JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 2, p 265-283, 2025
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.2.265-283

Challenges in the Implementation of Internet of Things (IoT) in Irrigation and Fertilizer Management System in Indonesia

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Article Info

Submitted: 26 February 2025
Revised: 5 May 2025
Accepted: 16 June 2025
Available online: 19 June 2025
Published: June 2025

Keywords:
Agriculture; Internet of Things; Irrigation system; Fertilizer system

How to cite:
Saptaji, K., Tumada, A., Alfakihuddin, M. L. B., Wardani, D. A., Dewi, T. K., Juniasih, O. A., Fikri, M. R., Achmad, M. S. H. (2025). Challenges in the Implementation of Internet of Things (IoT) in Irrigation and Fertilizer Management System in Indonesia, 13(2): 265-283. https://doi.org/10.19028/jtep.013.2.265-283.

Abstract

Agriculture is critical to many countries' economies, especially in terms of gross domestic product (GDP) and employment. However, industrialization has led to the problem of fulfilling expanding global food supply demand. The Internet of Things (IoT) can enhance automatic data transfer in agriculture, improve production, increase quality, improve cost-effectiveness, and reduce environmental impact. However, the obstacles related to IoT applications in agriculture have received little discussion, especially in developing countries, such as Indonesia. This study seeks to fill this gap by investigating the specific issues of adopting the Internet of Things (IoT) in the context of an irrigation and fertilizer management system in Indonesia. To study this, stratified multistage random sampling was conducted to acquire significant insights and data. According to the Structural Equation Modelling (SEM) of the interview results, respondents voiced concerns regarding IoT deployment in agriculture, including cost implementation (CI), their own knowledge (perceived knowledge (PK)), user experiences with the technology (perceived ease of use (PEU)), and intention to use (IU). The main result of this study shows that the intention to use IoT is significantly influenced by perceived simplicity of use (PEU), whereas cost (CI) and knowledge (PK) play less prominent roles. Furthermore, farmers who previously implemented IoT exhibited a greater inclination to expand their use of technology, indicating that experience and usability are crucial factors. Finally, researchers, policymakers, and agricultural stakeholders can leverage these insights to advance the IoT integration and sustainability in farming practices.

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1. Introduction

The world population is estimated to reach 9.7 billion by 2050 due to its rapid growth (Antony et al. 2020). This affects demand for agricultural products (Antony et al. 2020). Agriculture is known as the sector with the highest contribution to the economy of several countries including Pakistan, Indonesia, Thailand, Afghanistan, China, India, Australia, and others (Gheewala et al. 2018; Muradi and Boz 2018). For instance, it contributes 26 percent to the GDP of Pakistan and reduces the unemployment rate to 43% (Zia et al. 2021). Agricultural outputs were also observed to have caused a 14.4% increase in the national GDP of Indonesia and served as the main provider of jobs to local citizens (Kavianand et al. 2016). Nevertheless, there has been a continuous decrease in available agricultural land due to industrialization, commercial markets, and residential buildings. Simultaneously, there is an increasing need to boost agricultural production to combat the impending global food supply shortages (Grimblatt et al. 2019). Hence, addressing agricultural challenges such as water shortages, labour management, food safety, excessive pesticide and fertilizer use, and poor water management has become crucial (Pandithurai et al., 2017).

Addressing these challenges necessitates innovative approaches, and the implementation of a smart farming concept, such as leveraging the Internet of Things (IoT), has emerged as a promising solution. IoT, which is widely employed by industries, facilitates continuous and automated monitoring of scheduling and control systems in agricultural practices (Mulenga et al., 2018). This technology interconnects computing devices through a network, thereby enabling seamless data transfer without human intervention (Qazi et al., 2022). Defined as an emerging technology designed to connect living and non-living entities through the Internet, the IoT seeks to enhance the efficiency and accuracy of various tasks (Saiz-Rubio and Rovia-Mas 2020).

In the agricultural sector, despite its innovation, IoT has been noted to provide numerous advantages for users (farmers). The implementation of IoT in agriculture can enhance productivity and quality, reduce costs, and reduce environmental impact (Villa-Henriksen et al., 2020). The implementation of IoT has also been reported to provide information on potato growth, weather data, and pesticide distribution control (Antony et al., 2020).

The IoT, using a designed control system, was implemented to update the geographic sprinkle data from the GPS before sending it to the base station (Taneja and Bhatia, 2017). The system has also been proven to have the ability to collect real-time data using a sensor and web-based Graphical User Interface (GUI) (Taneja and Bhatia, 2017). Moreover, Nam et al. 2017 argued that Information and Communication Technology (ICT) and the Wireless Sensor Network (WSN) can be integrated to control the irrigation system and increase the efficiency and effectiveness of the facility. The adoption of ICT and WSN in precision agriculture (PA) reduced the cost, time, and human error due to the absence of manual identification analysis. There are two main agricultural challenges that can be

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solved by implementing IoT: water management (irrigation) and fertilization. These two issues occur in most countries because of poor management, while overuse and inappropriate use of pesticides and fertilizers increase the possibility of cancer, pollution, soil acidification, and environmental footprint (Giannoccaro et al., 2020).

There is a demand for an effective and strategic irrigation system to increase productivity due to the conditions related to food and agricultural supply. Zia et al. (2021) reported that a well-managed irrigation system in Pakistan could produce an 80% increase in agricultural output and reduce production costs. Moreover, the data presented by Saiz-Rubio and Rovira-Más (2020) showed the ability of an effective irrigation system to increase food supply by 40%. The control system used in this type also depends on the skills of the irrigator (Nam et al., 2017), which involves scheduling the irrigation process and manually controlling the water dosage at regular intervals without considering the mathematical computations required for each plant. However, it is relatively cheaper in terms of installation and maintenance than automated irrigation systems (Taneja and Bhatia, 2017). Automated irrigation is designed as a prominent solution to these problems, thereby increasing agri-output and minimizing excessive water wastage. Therefore, the implementation of IoT can support automated irrigation systems.

1.1 IoT for Irrigation Management System

IoT has been applied in the irrigation scheduling system for a wheat farm, which was found to reduce water usage by 25% compared to the traditional method (Saab et al., 2019). IoT is also known to use wireless sensor networks (WSNs) to gather data to create preventive or corrective actions, thus demonstrating its ability to monitor and control soil, wind, water, and fertilizers in both small and large areas (Sharma et al., 2018). The application of IoT along with image processing systems also allows users to visualize the real-time conditions of plants and soil, which can be accessed anytime and anywhere. A previous study showed that its implementation for irrigation scheduling could save 56.4% to 90% of water because of its ability to detect the moisture content of the land (Campos et al., 2020). Moreover, a data-driven robust model predictive control combined with IoT was able to provide automated irrigation, which reduced water consumption by up to 40 %. Another study also proposed the design of planning and scheduling of a water irrigation system using an Artificial Neural Network (ANN) (Fernández-López et al. 2020). In addition, Abba et al. 2019 designed a low-cost autonomous sensor to monitor and control the irrigation system installed in a remote location, and the system was able to provide flexibility and convenience while optimizing the quantity of water used. IoT, LoRa, LoraWan, and in-house 3D-ray launching radio planning were also integrated to develop a smart irrigation system to cover a large urban area, which led to a 23% degradation in water usage, an increase in the overall performance of the network, and a reduction in energy consumption (Froiz-Míguez et al. 2020).

Another system designed by combining an efficient scalable Data Collection Scheme (DCS) with Wireless Sensor Networks (WSNs) in PA was also reported to assist farmers in predicting the specific quantity of water needed to increase crop yield and improve water management efficiency by up to 89% (Karuniathy and Velusamy 2020). Furthermore, Mulenga et al. (2028) successfully created a simple and cost-effective automated irrigation system to monitor and control small-scale farming in Zambian Village. However, some of the limitations associated with this system include high setup costs, expensive hardware costs, and potential errors in the sensor during the process of reading data (Feng et al. 2019). The architectural design of an automated irrigation system depends on several factors, such as the (1) size of the farm, (2) soil moisture level, and (3) cost allocated to the system that determines its effectiveness. In addition to hardware, software and sensors are used in the field (Goap et al., 2018).

1.2 IoT for Fertilizer Management System

The IoT also contributes significantly to the process of monitoring and scheduling fertigation. This was observed in the proposals made in some studies to schedule a precise amount of water and fertilizer applied to crops based on the proposed algorithm (Fernández-López et al. 2020). The advancement of IoT through mechatronics also allows liquid and granular fertilizer optimization at a low cost (Giannoccaro et al., 2020). The framework for a fertilizer management system can be implemented for short-and long-term planning, with a focus on the effectiveness of the scheduling and monitoring processes. The short-term aspect focuses on providing fertilizer based on plant needs and configuring daily stock replenishment (Lin et al., 2020), while the long-term aspect involves determining the total amount of macronutrients needed to support plant growth over a certain period. The long-term plan also determines the environmental and economic constraints to be considered in the process, with every decision expected to be made based on the future impact of several factors such as the crop, soil moisture level, pH, and land humidity. The framework for the long-term plan is similar to the short plan but emphasizes the maximization of fertilizer available through the provision of the accurate ratio required by several crops in the plant within their growth period. However, the accurate ratio can be calculated using the Integer Linear Programming (ILP) method (Lin et al., 2020), which is highly recommended for creating a set of parameters or information needed, such as the pH, concentration of the fertilizer, and soil moisture, to provide the appropriate quantity of fertilizer, thereby ensuring economic cost. Moreover, the process of monitoring and scheduling fertilizer is similar to the short-term plan after all data have been set.

The compelling utilization of the IoT in agriculture, particularly in the optimization of irrigation and fertilizer systems, underscores its undeniable benefits. Despite this success, there is a significant lack of awareness among individuals, particularly farmers residing in rural and remote areas; Indonesia serves as a noteworthy example. Consequently, this study aims to explore the perceptions

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http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.2.265-283

of the Indonesian population regarding the integration of IoT into the agricultural sector by employing a survey methodology. The anticipated outcome of this study is poised to contribute valuable insights, facilitating the formulation of strategic approaches for the effective implementation of the IoT in Indonesia's agricultural landscape. 397 young Indonesian farmers regarding IoT adoption concerns. Data analysis and modelling were conducted using SMARTPLS, Excel, Python, and SPSS.

2. Materials and Methods

2.1 Research Design

This study employed both quantitative and qualitative research designs. The primary objective was to explore the receptiveness and feedback of Indonesian farmers toward the use of IoT, which contributes significantly to the process of monitoring and scheduling fertigation.

2.2 Study Area and Population

The survey was conducted across six major islands of Indonesia: Java, Kalimantan, Sumatra, Sulawesi, Maluku, and Papua. It involved the participation of ninety- seven individuals, with ages ranging from 17 to 40 years.

2.3 Sampling Method

A stratified random sampling was employed during the initial stages of the study. The population was stratified into homogeneous subgroups based on demographic variables such as gender, age, education, income, religion, and household composition. The sampling proportions were determined to ensure that the sample reflected the population distribution across the identified subgroups.

2.4 Survey Instruments

The respondent was subordinated to 16 questions, primarily focusing on their comprehension of adopting the Internet of Things (IoT) in agriculture. These inquiries were distributed into four distinct sections: the cost implications of adoption (CI), perceived knowledge (PK), perceived ease of use (Perceived Ease of Use, PEU), and inclination towards espousing IoT technology (Intention to Use IoT). The respondents were required to indicate their agreement on a scale ranging from 1 (‘strongly disagree’) to 5 (‘strongly agree’).

2.5 Data Collection Procedure and Data Analysis

The methodology adopted for this exploration assured obscurity in the submission of responses, a strategy aimed at fostering directness among the actors. Previous studies have indicated that a sample size exceeding 200 individuals is sufficient for conducting covariance Structural Equation Modelling (SEM). Similarly, the Central Limit Theorem suggests that sample sizes exceeding 30 actors can be considered to compare a normal distribution, with the delicacy of this approximation perfecting with increased sample size. In this study, the use of SMARTPLS facilitated the construction of

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Structural Equation Modelling (SEM). SEM is a statistical data analysis technique used to examine the complex relationships between observed variables and latent (unobserved) constructs (Akter et al. 2017). It combines the elements of factor analysis and multiple regression, allowing researchers to test hypotheses about direct and indirect relationships between variables in a theoretically grounded model (Marsh et al. 2014). In SmartPLS analysis, the first step is to evaluate the outer loadings to ensure that the indicators significantly contribute to their respective latent constructions. Reliability and validity were assessed using Cronbach's Alpha and Average Variance Extracted (AVE) to determine the consistency and legitimacy of the data. The next step involved checking for multicollinearity to ensure that there was no excessive linear correlation between the indicators. Finally, bootstrapping analysis was conducted to test the significance of the relationships between the variables in the model (Hacker and Hatemi 2006).

Demographic data analysis and additional statistical evaluations were performed independently using Microsoft Excel, Python, and SPSS. The investigation employed a quantitative approach, with questionnaires distributed via WhatsApp to leverage the platform's extensive networking capabilities to target a specific demographic. The details of the questionnaire are presented in Table 1.

Table 1. Construct questionnaire

Variable	Survey Item	Source
PEU 1	It would be easy for me to become skilful at using IoT technologies in agricultural practices	(Davis 1989).
PEU 2	Learning to operate the controls for IoT systems used for fertilizer and irrigation management would be easy for me	
PEU 3	My interaction with IoT technologies would be clear and understandable	
PEU 4	I would find IoT systems easy to use	
CI 1	The cost of using IoT products for agriculture is higher than using other agriculture product.	(Luarn and Lin 2005; Sun et al. 2021).
CI 2	Using IoT in agriculture is a cost burden for me	
CI 3	I think the initial expenses of using IoT in agriculture are outweighed by the long-term financial gains.	
CI 4	The IoT products for agriculture cost me a lot of money.	

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Variable	Survey Item	Source
PK 1	The prospect of integrating IoT into fertilizer and irrigation systems, what it can offer me, and its disadvantages are conceivable to me	(Alambaigi and Ahangari 2016).
PK 2	I am aware of the advantages and difficulties associated with integrating IoT into fertilizer and irrigation systems.	
PK 3	The process of using IoT in agriculture is tangibles for me	
PK 4	To ensure the successful application of IoT in agriculture, more educational programs are required.	
IU 1	I will use or start using IoT technologies to manage fertilizer and irrigation	(Hoyer et al. 2020; Li, L., & Cheng 2021)
IU 2	I am willing to learn the application of IoT Technology	
IU 3	I want to utilize IoT in agriculture because of its benefits	
IU 4	I will use the IoT application for myself and recommend it to other	

3. Results and Discussion

3.1 Responden Profiles

Figure 1 shows the respondent survey profiles. It can be seen that out of the 397 respondents, 80% identified themselves as farmers, indicating that the survey primarily targeted individuals involved in the agriculture sector. This aligns with our objective of gathering insights from those with hands-on experience in agriculture. Additionally, the data revealed that respondents with farming backgrounds had accumulated more than 20 years of experience in the field. This data presents an advantageous opportunity, as they provide a deep understanding of the challenges in the agricultural sector.

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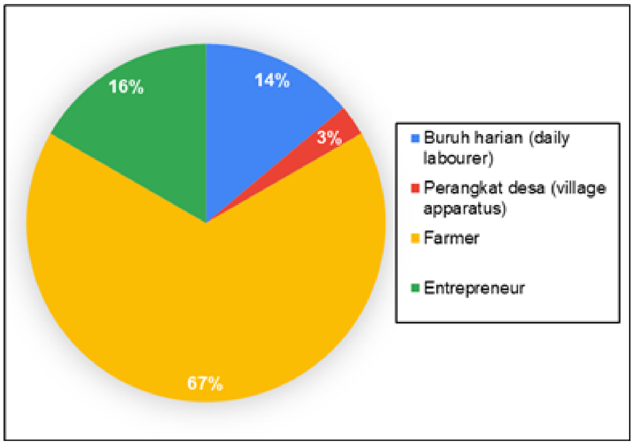


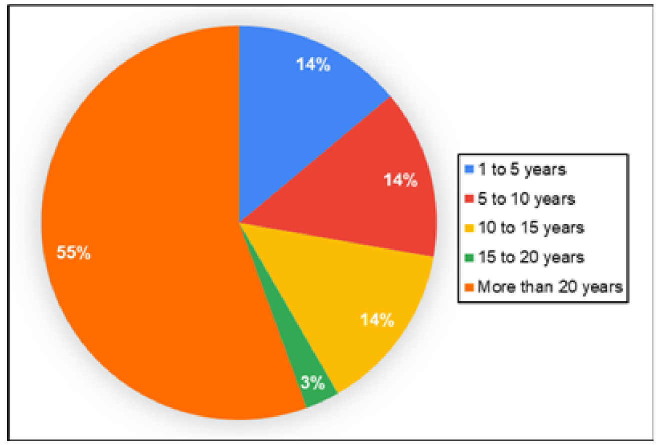
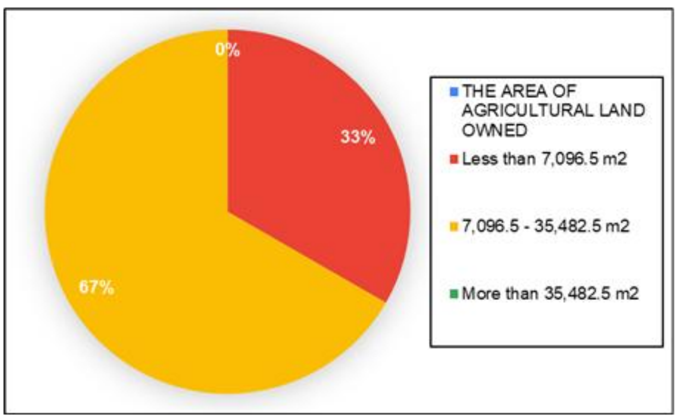


Figure 1. Respondent occupation background (left) and farming experience (right).

In addition, all the farmers surveyed had their own agricultural land, which ranged from 7,000 to 35,000 square meters (Figure 2, left). Most of the agricultural land is dedicated to rice production (Figure 2, right panel). Rice cultivation requires significant attention to the irrigation and fertilization processes. This aligns with the proposed Internet of Things (IoT) system, as its implementation can enhance efficiency and accuracy in managing these critical aspects of rice farming.



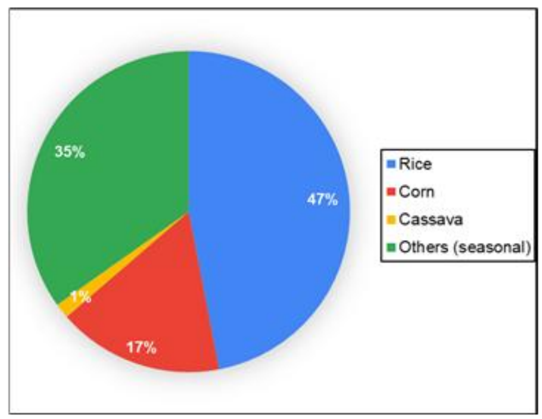


Figure 2. Agricultural area owned (Left) Type of main plant planted (Right)

Figure 3 is Structural Equation Modelling (SEM) created using the SMARTPLS software. SEM is a statistical method used to analyse the relationship between latent variables (not directly measurable) and observable variables. According to Hair et al. 2017, the ideal outer loading value is 0.7. This value indicates that the indicator significantly contributes to latent construction. Certain variables were eliminated from the analysis because their factor loadings were below the required threshold of 0.7. Excluded variables were IU 2, IU 4, CI 1, CI 4, PK 1, and PK 3. The surveyed items used can be seen in Table 2.

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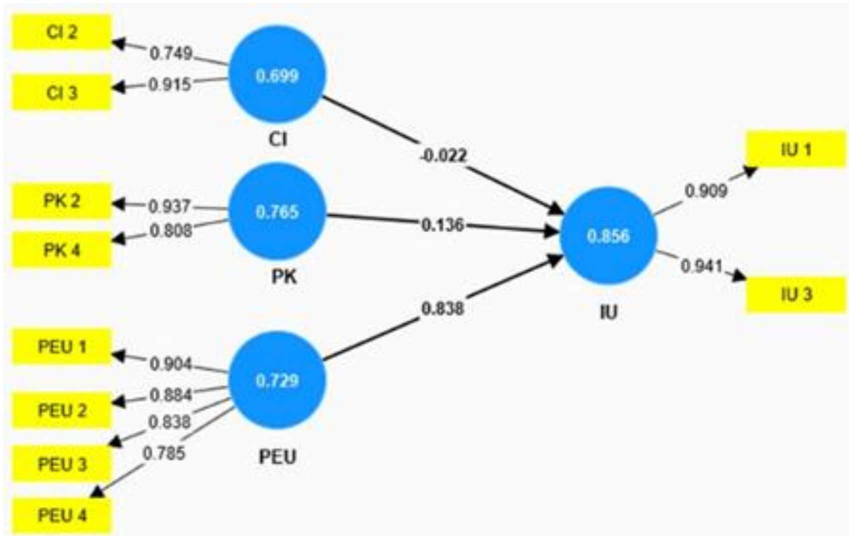

Figure 3. Outer loading structural equation Modelling of PEU, PK, CI, and IU.

Table 2. Construct Survey Questions.

Variable	Survey Item	Factor Loading
PEU	It would be easy for me to become skillful at using IoT technologies in agricultural practices	0.904
	Learning to operate the controls for IoT systems used for fertilizer and irrigation management would be easy for me	0.884
	My interaction with IoT technologies would be clear and understandable	0.838
	I would find IoT systems easy to use	0.785
CI	Using IoT in agriculture is a cost burden for me	0.749
	I think the initial expenses of using IoT in agriculture are outweighed by the long-term financial gains.	0.915
PK	I am aware of the advantages and difficulties associated with integrating IoT into fertilizer and irrigation systems.	0.937
	To ensure the successful application of IoT in agriculture, more educational programs are required.	0.808
IU	I will use or start using IoT technologies to manage fertilizer and irrigation	0.909
	I want to utilize IoT in agriculture because of its benefits	0.941

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3.2 Construct Reliability and Validity Result

Table 3 shows the reliability and validity of the results. It has strong reliability and validity. Cronbach's alpha and composite reliability exceeded 0.7, indicating a solid internal consistency. All AVE values were above 0.5, confirming convergent validity with no need for construct refinement.

Table 3. Construct Reliability and Validity Results

Variable	Alpha	Rho_a	Rho_c	AVE
CI	0.815	0.902	0.843	0.762
PK	0.850	0.933	0.863	0.731
PEU	0.840	0.937	0.945	0.723
IU	0.829	0.918	0.938	0.701

3.3 Path Coefficients: Mean, STDEV, T-values, P-values

The strength and significance of the relationships between the variables were observed using statistical methods, including path coefficients, standard deviations, T-statistics, and P-values. Table 4 presents the path coefficients. The results revealed that CI, PK, and PEU significantly affected IU, with p-values below 5%.

Table 4. Path Coefficients: Mean, STDEV, T-values, P-values.

Hypothetical Relationship	Original (O)	Mean (M)	STDEV	T stat	P values	Decision
H1: CI-> IU	0.3518	0.073	0.139	0.875	0.015	Supported
H2: PK-> IU	0.4995	0.410	0.154	2.183	0.015	Supported
H3: PEU-> IU	0.9642	0.233	0.133	1.691	0.005	Supported

3.4 Hypothesis Test

3.4.1 Hypothesis 1: Cost Implementation (CI) positively correlates with the Intention to Use IoT

Figure 4 shows the correlation analyses between Cost Implementation (CI) and Intention to Use IoT. Regression analysis revealed a model with the equation IU = 2 + (0.3518 × CI), indicating a relationship between Confidence Interval (CI) and Intention to Use (IU) Internet of Things (IoT) devices. Each incremental increase in CI corresponds to an expected rise of approximately 0.3518 IU under the assumption that all other variables remain constant. However, the model's R-squared value

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of 0.063 suggests that CI alone is not a robust predictor of IU in this dataset, indicating the presence of other influential factors beyond CI.

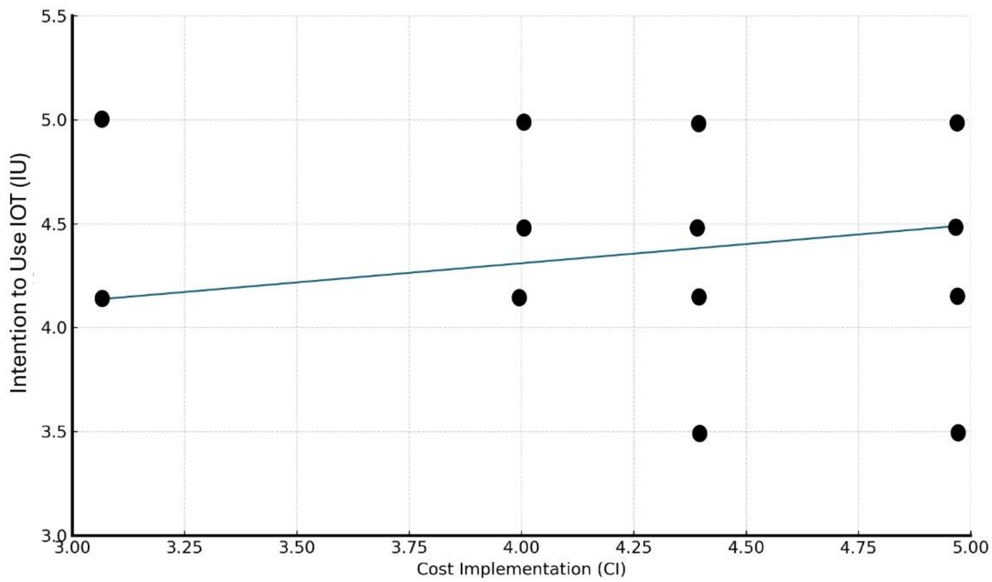

Figure 2. Correlation analyses between Cost Implementation (CI) and Intention to Use IoT.

Despite the modest predictive power of the CI, its statistical significance cannot be overlooked. Table 4. Hypothesis 1 showed a p-value of 0.015, below the standard alpha level of 0.05, and a statistically significant link between CI and IU. This underscores the importance of considering CI in understanding individuals' intentions to use IoT technologies, although additional factors may contribute to IU beyond those captured in the model. Further investigation of these other variables could enhance the predictive accuracy of the model and provide a more comprehensive understanding of IU in relation to IoT adoption.

These findings indicate a statistically significant correlation between Cognitive Integration and Intention to Use. However, the magnitude of this correlation is very low, as only a small amount of variation in Intention to Use can be explained by Cognitive Integration.

3.4.2 Hypothesis 2: Perceive Knowledge (PK) positively correlates with the Intention to Use IoT

Perceived Knowledge (PK) is positively correlated with the Intention to Use (IU) Internet of Things (IoT) devices, as evidenced by the regression equation IU = 2.2353 + 0.4995 × PK. This correlation is illustrated in Figure 5. This equation suggests that for every incremental increase in PK, there is an expected corresponding increase of approximately 0.4995 IU, all else being equal. Table 4., hypothesis 2 reflects the robust statistical significance impact of PK to IU (with a p-value < 0.05). Furthermore, the R-squared value of 0.174 indicated that PK alone did not robustly predict IU in this dataset.

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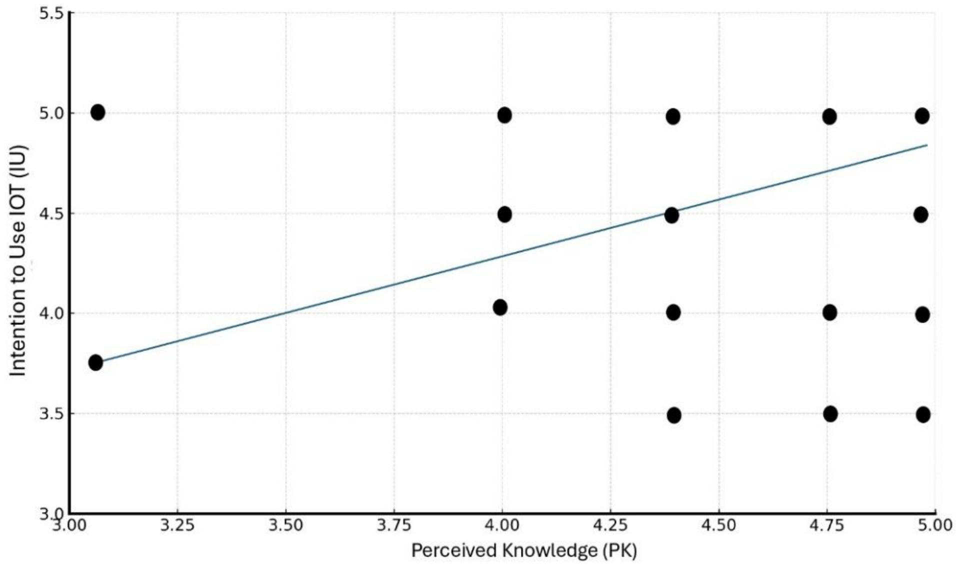

Figure 3. Correlation analyses between Perceived Knowledge (PK) to Intention to Use IoT

The comparatively low R-squared value suggests that there may be additional unaccounted factors influencing IU beyond PK. Although PK demonstrates a substantial link with IU, other variables that are not included in the model may also play a significant role. Thus, while PK is an important factor in understanding IU, further research is needed to explore additional variables that could enhance the predictive power of the model.

3.4.3 Hypothesis 3: Perceived ease of use (PEU) positively correlates with the Intention to Use IoT

As shown in Figure 6, perceived Ease of Use (PEU) exhibits a positive correlation with the Intention to Use (IU) Internet of Things (IoT) devices, as demonstrated by the regression equation IU = 0.1018 + (0.9642 × PEU). This equation implies that each increment increases PEU, and there is an expected corresponding increase of approximately 0.9642 IU, holding all other variables constant. The robustness of this relationship is further emphasized by the relatively high R-squared value of 0.7075, indicating that PEU accounts for a substantial proportion of the variance in IU within the dataset. Moreover, table 4. The statistical significance of PEU was confirmed by a p-value of 0.005 for the confidence interval, which was below the standard alpha level of 0.05. This statistical significance underscores the importance of PEU in influencing individuals' intention to adopt IoT technologies. Consequently, these findings highlight the critical role of perceived ease of PEU in shaping users' attitudes and behaviors towards IoT adoption, suggesting that efforts to enhance PEU may effectively drive IU and facilitate widespread IoT utilization.

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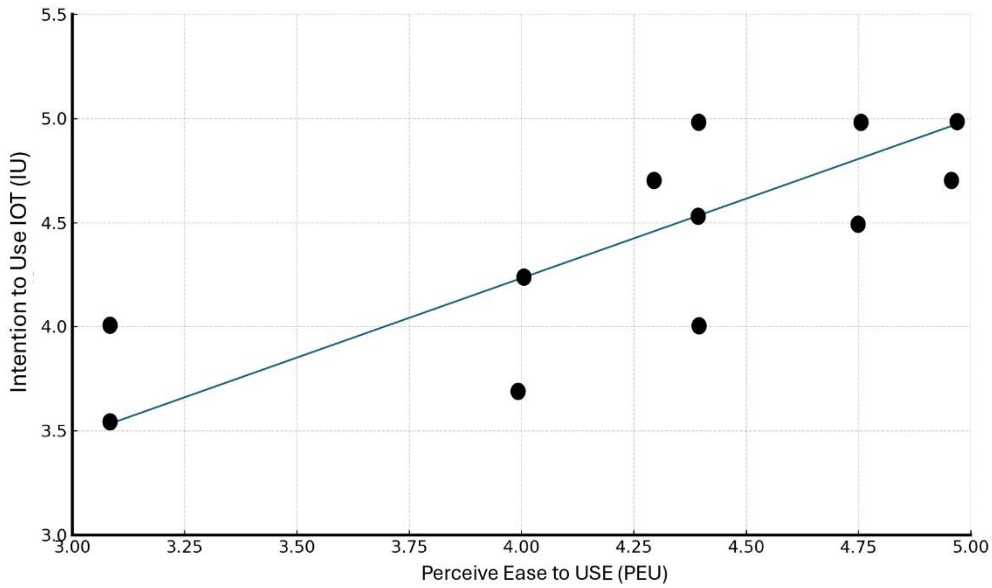

Figure 6. Correlation analyses between perceived ease of USE (PEU) and Intention to Use IoT.

3.5 Discussion

Respondents' concerns about the cost of implementation (CI), especially capital investment, aligned with the challenges faced in IoT implementation in rural areas. Furthermore, the research results on the problems and potential of IoT in agriculture provide a substantial contribution to the continuing discourse on this subject, as it examines the connections between perceived knowledge (PK) and Perceived Ease of use (PEU) in relation to the desire to utilize IoT. This study provides empirical evidence to support the theoretical claims stated in previous studies. The results align with the ideas emphasized by Sekaranom et al. (2021), which suggest that the adoption of technology is driven by a mix of factors, including cost knowledge and usability, to successfully deploy IoT devices in the Indonesian agriculture sector. It is essential to develop the right infrastructure, including the availability of dependable internet access and alternative energy sources (Miglani et al., 2020; Yildizbasi et al., 2020; Gawusu et al., 2022). Deployment of IoT devices in rural areas may require alternate energy sources, including solar power (Konstantinou 2022).

In addition, the low R-squared values of the cost of implementation (CI) and Perceived Knowledge (PK) correlations indicate that factors beyond those examined, such as cultural attitudes or governmental laws, may have a substantial impact on IoT adoption. Addressing the respondent's second issue of lack of knowledge (Perceived Knowledge) in technology implementation and user experience training and support to understand and properly use IoT devices needs to be addressed (Akhter and Sofi 2022; Sinha and Dhanalakshmi 2022). The successful implementation of IoT

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DOI: 10.19028/jtep.013.2.265-283

technologies in agriculture hinges upon the effect of functioning of these devices and user ability to analyze the big amount of generated data (Ronaghi and Forouharfar 2020; Thilakarathne et al., 2021). It is impossible to stress the importance of IoT implementation in agriculture through training, because it ensures that farmers can effectively use IoT devices and evaluate the data produced to enhance production and profitability. Moreover, technical assistance is crucial to ensuring that IoT devices to make decisions that are supported by thorough data analysis of IoT technologies in agriculture necessitate not only advanced equipment, but also sufficient support and training to allow farmers to realize the full potential of these technologies (Khana and Kaur 2019; Rehman et al., 2022).

Furthermore, the significant link between perceived ease of use (PEU) and the intention to utilize the Internet of Things (IoT) aligns with the study by Nugroho et al. (20219) and Sekaranom et al. (2021). A significant obstacle to the successful adoption of IoT in Indonesian agriculture is the country's limited access to technology, as most Indonesian farmers continue to use conventional farming methods for small-scale farmers who want to implement IoT technologies because they contain complex technologies such as sensor communication networks and data storage capabilities (Villa-Hendriksen et al., 2020). Further impeding the improvement of agricultural productivity is the low adoption of IoT devices owing to the lack of understanding of their advantages (Reddy Maddikunta et al., 2021; Qazi et al., 2022). Technological advancements and the need to reduce the environmental footprint have made automatic irrigation and fertigation systems a suitable alternative as a smart method for creating precision agriculture. This is because of the ability of the IoT in the sensor to create a system that turns off automatically based on the soil moisture level, thereby resolving the problems of insufficient water provided to the plant, allowing farmers to obtain information related to the soil, such as moisture content, pH, humidity, and temperature.

However, Lo Bianco et al. (2021) also showed that there is a higher possibility of having a poor automated system design, which normally requires a significant amount of money to fix. Vera et al. (2021) reported that the market price for crop yields is generally unstable, which means it is highly possible to have a higher cost of crop production than the selling price. Therefore, it is risky to select an automated system with a higher investment cost than the traditional method. Moreover, Atreya et al. (2019) found that it is usually difficult for both small- and medium-income farmers to apply an automated system because of their low level of technological skills.

4. Conclusion

The adoption of IoT technologies in Indonesia's agricultural sector is influenced by multiple interrelated factors. In this study, a stratified multistage random sampling technique was employed for data collection, and Structural Equation Modelling (SEM) using SMARTPLS, supplemented by SPSS, Excel, and Python, was used to analyse the data. This study shows that the Cost of Implementation (CI) and Perceived Knowledge (PK) correlate with the Intention to Use (IU) IoT systems, but their impact is relatively weak. In contrast, Perceived Ease of Use (PEU) has emerged as a significant predictor of farmers' willingness to adopt IoT, highlighting that usability and user-friendly design are critical for adoption among farmers with varying technological skills. To effectively promote IoT adoption in Indonesian agriculture, efforts should prioritize enhancing ease of use, providing dedicated training and support, and overcoming infrastructural barriers, rather than focusing solely on cost reduction or knowledge enhancement. This multidisciplinary approach can facilitate the widespread integration of IoT technologies into the farming industry in Indonesia, especially in improving agricultural productivity, resource efficiency, and environmental sustainability.

Acknowledgement

The authors would like to thank the Centre for Research and Community Service (CRCS) Sampoerna University for their support.

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