Indonesian Journal of Electrical Engineering and Computer Science
Vol. 40, No. 3, December 2025, pp. 1539~1548
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v40.i3.pp1539-1548

IoT-based intelligent crop rotation and recommendation system

Dave Emmanuel V. Nuada[1], Jerald M. Velonta[1], Christian Neri G. Tuazon[1], Jimuel Nyle D. Mallari[1], Arzel P. Pinpin[2], Grosby A. Dela Cruz[1], Marvin O. Mallari[1]
[1]Department of Computer Engineering, Holy Cross College Pampanga, Pampanga, Philippines
[2]Department of Information Technology, Holy Cross College Pampanga, Pampanga, Philippines

Article Info

Article history:

Received Mar 22, 2025
Revised Oct 14, 2025
Accepted Nov 16, 2025

Keywords:

Automated irrigation
Crop monitoring
Crop recommendation
IoT-based system
Soil nutrient analysis
Sustainable agriculture

ABSTRACT

Traditional farming practices often rely on manual monitoring and crop selection, leading to inefficient use of resources and limited crop diversification. This study addresses these issues through the development of an IoT-based intelligent crop rotation and recommendation system that automates crop monitoring, irrigation, and crop selection processes. The system integrates DHT11 and NPK sensors to measure temperature, humidity, soil moisture, and nutrient levels (N, P, K), with real-time data displayed on a web-based application interface. An automated irrigation and fertilizer subsystem with SMS notifications enhances user control and remote accessibility. A crop recommendation module using the Euclidean Distance algorithm analyzes soil-nutrient data to identify the most suitable crops for the next planting cycle. System evaluation based on the ISO/IEC 25010 software quality model indicated high functionality, usability, reliability, portability, and maintainability, with an overall weighted mean of 3.958 (Agree) and a cronbach's alpha of 0.9585, signifying excellent reliability. The system demonstrates the potential of internet of things (IoT)-based technologies in promoting crop diversification, optimizing farm productivity, and advancing sustainable agricultural practices.

Corresponding Author:

Dave Emmanuel V. Nuada
Department of Computer Engineering, Holy Cross College Pampanga
Sta. Lucia, Sta. Ana, Pampanga, Philippines
Email: davenuada025@gmail.com

1. INTRODUCTION

The integration of internet of things (IoT) technologies into agriculture has transformed conventional farming into a data-driven, intelligent practice [1]. Reza *et al.* [2] showed that IoT-based soil sensors enable real-time nutrient monitoring for precise fertilizer application, while Khanal *et al.* [3] and Perdana *et al.* [4] demonstrated how continuous soil and weather tracking can enhance productivity. These innovations reflect the growing role of smart farming and precision agriculture in optimizing inputs, increasing yields, and improving environmental resilience [5], [6].

Despite such advances, many farmers still lack information on soil nutrient composition and crop-specific needs, leading to inefficient fertilizer use and reduced yields [7], [8]. Smallholder farmers, in particular, struggle to access scientific data and decision-support tools due to cost and technical barriers. Although machine learning (ML) and deep learning (DL) methods can optimize yield prediction, they demand extensive datasets and computational resources, limiting their practicality for small-scale operations [9]–[11]. Consequently, sensor-based and rule-driven IoT frameworks offer a cost-effective alternative, providing accessible and real-time support for smallholders.

Low-cost IoT systems employing affordable sensors, microcontrollers, and lightweight web platforms can collect and process environmental data, providing insights without complex ML infrastructures [12]. Combined with rule-based logic, such systems enable real-time monitoring, irrigation, and fertilizer management at minimal cost.

Crop diversification, rotating or intercropping crops to enhance soil health and resilience, remains vital to sustainable agriculture [13], [14]. In the Philippines, challenges such as climate variability, fragmented landholdings, and high input costs hinder diversification. Although vegetable–rice-based systems in Pampanga and other parts of Central Luzon are slowly adopting diversification through government programs [15], uptake remains limited by low awareness, market dependence, and restricted access to related technologies [16]. Moreover, existing IoT systems seldom integrate crop-rotation decision support, highlighting a gap in practical crop recommendation frameworks.

Ensuring that IoT-based systems also meet software quality standards is critical for long-term reliability. The ISO/IEC 25010 model provides an internationally recognized framework for assessing functionality, usability, reliability, portability, and maintainability [17]. Studies by Alkhabbas *et al.* [18] and Kozlowski *et al.* [19] demonstrated that ISO-based evaluation improves the reliability of IoT and environmental-monitoring systems. These standards support this study's goal of achieving both agronomic efficiency and dependable technological performance.

This study presents a low-cost IoT-based intelligent crop rotation and recommendation system, designed to support farmers in identifying optimal crops based on real-time environmental and soil nutrient conditions. The system integrates sensors for monitoring temperature, humidity, soil moisture, and nutrient levels (nitrogen, phosphorus, and potassium) with a web-based interface through which users can visualize parameters to receive data-driven crop recommendations. The study was conducted in Candaba, Pampanga, a municipality known for its extensive rice and vegetable cultivation, providing a suitable context for agricultural validation.

The specific objectives of this study are to: (i) Design an environmental monitoring system with a web-based interface for tracking temperature, humidity, soil moisture, and nutrient levels (N, P, K). (ii) Implement an automated irrigation and fertilizer-dispensing subsystem with web controls and SMS notifications for user alerts and scheduling. (iii) Develop a crop recommendation feature that analyzes soil nutrients and identifies suitable crops based on their specific requirements. (iv) Evaluate the overall system's performance in terms of functionality, usability, reliability, portability, and maintainability following the ISO/IEC 25010 product quality model.

By integrating affordable IoT hardware with standardized software-quality evaluation, this study aims to deliver a sustainable, accessible, and data-driven decision-support tool. It directly addresses the persistent challenge of insufficient crop and soil information, promotes intelligent crop diversification, and contributes to improving agricultural productivity in resource-limited contexts.

2. RESEARCH METHODS

2.1. Research design

This study adopted a quantitative developmental research design anchored in the agile software development methodology [20]. The developmental approach was appropriate since the research focused on the iterative design, implementation, and evaluation of a technological system rather than experimental variable manipulation. The agile framework supported incremental development, adaptive planning, and continuous stakeholder feedback from faculty evaluators, IT professionals, and local agricultural practitioners, enabling refinement of hardware calibration, interface usability, and crop-recommendation logic. The methodology progressed through four main Agile phases: planning, development, testing, and evaluation.

The system incorporates intelligent decision-support logic through its crop recommendation module, which autonomously analyzes sensor-derived nutrient data and identifies the most suitable crops based on computed similarity values. This algorithmic reasoning enables the system to make context-aware recommendations without direct user intervention, qualifying it as an intelligent IoT-based framework.

The research was conducted in Candaba, Pampanga, Philippines, a municipality recognized for its extensive rice and vegetable cultivation and suitability for field-based testing. During the evaluation phase, respondents were selected through purposive sampling, a non-probability technique [21], ensuring inclusion of participants with expertise in agriculture and information systems. Data collection occurred during the evaluation phase, where respondents interacted with the functional prototype and its web-based interface to simulate real-world use. After testing, participants completed an evaluation instrument derived from the ISO/IEC 25010 software quality model, assessing functionality, usability, reliability, portability, and maintainability. Responses were analyzed quantitatively to determine the system's overall performance.

2.2. Crop recommendation algorithm

The crop recommendation module identifies the most suitable crop to cultivate based on current soil and environmental conditions. It employs the euclidean distance metric to measure similarity between sensor-acquired values and reference crop parameters. The equation is defined as:

$$D = \sqrt{(x1 - y1)^2 + (x2 - y2)^2 + \dots + (xn - yn)^2} \quad (1)$$

where: (a) x_i represents the measured soil nutrient parameters (nitrogen, phosphorus, potassium), (b) y_i denotes the reference nutrient and environmental values of each crop; and (c) D is the Euclidean distance indicating similarity.

The algorithm selects the crop with the lowest distance value as the optimal recommendation. This method offers a transparent and computationally efficient alternative to complex ML algorithms, making it well-suited for low-cost IoT-based agricultural systems [12].

2.3. Overview of nutrient requirements for selected crops

The system's recommendation logic required benchmark datasets describing the nutrient requirements (N, P, K) for commonly cultivated crops in vegetable-based farming systems. Nutrient concentrations are expressed in milligrams per kilogram (mg/kg), consistent with recognized soil-fertility standards [22]–[27]. These reference values served as the benchmark dataset for the Euclidean-distance-based crop-selection algorithm.

The reference data for broccoli, lettuce, celery, tomato, and carrot were adapted from the University of California Davis Cooperative Extension guidelines, while nutrient thresholds for Spinach were obtained from a published physiological study of Spinacia oleracea L. fertilization. Table 1 presents the summarized NPK sufficiency levels used by the system. These values represent the sufficiency levels for optimal crop growth under standard soil conditions and were used as comparative benchmarks for the system's recommendation module.

Table 1. Reference nutrient requirements for selected crops

Crop	N (mg/kg)	P (mg/kg)	K (mg/kg)	Source
Broccoli	20 mg/kg	60 mg/kg	150 mg/kg	[22]
Spinach	25 mg/kg	60 mg/kg	120 mg/kg	[23]
Lettuce	30 mg/kg	70 mg/kg	130 mg/kg	[24]
Celery	35 mg/kg	75 mg/kg	100 mg/kg	[25]
Tomato	90 mg/kg	40 mg/kg	160 mg/kg	[26]
Carrot	100 mg/kg	50 mg/kg	180 mg/kg	[27]

2.4. Research instrument

A structured questionnaire based on the ISO/IEC 25010 standard served as the principal evaluation tool. It assessed the developed system according to five software quality characteristics: functionality, usability, reliability, portability, and maintainability. Respondents rated each statement using a five-point Likert scale, where 1 = strongly disagree, 3 = neutral, and 5 = strongly agree. The results are shown in Table 2.

Table 2. ISO/IEC 25010 quality characteristics and criteria for evaluation

Categories		Questions
Functionality	1.	The system covers all specified tasks and objectives.
	2.	The system provides correct data and sends error reports with a degree of precision.
	3.	The system facilitates the accomplishment of tasks (monitoring and suggestion of crops).
Usability	4.	The system can aid users with crop diversification.
	5.	The system can be used by users to achieve the goals of learning to use it with effectiveness and efficiency.
	6.	The system is easy to operate and appropriate to use.
Reliability	7.	The system is operational and accessible when required to use.
	8.	The system operates as intended despite the presence of hardware or software faults.
	9.	The system can read, recover, and store data accurately and effectively.
Portability	10.	The system is portable and may be moved, installed and/or uninstalled from one location to another with ease.
	11.	The system's user interface is pleasing and satisfying for users to interact. And the system was designed to perform in both desktop and/or mobile devices.
Maintainability	12.	It is simple to diagnose the system for weaknesses or failure.
	13.	The system can be maintained and cleaned by the user with ease.

The instrument was reviewed by subject-matter experts in agriculture and information systems to ensure clarity and content validity. Employing the ISO/IEC 25010 framework provided a globally recognized standard for software-quality evaluation, enhancing the reliability of the assessment [16], [17]. The evaluation dimensions also align with IoT system-quality metrics proposed by Kozlowski *et al.* [19], who emphasized standardized frameworks for environmental-monitoring technologies.

The questionnaire's reliability was measured using cronbach's alpha (α) to determine internal consistency. Since no separate pilot testing was conducted, the analysis used the actual evaluation responses. The computed α = 0.9585 indicates excellent reliability, exceeding the accepted threshold of 0.70. This confirms that the questionnaire consistently measured the five ISO/IEC 25010 software-quality characteristics, validating its dependability for system evaluation.

2.5. Statistical data analysis

Quantitative data from evaluations were analyzed using descriptive statistics, focusing on the weighted mean as the primary measure of central tendency. The weighted mean was computed from the frequency distribution of responses and corresponding Likert-scale values to determine the average perception of each software-quality attribute. Interpretation of results followed the descriptive scale shown in Table 3. Descriptive statistical analysis summarized and interpreted the respondents' feedback, consistent with the study's non-experimental, developmental design. These results served as the empirical basis for evaluating the system's compliance with the ISO/IEC 25010 software-quality model.

Table 3. Descriptive evaluations chart per likert scale point

Descriptive reading	Weighted mean	Point scale
Strongly agree	4.01-5.00	5
Agree	3.01-4.00	4
Neutral	2.01-3.00	3
Disagree	1.01-2.00	2
Strongly disagree	0.01-1.00	1

3. RESULTS AND DISCUSSION

This chapter presents the results of the development, implementation, and evaluation of the IoT-based intelligent crop rotation and recommendation system. The presentation of results is arranged according to the four specific objectives stated in Chapter 1:

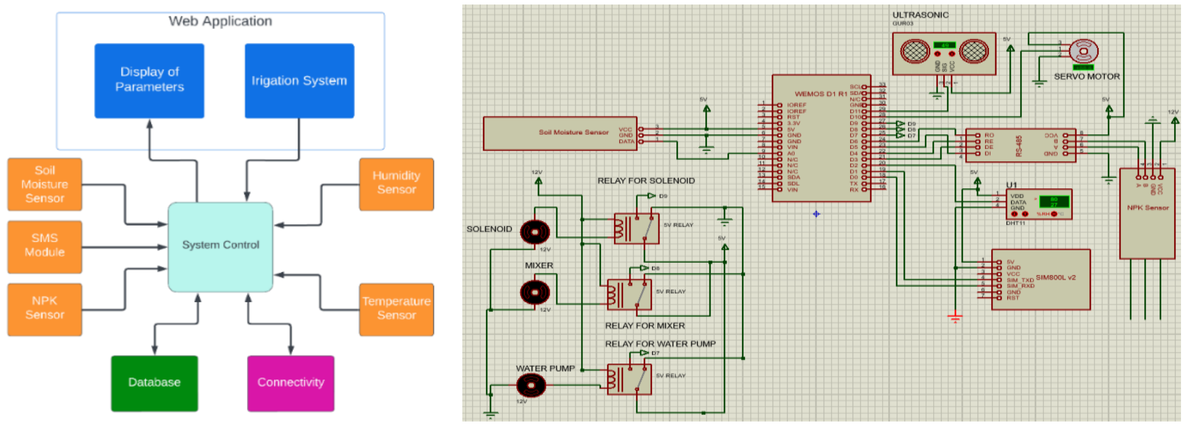
3.1. Design an environmental monitoring system with a web-based interface for tracking temperature, humidity, soil moisture, and nutrient levels (N, P, K)

The system integrates several IoT-based sensors connected to a central control unit that records key environmental parameters influencing crop growth. As shown in Figure 1, the system block diagram can see in Figure 1(a) and schematic diagram illustrate the configuration and signal flow of the sensing and monitoring components in in Figure 1(b). The setup includes DHT11 sensors for temperature and humidity, a soil-moisture sensor, and an NPK sensor for nutrient detection. These sensors interface with a microcontroller that processes and transmits data to the web server through a connectivity module. The web application provides two main modules: parameter display for real-time monitoring and irrigation control for manual or automated operation.

The physical prototype included a planting container equipped with soil and nutrient sensors, a water reservoir for irrigation, and control elements such as relays and a microcontroller housed in a protective enclosure. Designed using readily available materials, it ensures affordability and ease of replication. The integrated sensors continuously collect environmental and nutrient data and transmit them to the web server for real-time monitoring.

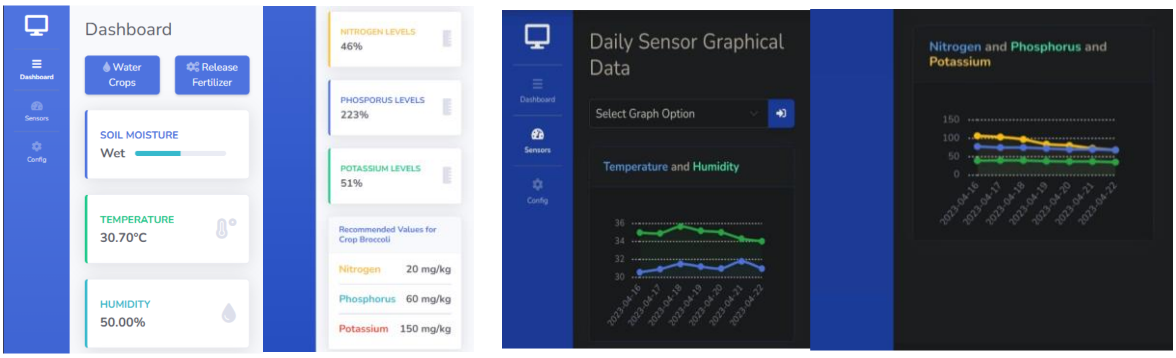
The web-based interface (Figure 2) serves as the central monitoring dashboard, in Figure 2(a) displaying real-time readings of soil moisture, temperature, humidity, and nutrient levels (N, P, K), together with graphical trends of aggregated daily data in Figure 2(b). This dual view enables users to observe immediate conditions and evaluate long-term variations that may influence crop performance. The dashboard also supports manual control of irrigation and fertilizer dispensing when thresholds require user action.

System testing confirmed accurate and consistent transmission of environmental data to the web platform with minimal delay. The reliability of both hardware and software demonstrates the system's capacity for continuous real-time monitoring, forming a foundation for the subsequent automation and recommendation modules. Similar IoT-based agricultural monitoring studies have also reported stable, real-time sensing using DHT11 and NPK sensors for soil-health assessment and crop management [2]-[4].



(a) (b)

Figure 1. The system block diagram (a) system block diagram and (b) schematic diagram of the environmental monitoring system



(a) (b)

Figure 2. Web interface showing (a) current sensor readings and (b) aggregated daily data

3.2. Implement an automated irrigation and fertilizer-dispensing subsystem with web controls and SMS notifications for user alerts and scheduling

The automated irrigation and fertilizer-dispensing subsystem regulates water and nutrient delivery based on real-time soil and environmental data gathered by the monitoring module. It integrates solenoid valves, relay modules, and pumps, all managed by the main microcontroller. The subsystem operates in two modes: automatic, activated when sensor readings reach preset thresholds, and manual, controlled through the web interface. Figure 3 shows the physical configuration of the subsystem. Figure 3(a) presents the fertilizer dispenser, which uses an electronically actuated solenoid valve connected to a nutrient reservoir for precise application, while Figure 3(b) shows the irrigation system with a PVC pipe network that distributes water evenly across the planting bed. This design ensures efficient nutrient and moisture management to support healthy crop growth.

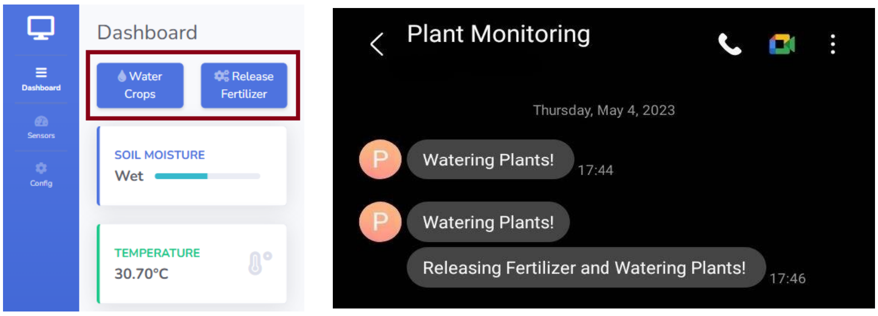
In Figure 4, the web-based control interface (Figure 4(a)) allows users to manually activate irrigation and fertilizer dispensing when needed. It includes dedicated control buttons for each function, enabling remote operation via the web. Commands issued through the interface are transmitted to the microcontroller, which triggers the corresponding relay to release water or fertilizer.

To enhance user awareness, SMS notifications are automatically sent to the registered user via the SIM800L V2 GSM module whenever an irrigation or fertilization action is executed, as shown in Figure 4(b). The system sends real-time alerts such as “Watering Plants” or “Releasing Fertilizer and Watering Plants,” allowing users to monitor subsystem activity even without direct access to the web interface.

System testing confirmed that the subsystem functioned effectively in both automatic and manual modes. The activation delay between user command and operation averaged less than one second, and SMS notifications were consistently delivered immediately after activation. These results demonstrate reliable, automated, and remotely controlled management of irrigation and fertilization, fulfilling the study’s second objective. Similar IoT-based irrigation systems have reported comparable responsiveness and efficiency when integrating solenoid-based control and GSM modules [12].

(a) (b)

Figure 3. The physical configuration (a) fertilizer dispenser subsystem and (b) irrigation system setup integrated into the planting bed



(a) (b)

Figure 4. The web-based control interface (a) web controls for manual dispensing and (b) SMS notification via GSM module

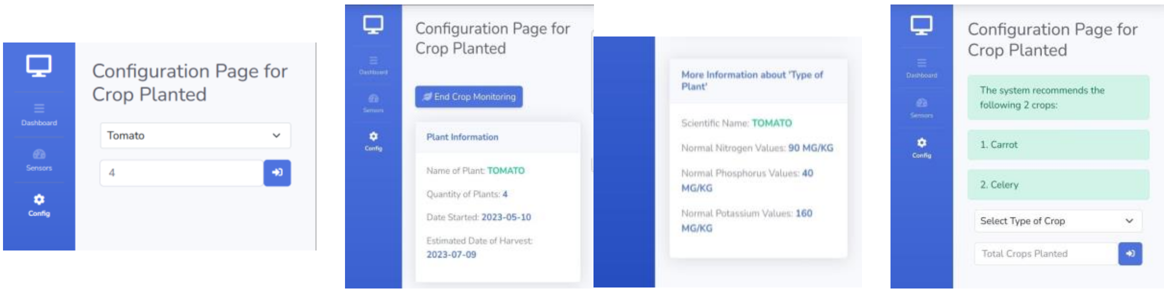
3.3. Develop a crop recommendation feature that analyzes soil nutrients and identifies suitable crops based on their specific requirements

The crop recommendation feature assists users in identifying suitable crops for planting based on current soil nutrient composition. The system analyzes nitrogen (N), phosphorus (P), and potassium (K) values obtained from sensors and compares them with reference nutrient levels stored in the database. Using the Euclidean distance formula described in the methodology, the system calculates the similarity between measured soil values and each crop's ideal nutrient requirements. The crop with the lowest computed distance is then recommended as the most compatible with the existing soil condition.

The recommendation process begins with the user selecting the type of crop to plant, followed by continuous monitoring of soil and environmental parameters. Once the crop reaches harvestable maturity, the system automatically analyzes the collected data and recommends the next suitable crop for planting based on nutrient compatibility and soil condition.

The configuration page of the web application is shown in Figure 5. In Figure 5(a), the user selects the crop type and number of plants to be monitored. Figure 5(b) displays the configuration interface showing details such as crop name, quantity, start date, and estimated harvest date, together with the nutrient requirements for the selected crop. When the user ends the monitoring session, as shown in Figure 5(c), the system analyzes recorded soil data and recommends potential crops for the next planting cycle, supporting crop rotation and diversification planning.

System testing confirmed that the crop recommendation module produced accurate and consistent results aligned with the stored nutrient profiles. It successfully integrated with environmental monitoring data and the web interface, providing users with actionable insights for sustainable crop management. These findings are consistent with prior IoT-based studies that applied nutrient-driven algorithms to support precision agriculture [5], [6].



(a) (b) (c)

Figure 5. Configuration page of crop planted: (a) crop selection and quantity, (b) configuration details and nutrient information, and (c) system-generated crop recommendations

3.4. Evaluate the overall system's performance in terms of functionality, usability, reliability, portability, and maintainability following the ISO/IEC 25010 product quality model

The system was evaluated using the ISO/IEC 25010 product quality model, focusing on five key characteristics: functionality, usability, reliability, portability, and maintainability. The evaluation aimed to determine whether the developed system met performance and user satisfaction standards. Data were gathered from respondents through a structured questionnaire based on the ISO/IEC 25010 framework, rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The responses were analyzed using the weighted mean for each criterion. Results are summarized in Table 4, presenting computed averages and descriptive interpretations.

Table 4. Summary of the system's overall evaluation using ISO/IEC 25010 product quality model

Evaluation criteria	Average weighted mean	Descriptive interpretation
Functionality	4.17	Strongly agree
Usability	4.00	Agree
Reliability	3.77	Agree
Portability	4.05	Strongly agree
Maintainability	3.80	Agree
Overall weighted mean	3.958	Agree

The findings indicate that respondents found the system acceptable, user-friendly, and functionally effective. Functionality (4.17) received the highest rating, showing that the system met operational goals such as monitoring, automation, and crop recommendation, while portability (4.05) also received a strongly agree, confirming its adaptability across setups. Usability (4.00), reliability (3.77), and maintainability (3.80) were rated Agree, reflecting satisfactory performance and ease of upkeep. These collectively affirm the system's effectiveness under ISO/IEC 25010 parameters. Moreover, the evaluation instrument's reliability, verified using cronbach's alpha ($\alpha = 0.9585$), indicates excellent internal consistency, as coefficients above 0.9 are generally regarded as highly reliable, confirming accurate measurement of all quality characteristics.

Overall, the mean score of 3.958 signifies strong agreement that the IoT-based intelligent crop rotation and recommendation system is reliable, functional, and aligned with its objectives. The evaluation validates that the system meets international software-quality standards and can be effectively applied in agricultural monitoring and management. Similar ISO/IEC 25010-based assessments in IoT systems by Alkhabbas *et al.* [17] and Kozlowski *et al.* [19] likewise confirmed the robustness of this evaluation approach.

4. CONCLUSION AND FUTURE WORK

The study successfully developed the IoT-based intelligent crop rotation and recommendation system, which integrates IoT sensors for real-time monitoring of temperature, humidity, soil moisture, and nutrient levels (N, P, K). The system includes an automated irrigation and fertilizer-dispensing subsystem with web controls and SMS notifications, enabling efficient and remote crop management. Using the Euclidean distance algorithm, it accurately recommended suitable crops based on soil-nutrient data.

Evaluation under the ISO/IEC 25010 product quality model confirmed high functionality, usability, reliability, portability, and maintainability, achieving an overall weighted mean of 3.958 (Agree) and a cronbach's alpha of 0.9585, indicating excellent reliability. These results align with prior IoT-based agricultural studies that reported comparable system performance in monitoring and crop recommendation.

For future work, the study recommends: (i) integrating image processing for harvest notifications, (ii) expanding the irrigation system with larger water storage and improved fertilizer management, and (iii) incorporating solar power for enhanced reliability during outages. These improvements can further strengthen system efficiency, promote crop diversification, and support sustainable agricultural practices.

FUNDING INFORMATION

The authors state there is no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Dave Emmanuel V. Nuada	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jerald M. Velonta	✓	✓		✓		✓	✓		✓				✓	✓
Christian Neri G. Tuazon				✓		✓	✓				✓			✓
Jimuel Nyle D. Mallari				✓		✓	✓							✓
Arzel P. Pinpin				✓	✓							✓	✓	
Grosby A. Dela Cruz				✓	✓							✓	✓	
Marvin O. Mallari				✓	✓							✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

The Authors have obtained informed consent from all individuals/respondents included in this study in accordance with the Philippines R.A. 10173, Data Privacy Act of 2012.

DATA AVAILABILITY

The data supporting the findings of this study are derived from previously published sources cited in references [22]–[27], which provided benchmark nutrient and physiological reference values used for comparison and analysis. The evaluation responses gathered during the study contain personal and confidential information and are therefore not publicly available.

REFERENCES

[1] A. Soussi, E. Zero, R. Sacile, D. Trinchero, and M. Fossa, "Smart sensors and smart data for precision agriculture: a review," *Sensors*, vol. 24, no. 8, p. 2647, Apr. 2024, doi: 10.3390/s24082647.

[2] M. N. Reza *et al.*, "Trends of soil and solution nutrient sensing for open field and hydroponic cultivation in facilitated smart agriculture," *Sensors*, vol. 25, no. 2, p. 453, Jan. 2025, doi: 10.3390/s25020453.

[3] K. Khanal, G. Ojha, S. Chataut, and U. K. Ghimire, "IoT-based real-time soil health monitoring system for precision agriculture," *International Research Journal of Engineering and Technology*, no. July, pp. 470–478, 2024, [Online]. Available: www.irjet.net.

[4] D. Perdana, O. Cahyono, and S. Suntoro, "Development of an IoT-based device for real-time detection of soil NPK nutrient content to optimize soybean yields," *Agrotechnology Research Journal*, vol. 8, no. 2, pp. 72–77, Dec. 2024, doi: 10.20961/agrotechresj.v8i2.98098.

[5] M. Bouni, B. Hssina, K. Douzi, and S. Douzi, "Integrated IoT approaches for crop recommendation and yield-prediction using machine-learning," *IoT*, vol. 5, no. 4, pp. 634–649, Sep. 2024, doi: 10.3390/iot5040028.

[6] M. K. Senapaty, A. Ray, and N. Padhy, "IoT-enabled soil nutrient analysis and crop recommendation model for precision agriculture," *Computers*, vol. 12, no. 3, p. 61, Mar. 2023, doi: 10.3390/computers12030061.

[7] K. A. Abay, M. H. Abay, M. Amare, G. Berhane, and E. Aynekulu, "Mismatch between soil nutrient deficiencies and fertilizer applications: Implications for yield responses in Ethiopia," *Agricultural Economics (United Kingdom)*, vol. 53, no. 2, pp. 215–230, Mar. 2022, doi: 10.1111/agec.12689.
[8] R. Dhillon and Q. Moncur, "Small-scale farming: a review of challenges and potential opportunities offered by technological advancements," *Sustainability*, vol. 15, no. 21, p. 15478, Oct. 2023, doi: 10.3390/su152115478.
[9] F. S. Prity *et al.*, "Enhancing agricultural productivity: a machine learning approach to crop recommendations," *Human-Centric Intelligent Systems*, vol. 4, no. 4, pp. 497–510, Sep. 2024, doi: 10.1007/s44230-024-00081-3.
[10] J. Li *et al.*, "Label-efficient learning in agriculture: A comprehensive review," *Computers and Electronics in Agriculture*, vol. 215, p. 108412, Dec. 2023, doi: 10.1016/j.compag.2023.108412.
[11] S. Kiruthika and D. Karthika, "IOT-BASED professional crop recommendation system using a weight-based long-term memory approach," *Measurement: Sensors*, vol. 27, p. 100722, Jun. 2023, doi: 10.1016/j.measen.2023.100722.
[12] A. Ibn Dahou Idrissi, A. Abouabdillah, M. Chikhaoui, and R. Bouabid, "Low-cost IoT-based monitoring system for precision agriculture," *E3S Web of Conferences*, vol. 492, p. 01003, Feb. 2024, doi: 10.1051/e3sconf/202449201003.
[13] T. B. Mihrete and F. B. Mihretu, "Crop diversification for ensuring sustainable agriculture, risk management and food security," *Global Challenges*, vol. 9, no. 2, Feb. 2025, doi: 10.1002/gch2.202400267.
[14] E. Raveloaritiana and T. Cherico Wanger, "Decades matter: agricultural diversification increases financial profitability, biodiversity, and ecosystem services over time," *arXiv preprint*, 2024, doi: 10.48550/arXiv.2403.05599.
[15] F. G. Horgan, E. A. Mundaca, B. A. R. Hadi, and E. Crisol-Martínez, "Diversified rice farms with vegetable plots and flower strips are associated with fewer pesticide applications in the Philippines," *Insects*, vol. 14, no. 10, p. 778, Sep. 2023, doi: 10.3390/insects14100778.
[16] T. J. P. de Leon and J. A. M. IV, "Affordances in crop diversification: three cases from the Philippines," *Asian Journal of Agriculture and Rural Development*, vol. 14, no. 2, pp. 34–50, May 2024, doi: 10.55493/5005.v14i2.5089.
[17] ISO/IEC25010, "Systems and software engineering-systems and software quality requirements and evaluation (SQuaRE)-product quality model," *Switzerland*, vol. 2023, 2023.
[18] F. Alkhabbas, H. Munir, R. Spalazzese, and P. Davidsson, "Quality characteristics in IoT systems: learnings from an industry multi case study," *Discover Internet of Things*, vol. 5, no. 1, p. 13, Feb. 2025, doi: 10.1007/s43926-025-00094-9.
[19] T. Kozlowski, O. Noran, and J. Trevathan, "Designing an evaluation framework for IoT Environmental monitoring systems," *Procedia Computer Science*, vol. 219, pp. 220–227, 2023, doi: 10.1016/j.procs.2023.01.284.
[20] Agile Alliance, "Agile essentials: Agile 101 what is Agile?," *Agile Alliance*, 2024. https://www.agilealliance.org/agile101/#:~:text=Agile is the ability to,an uncertain and turbulent environment. (accessed Oct. 17, 2025).
[21] Dovetail Editorial Team, "What is purposive sampling?," *Dovetail Research Pty. Ltd.*, 2023. https://www.scribbr.com/methodology/purposive-sampling/ (accessed Oct. 17, 2025).
[22] University of California Davis Cooperative Extension, "Broccoli nutrient management guidelines," 2024. http://geisseler.ucdavis.edu/Guidelines/Broccoli.html (accessed Oct. 21, 2025).
[23] L. E. Nemadodzi, H. Araya, M. Nkomo, W. Ngezimana, and N. F. Mudau, "Nitrogen, phosphorus, and potassium effects on the physiology and biomass yield of baby spinach (Spinacia oleracea L.)," *Journal of Plant Nutrition*, vol. 40, no. 14, pp. 2033–2044, Aug. 2017, doi: 10.1080/01904167.2017.1346121.
[24] University of California Davis Cooperative Extension, "Lettuce nutrient management guidelines," 2024. http://geisseler.ucdavis.edu/Guidelines/Lettuce.html (accessed Oct. 21, 2025).
[25] University of California Davis Cooperative Extension, "Celery nutrient management guidelines," 2024. http://geisseler.ucdavis.edu/Guidelines/Celery.html (accessed Oct. 21, 2025).
[26] P. Dawson, "Tomato nutrient management," *British Journal of Radiology*, 1991. http://geisseler.ucdavis.edu/Guidelines/Tomato.html (accessed Oct. 21, 2025).
[27] University of California Davis Cooperative Extension, "Carrot nutrient management guidelines," 2024. http://geisseler.ucdavis.edu/Guidelines/Carrot.html (accessed Oct. 21, 2025).

BIOGRAPHIES OF AUTHORS

Dave Emmanuel V. Nuada is an instructor and program chair of the Computer Engineering Department at the School of Engineering, Architecture, and Technology, National University Clark, Pampanga, Philippines. He received his B.Sc. degree in Computer Engineering from Holy Cross College, Pampanga, Philippines, and his M.Sc. degree in Computer Engineering with a Specialization in Data Science and Engineering from the Polytechnic University of the Philippines, Metro Manila, Philippines. He is a certified computer engineer accredited by the computer engineering certification Board (CpECB) and a licensed electronics technician registered with the professional regulation commission (PRC). He can be contacted at email: davenuada025@gmail.com.

Jerald M. Velonta received the B.Sc. degree in Computer Engineering from Holy Cross College, Pampanga, Philippines. He can be contacted at email: 081400@gmail.com.

Christian Neri G. Tuazon received the B.Sc. degree in Computer Engineering from Holy Cross College, Pampanga, Philippines. He can be contacted at email: tuazon.christian14@gmail.com.

Jimuel Nyle D. Mallari received the B.Sc. degree in Computer Engineering from Holy Cross College, Pampanga, Philippines. He can be contacted at email: jimboypogi2011@gmail.com.

Arzel P. Pinpin is a program head at Holy Cross College, Sta. Ana, Pampanga. He holds a master's degree in information technology with specialization in System Administration. He is also the acting MIS head with the same institution as he shares his technical skills in the field of Information Technology. He can be contacted at email: pinpinarzel012@gmail.com.

Dr. Grosby A. Dela Cruz is a professional computer engineer and licensed professional teacher. He earned his Bachelor of Science in Computer Engineering from the University of the Assumption, his master of Engineering major in Computer Engineering from Angeles University Foundation, and his Doctor of Philosophy in Engineering Management from Nueva Ecija University of Science and Technology. He is currently pursuing a Diploma in Computer Science at the University of the Philippines Open University (UPOU). Dr. Dela Cruz was recognized as one of the top 5 finalists for outstanding full-time teacher in the search for the outstanding PERAA members (TOPM) of the Private Education Retirement Annuity Association (PERAA), highlighting his academic and professional excellence. At present, he serves as the Program Chair of the Computer Engineering Department at Holy Cross College, where he is dedicated to advancing engineering education and research. His fields of interest and expertise include automation, control systems, and engineering management. He can be contacted at email: gadelacruz@dhvsu.edu.ph.

Dr. Marvin O. Mallari is a graduate of bachelor of Science in Computer Engineering (cum laude) at DATA College and a graduate of master of Science in Computer Engineering program at Bulacan State University. He earned his Ph.D. in Engineering Management at the Nueva Ecija University of Science and Technology. He currently serves as the Dean of the School of Computing, Information Technology and Engineering and concurrent Head of the Research and Development Unit (RDU) of Holy Cross College (Pampanga). He served as committee chair, panel and presented papers in the various international research conferences, such ICAMEROB, ICHESMET. Currently a Special Lecturer at Polytechnic University of the Philippines Graduate School – MS in Computer Engineering Program and a Part time Graduate School Professor at Nueva Ecija University of Science and Technology handling course in master of engineering management and Ph.D. in Engineering Management. Dr. Mallari holds the title of Professional Computer Engineer (PCpE); bestowed upon Computer Engineering Certification Board (CpECB) Inc., a Licensed Professional Teacher (Mathematics), holder of Civil Service Eligibility (Professional) and associate member of the National Research Council of the Philippines (NRCP) of the Department of Science and Technology (DOST). He currently serves as the Institute of Computer Engineers of the Philippines (ICpEP) Region III President. He is the Founder of Mechatronics and Robotics Society of the Philippines (MRSP) Pampanga Chapter and Bulacan Chapter and currently a serves as one of the MRSP National Board of Trustees re-elected for the year 2025-2026. He can be contacted at email: mallarimarvin022@gmail.com.