International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

INTERNATIONAL JOURNAL OF INNOVATION AND INDUSTRIAL REVOLUTION (IJIREV)
www.gaexcellence.com/ijirev

DEVELOPMENT OF AN IOT-DRIVEN REAL-TIME SOIL MONITORING AND AUTOMATED FERTILISER DISPENSING SYSTEM

Muhammad Aydil Mustaqim Abdullah Ismawi[1], Aznilinda Zainuddin[1]*, Yusliza Jamalut[2], Munirah Onn[3]

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA Johor Branch Pasir Gudang Campus, Malaysia
aydilmustaqim58@gmail.com, aznilinda@uitm.edu.my
https://orcid.org/0009-0005-5600-0311
https://orcid.org/0000-0003-1860-4454
[2]Faculty of Management, Multimedia University Persiaran Multimedia, 63100 Cyberjaya Selangor
yuslizajamalut@gmail.com
https://orcid.org/0009-0008-5244-7708
[3]Faculty of Applied Sciences, Universiti Teknologi MARA Johor Branch Pasir Gudang Campus, Malaysia
munirah591@uitm.edu.my
https://orcid.org/0000-0003-1640-2285
*Corresponding Author

Article Info:

Article history:
Received date: 07.06.2026
Revised date: 06.07.2026
Accepted date: 22.07.2026
Published date: 03.09.2026

To cite this document:

Ismawi, M. A. M. A., Zainuddin, A., Jamalut, Y., & Onn, M. (2026). Development Of an IoT-Driven Real-Time Soil Monitoring and Automated Fertiliser Dispensing System. *International Journal of Innovation and Industrial Revolution, 8*(26), 64-79.

Abstract:

The Internet of Things (IoT) is a rapidly growing technology that has been driving the development of smart agriculture systems, which seek to increase efficiency, sustainability, and resource management. However, conventional fertiliser tends to be based on manual checking or pre-set timings, therefore not based on the changing soil conditions and can lead to over or under fertilisation, delay corrective measures and poor utilisation of nutrients. This study demonstrates a real-time soil monitoring and automated fertiliser dispensing system for agriculture which is based on Internet of Things (IoT) technology achieved through the Conceive–Design–Implement–Operate engineering design process. The prototype comprises of a soil moisture sensor, a soil temperature sensor, a pH sensor, an ESP32 microcontroller, and the required components for the pump and valve. The prototype includes soil moisture sensor, soil temperature sensor, pH sensor, ESP32 microcontroller and the necessary parts for pump and valve. If the monitored parameters fall outside specified ranges, fertiliser or water is released by a mechanical mechanism that is controlled by a servo. The sensor readings, actuator status and system notifications are wirelessly sent to a cloud based IoT platform to be remotely monitored, visualised and log stored. Experimental testing over one month showed that the data could be transmitted continuously every minute and that the automatic dispensing worked when the soil moisture dropped below 40% or the pH was above the set value. After the intervention, the pH of soil stabilised between 6.6

and 7.1 were by approximately Day 7. The closed loop control architecture can help to minimize the need for human oversight by integrating real-time sensing with a threshold-based decision-making process and automated dispensing. Throughout the monitoring period, the system also kept wireless communication stable and effective, while providing good real-time data visualisation. The proposed system plays a role in precision agriculture by offering an integrated solution that enables precise management of fertiliser applications and automated response to soil conditions responses, which is particularly valuable for smallholder and resource-limited farming practice environments.

DOI:10.35631/IJIREV.826004

Keyword:

CDIO, Fertilization, IoT, Precision Agriculture, Soil Monitoring

Introduction

The demands put on global agricultural systems to be more productive while reducing environmental footprint and resource use are growing, (Shahab et al. 2025). The improper use of fertilizers is still one of the most serious problems in agriculture and is responsible for reducing soil fertility, polluting water bodies and reducing soil quality. In many agricultural production systems, the timing of fertiliser application remains largely based on predetermined schedules or subjective observation to determine when it is needed, which is ineffective and takes a time to correct. The advent of new Internet of Things (IoT) technologies has sped up the data-driven agriculture transition by allowing for constant environmental monitoring, wireless communication, and remote monitoring (B et al. 2022). The application of IoT-based soil monitoring system to monitor soil parameters including soil moisture, temperature, and pH is widespread due to the important information it offers about soil status and crop needs (A. Puangsuwan and Puttinaovarat 2025). While these changes have greatly enhanced situational awareness for managing agricultural operations, awareness is a necessary, but insufficient, condition for timely and effective intervention.

Current agricultural IoT systems have traditionally not been concerned with acting at the field level, but more with monitoring and decision-making. In most of the reported use cases, soil data are processed to provide recommendations for fertigation to the user via mobile applications or cloud dashboards (Rajak et al., 2023; Syamil et al., 2025). However, the last stage of fertilisation is still a human intervention. By separating the sensing and automated control, delays in response, reliance on human labour, and less effective real-time monitoring are created, especially in small scale and precision agriculture applications where quick changes in soil condition can significantly impact crop performance. Fertigation systems, in general, do not have localised control based on the real-time soil pH variability, which is an important parameter in nutrient availability and uptake (Adamo et al. 2025). Thus, the development of soil fertilization systems that can operate autonomously, with real-time sensing and direct, mechanical fertilization without irrigation facilities remains an interesting research field.

The identified research gap has been addressed by designing an IoT based knowledge-aware real-time soil monitoring and automatic fertiliser dispensing system, termed as AgroFertiTech. In contrast to traditional monitoring systems, AgroFertiTech combines continuous soil monitoring, automated decision making based on thresholds, automated fertiliser and water delivery, cloud-based monitoring, and data logging in one IoT platform. A continuous monitoring system is provided that utilizes embedded soil moisture, soil temperature and soil pH sensors to trigger the right dispensing mechanism when soil moisture, soil temperature and soil pH move out of defined limits. AgroFertiTech directly dispenses fertigation by implementing the sensing's–decision–action loop without much human interaction.

The rest of this paper is organized as follows. Section 2 summarizes the previous research on soil monitoring and soil fertilization systems based on Internet of Things. The technological challenges and research gaps identified will foster the development of the proposed innovative systems. Section 3 outlines the proposed CDIO-based system development methodology, which involves conceptual framework, system architecture, hardware–software integration, and operational logic. It is organized under the section "Conceive, Design, Implement and Operate". Finally, Section 4 wraps up the study, summarizing key contributions and suggesting future research and field deployment directions.

Literature Review

In recent years, the advent of the Internet of Things (IoT) technologies has greatly shaped the advancement of smart agriculture systems, specifically in the field of soil monitoring and crop management applications (Dhanasekar 2025). IOT based platforms have been extensively used to monitor important soil properties like moisture, temperature, pH, and nutrients and collect data continuously, which can later be visualised remotely. In comparison with traditional manual monitoring systems, these systems have shown improvements to situational awareness, decision support and operational efficiency.

There have been several studies that have concerned themselves with soil monitoring and fertiliser recommendation through sensor networks and cloud computing technologies with analytics (Mamun et al. 2025). Different data-driven systems such as rule-based system and machine learning models have been suggested to interpret soil conditions and suggest the best fertiliser application strategy (Srisawat et al. 2025). While, these techniques enhance the accuracy of the decision, but they usually require the user's involvement to implement fertilisation operations. As a results, this makes the effectiveness of real-time monitoring limitation due to delays, labour dependency, and field level gaps in implementation at field level.

Automated fertilisation methods have also been considered, especially for fertigation systems, which involve the application of fertiliser through irrigation systems. These systems provide for controlled nutrient distribution and are labour-saving devices, but they demand already developed irrigation systems and are mainly designed for controlled agriculture or large-scale production (Mubarik et al. n.d.). Furthermore, application of fertigation systems in soil-based fertigation and small farming systems is limited since the systems do not have adaptive control which considers the real time variability of the soil pH.

Recent IoT solutions have tried to combine monitoring with some degree of automation, e.g., automatic irrigation based on soil moisture levels (Choudhary et al. 2025). Nevertheless, fertiliser application is often not treated as an application part of an automation system, but as a separate process. However, these systems cannot respond immediately to dynamic soil nutrient conditions due to the lack of an integrated mechanical dispensing mechanism (Gupta et al., 2025).

Despite the considerable progress of smart agriculture, there are still several current IoT-based fertilisers management systems that achieve either soil monitoring or data visualisation or nutrient recommendation features (Gupta et al., 2025; Tiemann and Douxchamps, 2023). Fertiliser application is still largely driven by manual processes, fixed watering frequencies or pre-designed fertigation systems. This disconnects between soil sensing and application on the field can lead to late response, labour dependency and inefficient nutrient application. In addition, little focus has been placed on integrated systems that incorporate real time soil moisture, temperature and pH sensing in addition to automated fertiliser dispensing. Thus, there is a need for such a low cost, closed-loop IoT system which continuously monitors soil parameters, triggers decisions based on certain thresholds and automatically dispenses fertilizer or water without human involvement.

From the system development perspective, this is addressed by increasingly using structured engineering frameworks, like the CDIO approach, for the development of embedded and IoT-based systems (Wang et al. 2021). It emphasises on the entire system development process, covering conceptualising the problem through to operational validation (Effedi 2025), allowing for the seamless integration of sensing, control, automated system response and evaluation. This could be a good framework for developing an autonomous agricultural system with autonomous IoT which needs closed-loop functionality (Wang et al. 2021), as system conception and design realisation follow the same process as the operational testing.

Methodology

In this section, the methodology used to develop and test the proposed soil monitoring and fertiliser dispensing system with the use of IoT is discussed. The study adopts a CDIO (Construction, Design, Implementation and Operation) development process, which guarantees the systematic and traceable development process of a problem formulation to system operation and evaluation in a way of results (Wang et al. 2021).

CDIO-Based Project Management Approach

The overall project management flow was organized in a CDIO framework that describes a methodology for engineering system developments based on a lifecycle. The four-step Conceive-Design-Implement-Operate system integration process allows for a coherent approach to system conceptualisation, detailed design, prototype manufacturing, and operational validation (Lai, Ho, and Liao 2025).

During the Conceive stage, it was found that there was a soil condition monitoring problem as soil conditions were not monitored in real-time, which resulted in inefficient use of fertilizer. Based on literature findings and practical agricultural aspects, project objectives and functional requirements, constraints and system scope were determined. A conceptual model with high-level was developed to describe the proposed architecture and functionalities. The Design phase was a process of developing a detailed system design from the conceptual framework. This involved the design of block diagrams, flowcharts and control logic for interactions between each of the sensors, the embedded controller, communication module and actuators. To pre-emptively validate system behaviour, decision thresholds and data flow before hardware implementation, simulation and logical verification were performed.

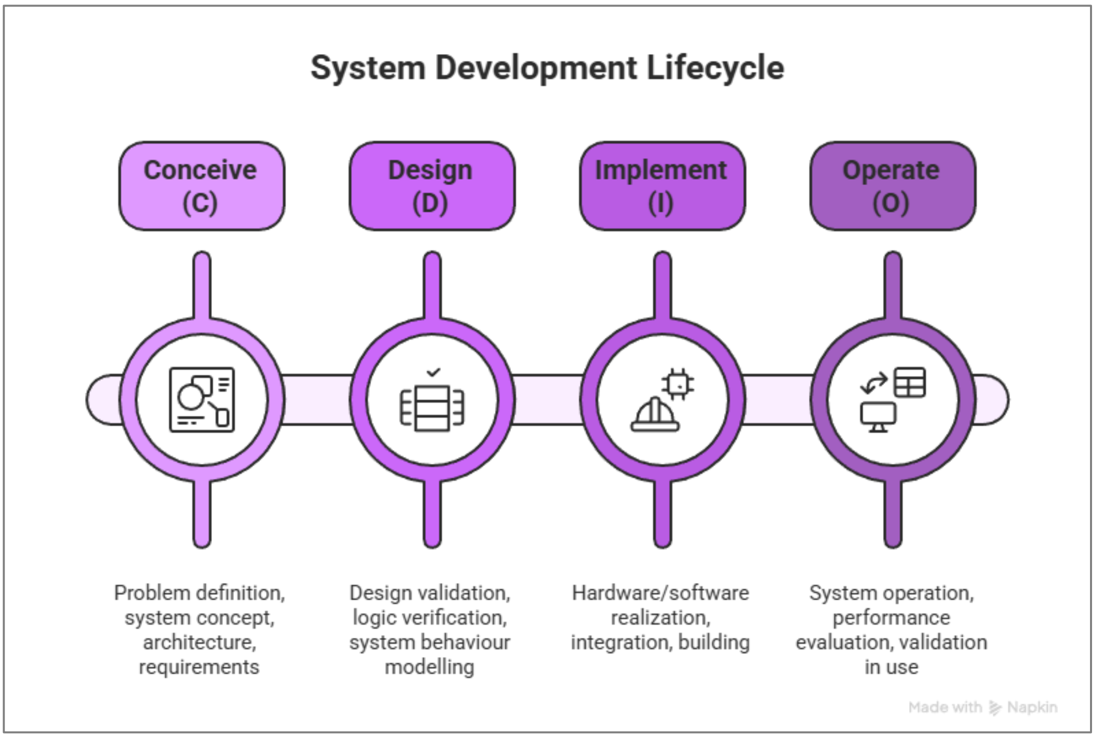


Figure 1: CDIO-Based System Development Lifecycle Illustrating the Conceive, Design, Implement, And Operate Phases Adopted in This Study.

The designed system was realised during the Implement phase. The hardware components were built, sensors and actuators were embedded, and firmware were designed for real-time data collection, decision making and wireless communication. A working prototype was built to the specified design requirements. Lastly, in the Operate phase, the testing and performance assessment of the system took place in a controlled environment. The prototype was tested to see if it was possible to run it in real time and test the monitoring ability, fertiliser dispensing response, wireless communication reliability, and user interaction with the application on the IoT. The experimental results were analysed to ensure the functionality of the system and to see how it can be improved. Overall, the CDIO-based methodology gave a structured development process with traceability of all project phases which facilitated the successful realization and evaluation of the proposed system.

Conceive Phase: System Conceptualisation and Framework Development

The Conceive phase of the CDIO approach involved defining the proposed concept of the AgroFertiTech system that would tackle the inefficiencies of conventional fertiliser application methods. Many of these inefficiencies are due to the lack of real-time soil condition assessment and using fixed application schedules that are not linked to the soil's current conditions. The higher-level system architecture and functional interactions are described in the proposed framework shown in Figure 2, before detailed design and implementation.

The framework includes four functional components: soil sensing, embedded control, wireless communication and automated control (as illustrated in **Figure 2).** The sensors for soil moisture, soil temperature and soil pH are installed strategically in the root zone to continuously measure the soil parameters that directly affect nutrient availability and fertiliser efficiency. The placement of pH sensors in relatively wetter areas of the soil ensures that they produce reliable readings since they require good soil moisture to be accurate. An embedded microcontroller consists of a microcontroller as the main unit, which is responsible for data acquisition, decision making and control actions.

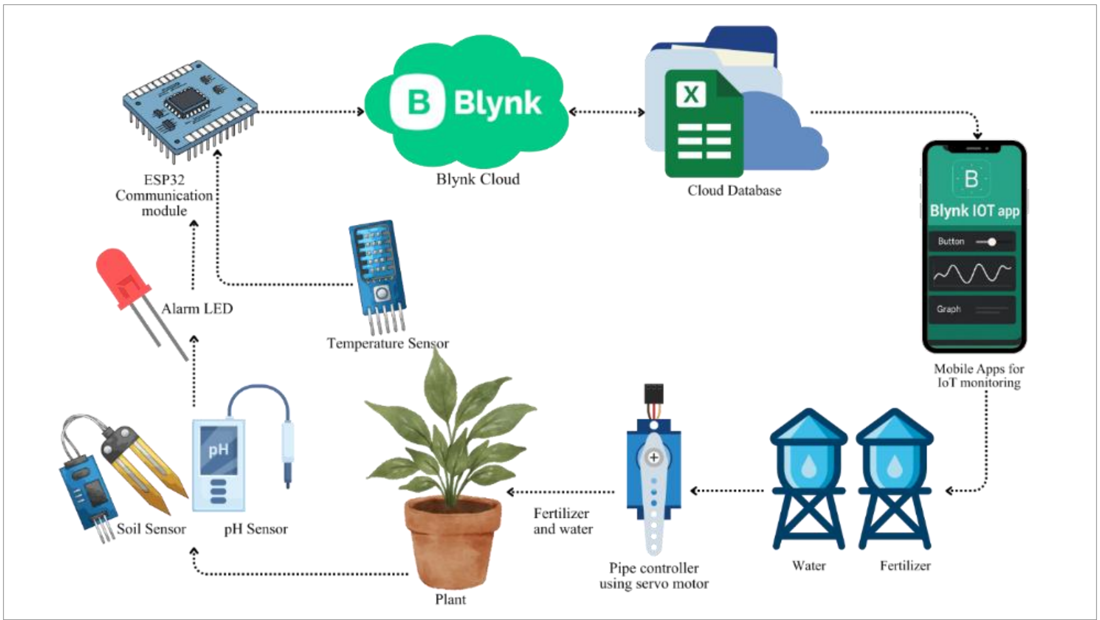


Figure 2: Proposed Framework of The Product Development

The framework is created based on the soil condition thresholds and involves a closed-loop sensing-decision-control concept, in which a mechanical mechanism for the fertiliser dispensing is activated autonomously depending on the deviations observed in the soil parameters. This type of automatic control does not require irrigation-based fertigation and reduces manual control. Wireless communication and cloud integration are embedded into the concept to facilitate remote monitoring, data visualisation, notification and historical data logging via a mobile IoT application.

This proposed framework defines the system boundaries, functional requirements and flow of interaction that will be used for subsequent Design, Implementation and Operation phases. The framework is a conceptual design of an integrated closed-loop control architecture, which offers a structured base for the realisation of an autonomous precision agriculture system.

International Journal of Innovation and Industrial Revolution IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

Design Phase: Operational Design and Simulation

The Design phase transforms the conceptual system into a highly structured and feasible system architecture. The system is designed as an integrated IoT based soil fertilisation system comprising of the sensing, control, communication, automated dispensing and power management subsystems. The ESP32 microcontroller is the main processing unit as it has onboard Wi-Fi functionality, a powerful processor and can be controlled by analogue and digital sensors. The working procedure of the proposed system is shown in **Figure 3**. It starts with the initialising of the system and the connection of the network.

Upon connection, soil moisture, soil temperature, and soil pH are continuously read. All these parameters are compared with threshold limits defined in the code. Once the soil moisture is below 40%, the system will turn on the water release mechanism via servo motor and present an LED indication. When the pH level is above the specified level, the fertiliser dispensing mechanism is activated. The sensor data and system status are then sent to Blynk IoT platform and stored in a cloud-based spreadsheet. The closed-loop logic provides real-time sensing, decision-making and automated dispensing.

The sensing subsystem consists of a soil moisture sensor, a pH sensor and a DHT22 temperature sensor at the root zone of plants. The sensors are directly connected to the ESP32, allowing for real-time monitoring and quick response of the system. The fertiliser and water are released under the control of a servo motor, which is activated by threshold-based control logic. LED indicators give instant visual information on soil conditions and actions taken by the system. Blynk IoT platform is used for remote monitoring and user interaction. Real-time information, alerts and system status are presented on a mobile App. This data is also recorded in a cloud-based spreadsheet where it can be analysed and used to evaluate performance in the past. A custom designed 5 v DC power supply converter has been put in place for stable operation of all electronic components, especially in resource constrained environments.

At this stage the system was designed and simulated using the Wokwi platform (wokwi.com), which is an online design platform that allows users to design and simulate digital circuits and microcontroller projects directly in a web browser. During the first development cycle Wokwi offers a virtual and accessible platform to develop embedded systems without having to use hardware. The system simulation with the Blynk mobile interface is shown in **Figure 4**. This simulation checks the sensor integration, the implementation of control logic, the automated dispensing and the wireless data transmission before it is physically realised. It validates correct threshold detection, real-time data visualisation and notification generation. This stage of validation verifies that the system is logical, reliable and less risky in terms of implementation before the development of the prototype.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

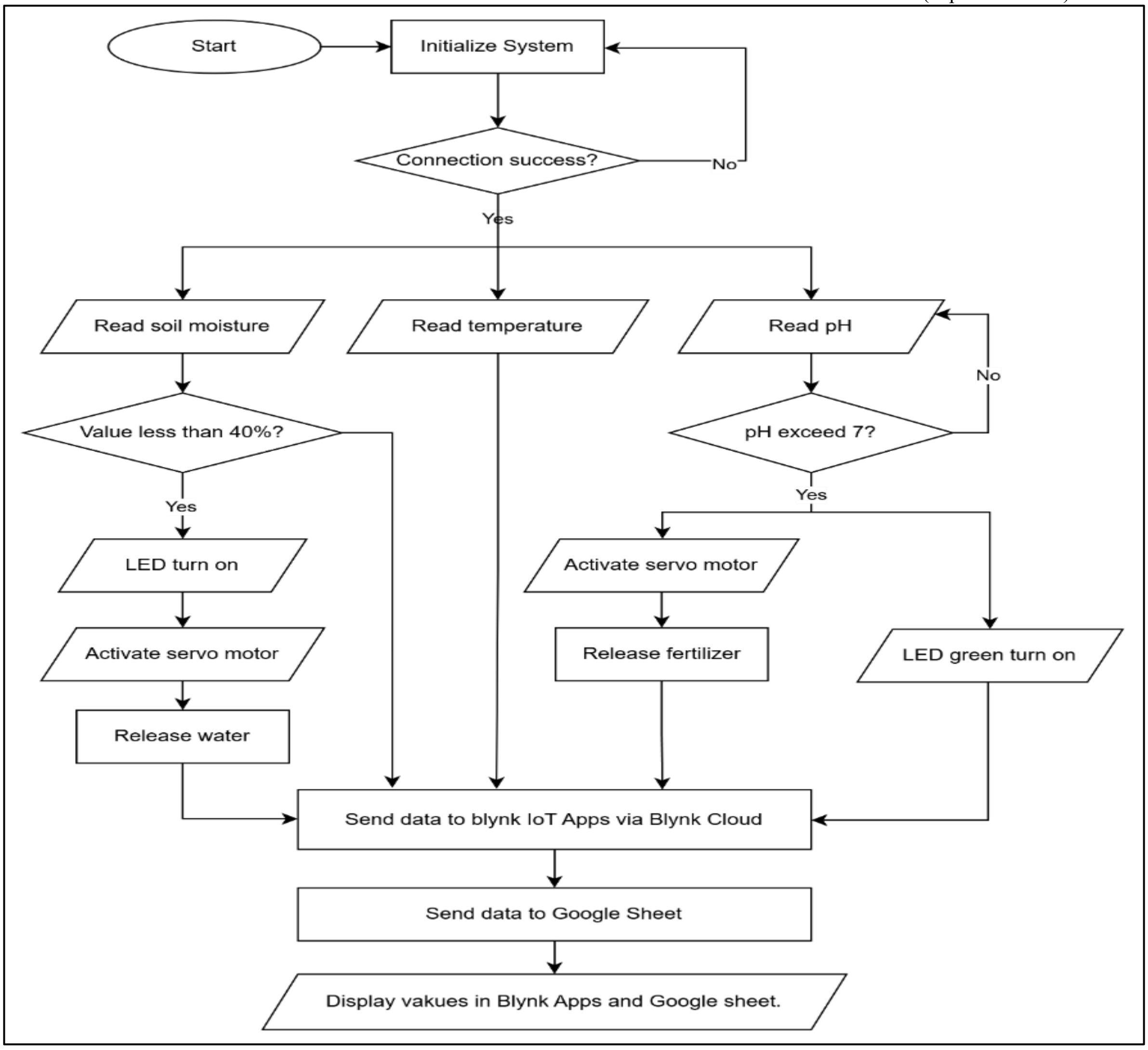


Figure 3: Operational flowchart of the proposed AgroFertiTech system.

The Design phase creates a comprehensive system design that connects all the above functions in an integrated IoT system, including sensors, decision making, automated dispensing, and cloud communication. The operation and the operational logic are implemented in a way that all the subsystems work together before physical realisation, and the simulation is performed and validated. The design's ability to confirm the behaviour of the actuators, actuator response, and wireless data transmission in a controlled simulation environment reduces the risk of integration and implementation problems. The structure and validation of the architecture provide a good basis for the next Implement phase where the hardware assembly and prototype realisation takes place.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

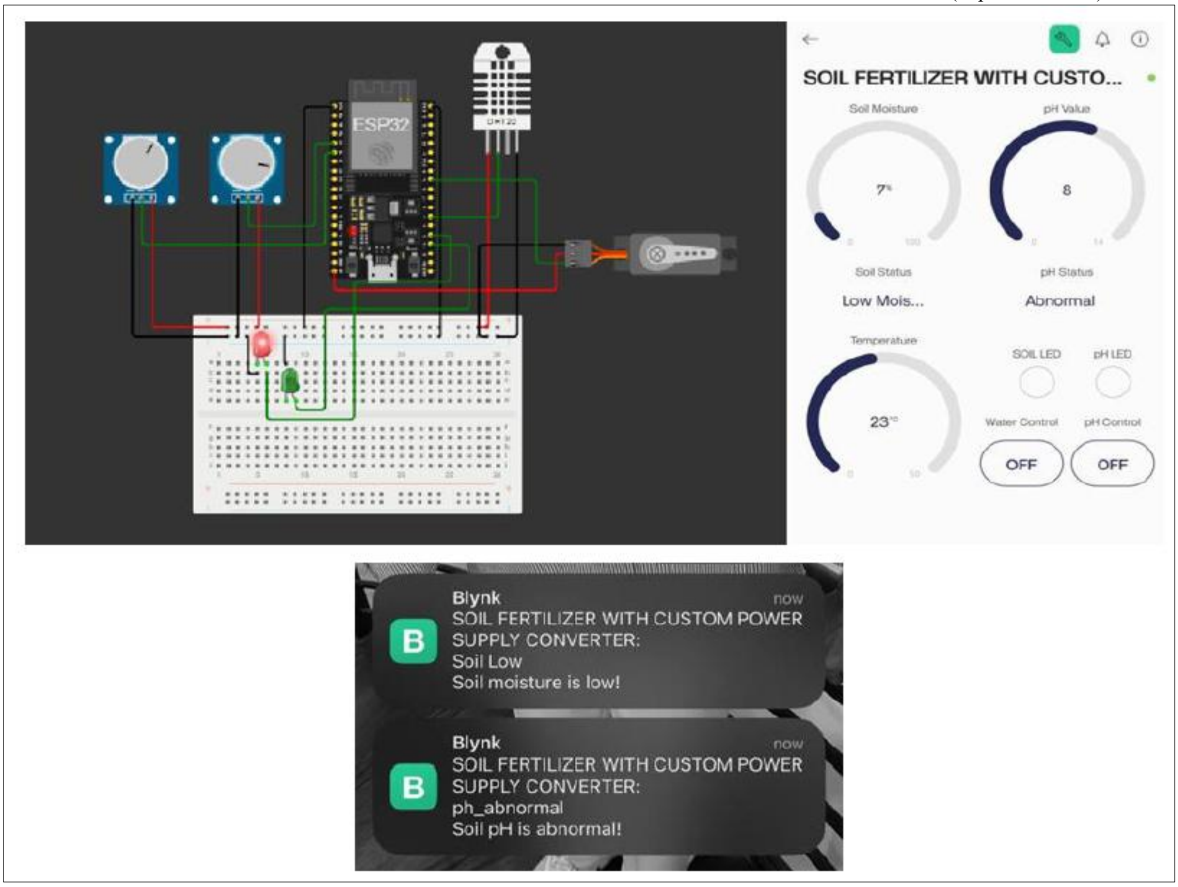


Figure 4: System Simulation Using the Wokwi Platform Integrated with The Blynk Mobile Application.

Implement Phase: Prototype Realisation and System Integration

The Implement is the phase where the designed system is realised by including the various hardware and software elements and creating a functional prototype that can be operated in real time. This phase is responsible for converting the validated system architecture and control logic to an operational AgroFertiTech system.

The prototype, shown in **Figure 5**, is a physical realization of the modular configuration of the sensing, control, and automated dispensing subsystems. The system is based on the ESP32 microcontroller, which has built-in Wi-Fi connectivity, low-power consumption, and supports cloud-based IoT platforms. The soil moisture, soil temperature and soil pH sensors related to a microcontroller to collect the data in real time at the plant root zone. The choice of these parameters was made because they directly affect the soil nutrient availability and fertiliser effectiveness. The connections of the sensors were done with the configuration designed, and a preliminary measurement calibration was performed to achieve stability and consistency in measurement.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

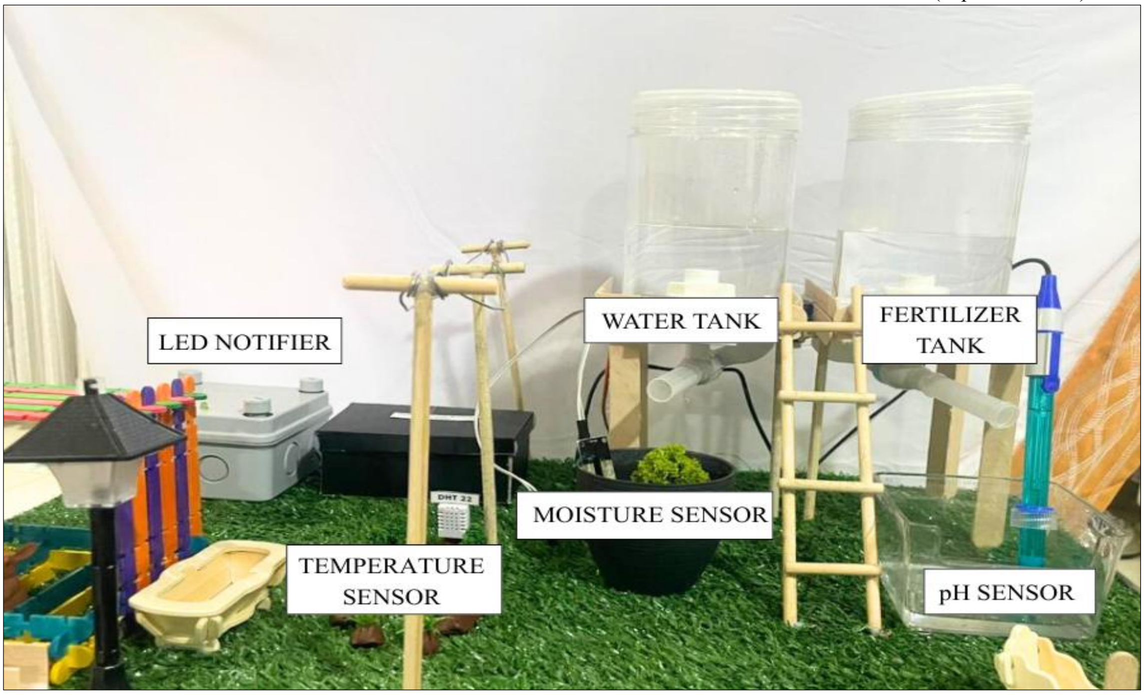


Figure 5: Physical Prototype of The Agrofertitech System.

The prototype consists of dedicated water and fertiliser storage tanks, with a dedicated servo-controlled dispensing mechanism as shown in **Figure 5**. The ESP32 has a threshold-based control logic which can be programmed to activate the dispensing system when the soil parameters go beyond certain threshold. When the system is in use, LED indicators offer instant visual feedback regarding system status and dispensing events. A wireless communication was implemented with the built-in Wi-Fi module of the ESP32, which was connected to the Blynk IoT platform. A mobile application displays real-time sensor data and system status and acts as a logging system for actuator events, which get automatically uploaded to a cloud-based spreadsheet for post analysis. The modularity of the assembly allows easy testing, troubleshooting and scalability for the system in the next phase (Operate), where its operational validation will be performed.

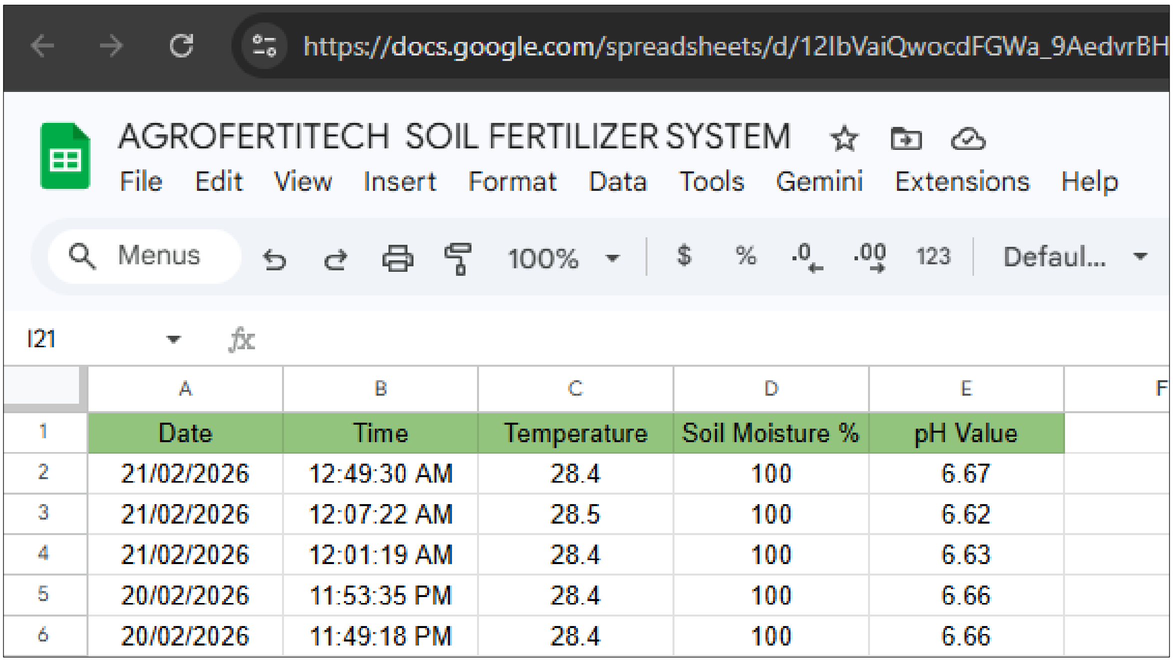
Operate Phase: Experimental Setup & Results

The Operate phase assesses functionality, reliability and performance of the implemented system in operational conditions. This phase is used to test the developed system and remote user interaction to make sure it works well. Testing of the systems was undertaken with a contained potted-plant environment. Root zone moisture, pH and temperature were continuously monitored. The data were transmitted to the cloud-based IoT platform where the data is accessible remotely. Then, the Mobile app user interface showed real-time sensor data, system status indicator and historical trending.

As shown in **Figure 6**, it displays the cloud-based Google Sheets interface displaying sensor data every minute. Each of the entries contains date, time, soil moisture percentage, and pH value. The structured data logging can be used to monitor the changes in soil condition continuously and will also aid in post analysis of system performance. The time-stamped records are stable, which reflects the dependable wireless communication and data

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

transmission during the operation. Throughout the one month of monitoring, sensor readings and actuator events were captured every one minute. The desired dispensing mechanisms were successfully triggered when the moisture content or pH level in the soil exceeded the set limits, with confirmation displayed on the LED screen, mobile notification and recorded in the cloud. The system was tested with the following adjusting of soil conditions, based on the pre-defined thresholds. The system self-activated the dispensing mechanism, which was servo controlled, when soil moisture or pH values fell outside of the acceptable ranges. Data loggers were used to monitor response time from the sensors to the automated controls and recorded for a month to measure system latency in 1-minute increments. Visual indication gave instant feedback on system actions while operating. Accessibility and interaction were also evaluated from a distance. The system was able to be manually controlled via the mobile IoT application, allowing for bidirectional communication between the embedded controller and the cloud platform. During the period of operation, wireless connectivity and stability and data transmission consistency were maintained.



	A	B	C	D	E
1	Date	Time	Temperature	Soil Moisture %	pH Value
2	21/02/2026	12:49:30 AM	28.4	100	6.67
3	21/02/2026	12:07:22 AM	28.5	100	6.62
4	21/02/2026	12:01:19 AM	28.4	100	6.63
5	20/02/2026	11:53:35 PM	28.4	100	6.66
6	20/02/2026	11:49:18 PM	28.4	100	6.66

Figure 6: Cloud-Based Data Logging Interface (Google Sheets) Displaying Reading with A 1-Minute Interval.

The comparison of maximum and minimum temperatures between the reference dataset retrieved from the Visual Crossing weather database (visualcrossing.com) and the proposed AgroFertiTech system throughout February 2026 is presented in Figure 7. The reference data, labelled as *System* were obtained from the Visual Crossing historical weather data for the period of monitoring. The AgroFertiTech dataset, on the other hand, contains the actual temperature measurements taken from the developed IoT prototype. This comparison helps to validate the proposed sensing architecture with respect to an external source of weather data. There are some fluctuations in certain days, but the general trend of temperature maximum and minimum variations remains same for both datasets. Thus, the shaded regions illustrate the daily temperature range differences for each system, enabling visual assessment of variation magnitude

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 26 (September 2026) PP. 64-79

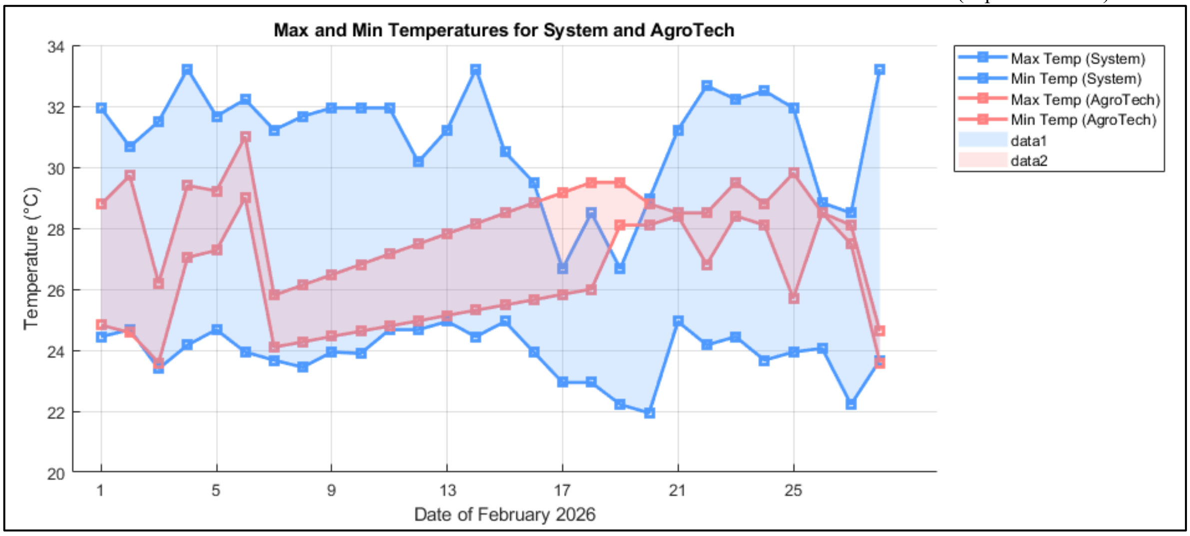


Figure 7: Comparison Of the Maximum and Minimum Temperature Ranges for The Developed System (Red) And the Reference Data Retrieved from The Visual Crossing Website (Blue).

The similarity in the trend behaviour shows that the proposed AgroFertiTech sensing architecture shows similar performance compared to the reference weather data source. The results indicate that the system can provide reliable real-time temperature monitoring that is suitable for precision agriculture application.

As shown in **Figure 8**, the proposed IoT system can monitor the change of soil pH and moisture level. The first couple days of February has some very unpredictable pH which will cause unstable soil conditions. After approximately Day 7, the pH value levels-off in the desired range of 6.6-7.1, indicating that the system is well regulated. Soil moisture status is mostly adequate but there are some slight variations in soil moisture during mid-late February. Of particular interest is the synergy between moisture reduction and pH changes, suggesting a coordinated response from the system. Moisture reading uniformity following the intervention is indicative of good moisture regulation.

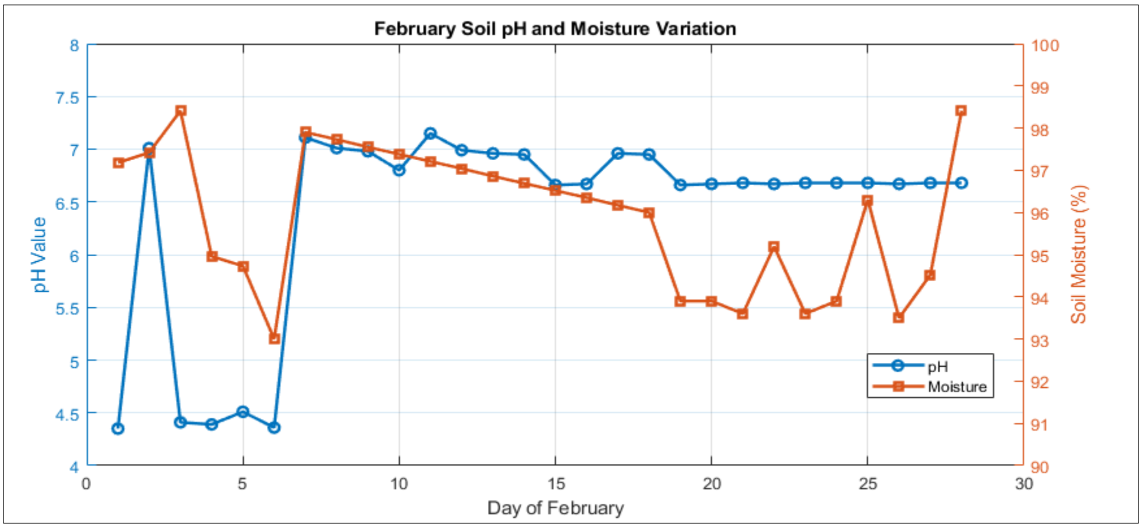


Figure 8: Variation Of Soil Ph and Moisture Levels Monitored by The Proposed Iot System

In general, good closed-loop performances were observed, where real-time soil sensing was well connected with autonomous decision making and mechanical fertiliser dispensing. The outcomes validate the potential of the proposed system as an intelligent precision agriculture solution and lay the groundwork for further advancements, such as long-term field implementation and adaptive control techniques.

Conclusion

The aim of this study was to develop and validate an IoT based real-time soil monitoring and fertiliser dispensing system called AgroFertiTech, to overcome the inefficiencies of conventional fertiliser management practices. The system automatically integrates soil moisture, soil temperature and soil pH sensing, as well as threshold soil moisture and soil temperature based autonomous dispensing, and it closes the sensing–decision–automated loop. The mechanical dispensing system is driven by a servo motor, which allows for direct application of fertiliser even without the need for irrigation systems, making it more adaptable to small-scale farms. The CDIO based development approach allowed for systematic development from conceptualisation to operational validation and ensured coherent integration of the subsystems. Experimental evaluation has shown stable wireless communication and immediate response of actuators to soil parameter limits exceeding the set parameters, while reliable real-time monitoring was achieved. The results validate that over-fertilisation, and under-fertilisation can be effectively prevented, and can expect a faster dynamic soil condition response time. Data logging in the cloud and mobile visualisation makes the management easier and helps to implement long-term soil management. However, the prototype was able to function reliably and show good stability, the experimental trials were performed in a controlled environment in a potted-plant setup. This study did not assess the influence of external environmental conditions including rainfall, variations in soil type, differences in crop size and longevity of the operation. Hence, a comprehensive field deployment is needed to ensure the robustness and scalability of the system in actual agricultural conditions. In future, the focus will be on long-term deployment in the field, adaptation of the threshold and incorporation of further nutrient sensors to improve the intelligence and scalability of the system.

Acknowledgements:	The authors would like to express their sincere gratitude to the Faculty of Electrical Engineering, Universiti Teknologi MARA, Johor Branch Pasir Gudang Campus, for providing the necessary resources and support throughout the course of this research.
Funding Statement:	This study received no external funding.
Conflict of Interest Statement:	The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the International Journal of Innovation and Industrial Revolution (IJIREV).
Ethics Statement:	This study did not engage in human participants, animal, or any data sensitive to ethical reviews. The authors confirm that they have followed the rules of academic integrity and ethical publication standards.
Author Contribution Statement:	All authors contributed significantly to the development of this manuscript. Muhammad Aydil Mustaqim Abdullah Ismawi was responsible for the original idea generation, conceptual design, prototype development, and system realisation. Aznilinda Zainuddin led the refinement of the conceptual framework, methodology development using the CDIO approach, and provided overall supervision of the study. Yusliza Jamalut and Munirah Onn were responsible for prototype testing, data collection, data analysis, and interpretation of experimental results. All authors contributed to manuscript drafting, critical revision, and approved the final version of the manuscript prior to submission.

References

Adamo, Tommaso, Danilo Caivano, Lucio Colizzi, Emanuela Guerriero, and Giovanni Dimauro. 2025. "Smart Agricultural Technology Optimization of Irrigation and Fertigation in Smart Agriculture : An IoT-Based Micro-Services Framework." *Smart Agricultural Technology* 11(March):100885. doi: 10.1016/j.atech.2025.100885.

Choudhary, Vijaya, Paramita Guha, Giovanni Pau, and Sunita Mishra. 2025. "Environmental and Sustainability Indicators An Overview of Smart Agriculture Using Internet of Things (IoT) and Web Services." *Environmental and Sustainability Indicators* 26(April 2024):100607. doi: 10.1016/j.indic.2025.100607.

Dhanasekar, S. 2025. "A Comprehensive Review on Current Issues and Advancements of Internet of Things in Precision Agriculture." *Computer Science Review* 55(August 2024):100694. doi: 10.1016/j.cosrev.2024.100694.

Effendi, M. Khoirul. 2025. "MethodsX The Impact of CDIO Implementation on Retrofitting CNC Based Universal Turn Drill in Vocational Education." *MethodsX* 15(August):103547. doi: 10.1016/j.mex.2025.103547.

Gupta, Subir, Subrata Chowdhury, Ramya Govindaraj, and Kassian T. T. Amesho. 2025. "Smart Agricultural Technology Smart Agriculture Using IoT for Automated Irrigation , Water and Energy Efficiency." *Smart Agricultural Technology* 12(January):101081. doi: 10.1016/j.atech.2025.101081.

Lai, Chien-hung, Liang-chieh Ho, and Zi-yi Liao. 2025. "Sustainability of Programming Education Through CDIO-Oriented Practice : An Empirical Study on Syntax-Level Structural Visualization for Functional Programming Languages."

Mamun, Rasel Al, Abu Kawsar Ahmed, Sidratul Muntaha Upoma, Mashurul Haque, and Muhammad Ashik-e-rabbani. 2025. "Smart Agricultural Technology IoT-Enabled Solar-Powered Smart Irrigation for Precision Agriculture." *Smart Agricultural Technology* 10(January):100773. doi: 10.1016/j.atech.2025.100773.

Mubarik, Mehak, Aaqib Raza, Haroon Rashid, Aznilinda Zainuddin, Zatul Iffah, and Abd Latiff. n.d. "Automatic Monitoring and Control System for Different Water Levels in Interconnected Multiple Twin Tanks with Dry Run Protection Using Microprocessor Orange Pi." 0–5.

Puangsuwan, Kritsada, and Supattra Puttinaovarat. 2025. "An Integrated IoT- and Machine Learning-Based Smart Management and Decision Support System for Sustainable Oil Palm Production."

Rajak, Prem, Abhratanu Ganguly, Satadal Adhikary, and Suchandra Bhattacharya. 2023. "Internet of Things and Smart Sensors in Agriculture : Scopes and Challenges." *Journal of Agriculture and Food Research* 14(September):100776. doi: 10.1016/j.jafr.2023.100776.

Shahab, Hammad, Muhammad Naeem, Muhammad Iqbal, Muhammad Aqeel, and Syed Sajid. 2025. "Smart Agricultural Technology IoT-Driven Smart Agricultural Technology for Real-Time Soil and Crop Optimization." *Smart Agricultural Technology* 10(February):100847. doi: 10.1016/j.atech.2025.100847.

Srisawat, Theera, Saytan Sakprom, Phruksa Kunsawat, and Kanokwan Praksong. 2025. "Industrial Crops & Products IoT-Enabled Agricultural Environmental Monitoring : Enhancing Growth and Yield Using Natural-Rubber Straw and Mulching Experiment." *Industrial Crops & Products* 225(December 2024):120524. doi: 10.1016/j.indcrop.2025.120524.

Syamil, Muhamad, Daniel Mohd, Muhammed Akram, Irfan Mohd, and Maisara Othman. 2025. "EEEE IoT Fertigation Dashboard for Precision Agriculture Monitoring and Control." 6(2):165–72.

Tiemann, Tassilo, and Sabine Douxchamps. 2023. "World Development Sustainability Opportunities and Challenges for Integrated Smallholder Farming Systems to Improve Soil Nutrient Management in Southeast Asia." *World Development Sustainability* 3(March 2022):100080. doi: 10.1016/j.wds.2023.100080.

Wang, Yuxin, Shuang Gao, Yuchen Liu, and Ying Fu. 2021. "Education for Chemical Engineers Design and Implementation of Project-Oriented CDIO Approach of Instrumental Analysis Experiment Course at Northeast Agricultural." *Education for Chemical Engineers* 34:47–56. doi: 10.1016/j.ece.2020.11.004.

Yusliza Jamalut, Mohd Fairuz, Abd Rahim, and Jeen-wei Ong. 2022. *A Framework on Intention to Adopt Internet of Things Among MSMEs in Farming*. Atlantis Press International BV.