Bima Journal of Science and Technology, Vol. 9(1B) Apr, 2025 ISSN: 2536-6041

DOI: 10.56892/bima.v9i1B.1276

Implementation of Wireless Sensor Network in Precision Irrigation and Fertilization

Chiagunye Theodore T.[1]*, Ndukwe GodsPower I.[1], Udeani Henrietta U.[1], Ilo Somtochukwu F.[1], and Okey Daniel O.[1,2]

[1]Department of Computer Engineering Michael Okpara University of Agriculture Umudike, Abia State, Nigeria.

[2]Center for Engineering, Modeling and Applied Science, Federal University of ABC, Santo Andre, Sao Paulo, Brazil

Corresponding Author: tchiagunye2@yahoo.com;

ABSTRACT

This research explores the design and implementation of an Internet of Things (IoT) based system for precision irrigation and fertilization in greenhouse environments. By integrating ESP32 microcontrollers with soil moisture, temperature, and Nitrogen potassium and phosphorus (NPK) sensors, the system enables real-time monitoring and automation of irrigation and nutrient management. The system collects and transmits sensor data to a central platform via Wi-Fi, allowing users to access real-time information through a web-based interface. Automated irrigation is achieved through solenoid valves, which adjust water flow based on soil moisture levels, while fertilization suggestions are provided when nutrient deficiencies are detected in the soil. To evaluate the system's accuracy and reliability, the sensor data was compared with manual measurements obtained using conventional methods. The results showed high accuracy, with soil moisture readings differing by no more than 5% from manual measurements, and soil temperature readings within a 1% range. The NPK sensor data showed a slight discrepancy of 10-15% for nitrogen and phosphorus levels, which is acceptable for soil nutrient testing, with potassium levels showing greater accuracy (within 5%). The research demonstrates the potential of IoT systems to improve greenhouse management by enhancing resource efficiency, enabling precise environmental control, and providing actionable insights for optimal plant growth. The results are consistent with previous studies on IoT-based agricultural systems, further supporting the feasibility of this technology for modernizing greenhouse farming. The project suggests opportunities for further refinement, including advanced machine learning for improved data analysis and sensor calibration.

Keyword: Wireless sensor, Precision Irrigation**,** ESP32 microcontrollers, internet of things (IOT), Soil.

INTRODUCTION

Suboptimal irrigation practices and nutrient deficiencies, which hinder crop yield and quality are unarguably one of the major challenges facing the production of staple crops such as tomatoes in Nigeria. Traditional irrigation methods are often inefficient, leading to excessive water consumption and poor crop performance. As greenhouse farming becomes more popular due to its ability to mitigate external weather conditions, there is a growing need to adopt innovative solutions for efficient water usage and resource management in such controlled environments (Hamami and Nassereddine, 2020; Mowla *et al.,* 2023).

One such solution is the use of Wireless Sensor Networks (WSN) which have gained significant attention in the agricultural sector. These networks enable real-time monitoring of soil moisture, temperature, pH, and other critical parameters that affect plant growth (Sanjeevi *et al.,* 2020). WSNs, integrated with Internet of Things (IoT) technologies to provide farmers with the ability to monitor and control irrigation systems remotely, leading to better resource allocation and reduced wastage has also been introduced by (Abu *et al.,* 2022).

The integration of Internet of Things (IoT) and Wireless Sensor Networks (WSNs) has made significant strides in greenhouse farming, leading to enhanced precision irrigation and resource management. Based on this, Kochhar and Kumar (2019) explored how Zigbee-based sensors could be used in greenhouses to monitor various environmental parameters such as temperature, humidity, and soil conditions. Also, Sanjeevi et al. (2020) further advanced precision farming by integrating soil health sensors for nutrient monitoring, a critical aspect of optimizing crop growth. Their system utilized electrical conductivity (EC) and pH sensors to assess soil fertility, allowing for automatic adjustments to fertilizer application based on real-time nutrient levels and building on this, Akter et al. (2024) developed an IoT-based automated irrigation system using WSNs to monitor soil moisture levels in real-time. The added feature of a mobile application allowed farmers to remotely monitor and control the system, offering convenience and the ability to make data-driven decisions instantly.

To further amplify the efforts that have been made in green farm technology, this research focuses on the implementation of a Wireless Sensor Network for Precision Irrigation and fertilization. The system consists of ESP32 microcontrollers, soil moisture sensors, soil temperature sensors, soil NPK sensors, and solenoid valves to regulate water flow. The data collected from these sensors are transmitted to a central system with an IoT interface, which will be developed using HTML, CSS, JavaScript, Python, and MySQL for database management. The system will feature automatic irrigation, where the solenoid valve will open or close based on soil moisture levels, and will also provide suggestions for fertilizer application when nutrient deficiencies are detected in the soil.

REVIEW OF RELATED WORKS

In The integration of Wireless Sensor Networks (WSNs) and IoT in agriculture has gained significant attention, with various studies exploring their applications in precision farming. One of the earlier contributions, Opare and Otchere (2020), developed an automatic sensor probe for soil moisture monitoring. Their system utilized soil moisture and temperature sensors, combined with an operational amplifier (op-amp)-based comparator circuit and relay-controlled water pumps to automate irrigation. By activating irrigation only, when necessary, their approach improved water efficiency and conservation.

Also, Ikechukwu-Edeh et al. (2024) investigated the implementation of a WSN in a naturally ventilated green farm. Their system, managed by an ESP32 microcontroller, integrated temperature, humidity, and soil moisture sensors for real-time environmental monitoring. Data was collected both manually—using gauges, thermometers, and moisture meters—and electronically via the sensor network. A comparative analysis of both methods revealed minimal discrepancies, with differences of 0.17% in soil moisture, 0.10% in soil temperature, and 1.15% in greenhouse relative humidity, demonstrating the system’s accuracy and reliability. In another related study, Odo et al. (2024) examined the role of WSN technology in enhancing agricultural productivity. Their research highlighted how sensor-based monitoring systems could transform farming practices, particularly in Nigeria's large-scale food production sector. By optimizing resource utilization and improving efficiency, WSNs were positioned as a critical tool for sustainable agriculture.

Expanding on the concept of WSN in smart agriculture, Mallikarathne et al. (2024) introduced a WSN-based smart irrigation system that integrates IoT and data fusion techniques. Their system, equipped with temperature, humidity, and soil moisture sensors, allows remote users to monitor key environmental parameters over the Internet. Water distribution is dynamically regulated across two separate fields based on real-time sensor readings, ensuring optimal irrigation efficiency. Additionally, all collected data is stored in a remote database, enabling further analysis and data-driven decision-making. Many existing studies on IoT-based agricultural systems primarily focus on environmental monitoring and automated irrigation but lack integration of real-time nutrient management.

While these studies demonstrate significant progress in sensor-based agricultural automation, they often focus solely on environmental monitoring or irrigation control, without incorporating real-time nutrient management. Hence, our proposed system bridges this gap by integrating real-time soil moisture, temperature, and NPK monitoring with automated irrigation and intelligent fertilization recommendations. By leveraging ESP32 microcontrollers and Wi-Fi connectivity, the system enhances precision agriculture in greenhouse environments, ensuring improved resource efficiency and crop productivity.

MATERIALS AND METHODS

The design of the wireless senor network was divided into two phases which are the hardware and the software phase

Hardware System Design

The design of the hardware system began with the drawing of the system block diagram to the circuit diagram and then physical integration of the hardware components using the circuit diagram as a guide.

(i) The System Block Diagram

The system block diagram shows the interconnection of the different modules that make up the system which includes the power module, the control module, the sensor module and the actuator. Figure 1 shows the block diagram of the Wireless Sensor Network for Precision Irrigation and fertilization

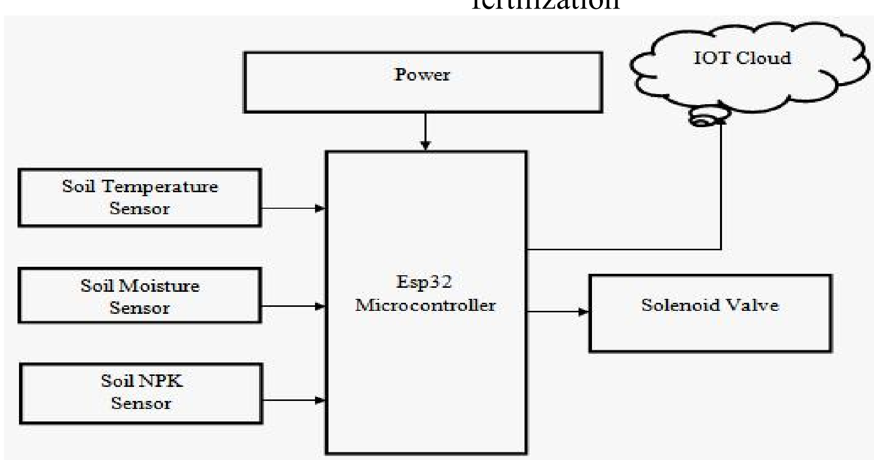


Figure 1: System Block Diagram.

DOI: 10.56892/bima.v9i1B.1276

(ii) System Circuit Diagram

The circuit diagram of the system shows the interconnection of the main components that make up the main electronics system. Figure 2 shows the circuit diagram of the wireless sensor network.

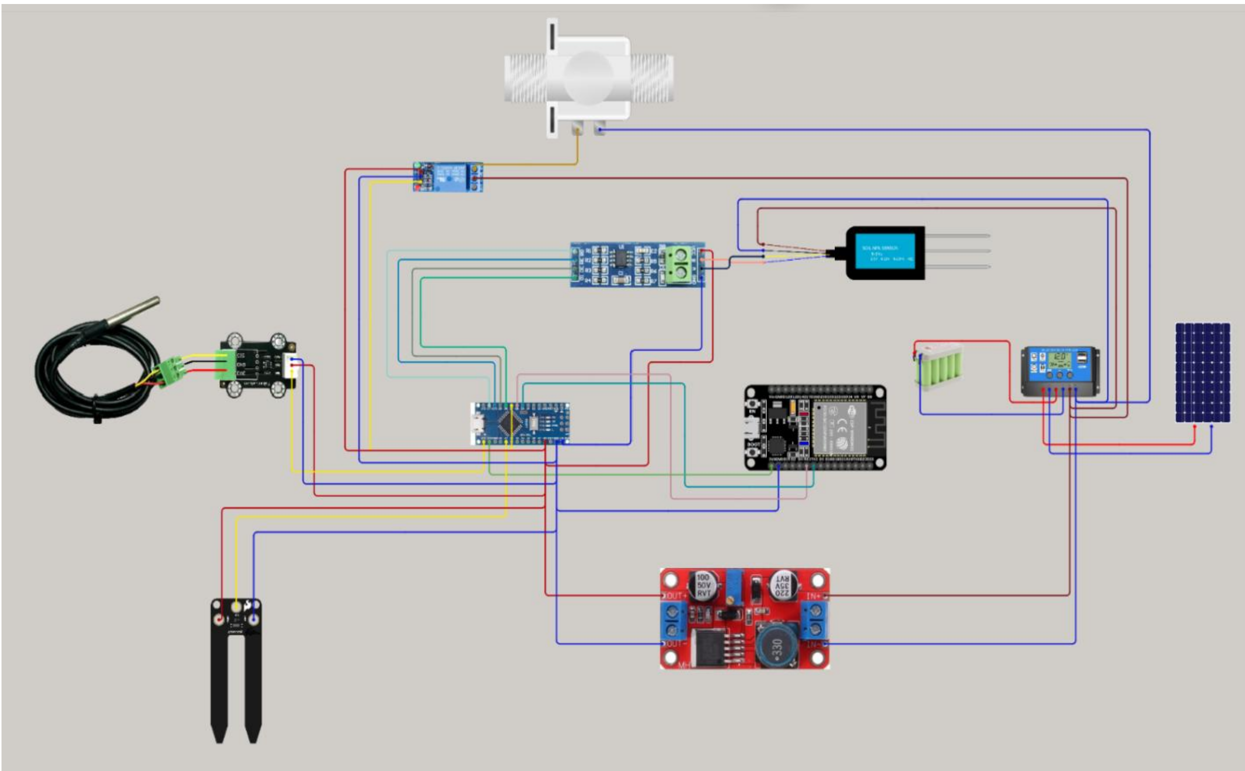


Figure 2: System circuit diagram

(iii) Integration of Hardware Components

The hardware integration of the system started with the power supply system consisting of a 30W solar panel, bulk converter, charge controller, and lead-acid battery which ensures the controller, the sensors and the solenoid valve are powered properly to the Arduino and ESP32 microcontrollers serving as the central control unit, collecting data from the soil moisture, temperature, and NPK sensors and transmitting the data to a remote Data base via Hypertext Transfer Protocol (HTTP) post Request. Finally, the valve opens based on the moisture threshold, allowing water flow to the crops, and closes when the moisture level is restored. The hardware integration was carried out using the circuit diagram as a guide.

Software System Design

The design of the software system involves the development of the C++ microcontroller code and the IOT interface.

(i) Implementation of the Microcontroller Code

The microcontroller code was developed using C++ and it is responsible for collecting the sensor data, uploading it to the IOT cloud and controlling the solenoid valve. Figure 3 shows the flow chart for the implementation of the microcontroller code.

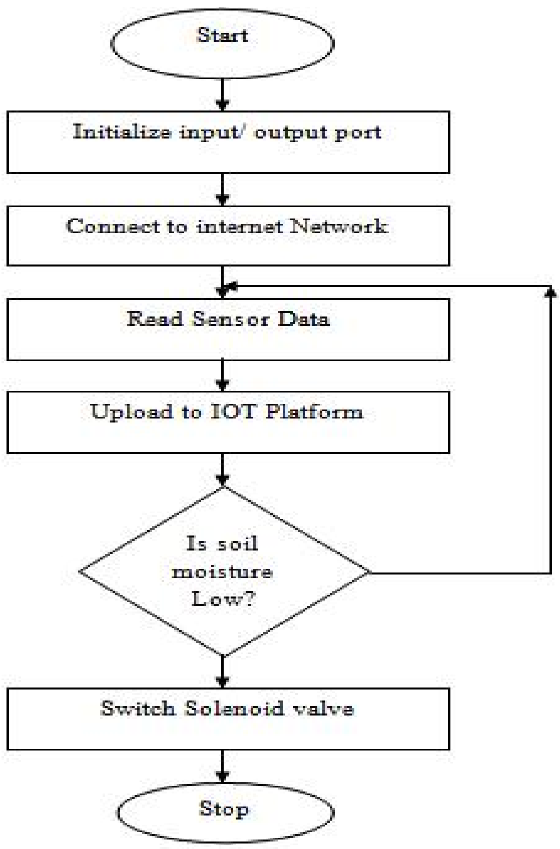


Figure 3: System flow chart

(ii) Implementation of Software Interface

The software implementation process for the sensor-based Wireless Sensor Network (WSN) involves programming the microcontrollers, handling data transmission, and designing both the frontend and backend systems for IoT integration. The ESP32 and Arduino microcontrollers are programmed using C++ to acquire data from soil sensors, including moisture, temperature, and NPK levels. The code utilizes functions to read both analog and digital signals from the sensors, process raw values, and apply calibration techniques for accurate measurements. The ESP32 is responsible for wireless communication, formatting the processed data into JSON, and transmitting it to an IoT platform using HTTP protocol at an interval of six hours. Additionally, the microcontroller software includes logic to control the solenoid valve based on soil moisture levels while implementing power-saving features such as deep sleep mode to enhance efficiency.

The IoT dashboard was built using web technologies to present real-time sensor data and enable real time fertilization suggestions. The frontend was developed with HTML for structure, CSS for styling and responsiveness, and JavaScript for dynamic updates via WebSocket. This interface allows users to monitor soil conditions in real time and receive real-time fertilization suggestions. The backend was implemented using Python and the Django framework, managing requests, processing sensor data, and storing information in a MySQL database. The database records real-time and historical sensor readings, allowing for trend analysis and informed decision-making. Figure 4 shows the screenshot of the IOT interface dashboard.

RESULTS AND DISCUSSION

To evaluate the accuracy and reliability of the automated system, the sensor data collected from the system was compared with manually obtained data from conventional measurement methods. The soil moisture data from the system was cross-checked with manual moisture readings using a standard soil moisture meter. The average moisture reading of the sensor and the manual reading was evaluated after 10 days and the average sensor reading was found to be 51.5%, while the average manual moisture reading was 54.1%. This indicates a percentage difference of about 5% between manual reading and sensor reading. Figure 5 shows the relationship between the soil moisture system reading and the Manual soil moisture readings.

Bima Journal of Science and Technology, Vol. 9(1B) Apr, 2025 ISSN: 2536-6041

DOI: 10.56892/bima.v9i1B.1276

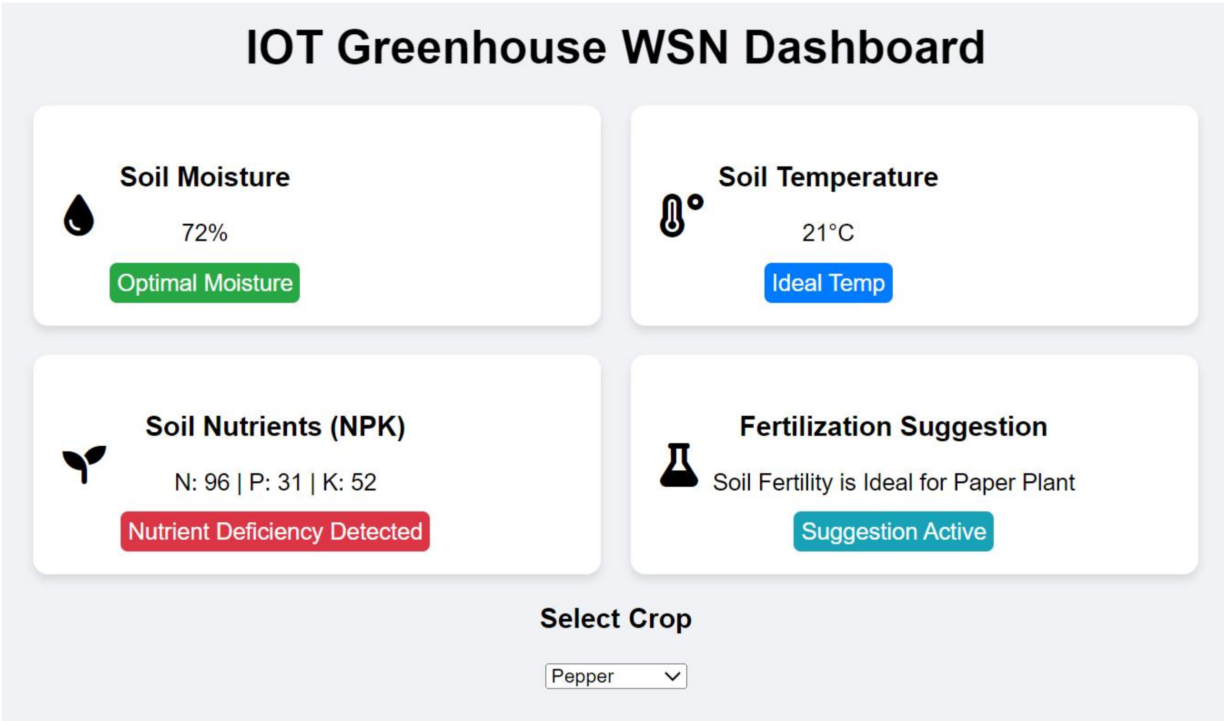


Figure 4: System IOT Interface

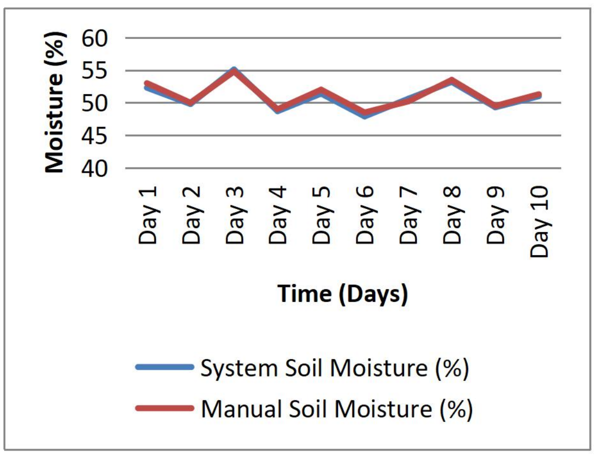


Figure 5: Soil Moisture Evaluation chart

The soil temperature sensor reading also showed consistent results when compared with manual thermometer reading. The difference in temperature readings between the system and the manual thermometer was typically within a 1% range with the system soil temperature reading having an average of 23.29°C, while the average manual soil temperature reading is 23.59°C thereby indicating that the system provides accurate temperature measurements hence providing the farmer with valuable information required for making decisions for maintaining the temperature range suitable for the growth of the crops in the green farm. Figure 6 shows the relationship between the system soil temperature reading and the Manual soil temperature readings over the period of 10 days.

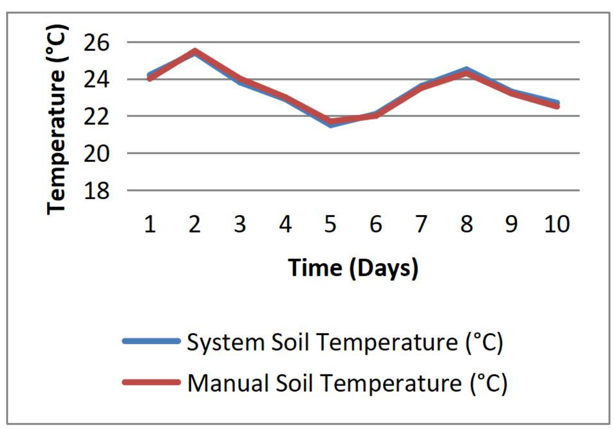


Figure 6: Soil Temperature Evaluation chart

DOI: 10.56892/bima.v9i1B.1276

The NPK sensors were compared with traditional chemical testing methods used in soil laboratories. All manual soil sample evaluations were carried out at Optimum Analytical Laboratories Umuahia. The system showed a discrepancy of about 5-10% for the nitrogen and phosphorus levels, while the potassium levels were found to be more accurately measured by the system, with only a 5% margin of error. This was obtained by weekly comparison of the results of the readings obtained from the sensors with the result of the manual laboratory test over the period of 8 weeks. Figure 7, 8 and 9 shows the comparison of the weekly NPK values obtained from the system with the laboratory values.

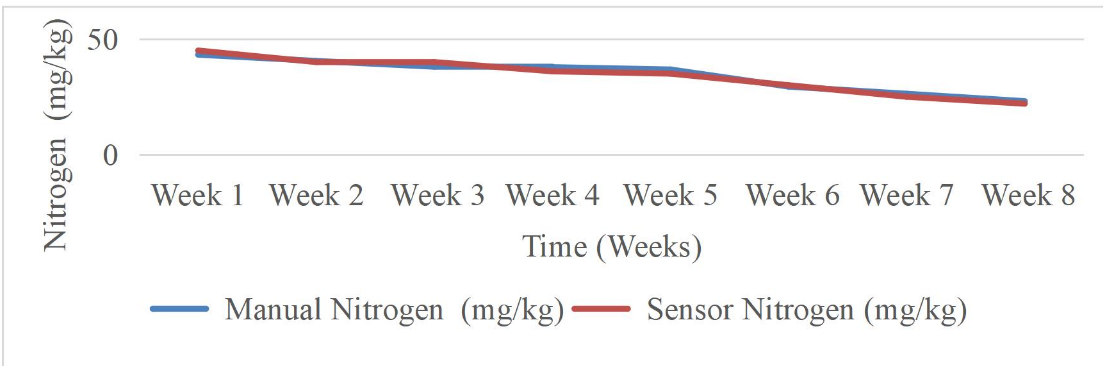


Figure 7: Manual Values Vs Sensor values of Nitrogen.

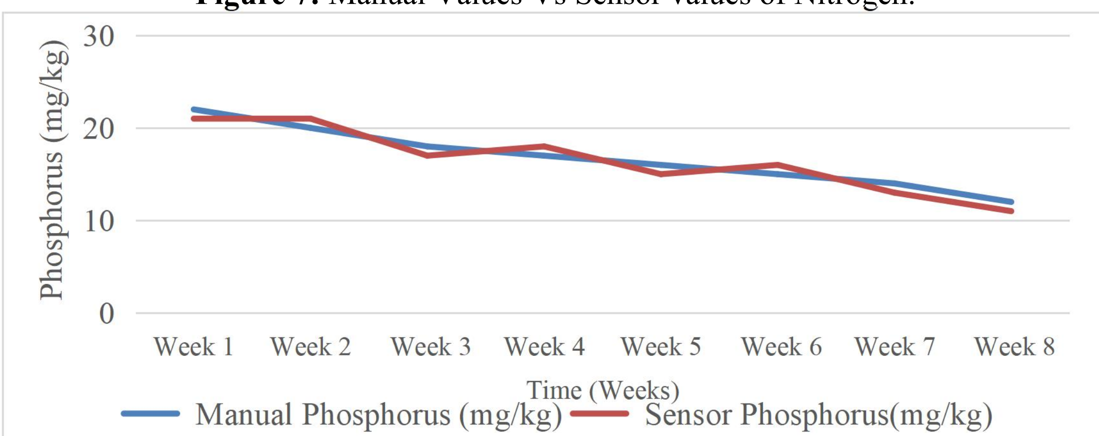
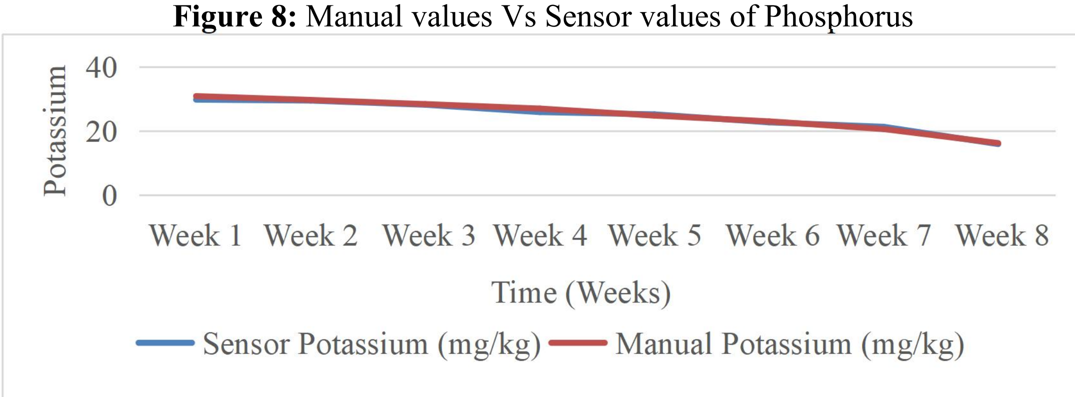


Figure 8: Manual values Vs Sensor values of Phosphorus



DOI: 10.56892/bima.v9i1B.1276

Figure 9: Manual values Vs Sensor values of Potassium

CONCLUSION

This research presents the development of an IoT-based system for precision irrigation and fertilization in a greenhouse setting. By utilizing ESP32 microcontrollers, soil moisture, temperature, and NPK sensors, the system provided real-time monitoring and automation capabilities, enabling efficient management of environmental conditions and resource usage and the integration of a web-based dashboard allowed for easy access to sensor data, while the fertilization suggestion feature provided timely recommendations based on nutrient deficiencies in the soil.

Through comparison with manual measurements, the system demonstrated high accuracy in monitoring key parameters such as soil moisture, temperature, and nutrient levels, with minimal discrepancies. This was further validated by referencing similar IoT-based systems in existing literature, which showed comparable results in terms of sensor accuracy and system performance. While there are opportunities to further improve sensor calibration and data analysis with advanced machine learning techniques, the system proves to be a valuable tool in modernizing greenhouse management.

REFERENCES

Abu, N. S., Bukhari, W. M., Ong, C. H., Kassim, A. M., Izzuddin, T. A., Sukhaimie, M. N., Norasikin, M. A., & Rasid, A. F. A. (2022). Internet of Things Applications in Precision Agriculture: A Review. *Journal of Robotics and Control (JRC)*, *3*(3), 338–347. https://doi.org/10.18196/jrc.v3i3.14159

Akter, T., Mahmud, T., Chakma, R., Datta, N., Hossain, M. S., & Andersson, K. (2024). IoT-based Precision Agriculture Monitoring System: Enhancing Agricultural Efficiency. *Proceedings - 2024 2nd International Conference on Inventive Computing and Informatics, ICICI 2024*, 749–754. https://doi.org/10.1109/ICICI62254.2024.00126

Hamami, L., & Nassereddine, B. (2020). Application of wireless sensor networks in the field of irrigation: A review. *Computers and Electronics in Agriculture*, *179*, 105782. https://doi.org/10.1016/j.compag.2020.105782

Ikechukwu-Edeh, C. E. and Ndukwe, G. I. (2024). Development Of A Green Farm Journal For A Naturally Ventilated Greenhouse In Abia State. Umudike Journal of Engineering and Technology (UJET); Vol. 10(1).

Kochhar, A., & Kumar, N. (2019). Wireless sensor networks for greenhouses: An end-to-end review. *Computers and Electronics in Agriculture*, *163*, 104877.

Mowla, M. N., Mowla, N., Shah, A. F. M. S., Rabie, K. M., & Shongwe, T. (2023). Internet of Things and Wireless Sensor Networks for Smart Agriculture Applications: A Survey. *IEEE Access*, *11*, 145813–145852. https://doi.org/10.1109/ACCESS.2023.3346299

Odo, K.O., Abonyi, D.O. and Eke, J (2024). Wireless sensor networks: A vital tool for improved agricultural practices in Nigeria. UNIZIK Journal of Engineering and Applied Sciences 3(5).

Ojha, T., Misra, S., & Raghuwanshi, N. S. (2015). Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges. *Computers and Electronics in Agriculture*, *118*, 66–84.

https://doi.org/10.1016/j.compag.2015.08.011

Sanjeevi, P., Prasanna, S., Siva Kumar, B., Gunasekaran, G., Alagiri, I., & Vijay Anand, R. (2020). Precision agriculture and farming using Internet of Things based on wireless sensor network. *Transactions on Emerging Telecommunications Technologies*, *31*(12), e3978. https://doi.org/10.1002/ett.3978

Thushani Mallikarathne, Peshala Madushani Perera, Gamlath G.A.H.K.M, Gamage H.T., Udayanga W.V.A and Maheepala S.A.D.H.P, (2024). Wireless Sensor Network Based Smart Irrigation System using IoT and Data Fusion 2024 4th International Conference on Advanced Research in Computing (ICARC), DOI: 10.1109/ICARC61713.2024.10499758

Wisdom Opare and Peter Otchere (2020). Design and Construction of an Automatic Sensor Probe for Soil Moisture Monitoring System, Saudi Journal of Engineering and Technology. 351- 360. DOI: 10.36348/sjet.2020.v05i10.002

Yang, X., He, Y., Ming, X., & Zhou, Q. (2023). Design of Agricultural Greenhouse Environment Monitoring System Based on Single Chip Computer. *ACM International Conference Proceeding Series*, *32*(11), 681–685. https://doi.org/10.1145/3653081.3653195.