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Analysis of Strengthening IoT-Based Sustainable Agriculture Digital Literacy Through Empowering the Sendangsari Millennial Farmer Community

Wardono*, Zaenal Abidin, Dyah Rini Indriyanti, Agung Setiawan, Bayu Murti Suryonegoro, Ifan Badra Wijaya, Marshanda Antika Putri, Ratna Wahyuningtyas, Zidna Nurus Sakinah, Irfan Fajar Prihantoro

Universitas Negeri Semarang, Indonesia

*Corresponding Author: wardono@mail.unnes.ac.id

Abstract
Sendangsari Village, Purworejo Regency, has significant agricultural potential, but its utilization is not optimal due to low digital literacy among farmers and minimal application of modern technology. This condition poses challenges in supporting sustainable agriculture, so technology-based innovation is needed. This study aims to analyze the strengthening of digital literacy in sustainable agriculture through the application of the Internet of Things (IoT) in empowering the Sendangsari Millennial Farmer Community. The method used was a mixed method with a questionnaire instrument, pre-test and post-test, and plant growth measurements in IoT-based and manual fields. The results showed a significant increase in participant understanding, marked by a 17.77% increase in post-test scores from the pre-test score of 70.8. The application of IoT in the experimental field also resulted in more optimal growth of tomato, lettuce, and caisim plants compared to manual methods, and increased the confidence of millennial farmers in adopting technology. This study concluded that agricultural digital literacy can be strengthened through socialization, training, and practice of the application of the Internet of Things (IoT). Village institutional support, expanding internet access, and developing the capacity of young farmers are recommended to accelerate the transformation towards sustainable agriculture.

Keywords: sustainable agriculture, digital literacy, internet of things, millennial farmers, community empowerment

INTRODUCTION

Sendangsari Village, located in Bener District, Purworejo Regency, Central Java Province, has significant agricultural potential. Located 1.5 km from the sub-district center, 12.5 km from the district center, and 103 km from the provincial capital, the village covers an area of 202 hectares divided into four hamlets: Pendemrejo, Krajan Wetan, Krajan Kulon, and Bandongan. According to 2023 data, the population of Sendangsari Village reached 2,441, consisting of 1,254 men and 1,187 women. Agricultural land covers 125 hectares of rice fields, 25 hectares of plantations, and 77 hectares of fields. These geographic and demographic conditions position Sendangsari Village as a pillar of food security in the surrounding area, but the existing agricultural sector has not been optimally utilized.

The agricultural sector in Sendangsari Village holds significant potential, but faces several fundamental challenges. Among them are the low level of education on sustainable agriculture, the lack of interest from the younger generation, and weak *digital farming literacy* , which are the main factors hindering the optimization of this potential (Azis & Suryana, 2023). This condition aligns with the findings of Ilyas (2022), who stated that millennial farmers actually have a strategic position in agricultural digitalization, but their capacity and involvement are still limited. Another challenge is the farmer regeneration crisis. The majority of farmers in the village are elderly, while millennials are reluctant to pursue agriculture because they are considered old-fashioned, labor-intensive, and financially unpromising. The Central Statistics Agency (BPS) (2023) noted that the proportion of farmers aged 19–39 years old is only around 21.93% of all farmers in Indonesia. Ilmi et al. (2025) emphasized that this regeneration crisis could threaten national food security in the long term.

Another major obstacle, in addition to the regeneration crisis, is farmers' low digital literacy. Low digital skills make it difficult for farmers to optimally utilize modern technology. Hoang and Tran (2023) showed that the adoption rate of digital technology by smallholder farmers is heavily influenced by access to information and digital literacy capacity. This situation is further exacerbated by external factors such as high investment costs, uneven internet infrastructure distribution, and limited supporting policies at the village level (Balayev & Mirzayev, 2022). Gebresenbet et al. (2023) also added that implementing integrated agricultural technology requires institutional and infrastructure support; without it, digitalization will only benefit a small percentage of farmers. This is also evident in Sendangsari Village, where limited capital and low digital skills prevent the potential for technology application from being widely utilized.

To address these challenges, understanding the concept of sustainable agriculture is crucial. This concept was introduced in the 1980s as an alternative to address natural resource degradation and pressure on food production (Efendi, 2016). The primary focus of this approach is resource conservation and improving the quality of life for rural communities. Irianto (2015) emphasized that sustainable agriculture is a practice that not only pursues economic profit but also preserves the environment and meets social needs. This concept is increasingly relevant, as it can be bridged through the digital transformation of agriculture. Abiri et al. (2023) found that the application of digital technology can increase productivity while reducing environmental impacts, while Birner et al. (2021) highlighted that the digital revolution in agriculture can only succeed if sustainability is a key pillar.

In this context, empowering millennial farmers is crucial because they are more open to modern technology. Marpaung and Bangun (2023) explain that the younger generation can bring innovation through digitalization, while Noviar and Fadhlain (2025) emphasize the importance of policy strategies focused on strengthening the role of millennial farmers in agricultural transformation. One approach that can be implemented is the use of *the Internet of Things* (IoT). IoT enables agricultural devices to connect to the internet, collect data, and operate automatically. Manoppo (2025) demonstrated that an IoT-based smart irrigation system improves water efficiency in Minahasa, while Wahyudi et al. (2025) demonstrated that the use of ESP32 can reduce water consumption by up to 30%. Thus, IoT has the potential to be a strategic solution to overcome limited digital literacy while simultaneously attracting the younger generation to re-engage in sustainable agriculture.

The results of the preliminary study showed that the average pre-test score for farmers' understanding reached 70.8, which is considered good. This finding indicates that farmers already possess basic agricultural knowledge, but this understanding is not sufficient to face the challenges of the digital era. This relatively good score indicates potential for further development, while also highlighting the ongoing gap between basic knowledge and practical skills in technology utilization. This finding aligns with the findings of Fharaz et al. (2022), who stated that farmers' digital literacy can be improved through intensive training and mentoring. Hoang and Tran (2023) also emphasized that limited digital literacy is a major obstacle to the adoption of modern technology, making capacity building a crucial prerequisite for the effective implementation of smart agricultural innovations. Therefore, the pre-test results indicate an urgent need to strengthen digital literacy through more targeted strategies.

The implementation of sustainable agricultural innovations, particularly through digital technologies such as *the Internet of Things* (IoT), is a strategic step to fill this gap. IoT not only serves to increase production efficiency but also re-engages the younger generation in actively participating in the agricultural sector. Abiri et al. (2023) emphasize that digital technology integration can increase productivity and reduce environmental impact, while Noviar and Fadhlain (2025) highlight the importance of millennial farmer-based policy strategies for impactful agricultural digitalization.

Therefore, this study aims to analyze the strengthening of IoT-based digital literacy in sustainable agriculture through empowering the Millennial Farmer Community in Sendangsari Village. The research focuses on improving knowledge, skills, and the application of IoT in agricultural practices, thereby supporting the formation of a modern, environmentally friendly, efficient, and sustainable agricultural ecosystem.

METHOD

This study used a *mixed methods approach* , combining quantitative and qualitative methods simultaneously to obtain more comprehensive data. According to Sugiyono (2017), a mixed methods approach allows researchers to obtain a more complete picture because quantitative results can be strengthened by qualitative data. The research subjects were the Millennial Farmer Community of Sendangsari Village who participated in a socialization, training, and mentoring program for the implementation of *Smart Farming 4.0 technology*.

Data collection was conducted using three instruments: a questionnaire, pre-test and post-test questions, and plant measurement data. The questionnaire was used to determine attitudes (e.g., openness to technological innovation), perceptions (e.g., the benefits of IoT for increasing agricultural yields), and farmers' skills in utilizing *Smart Farming 4.0 technology* . This instrument covers five dimensions: ecology, economy, social, institutional, and utilization of agricultural technology. The pre-test was administered before the socialization and mentoring activities, while the post-test was administered after the activities were completed, so that the increase in farmers' knowledge regarding *digital farming literacy* and modern agricultural innovation could be analyzed. Data from the pre-test and post-test were analyzed using a *Paired Sample t-test* to see how the differences were before and after the treatment.

Additionally, a comparison was conducted between the group of plants using *Smart Farming 4.0 technology* and the manually managed control group. Observed parameters included plant height and yield. Differences in yield between the two groups were analyzed using an *Independent Sample t-test* to determine the significant effect of technology implementation on agricultural productivity. Qualitative analysis was conducted through field observations and mentoring notes to strengthen the quantitative results, in accordance with the principle of qualitative triangulation (Creswell, 2018).

Based on this method design, the research is expected to provide an in-depth overview of the effectiveness of *Smart Farming 4.0 implementation* . Quantitative results demonstrate increased knowledge and productivity, while qualitative findings strengthen the interpretation of farmers' attitudes and experiences during the mentoring process. Therefore, this method design can systematically address the research objectives related to strengthening digital literacy in sustainable agriculture in Sendangsari Village.

RESULTS AND DISCUSSION

Agricultural Sustainability Index

The community service activity in Sendangsari Village began with a questionnaire analysis that generated an agricultural sustainability index based on five main dimensions: ecology, economics and marketing, social, institutional, and agricultural technology. The index values for each dimension were categorized as Poor, Less, Sufficient, and Good, providing a comprehensive overview of the actual conditions of the millennial farming community, both in terms of strengths and weaknesses that can serve as a basis for formulating sustainable agricultural development strategies. A similar approach was applied by Linda et al. (2018) in a study to assess the sustainability status of lowland rice farming in Denpasar, where the same five dimensions were used with the *Multi-Dimensional Scaling* (MDS) method and index indicators to group the sustainability status of the agricultural sector.

Ecological Dimension

Agricultural practices still face significant challenges. Fertilizer use scored 0.328 (Poor), indicating that fertilizer application does not meet the recommended types and dosages. Crop productivity showed better results, with an index of 0.734 (Sufficient). Pest attacks remain a major challenge, with an index of only 0.109 (Poor), consistent with field findings that pest control still relies on chemical pesticides without a clear schedule. Farmers' understanding of soil conservation reached an index of 0.516 (Sufficient), although actual implementation on the ground is inconsistent.

Economic and Marketing Dimensions

The analysis results show quite wide variations. Product price stability is in the Sufficient category with an index of 0.531. Land limitations are a serious problem, only achieving an index of 0.031 (Poor). Agricultural product promotion has been carried out through village social media and received a Sufficient category (0.547), while the feasibility of farming businesses remains low with a score of 0.359 (Poor). The use of Village-Owned Enterprises (BUMDes) to support marketing achieved an index of 0.875 (Good). This high score is supported by the existence of agricultural marketing business units that actively distribute products to local markets and online.

Social Dimension

The education level of young farmers only scored 0.484 (Poor). Land ownership was also relatively low, with an index of 0.281 (Poor). However, there is positive potential in terms of young farmers' participation in the community, which scored 0.703 (Sufficient). Farmers are still considered productive, with an index of 0.750 (Sufficient). The questionnaire results showed that the land inheritance system is largely traditional, where land is only inherited after the parents stop managing it. This pattern contributes to the low land ownership score of young farmers, which only achieved an index of 0.281 (Poor). Field observations also showed that some families have begun to provide opportunities for younger generations to become involved in land management earlier, although this practice remains limited.

Institutional Dimension

The role of agricultural institutions is considered quite good. Microfinance institutions scored 0.766 (Good), indicating relatively easy access to capital. Marketing institutions through Village-Owned Enterprises (BUMDes) scored even higher, at 0.875 (Good), reflecting strong institutional support in marketing products. Access to production facilities scored 0.641 (Sufficient), while the role of agricultural extension workers was in the Sufficient category (0.531). The distribution of institutional support is not evenly distributed across all hamlets. This is evident from the results of the questionnaire, which showed that some farmers in Pendemrejo Hamlet have not received regular extension assistance, while farmers in Krajan Wetan Hamlet receive more intensive services. This inequality impacts the variation in the index score for the role of agricultural extension workers, which is only in the Sufficient category (0.531).

Dimensions of Agricultural Technology

In the agricultural technology dimension, the gap is quite clear. Pest control efforts scored 0.328 (Poor), while post-harvest handling remained low, with a score of 0.500 (Poor). Land utilization and the use of organic fertilizer showed better results, with a score of 0.641 (Sufficient). The highest index was found in the application of *smart farming* , namely 0.859 (Good). The results of the questionnaire and field observations showed that some young farmers have tried using IoT systems for automatic irrigation and soil moisture monitoring, so the index value in this aspect is relatively higher than other technological aspects.

The analysis shows that agricultural sustainability in Sendangsari Village generally falls between *the Fair* to *Poor categories* , with some even falling *below Poor, with areas experiencing limited land, pest infestations, and low land ownership. However, institutional aspects and technology utilization are already in the Good* category , offering opportunities for strengthening through institutional support and the implementation of *the Internet of Things* (IoT) to improve digital literacy and promote sustainable agriculture.

Participant Knowledge Test Results

The average *post-test score* increased by 83.4, or an increase of 17.77% compared to the *pre-test score* . The results of the *Paired Sample t-test* showed a t value = -9.760 with p = 0.000 (<0.05). The t value is far from zero and the significant *p-value* proves a strong difference between the pre-test and post-test scores. Thus, there was an increase in participants' knowledge about IoT-based sustainable agriculture after the program was implemented.

Plant Growth

In addition to increasing knowledge, this activity also compared the growth of three types of plants in *an Internet of Things* (IoT)-based field with a manual field: tomatoes, lettuce, and Chinese cabbage. Parameters observed included plant height and yield.

Table 1. Comparison of Plant Growth

Number	Tomato	Caisim	Lettuce
1	28.5	15.5	1.5
2	29.7	16.0	3.5
3	30.1	17.0	1.5
4	31.0	11.5	2.0
5	30.5	12.0	1.0

6	32.0	13.0	3.0
7	29.8	17.0	3.0
8	31.3	13.0	2.5
9	30.7	-	2.5
10	28.9	-	5.5
11	44.5	22.5	6.7
12	46.2	15.5	6.7
13	47.1	22.0	5.5
14	45.8	23.0	8.7
15	47.5	21.5	6.0
16	48.0	26.5	6.2
17	46.7	20.0	5.5
18	45.9	20.7	6.2
19	48.3	-	6.5
20	47.2	-	7.2

a. Tomato Growth

Observations show that the average height of tomato plants in IoT-enabled fields reaches 46.72 cm, higher than in manual fields, which is only 30.25 cm. This suggests that tomato plant growth in IoT-enabled fields is more optimal. This finding aligns with research by Singh et al. (2023), which demonstrated that the implementation of an IoT-based precision irrigation system can improve tomato yield and quality through *real-time monitoring* and more efficient irrigation scheduling.

b. Lettuce Growth

In lettuce, the average plant height in the IoT field reached 6.52 cm, significantly higher than the 2.6 cm in the manual field, indicating superior growing conditions in the IoT field. This finding aligns with research by Derafi et al. (2024) which demonstrated that the application of the IoT system to NFT hydroponics can create an optimal growing environment for lettuce, with an average height of 22.07 cm and a fresh weight of approximately 119.8 g.

c. Caisim Growth

Chinese cabbage plants cultivated in IoT fields showed an average height of 21.46 cm, higher than those grown in manual fields, which were only 14.37 cm. This indicates that IoT fields are able to support the growth of Chinese cabbage more effectively. In terms of yield, IoT fields also provide higher productivity. The quantity and weight of harvests obtained from IoT fields are higher than those from manual fields, which still face limitations in terms of efficient use of water, fertilizer, and pest control.

Statistical Test of Plant Growth

Independent Sample t-test results showed a significant difference ($p < 0.05$) between IoT-based and manual fields for all observed crop types. This confirms that the higher average growth and yields in IoT fields are significantly influenced by the implementation of IoT-based automation technology.

Changes in Farmers' Attitudes

The questionnaire results also revealed a shift in millennial farmers' attitudes toward managing their farms. Most respondents felt more confident using new technology after the training. They also participated more actively in group discussions, field practice, and interactions during mentoring. This indicates a shift in the role of young farmers from mere recipients of technology to key actors in implementing sustainable agriculture in Sendangsari Village.

Analysis of Agricultural Sustainability in Sendangsari Village

The results of the index measurements indicate that agricultural sustainability in Sendangsari Village still faces serious challenges across several dimensions, particularly ecological, economic, and social dimensions. In the ecological dimension, fertilizer use is suboptimal with a low index, and pest infestations remain high. This situation indicates limitations in the implementation of appropriate and environmentally friendly fertilizer practices. A study by Fatimah and Muhafidin (2024) confirmed that the implementation of fertilizer policies in Indonesia often faces distribution and effectiveness issues, impacting farmers' fertilization practices in the field. This aligns with the findings of Warr and Yusuf (2014), which showed that fertilizer subsidies are often poorly targeted and actually reduce production efficiency. Excessive reliance on chemical fertilizers without technological innovation contributes to ecosystem vulnerability (Wirakusuma, 2020).

In the economic and marketing dimensions, the index results indicate limited land and low agricultural business feasibility, despite positive institutional support through *Village-Owned Enterprises* (BUMDes). These findings illustrate that local institutions can serve as a buffer when markets are less stable. Research by Papadopoulos et al. (2024) demonstrated that digital technology in agriculture can increase economic efficiency while lowering production costs, but institutional factors still play a crucial role in market stability. In the local context, the presence of an active BUMDes in Sendangsari Village demonstrates the strategic role of institutions in expanding market access and strengthening agricultural value. This institutional support has also been shown to be effective in strengthening regional resilience, as discussed by Yunandar et al. (2024) through a young farmer-based digitalization program.

The social dimension also presents significant obstacles. Young farmers' education levels and land ownership are relatively low, impacting the slow rate of farmer regeneration. This finding is consistent with research by Suriani et al. (2023), which demonstrated low interest among young people in agriculture due to the perception that this profession lacks economic promise. Furthermore, a study by Putrayasa et al. (2021) emphasized that motivational factors, access to land, and low social status in agriculture play a significant role in discouraging young people from engaging. Land inheritance patterns also exacerbate the problem by triggering land fragmentation and delaying regeneration.

In terms of the institutional dimension, the index results are relatively high. Microfinance institutions and village-owned enterprises (BUMDes) demonstrate real support for farming activities, although the quality and equity of support remain limited. According to Dai (2024), the success of sustainable agriculture is largely determined by the role of educational and extension institutions in expanding access to technology. Conditions in Sendangsari Village indicate that although local institutions are already functioning well, strengthening the role of external institutions such as agricultural extension workers and universities remains necessary.

The technological dimension demonstrates a dualism. Some indicators, such as organic fertilizer utilization and land management, are considered adequate, but adoption of pest control and post-harvest technologies remains low. However, the implementation of *smart farming* scored very high, indicating that some young farmers have successfully adopted digital innovations. This is consistent with Bunkar's (2024) study, which emphasized the importance of technology in strengthening agricultural extension services. Furthermore, Cao and Solangi's (2023) research highlights that barriers to technology adoption are often related to limited capital and internet access, necessitating an inclusive policy strategy.

Improving Digital Literacy and Knowledge of Millennial Farmers

The test results showed an increase in participants' knowledge, from an average score of 70.8 in the pre-test to 83.4 in the post-test. This 17.77% increase indicates that the outreach, training, and mentoring activities successfully strengthened the digital literacy of millennial farmers in Sendangsari Village. This increased understanding not only indicates the effectiveness of the applied learning methods but also confirms that young farmers are ready to adopt new technologies if given the right support. The Profit and Competitiveness Study (2023) explains that digital transformation in Indonesia's agricultural sector is highly dependent on improving human resource capacity, particularly in mastering technology. This is reinforced by Zhang et al. (2023), who found that the digital economy and agricultural technology innovation contribute significantly to increasing *green productivity* in the agricultural sector.

Increasing digital literacy also aligns with global efforts to promote sustainable agriculture. He et al. (2023) emphasized that the use of digital technology in agriculture is not only for efficiency, but also for preserving *agricultural heritage* and maintaining ecological balance. In the local context, the improved digital skills of Sendangsari Village farmers can lay the foundation for developing a sustainable agricultural system based on *smart farming* . Research by Apriani et al. (2018) also showed that the application of technology in rice cultivation has been shown to increase technical efficiency and farm productivity, demonstrating the direct relevance between digital literacy and increased agricultural yields.

Increasing digital literacy also impacts younger generations' interest in the agricultural sector. Suriani et al. (2023) highlighted that youth engagement in agriculture is significantly influenced by exposure to new technologies, which make the sector more attractive and competitive. Similar findings were demonstrated by research by Yunandar et al. (2024), where a young farmer-based agricultural digitalization program in Bogor was shown to increase agricultural entrepreneurship while strengthening regional resilience. Thus, the increased knowledge of millennial farmers in Sendangsari Village extends beyond technical skills and has a long-term impact on farmer regeneration.

The Effectiveness of IoT in Supporting Plant Growth

A comparison of cultivation results in IoT-based *and* manual cultivation showed significant differences. For tomato plants, the average plant height in the IoT field reached 46.72 cm, while in the manual field it was only 30.25 cm. Lettuce showed a more striking difference, at 6.52 cm in the IoT field compared to 2.6 cm in the manual field. Chinese cabbage also outperformed in the IoT field, with an average height of 21.46 cm, compared to 14.37 cm in the manual field. This difference confirms that the application of IoT can provide growing conditions more suited to plant needs, particularly through more accurate irrigation control. Research by Sari and Sari (2025) emphasized that IoT innovation supports sustainable agriculture by optimizing the use of water, fertilizer, and energy for optimal plant growth. A similar finding was demonstrated by Al-Jufri (2023), who demonstrated that *soil moisture sensor- based irrigation automation* can maintain water availability according to plant needs.

The role of IoT technology is also reflected in the automatic watering system, which activates the irrigation pump only when soil moisture falls below a threshold. This way, plants are protected from both under- and over-watering. This finding aligns with Alreshidi (2019), who developed the concept of *smart sustainable agriculture* based on IoT and *artificial intelligence* , where the sensor system proved effective in increasing water use efficiency by up to 35%. Meanwhile, Aulia's (2023) research on IoT implementation at the Limapuluh Kota Regency Agriculture Office found that the use of light sensors and automatic pumps significantly increased the growth of horticultural crops. For chili plants, Azman (2023) demonstrated that the application of *an IoT monitoring system* increased plant height by up to 40% compared to manual methods.

Field findings in Sendangsari Village are also consistent with global studies. Bulut and Wu (2023) in a systematic review of IoT in the agricultural sector stated that over the past two decades, the application of IoT has contributed significantly to increased productivity, resource efficiency, and reduced risk of crop failure. In the context of *precision agriculture* , Charibaldi et al. (2022) showed that the use of IoT in regosol soil allows for more precise monitoring of soil nutrients, thereby improving crop quality. Research by Cisse (2024) also confirms that IoT-based *smart farming management systems* support sustainable agriculture by integrating sensors, irrigation systems, and *real-time data analysis. Even deep learning*- based approaches , as described by Jin et al. (2020), can improve predictions of crop water and nutrient needs with greater precision, thereby improving long-term cultivation efficiency.

Thus, the results of field trials in Sendangsari Village, which demonstrated superior growth of tomatoes, lettuce, and Chinese cabbage (caisim) in IoT-enabled fields compared to manual ones, are not coincidental, but rather supported by previous research. IoT has proven effective in optimizing plant growth through environmental monitoring, irrigation automation, and efficient resource use. This strengthens the argument that implementing IoT is a strategy to accelerate the adoption of *smart farming* among millennial farmers.

Changing Attitudes and Roles of Millennial Farmers

The outreach and mentoring program not only yielded technical impacts in the form of increased plant growth, but also significantly influenced the attitudes and roles of millennial farmers in managing their farms. Field observations showed that after the training, participants were more confident in using new technologies and actively engaged in discussions to solve agricultural problems. This change reflects a shift from being mere recipients of innovation to being key drivers in implementing sustainable agriculture. This aligns with the findings of Suriani et al. (2023), who emphasized that the involvement of the younger generation is crucial for the future sustainability of agriculture, particularly through technological mastery.

The increasing motivation of the younger generation to return to the agricultural sector is also inseparable from the influence of digitalization. Desi (2023) reported that *IoT smart farming training* encouraged young farmers in Lampung to adopt technology more quickly, while simultaneously increasing their sense of ownership of the innovations implemented. A similar finding was found by Fitrianingsih (2023), who noted that the implementation of agricultural technology in Banyumas strengthened the entrepreneurial skills of young farmers and expanded product marketing opportunities. Thus, digitalization not only improves technical efficiency but also strengthens the socio-economic well-being of millennial farmers.

Farmer regeneration in Sendangsari Village also received positive encouragement through this program. Some families began involving the younger generation in land management at an early age, rather than simply waiting for inheritance after their parents retired. This trend aligns with research by Noviar and Fadhlain (2025), which emphasized the importance of millennial farmer-based policy strategies in agricultural digitalization. Furthermore, research by Yunandar et al. (2024) showed that the digitalization program in Bogor increased the interest of the younger generation in the agricultural sector while strengthening regional resilience. This demonstrates that the integration of digitalization not only modernizes agriculture but also serves as a mechanism for regeneration.

The changing role of millennial farmers also includes increased social participation. After participating in activities, they are more active in networking, sharing experiences, and developing innovative ideas. This situation aligns with Bunkar's (2024) view that technology can strengthen farmers' social networks in extension programs. Dai (2024) also emphasized that the role of universities in expanding agricultural technology also encourages the participation of the younger generation, as better access to knowledge encourages the emergence of *agents of change* in rural areas.

Thus, the changing attitudes and roles of millennial farmers in Sendangsari Village demonstrate that IoT-based technological innovations not only have technical impacts but also social ones. Adopting modern technology strengthens the motivation, engagement, and confidence of young farmers, while accelerating the regeneration of the agricultural workforce. This demonstrates that empowering millennial farmers is key to realizing sustainable agriculture that adapts to changing times.

CONCLUSION

This study concludes that empowering the Millennial Farmer Community through outreach, training, and mentoring has successfully increased understanding of the concept of *Internet of Things* (IoT)-based agriculture, as reflected in the significant increase in *post-test scores* and the significant difference in plant growth results in IoT-based fields compared to manual methods. As a recommendation, the application of IoT needs to be continuously expanded through infrastructure support, ongoing mentoring, and collaboration between the government, educational institutions, and young farmer communities so that sustainable agriculture can be realized while also attracting the interest of the younger generation to contribute to the modern agricultural sector.

REFERENCES

Abiri, R., Rizan, N., Balasundram, S.K., Shahbazi, A.B., & Abdul-Hamid, H. (2023). Application of digital technologies for ensuring agricultural productivity. *Heliyon, 9* (12), e22601. https://doi.org/10.1016/j.heliyon.2023.e22601

Al-Jufri, H. (2023). Agricultural automation with *soil moisture sensors* , light sensors, *LED grow lamps* , and water pumps for optimal plant growth. *Journal of Informatics and Applied Electrical Engineering* , 11(3). https://doi.org/10.23960/jitet.v11i3.3192

Alreshidi, E. (2019). *Smart sustainable agriculture (SSA) solution underpinned by internet of things (IoT) and artificial intelligence (AI). International Journal of Advanced Computer Science and Applications* , 10(5). https://doi.org/10.14569/ijacsa.2019.0100513

Apriani, D., Andriani, R., Rahayu, W., & Wibowo, Y. (2018). The effect of the level of implementation of integrated crop management (ICM) technology on the technical efficiency of rice farming. *Indonesian Agribusiness Journal* , 6(2), 121–132. https://doi.org/10.29244/jai.2018.6.2.121-132

Aulia, R. (2023). Application of *the internet of things (IoT)* in the food crops, horticulture, and plantations service of Limapuluh Kota district. *Journal of Indonesian Social Society (JISS)* , 1(3), 104–108. https://doi.org/10.59435/jiss.v1i3.177

Azis, M., & Suryana, EA (2023). Comparison and implementation of agricultural digitalization policies: Opportunities and challenges. *Agricultural and Environmental Policy Brief: Formulation of Strategic Studies in the Field of Agriculture and the Environment, 10* (3), 199–212. https://doi.org/10.29244/jkebijakan.v10i3.51083

Azman, N. (2023). *Smart agricultural monitoring system using IoT application for chili plants. Journal of Advanced Research in Applied Sciences and Engineering Technology* , 33(1), 53–66. https://doi.org/10.37934/araset.33.1.5366

Balayev, R.A., & Mirzayev, N.S. (2022). Digital agricultural technologies for sustainable rural

development: Opportunities and barriers. In *Engineering for Rural Development* (Vol. 21, pp. 110–115). https://doi.org/10.22616/ERDev.2022.21.TF009
Birner, R., Daum, T., & Pray, C. (2021). Who is driving the digital revolution in agriculture? A review of supply-side trends, players and challenges. *Applied Economic Perspectives and Policy, 43* (4), 1260–1285. https://doi.org/10.1002/aepp.13145
BPS. (2023, December 4, 2023). Complete results of the 2023 agricultural census - phase i. Retrieved January 15 from https://www.bps.go.id/id/pressrelease/2023/12/04/2050/hasil-pencacahan-lengkapsensus-pertanian-2023---tahap-i.html
Bulut, C., & Wu, P. (2023). More than two decades of research on IoT in agriculture: A systematic literature review. *Internet Research* , 34(3), 994–1016. https://doi.org/10.1108/intr-07-2022-0559
Bunkar, R. (2024). A review on levering technology for sustainable development in agricultural extension programs. *Archives of Current Research International* , 24(5), 543–556. https://doi.org/10.9734/acri/2024/v24i5731
Cao, J., & Solangi, Y. (2023). Analyzing and prioritizing the barriers and solutions of sustainable agriculture for promoting sustainable development goals in China. *Sustainability* , 15(10), 8317. https://doi.org/10.3390/su15108317
Charibaldi, N., Saidi, D., & Kodong, F. (2022). Precision agriculture using *internet of things* in regosol soil. *IOP Conference Series: Earth and Environmental Science* , 1018(1), 012006. https://doi.org/10.1088/1755-1315/1018/1/012006
Chinchmalatpure, U. R., & Tekale, V. S. (2021). Aspiration of rural youth towards agriculture. Indian Journal of Extension Education, 55(2), 25–30. Retrieved from https://epubs.icar.org.in/index.php/ijee/article/view/109192
Cisse, A. (2024). A *smart farming* management system based on IoT technologies for sustainable agriculture. *Advances in Science, Technology and Engineering Systems Journal* , 9(1), 1–8. https://doi.org/10.25046/aj090101
Creswell, J. W. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Thousand Oaks, CA: Sage Publications.
Dai, Z. (2024). Influence of university agricultural technology extension on efficient and sustainable agriculture. *Scientific Reports* , 14(1). https://doi.org/10.1038/s41598-024-55641-1
Derafi, R., Nurhidayat, I., Kholiq, I., & Siregar, RT (2024). Humidity monitoring and temperature control as well as lettuce nutrition provision in a prototype greenhouse with IoT-based nutrient film technique. Jurnal Ilmiah Bijak, 21(1), 22–30. https://ejurnal.stmik-budidarma.ac.id/index.php/mib/article/view/7674
Desi, D. (2023). Training and implementation of IoT *smart farming* in the Cintamulya Village farmer group, Candipuro District, South Lampung Regency. *J-Abdi: Journal of Community Service* , 3(1), 43–50. https://doi.org/10.53625/jabdi.v3i1.5731
Dirayati, F., Anggun Sari, R., & Purnomo, RF (2025). Design and Implementation of an Internet of Things-Based Smart Agriculture System to Increase Agricultural Productivity. *Journal of Informatics Media* , *6* (2), 863-872. https://doi.org/10.55338/jumin.v6i2.4982
Efendi, E. (2016). Implementation of sustainable agricultural systems to support agricultural production. *Warta Dharmawangsa* , (47). https://doi.org/10.46576/wdw.v0i47.231
Fatimah, AS, & Muhafidin, D. (2024). Dynamics of fertilizer subsidy implementation: A case study of agricultural policy in Indonesia. *International Journal of Science and Society, 6* (1), 315–327. https://doi.org/10.54783/ijsoc.v6i1.1068
Fharaz, VH, Kusnadi, N., & Rachmina, D. (2022). The influence of digital literacy on e-marketing literacy among farmers. *Jurnal Agribisnis Indonesia (Journal of Indonesian Agribusiness)* , *10* (1), 169-179. https://doi.org/10.29244/jai.2022.10.1.169-179
Fitrianingsih, F. (2023). Application of agricultural technology in the management of agricultural sub-sector food crops in Karangtalun Kidul Village, Banyumas. *Solidarity* , 12(1), 17–32. https://doi.org/10.15294/solidarity.v12i1.71446
Gebresenbet, G., Bosona, T., Patterson, D., Persson, H., Fischer, B., Mandaaluniz, N., Chirici, G., Zacepins, A., Komasilovs, V., Pitulac, T., & Nasirahmadi, A. (2023). A concept for application of integrated digital technologies to enhance future smart agricultural systems. *Smart Agricultural Technology, 5* , 100255. https://doi.org/10.1016/j.atech.2023.100255
Gomase, A., & Tekale, V.S. (2021). Agricultural aspirations of rural youth. Asian Journal of Agricultural Extension, Economics & Sociology, 39(12), 204–211. Retrieved from https://www.researchgate.net/publication/358173084_Agricultural_Aspiration_of_Rural_Youth
Halawa, DN (2024). The role of smart farming technology for Indonesia's agricultural generation. *Kridatama Journal of Science and Technology* , *6* (02), 502-512.

https://jurnal.umnu.ac.id/index.php/kst/article/view/1226/558
Hasani, M., & Wulandari, S. (2023). Implementation of the Internet of Things (IoT) in a Mobile-Based Plant Watering Automation System. *Ilkomnika* . https://doi.org/10.28926/ilkomnika.v5i3.573
He, M., Xiong, L., Ding, Y., & Yang, W. (2023). Innovative development and utilization of agricultural cultural heritage enabled by digital technologies. *Journal of Library and Information Science in Agriculture, 35* (3), 67–81. https://doi.org/10.13998/j.cnki.issn1002-1248.22-0822
Hoang, H.G., & Tran, H.D. (2023). Smallholder farmers' perception and adoption of digital agricultural technologies: An empirical evidence from Vietnam. *Outlook on Agriculture, 52* (4), 399–411. https://doi.org/10.1177/00307270231197825
Ilmi, MU, Gayatri, S., & Luqman, Y. (2025). The Impact of the Farmer Regeneration Crisis in Nolokerto Village, Kendal Regency. *Sospol* , *11* (2), 255–277. https://doi.org/10.22219/jurnalsospol.v11i2.41357
Ilyas, I. (2022). Optimizing the role of millennial farmers and agricultural digitalization in agricultural development in Indonesia. *Economic Forum, 24* (2), 197–207. https://doi.org/10.30872/jfor.v24i2.10364
Irianto, I Ketut. (2015). *Water quality towards sustainable agriculture*. Working Paper. Warmadewa University, Denpasar, Indonesia.
Jin, X., Yu, X., Wang, X., Bai, Y., Su, T., & Kong, J. (2020). Deep learning predictor for sustainable precision agriculture based on *internet of things* system. *Sustainability* , 12(4), 1433. https://doi.org/10.3390/su12041433
Kamaruddin, N., Hamzah, A., & Aziz, AA (2020). Empowering youth farmers through technology adoption: A pathway towards sustainable agriculture. *Asian Journal of Agriculture and Development* , 17(2), 77–89.
Laba, MS, & Saing, MM (2023). Digital transformation in the agricultural sector in Indonesia. *E-Business Journal of the Muhammadiyah Polewali Mandar Institute of Technology and Business* , 3(2). https://doi.org/10.59903/ebussiness.v3i2.82
Linda, AM, Ambarawati, IGAA, & Ustriyana, ING (2018). Sustainability status of lowland rice farming in Denpasar City. Journal of Agribusiness Management, 6(2), 97–110. https://ojs.unud.ac.id/index.php/agribisnis/article/view/44718
Manoppo, FGC (2025). *Application of Internet of Things (IoT) technology in smart irrigation systems in Minahasa Regency* . Community Service Journal (PKM) Vol. 2 No. 1. https://journal.ppipbr.com/index.php/pengamas/article/view/547
Marpaung, N., & Bangun, IC (2023). The Importance of Farmer Regeneration in Agricultural Modernization. *Journal of Agrarian Studies and Food Sovereignty (JKAKP)* , *2* (2), 27-33. https://doi.org/10.32734/jkakp.v2i2.14195
Noviar, H., & Fadhlain, S. (2025). Agricultural digitalization policy strategy based on millennial farmers in Indonesia: A SWOT analysis approach. *Farmer Business, 11* (1), 92–105. https://doi.org/10.35308/jbt.v11i1.12114
Papadopoulos, G., Arduini, S., Uyar, H., Psiroukis, V., Kasimati, A., & Fountas, S. (2024). Economic and environmental benefits of digital agricultural technologies in crop production: A review. *Smart Agricultural Technology* , 8, 100441. https://doi.org/10.1016/j.atech.2024.100441
Putrayasa, A., Adnyani, IGAD, & Sudiarta, IGP (2021). Why are young people reluctant to work in the agricultural sector? A structural equation model of the agricultural sector in Jembrana Regency. *E-Journal of Mathematics* , 10(2), 122–130. http://dx.doi.org/10.24843/MTK.2021.v10.i02.p331
Sari, YN, & Sari, M. (2025). IoT technology innovation to support sustainable agriculture. *Collaborative Journal of Science* , 8(1), 271–284. https://doi.org/10.56338/jks.v8i1.6737
Singh, D., Kumar, M., & Kumari, P. (2023). Smart high-yield tomato cultivation: Precision irrigation system using the Internet of Things. Frontiers in Plant Science, 14, 1239594. https://doi.org/10.3389/fpls.2023.1239594
Sugiyono. (2017). *Quantitative, qualitative, and R&D research methods* . Bandung: Alfabeta.
Sulis Dyah Candra, S., Sutiharni, E., Ansar, M., & Rosmalah, S. (2024). *Agricultural innovation increases productivity and sustainability* . Padang: GET PRESS Indonesia. https://www.researchgate.net/publication/386871164_INOVASI_PERTANIAN_MENINGKATKAN_PRODUKTIVITAS_DAN_KEBERLANTAN
Suriani, N., Sari, YP, Handayani, F., & Noviar, H. (2023). The younger generation and the future of agriculture. *Triton Journal* , 14(2), 384–392. https://doi.org/10.47687/jt.v14i2.468
The Smart IoT based Automated Irrigation System using Arduino UNO and Soil Moisture Sensor. (2022). *2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT)* . https://doi.org/10.1109/icssit53264.2022.9716368

Wahyudi, W., Pradana, AI, & Permatasari, H. (2025). *Implementation of an IoT-Based Automatic Irrigation System for Greenhouse Agriculture* . Indonesian Journal of Education and Technology, 5(2), 435–446. https://doi.org/10.52436/1.jpti.656
Warr, P., & Yusuf, A. A. (2014). Fertilizer subsidies and food self-sufficiency in Indonesia. *Agricultural Economics* , 45(5), 571–588. https://doi.org/10.1111/agec.12107
Widjaja, E., Roshetko, JM, Arifin, B., Pramudya, B., Sardjono, MA, & van Noordwijk, M. (2024). Sustainability index analysis for environmentally low-input integrated farming. Global Journal of Environmental Science and Management, 10(2), 267–286. https://doi.org/10.22034/GJESM.2024.02.08
Wirakusuma, G. (2020). Is input subsidy still useful for Indonesian agriculture? *Journal of Economics and Development* , 28(1), 17–28. https://doi.org/10.14203/jep.28.1.2020.17-28
Yunandar, DT, Nuryanti, N., & Parasdya, SD (2024). Increasing the interest of the younger generation of farmers through a digitalization program to increase agricultural entrepreneurship and its implications for regional resilience in Bogor, West Java. *Journal of National Resilience* , 30(2), 243–259. https://doi.org/10.22146/jkn.94965
Zhang, Y. F., Ji, M. X., & Zheng, X. Z. (2023). Digital economy, agricultural technology innovation, and agricultural green total factor productivity. *SAGE Open* , 13(3). https://doi.org/10.1177/21582440231194388