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Industrial Revolution 4.0 and the Future of the Agricultural Sector: A Theoretical Study on Technological Adaptation and Its Impact on Farmers' Welfare

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ABSTRACT

This study aims to theoretically examine the influence of the Fourth Industrial Revolution on the future of the agricultural sector, particularly in the context of technological adaptation and its impact on farmers' welfare. Using a literature review method and a descriptive qualitative approach, this research analyzes various scholarly sources obtained from Google Scholar and credible websites such as the World Economic Forum between 1989 and 2025. Out of 50 articles initially identified, only 26 were selected after a rigorous screening process based on relevance and credibility. The analysis results indicate that the application of digital technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) has a significant impact on improving productivity, efficiency, and farmers' welfare. Theories such as the Diffusion of Innovation, Technology Acceptance Model, and Sustainable Livelihood Framework are used to explain the process of technology adoption and its socio-economic effects on farmers' lives. However, the study also reveals that challenges such as low digital literacy, limited infrastructure, and unequal access to technology remain major barriers to the implementation of Industry 4.0-based agriculture in Indonesia.

ABSTRAK

Penelitian ini bertujuan untuk mengkaji secara teoretis pengaruh Revolusi Industri 4.0 terhadap masa depan sektor pertanian, khususnya dalam konteks adaptasi teknologi dan dampaknya terhadap kesejahteraan petani. Dengan menggunakan metode tinjauan pustaka dan pendekatan kualitatif deskriptif, penelitian ini menganalisis berbagai sumber ilmiah yang diperoleh dari Google Scholar dan website kredibel seperti World Economic Forum dalam rentang waktu 1989–2025. Dari 50 artikel yang ditemukan, hanya 26 artikel yang dipilih setelah melalui proses seleksi ketat berdasarkan relevansi dan kredibilitas. Hasil analisis menunjukkan bahwa penerapan teknologi digital seperti Internet of Things (IoT), big data analytics, dan kecerdasan buatan (AI) memiliki pengaruh signifikan terhadap peningkatan produktivitas, efisiensi, dan kesejahteraan petani. Teori Diffusion of Innovation, Technology Acceptance Model, dan Sustainable Livelihood Framework digunakan untuk menjelaskan proses adopsi teknologi dan dampaknya terhadap kehidupan sosial-ekonomi petani. Namun, penelitian juga menemukan bahwa hambatan seperti rendahnya literasi digital, keterbatasan infrastruktur, dan kesenjangan akses teknologi masih menjadi tantangan utama dalam implementasi pertanian berbasis Revolusi Industri 4.0 di Indonesia.

1. INTRODUCTION

The development of the Fourth Industrial Revolution has brought major changes to various sectors of human life, including agriculture, which has long been associated with traditional and labor-intensive practices. This era is marked by the emergence of digital technologies, artificial intelligence (AI), the Internet of Things (IoT), big data, and automation systems that transform how people work, produce, and interact. In the agricultural context, Industry 4.0 opens significant opportunities to enhance productivity and efficiency through the use of advanced technologies such as soil sensors, agricultural drones, automated irrigation systems, and real-

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time data monitoring. However, this transformation also presents distinct challenges, especially for smallholder farmers who still rely on traditional methods. Disparities in technology access, low digital literacy, and limited capital are among the primary obstacles preventing many farmers from benefiting from the digital transformation in agriculture (Hidayati et al., 2025; Satria et al., 2025).

The transition toward digital agriculture, commonly referred to as smart farming, requires a paradigm shift from conventional farming methods to data-driven and technology-based practices. The use of IoT enables farmers to monitor land conditions, soil moisture, nutrient levels, and weather patterns with high accuracy, allowing for more precise and efficient decision-making (Hartono et al., 2024; Joshi, 2023). Furthermore, the application of big data analytics assists in predicting crop yields and optimizing the use of natural resources such as water and fertilizers, which were previously managed manually. In this context, production efficiency increases, operational costs decrease, and crop yields improve significantly. However, the success of these technological applications depends heavily on farmers' ability to adapt and the government's role in providing adequate digital infrastructure in rural areas.

Beyond the technological aspect, the Fourth Industrial Revolution is also reshaping the social and economic structure of the agricultural sector. Farmers who successfully adopt modern technologies have greater opportunities to increase income and expand their market reach, both locally and globally. Conversely, farmers who fail to keep up with these developments risk being left behind and further marginalized within the modern economy. The digital divide between modern and traditional farmers can widen the welfare gap, creating new forms of social stratification in rural communities (Liu & Zhou, 2023; Revenko & Revenko, 2022). In the long term, this condition may reduce young people's interest in pursuing farming as a profession, as it is perceived as less promising economically and socially. Ensuring the sustainability of agriculture in the digital era therefore requires adaptation strategies centered on human development and social inclusivity.

Adaptation is the key factor in determining the extent to which the Fourth Industrial Revolution can positively influence farmers' welfare. Adaptation here refers to the farmers' ability to understand, access, and effectively utilize technology in their agricultural activities. The Technology Acceptance Model (TAM), developed by Davis (1989), explains how perceived ease of use and perceived usefulness influence farmers' decisions to adopt new technologies. Farmers who observe tangible benefits from using technology—such as increased yields or reduced labor time—are more likely to develop positive attitudes toward digital innovation. However, without sufficient training, mentoring, and access to necessary resources, the adaptation process can be slow or even fail to be implemented sustainably.

Furthermore, it is essential to highlight the role of the government, educational institutions, and the private sector in supporting technological adaptation within the agricultural sector. The government, through its digital agriculture transformation policies, can act as a facilitator by providing network infrastructure, access to financing, and technological education and training for farmers. Meanwhile, educational institutions can serve as centers of innovation and research that develop technological solutions tailored to local needs. On the other hand, the private sector holds great potential in creating a digital ecosystem through collaborations with agritech startups such as eFishery, TaniHub, and Sayurbox, which have successfully helped Indonesian farmers gain access to broader online markets. This cross-sector collaboration is crucial to ensure that the implementation of the Fourth Industrial Revolution in agriculture produces tangible socioeconomic benefits for farmers.

Farmers' welfare serves as a key indicator of the success of digital transformation in agriculture. Improvements in welfare can be measured through enhancements in quality of life, access to education and healthcare, and economic stability of farming households (Hidayatulloh, 2019). In this context, the use of technology can strengthen farmers' positions within the agricultural value chain by providing direct market access without intermediaries, increasing bargaining power, and reducing dependence on middlemen. However, such welfare improvements can only be achieved if agricultural digitalization is accompanied by inclusive policies that ensure all segments of the farming community have equal opportunities to benefit from technological advancements.

Nevertheless, various challenges continue to hinder the acceleration of technological adaptation in the agricultural sector, especially in developing countries such as Indonesia. Limited internet infrastructure in rural areas, the high cost of digital equipment investment, and low digital literacy levels are among the main barriers (Hidayati et al., 2025). Moreover, most Indonesian farmers are smallholders with limited land ownership, leading them to perceive technology as expensive and irrelevant to their scale of production. This

situation has resulted in a growing technological adoption gap between urban and rural areas, as well as between large and small-scale farmers. Therefore, a contextual and locally-driven approach must be developed to ensure that technology truly serves as a tool for empowerment rather than a source of new inequality.

From a long-term perspective, the Fourth Industrial Revolution holds the potential to transform agriculture into a more modern, efficient, and sustainable sector. Technology-driven agriculture can contribute to achieving the Sustainable Development Goals (SDGs), particularly in eradicating poverty, ending hunger, and ensuring food security. By utilizing technologies such as AI-based weather prediction systems, land-monitoring drones, and digital platforms for crop trade, future agriculture will become more adaptive to climate change and global market dynamics (Agrawal & Arafat, 2024; Chandran, 2022). However, this success can only be realized if all stakeholders actively participate in creating an environment that supports innovation, collaboration, and equitable technological access among farmers.

Based on the above discussion, this study aims to theoretically examine how the Fourth Industrial Revolution influences the agricultural sector, particularly in the context of technological adaptation and its impact on farmers' welfare. This theoretical review is expected to provide a deeper understanding of the dynamics of digital transformation in agriculture and offer a conceptual perspective on effective adaptation strategies for addressing structural changes in the era of the Fourth Industrial Revolution.

2. THEORETICAL FRAMEWORK AND HYPOTHESES

Industrial Revolution 4.0

The Fourth Industrial Revolution represents a major transformation in global production systems and economic structures, characterized by the integration of digital technology, automation, artificial intelligence (AI), the Internet of Things (IoT), big data, and cyber-physical systems into various sectors of human life, including agriculture (Morella et al., 2021). This revolution creates a new pattern of interaction between humans, machines, and data. In the agricultural context, Industry 4.0 introduces a new paradigm that emphasizes efficiency, precision, and sustainability through the use of digital technology to optimize the entire production chain—from land management and crop maintenance to post-harvest distribution. The Fourth Industrial Revolution serves as the foundation for the emergence of modern agriculture that is adaptive to climate change, global market demands, and future food security challenges.

Digital Agriculture

Digital agriculture, or smart farming, refers to the application of digital technologies throughout the entire agricultural process to enhance efficiency, productivity, and sustainability (Sari, 2023). By utilizing tools such as soil sensors, drones, automated irrigation systems, data-driven applications, and agricultural e-commerce platforms, farmers can monitor land, weather, and crop conditions in real time, allowing for faster and more accurate decision-making. Digital agriculture also enables more efficient use of resources such as water and fertilizers while reducing the risk of crop failure caused by improper land management. In Indonesia, the implementation of digital agriculture has been growing with the emergence of various agritech startups such as eFishery, TaniHub, and Sayurbox, which help farmers increase market access and income. Thus, digital agriculture serves as a key element in realizing sustainable agricultural transformation in the era of the Fourth Industrial Revolution.

Technological Adaptation

Technological adaptation in the agricultural sector refers to the process by which farmers and agribusiness actors adjust to the use of new technologies arising from the advancements of the Fourth Industrial Revolution. This process involves understanding, accepting, and applying digital technologies in agricultural production, distribution, and marketing activities. According to the Technology Acceptance Model (Davis, 1989), the success of adaptation is strongly influenced by farmers' perceptions of the usefulness and ease of use of the technology. Adaptation encompasses the mental, social, and economic readiness of farmers to transition from traditional to digital farming practices. Practically, technological adaptation requires support through training, mentoring, and policies that facilitate access to digital tools and internet infrastructure. With proper adaptation, farmers can enhance productivity, efficiency, and competitiveness in an increasingly dynamic and competitive global market.

Farmers' Welfare

Farmers' welfare reflects the overall quality of life among farmers, encompassing economic, social, and psychological dimensions such as stable income, food security, access to education and healthcare, and job satisfaction (Lumbantoruan et al., 2024; Rozci & Laily, 2023). In the context of the Fourth Industrial Revolution, farmers' welfare is measured by their ability to utilize technology to improve work efficiency and expand market access. The adoption of digital technology allows farmers to reduce dependence on middlemen, gain transparent access to market price information, and sell products directly to consumers through online platforms. Thus, technology plays a vital role in strengthening farmers' bargaining power and promoting economic equity within the agricultural supply chain. However, to ensure that welfare improvements are distributed evenly, inclusive policies are necessary to guarantee that all groups of farmers have the access and capacity to participate in the ongoing digital transformation of agriculture.

3. RESEARCH METHOD

This study employs a literature review method with a qualitative approach, aiming to gain an in-depth understanding of the phenomenon of technological adaptation within the context of the Fourth Industrial Revolution and its impact on farmers' welfare. The qualitative approach was chosen because it allows for comprehensive and interpretative analysis of data by examining concepts, theories, and empirical findings presented in previous studies. Through this approach, the research focuses on exploring the meaning, interrelationships, and dynamics of each study relevant to the research topic. The type of data used in this research is secondary data obtained from various scholarly sources, such as journal articles, conference proceedings, research reports, and official publications related to the theme "The Fourth Industrial Revolution and the Future of the Agricultural Sector: A Theoretical Study on Technological Adaptation and Its Impact on Farmers' Welfare." Data were collected through searches on Google Scholar and several credible websites, including the official site of the Ministry of Agriculture of the Republic of Indonesia, the Food and Agriculture Organization (FAO), the World Bank, and other reputable international research institutions specializing in agriculture and technology.

The data collection process was carried out using keywords such as Industrial Revolution 4.0 in agriculture, smart farming, digital transformation in agriculture, technology adaptation, and farmers' welfare. The initial search identified 50 scientific articles relevant to the research topic. The next step involved a selection process based on several criteria: (1) articles published between 1989 and 2025, (2) studies focusing on the application of agricultural technologies in the era of the Fourth Industrial Revolution, (3) inclusion of empirical data or theoretical frameworks supporting discussions on technological adaptation and farmers' welfare, and (4) publication in accredited journals or reputable research institutions. After a rigorous selection process based on relevance, source credibility, and depth of analysis, only 26 scientific articles were selected as the main sources for this study. These articles were chosen for their strong alignment with the research focus and their conceptual contributions to the discussion on technological adaptation in the agricultural sector. The selection was carried out carefully to ensure that each source used provided significant academic value and supported the analytical outcomes.

The analytical method applied in this study is qualitative descriptive analysis, in which each selected article was examined to identify patterns, themes, and relationships among key concepts such as technological adaptation, digital agricultural transformation, and farmers' welfare. The analysis involved an in-depth reading of the articles, noting key findings, and comparing previous research results to develop a comprehensive theoretical understanding. The findings were then presented in a systematic descriptive form to illustrate how the Fourth Industrial Revolution has influenced the socio-economic structures and welfare dynamics of farmers across different contexts. Throughout the research process, principles of academic transparency, data validity, and interpretative accuracy were strictly maintained. To enhance the reliability of findings, each piece of information obtained from articles or web sources was verified for authenticity and cross-checked against other relevant sources.

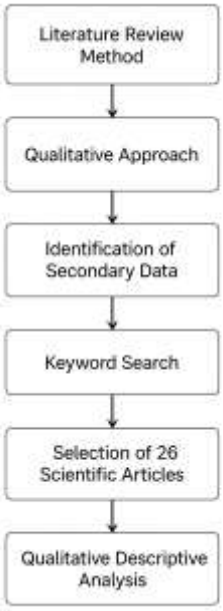


Figure 1. Research Flowchart

4. DATA ANALYSIS AND DISCUSSION

The Fourth Industrial Revolution marks an era in which the integration of digital, physical, and biological technologies has transformed how humans work, produce, and interact, including within the agricultural sector, which has traditionally relied on manual labor and natural factors. Within the framework of the Diffusion of Innovation theory introduced by Rogers et al. (2019), this transformation can be understood as a social process that emphasizes the importance of individuals or groups in gradually disseminating and adopting innovations. In agriculture, innovations such as soil moisture sensors, drones for land monitoring, and Internet of Things (IoT) systems for irrigation management represent tangible applications of the Fourth Industrial Revolution that shift farmers' work patterns from intuition-based to data-driven decision-making. In Indonesia, the adoption of digital technology in agriculture has shown promising results in several regions, including Karawang Regency. Through the irrigation modernization program developed by BBWS Citarum under the Strategic Irrigation Modernization and Urgent Rehabilitation Project (SIMURP), irrigation systems in this area have started utilizing sensors and weather data to regulate water distribution more efficiently based on field requirements (BBWS Citarum, 2022; SIMURP, 2021). This smart irrigation approach enables farmers to optimize water usage, reduce waste by up to 30%, and improve production stability amidst climate variability. This success demonstrates that the integration of digital technology in agriculture provides a concrete solution to long-standing challenges such as resource inefficiency and crop uncertainty, while promoting a more adaptive and sustainable agricultural system.

The development of digital technology in the agricultural sector has had a significant impact on improving farmers' productivity and welfare, particularly in developing countries like Indonesia, where the economy heavily depends on agriculture. According to Agrifi (2025), the adoption of data-driven technologies, including drones, environmental sensors, and digital farm management systems, can increase average crop yields by 15–30% while reducing resource waste. This indicates that digitalization strengthens food security by optimizing production processes. In Indonesia, research by Satria et al. (2025) further supports these findings, showing that the implementation of IoT technology in horticultural farming in East Java reduces operational costs while increasing labor efficiency and crop quality. Another critical impact is the enhancement of farmers' bargaining power in both domestic and export markets, as digital systems allow them to maintain consistent product quality and quantity. However, the success of this technological adoption depends greatly on human resource readiness, particularly in digital literacy, data interpretation, and technology-based business management. The success of digital transformation in agriculture is thus determined by how well farmers can understand and manage innovations as part of their long-term business and welfare strategies.

Psychological factors and farmers' perceptions of technology are vital in ensuring the success of digital innovation adoption in agriculture, as explained by the Technology Acceptance Model (TAM) developed by Davis (1989). This model asserts that an individual's intention to use technology is strongly influenced by two key factors: perceived usefulness—how much they believe the technology will improve their performance—and perceived ease of use—the degree to which the technology is seen as easy to operate. In practice, farmers who recognize the tangible benefits of technology, such as time efficiency, cost reduction, or yield improvement, tend to have a positive attitude toward digital adoption. A concrete example can be found in the TaniHub platform, where farmers can sell their produce directly to consumers without intermediaries, gaining up to 20% higher profit margins while expanding their market reach (Ningtyas et al., 2023). This success fosters a positive perception that technology is not a threat but rather an empowering tool that simplifies agricultural business processes. Furthermore, such perceptions tend to spread within farming communities through social interaction, creating a snowball effect that accelerates agricultural digitalization. Strengthening confidence and perceived benefits of digital technology forms a crucial psychological foundation for the successful transformation toward smart and sustainable agriculture.

The Sustainable Livelihood Framework (Chambers & Conway, 1992) offers a comprehensive perspective for understanding how the adoption of agricultural technology in the Fourth Industrial Revolution era enhances farmers' welfare holistically. This theory highlights the importance of five core assets—human, natural, financial, social, and physical—which interact to build resilience and sustainability in agrarian livelihoods. When digital technologies such as precision agriculture, soil sensors, and drones are applied effectively, these five assets experience synergistic improvement. For instance, human assets increase through enhanced farmer skills in digital data interpretation; natural assets are preserved through more efficient use of fertilizers and water; financial assets grow due to higher productivity; social assets strengthen through community-based technology collaboration; and physical assets expand with improved access to digital agricultural infrastructure. A notable example is found in Sleman, Yogyakarta, where the use of drone-based precision agriculture helped chili farmers detect pests early and reduce crop failure risks by up to 40% (Kuntadi, 2024). Technology in the Fourth Industrial Revolution serves as a medium for economic, social, and environmental empowerment, oriented toward sustainable well-being. This approach underscores that the success of technology adoption is measured not only by innovation itself but also by the extent to which it strengthens farmers' capacity to sustain their livelihoods.

Although the potential of digital technology in agriculture is immense, various structural, economic, and social barriers remain major obstacles to digital transformation in developing countries such as Indonesia. According to Satria et al. (2025), the most fundamental challenge lies in the limited digital infrastructure in rural areas, particularly weak and uneven internet access. This issue is compounded by the low level of digital literacy among farmers, which prevents many from being able to operate technological devices or interpret data from IoT and precision farming systems. Furthermore, economic constraints pose a critical challenge, as the cost of technologies such as soil sensors, drones, and digital analysis tools remains relatively high for small-scale farmers, making them accessible only to larger agricultural enterprises. As a result, digitalization risks widening the inequality gap between economically empowered farmers and smallholders. Without affirmative government policies, intensive training, and technology subsidies, agricultural digitalization may create new forms of social disparity. Public policy intervention thus becomes a key element to ensure that the benefits of the Fourth Industrial Revolution are distributed equitably. Collaboration among government institutions, educational bodies, and the private sector is essential to provide digital infrastructure, expand access to technological financing, and enhance human resource capacity so that digital agricultural transformation can be truly inclusive and socially just.

From a social perspective, the Fourth Industrial Revolution has brought fundamental changes to the structure and dynamics of rural life, particularly in terms of agricultural workforce regeneration. For decades, agriculture has often been perceived as an unattractive sector by younger generations due to its association with outdated practices and high risks from unpredictable weather and volatile market prices. However, with the emergence of digital technologies such as IoT systems, smart farming, and online marketing platforms, the image of agriculture is gradually shifting toward a modern, innovative, and promising profession. The "Petani Muda Keren" community in Yogyakarta exemplifies how technology can inspire young people to re-engage in agriculture using more professional and efficient approaches. By utilizing IoT sensors to monitor soil moisture and data-driven applications to manage planting schedules, these young farmers have succeeded in increasing productivity while reducing reliance on manual forecasts (Petani Muda Keren,

2023). This initiative has also strengthened social solidarity and built a sustainable, environmentally friendly modern agricultural ecosystem. This phenomenon demonstrates that digitalization generates significant cultural and social transformation. The Fourth Industrial Revolution can thus serve as a catalyst for agricultural regeneration in Indonesia, transforming the traditional perception of farming as a conventional occupation into a strategic profession oriented toward innovation, collaboration, and sustainable development.

From an economic standpoint, the digital transformation brought by the Fourth Industrial Revolution has created a new paradigm in agricultural supply chains, where relationships between producers and consumers have become more direct, transparent, and efficient. The emergence of digital platforms such as Sayurbox, EdenFarm, and TaniHub has revolutionized how farmers sell their produce by cutting out lengthy distribution chains traditionally controlled by middlemen and large traders (Nurjati, 2021). Through the farm-to-table system, farmers can sell directly to end consumers, restaurants, hotels, and supermarkets at more profitable prices. This mechanism reduces the risks of price fluctuations and market uncertainties that often disadvantage producers. Research by Lubis et al. (2025) supports this by showing that agricultural digital marketplaces increase farmers' income through price transparency, stronger bargaining power, and transaction efficiency. In Indonesia, this business model has also created a new digital rural economy ecosystem, where farmers can access wider markets beyond geographic constraints. Moreover, the use of consumer demand data generated by digital platforms allows farmers to conduct more precise planting planning, minimizing risks of overproduction and post-harvest waste. Digitalization in agriculture thus serves as a strategic economic instrument that strengthens farmers' positions as key players in the national agribusiness value chain.

Although the benefits of agricultural digitalization have been empirically proven, the long-term success of this transformation depends on human adaptability as the core of change. Farmers are required to understand data-driven management concepts in order to integrate them into daily farming practices. Hence, synergy between the government, educational institutions, and the private sector is crucial in building an inclusive and equitable digital agricultural ecosystem. The government must expand network infrastructure in rural areas to eliminate internet access barriers, while educational and training institutions should provide practical, needs-based digital literacy programs tailored to farmers' realities. Private sector support can be realized through subsidizing technology-based agricultural tools and implementing sustainable mentoring programs. Universities also hold a strategic role in developing applied research tailored to local contexts, such as creating crop-monitoring applications in regional languages or voice-based notification systems for farmers with limited literacy. Through a human-centered and contextual approach, the digital transformation process can enhance farmers' social capacity and independence, turning digitalization into an empowering process that opens both economic and social opportunities across rural communities.

As a long-term effort, digital agricultural transformation requires an integrative policy framework that unites technological, social, and economic dimensions under a sustainable national development strategy. The government plays a central role in designing policies focused on human resource readiness and institutional capacity at the local level. One strategic initiative that can be implemented is the "Digital Smart Farming Village" program—a community-based model emphasizing intensive training, applied research, and direct assistance to help farmers utilize digital technology optimally. This program can be integrated with support from agritech startups such as eFishery and Habibi Garden, both of which have demonstrated success in improving farmers' and fish cultivators' production efficiency through automated sensors and data analytics (Habibi Garden, 2024; Sabran & Rusfian, 2023). Cross-sector collaboration among local governments, research institutions, and technology industries can further accelerate knowledge transfer and foster adaptive agricultural business models aligned with global market dynamics. In addition, fiscal policies such as tax incentives for local agritech enterprises and improved capital access for technology-adopting farmers can strengthen program sustainability. With a targeted and inclusive approach, the Fourth Industrial Revolution in agriculture can serve as a foundation for improving farmers' welfare, enhancing national food security, and achieving sustainable rural economic independence in Indonesia.

Table 1. Digital Transformation in Agriculture within the Fourth Industrial Revolution

No	Main Theme	Key Findings	Supporting Evidence / Example	Implications
1	**Technological Integration and**	The Fourth Industrial Revolution transforms traditional ag-	BBWS Citarum's SIMURP program in Karawang uses sensors and weather data to	Demonstrates efficiency improvement and adap-

	Innovation Diffusion	riculture into data-driven systems through IoT, drones, and smart irrigation.	optimize irrigation, reducing water waste by 30%.	tation to climate variability through digital technologies.
2	**Productivity and Farmer Welfare**	Adoption of digital tools increases productivity by 15–30% and enhances farmers' income and market access.	Agrifi (2025); Satria et al. (2025) findings in East Java; improved labor efficiency and crop quality.	Strengthens food security and reduces resource inefficiency, fostering sustainable agricultural growth.
3	**Psychological and Perceptual Factors (TAM)**	Farmers' intention to adopt technology depends on perceived usefulness and ease of use.	TaniHub platform increases farmers' profits by up to 20% while expanding markets.	Positive technology perception encourages widespread adoption and collective digital transformation.
4	**Sustainable Livelihood Framework**	Digital technologies improve the five livelihood assets: human, natural, financial, social, and physical.	Drone-assisted chili farming in Sleman reduced pest risks by 40%.	Enhances sustainability and resilience of rural livelihoods through technology-based empowerment.
5	**Structural and Economic Barriers**	Rural digital infrastructure gaps and low literacy hinder adoption; high costs limit smallholders' access.	Limited internet access and affordability of drones and IoT tools in developing areas.	Requires government intervention, training, and subsidies for inclusive digital agriculture.
6	**Social Transformation and Youth Engagement**	Digitalization rebrands agriculture as a modern and attractive sector for youth.	"Petani Muda Keren" community in Yogyakarta uses IoT-based monitoring to improve productivity.	Encourages generational regeneration and sustainable modern farming culture.
7	**Economic Transformation and Supply Chain Efficiency**	Digital platforms reduce intermediaries, enabling direct sales and higher profits.	Sayurbox, EdenFarm, and TaniHub connect farmers directly with consumers and markets.	Strengthens farmers' bargaining power and transparency in agricultural markets.
8	**Human-Centered Adaptability and Collaboration**	Success depends on farmers' ability to manage data and cross-sector collaboration.	Government, academia, and private sectors jointly build inclusive ecosystems.	Encourages practical training, localized research, and contextual digital literacy programs.
9	**Policy and Institutional Support**	Integrative national policy frameworks are needed for sustainable digital transformation.	"Digital Smart Farming Village" concept with eFishery and Habibi Garden as partners.	Supports innovation diffusion, fiscal incentives, and long-term agricultural resilience.
10	**Overall Impact**	Digitalization redefines agriculture as a driver of economic empowerment and sustainability.	Holistic integration of technology, human capital, and institutional support.	Promotes food security, rural independence, and equitable development in Indonesia.

5. CONCLUSION, IMPLICATION, SUGGESTION, AND LIMITATIONS

This study concludes that the Fourth Industrial Revolution has brought fundamental transformations to the agricultural sector through the application of digital technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and automation systems that enhance efficiency, productivity, and farmers' competitiveness. Adaptation to these technologies has shown a positive impact on farmers' welfare, both in terms of increased income, time efficiency, and expanded market access. Based on the Diffusion of Innovation Theory, the Technology Acceptance Model, and the Sustainable Livelihood Framework, the success of technology adoption is largely determined by farmers' perceptions of its usefulness and ease of use, government policy support, and the availability of digital infrastructure. However, gaps in digital literacy and limited access to technological resources remain major challenges in accelerating the transition toward technology-driven agriculture in Indonesia.

Theoretically, the findings of this study indicate that technology adoption in agriculture cannot be understood merely as a technical process but rather as a socio-economic phenomenon influenced by cultural,

psychological, and structural factors. Therefore, a multidimensional approach that integrates innovation theory, technology adoption models, and economic sustainability perspectives is essential for comprehending the dynamics of agricultural digitalization. Practically, the results of this study provide a foundation for policymakers, academics, and industry stakeholders to design more inclusive and adaptive strategies for agricultural transformation. The government can utilize these findings as a reference for developing national agricultural digitalization policies—such as community-based smart farming programs, farmer digital literacy training, and the expansion of technological infrastructure in rural areas.

This study, however, acknowledges several limitations. First, as it employs a literature review approach, the research findings rely entirely on the quality and relevance of the analyzed sources. The data used were drawn from scientific publications and credible websites spanning the period of 1989–2025; thus, the findings are conceptual in nature and not supported by empirical field data. Second, most of the analyzed literature focuses on agriculture in developing countries in general, meaning it may not fully represent the specific socio-economic and ecological conditions of farmers across different regions in Indonesia. Third, this study does not provide an in-depth discussion of financing mechanisms, regulatory frameworks, or digital infrastructure readiness, all of which may serve as critical factors in determining the success of technological adoption in the agricultural sector.

Based on the results and limitations of this study, several recommendations can be proposed for future research and policy development. First, future empirical research should employ field-based approaches to directly identify the challenges and opportunities farmers encounter in adopting technologies associated with the Fourth Industrial Revolution. This can be achieved through surveys, interviews, or case studies conducted across various agricultural regions in Indonesia. Second, collaboration between government institutions, educational bodies, and the private sector is essential for creating an inclusive digital agricultural ecosystem. Programs such as the Digital Smart Farming Village can serve as national models to accelerate the technological transformation of agriculture. Third, the government should focus on expanding internet access, subsidizing technological equipment, and conducting digital literacy training for rural farmers to minimize the technological divide. Fourth, for academics and researchers, further studies are needed to develop theoretical models that integrate social, economic, and technological factors to comprehensively understand the relationship between agricultural digitalization and farmers' welfare in the era of the Fourth Industrial Revolution.

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