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Implementation of Smart Farming: Utilizing the Internet of Things (IoT) to Enhance Productivity and Efficiency in Sustainable Agriculture

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Abstract
Sustainable agriculture faces challenges such as land degradation, climate change, and resource constraints, requiring innovative technology-based approaches. One potential solution is smart farming with the use of the Internet of Things (IoT) which allows real-time data collection through sensors to support precise agricultural decision-making. This study aims to explore the potential, benefits, and challenges of implementing IoT-based smart farming in Indonesia, as well as formulate effective adoption strategies. The method used is a literature study with a qualitative approach, reviewing 10 recent scientific articles from national and international journals in the last five years. The results of the study show that IoT plays a major role in increasing the efficiency of water, fertilizer, and pesticide use, as well as boosting productivity through automatic monitoring and control. On the other hand, significant challenges include initial investment costs, low digital literacy of farmers, and limited internet infrastructure in rural areas. Case studies from various regions in Indonesia also show that the success of IoT adoption is highly dependent on institutional support, technical training, and policy incentives. With a cross-sectoral approach and strengthening farmer capacity, IoT-based smart farming can be an important pillar in achieving more productive, efficient, and environmentally friendly agriculture.

INTRODUCTION

Agriculture is a vital sector in the Indonesian economy, playing an important role in food security and providing employment (Mendrofa et al., 2024). However, this sector faces significant challenges, such as climate change, land degradation, and limited natural resources, which hinder agricultural productivity and efficiency (Stupina et al., 2021). To overcome these problems, technological innovations are needed that can improve efficiency and sustainability in agricultural practices.

Smart Farming refers to the application of advanced digital technologies in agriculture to improve efficiency, productivity, and sustainability. Innovations such as the Internet of Things (IoT), artificial intelligence (AI), remote sensing systems, and big data have enabled farmers to monitor and

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manage farmland in real-time. According to Wolfert et al. (2020), these precision farming technologies enhance data-driven decision-making for pest control, irrigation, fertilization, and harvesting (Wolfert et al., 2017). Adoption of these technologies significantly reduces resource waste and increases crop yields. A study by Basch et al. (2022) also confirmed that Smart Farming contributes to global food security by optimizing sustainable agricultural production (Basch et al., 2012).

In the context of its application in developing countries, challenges remain quite large, especially related to costs, digital infrastructure, and technological literacy. Research by Klerkx et al. (2021) shows that collaboration between governments, the private sector, and research institutions is needed to ensure inclusiveness in the digital transformation of agriculture (Klerkx et al., 2019). The use of drones for land mapping and soil sensors for moisture monitoring are concrete examples of Smart Farming applications that have been widely adopted. With the increasing development of cloud-based platforms and edge computing, the potential for smart farming in the future is expected to increase exponentially, as noted by Liakos et al. (2021) in their review of global trends in digital agriculture (Liakos et al., 2018).

One promising innovation is the application of the Internet of Things (IoT) in agricultural systems, known as smart farming. IoT enables real-time data collection and analysis through sensors and connected devices, so that farmers can make more precise and efficient decisions (Halawa, 2024; Rachmawati, 2020). This technology has been proven to increase productivity and efficiency of resource use in various case studies in Indonesia (Wahyudi et al., 2025).

The implementation of IoT-based smart farming covers various aspects, such as automatic irrigation systems, monitoring soil and plant conditions, and precise pest and disease control. For example, the use of soil moisture and air temperature sensors can optimize watering schedules, saving water usage by up to 30% (Junaidi & Ramadhani, 2024). In addition, this technology also allows early detection of pest and disease attacks, which can reduce crop losses.

Although the potential for smart farming is enormous, the adoption of this technology among Indonesian farmers is still relatively low. Factors such as limited access to technology, lack of knowledge, and initial investment costs are major barriers to the implementation of IoT in the agricultural sector (Mendrofa et al., 2024). Therefore, further research is needed to identify effective strategies to encourage the adoption of smart farming in Indonesia.

This research is important to explore the potential of implementing IoT-based smart farming in increasing the productivity and efficiency of sustainable agriculture in Indonesia. By understanding the benefits and challenges of implementing this technology, it is hoped that the right strategy can be formulated to encourage the adoption of smart farming by farmers, thereby supporting food security and community welfare.

Several previous studies have discussed the application of IoT in agriculture, such as a study by Wahyudi et al. (2025) which showed an increase in water use efficiency through an IoT-based automatic irrigation system (Wahyudi et al., 2025). However, research on the adoption strategy of this technology among Indonesian farmers is still limited, so a more in-depth study is needed to understand the factors that influence the acceptance and use of smart farming.

This study aims to analyze the potential of implementing Internet of Things (IoT)-based smart farming in increasing the productivity and efficiency of sustainable agriculture in Indonesia, identifying factors that influence the level of adoption of this technology by farmers, and formulating effective strategies to encourage the implementation of smart farming more broadly and in a structured manner in the national agricultural sector.

METHOD

This study uses a qualitative approach with a literature review as the main method. This approach was chosen to explore in depth various findings, theories, and previous research results related to the application of Internet of Things (IoT) technology in the Smart Farming system, especially in the context of increasing sustainable agricultural productivity and efficiency. Literature studies allow researchers to analyze existing knowledge systematically and critically in order to build a strong conceptual framework (Snyder, 2019).

The data sources in this study come from secondary literature obtained through scientific publications in the form of national and international accredited journal articles, conference proceedings, academic books, and institutional reports from organizations such as FAO and OECD that are relevant to the research topic. The selected literature has a time span of the last five years (2018–2023) to ensure the relevance and currency of the information. Access to literature is obtained from scientific databases such as ScienceDirect, SpringerLink, Wiley Online Library, MDPI, and Google Scholar to expand the scope of the search.

The data collection technique was carried out through a literature search process using keywords such as "Smart Farming," "Internet of Things," "precision agriculture," "agricultural sustainability," and "digital agriculture." Furthermore, a selection process was carried out based on the relevance of the title, abstract, and suitability of the content to the research focus. Only sources that meet academic criteria and have made significant contributions to the Smart Farming discourse were used as analysis material.

The data analysis method used was thematic content analysis. In this process, each selected literature was analyzed to identify the main themes, relationship patterns, and differences in perspectives between researchers. This analysis was carried out through the stages of coding, categorization, and in-depth interpretation of the findings of the existing literature. The aim is to develop a comprehensive understanding of how IoT is applied in the agricultural sector and how it contributes to productivity and sustainability (Bowen, 2009). The results of the analysis are used to develop a conceptual framework and formulate theoretical conclusions that can be the basis for further research and practical applications.

RESULT AND DISCUSSION

The following is a table of bibliographic data which is the result of a selection of 10 recent and relevant scientific articles on the application of the Internet of Things (IoT) in smart farming to increase productivity and efficiency in sustainable agriculture. These articles were selected through a screening process from various credible international academic sources that have not been previously mentioned in this discussion.

Table 1. Literature Review

No	Author	Title	Research Focus
1	Kumar et al. (2024)	A Comprehensive Review on Smart and Sustainable Agriculture Using IoT Technologies	Comprehensive review of IoT use in agriculture
2	Mohamed et al. (2021	Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture	Wireless sensor applications in agriculture
3	Shahab et al. (2024)	IoT-Based Agriculture Management Techniques for Sustainable Farming	Integration of AI and IoT in agriculture
4	Gowda et al. (2021)	IoT in Developing the Smart Farming and Agricultural Technologies	IoT application in developing countries

5	Navarro et al. (2020)	A Systematic Review of IoT Solutions for Smart Farming	Identification of IoT devices and platforms in agriculture
6	Dhanaraju et al. (2022)	Smart Farming and How IoT and Sensors are Changing Agriculture	Role of sensors and IoT in modern agriculture
7	Duguma & Bai et al. (2024)	How the Internet of Things Technology Improves Agricultural Efficiency	Improving agricultural efficiency through IoT
8	Güven et al. (2023)	Smart Farming Technologies for Sustainable Agriculture	Integration of information technology in agriculture
9	Mansoor et al. (2025)	Integration of Smart Sensors and IoT in Precision Agriculture	Integration of smart sensors and IoT in precision agriculture
10	Assimakopoulos et al. (2024)	The Implementation of "Smart" Technologies in the Agricultural Sector	Application of smart technology in agriculture

The results of a literature study reviewed from ten scientific articles show that the application of the Internet of Things (IoT) in the agricultural sector, known as smart farming, has become a major concern in the transformation of modern agriculture towards a more productive and sustainable system. Each article in this study reveals various aspects of implementation, technological advantages, and challenges that are still faced in the adoption of IoT in real agricultural environments.

In general, it was found that IoT plays a crucial role in the digital transformation process of the agricultural sector, especially through real-time data collection mechanisms that facilitate more accurate decision-making. The article by Kumar et al. (2024) emphasizes that the use of IoT devices such as soil moisture sensors, surveillance cameras, and climate control devices allows for increased efficiency in water use, fertilization, and pest and plant disease control. This leads to input efficiency as well as increased crop yields (Kumar et al., 2024).

Several studies highlight the synergistic role between IoT and other technologies such as artificial intelligence (AI). The article by Mohamed et al. (2021) explains how AI algorithms integrated into smart farming systems can process data from IoT sensors to predict plant nutrient needs, respond to weather changes, and guide automatic irrigation actions. This combination enables the emergence of precision farming systems that dynamically adjust agricultural inputs to actual land and crop conditions (Mohamed et al., 2021).

In addition, the existence of wireless sensor networks and cloud computing platforms is also discussed intensively. Research by Shahab et al. (2024) shows that cloud-based systems not only function as data storage but also provide analytical dashboards that help farmers understand trends, analyze results, and plan long-term cultivation activities. Thus, farmers' decisions are no longer based on intuition or habit, but on scientifically verifiable data (Shahab et al., 2024).

Resource efficiency is the main focus in almost all articles reviewed. The use of water, fertilizers, and pesticides can be reduced by 20–40% through automatic data-based settings. For example, an IoT-based irrigation system that monitors local humidity and rainfall levels has been shown to significantly reduce water waste, while ensuring that plants receive the optimal amount of water (Gowda et al., 2021).

In terms of sustainability, a study by Navarro et al. (2020) emphasized that smart farming supports environmentally friendly agricultural practices by minimizing the use of excessive chemicals and reducing carbon emissions from the production process. This is an important contribution to reducing the impact of climate change and maintaining the balance of the agricultural ecosystem (Navarro et al., 2020).

However, the literature also notes various implementation challenges, especially in developing countries. Articles from Dhanaraju et al. (2022) and Duguma & Bai et al. (2024) show that limited digital infrastructure, low technological literacy among farmers, and high initial investment costs are major obstacles to the widespread adoption of IoT in the agricultural sector. In addition, there are concerns about data security and integration between platforms that have not been fully resolved (Dhanaraju et al., 2022; Duguma & Bai, 2024).

Studies from Güven et al. (2023) and Mansoor et al. (2025) add that government policy factors, fiscal incentives, and adequate technical training are important prerequisites for encouraging IoT adoption by small and medium-scale farmers. Government intervention is needed to provide rural internet networks, subsidize IoT devices, and build smart agricultural technology training centers (Güven et al., 2023; Mansoor et al., 2025).

In terms of practical applications, various usage scenarios have been implemented. For example, a smart greenhouse controlled by climate sensors and actuators is able to automatically maintain temperature, humidity, and lighting according to plant needs. On the other hand, the use of IoT-based drones for land mapping, crop monitoring, and precision pesticide spraying has shown promising results in terms of work efficiency and farmer safety (Assimakopoulos et al., 2024).

Overall, the findings show that IoT-based smart farming is not just a trend, but a long-term strategy that has a real impact on agricultural productivity, resource efficiency, and environmental sustainability. However, in order for this potential to be maximized evenly, cross-sector support is needed — from government policies, the private sector, to educational institutions to strengthen the national digital agricultural ecosystem.

Discussion

The Potential of IoT-Based Smart Farming in Indonesia

The application of Internet of Things (IoT) technology in Indonesia's agricultural sector shows great potential in increasing productivity and efficiency, especially in the context of sustainable agriculture. The integration of smart sensors, automated irrigation systems, and real-time data analytics enables more precise land management that is responsive to environmental changes.

One prominent case study is the application of an IoT-based smart irrigation system in West Sumatra. Research by Pratama and Mandela (2024) shows that the use of this irrigation system increases crop productivity by 34.9% compared to traditional irrigation systems. In addition, water use efficiency increases with savings of up to 47.8%, showing a significant contribution to the sustainability of agriculture in the region (Julianto Pratama & Mandela, 2024).

In the plantation sector, the implementation of IoT technology at cocoa research stations in Indonesia has helped farmers monitor environmental conditions in real time. By using Waspmote sensors and cloud-based analytics, farmers can optimize cocoa production and face the challenges of climate change more effectively (Libelium, 2024).

However, the adoption of this technology still faces challenges, especially in rural areas that have limited digital infrastructure and internet access. To address this, the architectural design of the IoT agricultural system in Indonesia has been developed using energy-efficient LoRa technology that is suitable for long-distance communication in areas with unstable networks. This system allows independent monitoring and control of the agricultural environment, which ultimately increases agricultural efficiency and productivity (Purbohadi et al., 2024).

Overall, the implementation of IoT-based smart farming in Indonesia shows promising results in increasing agricultural productivity and efficiency. However, to achieve wider adoption, investment is needed in digital infrastructure, farmer training, and policies that support the integration of this technology into daily agricultural practices.

Based on empirical and literature reviews, the main factors influencing IoT adoption in agriculture in Indonesia include:

Table 2. Factors Influencing IoT Adoption by Farmers

Factors	Explanation
Access to digital infrastructure	Many farmers in rural areas do not have stable access to the internet or electricity.
Initial investment costs	IoT devices are still considered expensive and less affordable for small farmers.
Farmers' digital literacy	The majority of older farmers are less familiar with advanced technology.
Perception of benefits and risks	Many farmers have not seen the direct benefits of this technology or are concerned about its complexity.
Institutional support	Lack of training, incentives, and regulations that encourage the use of digital technology.

Research conducted by Sihombing et al. (2024) in Tuban Regency used the Unified Theory of Acceptance and Use of Technology (UTAUT) model to analyze the factors that influence the intention and behavior of small-scale farmers in adopting digital agricultural applications. The results showed that performance expectations, effort expectations, and facilitation conditions jointly influenced the behavior of using digital agricultural applications through farmers' behavioral intentions. Individual characteristics such as age were also found to have a moderating effect on the relationship between variables. Younger farmers are more likely to adopt this technology compared to older farmers. This study emphasizes the importance of adequate training and facility support to encourage the adoption of digital agricultural technology by small-scale farmers (Sihombing et al., 2024).

Another study conducted in Sumenep Regency showed that the process of adopting agricultural technology is influenced by several socio-economic factors, including age, education, and farming experience. Younger and more educated farmers tend to be quicker to adopt new technologies compared to older and less educated farmers. In addition, farming experience also affects the level of technology adoption, where farmers with more experience tend to be more open to technological innovation (Sudarmadji, 2012).

In Jayapura Regency, the use of rice transplanters shows that farmers' income has a significant effect on the adoption rate of this technology. Farmers with higher incomes are more likely to adopt modern agricultural technology compared to low-income farmers. However, age and education variables do not significantly affect the adoption rate of the use of transplanters. This shows that economic factors play an important role in farmers' decisions to adopt new technologies (Wulandari & Palobo, 2020).

The adoption of IoT technology in agriculture in Indonesia is influenced by various factors, including access to digital infrastructure, initial investment costs, farmers' digital literacy, perceptions of benefits and risks, and institutional support. Case studies in various regions show that these factors interact with each other and influence farmers' decisions to adopt modern agricultural technology. To encourage wider adoption, a concerted effort is needed from the government, educational institutions, and the private sector in providing adequate training, financial support, and infrastructure.

Effective Strategies to Encourage Smart Farming Implementation in Indonesia

To accelerate the adoption of smart farming widely and in a structured manner, an integrated approach is needed that includes strengthening infrastructure, economic incentives, increasing farmer capacity, and national policy support.

First, building digital infrastructure in remote agricultural areas—including expanding internet networks and providing alternative energy such as solar panels—is the main foundation. Second, providing subsidies for IoT equipment or access to microcredit can ease the burden of initial investment, especially for small farmers. Third, education and training through the Agricultural Extension Center (BPP), universities, and agritech startup partners will improve digital literacy and farmers' readiness to operate the technology. Finally, integrating smart farming into the National Agricultural Strategic Plan and developing system interoperability standards are important to ensure the sustainability and consistency of the implementation of this technology across regions.

CONCLUSION

The application of IoT-based smart farming has been proven to provide a real contribution to increasing agricultural productivity and efficiency in Indonesia, especially in the context of sustainability. Through the use of sensor technology, automatic irrigation systems, and cloud-based data analysis, farmers can manage land precisely and responsively to environmental changes. In addition, the application of this technology can reduce resource waste and negative environmental impacts from conventional agricultural practices.

To accelerate the adoption of smart farming in Indonesia, the government and stakeholders need to build rural digital infrastructure, provide subsidies or microcredit for IoT devices, and increase farmer capacity through integrated training. Educational institutions and agritech startups can also act as partners in technology transfer and system development based on local needs.

Field research based on case studies or quantitative approaches is needed to specifically measure the impact of IoT on crop yields, operational costs, and farmer welfare. Further research also needs to examine technology adoption models that are in accordance with the socio-cultural characteristics of Indonesian farmers so that the implementation of digital agricultural technology is more contextual and sustainable.

REFERENCE

Assimakopoulos, F., Vassilakis, C., Margaris, D., Kotis, K., & Spiliotopoulos, D. (2024). The implementation of "smart" technologies in the agricultural sector: a review. *Information*, *15*(8), 466.

Basch, G., Kassam, A., Friedrich, T., Santos, F. L., Gubiani, P. I., Calegari, A., Reichert, J. M., & Dos Santos, D. R. (2012). *Sustainable soil water management systems*.

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27–40.

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, *12*(10), 1745.

Duguma, A. L., & Bai, X. (2024). How the internet of things technology improves agricultural efficiency. *Artificial Intelligence Review*, *58*(2), 63.

Gowda, V. D., Prabhu, M. S., Ramesha, M., Kudari, J. M., & Samal, A. (2021). Smart agriculture and smart farming using IoT technology. *Journal of Physics: Conference Series*, *2089*(1), 12038.

Güven, B., Baz, İ., Kocaoğlu, B., Toprak, E., Erol Barkana, D., & Soğutmaz Özdemir, B. (2023). Smart farming technologies for sustainable agriculture: From food to energy. In *A sustainable green future: Perspectives on energy, economy, industry, cities and environment* (pp. 481–506). Springer.

Halawa, D. N. (2024). Peran teknologi pertanian cerdas (smart farming) untuk generasi pertanian

Indonesia. *Jurnal Kridatama Sains Dan Teknologi*, *6*(02), 502–512.

Julianto Pratama, A., & Mandela, R. (2024). Evaluating the Effectiveness of Smart Irrigation Systems in Improving Agricultural Productivity. *Agriculture Power Journal*, *1*(4 SE-Articles), 1–9. https://doi.org/10.70076/apj.v1i4.43

Junaidi, J., & Ramadhani, K. (2024). Efektivitas internet of things (iot) pada sektor pertanian. *Jurnal Teknisi*, *4*(1), 12–15.

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS-Wageningen Journal of Life Sciences*, *90*, 100315.

Kumar, V., Sharma, K. V., Kedam, N., Patel, A., Kate, T. R., & Rathnayake, U. (2024). A comprehensive review on smart and sustainable agriculture using IoT technologies. *Smart Agricultural Technology*, 100487.

Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors*, *18*(8), 2674.

Libelium. (2024). *Sustainable Farming and the IoT: Cocoa Research Station in Indonesia*. https://www.libelium.com/libeliumworld/success-stories/sustainable-farming-and-the-iot-cocoa-research-station-in-indonesia/?utm_source=chatgpt.com

Mansoor, S., Iqbal, S., Popescu, S. M., Kim, S. L., Chung, Y. S., & Baek, J.-H. (2025). Integration of smart sensors and IOT in precision agriculture: trends, challenges and future prospectives. *Frontiers in Plant Science*, *16*, 1587869.

Mendrofa, J. S., Zendrato, M. W., Halawa, N., Zalukhu, E. E., & Lase, N. K. (2024). Peran teknologi dalam meningkatkan efisiensi pertanian. *Tumbuhan: Publikasi Ilmu Sosiologi Pertanian Dan Ilmu Kehutanan*, *1*(3), 1–12.

Mohamed, E. S., Belal, A. A., Abd-Elmabod, S. K., El-Shirbeny, M. A., Gad, A., & Zahran, M. B. (2021). Smart farming for improving agricultural management. *The Egyptian Journal of Remote Sensing and Space Science*, *24*(3), 971–981.

Navarro, E., Costa, N., & Pereira, A. (2020). A systematic review of IoT solutions for smart farming. *Sensors*, *20*(15), 4231.

Purbohadi, D., Azizah, L. M., & Prahara, P. J. (2024). Architectural Design of IoT Agricultural System in Indonesia. *BIO Web of Conferences*, *137*, 1012.

Rachmawati, R. R. (2020). Smart farming 4.0 untuk mewujudkan pertanian Indonesia maju, mandiri, dan modern. *Forum Penelitian Agro Ekonomi*, *38*(2), 137–154.

Shahab, H., Iqbal, M., Sohaib, A., Khan, F. U., & Waqas, M. (2024). IoT-based agriculture management techniques for sustainable farming: A comprehensive review. *Computers and Electronics in Agriculture*, *220*, 108851.

Sihombing, M. T., Hubeis, M., & Cahyadi, E. R. (2024). Analisis Adopsi dan Penggunaan Aplikasi Pertanian Digital oleh Petani Skala Kecil di Kabupaten Tuban dengan Model UTAUT. *MANAJEMEN IKM: Jurnal Manajemen Pengembangan Industri Kecil Menengah*, *19*(2), 80–92.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339.

Stupina, A. A., Rozhkova, A. V, Olentsova, J. A., & Rozhkov, S. E. (2021). Digital technologies as a tool for improving the efficiency of the agricultural sector. *IOP Conference Series: Earth and Environmental Science*, *839*(2), 22092.

Sudarmadji, H. (2012). Analisis Faktor-Faktor Yang Mempengaruhi Adopsi Teknologi Pada Usahatani Padi Pola Tanam SRI (System of Rice Intensification) Di Kabupaten Sumenep. *JURNAL PERTANIAN CEMARA*, *9*(1), 35–49.

Wahyudi, W., Pradana, A. I., & Permatasari, H. (2025). Implementasi Sistem Irigasi Otomatis Berbasis IoT untuk Pertanian Greenhouse . *Jurnal Pendidikan Dan Teknologi Indonesia*, *5*(2 SE-), 435–446. https://doi.org/10.52436/1.jpti.656

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big data in smart farming–a review.

Agricultural Systems, *153*, 69–80.

Wulandari, Y. I., & Palobo, F. (2020). Faktor-Faktor yang Mempengaruhi Tingkat Adopsi Teknologi Petani Terhadap Pengunaan Rice Transplanter di Kampung Koya Barat. *Buletin Inovasi Teknologi Pertanian Spesifik Lokasi, Edisi*, *2*.