

Smart Agriculture Fertilization System By Using A Unified Multi Parameter Sensor

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ABSTRACT

India needs to use intelligent and effective farming practices due to the growing population which results stress on agricultural resources. Inefficient use of fertilizer in conventional agriculture, often leads to reduced crop yields, increased costs and environmental degradation. The main aim of this study is to develop a IoT based Smart Agriculture Fertilization System using Unified Multi-Parameter Sensor (UMPS). The proposed integrated sensor monitors real-time soil condition and measures soil moisture, pH, temperature, electrical conductivity and nutrients like Nitrogen (N), Phosphorus (P), Potassium (K) concentrations simultaneously. The proposed method consists of microcontroller-based hardware and the software by using Raspberry Pi 3, Python and a cloud-based dashboard for data visualization. The performance of sensor was tested at various agricultural soil locations in Sangli District of Pune Region, southeast of Maharashtra, India to evaluate performance. The sensor accuracy was compared to standard laboratory soil reports. The obtained result shows that accuracy was more than 95% to determine soil nutrients (NPK) and other selected parameters.

KEYWORDS SMART AGRICULTURE, FERTILIZATION SYSTEM, INTERNET OF THINGS (IOT), SOIL INTEGRATED SENSOR, NITROGEN (N), PHOSPHORUS (P), POTASSIUM (K)

1. INTRODUCTION

India, with its vast and diverse agricultural landscape, is one of the world's leading farming economies, employing of workforce and contributing significantly to the country's GDP. Despite its crucial role, Indian agriculture continues to grapple with multiple challenges such as inconsistent rainfall, declining soil fertility, inefficient use of fertilizers, and lack of real-time monitoring technologies [1]. Traditional farming practices, often based on intuition rather than data, have led to suboptimal crop yields and environmental degradation, including groundwater contamination due to excessive and improper fertilizer application [2].

Farming is the primary occupation leading to the looming food shortages. It will succeed only if the farmers can generate greater yields in their farming and advance at the same time [3]. Due to the decrease in cultivation and output in the field of agriculture, the income of the developing country is seen to be greatly affected, thus, a key factor contributing to the low production is the incorrect application of fertilizers by farmers [4]. When the soil is deficient in nutrients, fertilizers can be applied in proper and precise amounts. Consequently, it is essential to analyze the soil for available nutrients for adequate plant development prior to using fertilizers

Soil analysis is commonly utilized to assess the presence of vital nutrients in the soil necessary for healthy plant growth. The primary result of testing soil is the purpose of fertilizer guidelines for optimal plant growth [5]. Soil testing for micronutrients nitrogen, phosphorus and potassium is done separately and is time consuming as well as uneconomical for farmers [11]. However, testing soil by farmers is infrequently conducted because of intricate laboratory processes [6]. Typically, soil nutrient testing is conducted manually in commercial labs, which is inconvenient for farmers because it is time-consuming and expensive [7]. Conducting soil tests can help avoid excessive fertilizer application and lower fertilizer expenses. Additionally, understanding the existing soil condition enhances farmers capacity to preserve soil fertility, thereby preventing soil degradation [8]. Typically, soil testing measures soil pH, nitrogen, potassium, and phosphorus, which are macronutrients, along with tests for minerals such as zinc, calcium, copper, and lead, classified as micronutrients, etc [10] in a different way. Different tools for soil testing include inductively coupled plasma spectrometers (ICPs), atomic absorption spectrophotometers, lachat flow injection analysers, colorimeters and standard laboratory equipment. Every device employs a method of chemical analysis, electrolysis, spectroscopy, colorimetry, etc.

The extra use of fertilizer influences the unit weight, tensile strength, moisture content, permeability and so forth of the soil. Advanced nations are urging their farmers to modernize traditional practices more intelligently through the use of the Internet of Things (IoT)[12-15]. IoT raises to the idea of connecting tangible items that can send data from sensors located in soil via the Internet [16]. A key factor behind the increase of IoT in the modern world was to automate processes and enable remote management and observation of systems via the internet [17].

This study proposes a smart agriculture fertilization system specifically designed for the Indian agricultural context, where small and marginal farmers dominate and cost-effective solutions are vital. The system utilizes a unified multi-Parameter sensor capable of simultaneously monitoring soil as well as environmental parameters such as moisture, EC, temperature, pH, and NPK nutrient levels. By providing farmers with accurate, real-time data, the system aims to facilitate informed fertilization decisions, enhance crop productivity, reduce input costs, maintain soil quality and promote sustainable farming practices across diverse Indian agro-climatic regions. The key contributions are selection and implementation of multi parameter sensor for sensing soil temperature, electrical conductivity (EC), NPK and pH of the soil. Combining the sensor with software built into the microcontroller unit for evaluating the detected value. Information will be provided to farmers about present nutrient content on electronic gadgets at regular intervals from remote location through an internet.

2. RELATED WORK

This section highlights the step-by-step progress of our solution with indications, including the right principles in sensor design and soil nutrient analysis. A. Doyle et al. [18] have presented a highly precise technique for identifying chemicals in solution is employing the colorimetric principle. The laboratory test conducted for identification of carbon and nitrogen in soil samples. Y. He et al. [19] have proposed a colorimetric-based assay was proposed for the detection of urinalysis dipsticks in urine samples. A. R. Henriksen and A. Selmer-Olsen [20] established the presence of nitrate and nitrite in water and soil samples through the colorimetric method. R. G. Regalado [21] have examined Soil pH and nutrient levels through the colorimetric method, focusing on nitrogen, phosphorus, and potassium in the soil, aided by a color sensor. Nevertheless, this system did not provide farmers with guidance on which fertilizer to apply for particular nutrients. D. V. Ramane et al. [22] have identified concentrated NPK nutrients through the colorimetric method utilizing fiber optic channels for transmitting light. E. Ben-Dor and A. Banin [23] suggested infrared assessment to analyze soil characteristics. Nonetheless, manual testing is a time-consuming and costly endeavour for farmers. Based on our data, it has been observed that while researchers have performed tests to evaluate the nutrient levels in soil, the most of the farmers remain uninformed about its impacts and the required actions during farming. Therefore, it is necessary to find a method to perform nutrient soil testing on agricultural land by utilizing the frequency reflection domain principle, using high-frequency electronics technology by the multiparameter NPKM7-102 sensor.

Numerous sensor types have been developed based on the colorimetric principle for diverse applications of chemical characteristics. An optical sensor has been created to measure fluoride and pH levels for assessing water quality through the colorimetric principle [24]. Additionally, a colorimetric barcode sensor has been suggested for evaluating food quality and spoilage, utilizing a disposable optical sensor [25]. D. Kim et al. [26] suggested a portable array reader for identifying color changes in colorimetric strips reacting to different hazardous gases through a CMOS image sensor. An optical sensor introduced following the colorimetric principle utilizing a sensing film of a-naphtholphthein as the PolyIBM layer [27], and a pesticide colorimetric sensor developed using L-Cystene modified silver nanoparticles [29]. All the aforementioned sensor design efforts rely on components that emit colored light and those that reflect varying intensities. S. Kumari et al. [30] have discussed IoT-based smart agriculture combines computerisation technology, data analytics and sensor networks to improve precise farming, maximize resources, and continuously watch the crops. A. U. Karimy et al. [31] have developed privacy mechanisms to improve security for IoT environment.

Typically, nutrient deficiency evaluation was conducted on the measurement side by utilizing a microprocessor-based unit. An appropriate logical framework is needed to evaluate soil nutrient concentrations based on data from sensors at the edge level. Due to the ambiguous and uncertain sensor data from the NPK sensor, making decisions regarding the soil's nutrient levels is challenging.

Table 1. Comparison of sensor categories and operational principles

Sensor Type	Working Principle	Target Nutrients	Advantages	Limitations	References
Ion-Selective Electrodes (ISEs)	Measures specific ion activity using selective membranes	NO_3^- , NH_4^+ , K^+ , Ca^{2+} , Cl^-	High specificity, real-time data; portable	Requires frequent calibration; affected by pH/temperature	[33], [34]
Optical Sensors (e.g., NDVI, spectrometers)	Measure light reflectance/absorption; correlate with nutrient status	N (chlorophyll), P (indirect), K (indirect)	Non-destructive; remote sensing possible	Indirect measurement; needs calibration models	[35], [36]
Electrochemical Sensors (e.g., EC, potentiometric)	Measures changes in electrical properties of solution/soil	General ions (non-specific)	Simple design; low cost; fast response	Not ion-specific; total ionic content only	[37], [38]
Microfluidic Sensors / Lab-on-a-Chip	Miniaturized chemical reactions and detection via microchannels	N, P, K, micronutrients	Portable; small sample volume; multi-analyte detection	Complex design; still emerging in field settings	[39], [40]
Biosensors	Use enzymes or antibodies to detect specific nutrients	NO_3^- , PO_4^{3-} , heavy metals	Highly specific; very sensitive	Sensitive to environmental conditions; limited lifetime	[41], [42]
Colorimetric Sensors	Color change from reaction with nutrient-specific reagents	N, P, K (limited)	Inexpensive, simple field use	Semi-quantitative; subjective color interpretation	[43], [44]

3. PROPOSED IoT BASED SYSTEM FOR FERTILIZER NOTIFICATION

Owing to the constraints of conventional soil testing in laboratories followed by reports for farmers to begin cultivation, this paper recommends an IoT system that tracks the present nutrients in the soil and subsequently continuously notifies farmers regarding the quality of soil and quantity fertilizer need to apply while working on their fields. Figure 1 illustrates the suggested IoT system that monitors the soil for the levels of nutrients contained in it.



Figure 1. Block diagram of the proposed IoT based fertilizer notification system

3.1 Soil integrated sensor

Soil-integrated sensors assess the levels of vital nutrients in the soil, supporting accurate fertilization methods. When selecting an NPK sensor, take the following aspects into account:

- Accuracy and Reliability: Opt for sensors with proven accuracy, preferably validated against laboratory tests.
- Soil Compatibility: Ensure the sensor is suitable for your specific soil type and conditions.
- Integration Capabilities: Check if the sensor supports standard communication protocols (e.g., RS485, MODBUS) for seamless integration with your existing systems.
- Durability: Look for sensors with corrosion-resistant materials, especially if used in varying environmental conditions.
- Ease of Calibration: Sensors that allow for easy calibration can adapt better to different soil conditions, enhancing accuracy.

Based on the above considerations, we propose the NPKM7-102 sensor, it was multiparameter soil integrated sensor, developed for agriculture and environmental monitoring technology. This sensor was designed to measure key soil nutrients typically nitrogen(N), phosphorus(P), potassium(K), EC, temperature, pH and moisture in real time. Its working principle combines electrochemical sensing techniques and digital signal processing, which might suit our needs.

3.1.1 sensor probe and material interaction

- The sensor uses electrochemical probes embedded in a corrosion-resistant, waterproof housing.
- When the probe is inserted into soil, the ion activity of available N, P, and K nutrients interacts with selective coatings or embedded materials on the sensor surface.
- These materials are reactive to nutrient ions in the soil water (soil solution), allowing detection of ionic concentrations.

3.1.2 Electrochemical Detection Mechanism

The core mechanism is based on ion-selective electrode (ISE) principles:

- Each nutrient ion (e.g., NO_3^- for nitrogen, PO_4^{3-} for phosphorus, K^+ for potassium) is detected by a membrane or sensor element that develops a potential (voltage) proportional to the ion concentration.
- The sensor converts electrical signals generated from ion exchange or potential differences into digital data using internal circuitry.
- Electrical conductivity measurement (for EC): The total electrical conductivity of the soil solution is measured to assess overall ion content, supplementing the specific ion detection.

3.1.3 Signal Processing

The raw voltage signals are processed by an internal microcontroller:

- Analog-to-digital conversion (ADC)
- Signal filtering to reduce noise
- Application of calibration curves to translate electrical signals into nutrient concentration values (usually in mg/kg or ppm)

3.1.4 Output and Communication

The processed data are transmitted using communication protocols RS485 Modbus remote terminal unit (RTU - standard). This allows integration with data loggers, agricultural monitoring systems, or IoT platforms.

3.2 Mathematical Model of JXCT Soil Nutrient Sensor

3.2.1 Nernst Equation (for each ion-selective electrode)

The Nernst equation is fundamental in understanding the behaviour of ion-selective electrodes (ISEs), as it relates the electrode potential to the activity (or concentration) of a specific ion. The voltage is related to ion concentration by the Nernst equation:

$$E = E_0 + \frac{RT}{zF} \ln [Ion] \quad [1]$$

Where:

E = electrode potential

E^0 = standard electrode potential

R = gas constant

T = temperature (in K)

z = charge of the ion

F = Faraday constant

[Ion] = activity/concentration of ion in solution

For practical use, activity is often approximated by concentration in diluted soil solutions:

$$E \approx E^0 + \frac{RT}{zF} \ln [C_{ion}] \quad [2]$$

3.2.2 Linear Form (Used in Calibration)

$$E = A \cdot \log_{10}(C_{ion}) + B \quad [3]$$

Where

$$A = (2.303 \cdot RT) / zF$$

B = E^0 and other system calibration constants

C_{ion} : Ion concentration (mg/L or ppm)

For a monovalent ion at 25°C (298K):

$$A \approx 59.16 \text{ mV/decade}$$

3.2.3 Calibration Equation (Sensor Output to Nutrient Level)

Multiparameter sensor use internal lookup tables or software calibration curves, typically fitting a linear or nonlinear equation like

$$\text{Nutrient Level (mg/kg)} = \alpha \cdot E + b$$

Where

E = Sensor output in mV

a, b = Calibration constants determined from lab calibration or field calibration with soil samples

3.2.4 Temperature Compensation

Because E depends on temperature, sensors may apply compensation:

$$E_{corrected} = E_{measured} + \alpha \cdot (T_{ref} - T_{measured})$$

Where:

α : Temperature coefficient (mV/°C)

T_{ref} : Reference temperature (e.g., 25°C)

e. Conductivity Supplement (Total Ion Content)

For total ion concentration or salinity (not specific to N, P, or K):

$$EC = \sum_i [\lambda_i \cdot C_i] \quad [4]$$

Where:

λ_i : Molar conductivity of ion i

C_i : Concentration of ion i

3.3 Soil sensor interfacing with Raspberry Pi

Connecting the soil sensor to a Raspberry Pi 3 requires using an RS485 interface for the sensor along with suitable software to read and analyze the data. The sensor typically returns data in a specific format, often using the Modbus RTU protocol. USB to 485 converter was used for connection with the Raspberry Pi. Each parameter (e.g., Nitrogen, Phosphorus, Potassium, pH, moisture, temperature, conductivity) is represented by specific bytes in the response, by referring to the sensor datasheet to parse and convert these bytes into meaningful values.

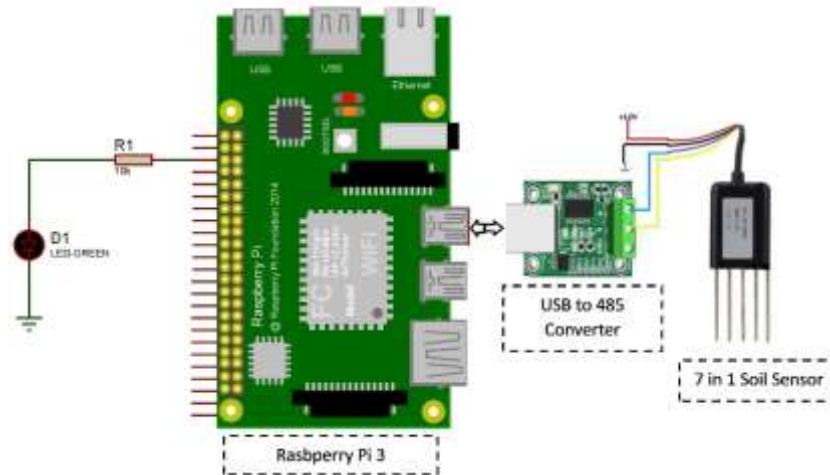


Figure 2. Interfacing of soil sensor with Raspberry pi 3

Once the sensor detects the data, it analyzes to find the existing levels of nitrogen, phosphorus, potassium, pH, moisture, temperature, and electrical conductivity in the soil. Typically, there are two methods to assess sensor data - fog computing and edge computing. The initial processor evaluates identified information utilizing a processor that interacts with the physical environment, whereas the second processes sensor data via the internet on a centralized compact edge server referred to as a cloudlet [29]. Data detected by the multiparameter sensor was voltage related to the ion concentration in the soil. The analysis was conducted at the edge level to assess the amounts of NPK, EC, pH, moisture and temperature in the soil

Examining the sensor data leads to determining the amount of fertilizer to apply prior to planting. This task was complicated because the sensor collects data from the soil using 485 Modbus, requiring proper access to data commands from the registered addresses. The diagram of the suggested system is illustrated in Fig 3.

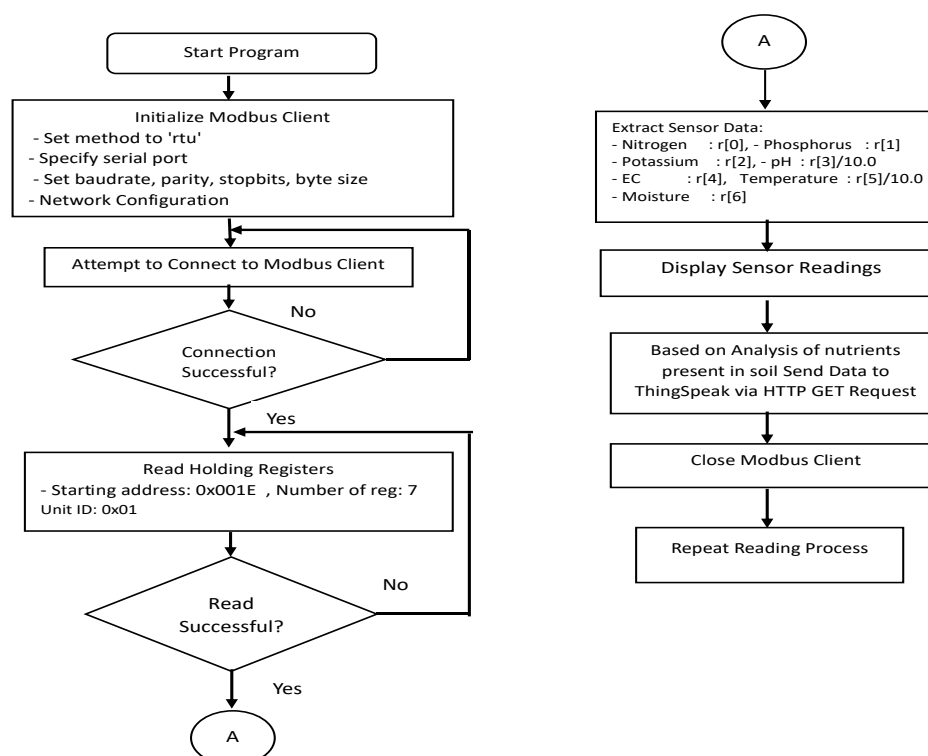


Figure 3. Flow chart for reading data from sensor

3.3.1 Experimental setup of the system

The developed system was first installed in the laboratory to determine its performance, as shown in Fig. 4. The system was running in indoor conditions. It was able to store data and efficiently send data to things speak database using wireless communication. Then, for the field test, the system was installed in outdoor environmental conditions shown in Fig. 5(a,b and c) The system was able to run, the field test was conducted and all the soil related data was stored at interval of 5-minute.



Fig.4 Experimental setup of the system



(a) Site - A



(b) Site - B



(c) Site - C

Fig.5 Soil samples taken from various Site A, B and C

Note: Soil samples and test was conducted site-A location *Sangli-Miraj-Kupwad area*, site-B location *Vidyanagar area* and Site-c location *MIDC industrial area sangli*. All locations are from Sangli District, Maharashtra State, India.

4. IoT PROTOCOL STACK

The swift advancement in information and communication technologies (ICT) has empowered the Internet of Things (IoT) to connect physical items with a distinct identifier to share data online without human involvement [32]. There are more gateways and resources in the IoT structure due to this increased energy consumption and high delay rate. Use improved reptile search algorithm for resource allocation [45]. By utilizing ICT to automate physical objects, they can be managed and observed with minimal human involvement. Any tangible item transforms into a smart object by incorporating specific sensors and processing units through the Internet. The creation of an IoT enable system includes the development of hardware, software and network communication interfaces. The suggested IoT system is depicted in Fig. 6.

This suggested IoT system can be expanded and applied to farmland to furnish farmers with essential information regarding fertilizers. Following edge analysis utilizing fuzzy logic on Raspberry Pi, various sensor units send the data from the relevant NPK sensor to a cloud database through the Internet. The physical layer comprises an NPK, moisture, EC, temperature, and pH sensor along with a microcontroller unit that analyzes the detected values and identifies nutrient deficiencies in the soil. This layer employs IEEE 802.11 ah to deliver a wireless medium access protocol (i.e., WIFI).

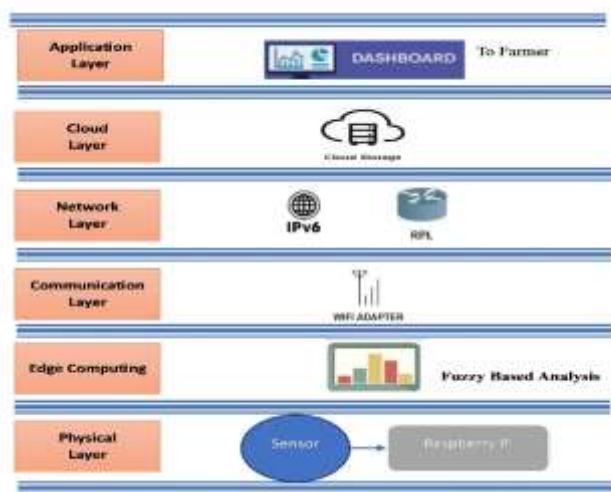


Figure 6. IoT Functional Architecture Design.

When a sensor node is prepared to send its data to the cloud database via HTTP using Raspberry Pi. Authentication is typically done using an access token or device-specific credentials. Devices send sensor readings to things board as time-series data. This data is stored in a time-series database for analysis and visualization. Soil sensor node is transferred to the ThingSpeak IoT platform, by utilize either HTTP requests (GET or POST) or MQTT protocols. This method involves sending data by appending it to the URL as query parameters and in the body of the request, which can be more secure and allows for more data to be sent. In the application layer, ThingSpeak stores the incoming data in your channel, allowing you to visualize it through graphs, charts, or export it for further analysis of the soil nutrients by the farmers.

5. EXECUTION OF CLOUD DATABASE

In the suggested system, the collected information is sent to the ThingsSpeak database cloud for storage for future analysis and to enable real-time soil nutrients in soil nutrients by agriculture officials at the National or State level. The procedure for sending the sensor data to the Things Speak database is as outlined below

Step 1: Create a New Channel Navigate to the "Channels" tab and click on "New Channel" and provide a name and description for your channel. Also enable the fields corresponding to the data you plan to collect and save the channel.

Step 2: Note Your API Keys After creating the channel, go to the "API Keys" tab. Copy the Write API Key; you'll need this to send data to ThingSpeak by using a Raspberry Pi.

Step 3: Visualize Data on ThingSpeak by accessing of channel. Log in to ThingSpeak and navigate to your channel. And to create Visualizations, click on the "Private View" or "Public View" tab.

Step 4: Analyze and act on Data the ThingSpeak allows to perform data analysis and trigger actions for data analysis use MATLAB integration to process and analyze your data, and for alerts and actions, set up alerts or trigger web services when data meets certain conditions.

6. RESULTS AND DISCUSSIONS

The outcomes of the suggested hardware of smart agriculture fertilization system by using a unified multiparameter sensor for intelligent agriculture. The system is evaluated across three different soil locations site A, B and C. Soil nutrient NPK, pH, EC, temperature and moisture content was measured using sensor. Samples were collected from these sites for standard chemical soil analysis performed at the Indian Farmers crop Lab, Nashik (India).

The installed sensor location was at root zone depth (typically 10–20 cm) in the field to monitor soil conditions where plant roots were most active. The laboratory testing procedure for soil sample preparation the soil samples were collected from the various field at root depth (10–20 cm), air-dried, sieved (2 mm mesh), and homogenized before analysis and laboratory.

To confirm the sensor's functionality, the soil sensor was initially examined by quantifying the existing nutrients in the soil. A test is conducted using a soil solution sample consisting of 500 g of soil and 100 ml of water. This examination is conducted to demonstrate that the sensor operates in accordance with the equations. (1) and (2) referenced in Section 3.2 As the nutrients in the soil change, the sensor's output changes as well. Fig. 7 illustrates that the value of the nutrient parameter varies in proportion to the changes in soil nutrient parameters. This verifies that the utilized sensor operates as outlined in its datasheet

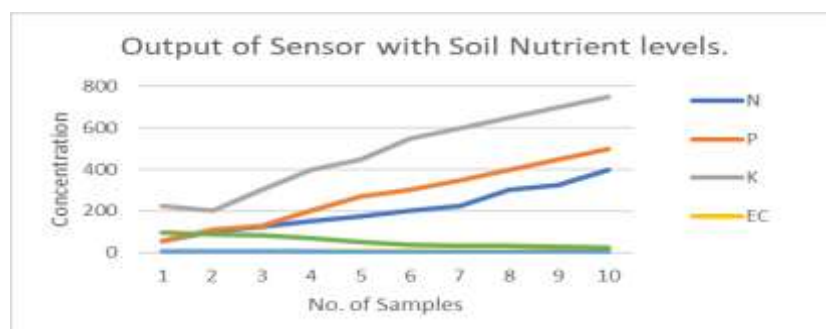


Figure 7 Output of NPK sensor showing nutrient concentrations

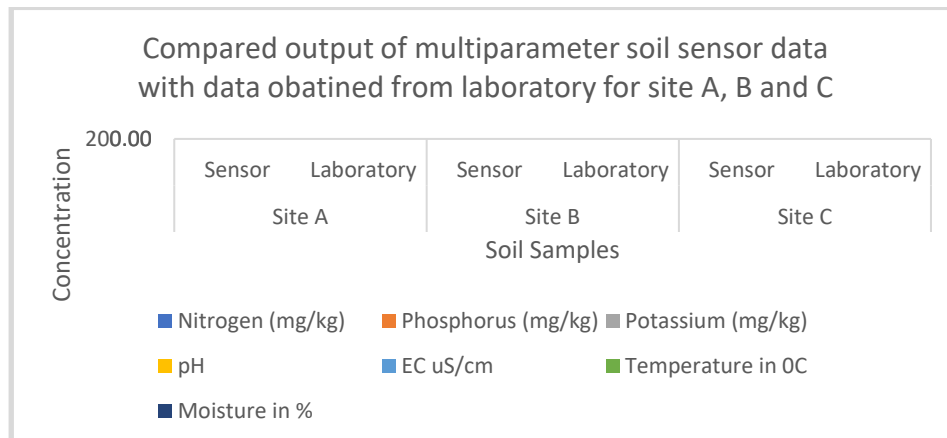
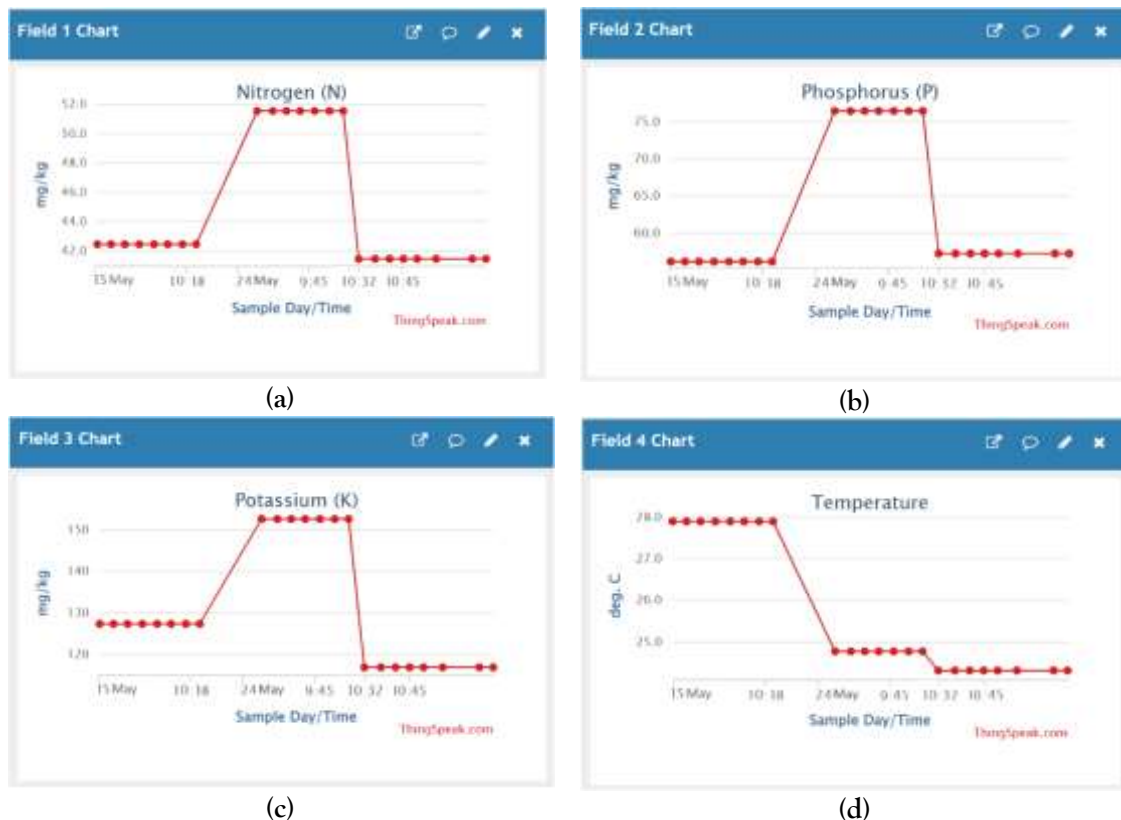


Figure 8. Comparison of NPK, pH, EC, temperature and moisture values from real time sensor and data obtained from laboratory

From the Fig.8 comparison between sensor-based and laboratory measurements for nitrogen, phosphorus, potassium, pH, temperature, moisture and EC levels across three sites. The result analysis based on comparing Sensor and Laboratory values for Site A, Site B, and Site C across various soil parameters. For nitrogen sensor values are close to lab results. Site A shows a slightly more (~5.5%). Sensor accuracy overall was good. Phosphorus minor deviation by sensors (~1-2%). Indicates that high accuracy in phosphorus detection. Potassium Site B shows a notable deviation (~5.2%), but other sites are quite close. All pH readings are within ± 0.12 pH units it was very reliable. EC Sensor generally higher side electrical conductivity, but within acceptable limits. The difference in soil temperature between sites was less than 2%, showing that sensor readings and laboratory readings were accurate.

The soil sensor data transmitted to ThingSpeak closely aligned with laboratory analysis, confirming the accuracy of the IoT-based monitoring setup as shown Fig. 9.



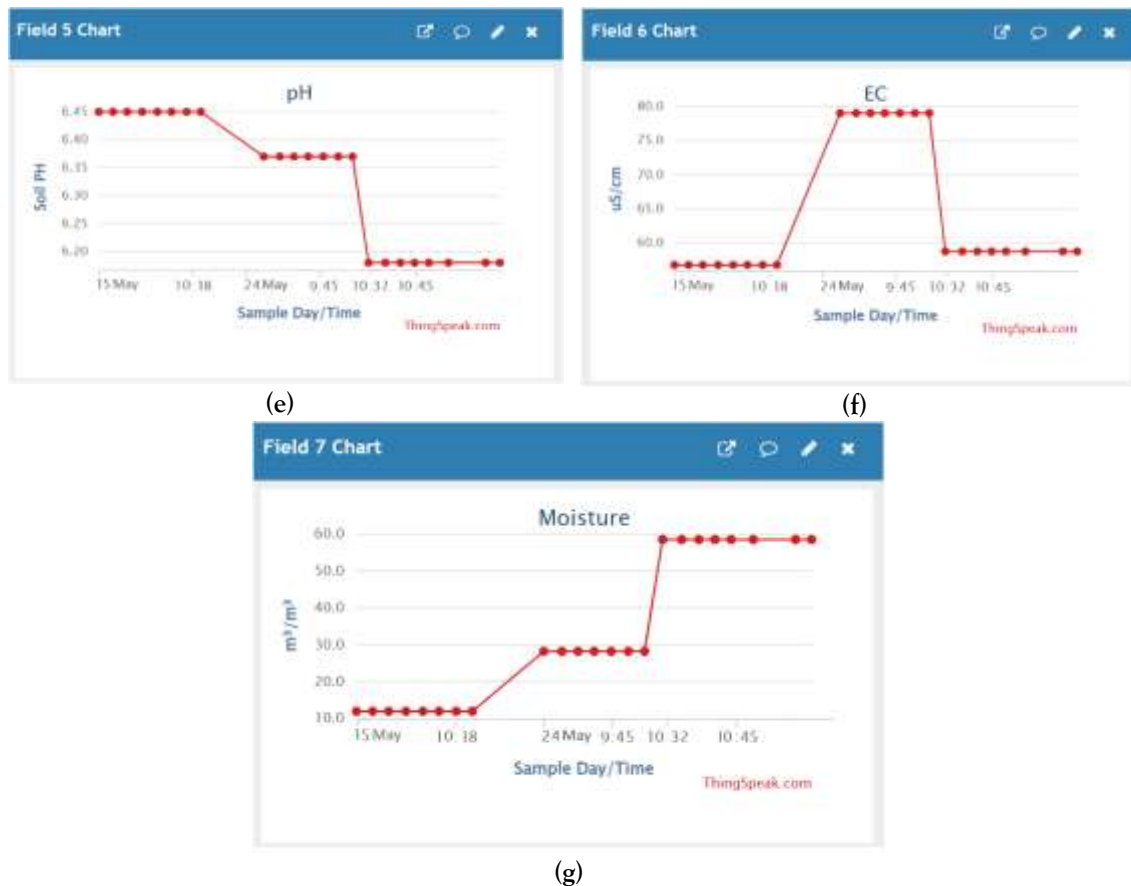


Figure 9. Web interface of real-time data monitoring (a) Nitrogen(N), (b) Phosphorus(P), (c) Potassium(K), (d) Temperature, (e) pH, (f) Electrical conductivity and (g) Moisture

Based on the current soil nutrient level sent by Internet build IoT system, the system outputs the correct level of fertilizer application prediction. Fig. 9 shows the screenshot of the dashboard. It reports that level nutrient content in the soil which has all the three macronutrients- Nitrogen, Phosphorus and Potassium in the adequate level along with pH, temperature, electrical conductivity (EC), and soil moisture which is major role while dosing the nutrient to crops.

The proposed system plays an effective role to increase the yield of crops. It will help farmers to select appropriate fertilizer based on the current nutrient's levels in the soil.

7. CONCLUSION

Consistent determination of soil nutrients in agriculture is challenging due to the manual testing requirements of laboratories and their testing costs. This leads to farmers being careless about the nutrient levels in the soil and using fertilizers at the wrong time. The presented system provides farmers with accurate information on the deficiencies of the major soil nutrients nitrogen, phosphorus, and potassium with other environmental parameter EC, pH and moisture through IoT using multiparameter sensors. Experimental tests are conducted to understand the functionality of the developed IoT system and clarify its purpose. The experiment results show greater accuracy and the deviation of error is $\pm 10\%$ which is within limit. It can be used as a tool to assist farmers for agricultural purposes which provides information about the fertilizer to be applied at the right time.

8. CONFLICTS OF INTEREST

The authors declare that no conflicts of interest.

REFERENCES

- [1] E. V. S. Prakasa Rao and K. V. Ramesh, (2023) "Digital Agriculture: Prospects and Challenges in India," in *Proc. National Symposium on Digital Farming: The Future of Indian Agriculture*, ICAR-IISS, Bhopal, India.
- [2] D. R. K. Saikanth, et al, (2023) "Environmental Sustainability and Food Security of Traditional Agricultural Practices in India: A Review," *Int. J. Environ. Clim. Change*, vol. 13, no. 8, pp. 1847–1856.
- [3] L. Ruiz-Garcia and L. Lanadei, (2017) "The role of RFID in agriculture: Applications, limitations and changes," *Comput. Electron. Agric.*, vol. 136, pp. 42–50.
- [4] T. Ojha, S. Misra, and N. Singh, (2015) "Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges," *Comput. Electron. Agric.*, vol. 118, pp. 66–84.
- [5] E. Ben-Dor and A. Banin, (1993) "Near-infrared analysis as a rapid method to simultaneously evaluate several soil properties," *Soil Sci. Soc. Am. J.*, vol. 57, no. 2, pp. 364–372.
- [6] W. Van Lierop, (1988) "Determination of available phosphorus in acid and calcareous soils with the Kelowna multiple-element extractant," *Soil Sci.*, vol. 146, no. 4, pp. 284–291.
- [7] A. B. Ghosh, J. C. Bajaj, R. Hasan, and D. Singh, (1983) "Soil and Water Testing Methods: A Laboratory Manual". New Delhi, India: Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute (IARI).
- [8] P. Qian, J. J. Schoenau, and R. E. Karamanos, (1994) "Simultaneous extraction of available phosphorus and potassium with a new soil test: A modification of Kelowna extraction," *J. Soil Sci. Plant Anal.*, vol. 25, no. 5–6, pp. 627–635.
- [9] D. R. Keeney and J. M. Bremner, (1966) "Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability," *Agron. J.*, vol. 58, no. 5, pp. 498–503, 1966.
- [10] A. Doyle, M. N. Weintraub, and J. P. Schimel, (2002) "Persulfate digestion and simultaneous colorimetric analysis of carbon and nitrogen in soil extracts," *Soil Sci. Soc. Am. J.*, vol. 66, no. 2, pp. 669–676.
- [11] A. B. Ghosh and R. Hasan, (1980) "Nitrogen fertility status of soils of India," *Fertil. News*, vol. 25, no. 11, pp. 11–15.
- [12] J. C. Ezeokonkwo, (2011) "Engineering properties of NPK fertilizer modified soil," *J. Emerg. Trends Eng. Appl. Sci.*, vol. 2, no. 6, pp. 962–966.
- [13] A. Zanella, A. Castellani, and L. Vangelista, (2014) "Internet of things for smart city," *IEEE Internet Things J.*, vol. 1, no. 1, pp. 3–9.
- [14] O. Elijah, I. Orikumhi, T. A. Rahman, S. A. Babale, and S. I. Orakwue, (2017) "Enabling smart agriculture in Nigeria: Application of IoT and data analytics," in *Proc. IEEE 3rd Int. Conf. Electro-Technology for National Development (NIGERCON)*, Owerri, Nigeria, pp. 1–6.
- [15] S. Heble, A. Kumar, K. V. V. D. Prasad, S. Samirana, P. Rajalakshmi, and U. B. Desai, (2018) "A low power IoT network for smart agriculture," in *Proc. IEEE 4th World Forum Internet Things (WF-IoT)*, Singapore, pp. 609–614.
- [16] M. Luvisotto, F. Tamarin, L. Vangelista, and S. Vitturi, "On the use of LoRaWAN for indoor industrial IoT applications," *Wireless Commun. Mobile Comput.*, vol. 2018, Art. no. 3982646, 2018.
- [17] S. Lavanya, G. Lavanya, and J. Divyabharathi, (2017) "Remote prescription and I-home health base on IoT," in *Proc. IEEE Int. Conf. Innovations in Green Energy and Healthcare Technologies (IGEHT)*, Coimbatore, India, pp. 1–5.
- [18] A. Doyle, M. N. Weintraub, and J. P. Schimel, "Persulfate digestion and simultaneous colorimetric analysis of carbon and nitrogen in soil extracts," *Soil Sci. Soc. Am. J.*, vol. 66, no. 2, pp. 669–676, 2002.
- [19] Y. He, K. Dong, Y. Hu, and T. Dong, (2017) "Colorimetric recognition for urinalysis dipsticks based on quadratic discriminant analysis," in *Proc. 39th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBC)*, Jeju, South Korea, pp. 3185–3188.
- [20] A. R. Henriksen and A. Selmer-Olsen, (1970) "Automatic methods for determining nitrate and nitrite in water and soil extracts," *Analyst*, vol. 95, no. 1131, pp. 514–518.
- [21] R. G. Regalado and J. C. Dela Cruz, "Soil pH and nutrient (nitrogen, phosphorus and potassium) analyzer using colorimetry," in *Proc. IEEE TENCON*, Singapore, Nov. 2016, pp. 2656–2661.
- [22] D. V. Ramane, S. S. Patel, and A. D. Shaligram, (2015) "Detection of NPK nutrient in soil using fiber optic sensor," *Int. J. Res. Advent Technol.*, vol. 3, no. 2, pp. 66–70.
- [23] E. Ben-Dor and A. Banin, (1993) "Near infrared analysis as a rapid method to simultaneously evaluate several soil properties," *Soil Sci. Soc. Am. J.*, vol. 57, no. 2, pp. 364–372.
- [24] H. Dissanayake, B. C. L. Athapattu, and H. Pasqual, (2017) "Economical colorimetric smart sensor to measure water quality of drinking water in CKDu prevalence areas," *IEEE Sens. J.*, vol. 17, no. 18, pp. 5885–5891.
- [25] Y. Chen, G. Fu, Y. Zilberman, W. Ruan, S. K. Ameri, E. Miller, and S. Sonkusale, (2017) "Disposable colorimetric geometric barcode sensor for food quality monitoring," in *Proc. 19th Int. Conf. Solid-State Sensors, Actuators Microsyst. (TRANSDUCERS)*, Kaohsiung, Taiwan, pp. 37–40.
- [26] D. Kim, S. Kim, J. An, and S. Kim, (2017) "A portable colorimetric array reader for toxic gas detection," in *Proc. ISOCS/IEEE Int. Symp. Olfaction Electron. Nose (ISOEN)*, Montreal, QC, Canada, pp. 1–3.

- [27] C.-S. Chu and M.-W. Hsieh, (2017) "Optical carbon dioxide sensor based on the colorimetric change of α -naphtholphthalein and internal reference fluorescent CIS/ZnS QDs," in *Proc. 25th Opt. Fiber Sensors Conf. (OFS)*, Jeju, South Korea, pp. 1-4.
- [28] A. Kodir, C. Imawan, I. S. Permana, and W. Handayani, (2017) "Pesticide colorimetric sensor based on silver nanoparticles modified by L-cysteine," in *Proc. Int. Semin. Sensors, Instrum., Meas., Metrol. (ISSIMM)*, Bandung, Indonesia, pp. 31-34.
- [29] X. Chen, Q. Shi, L. Yang, and X. Jie, (2018) "Thrifty Edge: Resource-efficient edge computing for intelligent IoT applications," *IEEE Netw.*, vol. 32, no. 1, pp. 61-67,.
- [30] S. Kumari, S. Tiwari, K. Naithani, and P. Subbiah, (2024) "Internet of Things for smart agriculture," in *Internet of Things in Smart Technologies for Sustainable Urban Development*, IGI Global, pp. 100-121. doi: 10.4018/979-8-3693-5266-3.ch005.
- [31] A. U. Karimy and P. C. Reddy, (2024) "Enhancing IoT security: A novel approach with federated learning and differential privacy integration," *Int. J. Comput. Netw. Commun. (IJCNC)*, vol. 16, no. 4, pp. 1-14, Jul. 2024, doi: 10.5121/ijcnc.
- [32] I. Lee and K. Lee, (2015) "The Internet of Things (IoT): Applications, investments, and challenges for enterprises," *Bus. Horiz.*, vol. 58, no. 4, pp. 431-440.
- [33] E. Bakker, P. Buhlmann, and E. Pretsch, (1997) "Carrier-based ion-selective electrodes and bulk optodes. 1. General characteristics," *Chem. Rev.*, vol. 97, no. 8, pp. 3083-3132.
- [34] R. Michalski and I. Kurzyca, (2006) "Determination of nitrate and nitrite in water by ion chromatography," *Pol. J. Environ. Stud.*, vol. 15, no. 5, pp. 733-741.
- [35] C. J. Tucker, (1979) "Red and photographic infrared linear combinations for monitoring vegetation," *Remote Sens. Environ.*, vol. 8, no. 2, pp. 127-150.
- [36] F. Li, B. Mistele, and U. Schmidhalter, "Spectral assessments of wheat nitrogen status," *Field Crops Res.*, vol. 124, no. 1, pp. 74-84, 2012.
- [37] D. L. Corwin and S. M. Lesch, (2005) "Characterizing soil spatial variability with apparent soil electrical conductivity," *Comput. Electron. Agric.*, vol. 46, no. 1-3, pp. 103-133.
- [38] K. A. Sudduth *et al.*, (2005) "Electrochemical methods for nutrient sensing," *Precision Agric.*, ASABE, vol. 6, no. 4, pp. 361-384.
- [39] A. Ymeti *et al.*, (2007) "Fast, ultrasensitive virus detection using a Young interferometer sensor," *Nano Lett.*, vol. 7, no. 2, pp. 394-397.
- [40] T. H. Park and M. L. Shuler, "Integration of cell culture and microfluidics for sensing applications," *Biotechnol. Prog.*, vol. 19, no. 1, pp. 243-253, 2003.
- [41] A. Sassolas, B. D. Leca-Bouvier, and L. J. Blum, (2008) "DNA biosensors and microarrays," *Chem. Rev.*, vol. 108, no. 1, pp. 109-139.
- [42] J. Wang, (2006) "Analytical Electrochemistry", 3rd ed. Hoboken, NJ, USA: Wiley-VCH,
- [43] Hach Company, (2006) *Water Quality Test Strips and Kits*, Hach, [Commercial product], [Online]. Available: <https://www.hach.com>
- [44] M. A. Shepherd *et al.*, "Visual soil evaluation," *Soil Use Manag.*, vol. 17, no. 1, pp. 20-30, 2001.
- [45] P. N. Kota, P. B. Chopade, B. D. Jadhav, P. M. Ghate, and S. D. Chavan, (2023) "IoT resource allocation and optimization using improved reptile search algorithm," *Int. J. Comput. Netw. Commun. (IJCNC)*, vol. 15, no. 4, pp. 39-54, Jul. 2023, doi: 10.5121/ijcnc.



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