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Assessing the Usability of IoT-Based Smart Farming for Sustainable Organic Agriculture

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Abstract: This study evaluates the usability of an IoT-based smart farming system developed to support organic agriculture in Thailand. Many small-scale farmers still spend considerable time manually monitoring soil conditions and managing irrigation, often without access to practical technology. This slows farm operations and makes efficient water use more difficult. To address these challenges, the system was designed with wireless soil-moisture sensors that collect real-time data and automatically control irrigation. It operates in automatic mode during the day and allows manual control at night through a mobile app. The aim is to reduce daily workload, conserve water, and improve decision-making on the farm. Usability was assessed using the System Usability Scale (SUS). Twenty organic farmers in Thailand participated in the evaluation after using the system under real working conditions. The results showed an average SUS score of 86, which is considered excellent and reflects a high level of user satisfaction. The findings suggest that this type of smart farming system can be a valuable tool for small-scale organic farmers. It provides a simple and accessible way to adopt agricultural technology without requiring advanced technical skills. By making irrigation easier and more efficient, the system supports sustainable practices and helps farmers manage their time and resources more effectively.

Keywords: Internet of Things (IoT); Smart Farming; Usability; System Usability Scale (SUS); Organic Agriculture

Introduction

While organic agriculture has traditionally relied on manual practices, many farmers are now turning to new technology to improve efficiency and sustainability. One of the most widely adopted technologies in this shift is the Internet of Things (IoT), which plays a central role in supporting smart farming systems by enabling real-time monitoring, automation, and data-driven decision making (Klerkx et al., 2019; Rose et al., 2021). However, even though IoT technologies offer significant potential, they must be carefully evaluated in real-world farming environments to ensure that they are practical, usable, and aligned with farmers' needs, especially in small-scale organic settings.

In Thailand, many farmers have limited access to advanced agricultural technologies and often lack the technological background needed to adopt them. Therefore, usability and simplicity must be prioritized when introducing IoT systems into these low-tech farming environments. Regardless of their potential benefits, smart farming systems risk abandonment if they are too difficult to use. This study focuses on evaluating an IoT-based smart farming system designed specifically for new or inexperienced users—farmers who may have never interacted with such technology before. The aim is to make the system functional, user-friendly, and accessible to those with little or no technical experience. In doing so, this study supports the broader adoption of smart farming practices among Thai farmers and helps reduce barriers caused by digital unfamiliarity (Lemke & Weber, 2022).

While a system may seem solid during development, its performance when used by real farmers is what truly matters. For many small organic farmers, especially those with limited technological experience, seemingly minor design details can carry significant weight. Something as simple as a vague button label or a lack of system feedback can lead to hesitation or, in the worst case, complete disengagement. While there is growing interest in smart farming, relatively few studies investigate how these systems function in the hands of small farmers trying to integrate them into their daily routines.

To better understand this issue, the study used a mixed approach. It began with a heuristic evaluation based on Nielsen's principles, examining factors such as learnability, user control, and the quality of system feedback (Nielsen, 1994). Following this, farmers were asked about their experience using the system, and their responses were scored using the System Usability Scale (SUS) (Sauro & Lewis, 2011). This provided two perspectives: one from design experts and one from real users attempting to incorporate the system into their workflow. Together, these perspectives helped determine not only what the system was intended to do, but whether it actually worked for farmers without a technical background.

Smart Farming and IoT Technology

The integration of Internet of Things (IoT) technology has brought noticeable changes to agriculture, particularly in the way farms manage resources, improve productivity, and shift toward more sustainable practices. With sensors, wireless communication, and data analytics working together, these systems enable real-time monitoring, automate routine processes, and reduce unnecessary resource use (Ayaz et al., 2019).

A key technology used in this study is the wireless soil-moisture sensor. These sensors continuously monitor soil conditions, enabling automated irrigation and reducing guesswork. The data they provide—such as moisture levels, pH, and nutrient content—give farmers insight into what their crops need and when, whether it is watering, fertilising, or planning the next planting (Muhammad et al., 2019; Qu et al., 2022).

Most IoT-based smart farming systems follow three core stages (Maduranga & Abeysekera, 2020; Muthumanickam et al., 2022):

1. **Data collection** – Sensors gather environmental information such as soil moisture, temperature, and humidity.
2. **Data transmission** – The data are sent wirelessly to a central system or cloud platform.
3. **Data analysis and action** – The system interprets the data and provides insights or automates actions to support farm management.

Farmers who adopt these systems often report benefits such as higher yields, improved water efficiency, and reduced manual labour. For example, one study reported a 15% increase in crop yield and a 20% reduction in water use compared with traditional practices (Maduranga & Abeysekera, 2020). However, challenges remain, including installation complexity, initial investment costs, and the basic technical skills required to operate and maintain such systems.

Usability in Smart Farming IoT Systems

Usability plays a crucial role in how well users can interact with a system to accomplish their goals (Navarro et al., 2020). According to ISO 9241-11, it refers to the extent to which a product can be used by specific users to achieve particular objectives effectively, efficiently, and with satisfaction in a defined context (International Organization for Standardization, 2018). Although several studies have examined usability in agricultural technology more broadly, smart farming systems that integrate IoT bring new and sometimes unfamiliar challenges. These platforms often include real-time data collection, automation, and digital interfaces, which can be difficult to navigate, especially for users with little technical background. This is why usability evaluation becomes so important: it helps ensure that these systems are not only functional, but also practical and approachable for people using them in the field.

Usability is typically examined through four key dimensions:

- Learnability – how quickly and easily users can begin using the system
- Efficiency – how well users can complete tasks with accuracy and speed
- Error tolerance – how the system helps users avoid mistakes or recover when they occur
- Satisfaction – the overall user experience, including confidence and comfort during use

To explore these dimensions more thoroughly, this study also applied Nielsen's (1994) ten heuristic principles as part of the usability assessment. These heuristics are widely recognized in human-computer interaction for identifying interface design issues and improving user experience. They include:

1. Visibility of system status
2. Match between system and the real world
3. User control and freedom
4. Consistency and standards
5. Error prevention
6. Recognition rather than recall
7. Flexibility and efficiency of use
8. Aesthetic and minimalist design
9. Help users recognize, diagnose, and recover from errors
10. Help and documentation

These principles served as a practical guide to identify areas where users might struggle or where the system could be made more intuitive. Good usability design aims to reduce complexity. That often means making navigation more intuitive, reducing the mental effort needed to use the system, ensuring a consistent interface, and providing clear feedback (Quý et al., 2022). In smart farming, these elements matter even more. When decisions rely on real-time sensor data, the way information is displayed can affect how quickly and accurately farmers respond. Clear visuals, simple layouts, and dashboards that make sense at a glance can all support better decision-making—and ultimately lead to more productive and sustainable farming.

System Usability Scale

The System Usability Scale (SUS) is composed of ten items that assess users' overall perceptions of a system's usability. To minimize acquiescence bias and encourage critical engagement, the scale alternates between positively and negatively worded statements. Items 1, 3, 5, 7, and 9 are phrased positively, reflecting favorable experiences such as clarity, ease of use, and user confidence. In contrast, items 2, 4, 6, 8, and 10 are phrased negatively to capture issues such as inconsistency, complexity, or difficulty in learning. This alternating format is intended to prompt respondents to consider each statement independently and avoid patterned responses.

The calculation of the SUS score follows a standard procedure. Responses to positively worded items are adjusted by subtracting 1 from the original score, while responses to negatively worded items are adjusted by subtracting the score from 5. This converts each item to a value on a 0–4 scale. The ten adjusted scores are then summed and multiplied by 2.5 to yield a final score ranging from 0 to 100. Higher scores indicate more favorable usability perceptions. While a SUS score above 68 is typically interpreted as acceptable, the specific context and characteristics of the user population may influence how these scores are evaluated (Brooke, 2013; Sauro & Lewis, 2011).

Materials and Methods

System Design and Development

This study focused on building and testing a smart farming system designed to help organic farmers manage irrigation more efficiently. The system used IoT technology to monitor environmental conditions, collect data, and automate watering based on real-time soil moisture levels. It was developed with small-scale farmers in mind, particularly those with limited technical experience, with the goal of reducing unnecessary water use and simplifying daily tasks. The setup included soil moisture sensors, a microcontroller unit (MCU), wireless communication modules, cloud-based processing, and a mobile dashboard for monitoring and control (Morchid et al., 2024). The overall architecture of the system is illustrated in Figure 1, which presents the interaction between the hardware components and the communication layers designed to support automated irrigation management.

The hardware configuration was centered on the ESP32 microcontroller (Espressif Systems), which was selected for its enhanced processing capabilities, low power consumption, and integrated wireless communication (Wi-Fi and Bluetooth). These features offered a significant advantage over entry-level microcontrollers such as the ESP8266, particularly in rural deployment scenarios where stable wireless connectivity is essential (Al Mamun et al., 2025).

To ensure robust data acquisition, the system employed industrial-grade soil moisture sensors that utilize the Modbus RS-485 communication standard. These sensors were chosen based on their high signal integrity, resistance to environmental noise, and suitability for long-distance wired deployment in agricultural fields (Sayem et al., 2023).

Sensor data were transmitted to the ESP32 via RS-485 and subsequently relayed to the cloud using the Blynk Legacy IoT platform. Blynk was selected due to its developer-friendly environment, extensive documentation, and widespread use among embedded system practitioners. This made the platform particularly well-suited for rapid prototyping and deployment in field trials involving users with limited technical expertise (Muhammad et al., 2019).

In addition to technical performance, the selection of system components in this study was informed by practical considerations relevant to rural agricultural deployment, such as cost-efficiency, local market availability, and ease of maintenance. The ESP32 microcontroller was chosen not only for its integrated Wi-Fi and Bluetooth connectivity but also for its affordability and widespread accessibility in the Thai electronics market. These characteristics make it particularly suitable for smallholder farmers and research teams operating under financial and infrastructural constraints (Muthumanickam et al., 2022; Lemke & Weber, 2022).

Similarly, Modbus RS-485 soil moisture sensors were selected due to their durability, resistance to electrical noise, and long-distance communication capabilities, which are critical for field conditions that require signal stability and future system scalability. The sensors are also readily available in the local market and exhibit low measurement error, contributing to the reliability of the automated irrigation process (Sayem et al., 2023). Prioritizing cost-effective, commercially available, and robust components was essential to ensuring that the smart farming system would be both practical for real-world agricultural use and replicable across other low-resource settings (Ayaz et al., 2019).

The sensors collected data such as moisture, temperature, and humidity and sent it to the MCU. Once the readings dropped below a set threshold, the controller activated the irrigation system, opening solenoid valves and running pumps to deliver water precisely where it was needed (Song, Bi, & Wang, 2024). This process was run automatically during daytime hours. At night, the system was shifted to manual mode, allowing farmers to control irrigation through a mobile application. The system used Wi-Fi, MQTT and LoRa for wireless communication, supporting stable data transmission and remote access (Al Mamun et al., 2025). Cloud integration enabled the storage of historical data and supported adaptive irrigation scheduling based on environmental trends (Thameeza & Mohammed Tanzeem, 2021). Taken together, these elements aimed to support more responsive and sustainable farming practices (Raza et al., 2021; Morchid et al., 2024).

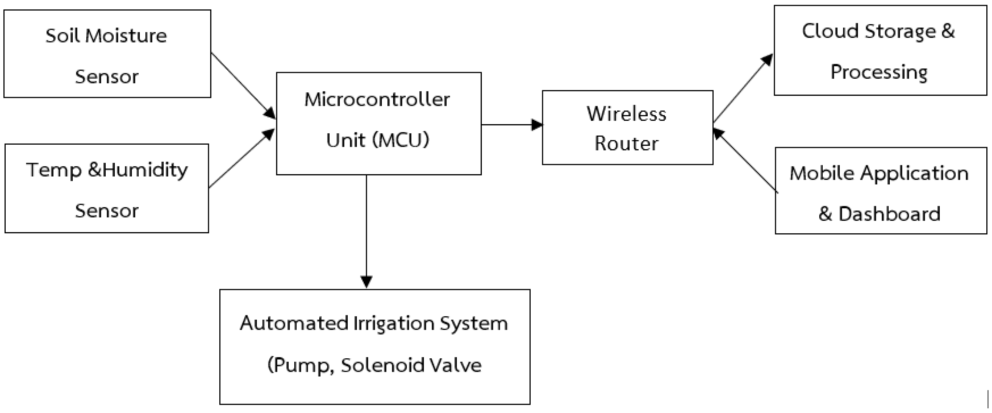

Fig. 1. System architecture of the IoT-based smart farming system for automated irrigation.

To better understand how farmers interacted with the system in practice, we used a combination of qualitative and quantitative evaluation methods. For the qualitative part, a heuristic evaluation was conducted with five participants drawn from the larger pool of twenty farmers. This approach followed Nielsen's (1994) usability principles, focusing on key aspects such as clarity, consistency, user control, and error prevention. The choice to involve five users was informed by Nielsen's (2000) well-established guideline, which suggests that a small group of five participants is typically sufficient to identify the majority of usability issues without producing repetitive or redundant data.

On the quantitative side, all twenty participants completed the System Usability Scale (SUS), which offered a structured way to measure perceived usability across several dimensions, including ease of use, satisfaction, and overall system effectiveness (Brooke, 2013; Sauro & Lewis, 2011). By combining these two approaches, the study was able to capture both detailed design feedback and broader user impressions, providing a more complete and grounded assessment of the system's real-world usability.

System Deployment and Testing

The IoT-based smart farming system was deployed in an actual agricultural setting to evaluate how well it performed under real conditions. This phase involved setting up sensors in the field, integrating cloud-based services, calibrating moisture thresholds, and testing the system's ability to manage irrigation automatically. The purpose of this deployment was to observe how the system handled daily fluctuations in temperature and soil moisture, and whether it could deliver consistent, efficient irrigation while reducing the need for manual labour (Et-taibi et al., 2024).

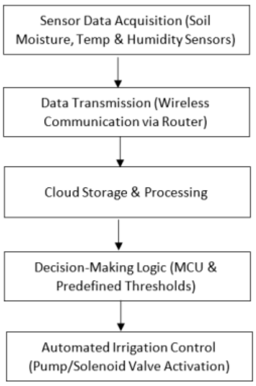

Fig. 2. Workflow of the smart irrigation system from sensing to automated control.

As shown in Figure 2, the system operates through a structured process that includes environmental data collection, wireless transmission, cloud-based analysis, and automated decision-making. Sensors continuously track soil moisture, temperature, and humidity, sending the data via communication protocols such as Wi-Fi, MQTT, or LoRa to the cloud. There, the information is processed and stored in real time. The microcontroller unit (MCU) compares incoming sensor data to preset thresholds to determine whether irrigation is needed (Bwambale, Abagale, & Anornu, 2022). When moisture levels drop below the set point, the system automatically triggers the pump or solenoid valve, allowing water to be delivered directly to the soil. This process minimizes waste and helps maintain ideal growing conditions by preventing both under- and over-irrigation (Sayem et al., 2023).

Before deploying the system in the field, we took time to calibrate and validate the soil moisture sensors to make sure the data they provided would be trustworthy. We followed standard procedures during calibration, and the sensors maintained an error margin of ±3%, which we considered acceptable for field-level monitoring (Al Mamun et al., 2025). Once the system was up and running, we tested it under a mix of weather and soil conditions—changes in temperature, humidity, and moisture levels—to see how well it could adapt. These tests helped us evaluate how reliably the system responded to real-time changes and whether the irrigation logic performed as intended (Et-taibi et al., 2024).

The soil moisture threshold used to trigger irrigation was determined based on empirical field testing and consultation with local farmers in the Surin Province. Rather than relying on crop-specific agronomic tables, we adopted a region-specific approach that reflected the prevailing conditions for small-scale organic farming in the area. Initial thresholds were refined through iterative testing to balance under- and over-irrigation, with adjustments based on feedback from participating farmers. This pragmatic calibration ensured that the system could respond effectively to localized soil conditions while maintaining generalizability across similar agricultural settings.

The mobile application served as the primary interface for users to interact with the irrigation system. Developed using the Blynk platform, the app provided real-time access to soil moisture readings, control over irrigation components, and the ability to switch between Auto and Manual operating modes. The interface was intentionally designed for simplicity, with large, clearly labeled buttons, colour-coded status indicators, and minimal text—making it accessible even to users with limited experience in digital technology.

Fig. 3a. Application interface in Manual mode

Fig. 3b. Application interface in Auto mode

As shown in Figure 3a, the system operates in Manual Mode, allowing users to directly control the pump and individual solenoid valves. This mode is intended for situations in which farmers prefer full control, particularly during nighttime hours or when manual intervention is necessary. The interface includes a slider to set the desired soil moisture threshold, as well as a visual gauge that continuously displays real-time soil moisture percentage.

In contrast, Figure 3b displays the application in Auto Mode. In this configuration, the system automatically activates irrigation when the measured soil moisture falls below the defined threshold. While control buttons remain visible, their function is governed by sensor data, and users are provided with continuous feedback on system status and environmental conditions. This design ensures transparency in automated operations while retaining user awareness and confidence.

To understand how usable the system was from the farmer's point of view, we applied the System Usability Scale (SUS). This helped us measure things like how intuitive the interface felt, how smooth the operation was, and whether users felt comfortable using the system in their daily routines (Brooke, 2013). Usability is a big deal, especially when we are talking about farmers who may not be familiar with digital tools. Previous studies have pointed out that even if technology works, poor usability can prevent it from being adopted, especially in small-scale or low-resource agricultural settings (Sayem et al., 2023).

The feedback we received offered a lot of insight. Most users were positive overall, but there were some areas that stood out for improvement, such as making the interface easier to navigate, improving how data is displayed in real time, and fine-tuning the way automated controls respond. These kinds of adjustments are important if we want to make the system scalable and sustainable in the long term. In short, what we learnt reaffirmed the importance of designing with the end user in mind, not just building a system that works technically, but one that people actually want to use (Bwambale et al., 2022).

System Workflow Diagram

The smart irrigation system developed in this study operates based on a time-aware and sensor-driven workflow designed to optimize water usage while preserving user control. The system dynamically switches between Auto Mode and Manual Mode based on predefined time intervals and real-time environmental data, aiming to reduce farmers' workload without compromising adaptability or precision.

The decision to implement automated irrigation during daytime hours and manual control during nighttime was guided by both agronomic rationale and system reliability considerations. In organic farming practices, nighttime watering is generally discouraged due to plants' reduced ability to absorb water in the absence of photosynthesis, and the increased risk of fungal growth in humid conditions. Local farmers in the study area confirmed that nighttime irrigation is rarely necessary, further supporting the appropriateness of this design. In addition, restricting automated operations to daylight hours reduces the likelihood of unintended system activation caused by sensor anomalies, data latency, or network disruptions, which may go unnoticed during off-hours. By offering manual override functionality at night, the system enhances user agency while minimizing unnecessary water usage. This hybrid control approach reflects a deliberate balance between automation, safety, and local farming practices.

From 6:00 a.m. to 6:00 p.m., the system functions in Auto Mode, autonomously monitoring soil moisture levels and initiating irrigation when values fall below the preset threshold. This configuration supports efficient water use during active farming hours. Between 6:00 p.m. and 6:00 a.m., the system transitions to Manual Mode, requiring farmers to use the mobile application for irrigation control. This structure allows for greater oversight during nighttime hours, when automation is less desirable.

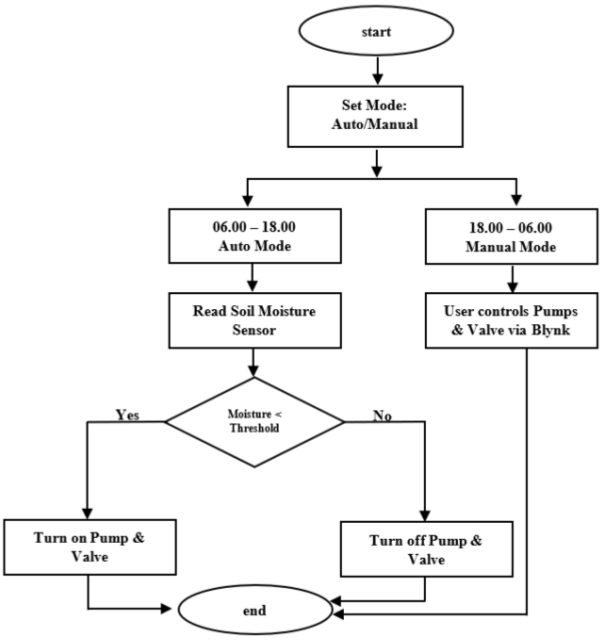

Fig. 4. System workflow diagram of smart irrigation control.

As illustrated in Figure 4, the workflow begins with system initialization, network connection, and configuration loading. The microcontroller then checks the current time to determine whether to operate in Auto or Manual Mode. In Auto Mode, soil moisture data is continuously evaluated, and the system automatically triggers pumps and solenoid valves when moisture levels fall below the defined threshold. In Manual Mode, automatic triggering is disabled, allowing farmers to activate irrigation components manually via the mobile dashboard. This modular logic enables the system to adapt to changing environmental conditions while ensuring users retain meaningful control over their farming operations.

System usability was assessed from the perspective of end users—specifically, smallholder farmers—by applying the System Usability Scale (SUS). This standardized evaluation method enabled a structured examination of interface intuitiveness, operational smoothness, and overall user comfort (Brooke, 2013). Usability remains a critical factor for digital tools in agriculture, particularly when adopted by users with limited technical experience. Prior research has shown that even technically sound systems may face adoption barriers if usability is poor, especially in small-scale or resource-constrained contexts (Sayem et al., 2023).

User feedback from field testing yielded valuable insights. While the majority of responses were positive, several usability issues were identified, including difficulties in navigation, unclear real-time data presentation, and the need for more responsive automation logic. These findings underscore the importance of iterative refinement to enhance user experience. Addressing such concerns is vital not only for immediate system effectiveness but also for long-term scalability and sustainability. Overall, the evaluation reinforced the principle that successful technology deployment in agriculture must prioritize user-centered design—ensuring that systems are not only functional but also accessible and desirable for their intended users (Bwambale et al., 2022).

Beyond the standardized SUS assessment, qualitative feedback from participants provided deeper insights into the system's usability in real-world settings. Thematic analysis of open-ended responses revealed three recurring patterns: operational simplicity, perceived reliability of the automated functions, and suitability for local farming routines. Farmers consistently highlighted the intuitive nature of the interface, with one stating, "I just tapped a button and the system did the rest," indicating low cognitive load and ease of use. Trust in the system's autonomous logic also emerged as a prominent theme; as one respondent noted, "I don't worry about forgetting to water now," suggesting confidence in the automation process. Moreover, the system's alignment with daily agricultural practices—such as its default manual mode at night—was seen as contextually appropriate. These qualitative findings complemented the quantitative results, reinforcing the value of designing for usability and contextual relevance in smallholder agricultural environments.

Unlike traditional irrigation practices that rely on fixed schedules without real-time environmental feedback, the smart system developed in this study offered data-driven control based on actual soil conditions. During a four-week deployment, the system achieved a 27% reduction in water usage compared to baseline manual methods, primarily by preventing unnecessary watering during periods of adequate soil moisture. Furthermore, farmers reported a 40% decrease in daily time spent managing irrigation, as mobile-based remote control and automated triggers minimized the need for constant supervision. These outcomes align with prior research showing that IoT-based precision irrigation can significantly improve efficiency and reduce labour input in small-scale farming contexts (Raza et al., 2021; Al Mamun et al., 2025). The comparative advantage of the system demonstrates its potential to replace conventional approaches with more sustainable, responsive solutions suited for resource-constrained environments.

Participants

Twenty organic farmers were chosen for this study from the Nongsani Subdistrict Administrative Organization in Thailand's Surin Province. Purposive sampling was used to select participants, with an emphasis on those who had never used the smart farming system before. This approach ensured that the evaluation captured the perspectives of novice users operating in real agricultural environments.

This study followed Nielsen's (2000) well-regarded recommendations for usability testing. For the qualitative phase, five participants took part in a heuristic evaluation—a sample size sufficient to identify the most common usability issues without redundancy. For the quantitative phase, 20 participants completed the System Usability Scale (SUS), providing broader insights into user perceptions and satisfaction with the system. As Nielsen emphasized, a small group can reveal major usability problems, while expanding to 20 users helps uncover less frequent issues and supports more comprehensive analysis.

Demographic variables such as age, gender, or digital literacy were not collected, as the questionnaire focused solely on usability evaluation.

Procedure

At the beginning of the study, participants were informed about the research objectives and procedures, and each was asked to sign a consent form before taking part. They then received a short training session to help them understand how to use the smart farming system and its main features.

After the training, participants tested the system during their normal farming routines. While they used the system, the researcher quietly observed their interactions using heuristic evaluation principles. This allowed for the identification of any usability issues, such as unclear interfaces, lack of feedback, or difficulties in system control—all without interrupting the participants' usual workflow.

Once the testing was completed, participants filled out the System Usability Scale (SUS) questionnaire to rate their experience. From the observations made during the testing phase, five participants were carefully selected for follow-up interviews. These interviews aimed to explore specific usability concerns in more depth, focusing on how easy the system was to use, how well the data was presented, and how responsive the system felt during real-world use.

Data Analysis

To evaluate the usability of the smart farming system, this study applied both qualitative and quantitative methods. The qualitative part involved a heuristic evaluation with five participants, based on Nielsen's (1994) usability framework. Rather than focusing on the number of issues found, the evaluation aimed to explore the types of challenges users encountered, how they navigated the system, and where the interface could be improved. Participant observations and feedback were analyzed thematically to highlight patterns in usability problems and to gather suggestions for system refinement.

For the quantitative part, the System Usability Scale (SUS) was used to measure how users perceived the system in terms of ease of use and overall satisfaction. Twenty participants filled out the SUS, which includes ten alternating positive and negative statements rated on a five-point Likert scale. Scoring followed the method outlined by Brooke (2013): for each response, scores were adjusted—subtracting 1 from positive items and subtracting negative items from 5. The total score was then multiplied by 2.5, giving a final value between 0 and 100. As Sauro and Lewis (2011) noted, scores above 68 suggest that the system is generally usable, while lower scores may indicate usability concerns. These results helped capture the participants' overall impression of the system, complementing the qualitative findings and offering a more complete view of how well the system supports users in practice.

Results and Discussion

This study used a mixed-methods approach to explore how farmers interacted with the system and how usable it felt in practice. On the quantitative side, data were collected through the System Usability Scale (SUS), which resulted in an average score of 86. This is well above the commonly accepted benchmark of 68 (Brooke, 2013), placing the system in the "excellent" category (Bangor et al., 2008). In simple terms, most participants found the system easy to use and well-suited to their everyday needs.

Many farmers mentioned that once they got past the first few minutes of testing, the interface felt straightforward. They liked how the dashboard displayed real-time data and said it helped them stay on top of their field conditions. One feature that stood out for nearly everyone was the automated irrigation. As soon as the soil dried past a certain level, the system triggered the water pump on its own. Several participants pointed out that this saved them time and meant one less thing to worry about during busy mornings.

However, not every user had a smooth experience right from the start. A few participants hesitated while using the mobile app for the first time. Some icons were unclear, and the navigation took a bit of trial and error. While most of them figured it out quickly, these moments highlight small areas where the design could be refined—possibly with better labeling or a short walkthrough at the beginning.

Qualitative data was collected from five participants who were selected for follow-up interviews. These individuals were chosen based on what was observed during the testing phase using heuristic evaluation. That process followed Nielsen's (1994) usability principles, things like visibility of system status, consistency, user control, and error prevention. All five participants in the heuristic evaluation expressed overall satisfaction with the system, noting that it was intuitive, reliable, and well-suited to their daily farming routines. The interviews helped explain what the numbers couldn't. The five participants shared thoughtful, specific feedback about how the system fit into their routine. While some admitted that it took a little time to get used to, all of them agreed that it ultimately made things easier. For them, the system didn't just function—it added real value to their daily work.

Research Contribution

This study contributes to the growing literature on smart farming by providing empirical evidence of the usability and functionality of an IoT-based farming system. The high SUS score indicates strong user acceptance and effectiveness in supporting small-scale organic farming.

The validation of an autonomous soil moisture monitoring system highlights the potential to reduce labour, conserve water, and simplify farm management. By combining quantitative and qualitative usability analysis, the study demonstrates how user feedback can inform system design and improve adoption of agricultural technology.

Furthermore, the results support the continued use of the SUS in the evaluation of digital farming platforms, offering developers and policymakers actionable insights into the design of technologies that are both effective and user-friendly.

Limitations and Future Research

While the system demonstrated promising outcomes in reducing water usage and improving usability among smallholder farmers, several limitations warrant consideration. First, the evaluation was conducted over a relatively short four-week deployment period, which may not capture seasonal variations or long-term adoption behaviors. Second, the study was limited to a single geographic location and crop type, potentially constraining the generalizability of the findings to broader agricultural contexts.

Future research could expand the deployment period to include different weather cycles and assess system resilience under prolonged field conditions. Moreover, incorporating crop-specific irrigation models and integrating external data sources such as weather forecasts or evapotranspiration indices may further enhance decision-making accuracy. Additional usability testing across diverse user groups—varying in age, digital literacy, and farming experience—would also help refine the system for broader adoption. Finally, economic analysis of cost-benefit trade-offs and scalability potential should be undertaken to assess the viability of widespread implementation in resource-constrained environments.

Conclusion

This study set out to understand how usable an IoT-based smart farming system would be in the context of small-scale organic agriculture. Using a mixed-methods approach, the System Usability Scale (SUS) offered a structured starting point, yielding an average score of 86. That score, well above the typical benchmark, suggests the system is generally easy to use and well suited to this farming context—even for those without much experience in digital tools.

What stood out most, however, were the farmers' reactions to the automated irrigation feature. By relying on real-time soil moisture data, the system could trigger watering without constant oversight. Many participants said this helped them save time and reduced the mental load of daily decision-making. It wasn't just about automation—it was about trust and relief.

Not everyone had a seamless experience at first. A few users needed time to get comfortable with the mobile interface. But through trial and error, most were able to navigate the system effectively. That's where the qualitative findings helped clarify the picture. Interviews with five participants—selected based on heuristic evaluation, following Nielsen's (1994) usability principles—revealed how the system fit into their routines and where small adjustments might improve the experience.

Importantly, this study evaluated the system not in a lab, but in real-world conditions. That matters. Usability tests in actual farming environments help determine whether technology truly supports the people it's designed for. By combining structured usability metrics with direct farmer feedback, this study shows that the system isn't just technically sound—it's workable, valuable, and realistic for day-to-day agricultural use.

In the end, the findings highlight why usability matters so much. Smart systems won't make a difference if they're hard to use. When tools are intuitive, responsive, and aligned with the farmer's workflow, they're more likely to be adopted—and more likely to deliver real impact on the ground.

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Author's Contributions

Arisaphat Suttidee developed the core research idea, designed the study framework, secured funding, and carried out the literature review and data analysis. She also led the writing process and coordinated revisions throughout the manuscript.

Pankom Sriboonlue oversaw the project, helped manage communication with participants, and handled administrative and ethical review procedures.

Sompoch Tongnamtiang, the corresponding author, was responsible for building and maintaining the smart farming system. He managed the technical aspects and supported the fieldwork during system deployment.

Varitha Lakkham assisted with collecting data in the field, coordinated activities during testing, and acted as a point of contact between the research team and local farmers.

All authors reviewed and approved the final version of the manuscript.

Ethics

This study was conducted in accordance with ethical standards for research involving human participants. Prior to data collection, participants were informed about the objectives of the study, the voluntary nature of their participation, and their right to withdraw at any time without consequence. Informed consent was obtained from all participants before they completed the System Usability Scale (SUS) questionnaire and participated in interviews.

The research protocol was reviewed and approved by the Research Ethics Committee of Mahasarakham University, Thailand. All data were collected and handled in a manner that ensured participant anonymity and confidentiality.

Data Availability

The data supporting the findings of this study are available upon reasonable request. Interested researchers may contact the author via email at sompoch.t@msu.ac.th to request access to the datasets used and analyzed during the current study.

Conflicts of Interest

The authors declare that there are no conflicts of interest associated with this research.

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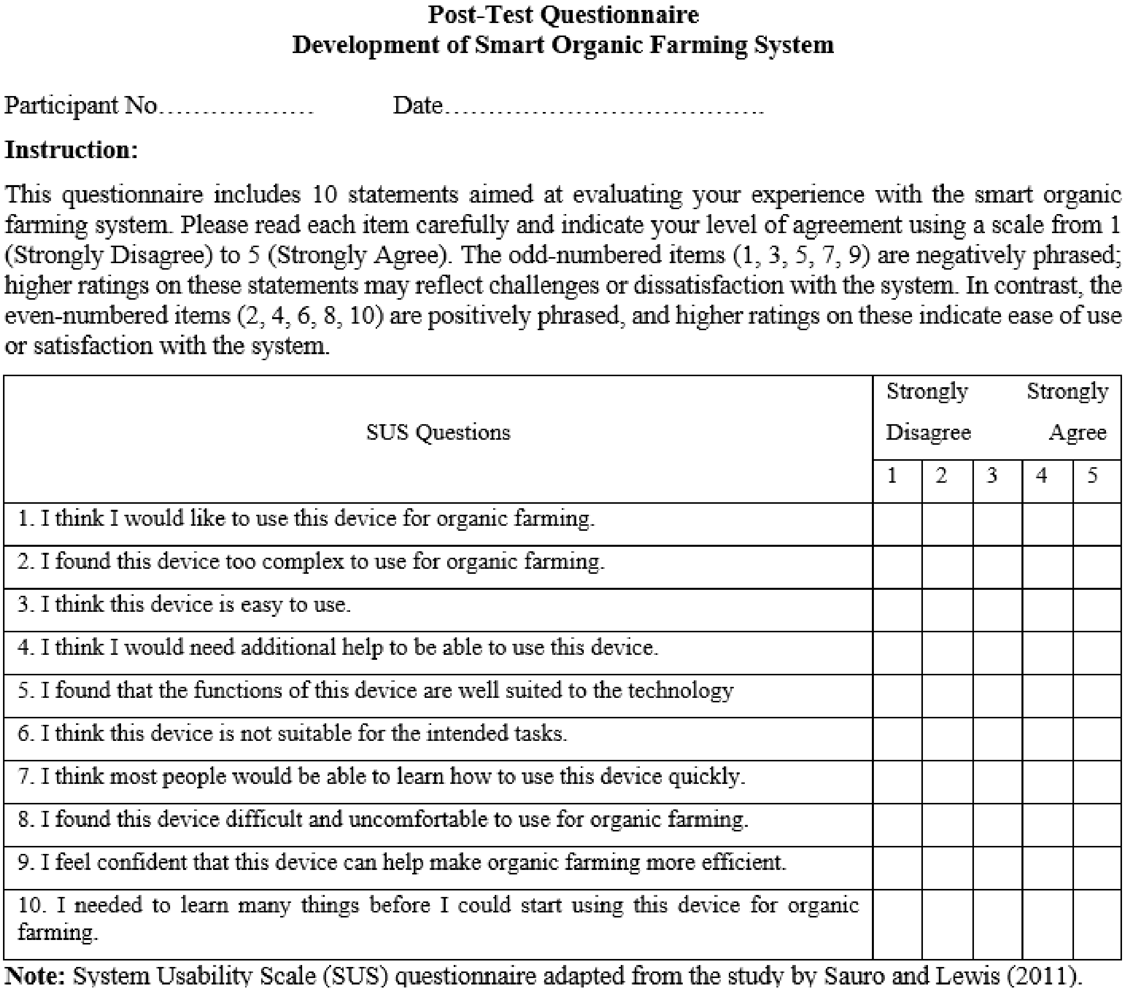
Supplementary Figures



Post-Test Questionnaire
Development of Smart Organic Farming System

Participant No……………… Date…………………………………..

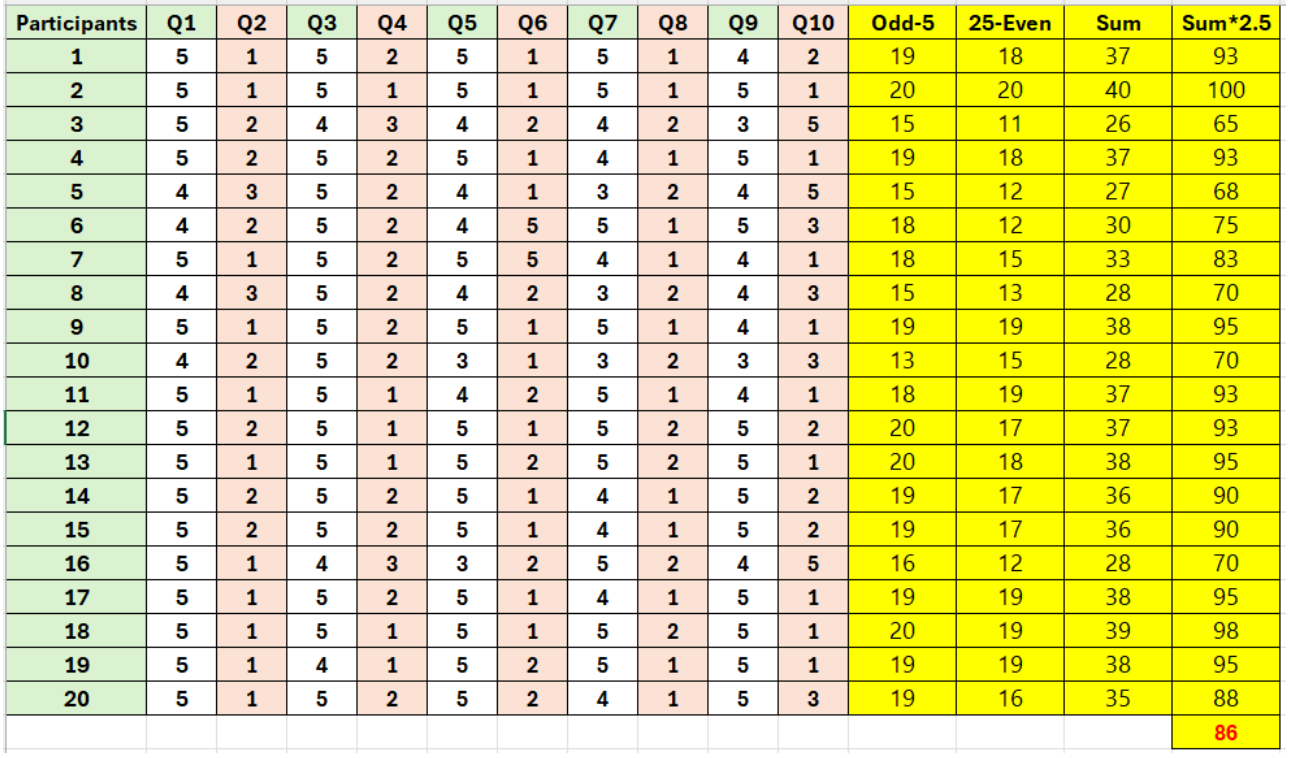
Instruction:

This questionnaire includes 10 statements aimed at evaluating your experience with the smart organic farming system. Please read each item carefully and indicate your level of agreement using a scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The odd-numbered items (1, 3, 5, 7, 9) are negatively phrased; higher ratings on these statements may reflect challenges or dissatisfaction with the system. In contrast, the even-numbered items (2, 4, 6, 8, 10) are positively phrased, and higher ratings on these indicate ease of use or satisfaction with the system.

SUS Questions	Strongly Disagree				Strongly Agree
	1	2	3	4	5
1. I think I would like to use this device for organic farming.					
2. I found this device too complex to use for organic farming.					
3. I think this device is easy to use.					
4. I think I would need additional help to be able to use this device.					
5. I found that the functions of this device are well suited to the technology					
6. I think this device is not suitable for the intended tasks.					
7. I think most people would be able to learn how to use this device quickly.					
8. I found this device difficult and uncomfortable to use for organic farming.					
9. I feel confident that this device can help make organic farming more efficient.					
10. I needed to learn many things before I could start using this device for organic farming.					

Note: System Usability Scale (SUS) questionnaire adapted from the study by Sauro and Lewis (2011).

Figure.S1. Full system usability scale (SUS) questionnaire used in this study.



Participants	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Odd-5	25-Even	Sum	Sum*2.5
1	5	1	5	2	5	1	5	1	4	2	19	18	37	93
2	5	1	5	1	5	1	5	1	5	1	20	20	40	100
3	5	2	4	3	4	2	4	2	3	5	15	11	26	65
4	5	2	5	2	5	1	4	1	5	1	19	18	37	93
5	4	3	5	2	4	1	3	2	4	5	15	12	27	68
6	4	2	5	2	4	5	5	1	5	3	18	12	30	75
7	5	1	5	2	5	5	4	1	4	1	18	15	33	83
8	4	3	5	2	4	2	3	2	4	3	15	13	28	70
9	5	1	5	2	5	1	5	1	4	1	19	19	38	95
10	4	2	5	2	3	1	3	2	3	3	13	15	28	70
11	5	1	5	1	4	2	5	1	4	1	18	19	37	93
12	5	2	5	1	5	1	5	2	5	2	20	17	37	93
13	5	1	5	1	5	2	5	2	5	1	20	18	38	95
14	5	2	5	2	5	1	4	1	5	2	19	17	36	90
15	5	2	5	2	5	1	4	1	5	2	19	17	36	90
16	5	1	4	3	3	2	5	2	4	5	16	12	28	70
17	5	1	5	2	5	1	4	1	5	1	19	19	38	95
18	5	1	5	1	5	1	5	2	5	1	20	19	39	98
19	5	1	4	1	5	2	5	1	5	1	19	19	38	95
20	5	1	5	2	5	2	4	1	5	3	19	16	35	88
														86

Figure.S2. SUS score results based on the methodology of Sauro and Lewis (2011)