural areas. Many farmers struggle to operate digital applications without ongoing training or technical assistance. Furthermore, limited access to devices like smartphones and the high initial investment costs for sophisticated tools like drones and sensors are significant barriers. Dependence on external actors, such as app developers or donor agencies, also hinders technology adoption from being fully independent and sustainable. Other challenges include a lack of long-term institutional support, gender and generational gaps, with women farmers and farmers outside Java facing less access, and resistance to changes in traditional work patterns. Another emerging issue is suboptimal agricultural data management due to a lack of comprehensive data integration and analysis. Furthermore, issues of personal data protection and regulation are also gaining attention with the increasing digitalization. These challenges underscore the importance of a more inclusive, contextual, and adaptive approach to ensure the digital transformation of agriculture is effective and reaches all levels of farmers in Indonesia.

Digitalization in Agriculture Shapes the Social Shaping of Technology

The Social Shaping of Technology (SST) approach emphasizes that technology is not neutral or standalone, but rather the result of interactions between technology and social actors such as farmers, government, extension workers, and educational institutions. Adopting the Social Shaping of Technology approach helps us understand that to achieve success in sustainable agricultural extension, we need to consider how technology is shaped by and shapes social practices within agricultural communities. For example, in the article by [20] explaining the interaction between Technology and Agricultural Practices, technology adoption depends not only on its technical sophistication, but also on how farmers and extension workers adapt the technology in their daily practices. In this regard, agricultural extension workers have a very important role, not only as a channel of information and resources, but also as a driver in the application of technology that can transform the agricultural sector to be more efficient and resilient. [20] also explain the paradigm shift in agricultural extension towards society 5.0 focusing on the integration of humans, technology, and the environment. This can be interpreted as meaning that technological solutions cannot be implemented directly without considering the social context and local characteristics of farmers.

Digital technologies, such as agricultural applications, do not exist as neutral entities, but are shaped by farmers' needs, local power structures, and interactions between actors such as farmers, extension workers, government agencies, NGOs, and development institutions [18]. A concrete example is the use of WhatsApp by farmer groups for fertilizer distribution and crop sales, demonstrating the social adaptation of common technologies to suit local practices. Within the SST framework, farmers are viewed as active actors modifying and shaping the technology's function, not merely passive recipients. The success of technology adoption depends heavily on the social negotiation process between the various parties involved, as well as on how the technology is adapted to local languages, customs, and communication styles.

5. CONCLUSION

Agricultural digitalization in Indonesia is showing positive progress, although it is not yet evenly distributed. Digital technology adoption is influenced by factors such as age, education, infrastructure, and socio-cultural dynamics. The Social Shaping of Technology approach emphasizes that the success of digital transformation depends not only on technological sophistication but also on social adaptation

and the participation of various stakeholders. Barriers such as low digital literacy, limited infrastructure, and high investment costs need to be addressed through inclusive policies, continuous training, and cross-sector collaboration. With the right strategy, digitalization can strengthen food security and improve farmer welfare sustainably.

STUDY FORWARD

It is recommended that future research focus more on evaluating the implementation of digital technology across diverse geographic and socio-cultural contexts, particularly outside Java, which still lags behind in technology adoption. Furthermore, participatory approaches involving farmers as active participants in the innovation process need to be developed to better understand how technology is adopted and adapted to local needs.

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