

Development and Performance Analysis of an IoT-Based Automatic Irrigation System for Chili Plants

Muzalifah Mohd Said^{1*}, Nurul Elyana Zulkiflee¹, Siti Aisah Mat Junos², Faiz Arith¹.

¹Faculty of Electronics and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), 76100, Melaka, Malaysia.

²School of Technical Foundation and Diploma Studies, Universiti Teknikal Malaysia Melaka (UTeM), 76100, Melaka, Malaysia.

*Corresponding Author

DOI: <https://doi.org/10.47772/IJRISS.2026.100900111>

Received: 10 September 2026; Accepted: 15 September 2026; Published: 02 October 2026

ABSTRACT

Efficient irrigation management is important for maintaining suitable soil moisture conditions for chili plant growth while reducing unnecessary manual intervention. This paper presents the development of an Internet of Things (IoT)-based automatic irrigation system using an ESP32 microcontroller, soil moisture sensors, a DHT22 temperature sensor, a relay module, and water pumps. Sensor measurements are transmitted through Wi-Fi to the Blynk IoT platform for real-time monitoring and manual override. A preliminary cultivation experiment was conducted using three chili plants maintained under three target soil-moisture regimes: 81–100%, 60–80%, and 30–50%. The observed results showed that the plant maintained within the 60–80% range achieved the highest recorded vegetative growth, reaching 57 cm by Week 9, and the largest recorded fruit length of 5.5 cm during Weeks 13–17. These observations suggest that the moderate moisture regime was more favourable than the wetter and drier regimes in this preliminary experiment. However, because only one plant was used for each moisture condition and no independent control group or inferential statistical analysis was included, the findings should be interpreted as preliminary rather than statistically generalizable. The prototype demonstrates the feasibility of threshold-based IoT irrigation for small-scale chili cultivation and provides a basis for future replicated field experiments.

Keywords—IoT, automatic irrigation, ESP32, soil moisture sensor, chili plants, smart agriculture.

INTRODUCTION

Chili (*Capsicum annuum* L.) is one of the most widely cultivated horticultural crops due to its high economic value and strong demand in the food industry. The growth and productivity of chili plants are highly dependent on proper irrigation management, particularly soil moisture control. Inadequate watering practices, such as excessive or insufficient irrigation, can negatively affect root development, nutrient absorption, and overall plant health [1]. In small-scale farming and household cultivation, irrigation is still commonly performed manually, which often leads to inefficient water usage and inconsistent soil moisture levels [2].

Manual irrigation methods rely heavily on human judgment and fixed watering schedules, making them prone to human error and unsuitable for continuous plant monitoring [3]. Studies have shown that such practices may result in water wastage and uneven soil moisture distribution, which can delay plant growth and reduce crop yield [4]. These limitations are further intensified in urban farming environments, where growers have limited time and space to frequently monitor crop conditions [5].

To address these challenges, efficient and automated irrigation systems are required to ensure that chili plants receive an adequate and consistent water supply. Research indicates that chili plants generally require soil moisture levels within a specific range to achieve optimal growth and fruit development [6]. Maintaining this

range manually is difficult, particularly during varying weather conditions, which highlights the importance of real-time monitoring and control mechanisms [7].

The emergence of the Internet of Things (IoT) has enabled the development of smart agricultural systems that integrate sensors, microcontrollers, and cloud platforms to automate irrigation processes. IoT-based irrigation systems allow soil moisture data to be collected continuously and used to trigger irrigation only when required, thereby improving water-use efficiency and reducing manual labour [8]. Several studies have demonstrated that IoT-enabled irrigation systems can enhance crop management by providing real-time monitoring and remote access through mobile or web-based applications [9].

Among the available microcontrollers, the ESP32 has gained significant attention for IoT applications due to its built-in Wi-Fi and Bluetooth capabilities, low power consumption, and compatibility with multiple sensors and cloud platforms [10]. These features make the ESP32 suitable for developing low-cost and scalable smart irrigation systems tailored for small-scale agricultural applications.

In this work, an IoT-based automatic irrigation system for chili plants is developed using an ESP32 microcontroller and soil moisture sensors. The proposed system monitors soil moisture levels in real time and controls water pumps based on predefined moisture thresholds. By implementing a sensor-driven irrigation strategy, this study aims to improve water efficiency, reduce manual intervention, and support healthier chili plant growth in small-scale and home farming environments.

RELATED WORK

Recent studies have increasingly focused on the application of Internet of Things (IoT) technology to improve irrigation efficiency and crop management. Advanced IoT-based irrigation systems integrate sensors, controllers, and communication platforms to automate watering processes based on real-time environmental data. For chili plant cultivation, intelligent irrigation systems have been proposed to address challenges related to inconsistent watering and inefficient fertilizer usage [10].

One notable approach involves the integration of smart irrigation and fertilization systems using fuzzy logic control. By considering multiple input parameters such as soil moisture and pH levels, fuzzy logic-based systems are able to determine suitable irrigation and nutrient delivery rates more precisely compared to conventional rule-based control [10]. Although this approach improves decision accuracy, it introduces higher system complexity and computational overhead.

Comparative studies between traditional irrigation methods and IoT-based systems have shown that automated irrigation significantly enhances water-use efficiency and crop growth performance. Experimental evaluations demonstrate that IoT-based irrigation systems can maintain more stable soil moisture levels while reducing manual intervention and water wastage [11]. These findings highlight the potential benefits of smart irrigation solutions for sustainable agriculture.

Further research has explored the integration of smart sensors and IoT technologies in precision agriculture. The use of soil moisture, temperature, and humidity sensors enables continuous monitoring of crop conditions, allowing irrigation decisions to be made based on real-time data rather than fixed schedules [12]. Such systems support data-driven agricultural practices and improve overall resource management.

In addition to system architecture, the performance and reliability of soil moisture sensors play a critical role in smart irrigation systems. Studies investigating capacitive soil moisture sensors have reported improved stability, reduced corrosion, and better long-term performance compared to resistive sensors, particularly in smart irrigation applications [13]. Accurate sensor performance is essential to ensure reliable irrigation control and prevent incorrect watering decisions.

Several recent implementations have also emphasized low-cost and scalable irrigation system designs suitable for small-scale and home farming environments. By utilizing affordable microcontrollers and cloud-based monitoring platforms, these systems aim to balance performance, cost, and ease of deployment [14]. Despite

these advancements, there remains a need for a simple threshold-based irrigation system that focuses on practical implementation and experimental evaluation specifically for chili plant cultivation. This study addresses this gap by developing an ESP32-based automatic irrigation system with real-time soil moisture monitoring and predefined threshold control.

METHODOLOGY

System Overview

This study presents the design and implementation of an IoT-based automatic irrigation system for real-time soil moisture monitoring and precision water delivery to chili plants. The proposed architecture is structured into three primary subsystems: the sensing unit, the control unit and the actuation unit.

The sensors were selected primarily because of their low cost and simple interfacing. Because resistive sensors may be affected by electrode degradation and soil properties, calibration and long-term stability testing are important.

The ESP32 was selected as the main controller due to its integrated Wi-Fi capability, low power consumption and suitability for IoT-based applications requiring real-time data transmission. The control logic continuously compares measured soil moisture values against predefined lower and upper threshold limits. When the moisture level drops below the minimum threshold, the system activates the irrigation mechanism via a relay-controlled water pump. Irrigation is automatically terminated once the upper threshold is achieved, thereby preventing overwatering and ensuring optimal soil moisture conditions [15].

The actuation unit comprises a relay module interfaced with a DC water pump, responsible for regulating water flow to the plant root zone. This closed-loop control mechanism ensures that irrigation decisions are based on actual soil conditions rather than fixed time intervals, enhancing water-use efficiency and system reliability [16].

The overall system workflow is illustrated in Fig. 1. The architecture integrates the ESP32 controller, soil moisture sensors, relay module, DC water pump, and IoT monitoring interface. The ESP32 acquires sensor data, compares the readings with the predefined thresholds, controls the pump, and transmits selected measurements to the cloud platform. The architecture is intended as a low-cost prototype for small-scale cultivation rather than a fully validated commercial agricultural system.

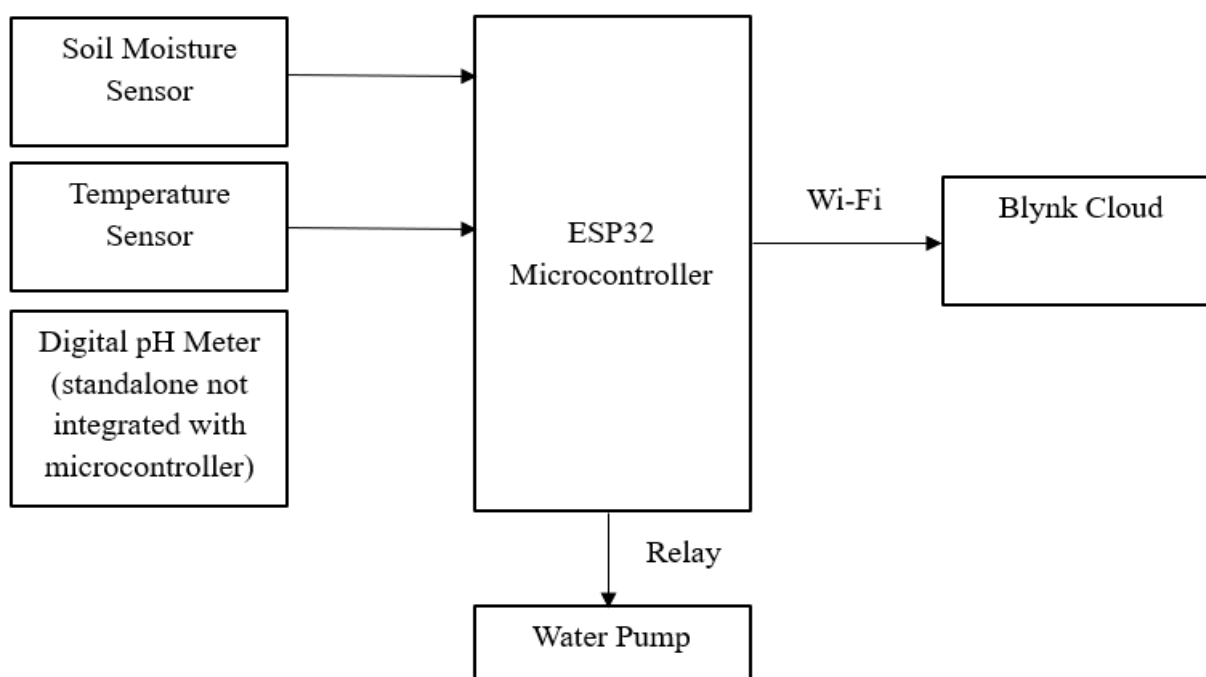


Fig. 1: Overall system architecture of the proposed iot-based automatic irrigation system

Hardware Setup

The hardware architecture comprises an ESP32 microcontroller, resistive soil moisture sensors, a relay module, a DC water pump, and the DHT22 temperature sensor. The soil moisture sensor provides an analog signal associated with soil electrical resistance, which is sampled using the ESP32 ADC. The DHT22 provides ambient temperature information for monitoring. In the present study, irrigation decisions are based primarily on soil moisture, while temperature data are displayed through the IoT interface.

The ESP32 serves as the central processing and communication unit of the system. It processes the acquired soil moisture data and compares the measured values against predefined threshold limits. When the soil moisture level falls below the specified threshold, the ESP32 activates the relay module to initiate irrigation by powering the DC water pump. Once the soil moisture reaches the desired range, the relay is deactivated to terminate water supply. This threshold-based control strategy enables automated irrigation while minimizing water wastage [18].

Each soil moisture sensor is installed within the effective root zone of its corresponding plant. The manuscript should report the exact sensor model, insertion depth, soil type, container dimensions, and sensor spacing to improve experimental reproducibility.



Fig. 2: Hardware setup

Software Architecture

The system firmware was developed using the Arduino IDE, where the ESP32 is programmed to perform continuous soil moisture acquisition, threshold evaluation, irrigation control and wireless data transmission. The microcontroller executes a periodic sampling routine to read analog sensor values through its ADC interface, apply calibration mapping and determine irrigation status based on predefined control parameters.

Measured soil moisture data, along with pump status indicators, are transmitted via Wi-Fi to the IoT cloud platform for real-time visualization, remote monitoring, and historical data logging. IoT-enabled irrigation architectures enhance system accessibility, scalability and centralized data management, enabling users to monitor soil conditions without physical site presence [19].

The system operates under two control modes: automatic and manual override. In automatic mode, irrigation is governed by the threshold-based algorithm with hysteresis control to ensure stable switching behavior. The pump is activated when the moisture level drops below the lower threshold and deactivated when the upper threshold is achieved. In manual override mode, users can remotely trigger pump activation via the mobile interface for system testing, calibration verification, or maintenance procedures. This dual-mode configuration improves operational flexibility while maintaining autonomous functionality.

The detailed operational sequence of the firmware logic is illustrated in **Fig. 3**, which presents the system control flowchart implemented in this study.

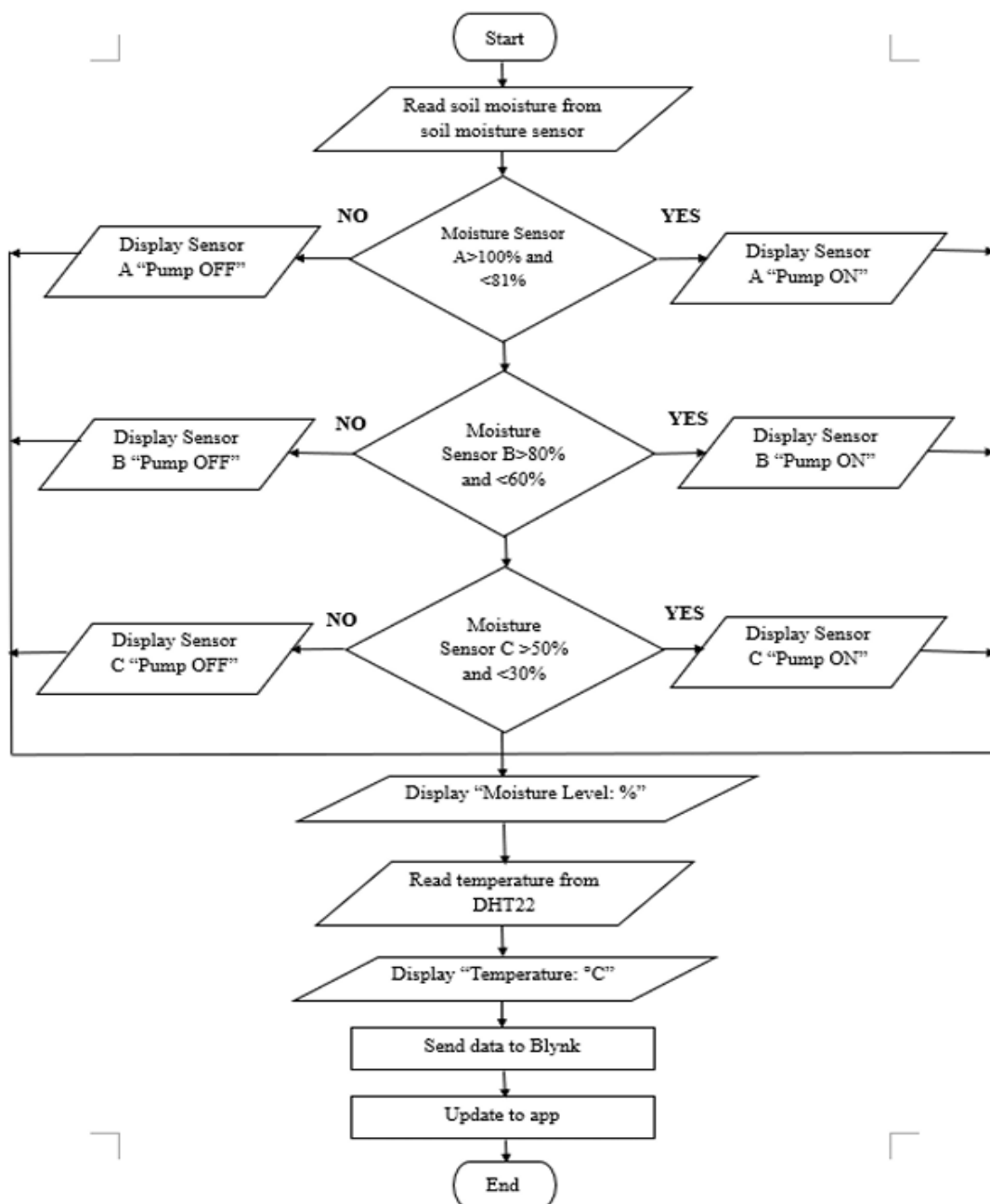


Fig. 3: Flowchart of the automatic irrigation process

Control Algorithm And Decision Logic

The soil moisture sensor produces an analog signal related to soil electrical resistance. The ESP32 reads the signal using its 12-bit ADC, producing nominal digital readings from 0 to 4095. The raw ADC value is converted to a normalized moisture index using calibration values obtained under dry and fully saturated reference conditions. Because this two-point mapping is a prototype calibration rather than a direct measurement of volumetric water content, the reported percentages are treated as calibrated sensor moisture indices unless an independent gravimetric or reference-meter validation is provided. M

$$M = \frac{ADC_{max} - ADC_{read}}{ADC_{max} - ADC_{min}} \times 100\%$$

where ADC_{read} represents the measured ADC value, while ADC_{min} and ADC_{max} correspond to calibration values obtained under dry and fully saturated soil conditions, respectively [20].

A threshold-based irrigation strategy is implemented to automate watering control. The irrigation pump is activated when:

$$M < M_{low}$$

and deactivated when:

$$M > M_{high}$$

where M_{low} and M_{high} define the lower and upper moisture thresholds.

To prevent rapid switching (relay chattering) due to minor fluctuations in sensor readings, a hysteresis control mechanism is implemented such that:

$$M_{high} > M_{low}$$

This hysteresis band improves system stability and enhances the operational lifespan of the relay and pump components [20].

Sensor Calibration

In order to obtain a consistent sensor response, the resistive soil moisture sensors were calibrated before deployment using two reference conditions: completely dry soil and fully saturated soil. A linear mapping was then used to convert raw ADC readings into a normalized moisture index. This procedure establishes the operating scale used by the irrigation controller. However, the present study does not report calibration error, repeatability, or comparison against an independent soil-moisture reference; these measurements should therefore be included in future validation.

The calibrated soil moisture value M is expressed as:

$$M = a(ADC_{read}) + b$$

where a and b are calibration constants derived from the dry and wet reference measurements [21].

This calibration process reduces measurement deviation and improves irrigation decision accuracy.

RESULT AND ANALYSIS

Soil Moisture Control Performance

The weekly soil moisture stability achieved by the proposed irrigation system is presented in Fig. 4.

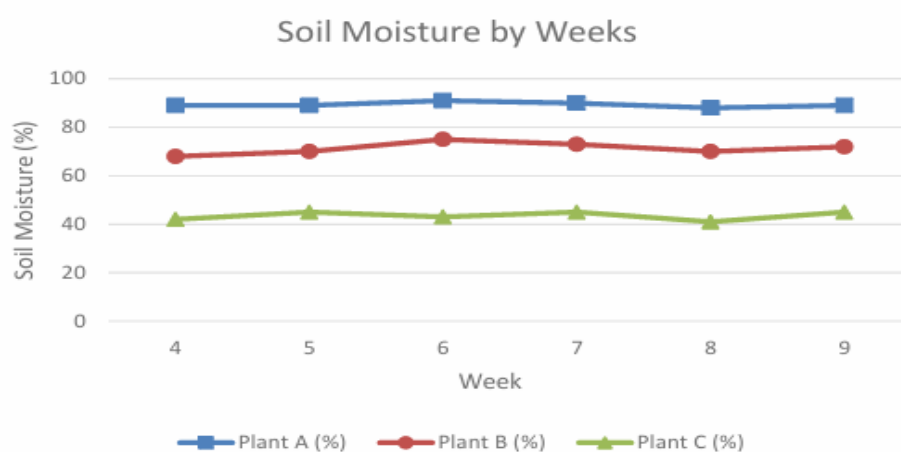


Fig. 4: Weekly soil moisture percentage for Plant A, Plant B and Plant C.

Fig. 4 illustrates the weekly average soil moisture percentages recorded for the three chili plants under different predefined threshold ranges. The results demonstrate that the proposed threshold-based irrigation algorithm effectively regulated soil moisture within the targeted intervals throughout the monitoring period. Plant A maintained values between 88% and 91%, Plant B between 68% and 75%, and Plant C between 41% and 45%, with only minor fluctuations observed.

The relatively narrow variation is consistent with stable closed-loop control during the test period. Nevertheless, system reliability should be quantified in future work using metrics such as threshold-crossing response time, sensor repeatability, pump activation frequency, communication uptime, and measurement error.

Plant Growth Performance Analysis

The observed plant-height trends under the three moisture regimes are presented in Fig. 5. Plant B, maintained within the 60–80% target range, showed the highest recorded growth and reached 57 cm by Week 9. Plant A, maintained under the wetter 81–100% range, showed slower height progression, while Plant C under the 30–50% range showed comparatively constrained growth. These observations are consistent with the expected importance of avoiding both excessive wetness and prolonged moisture deficit. However, the experiment contains only one plant per condition, so treatment effects cannot be separated from natural plant-to-plant variation.

In contrast, Plant A, which was maintained under higher moisture conditions (81–100%), demonstrated comparatively slower height progression. Although adequate water was continuously available, excessive soil saturation may have reduced oxygen diffusion within the root zone, potentially limiting metabolic efficiency. Plant C, operating within the lower moisture range (30–50%), showed moderate but comparatively constrained growth. The relatively drier soil condition may have introduced mild water stress, influencing stomatal regulation and photosynthetic efficiency [22].

Within this three-plant preliminary experiment, the moderate 60–80% moisture regime was associated with the strongest observed vegetative growth. This result supports the need to evaluate threshold selection experimentally, but it should not be presented as a statistically validated optimum without replicated experiments.

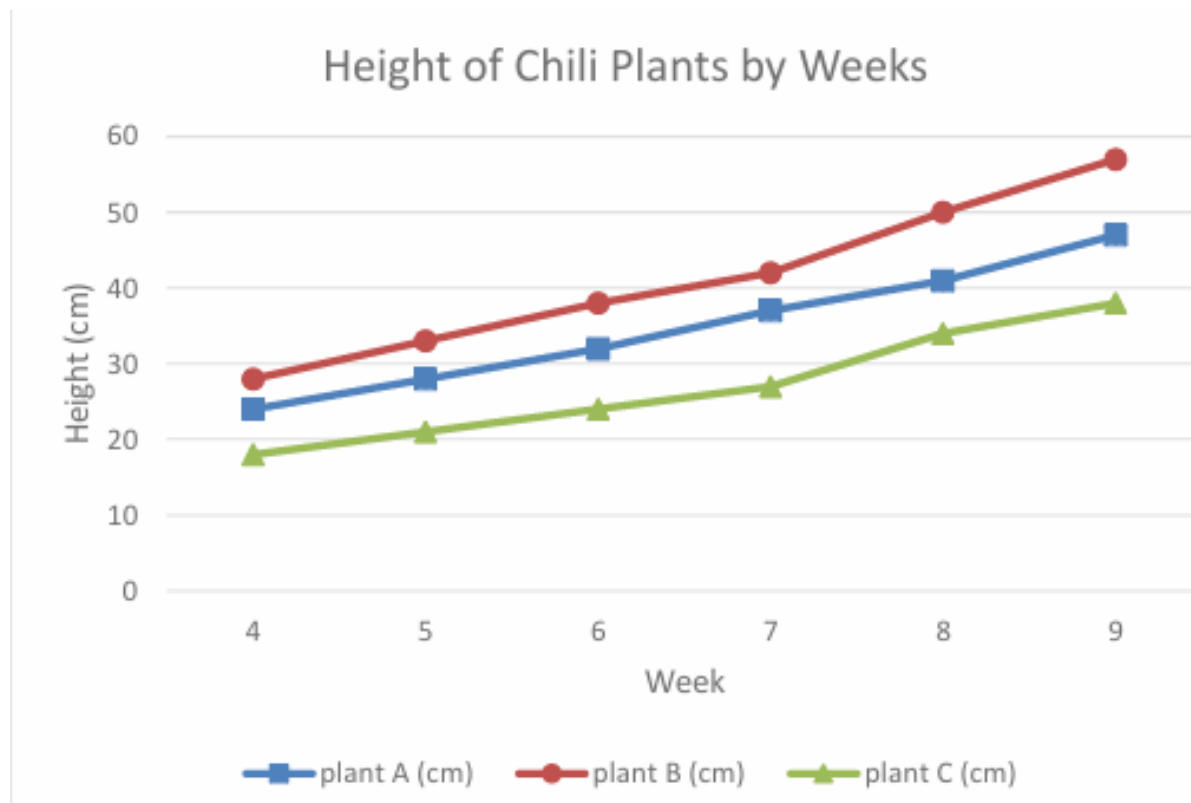


Fig. 5: Height of chili plants by weeks

Chili Fruit Development Analysis

Reproductive performance was evaluated through fruit length measurement, as shown in Fig. 6. The results indicate a strong correlation between optimized soil moisture control and fruit development. Plant B produced the most significant fruit growth, reaching a maximum average length of 5.5 cm between Week 13 and Week 17. The steady increase in fruit size suggests that the moderate irrigation regime supported consistent flowering, pollination, and nutrient allocation toward reproductive structures.

Conversely, Plant A exhibited reduced fruit elongation despite higher moisture availability. Excessive soil wetness may have contributed to suboptimal root aeration, indirectly influencing reproductive efficiency. Plant C did not demonstrate substantial fruit development within the observation period, likely due to prolonged exposure to lower moisture levels that may have limited energy distribution toward fruit formation.

The observed fruit-development pattern further indicates that irrigation threshold selection may influence reproductive performance. Nevertheless, additional biological and environmental factors may also contribute to fruit development. Replicated trials are required before the 60–80% range can be recommended as a general optimum for chili cultivation.

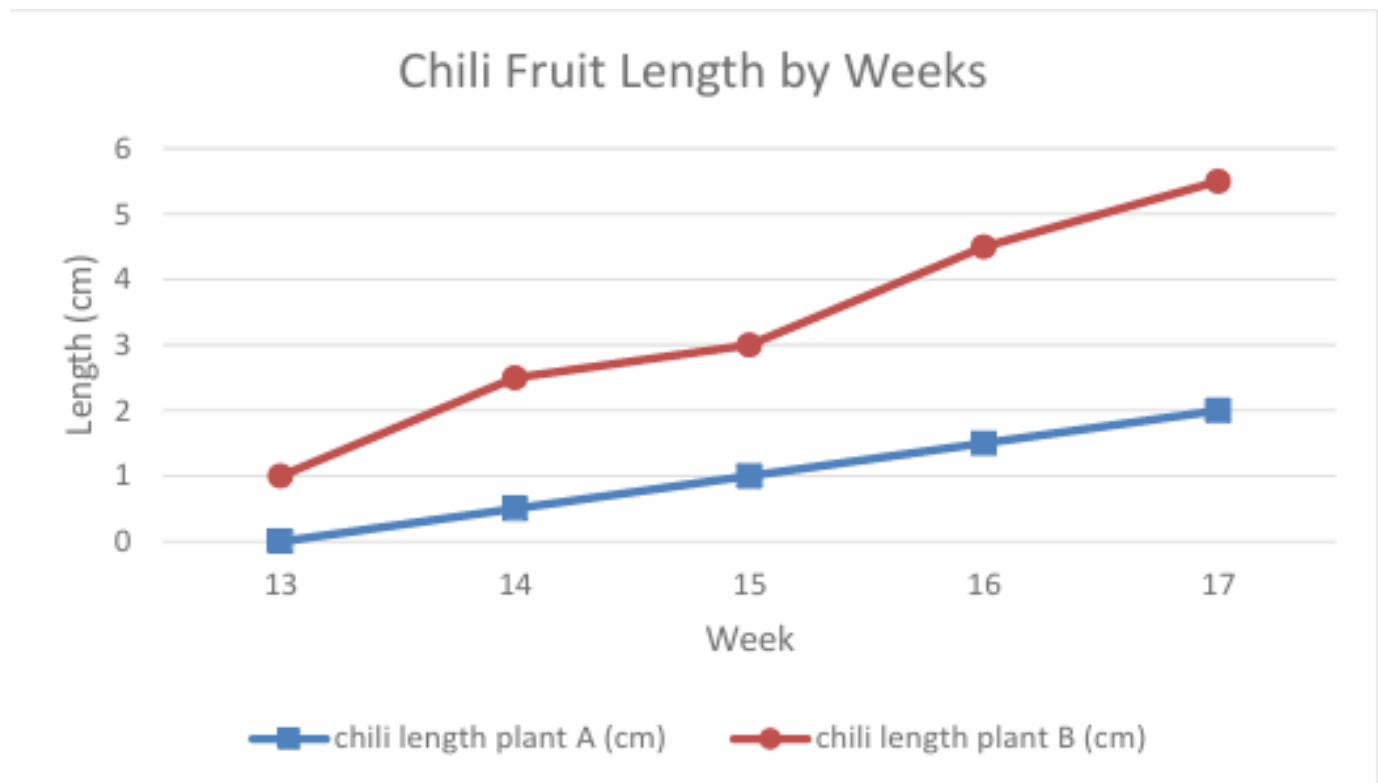


Fig. 6: Chili fruit length development under different moisture conditions by weeks.

Analysis of Relationship Between Plant Height and Soil Moisture

To further examine the observed relationship between soil moisture and vegetative development, weekly averaged soil-moisture and plant-height data were compared as shown in Fig. 7. The comparison is descriptive because the dataset represents three individual plants rather than replicated treatment groups.

The descriptive comparison shows that Plant B, operating within the 60–80% moisture range, achieved the greatest height increment. Plant A under the 81–100% range showed comparatively limited improvement, while Plant C under the 30–50% range showed slower growth. The pattern is compatible with a non-linear plant response in which both excessive moisture and moisture deficit can constrain growth. A numerical correlation coefficient or regression model is not reported in this study and should be added only after the underlying observations are available and the assumptions of the selected statistical method are satisfied.

Under excessive moisture conditions (81%–100%), growth improvement was marginal, suggesting possible oxygen diffusion limitations in the root zone. Conversely, under lower moisture conditions (30%–50%), water stress reduced physiological efficiency, leading to slower vertical growth. These findings suggest the presence of a nonlinear relationship between soil moisture and plant height, where maximum vegetative performance occurs within a moderate moisture interval rather than at extreme values[22],[23].

This behavior aligns with previous studies on *Capsicum annuum*, which report that optimal irrigation levels significantly enhance vegetative growth, while both over-irrigation and water deficit negatively affect plant development [24].

Overall, the descriptive results highlight the importance of selecting appropriate irrigation thresholds. The current dataset provides preliminary evidence for the benefit of moderate moisture conditions, but it is insufficient to statistically confirm the magnitude or significance of the relationship between soil moisture and plant height.

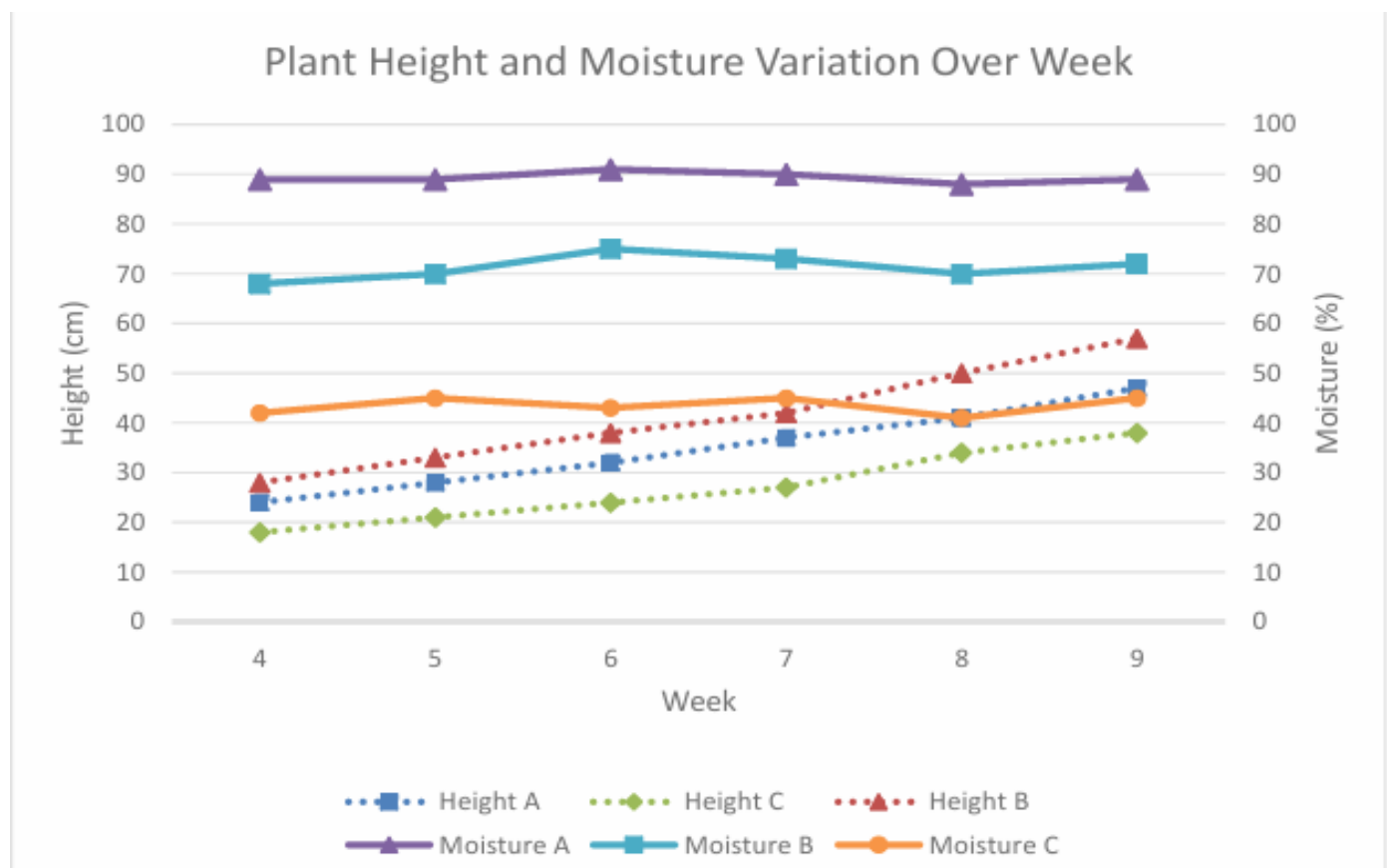


Fig. 7: Relationship Between Plant Height and Soil Moisture for Chili Plants

Real Time Monitoring Interface

The real-time monitoring interface is shown in Fig. 8. The Android application receives sensor data through the Blynk cloud platform and displays soil moisture, ambient temperature, and pump status. The manual override function allows the user to activate the pump for testing and maintenance. The interface demonstrates the remote-monitoring capability of the prototype; however, communication latency, packet loss, cloud availability, and long-term connectivity were not quantitatively evaluated.

Additionally, the application incorporates manual override functionality, allowing users to activate irrigation when necessary. This hybrid control approach enhances operational flexibility while preserving automated decision-making. The implementation confirms that the system achieves not only autonomous irrigation control but also user-centered monitoring accessibility, which is essential for modern smart agriculture frameworks.

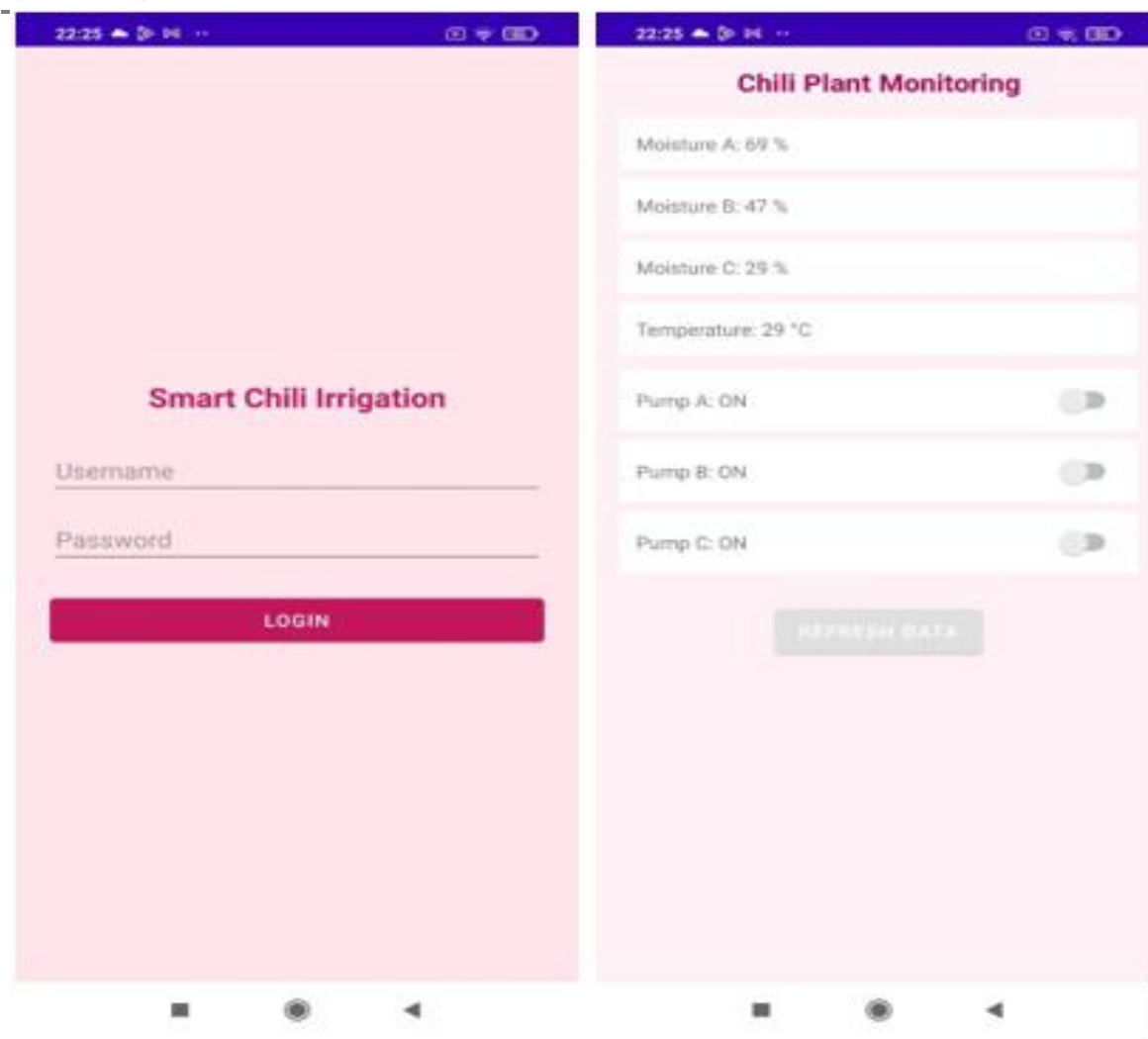


Fig. 8: Illustrates the mobile application interface designed to provide real-time visualization of sensor readings and irrigation control status.

CONCLUSION

This study presented the design and preliminary evaluation of an IoT-based automatic irrigation prototype for chili plants using an ESP32 microcontroller, soil moisture sensing, pump control, and cloud-based monitoring. The threshold-driven controller maintained the three experimental plants within their assigned moisture bands during the observation period.

The recorded moisture ranges were 88–91% for Plant A, 68–75% for Plant B, and 41–45% for Plant C. Plant B, maintained at 60–80%, reached 57 cm by Week 9 and recorded a maximum fruit length of 5.5 cm during Weeks 13–17. These observations indicate that the moderate moisture condition was associated with the best observed growth performance among the three plants.

The integration of wireless communication and a mobile monitoring application further enhanced system accessibility by enabling real-time supervision and manual override functionality. Overall, the proposed system achieved stable irrigation control, improved plant growth performance under optimized conditions, and demonstrated the feasibility of low-cost IoT-based precision agriculture for small-scale farming applications.

Future Work

Although the prototype demonstrated stable moisture control during the reported experiment, the study has important limitations. Only three plants were evaluated, with one plant assigned to each moisture regime, and no independent control group was included. In addition, sensor accuracy, water consumption, communication

reliability, and long-term field performance were not quantitatively evaluated. Future studies should address these limitations before the system is generalized to broader agricultural applications.

Firstly, future research may incorporate adaptive irrigation strategies based on machine learning or data-driven optimization models. Such approaches would enable dynamic adjustment of soil moisture thresholds according to plant growth stages, microclimate variations, and historical irrigation data. This would reduce dependency on fixed threshold parameters and improve long-term irrigation efficiency and resource utilization.

Secondly, the integration of additional environmental sensing parameters—including automated soil pH monitoring, light intensity measurement, and ambient humidity detection—would provide a more comprehensive agronomic monitoring framework. In the current implementation, soil pH assessment is conducted manually, automating this process would enhance data reliability, enable multi-parameter decision-making and support more precise irrigation control strategies.

Thirdly, extended field validation under diverse climatic conditions is recommended to assess system durability, waterproofing integrity, and long-term sensor stability. Evaluating performance across seasonal variations would strengthen the robustness of the proposed architecture and establish its suitability for practical agricultural deployment.

Finally, expanding the cloud infrastructure to include advanced data analytics and predictive modeling capabilities may support yield estimation, anomaly detection, and scalable farm management. The incorporation of data visualization dashboards and historical trend analysis would further enhance decision-support functionality for end users.

Collectively, these enhancements would advance the current prototype toward a more intelligent, adaptive, and scalable precision irrigation platform suitable for broader agricultural applications.

REFERENCES

1. Andri Rifai, J., & Al Furqoni, M. I. (2024). Soil moisture monitoring and water drip irrigation on chili plants using solar panels.
2. Ramadhani, S. F., Lasulika, M. E., Bode, A., Djailani, M. A., & Posumah, R. R. (2024). Design of a watering control system for chili seedlings using Arduino Uno. *International Journal Software Engineering and Computer Science*, 4(3), 1163–1172. <https://doi.org/10.35870/ijsecs.v4i3.3225>
3. Jeanine, U., Owido, S. F. O., Joyce, P., & Lelei, J. (n.d.). Influence of irrigation levels and mulching types on growth and yield of bean in drought prone area of Bugesera, Eastern Rwanda. *AJPO Journals*. <https://www.ajpojournals.org>
4. Maitra, S., Sairam, M., Santosh, D. T., Gaikwad, D. J., & Sahoo, U. (2024). Growth, productivity and quality of colored capsicum (*Capsicum annum* L.) as influenced by hybrids and plant growth regulators under controlled environment conditions. *Research on Crops*, 25(2), 328–335. <https://doi.org/10.31830/2348-7542.2024.ROC-1079>
5. Halim, A. A. A., Mohamad, R., Rahman, F. Y. A., Harun, H., & Anas, N. M. (2023). IoT based smart irrigation, control, and monitoring system for chilli plants using NodeMCU-ESP8266. *Bulletin of Electrical Engineering and Informatics*, 12(5), 3053–3060. <https://doi.org/10.11591/eei.v12i5.5266>
6. Aisyah, S., Nasution, M. I., & Nasution, N. (2024). Design and construction of an automatic chili plants watering system based on the Internet of Things (IoT) using the Blynk app. *Jurnal Pijar Mipa*, 19(3), 540–546. <https://doi.org/10.29303/jpm.v19i3.6772>
7. Proceedings, ICECOS 2017 conference: Sustaining the cultural heritage toward the smart environment for better future: August 22–23, 2017, Horison Ultima Hotel, Palembang. (2017). IEEE.
8. Azhan, N. H., Azhariddin, N. M., & Ismail, M. B. (2023). Development of solar-powered IoT smart irrigation system for chili crops cultivation in greenhouse. In *2023 International Conference on Engineering Technology and Technopreneurship (ICE2T 2023)* (pp. 100–105). IEEE. <https://doi.org/10.1109/ICE2T58637.2023.10540533>
9. 2020 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS). (2020). IEEE.

10. Zia, H., Rehman, A., Harris, N. R., Fatima, S., & Khurram, M. (2021). An experimental comparison of IoT-based and traditional irrigation scheduling on a flood-irrigated subtropical lemon farm. *Sensors*, 21(12), Article 4175. <https://doi.org/10.3390/s21124175>
11. Mansoor, S., Iqbal, S., Popescu, S. M., Kim, S. L., Chung, Y. S., & Baek, J. H. (2025). Integration of smart sensors and IoT in precision agriculture: Trends, challenges and future perspectives. *Frontiers in Plant Science*. <https://doi.org/10.3389/fpls.2025.1587869>
12. Ali, A., Hussain, T., & Zahid, A. (2025). Smart irrigation technologies and prospects for enhancing water use efficiency for sustainable agriculture. *Agricultural Engineering*, 7(4), Article 106. <https://doi.org/10.3390/agriengineering7040106>
13. Abedalrahim, J., et al. (n.d.). Greenhouse horticulture automation with crops protection by using Arduino. *International Journal of Advanced Computer Science and Applications*. <https://www.ijacsa.thesai.org>
14. Gopalakrishnan, M. A. (n.d.). Performance investigation on a capacitive soil moisture sensor for smart home irrigation system. *Universiti Teknikal Malaysia Melaka*.
15. Khadake, S., et al. (2025). Smart plant monitoring and automated irrigation system using IoT. *International Journal of Advanced Research in Science, Communication and Technology*, 5(4). <https://doi.org/10.48175/IJAR SCT-26481>
16. García, L., Parra, L., Jimenez, J. M., Lloret, J., & Lorenz, P. (2020). IoT-based smart irrigation systems: An overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture. *Sensors*, 20(4), Article 1042. <https://doi.org/10.3390/s20041042>
17. Ariffin, N., & Zin, R. M. (2021). An Internet of Things (IoT) based plant irrigation and monitoring system for chili plant. *Evolution in Electrical and Electronic Engineering*, 2(2), 70–76. <https://doi.org/10.30880/eeee.2021.02.02.009>
18. Yap, H. Y. (2019). Demand-operated plant watering system [Bachelor's thesis, Universiti Teknikal Malaysia Melaka].
19. Jahava, M. B. (2021). Development of plant automated monitoring and self-watering system [Thesis, Faculty of Electrical and Electronic Engineering Technology].
20. Ha, C. D., et al. (2023). IoT solutions for smart farming: A comprehensive review on the current trends, challenges and future prospects for sustainable agriculture. *Journal of Forestry Science and Technology*, 8(2), 28–35. <https://doi.org/10.55250/jo.vnuf.8.2.2023.028-035>
21. Amir, M. B., & [Author details incomplete]. (2020). Smart water system with Internet of Things (IoT) [Project/thesis, Faculty of Electronic and Computer Engineering].
22. Bierhuizen, J. F. (1959). Plant growth and soil moisture relationships. *Verspreide overdrukken. Instituut voor Cultuurtechniek en Waterhuishouding*, No. 2.
23. Pedroza-Sandoval, A., Minjares-Fuentes, J. R., Trejo-Calzada, R., & Gramillo-Avila, I. (2024). Physiological and productivity responses in two chili pepper morphotypes (*Capsicum annuum* L.) under different soil moisture contents. *Horticulturae*, 10(1), Article 92. <https://doi.org/10.3390/horticulturae10010092>
24. Macias-Bobadilla, I., Vargas-Hernandez, M., Guevara-Gonzalez, R. G., Rico-Garcia, E., Ocampo-Velazquez, R. V., & Torres-Pacheco, I. (2020). Differential response to water deficit in chili pepper (*Capsicum annuum* L.) growing in two types of soil under different irrigation regimes. *Agriculture*, 10(9), Article 381. <https://doi.org/10.3390/agriculture10090381>