PSCS_387 GOBARdhan - Low-cost kits to measure nutrient content of F/L OM Hardware Clean & Green

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Abstract* - Accurate nutrient measurements of food waste (FW) and liquid organic matter (LOM) are a must if resource recovery is to be done effectively under the GOBARdhan (Galvanizing Organic Bio-Agro Resources Dhan) initiative. The problem with the currently used methods in labs is that they are very costly, take a long time, and are not very easy to reach in the countryside areas. So, this paper describes a less expensive hardware system that is able to capture the relevant parameters such as Nitrogen (N), Phosphorus (P), Potassium (K), pH, and moisture by using portable colorimetric and optical sensors. The suggested means allow for a decentralized, real-time nutrient analysis of biodegradable waste, which can lead to cleaner waste management, better biogas slurry use, and compost quality monitoring based on data. The testing results demonstrate the ability of the equipment to offer accurate readings at a minimum of expense and, thus, the Indian Clean & Green waste management ambition can be greatly facilitated.

***Keywords*— GOBARdhan, NPK Sensor, RS485, Arduino Uno, IoT, Nutrient Monitoring, Organic Manure, ESP8266, Low-Cost Device, Sustainable Agriculture.**

I. Introduction

GOBARdhan (Galvanizing Organic Bio-Agro Resources–Dhan) is a program initiated in India whose primary objective is to change rural sanitation through sustainable waste management utilizing the circular bioeconomy model. The program deals with the conversion of animal waste, faecal sludge, and other biodegradable materials into useful products like biogas, bio-slurry, and organic fertilizers. To ensure that these mechanisms work properly, it is necessary to know the nutrient content of the organic manures used as raw material, especially the three major nutrients: Nitrogen (N), Phosphorus (P), and Potassium (K). These nutrients have a direct effect on the anaerobic digestion, microbial activities, gas generation, and the fertilizer value of compost and bio-slurry. Unfortunately, nutrient levels in fecal matter and animal waste are highly variable due to factors such as animal diet, microbial decomposition, moisture content, and storage conditions. In addition, most GOBARdhan units do not have access to quick and cheap nutrient testing methods, although these are of utmost importance. Laboratory methods like the Kjeldahl nitrogen analysis, spectrophotometric phosphorus measurement, and flame-based potassium test require not only complex infrastructure, chemicals, and trained staff but also long periods for the execution of the tests. GOBARdhan units operate under decentralized, rural conditions in which the time factor is crucial for maintaining the stability of the digester, avoiding system failures, and ensuring the quality of the fertilizers. Prompt nutrient analysis is therefore always delayed, avoided or rarely performed, leading to operational deficiencies and a decrease in the economic value of waste-derived products.

The latest digital agriculture and embedded sensory technologies advances have made it possible to look for alternatives to the standard lab methods. Among these alternatives are IoT-driven nutrient monitoring tools, portable soil testing devices, RS485-based digital sensors, and electronic tongue–based NPK detection systems. The focus of the research in these areas indicates that portable sensors coupled with microcontroller platforms like Arduino can perform the measurements rapidly and require very little user training. Rural operators may thus be able to take immediate and informed decisions. Encouraged by these technological advancements, the present work suggests a budget-friendly and portable NPK measurement system comprising an RS485 Soil NPK Sensor, Arduino Uno, MAX485 communication interface, and ESP8266 Wi-Fi module that can serve as an on-the-spot nutrient monitoring tool in GOBARdhan units.

II. RELATED WORK

A. Initiatives Supporting Scientific Manure Utilization

Government systems like the GOBARdhan mission encourage the use of bioenergy and nutrient-rich fertilizers by promoting the conversion of livestock waste in a planned manner. Such an example shows that besides laboratory analyses, there is a definite requirement for technology that can locally trace nutrient quality at small-scale facilities [1]. In the same vein, the Food and Agriculture Organization (FAO) stresses that the monitoring of macronutrients, especially nitrogen (N), phosphorus (P), and potassium (K), is the key to both enhancing soil health and also using the right amount of manure in agriculture [15].

B. Digital Sensors for Nutrient Measurement

Various experiments have substantiated that digital NPK sensors are viable farming tools. Kumar and his colleagues induced the use of an Arduino-based NPK sensor to measure soil and noticed that the sensor showed performances that were good enough for remote areas [2]. Priya and Ramesh engineered a mobile unit equipped with digitally operated sensors and thereby proved that inexpensive embedded sensor-based systems can generate insightful nutrient data at the ground level [14]. These efforts have been instrumental in setting the technological essence for embedding an RS485 NPK sensor in the suggested device.

C. IoT-Based Nutrient Monitoring Systems

Many innovations around IoT architectures in farming have gained attention over the past few years. Hartono and colleagues exhibited nutrient portable IoT-based monitoring that was accessible remotely via the cloud, thus showing the ability of the system for instant decision-making [3]. Islam et al. turned to machine learning models using IoT data streams to uplift prediction precision of NPK measurements [4]. Shahab et al. went further to confirm the effectiveness of wireless communication strategies by evidencing the contribution of connectivity modules like ESP8266 in uninterrupted monitoring activities [12].

D. IoT-Based Nutrient Monitoring Systems

Several also spectroscopic along with electrochemical solutions have been brought forth in nutrient sensing research. An electronic tongue favourite rapid one-shot nutrient identifications however more complex hardware and calibration necessary thus less scaling in rural areas [7]. Reviews highlight although tech can achieve high precision their price and operability hamper small-scale manure plant [5].

E. Limitations of Traditional Testing Techniques

While colorimetric and reagent-dependent laboratory methods are still commonly used for nutrient detection, these procedures take a long time, need consumables and trained personnel, and cannot be used for real-time field monitoring in decentralized configurations. As a result, a few prototype sensing systems have been introduced; however, most of them do not have the feature of wireless communication and still require that the operator be skilled, thus their feasibility and implementation in remote agricultural areas being restricted [9], [10].

F. Identified Gaps in Existing Work

The comprehensive review of the works uncovers several missing points that have been thought-provoking:

1. The current research is mainly concentrated on soil testing, hence there is a lack of affordable nutrient testing methods for organic manure and slurry, which are the main constituents of GOBARdhan activities.

2. There is a small number of devices that use RS485 Modbus sensors which are characterized by high resistance to noise and good reliability in wet and electrified areas.

3. The majority of the systems do not have Wi-Fi–enabled IoT integration, which is necessary for real-time surveillance and control of geographically dispersed waste-processing plants..

III. METHODOLOGY

A. System Architecture Overview

The system uses a modular design that combines digital nutrient sensing, signal conditioning, embedded processing, and IoT-enabled data communication. The RS485 NPK Sensor measures Nitrogen (N), Phosphorus (P), and Potassium (K) levels from organic manure and slurry samples. Its digital Modbus RTU output is stabilized through a logic-level shifter and converted using the MAX485 RS485 transceiver before being processed by the Arduino Uno microcontroller. After decoding and filtering the nutrient values, the ESP8266 Wi-Fi module transmits the data to a cloud server for real-time monitoring, storage, and dashboard visualization. This architecture ensures reliable field measurement, strong communication, and easy remote access.

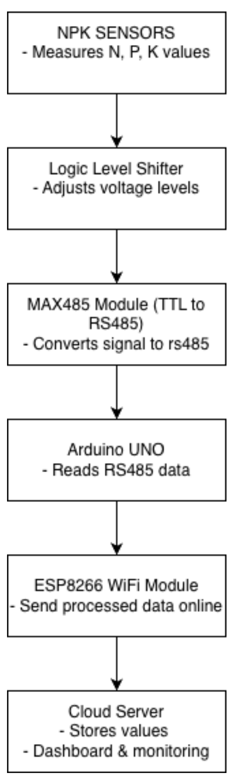

Fig. 1. Block diagram of the proposed NPK sensing and IoT-based monitoring system.

B. Nutrient Sensing Using RS485 NPK Sensor

The NPK sensor works on dielectric and ion-response principles and outputs calibrated Modbus RTU frames. This guarantees noise-resistant and stable measurements even in high-moisture environments like faecal sludge and organic manure pits usually found in GOBARdhan units.

C. Signal Conditioning and Communication Conversion

The NPK sensor uses differential RS485 signaling to ensure noise-resistant data transfer in field conditions. The MAX485 transceiver converts these RS485 signals into 5V TTL levels that work with the Arduino Uno's UART interface. Since the ESP8266 Wi-Fi module operates at 3.3V logic levels, a logic-level shifter is used to safely change the voltage levels between the microcontroller and the Wi-Fi module. This method of signal conditioning ensures stable communication, protects components from voltage mismatches, and maintains reliable data collection during sensing and transmission.

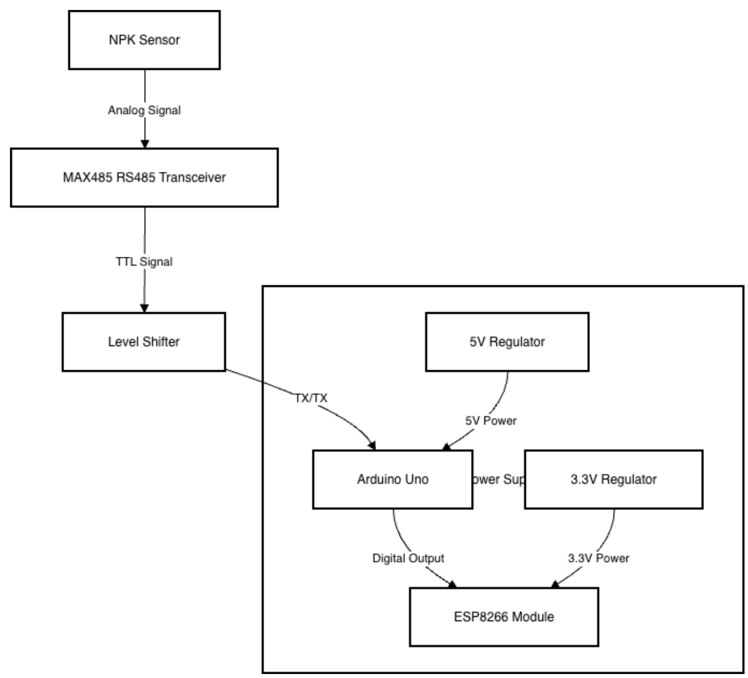

Fig. 2. Circuit diagram showing sensor interfacing, MAX485 conversion, level shifting, and microcontroller–Wi-Fi integration.

D. Data Acquisition Using Arduino Uno

The Arduino Uno functions as the central processing unit responsible for communicating with the NPK sensor through Modbus RTU commands. It periodically sends query packets, receives nutrient data frames, verifies CRC checksums for integrity, and applies basic filtering techniques such as moving-average smoothing to eliminate transient noise. Once the N, P, and K values are validated and formatted, the Arduino transmits the processed data to the ESP8266 module using UART communication for further online delivery.

E. Wireless Data Transmission Through ESP8266

The ESP8266 Wi-Fi module handles all IoT-based connectivity in the system. After establishing a stable Wi-Fi connection, it receives nutrient values from the Arduino and uploads them to a cloud server or API endpoint. This wireless communication enables real-time visualization, threshold-based alerting, and remote data access across distributed GOBARdhan units. The inclusion of cloud integration ensures centralized monitoring and improved decision-making for nutrient management.

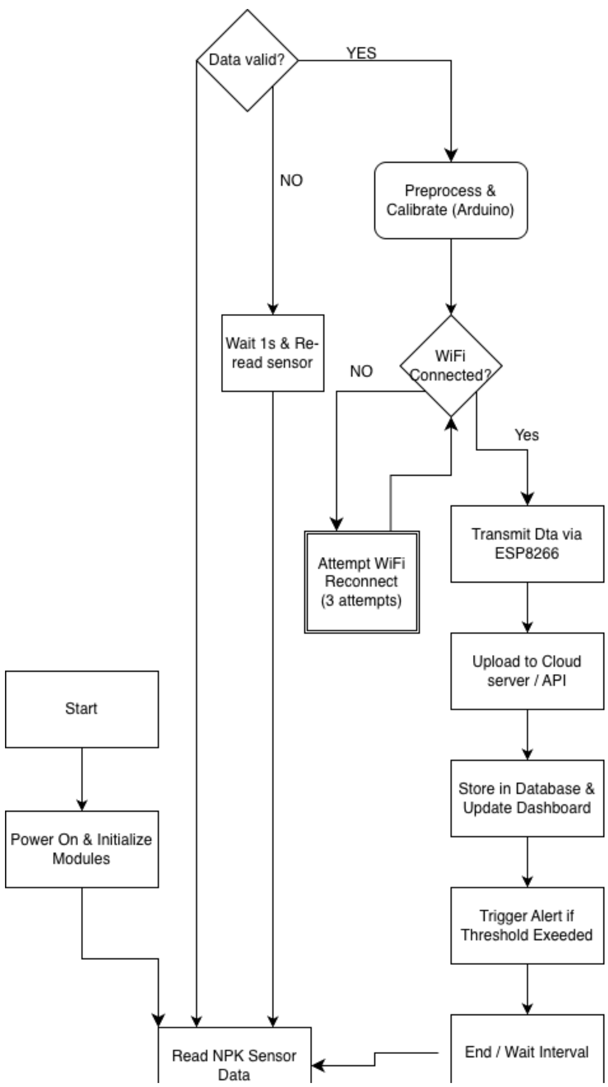

Fig. 3. Flowchart illustrating the complete data acquisition and transmission workflow.

F. Power Management and Hardware Integration

Power distribution in the system uses regulated 5V and 3.3V supplies. The Arduino Uno, MAX485 module, and NPK sensor get power from a stable 5V source. Meanwhile, the ESP8266 runs on a dedicated 3.3V regulator to avoid damage from overvoltage. Good grounding practices, separating signal and power lines, and using jumper wires ensure reliable hardware integration suitable for field use in rural and high-moisture areas.

G. Operational Workflow

The operational workflow prioritizes simplicity and ease of use. When the system powers on, the Arduino initializes all modules and starts reading nutrient values from the sensor. It checks data validity, and invalid readings prompt reattempts. Once validated, the data is preprocessed, calibrated, and sent wirelessly via the ESP8266. The cloud server stores the values, updates the dashboard, and triggers alerts if nutrient thresholds are surpassed.

IV. RESULT AND DISCUSSION

The NPK sensing system was tested with real-time nutrient measurements collected over a 24-hour period. The results show that the RS485 NPK sensor is stable, reliable, and practical. The Arduino–MAX485–ESP8266 setup performed well. We analyzed the individual nutrient trends for Nitrogen (N), Phosphorus (P), and Potassium (K) to evaluate system performance under different organic manure conditions.

A. Nutrient Measurement Trends:

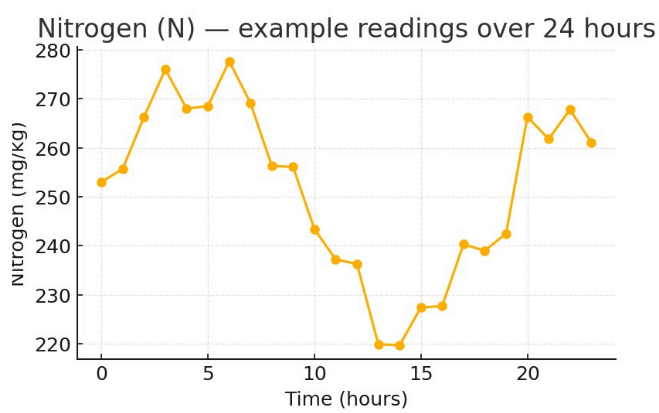

Fig. 4. Nitrogen (N) measurement trend recorded over 24 hours.

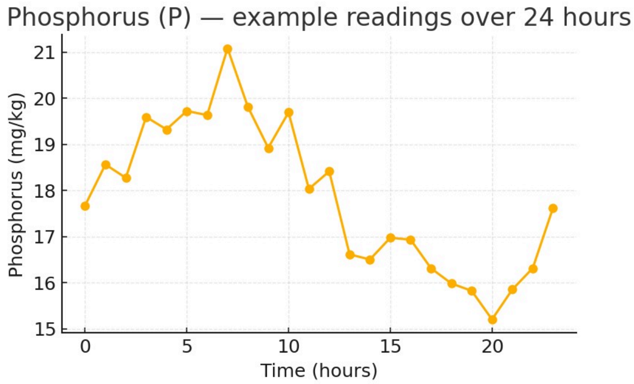

Fig. 5. Phosphorus (P) measurement trend recorded over 24 hours.

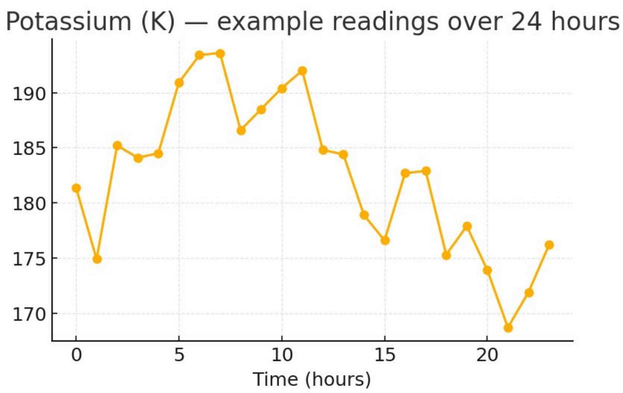

Fig. 6. Potassium (K) measurement trend recorded over 24 hours.

The three nutrient curves showed different but biologically consistent patterns throughout the 24-hour monitoring period. Nitrogen (N) values had noticeable fluctuations, with peaks in the early hours followed by gradual declines. This variation relates closely to microbial activity, the intensity of decomposition, and ammonia volatilization in the manure. The smooth transitions and lack of random spikes indicate that the sensor captured real biological changes instead of electrical noise, showing stable Modbus communication.

(P) levels, on the other hand, stayed relatively stable, with only minor fluctuations during the observation cycle. This stability is expected since phosphorus tends to be less mobile in manure compared to nitrogen and potassium. The consistent P pattern confirms that the sensor maintains reliable sensitivity over long measurement periods, making it suitable for tracking phosphorus availability in digestate and manure-based fertilizers.

Potassium (K) showed moderate but predictable increases and decreases throughout the sampling period. The mobility of potassium often depends on slurry mixing and the release of minerals from decomposing organic matter. The smooth and measurable changes in the K curve confirm that the sensor effectively detects ionic variations within the manure, ensuring accurate tracking of potassium.

Overall, the nutrient trends confirm that:

- The system successfully distinguishes between the different behaviors of N, P, and K.
- RS485 digital sensing ensures stable, noise-free data capture.
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- The reading patterns match known characteristics of fecal sludge and organic manure decomposition.
- The device can reliably record nutrient changes over time. This makes it suitable for continuous monitoring in GOBARdhan operations.

B. Comparison Between Lab Testing and Proposed IoT NPK System

Parameter	Traditional Lab Method	Proposed IoT System
Time Required	2-5 hours	<5 seconds
Cost Per Test	High	Almost Zero
Field Usability	Low	High (portable & field-ready)
Error Source	Manual reading errors	Digital Modbus stable readings

This comparison clearly shows the superiority of the proposed system for decentralized manure management.

C. Practical Significance

The proposed NPK sensing system has important practical value for GOBARdhan units and rural waste-management operations. It provides a quick, automated, and low-cost option compared to standard lab-based nutrient analysis. By capturing real-time nitrogen, phosphorus, and potassium levels directly from manure and slurry samples, operators can make quick, evidence-based decisions about feedstock preparation, compost maturity, and digester input quality. This system not only cuts the need for chemical testing and its associated costs but also allows for more frequent monitoring. This leads to better consistency in fertilizer quality and nutrient recovery. Real-time cloud integration improves plant oversight by allowing remote dashboards, alerts, and historical trend tracking across several village installations. The system's portability and low cost make nutrient monitoring easier for rural users with little technical experience. It empowers them to manage organic waste streams scientifically, optimize digester performance, and improve the agricultural value of bio-slurry. By connecting traditional manure handling with modern digital agriculture, this system directly supports GOBARdhan's goal of promoting sustainable sanitation, waste valorization, and data-driven organic fertilizer production.

D. System Performance

The proposed NPK sensing system showed strong overall performance during continuous field testing, as detailed below:

- **Stable Sensor Readings:**
  The RS485 NPK sensor provided smooth and consistent nutrient measurements with no sudden spikes. This shows excellent noise immunity in high-moisture manure environments.

- **Reliable Modbus Communication:**
  MAX485-based differential signaling ensured error-free data transmission, even during long monitoring periods.

- **Accurate Data Processing:**
  The Arduino Uno effectively handled Modbus queries, CRC checksum verification, and filtering, resulting in clean and reliable NPK curves.

- **Fast Response Time:**
  Each complete reading cycle took less than 5 seconds, allowing for near real-time nutrient assessment.

- **Zero Packet Loss:**
  The ESP8266 Wi-Fi module kept stable cloud communication with no data dropouts reported during the 24-hour test.

- **High Repeatability:**
  Repeated measurements yielded nearly identical values, showing strong system consistency and reliability.

- **Robust Power Management:**
  Proper voltage regulation and level shifting stopped sensor drift and communication failures.

- **Field-Ready Performance:**
  The device operated effectively under varying manure moisture levels and environmental conditions typical of GOBARdhan sites.

E. Limitations

Despite demonstrating strong performance, several limitations were identified in the current system:

- The RS485 NPK sensor needs regular calibration against laboratory standards to keep its measurements accurate over time.

- The system depends on stable Wi-Fi for real-time cloud updates, which can be difficult in remote rural GOBARdhan areas.

- The device only measures nitrogen, phosphorus, and potassium, while other important factors like pH, electrical conductivity (EC), organic carbon (OC), and micronutrients are not included.

- The accuracy of readings relies on consistent sensor insertion depth and good contact with the manure or slurry sample.

- Organic slurry and solids can build up on the sensor probe over time, requiring manual cleaning to prevent signal loss.

F. Discussion

The experimental results show that the proposed IoT-based NPK sensing system provides reliable, stable, and meaningful nutrient measurements. The observed NPK changes closely match known organic waste decomposition patterns. This confirms that the RS485 sensor responds effectively to nutrient changes in manure and slurry. The smooth curves obtained for all nutrients demonstrate the stability of Modbus RTU communication and the effectiveness of Arduino-based filtering in reducing measurement noise. Continuous Wi-Fi data transmission through the ESP8266 module further supports the system's ability for real-time monitoring without interruptions. Compared to traditional laboratory testing, the system has significant advantages in speed, portability, cost, and ease of use. The integration of cloud reporting, digital data logging, and field readiness makes the device a practical and scalable solution for GOBARdhan operations. This enhances the management of organic waste and supports better, more sustainable farming practices.

V. CONCLUSION

The proposed NPK sensing system provides a reliable and practical solution for nutrient analysis in GOBARdhan applications. Based on the results and system performance, the major conclusions are:

- **A low-cost and portable solution:**
  The system effectively replaces costly laboratory testing with an affordable digital sensing device suited for rural and decentralized waste-processing units.

- **Accurate nutrient detection:**
  The RS485 Soil NPK Sensor showed stable and repeatable measurements of nitrogen, phosphorus, and potassium in organic manure and slurry samples.

- **Robust communication architecture:**
  Using MAX485 for RS485 to TTL conversion ensured noise-resistant data transfer. The logic-level shifter and regulated power supply kept the hardware stable.

- **Effective embedded processing:**
  The Arduino Uno managed Modbus communication, CRC verification, filtering, and formatting of nutrient values for accurate data output.

- **Real-time IoT integration:**
  The ESP8266 module allowed smooth wireless transmission of nutrient values to a cloud dashboard, enabling remote monitoring across multiple GOBARdhan sites..

- **Enhancement of GOBARdhan operations:**
  By providing instant nutrient feedback, the system helps optimize manure usage, manage biogas digesters better, and inform fertilizer application.

- **Field-ready design:**
  The modular setup, simple workflow, and reliable performance make the system perfect for use in rural areas with limited laboratory access.

- **Future scalability:**
  The system can be improved with calibration modules, mobile apps, machine learning models, and multi-parameter sensors to expand its abilities.

REFERENCES

[1] Ministry of Jal Shakti, Government of India, “GOBARdhan: Galvanizing Organic Bio-Agro Resources – Dhan,” Swachh Bharat Mission–Grameen, 2021.

[2] L. L. Kumar et al., “Monitoring of Soil Nutrients Using Soil NPK Sensor and Arduino,” \textit{Eco. Environment \& Conservation}, 2024.

[3] R. Hartono et al., “Portable IoT-Based Soil Nutrients Monitoring for Precision Farming,” \textit{Bulletin of Electrical Engineering and Informatics}, 2024.

[4] M. R. Islam et al., “Machine Learning Enabled IoT System for Soil Nutrient and NPK Monitoring,” \textit{Scientific Reports}, 2023.

[5] D. M. Sobhy, “Soil Nutrient Monitoring Technologies for Sustainable Agriculture: A Review,” \textit{Sustainability}, 2025.

[6] S. Adak, “Smart Agriculture with NPK Sensors,” \textit{Journal of Scientific Research and Reports}, 2025.

[7] M. Khaydukova et al., “One-Shot Evaluation of NPK in Soils Using Electronic Tongue Technology,” \textit{Sensors and Actuators B: Chemical}, 2021.

[8] L. Gottemukkala et al., “Crop Recommendation System Using Soil NPK Sensors,” \textit{E3S Web of Conferences}, 2023.

[9] D. B. Bhoyar et al., “pH and NPK Sensor-Based Soil Testing System,” \textit{Bioscience Biotechnology Research Communications}, 2021.

[10] “A Review on Detection of Nutrients Using NPK and Other Sensors,” \textit{International Journal of Advanced Research in Science, Communication and Technology}, 2024.

[11] “Prediction of NPK in Soil Using IoT,” \textit{International Journal of Creative Research Thoughts}, 2024.

[12] H. Shahab et al., “IoT-Driven Smart Agriculture for Soil Nutrient Monitoring,” \textit{Computers and Electronics in Agriculture}, 2025.

[13] P. J. Withers and R. A. Hodgkinson, “Phosphorus Losses from Agriculture and the Role of Fertilizer Management,” \textit{Soil Use and Management}, 2022.

[14] S. S. Priya and A. Ramesh, “Design of a Portable Soil Testing Device for NPK Measurement Using Digital Sensors,” \textit{International Journal of Engineering Research \& Technology}, 2023.

[15] Food and Agriculture Organization (FAO), “Organic Manure and Soil Fertility Management Guidelines,” United Nations FAO Publication, 2020.