Smart Agricultural Device for Soil Fertility Assessment and Tomato Crop Growth Prediction

Maria Nicole Galigao Fabito [1], Maricar Lagrada Mateo [2], Chammuel Aldave Villaluz [3], Vivien Accad Agustin [4], Ronald Burdios Fernandez [5]

[1,2,3] Jesus Reigns Christian College, Malate, Manila, Philippines

[4,5] La Consolacion University, Philippines

DOI: https://doi.org/10.51584/IJRIAS.2026.111500017

Received: 15 May 2026; Accepted: 20 May 2026; Published: 13 June 2026

ABSTRACT

This study developed a Smart Agricultural Device for Soil Fertility Assessment and Tomato Crop Growth Prediction using Internet of Things (IoT) technology and rule-based analysis techniques to support soil monitoring and improve agricultural decision-making for tomato cultivation. Soil fertility plays an important role in determining tomato crop productivity, as factors such as soil moisture, pH level, and nutrient availability significantly influence plant growth and yield. However, traditional soil assessment methods often require laboratory testing, which may be costly, time-consuming, and inaccessible to many small-scale farmers. In response to these challenges, the study proposed an IoT-enabled monitoring system capable of collecting, processing, and presenting soil-related information in a more accessible and timely manner.

The developed system integrates several hardware components, including a soil moisture sensor, soil pH sensor, and NPK sensor, which are connected to an ESP32 microcontroller to collect essential soil parameters necessary for tomato crop development. The NPK sensor communicates through an RS485 communication module and utilizes a switching power supply to ensure stable nutrient monitoring and system performance. The ESP32 microcontroller serves as the main processing unit responsible for gathering sensor readings and transmitting collected soil information through Wi-Fi connectivity to a MySQL database managed using XAMPP for storage and monitoring purposes. The system also incorporates an LCD display and a web-based dashboard to present soil readings, fertility classifications, crop growth assessment, and recommendation outputs in an understandable and accessible format.

The study employed a developmental research design guided by the Agile Software Development Life Cycle (SDLC) to support continuous system development, testing, and refinement. The Agile methodology enabled iterative improvements throughout the planning, designing, development, and testing stages to ensure system functionality and reliability. The developed system applied a rule-based soil fertility assessment and crop growth estimation approach using predefined threshold values obtained from documented agricultural references and publicly available datasets related to tomato cultivation. Collected soil parameter values, including soil moisture, pH level, and nutrient content, were compared with standard soil requirements suitable for tomato growth to classify soil fertility conditions and estimate possible crop growth outcomes.

Results of the study showed that the developed system successfully performed soil monitoring, data processing, Wi-Fi transmission, database storage, dashboard visualization, and recommendation generation during system testing. The developed device was able to gather soil-related information and display soil fertility status through both the LCD interface and web-based dashboard. Sample soil parameter classifications generated by the system indicated varying fertility conditions, including poor and moderate soil quality, based on moisture level, pH balance, and nutrient availability. The system also generated corresponding recommendations regarding irrigation scheduling and fertilizer application to support improved soil management and crop productivity.

Although the study was limited to system development and functionality testing, findings demonstrated the feasibility and potential of integrating IoT-based monitoring and predictive soil assessment in smart agriculture applications. The developed system provides an alternative approach for monitoring soil conditions while assisting users in making more informed agricultural decisions related to tomato crop cultivation. Furthermore, the study highlights the importance of technology-driven agricultural solutions in promoting efficient resource management, soil monitoring, and sustainable farming practices. Future studies may focus on wider field implementation, laboratory validation of sensor readings, and the incorporation of more advanced predictive techniques to further improve system performance and accuracy.

Keywords: Internet of Things (IoT), Soil Fertility Monitoring, Tomato Crop Growth Prediction, ESP32 Microcontroller, Smart Agriculture, Soil Monitoring System

INTRODUCTION

Agriculture plays a vital role in the economy of the Philippines, serving as one of the primary sources of employment, food production, and rural livelihood. It contributes significantly to national food security and supports the economic stability of many communities, particularly in rural areas where farming remains the dominant occupation. Among various agricultural commodities, tomato (*Solanum lycopersicum*) is one of the most widely cultivated crops in the country due to its high nutritional value, versatility in culinary use, and strong market demand. Tomatoes are commonly grown in both small-scale farms and commercial agricultural systems, making them an important crop for both subsistence and income generation.

Despite its importance, tomato production is highly sensitive to environmental and soil conditions. Soil fertility is one of the most critical factors affecting crop growth, yield quality, and production efficiency. Key soil parameters such as soil moisture, soil pH level, and essential nutrients including nitrogen (N), phosphorus (P), and potassium (K) directly influence plant development and productivity. Soil moisture affects water availability for plant uptake, soil pH influences nutrient solubility and absorption, while NPK nutrients play a central role in vegetative growth, root development, and fruit production. Imbalances or deficiencies in these soil parameters can lead to poor crop performance, reduced yield, and increased vulnerability to pests and diseases.

In many agricultural areas in the Philippines, soil monitoring is still conducted using traditional methods such as visual inspection or laboratory soil testing. While laboratory analysis provides accurate results, it is often expensive, time-consuming, and not readily accessible to small-scale farmers. In addition, delays in obtaining soil test results may prevent farmers from making timely decisions regarding irrigation and fertilizer application. As a result, many farmers rely on experience-based judgment rather than data-driven soil analysis, which can lead to inefficient resource utilization and suboptimal crop production.

The rapid advancement of technology, particularly in the field of the Internet of Things (IoT), has introduced new possibilities for modernizing agricultural practices. IoT enables the integration of sensors, microcontrollers, and wireless communication systems to facilitate real-time data collection and remote monitoring. In agriculture, IoT-based systems can continuously monitor soil and environmental conditions, allowing farmers to gain immediate insights into the state of their crops. These systems support more efficient decision-making by providing real-time data on soil conditions, thereby improving irrigation planning, fertilizer management, and overall farm productivity.

In addition to IoT technology, rule-based analysis techniques have been widely used in decision-support systems where predefined conditions and threshold values are applied to interpret data. In agricultural applications, rule-based systems can classify soil conditions based on established agronomic standards without requiring complex computational models. This approach is particularly useful in situations where data availability is limited or when lightweight decision-making systems are preferred. By combining IoT-based data collection with rule-based analysis, it becomes possible to develop a practical and cost-effective agricultural monitoring system suitable for small and medium-scale farmers.

In response to these challenges, this study developed a Smart Agricultural Device for Soil Fertility Assessment

and Tomato Crop Growth Prediction using IoT technology and rule-based analysis techniques. The system integrates a soil moisture sensor, soil pH sensor, and NPK sensor connected to an ESP32 microcontroller, which serves as the main processing unit of the system. The device is designed to collect soil parameter data in real time and transmit the gathered information through Wi-Fi connectivity to a database for storage and monitoring. The system processes the collected data using predefined threshold values derived from agricultural references to assess soil fertility conditions and estimate tomato crop growth stages.

The system also provides recommendations for irrigation and fertilizer application based on the interpreted soil conditions. These recommendations aim to assist farmers in making timely and informed agricultural decisions that can improve soil quality and enhance crop productivity. Furthermore, the system includes a web-based dashboard that displays soil moisture levels, soil pH, nutrient values, fertility classification, and crop growth assessment in a clear and accessible format. This allows users to easily monitor soil conditions and understand the current state of their agricultural environment.

The study specifically aims to (1) develop a web-based real-time soil monitoring system using IoT technology, (2) assess soil fertility conditions based on collected soil parameters such as moisture, pH, and NPK values, (3) generate tomato crop growth assessments and recommendations using rule-based analysis, and (4) design a user-friendly interface for real-time monitoring and decision support. Additionally, the study seeks to demonstrate how IoT-based monitoring combined with rule-based analysis can improve soil fertility assessment and support data-driven decision-making in tomato crop production.

In essence, this research emphasizes the potential of integrating IoT systems with rule-based decision-making in addressing agricultural challenges in the Philippines. By providing a low-cost, accessible, and real-time soil monitoring solution, the proposed system aims to support farmers in improving productivity, optimizing resource usage, and promoting sustainable agricultural practices. The study also highlights the importance of technology adoption in modern agriculture, particularly in enhancing efficiency and reducing dependency on traditional soil testing methods.

METHODOLOGY

Research Design

This study utilized a developmental research design following the Agile Software Development Life Cycle (SDLC). The Agile approach was selected because it supports iterative development, continuous testing, and system improvement throughout the project stages. The development process included planning, designing, building, testing, release, and feedback phases. These phases ensured flexibility in system development and allowed improvements based on testing and user evaluation.

Data Source and Data Collection Procedure

This study utilized both primary and secondary data sources in the development of the Smart Agricultural Device for Soil Fertility Assessment and Tomato Crop Growth Prediction. Primary data were obtained through the developed system using soil moisture, soil pH, and NPK sensors integrated with an ESP32 microcontroller to test sensor connectivity, data transmission, and dashboard visualization within an IoT-enabled environment. An actual site visit was conducted at an urban farm in BGC, Taguig City to observe farming practices, environmental conditions, and relevant soil management approaches related to tomato cultivation. The visit provided contextual understanding to support the development and practical relevance of the proposed system.

Secondary data used for soil fertility assessment and tomato growth prediction were collected from publicly available online agricultural datasets, published journals, and soil references related to tomato cultivation. Standard soil parameter values, including moisture level, soil pH, nitrogen, phosphorus, and potassium (NPK), were used to simulate different soil fertility conditions. A rule-based prediction approach was applied to classify soil conditions and generate corresponding recommendations for irrigation and fertilizer application. Since the study focused on system development, large-scale farm deployment and laboratory validation were not conducted and are recognized as limitations of the study.

Table 1. Hardware Components

Components	Model/Type	Function	Range	Accuracy
ESP32 Microcontroller	ESP32 Devkit V1	Data processing and Wi-Fi communication	—	—
Soil Moisture Sensor	Soil Moisture Sensor Hygrometer Humidity Detection module Kit	Measures soil moisture level	0–100%	3%
Soil pH Sensor	Analog pH Sensor Kit	Measures soil acidity/alkalinity	pH 0–14	0.1 pH
NPK Sensor	RS485 Soil NPK Sensor	Measures nitrogen, phosphorus, potassium	0–1999 mg/kg	5%
RS485 Module	MAX485 TTL to RS485	Communication interface for NPK sensor	—	—
LCD Display	16×2 LCD with I2C	Displays sensor results	—	—

Software and Prediction Method

The software components used in the study include the Arduino IDE for programming the ESP32 microcontroller, Visual Studio Code for interface development, and database technologies for data storage and retrieval. The system utilizes a prediction method based on predefined soil parameter thresholds to assess soil fertility conditions and estimate tomato crop growth conditions.

The prediction process analyzes soil moisture, pH level, and NPK values collected by the sensors and compares them with standard tomato cultivation ranges obtained from agricultural references and published literature. Based on the evaluated parameters, the system categorizes soil conditions into classifications such as poor, moderate, or optimal and generates corresponding recommendations for irrigation and fertilizer application. This approach enables the system to interpret soil conditions and provide practical insights to support tomato crop monitoring and management.

System Testing and Functional Evaluation

The system will undergo for functional testing to determine its capability to perform the intended operations of soil monitoring, data transmission, and dashboard visualization. Testing focused on verifying the connectivity of the soil moisture, pH, and NPK sensors with the ESP32 microcontroller, as well as the successful transmission of data through wireless connectivity.

The system will also be evaluated based on its ability to display soil parameter readings, classify soil fertility conditions, and generate corresponding recommendations for irrigation and fertilizer application. Since the study focused on prototype development, testing was limited to system functionality and simulated soil conditions using reference agricultural data.

Figure 1 System Architecture

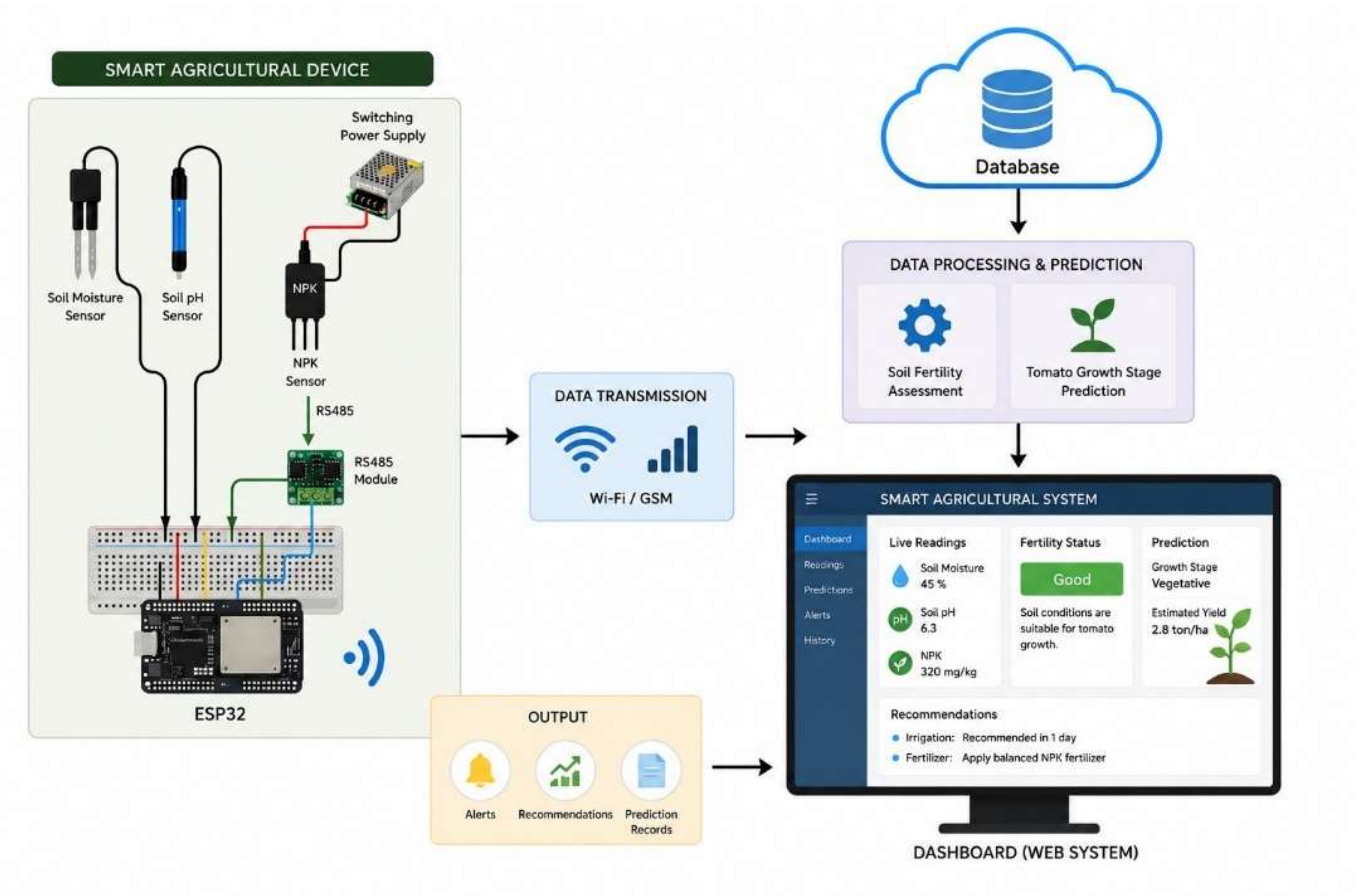

Figure 1 illustrates the overall architecture of the proposed smart agricultural monitoring system. The system uses soil moisture, soil pH, and NPK sensors connected to an ESP32 microcontroller to collect near real-time soil data. The NPK sensor communicates through an RS485 module and uses a separate switching power supply to ensure stable operation.

The ESP32 processes the sensor readings and transmits the collected data through Wi-Fi or GSM connectivity to the system database. The database stores soil readings, prediction results, timestamps, and recommendation records in structured tables for monitoring and analysis. The system was implemented using a MySQL database managed through XAMPP for local and cloud-based data handling.

To address unstable internet connectivity, which is common in agricultural areas in the Philippines, the ESP32 is designed to temporarily store sensor readings in its local memory whenever Wi-Fi or GSM connectivity becomes unavailable. Once the connection is restored, the stored data are automatically synchronized with the database to prevent data loss. This approach allows the system to continue collecting soil information even during temporary network interruptions.

Basic security and privacy measures were also considered in the system design. Data transmission between the ESP32 and the database is limited to authorized devices and authenticated connections to prevent unauthorized access. The database only stores agricultural monitoring data and does not collect personal or sensitive farmer information.

After transmission, the collected data are processed by the web system to evaluate soil fertility and predict tomato growth stages. The processed information is displayed through a user-friendly dashboard where farmers can monitor soil conditions, receive fertilizer and irrigation recommendations, and view prediction records in real time.

Database Management and Connectivity

The system will utilize a MySQL database managed through XAMPP to store and manage soil monitoring data collected from the sensors. Soil parameter readings, including soil moisture, pH, nitrogen, phosphorus, and potassium (NPK) values, are transmitted by the ESP32 microcontroller through Wi-Fi connectivity and stored in the database for processing and visualization. The stored data are organized into structured tables containing sensor readings, timestamps, and corresponding soil condition classifications to support efficient monitoring and retrieval of information.

The database enables near real-time synchronization between the hardware components and the web-based dashboard, allowing users to monitor soil conditions and system outputs remotely. Basic security measures, including authenticated database access and controlled user permissions within the local server environment, were considered to help protect stored information from unauthorized modification. Since the system relies on Wi-Fi connectivity for data transmission, unstable internet conditions may temporarily delay data updates; however, monitoring resumes once a stable connection is restored.

Wi-Fi Connectivity and Data Transmission

The system will utilize the built-in Wi-Fi capability of the ESP32 microcontroller to transmit collected soil data to the MySQL database managed through XAMPP for monitoring and visualization. Since the system is designed for near real-time monitoring, internet connectivity is required for successful data transmission and dashboard updates. In cases where Wi-Fi connectivity becomes temporarily unavailable, sensor readings may not be immediately transmitted to the database, resulting in delayed updates within the dashboard interface.

Due to the developmental scope of the study, local data storage and automatic synchronization after connectivity restoration were not implemented in the current version of the system. Instead, the system resumes data transmission once a stable internet connection becomes available. Future enhancements may include local storage mechanisms, such as SD card integration or ESP32 internal memory buffering, to temporarily save sensor readings during connectivity interruptions and automatically synchronize data once the network connection is restored.

System Testing and Functional Evaluation

The system will undergo functional testing to determine its capability to perform the intended operations of soil monitoring, data transmission, and dashboard visualization. Testing focused on verifying the connectivity of the soil moisture, pH, and NPK sensors with the ESP32 microcontroller, as well as the successful transmission of data through wireless connectivity. The system will be evaluated based on its ability to display soil parameter readings, classify soil fertility conditions, and generate corresponding recommendations for irrigation and fertilizer application. Since the study focused on prototype development, testing was limited to system functionality and simulated soil conditions using reference agricultural data.

Methods and Tools

This section presents the methods and tools utilized in the development of the Smart Agricultural Device for Soil Fertility Assessment and Tomato Crop Growth Prediction. The study employed an integrated approach that combines Internet of Things (IoT)-based soil monitoring, rule-based soil fertility assessment, crop growth estimation, and data visualization techniques to support soil monitoring and agricultural decision-making. These methods were selected to ensure that the system can effectively collect soil-related information, process and analyze gathered data, and provide understandable outputs and recommendations to users through a monitoring dashboard.

METHODS

For the Soil Fertility Monitoring feature, the proponents employed an Internet of Things (IoT)-based data collection and monitoring method to capture timely soil conditions necessary for tomato crop growth assessment.

The developed system utilizes several soil sensors, including a soil moisture sensor, soil pH sensor, and NPK sensor, to gather essential soil parameters related to fertility and crop development. These sensors are connected to an ESP32 microcontroller, which serves as the main processing unit responsible for collecting and interpreting sensor readings at predefined intervals.

During system operation, the gathered soil readings are processed by the ESP32 and transmitted through its built-in Wi-Fi connectivity to a centralized database for storage and monitoring purposes. The NPK sensor communicates through an RS485 module and uses a dedicated power supply to maintain stable operation and ensure reliable nutrient monitoring. Additionally, calibration and functionality testing were conducted to assess sensor responsiveness and maintain consistent system output under varying conditions. Through this process, the system enables continuous monitoring of soil conditions, providing updated soil information necessary for fertility assessment and crop monitoring.

Figure 2. Soil Fertility Monitoring Process

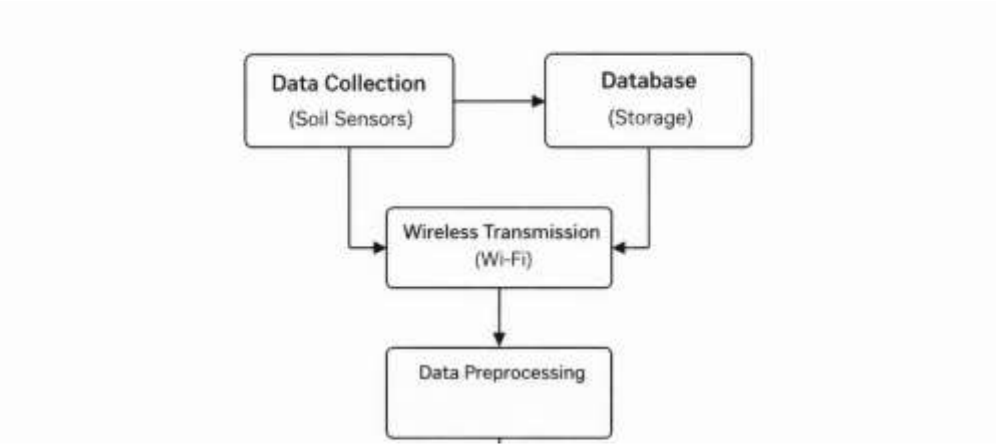

Figure 2. illustrates the IoT-based soil fertility monitoring workflow where soil data is collected through sensors and stored in a database. The information is transmitted wirelessly using Wi-Fi, followed by data preprocessing to prepare the readings for further analysis and crop growth prediction.

For the Crop Growth Assessment and Prediction feature, the proponents utilized a rule-based soil analysis and crop assessment method to estimate tomato crop growth conditions based on gathered soil parameters. Since tomato crop development is highly influenced by soil moisture, pH level, and nutrient availability, the collected sensor readings undergo data processing and validation before analysis. The gathered values are compared with documented agricultural references and standard threshold values suitable for tomato cultivation obtained from agricultural literature and secondary online datasets.

Figure 3. Crop Growth Prediction Process

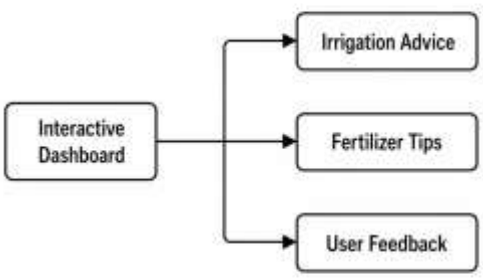

Figure 3 illustrates the interactive dashboard interface that provides users with irrigation advice, fertilizer recommendations, and feedback support based on the analyzed soil data and crop conditions.

For the Data Visualization and Recommendation feature, the proponents applied a user-centered design and data visualization method to ensure that generated information is accessible and understandable to users. The processed soil information, fertility status, and crop growth assessment are displayed through a web-based dashboard, enabling users to monitor soil conditions in a near real-time environment. The dashboard presents soil moisture, pH level, and nutrient readings together with soil fertility classification and crop growth assessment results.

Figure 4. Data Visualization and Recommendation Process

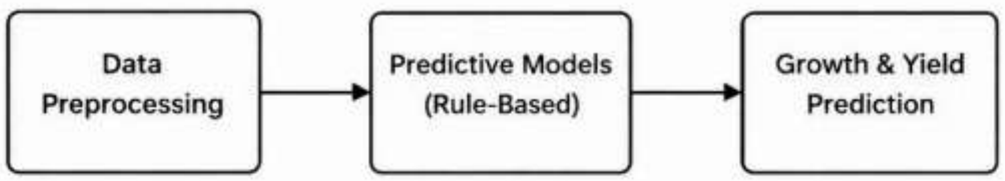

Figure 4 illustrates the rule-based predictive modeling process where preprocessed soil data is analyzed to estimate crop growth stages and predict yield outcomes for better agricultural decision-making.

Tools

The study utilized various hardware, software, and system design tools to support the development and implementation of the proposed system. Hardware tools included the ESP32 microcontroller, soil moisture sensor, soil pH sensor, NPK sensor, RS485 communication module, LCD display, breadboard, jumper wires, and switching power supply, which were used for soil monitoring, data processing, and system operation.

Software tools utilized in the study included Arduino IDE for programming and configuring the ESP32 microcontroller and MySQL integrated with XAMPP for database management and local storage of collected sensor readings. The developed web-based dashboard was used to display monitored soil conditions, soil fertility classifications, crop growth assessments, and recommendation outputs in a near real-time environment.

Furthermore, several system design tools were utilized to organize and visualize the structure and functionality of the proposed system. Flowcharts were used to illustrate the step-by-step operational process of the system, beginning from soil data collection to output generation.

Data Flow Diagrams (DFDs) were employed to demonstrate how soil data move throughout the system, including data input, processing, storage, and output. Entity-Relationship Diagrams (ERDs) were used to define the database structure and relationships among stored soil monitoring data and generated results. Lastly, Use Case Diagrams were utilized to represent the interaction between the farmer and the proposed system, highlighting system functionalities such as monitoring soil conditions, viewing fertility status, assessing crop growth, and receiving recommendations.

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue XV June 2026
Special Issue on Next-Generation Approaches in Plant Sciences and Agriculture

RESULTS AND DISCUSSION

Figure 2 Design and assemble a portable device equipped with moisture, pH, and nutrient sensors to provide timely soil fertility data.

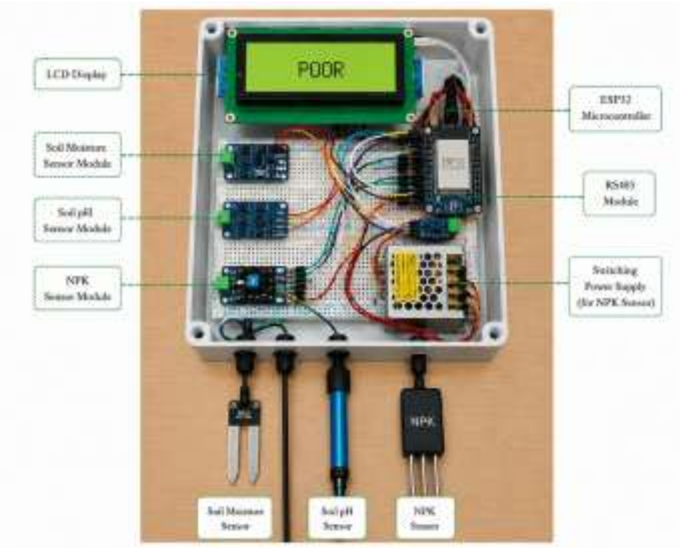

Figure 2: shows the assembled smart agricultural device designed to monitor soil conditions and provide soil fertility information for precision farming applications. The system is composed of several integrated hardware components, including a soil moisture sensor, soil pH sensor, nutrient sensor, ESP32 microcontroller, RS485 communication module, LCD display, breadboard, and switching power supply. These components work together to collect, process, and display important soil data that can assist farmers in managing irrigation and fertilizer application more effectively.

The soil moisture sensor is used to measure the amount of water present in the soil, while the soil pH sensor determines the acidity or alkalinity level of the soil. The nutrient sensor detects essential soil nutrients required for healthy crop growth. The collected sensor readings are transmitted to the ESP32 microcontroller, which serves as the main processing unit of the system. The ESP32 processes and analyzes the gathered data based on predefined soil fertility conditions.

The RS485 module provides stable communication between the sensors and the microcontroller, ensuring accurate data transmission within the system. A breadboard is utilized to organize and connect the electronic components during the prototype setup, while the switching power supply delivers the necessary electrical power for proper device operation.

The analyzed soil information is then displayed on the LCD screen, allowing users to easily monitor the current soil fertility condition. In the figure, the LCD shows the fertility status as “POOR,” indicating that the soil condition may require additional nutrients or soil treatment to improve crop productivity.

Table 2. Functional Testing

Components	Function	Result
Soil Moisture Sensor	Soil moisture reading	Functional
Soil Ph Sensor	Soil acidity detection	Functional
NPK Sensor	Nutrient monitoring	Functional
ESP32 Wi-fi	Data transmission	Functional

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue XV June 2026
Special Issue on Next-Generation Approaches in Plant Sciences and Agriculture

Dashboard	Display monitoring results	Functional
MySQL/XAMPP	Store sensor readings	Functional
Recommendation Module	Generate fertilizer/irrigation suggestion	Functional

Table 2: presents the functional testing results of the developed prototype. The system successfully performed soil parameter monitoring, Wi-Fi data transmission, database storage, dashboard visualization, and recommendation generation. Results indicate that the prototype was able to collect and process soil-related information in a near real-time environment.

Figure 3 Design a system that analyzes soil readings and uses them to predict tomato crop growth stages.

Figure 3 shows the developed Smart Agricultural Device dashboard used for soil monitoring and fertility assessment. The dashboard displays important soil parameters, including soil moisture, pH level, and NPK nutrient readings collected through sensors connected to the ESP32 microcontroller. The gathered sensor data is

processed by the system to evaluate the overall soil fertility condition and provide information that can support agricultural decision-making.

Based on the collected data, the system classified the soil fertility condition as "POOR" due to low soil moisture, acidic soil pH, and insufficient nutrient values. These conditions indicate that the soil may not provide the ideal environment required for healthy tomato crop growth and development. The dashboard allows users to easily observe the current soil status and identify possible soil deficiencies that may affect crop productivity.

In addition, the displayed results can help guide proper farm management practices, such as irrigation scheduling and fertilizer application, to improve soil quality and support better crop performance. The developed dashboard demonstrates the application of IoT technology in simplifying soil condition monitoring and assisting farmers in making more informed agricultural decisions.

Table 3. Sample Soil Parameter Classification

Sample	**Moisture**	**Ph**	**NPK**	**Fertility**	**Growth**
1	4%	3.9	2	Poor	Poor Growth
2	19%	3.9	2	Poor	Poor Growth
3	19%	4.2	5	Poor	Poor Growth
4	40%	5.6	12	Poor	Poor Growth
5	19%	4.6	8	Poor	Poor Growth
6	54%	6.5	21	Moderate	Early Growth
7	34%	5.2	10	Poor	Poor Growth

Table 3: presents the sample soil parameter readings and fertility classification generated by the proposed system. The results show that most of the collected samples were classified under poor soil fertility condition, resulting in poor crop growth prediction. Samples 1 to 5 and Sample 7 recorded low soil moisture levels, acidic pH values ranging from 3.9 to 5.6, and insufficient nutrient levels, which contributed to poor fertility assessment. These findings suggest that the soil conditions may not be suitable for optimal tomato crop growth and may require soil treatment, irrigation, and fertilizer application to improve productivity.

On the other hand, Sample 6 obtained a moderate soil fertility classification with a moisture level of 54%, pH value of 6.5, and higher nutrient content (NPK = 21), resulting in an early growth prediction. This indicates that improved soil moisture, balanced pH, and adequate nutrient availability positively influence tomato crop growth. The results demonstrate the capability of the proposed system to analyze soil conditions and provide fertility assessment and crop growth prediction based on collected sensor data.

CONCLUSION

The findings of the study demonstrate that the developed Smart Agricultural Device for Soil Fertility Assessment and Tomato Crop Growth Prediction was capable of monitoring essential soil parameters, including soil moisture, pH level, and nutrient content (NPK), through an IoT-enabled monitoring system. The developed system successfully integrated soil sensors with the ESP32 microcontroller, enabling the collection, processing, and visualization of soil-related information in a near real-time environment. The system architecture, which includes Wi-Fi connectivity, a MySQL database managed through XAMPP, and a web-based dashboard, provided an accessible platform for monitoring soil conditions and generating system outputs.

Results from the functional testing revealed that the major system components, including the soil sensors, ESP32 Wi-Fi connectivity, database storage, dashboard interface, and recommendation module, functioned successfully during system testing. The developed system was able to collect and process soil data, classify soil fertility conditions, and generate recommendations based on predefined soil parameter thresholds suitable for tomato crop growth. This indicates that the system has the capability to support agricultural monitoring by providing timely soil condition assessments and crop-related information.

Moreover, the generated sample soil classifications revealed that most soil samples exhibited poor fertility conditions, primarily due to low soil moisture, acidic pH levels, and insufficient nutrient availability. These conditions resulted in poor growth predictions, emphasizing the importance of balanced soil nutrients and proper environmental conditions for tomato cultivation. In contrast, one sample demonstrated moderate soil fertility and early growth potential, suggesting that improved moisture levels, balanced pH, and adequate nutrient content positively influence tomato crop development.

Overall, the proposed system demonstrated its feasibility as a smart agricultural solution for soil fertility monitoring and tomato crop growth assessment. Although the study did not include large-scale field deployment or laboratory validation of soil measurements, the findings highlight the potential of IoT-based agricultural technologies in supporting informed decision-making, improving soil management practices, and promoting sustainable farming. Future improvements may focus on field implementation, laboratory validation, and the integration of more advanced predictive techniques to further enhance system accuracy and performance.

LIMITATIONS AND FUTURE WORK

This study has several limitations that should be addressed in future research. First, the developed system was evaluated within a limited scope and was not deployed on a large-scale agricultural setting, which may limit its applicability across different soil conditions and farming environments in the Philippines. Although an actual site visit was conducted at an urban farm in BGC, Taguig City for observation purposes, formal large-scale soil sample collection from multiple agricultural locations was not performed.

Second, validation of sensor readings against certified laboratory soil analysis was not conducted. As a result, the quantitative accuracy of the soil moisture, pH, and NPK sensor readings remains a limitation of the study. Future research may incorporate laboratory testing and comparison with certified soil analysis results to improve system reliability and measurement accuracy.

Third, the developed system utilized rule-based soil fertility assessment and crop growth estimation using documented agricultural references and publicly available datasets. Future studies may explore the integration of advanced predictive analytics or machine learning techniques using larger agricultural datasets collected from different geographic regions and growing seasons to improve prediction capability and adaptability.

Fourth, the long-term durability, environmental resistance, and performance stability of the developed device under prolonged field conditions were not evaluated. Factors such as varying weather conditions, network interruptions, and prolonged sensor exposure may influence system performance and should be examined in future implementations.

Lastly, the cost-effectiveness and usability of the system among farmers were not formally assessed. Future work may include farmer user acceptance testing, economic feasibility analysis, and integration with existing agricultural management platforms to enhance practicality, accessibility, and adoption of the proposed system.

ACKNOWLEDGEMENT

The researchers would like to express their sincere gratitude to everyone who contributed to the completion of this study entitled Smart Agricultural Device for Soil Fertility Assessment and Tomato Crop Growth Prediction.

First and foremost, the researchers thank Almighty God for providing guidance, strength, wisdom, and perseverance throughout the conduct of this study.

The researchers would also like to extend their heartfelt appreciation to their research adviser, Vivien Agustin, and to the IT Department Head, Ronald Fernandez, for their valuable suggestions, guidance, and support that greatly helped improve the study.

Special thanks are given to the families and friends of the researchers, especially Regine Ramos and Orven Balaba, for their encouragement, understanding, and continuous moral support throughout the development of the project.

The researchers are also grateful to all individuals who shared their knowledge and feedback during the design, development of the system.

Lastly, the researchers sincerely thank everyone who, in one way or another, contributed to the successful completion of this research study.

REFERENCE

1. Ampo, M. V., Castro J. A. D., Ramoso, J. P., Ilang-Ilang, M., Rodulfo, V. A., Del Rosario, A., Reyes, D. D., and De Guzman, J. J. (2024). Design and development of a sensor and actuator network for smart irrigation and fertilization in tomato production. University of the Philippines Los Baños Journal Articles. Retrieved from https://www.ukdr.uplb.edu.ph/cgi/viewcontent.cgi?article=7073&context=journal-articles
2. Dela Cruz, B., Ramos, R., Carambas, G. M., Peronce, I. P., and Perreras, J. (2025). Digging deeper: Soil quality monitoring system for Alaminos City farmers. Retrieved from https://doi.org/10.47772/IJRISS.2025.9020126
3. Fajir, Y., Qayoom, A., Erasmus, E., Schutte-Smith, M., and Visser, H. (2024). A review on the application of advanced soil and plant sensors in the agriculture sector. Computers and Electronics in Agriculture, 226, 109395. https://www.sciencedirect.com/science/article/pii/S0168169924007762
4. Kumar, S. N., Suriyan, K., Jacob, A. T., Varghese, A., and Francis, Emma. (2025). Smart farming for a sustainable future: Implementing IoT-based systems in precision agriculture. Bulletin of the National Research Centre, 49, Article 66. https://bnrc.springeropen.com/articles/10.1186/s42269-025-01366-8
5. Lionel, B. M., Musabe, R., Gatera, O., and Twizere, C., (2025). A comparative study of machine learning models in predicting crop yield. Discover Agriculture, 3, Article 35. https://link.springer.com/article/10.1007/s44279-025-00335-z
6. Martinez, C. G., Aringo, M. Q., Ella, V., and Martinez O. G. (2022). Development of low-cost soil moisture monitoring system for efficient irrigation water management of upland crops. International Journal of Scientific and Research Publications, 12(6), 530–536. Retrieved from https://www.researchgate.net/publication/361458669_Development_of_Low-cost_Soil_Moisture_Monitoring_System_for_Efficient_Irrigation_Water_Management_of_Upland_Crops
7. Montañez, J. J., and Sarmiento, J. (2024). Machine learning for the detection of soil pH, macronutrients, and micronutrients with crop and fertilizer recommendations. International Journal of Artificial Intelligence, 14(1), 439–446. https://doi.org/10.11591/ijai.v14.i1.pp439-446
8. Mukherjee, S., Dash, P. K., Das D., and Das, S. (2023). Growth, yield and water productivity of tomato as influenced by deficit irrigation water management. Irrigation Science, 41, 645–659. https://pmc.ncbi.nlm.nih.gov/articles/PMC10384587/
9. Ramzan, S., Ali, B., Raza, A., Hussain I., Fitriyani, N. L., Gu, Y., and Syafrudin M. (2024). An innovative artificial neural network model for smart crop prediction using sensory network-based soil data. Scientific Reports, 14, Article 28658. https://pmc.ncbi.nlm.nih.gov/articles/PMC11623066/
10. Sobhy, D. M., and Anandhi, A. (2025). Soil nutrient monitoring technologies for sustainable agriculture: A systematic review. Sustainability, 17(18), 8477. https://www.mdpi.com/2071-1050/17/18/8477
11. Sujatha, M., and Jaidhar, C. D. (2024). Machine learning-based approaches to enhance soil fertility—A review. Expert Systems with Applications, 237, 121565. https://www.sciencedirect.com/science/article/abs/pii/S0957417423030592

12. Chaudhary A., Singh P. D., Verma R., and Sharma, M. (2025). Monitoring soil health using machine learning techniques for improved crop yield prediction. Cureus, 16(4), e4577. Retrieved from https://www.cureusjournals.com/articles/4577-monitoring-soil-health-using-machine-learning-techniques-for-improved-crop-yield-prediction
13. Fauziah, N. O., Fitriatin, B. N., Fakhrurroja, H., and Simarmata, T. (2024). Enhancing Soil Nutritional Status in Smart Farming: The Role of IoT-Based Management for Meeting Plant Requirements. Retrieved from https://onlinelibrary.wiley.com/doi/10.1155/2024/8874325