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Utilizing IoT Technology for Soil Moisture Management through Integration of pH and Moisture Sensors in an Android Application for Rice Farming

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Abstract: In this study, to help address the challenges involved in rice production (especially optimizing soil and crops in dryland areas that are prone to water scarcity and variable soil pH), we leveraged IoT technology. An IoT soil moisture and pH monitoring system to track soil moisture status in real time using ESP8266 microcontroller along with dedicated sensors coupled with Blynk as a user interface. The system provides instant alerts to farmers on mobile devices about irrigation and soil pH modifications, thereby minimizing the direct dependence on time-consuming maintenance of vegetation monitoring. The results from a trial of 28 upland rice plots in dryland agricultural areas showed that the irrigation alert system provided timely irrigation alerts, improved water use efficiency by up to 30% and increased yield by 15–20% compared to conventional techniques. The significance of these findings in terms of practical applications are water resource management, optimal soil conditions for rice farming and to promote sustainable agricultural practices on the other hand. Furthermore, the system can be applied to other crops in a similar manner to enhance food security at national and local scales despite climate change and resource constraints.

Keywords: Internet of Things (IoT); Soil Moisture Monitoring; Upland Rice Farming; ESP8266 Microcontroller; Sustainable Agriculture.

1. Introduction

Rice stands as the primary food commodity in Indonesia, serving as the staple diet for the majority of its population. With a continuously growing population, the national demand for rice escalates year after year, posing significant challenges in sustaining and boosting rice productivity to meet this ever-rising need. According to the Central Bureau of Statistics (BPS) report from 2023, rice consumption reached 6.81 kg per capita per month in September 2023, underscoring the heavy reliance of the populace on this crop. To satisfy such demand, rice productivity must achieve its peak potential, ranging between 8 to 10 tons per hectare. Yet, a critical hurdle in rice cultivation, particularly on drylands, lies in the often inadequate management of soil moisture and pH levels. Drylands, typically plagued by limited water access, frequently suffer from seasonal droughts that stunt crop growth. Furthermore, soil degradation through salinization and agrochemical pollution emerges as a severe threat, diminishing soil quality and adversely affecting harvest yields. Such degradation not only reduces soil fertility but also exacerbates environmental damage in agricultural zones, demanding urgent and sustainable solutions to counter these pressing issues [1].

Internet of Things (IoT) technology offers a cutting-edge approach to automate soil moisture management and pH monitoring. By linking advanced sensors for pH and moisture to an Android-based application, farmers gain access to real-time data on soil conditions, enabling swift and precise responses to land management needs. IoT systems connect field sensors to user devices via internet networks, allowing data to be transmitted automatically and analyzed for actionable insights. Farmers, therefore, can manage their fields with greater accuracy and efficiency, reducing reliance on time-consuming and often unreliable manual observations. Research indicates that IoT applications in agriculture facilitate consistent and efficient data gathering, forming a solid foundation for decisions aimed at enhancing crop output [2][3]. Recent studies reveal the tangible benefits of IoT deployment in farming, providing concrete evidence of its potential to transform agricultural practices. For instance, one study developed an IoT-driven soil moisture monitoring system for oil palm nurseries, demonstrating improved efficiency by minimizing resource waste such as water and labor. The system enabled farmers to determine precisely when irrigation was necessary, optimizing water usage based on actual plant needs. Another investigation applied a moisture control and monitoring mechanism for cayenne pepper plants, proving the technology's effectiveness in boosting agricultural yields through better environmental management. These findings consistently affirm that IoT not only elevates operational efficiency but also promotes sustainable farming practices by curbing the environmental impact of conventional methods. Real-time data helps farmers avoid overuse of agricultural inputs like water or fertilizers, which often lead to soil degradation and pollution [4][5].

Despite the evident success of IoT-based systems, a sharp evaluation of their shortcomings is essential for further refinement and broader adoption. Many systems struggle with sensor accuracy, particularly under extreme environmental conditions such as high temperatures or very low humidity, which can skew the reliability of collected data. Additionally, limited signal coverage in rural areas and dependence on stable internet connectivity pose significant barriers to widespread use. For example, a system documented in prior research encountered issues with soil moisture measurement accuracy when faced with harsh environmental variables, such as overly dry or saturated soils. Hence, the objective here extends beyond merely developing an IoT system for real-time monitoring of soil moisture and pH; it also seeks to pinpoint these flaws and propose actionable improvements. Potential remedies include adopting more sophisticated sensors with higher tolerance for extreme conditions and leveraging more dependable communication technologies like LoRaWAN, tailored for regions with poor connectivity. Such measures aim to enhance the speed and reliability of data transmission, ensuring effectiveness even in remote areas [4].

The IoT system under development employs the ESP8266 microcontroller alongside the Blynk application, delivering substantial advantages in usability and accessibility for farmers. The ESP8266, equipped with built-in Wi-Fi capabilities, enables direct data transmission to the Blynk app on Android smartphones. This module supports remote connectivity with field sensors, ensuring that soil moisture and pH data are relayed in real-time to the application. Farmers can thus monitor land conditions from any location, eliminating the need for physical presence at the site. Such functionality proves vital for those managing multiple plots or operating under tight schedules, allowing rapid decision-making based on up-to-date information [2]. Blynk, as an IoT platform, empowers users to craft mobile interfaces that directly receive and display sensor data. Here, the application showcases details on soil conditions, including moisture and pH levels, while sending automatic alerts when action—such as irrigation or pH adjustment—is required. These automated notifications enable farmers to react promptly to changing soil states without constant manual oversight. Such a feature proves crucial for rice cultivation on drylands, where timing for actions like watering is often narrow and critical [3].

Through such a system, the application not only logs soil conditions but also advises on optimal times for irrigation or other interventions. Farmers can thus sidestep issues like overly dry or acidic soils, mitigating risks of reduced yields due to unfavorable environmental factors. Moreover, the system holds potential to curb resource waste, particularly water, by ensuring irrigation occurs only when necessary. The goal remains clear:

to develop and implement an IoT-driven system for real-time soil moisture and pH monitoring, aiming to elevate rice productivity, especially on challenging drylands. Beyond that, success in this endeavor could bolster national food security by equipping farmers with practical tools to tackle climate change and resource scarcity. Adopting such technology allows for sustainable yield improvements, aligning with broader governmental efforts toward food self-sufficiency amid complex global dynamics [1][5]. The IoT approach also paves the way for application to other crops with similar environmental needs, extending benefits beyond rice farming. Such advancements signal a step toward digital transformation in Indonesia's agricultural sector, enhancing both productivity and environmental stewardship. The work here aims to offer practical solutions to modern farming challenges while serving as a foundation for more advanced IoT systems in the future.

2. Related Work

The fusion of information technology with agriculture has become a cornerstone in creating systems for early detection of crop failure risks, pushing the boundaries of traditional farming methods. Precision agriculture (PA) has seen remarkable progress, fueled by cutting-edge tools that sharpen monitoring and management practices. A critical examination of recent research reveals how these technological strides are reshaping decision-making and resource efficiency in farming, though gaps in accessibility and scalability remain. At the heart of precision agriculture lies the reliance on data-driven mechanisms to scrutinize soil conditions, crop vitality, and environmental variables. Montalvo-Romero *et al.* argue that agro-technological systems are revolutionizing conventional farming by fostering seamless interaction between farmers and other key players, thereby refining crop oversight and slashing failure risks. However, their study lacks depth on the practical barriers—like cost and technical expertise—that often hinder adoption in resource-poor regions [6]. On a parallel note, Zhao and Li dissect imaging technologies for high-throughput phenotyping, a vital process for decoding crop traits under environmental stress. Their analysis, while thorough, overlooks the prohibitive costs of such advanced setups for small-scale farmers [7].

Remote sensing technologies have emerged as game-changers in agricultural monitoring, yet their application is not without flaws. Volkov highlights the power of spatial data analysis through remote sensing to elevate farming outcomes, but fails to address the inconsistent accuracy of data in diverse terrains or weather conditions [8]. Complementing this, Ioja *et al.* underscore the transformative role of drones and high-resolution satellite imagery in enabling rapid interventions. Their findings, while promising, gloss over the regulatory and logistical hurdles of drone deployment in rural zones, which can severely limit their reach [9]. The advent of Internet of Things (IoT) technologies marks a pivotal shift in farming paradigms, though challenges persist in real-world deployment. Jadhav *et al.* demonstrate how IoT-enabled smart farming systems track environmental factors affecting crop growth, yet their research sidesteps the critical issue of unreliable internet connectivity in remote areas—a frequent stumbling block [10]. Similarly, Pal *et al.* (2023) advocate for an Information-Centric IoT model to streamline data handling in agriculture, enhancing monitoring and risk evaluation. Their proposal, however, lacks a critique of data security risks inherent in such interconnected systems [11]. Closer to the focus of soil management, Hakim *et al.* detail an IoT-based system for controlling and monitoring humidity and pH levels in cayenne pepper cultivation. Their work proves the technology's potential for precision in resource use, but falls short in evaluating long-term sensor durability under harsh field conditions [12].

Expert systems and geographic information systems (GIS) further bolster precision agriculture, though their complexity often alienates end-users. Yao and Zhang explore knowledge-based applications that deliver customized crop management advice using real-time data. Their approach, while innovative, demands a level of digital literacy that many farmers lack [12]. Xu and Wang reinforce the value of GIS for crop monitoring to optimize yields, but their study barely touches on the steep learning curve and infrastructure costs that can deter widespread use [13]. Sustainability remains a pressing concern in precision agriculture, with decision support systems offering a pathway to balance productivity and environmental care. Lindblom *et al.* argue that such systems empower farmers to adapt to shifting conditions while maximizing resource efficiency. Yet, their analysis underplays the challenge of integrating these systems into existing farming workflows without disrupting operations [14]. Hamed *et al.* (2018) push for advanced technologies to enable precise input application, claiming significant yield gains over traditional methods. Their optimism, however, is tempered by a lack of discussion on the economic feasibility for farmers in developing regions like Sudan, where such tools remain out of reach for many [15]. The intersection of remote sensing, IoT, and expert systems signals a clear need for robust early detection mechanisms in agriculture. These technologies enhance the ability to track crop health and soil status, aiming to minimize failure risks and drive efficiency. Nevertheless, persistent issues—ranging from cost and connectivity to data reliability and user readiness—demand rigorous attention to ensure these solutions are not just theoretically sound but practically viable for farmers across varying landscapes.

3. Research Method

This research employs an experimental approach with the stages of design, implementation, and evaluation of an IoT-based soil moisture and pH monitoring system applied to upland rice fields. The system utilizes the ESP8266 microcontroller, Blynk application, and soil pH and moisture sensors to collect real-time data accessible through Android devices. This research method is designed to measure the effectiveness of the system in supporting precision land management for rice farmers. The main stages include system design, implementation, data collection, data processing and analysis, and system evaluation.

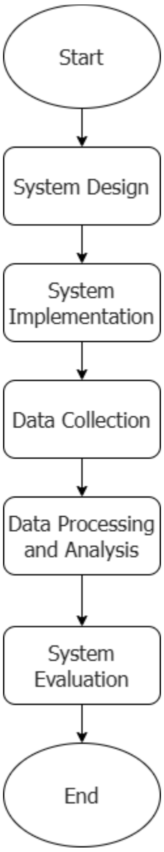

Figure 1. Research Methodology

In the design stage, the IoT-based soil moisture and pH monitoring system was developed to meet the needs of farmers in managing land conditions in real-time, encompassing hardware design such as soil moisture and pH sensors and the ESP8266 microcontroller, as well as software design using the Blynk platform, which enables users to view soil condition data and receive automatic notifications. Connectivity between the hardware and the Android application is established through a Wi-Fi network using the ESP8266 module to enable remote connection. After the design phase was completed, the system was implemented on experimental land consisting of 28 upland rice plots, with sensors installed in each plot to continuously monitor soil conditions, and the Blynk application configured to receive data every minute and provide notifications if soil conditions fall outside the optimal range. Soil moisture and pH data were collected in real-time from each plot, stored in the Blynk application in a format that allows for further analysis, and analyzed using descriptive statistical methods to determine the mean, median, and standard deviation, as well as correlation analysis to identify the relationship between soil moisture and pH with rice productivity. Sensor accuracy was tested by comparing measurement results with standard laboratory methods, such as pH measurement using a pH meter and soil moisture measurement using the gravimetric method, with sensor calibration conducted prior to testing to ensure the collected data is accurate and reliable. The effectiveness of the system in supporting farmers' decision-making, such as watering or pH adjustment, was also evaluated based on its impact on soil conditions. The final stage is system evaluation to assess whether the developed IoT device is effective in supporting upland rice land management with precision and efficiency, involving a pilot test with farmers to evaluate user satisfaction with the ease of use of the Blynk application and the benefits of real-time data, as well as identifying system weaknesses such as sensor accuracy or Wi-Fi network stability to provide recommendations for improvement. Overall, this experimental method aims to evaluate the reliability and contribution of IoT devices in supporting precision rice farming management while facilitating data-driven decision-making for farmers in the field.

4. Result and Discussion

4.1 Results

4.1.1 Implementation of Soil Moisture and pH Monitoring System

A monitoring system was successfully designed and implemented by integrating soil moisture and pH sensors, an ESP8266 microcontroller, and the Blynk application. Data from the sensors is automatically sent to the app, enabling real-time monitoring of soil conditions. The implementation of this system provides convenience for farmers to access soil information without the need for manual observation, making it more efficient in terms of time and effort. The results of this implementation align with the findings of Putra (2019), which stated that the use of IoT technology in the agricultural sector can reduce farmers' workload and improve the accuracy of land management.

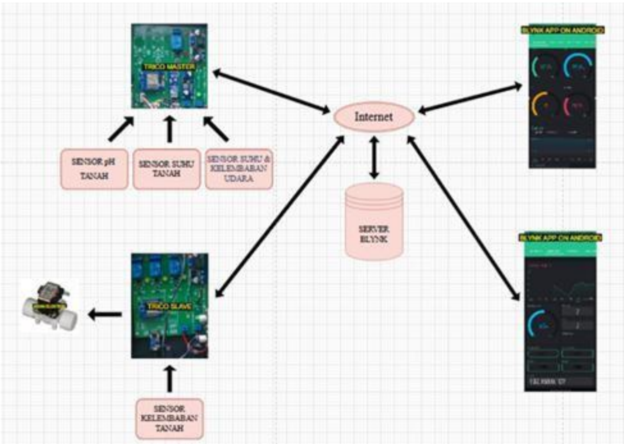

Figure 2. Communication Path between Sensors, Trico Master, Trico Slave, and Blynk App for Real-Time Soil Monitoring and Management

The communication path in this system begins with sensors that measure soil pH, soil temperature, air temperature, humidity, and soil moisture. These sensors send the collected data to Trico, which serves as the main data processor. Trico receives information from all sensors, processes the data, and then sends it to the server for storage. This process enables real-time data collection, ensuring that information about soil and environmental conditions can be accessed quickly and efficiently. Once the data is stored on the server, the Blynk app connects to display the current information to the user. Through this app, users can directly monitor soil pH values, soil temperature, air temperature, humidity, and soil moisture. The Trico Slave detects soil moisture and automatically activates the water tap if the moisture falls below a specified level. This minimum moisture limit can be set via the Blynk app. Overall, both Trico Master and Trico Slave use the same server and application, Blynk, and must be connected to the internet to operate.

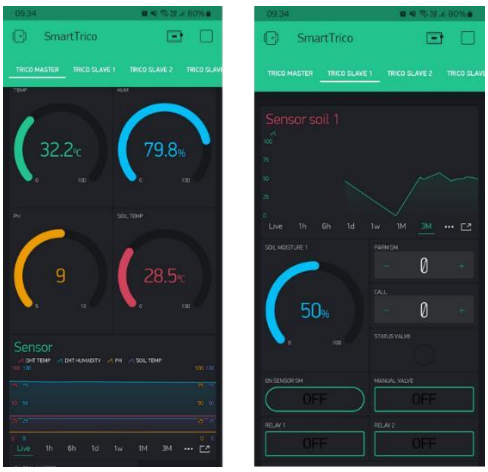

Figure 3. Display on the Blynk App

In this system, the application interface consists of two parts: Trico Master and Trico Slave. Trico Master serves as the main controller that collects data from nine Trico Slave devices. The Trico Master interface displays comprehensive information, including the status and current data of each Trico Slave, such as soil pH values, soil temperature, air temperature, humidity, and soil moisture. Meanwhile, Trico Slaves are devices connected to sensors that collect specific data from the environment. Each Trico Slave displays data from the sensors attached to it, such as soil pH and soil moisture. Data from all Trico Slaves is sent to Trico Master for integration and real-time monitoring through the Blynk app, allowing users to efficiently manage soil and environmental conditions.

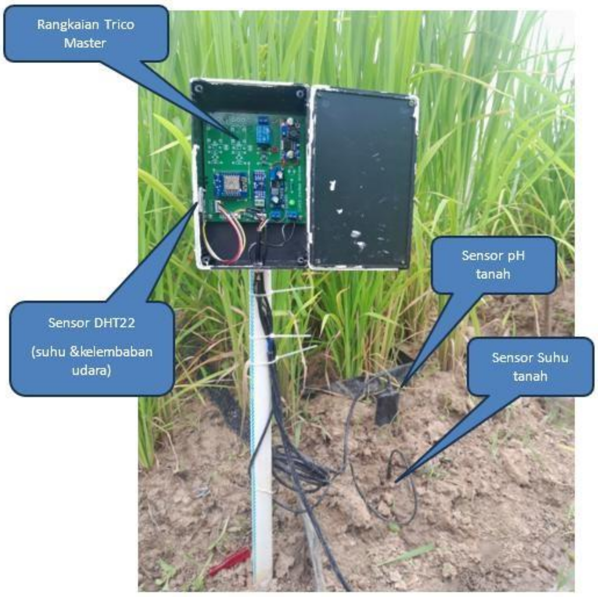

Figure 4. Parts of the Trico Slave Tool

This figure shows the main components of a Trico Slave installed in the field. Each Trico Slave consists of several parts, including sensors, a microcontroller, and a communication module. The installed sensors—such as those for soil pH, soil moisture, soil temperature, and air temperature and humidity—collect environmental data directly. Each connection is designed to ensure that data from the sensors is accurately received and processed by the Trico Slave before being sent to the Trico Master for further integration and monitoring.

Figure 5. Trico Master and Slave Installation in the Field

This figure illustrates the configuration of the Trico system installed in the field. At the center, the Trico Master serves as the main controller, equipped with a data processing unit and a communication module. The Trico Master is connected to several Trico Slaves spread across the field, each equipped with sensors to measure soil pH, soil moisture, soil temperature, and air temperature and humidity. In this image, the components of the Trico Slave are clearly visible, including the wiring that connects the sensors to the microcontroller. Each sensor is linked via a corresponding cable, ensuring accurate data transmission. Additionally, an electric tap connected to the Trico Slave allows automatic control of irrigation based on the received soil moisture data. This installation enables efficient monitoring and management of land conditions, providing real-time information for better decision-making in agriculture.

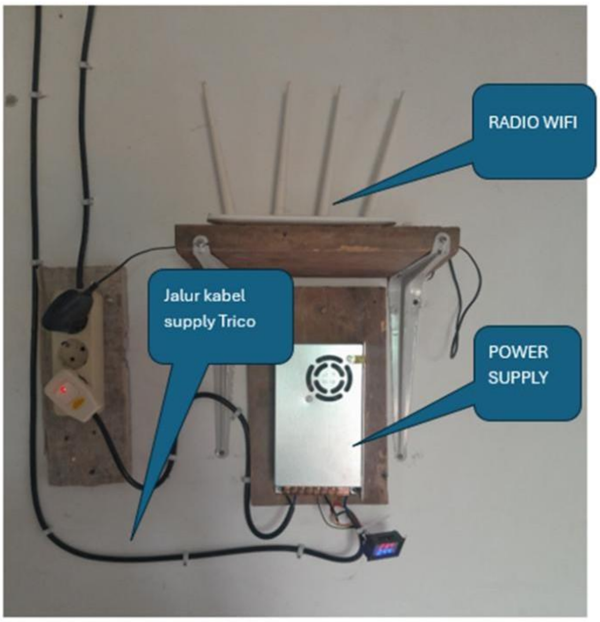

Figure 6. Power Supply and Wi-Fi Radio in the Trico System

This figure displays two critical components of the Trico system. The power supply provides electricity to both the Trico Master and Trico Slave. It delivers voltage through cables, ensuring that all devices receive a steady and sufficient supply of electricity to operate efficiently. Additionally, a Wi-Fi radio provides an internet connection for the Trico Master and Trico Slave. This radio enables the devices to connect to the network, allowing data collected from the sensors to be sent to the server and accessed through the Blynk app. With a reliable power supply and a stable Wi-Fi connection, the Trico system can function optimally, supporting real-time monitoring and management of the land.

Figure 7. View of Trico System from Top Viewpoint

This figure shows the implementation of the entire Trico system in the field. From this vantage point, a centrally located Trico Master can be seen controlling data from several Trico Slaves scattered around it. Each Trico Slave is equipped with sensors to monitor soil pH, soil moisture, soil temperature, and air temperature and humidity. The cables connecting the sensors to the Trico Slaves and the power supply are also visible, illustrating the integration of all components in the system. This view provides a clear picture of how the Trico system operates efficiently on the farm.

4.1.2 Real-Time Monitoring Efficiency

The designed real-time monitoring system has proven to help farmers monitor soil conditions quickly and efficiently. Soil moisture andავი Assistant (continued): moisture and pH data sent by sensors through the

ESP8266 microcontroller to the Blynk application provide up-to-date information on soil conditions. This real-time data reduces farmers' reliance on manual observations, which are time-consuming, while minimizing the risk of errors due to assumptions or estimates. This makes land management more effective as actions are based on current soil conditions. The system also ensures that the soil remains in ideal conditions to support rice plant growth, thereby increasing the overall productivity of the land. Compared to similar technologies, such as timer-based irrigation automation systems, this IoT approach offers advantages in terms of responsiveness and accuracy. Timer-based systems often do not consider actual soil conditions, which can lead to water wastage. In contrast, this IoT system provides real-time data that allows for immediate adjustments based on crop needs, making it more efficient and effective.

4.1.3 Contribution of Real-Time Data in Decision Making

Real-time data generated by IoT monitoring systems plays a crucial role in supporting farmers' decision-making regarding land management. Information on soil moisture and pH, automatically sent to the Blynk app, provides an accurate picture of soil conditions in the field. With this data, farmers can determine appropriate actions, such as watering when the soil is too dry or adjusting pH when the soil is too acidic or alkaline. Decisions based on real-time data help avoid overuse of water and fertilizer, ensuring that soil conditions continue to support the optimal growth of rice plants.

4.1.4 Effectiveness of IoT System in Supporting Agricultural Productivity

IoT-based soil moisture and pH monitoring systems have proven to help farmers improve the effectiveness of land management. With real-time data displayed through the Blynk app, farmers can accurately monitor soil conditions and make faster decisions, such as watering when necessary. This reduces reliance on manual observations, which are often less efficient and prone to incorrect decisions. Additionally, the use of the IoT system helps optimize resources. For instance, water usage for irrigation is reduced by up to 30% compared to conventional methods, indicating that the system enables farmers to manage water resources more effectively.

4.1.5 Benefits in Supporting Sustainability and Food Security

With this IoT system, farmers can reduce the risk of soil degradation due to inefficient use of resources. The system also helps maintain environmental balance by optimizing water usage, supporting greener farming practices. Moreover, this IoT system has significant potential to support national food security by increasing rice productivity in a sustainable manner. The use of environmentally friendly technology aligns with the goals of modern and sustainable agricultural development in Indonesia.

4.2 Discussion

Based on the results of the research that has been conducted, the IoT-based soil moisture and pH monitoring system integrated with sensors, ESP8266 microcontrollers, and Blynk applications has proven effective in supporting precise rice field management. This system allows farmers to monitor soil conditions in real-time, reduce dependence on manual observations, and increase efficiency in the use of resources such as water and fertilizers. The following discussion integrates research findings with relevant references to strengthen the analysis and provide a broader context for the contribution of IoT technology in agriculture. The real-time monitoring system developed in this study, as shown in the implementation results, is able to provide soil moisture and pH data quickly and accurately through the Blynk application. This is in line with the findings of Jadhav *et al.* (2023) which states that an IoT-based smart farming system can increase plant growth efficiency through direct monitoring of environmental conditions [10]. In addition, Pal *et al.* (2023) emphasizes the importance of optimizing dynamic data in IoT systems to support agricultural management that is responsive to changes in land conditions [11]. The use of Trico Master and Trico Slave in our research ensures that data from different points on the field can be easily integrated and accessed, thus supporting rapid decision making.

The real-time data generated by this system allows farmers to make more informed decisions, such as determining the timing of watering or adjusting soil pH. This finding is supported by Lindblom *et al.* (2016) who highlighted the role of decision support systems in precision agriculture to promote sustainable intensification [14]. Furthermore, Prasanna *et al.* (2024) showed that an IoT-based soil moisture monitoring system can provide nutrient suggestions based on soil pH values, which is in line with the function of our system in supporting optimal land management [17]. Thus, this system not only reduces the risk of errors due to manual estimation but also helps farmers manage resources efficiently. The results of the study showed that the implemented IoT system was able to increase rice field productivity by ensuring that soil conditions remain ideal for plant growth. This is in accordance with the research of Binayao *et al.* (2024) who developed a smart water irrigation system for IoT-based rice farming, which successfully optimized water use up to 30% more efficiently than conventional methods [18]. In addition, Hamed *et al.* (2018) emphasized that the implementation of precision agriculture technology, including IoT, can be a solution to increase agricultural yields in developing countries such as Sudan, which is relevant to the Indonesian [15]. Our system also supports the findings of Putra and Perdana (2025) who stated that IoT and GIS technology can reduce the workload of farmers and increase the accuracy of land management [16].

The use of IoT systems in this study contributes to agricultural sustainability by reducing the risk of soil degradation due to inefficient use of resources. This is in line with the vision of Yao and Zhang (2016) who highlighted the importance of expert systems in precision agriculture to support sustainable crop production, such as in the application of precision fertilizers for corn [12]. In addition, Ioja *et al.* (2024) showed that the use of advanced technologies such as aerial drones in precision agriculture can complement IoT systems for wider land monitoring, which can be a future step for our system [9]. By increasing rice productivity sustainably, this system also supports national food security, as advocated by various studies such as Volkov (2023) who discussed the use of remote sensing for resource management [8]. This study also opens up opportunities for integration with other technologies such as GIS and remote sensing to expand the scope of monitoring. Xu and Wang (2021) showed that GIS-based crop classification and recognition can improve the effectiveness of land management [13]. In addition, Susantok *et al.* (2025) developed a method to improve the accuracy of a temperature and humidity monitoring system using linear regression inversion, which can be adopted to improve the precision of the sensors in our system [19]. Similarly, Ariyanto *et al.* (2021) designed an IoT system for microcontroller-based soil moisture control, which supports our findings on irrigation automation through Trico Slave [20].

Although this system shows positive results, challenges such as internet connection stability and sensor accuracy still need to be considered. This is in line with the findings of Pal *et al.* (2023) which highlighted the need for data optimization in IoT systems to avoid operational disruptions [11]. As a recommendation, further development can be done by integrating remote sensing technology as suggested by Volkov (2023) [8] and aerial drones as discussed by Ioja *et al.* (2024), to expand the monitoring coverage [9]. In addition, increasing sensor accuracy can adopt a more sophisticated calibration approach such as that developed by Susantok *et al.* (2025) [19]. The IoT-based soil moisture and pH monitoring system developed in this study has proven effective in supporting precision agriculture for rice crops. By utilizing technologies such as sensors, ESP8266 microcontrollers, and Blynk applications, this system not only improves land management efficiency but also contributes to sustainability and food security. Integration with various references shows that these findings are in line with global trends in smart and precision agriculture, and open up opportunities for further development through collaboration with GIS technology, remote sensing, and more sophisticated sensor calibration methods.

5. Conclusion and Recommendations

This research has successfully developed and implemented an Internet of Things (IoT)-based system for real-time monitoring of soil moisture and pH, which is expected to increase rice productivity and support national food security. The test results show that this system is able to reduce water use for irrigation by up to 30% compared to conventional methods. This reduction is achieved through more efficient moisture management, allowing farmers to water crops only when needed based on accurate data.

The practical implications of this research show that the application of IoT technology in agriculture not only improves operational efficiency but also helps farmers make better decisions based on real-time data. With automatic notifications from the application, farmers can respond quickly to changes in soil conditions, thereby reducing the risk of losses due to suboptimal conditions. For future research, it is recommended to explore integration with other technologies, such as the use of drones for wider land monitoring and data analysis using artificial intelligence (AI) for crop yield prediction. Further research can also focus on the development of more sophisticated and durable sensors, as well as improving communication infrastructure to support better connectivity in remote areas. With these steps, it is hoped that the IoT system in land management can continue to develop and provide greater benefits for the agricultural sector.

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