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A Sensor-Based Data Acquisition System for Soil Parameters to Determine Suitable Crops

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Abstract - Soil parameters monitoring is significant in sustainable crop and food production. The standard strategy of soil parameters monitoring in developing and underdeveloped nations uses manual labor, resulting in wrong decisions in soil management. Inaccurate measurements due to sensor miscalibration or low sensor quality can lead to incorrect soil management decisions and negatively impact crop yield and environmental sustainability. Due to the mentioned challenges, this work aims to develop a Sensor-based Data Acquisition System for Soil Parameters that will enable users to observe various soil parameters like temperature, humidity, water level and soil pH. The system was developed using the combination of hardware and software components. The hardware component comprises of sensory and processing parts. The study calibrates sensors using known pH, moisture, and temperature values for specific crops to grow in Nigeria. The system will aid farmers in determining suitable crops for their farmland and increasing crop yield. The system collects data through a network of sensors installed in the soil and wirelessly transmits the data to a cloud-based server. The collected data is then analyzed and visualized in through a web-based dashboard, providing farmers with information about the state of their soil. The performance evaluation of the system was carried out using response time and accuracy. The average response time of the system was 4 seconds, and the percentage error for temperature and humidity readings when compared to weather forecast readings were 8.20% and 5.08%, respectively. The results show that the proposed system can provide accurate and reliable measurements of soil parameters and can be easily deployed and operated by small-scale farmers. Using this system can result in improved crop yields, reduced wastage, and better overall efficiency in agricultural operations.

Keywords*: Data acquisition, Soil Parameters, Monitoring system, IoT, Sensors*

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1 Introduction

Agriculture and food production rely heavily on the ever-changing environment, impacting food production and various humans. The components of nature comprise land and water resources and climatic factors, including temperature, precipitation, and relative humidity [1]. Despite significant technical and agricultural yield developments, the environment still hugely impacts food production since solar radiation, temperature, and precipitation are the primary factors affecting crop growth. Soil parameters such as pH, temperature, and water content can directly impact crop growth and yield, and by measuring these parameters, farmers can optimize crop production by adjusting soil conditions through fertilization and irrigation practices [2]. The "master soil variable" is the soil pH, which influences several biological, chemical, and physical aspects and processes that affect plant development and biomass production [3]. Soil pH and other parameters such as soil moisture, temperature and humidity are the main catalysts in determining the yield of crops.

Precision Agriculture (PA) involves the gathering and analysis of a significant volume of crop health data [4]. The benefit of PA is that it helps better use of farmland with few resources. The practice of PA significantly contributes to long-term sustainable farming since it increases crop quality and output while minimizing environmental consequences. Also, PA has recently benefited from the introduction of Internet-of-Things (IoT) technologies. To improve productivity and food security with modern technology, the IoT, a rapidly expanding emergent technology, is being used in agriculture. It is a wide-open, complex network of intelligent objects that can self-organize, share information, data, and resources, and react to environmental occurrences [5]. IoT uses various technologies to monitor physical and other things remotely in the real world. It links sensors and embedded technology on a network that allows for real-time data collection, transmission, and monitoring, often stored in the cloud.

Data Acquisition System (DASs) acts as a link between analog waveforms and computer-operable digital numerical values. They are frequently utilized in laboratories for testing and measurements in many industries and are especially adequate for monitoring voltage signals and currents [6], [7]. In addition to their extensive use in laboratories for testing and measurements, DASs have found wide application in various areas of industry. They play a crucial role in automation and control processes and also act as intermediaries, converting analog signals from sensors and actuators into digital data that can be processed by computers or Programmable Logic Controllers (PLCs). DASs enable real-time monitoring, managing, and enhancing industrial processes, which raises productivity, decreases downtime, and increases safety.

Significant progress has been achieved in monitoring soil parameters, and many open areas of research opportunity remain. Expanding on these works opens areas of opportunity to explore several avenues to enhance the monitoring of soil parameters, such as continuous monitoring of soil pH and nutrient levels. Also, these parameters can help optimize fertilizer application, soil amendment strategies, and nutrient management practices. The novelty of this work is a sensor-based DAS that can recommend appropriate crops to be grown in an area in Nigeria based on threshold data of some specific crops in the country. The contributions of the study are as follows:

1. Development of a cost-effective sensor-based DAS that keeps track of soil parameters such as temperature, humidity, pH, and moisture level.

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2. Calibration of sensors using a standard range of known pH and temperature values for some specific crops and.
3. Recommend appropriate crops that can be grown in Nigeria to increase crop yield.

The remaining part of this article is organized as follows: section two gives the related work on the subject matter, and section three relates the design process of the proposed sensor-based DAS. Section four provides results, the discussion is based on the testing of the developed system, and section five presents the study's conclusion and proposes future work.

2 Related Work

Plants' optimum development, health, and production are crucial in contemporary agriculture and horticulture. As the global population continues to rise and the need for food and other plant-based goods rises, this process has assumed growing importance in research. One significant benefit of plant monitoring is preventing significant yield losses [8], [9]. Many studies have been carried out to explore the benefits of DASs and IoT systems in agriculture. Ref. [10] proposed a remote monitoring system that measured moisture, temperature, and pH and interfaced with an Arduino. The sensors connected to the Arduino gather the parameter data and then send it to the client's mobile device using an SMS through a GSM network to transfer data. Using less power ensures this method can send data over a long distance. Ichwana *et al.* in ref. [11] designed a DAS in a greenhouse using multiple sensors. Using Arduino and Excel add-ins, the system monitors real-time data from several sensors in the greenhouse. The significant sensors deployed are DHT22 and BH1750, which provide precise temperature, humidity, and light intensity values, respectively. While the system could detect temperature, humidity, and light intensity, it could not monitor soil moisture or pH.

Boobalan., *et al.* in [12] proposed an IoT-based Agriculture Monitoring System using temperature and humidity sensors interfaced with a Raspberry Pi. When obstacles enter the restricted region, a PIR sensor detects and updates the cloud. The user can regulate the functioning of the motor based on this data. While the study could monitor temperature and humidity, it did not cater to other soil parameters like pH and light intensity, as in ref. [10]. This method improves irrigation conservation but does not address the pH of the soil. Rao., *et al.* in ref. [13] developed a monitoring and automation irrigation system for soil parameters using Raspberry Pi and a cloud-based service. It uses a temperature and soil moisture sensor, and it controls irrigation. While the system improved irrigation conservation, the design did not consider soil pH.

According to ref. [7] an IoT-based smart agriculture management system that measures temperature and soil moisture using DHT-11 and Hygrometer was proposed. The sensors are interfaced with a Raspberry Pi 3 and NodeMCU Devkit. The sensed data is sent to a cloud and accessed through a mobile application. It is cost-effective and helps in analyzing sensed data. An embedded system for measuring humidity, soil moisture, and temperature in a polyhouse using an 89E516RD Microcontroller was developed by Kolapkar *et al.* in [14]. The system was conceived and developed to measure, display, and manage polyhouse-related environmental parameters such as humidity, soil moisture, and temperature. The system also provides automated ON-OFF control action for the exhaust fan, heater, and fogger. This system did not cater for the pH of the soil and light intensity.

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An IoT-based smart agriculture for monitoring soil parameters and controlling soil moisture was proposed in ref. [15]. The system measures soil moisture, humidity, and temperature. Only the soil moisture is controlled. It uses an Arduino Microcontroller and Raspberry Pi; the sensed data is transmitted using ZigBee modules. While this approach provides a way to monitor and control soil parameters, it also requires multiple stations to work effectively, which adds to the system's maintenance cost. Ashifuddin & Rehena in [16] developed an IoT-based intelligent agriculture field monitoring system that performs automatic irrigation using actuators interfaced with an Arduino UNO, a temperature sensor, and a humidity sensor. The system offers Continuous field monitoring, which also sets off the actual events as needed. It somewhat lessens the labour requirements and expenses associated with farming.

Saini & Saini in ref. [17] proposed agriculture monitoring and prediction using IoT. Irrigation is done automatically using the data collected from the sensors, thereby reducing human efforts. It simplifies farming techniques, but the design did not consider the soil pH. Also, an IoT-based smart agriculture system was developed using an ESP8266 WiFi module and the GSM module together with sensors like the LM35 temperature, humidity, and moisture sensors. An Arduino Uno R3 Microcontroller board was interfaced with an Android App that enables the construction of a profile for specified irrigation based on the seasons or daily and weekly modes. Motion sensors were included in the design to identify animal infiltration [18].

Significant advancements have been made in monitoring soil parameters, and a few research works have catered for soil moisture, temperature, humidity, and pH simultaneously, which are the main catalysts for plant growth. Also, little advancement has been made in recommending crops suitable for growing plants in Nigeria. The available research works are peculiar to a country like India. For effective monitoring, the sensor-based DAS for soil parameters utilizes various sensors to keep track of the soil's temperature, humidity, pH, and moisture level while also recommending some specific kind of crop that can be grown in Nigeria to increase crop yield. Because of these, this study develops an efficient and precise data collection method to enable users to make better decisions. The sensor-based DAS for soil parameters collects data such as soil pH, moisture, temperature, and humidity from the farm site. Sensors are calibrated using known pH, moisture, and temperature values for specific crops, aiding farmers in determining suitable crops for their land and increasing crop yield.

3 Materials and Methods

This research paper proposes a sensor-based DAS for soil parameters to determine a suitable crop for cultivating in a particular environment. This technology will provide comprehensive data for enhancing crop production by enabling farmers to make decisions. Data acquired by sensors are sent to the cloud to ease future analysis. In this section, the hardware and software design considerations, together with the crop determination process, are presented.

3.1 Hardware Design Consideration

Hardware design is one of the significant processes in achieving the aim of this study. The major hardware components of the system include temperature, humidity, soil moisture, soil pH sensors, Arduino, and ESP8266

- WIFI Module. Table 1 describes the hardware components used and their specifications. When the system is initialized, the sensory parts of the proposed model will conduct data collection of two soil parameters, the soil moisture and soil pH, and two weather data: the temperature and relative humidity. These collected data are sent to the Arduino microcontroller for processing. ESP8266-WiFi Module plays the role of transmitting the sensed soil parameter data to the cloud for analysis. The data collected by the proposed model and the data analysis can be accessed online through a personal computer or smartphone. Figure 1 presents the conceptual framework of the proposed sensor-based DAS.

Table 1: Hardware Components Specification

S/N	Components	Operating Voltage	Operating Current
1	Soil pH sensor	3.3~5V	1.2mA
2	Soil moisture sensor	5V	15mA
3	Temperature and humidity sensor	3.3V or 5V	0,3mA
4	Arduino	3.3~5V	20-30mA
5	ESP8266 - WIFI Module.	3.3V	70-250mA

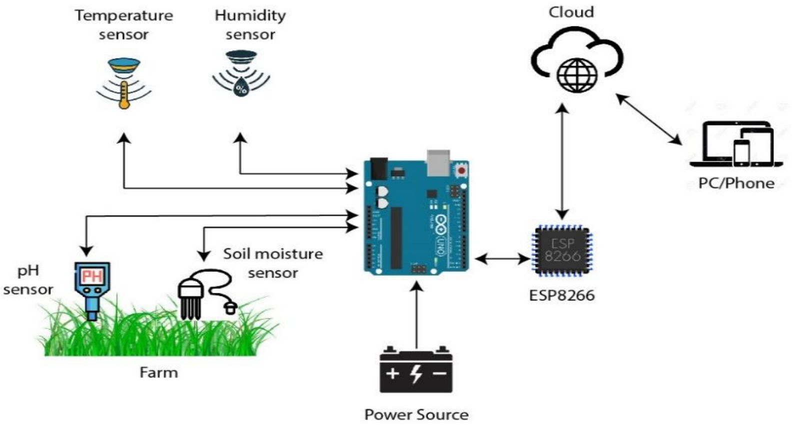

Figure 1: Conceptual Framework of the Proposed Sensor-based DASs

3.2 Software Design Consideration

Another critical step in developing the sensor-based DAS for soil parameters is the software design process. Arduino Development Environment is used to write code that enables the sensor-based DAS process. One of the advantages of this environment is that it is an open-source platform. Through this environment, the sensors' initialization, functions to take a reading by the sensors, processing of the data, sending of the data to the cloud and displaying the appropriate crop for the farmland are enabled. Also, a cloud-based database makes up another

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software in this work. The ThingSpeak platform allows the user to visualize and analyze the acquired values from the sensors. It also provides the scalability and flexibility of a cloud platform.

3.3 Crop Determination

In determining the crop that will grow on the farmland, the data acquired by the sensors are compared with the standard pH range, temperature, and soil moisture to help users know if certain crops will grow on a particular farmland. Optimal values for some specific crops grown in Nigeria have been outlined in Table 2. When the sensed readings match the threshold values in Table 2, the sensor-based DAS displays the crop that will grow.

Table 2: Threshold sensor values for specific crops to grow in Nigeria *[19, 20, 21, 22, 23, 24, 25, 26]*.

Moisture (%)	**Temperature**	**pH**	**Humidity**	**Crop**
65-75	25-30	5.5-6.5	70-80	Yam
60-70	25 -35	4.5-7.0	60-90	Cassava
70-80	20-30	5.5-6.5	70-80	Sweet potato
70-80	18 -22	4.8-5.5	70-80	Potato
12-14	20-30	5.5-7.0	60-70	Maize
12-14	20 -35	6.0-7.0	70-80	Rice
11-13	25 -35	5.5-7.5	60-90	Sorghum
9-13	20 -35	5.0-7.0	60-80	Millet
60-80	21 -27	6.0-7.0	50-70	Tomato
50-75	15 -20	6.0-7.5	50-70	Cabbage
60-80	25-30	5.5-7.0	50-70	Okra

For instance, if the values acquired from the sensors align with the threshold range values required for cassava to grow, which is 60%-70% for moisture, 25°c -35°c for temperature, 4.5-7.0 for soil pH, 60%-90% humidity, it displays cassava alongside the acquired soil parameters else, it only shows the obtained soil parameters. The values obtained are sent to the cloud storage in real-time.

The system design and construction were carried out with a step-by-step approach to ensure proper integration of the entire system. The hardware was constructed with all sensors and microcontrollers tested to ensure proper functioning. Figure 4 depicts the fabrication prototype of the sensor-based DAS.

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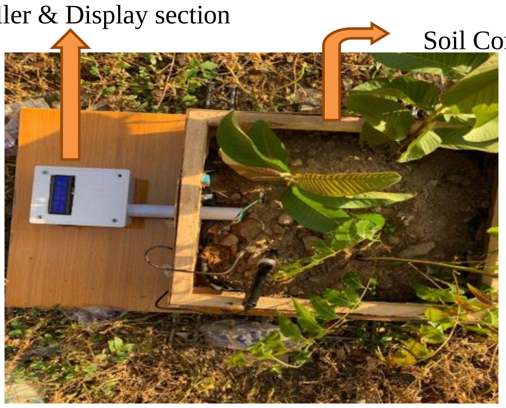

Figure 4: Prototype of the Smart Data Acquisition System

4 Evaluation of Response Time Results

The response time metric was evaluated, and the time taken to send and receive 18 samples of acquired values for temperature, humidity, soil moisture, and soil pH to the cloud was recorded. Table 3 shows the result of the test. The average response time of the system was 4 seconds. Response time for 18 samples, as displayed in Table 3, revealed a slight difference in the results. The values recorded varied from 3 to 9, potentially due to the poor GSM network service. The recorded average reaction time was 4 seconds. It took roughly 4 seconds to send the acquired sensor values to the database when the system was initialized. This value is average satisfaction. Microsoft Excel is used to show a graphical illustration of the system's response. Figure 5 represents the data visualization of the system’s response time. The graph is zigzag due to the effectiveness of the GSM network service. The shooting of the graph to 9 seconds at the fifth instance might be due to the sensors' response in the proposed system.

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Table 3: Response Time for the System

Trial(s)	Soil Moisture (%)	Soil pH	Temp (°c)	Humidity (%)	Time Received (T_R)	Time Sent (T_s)	Response Time (T_R-T_s) (sec)
1	28	8	33.2	56.4	10:42:12	10:42:09	3
2	30	8	33.3	56.0	10:43:30	10:43:27	3
3	30	8	33.4	56.1	10:44:12	10:44:07	5
4	32	7	32.4	48.9	18:21:06	18:21:04	2
5	32	7	33.3	51.0	18:22:23	18:22:14	9
6	32	7	33.4	50.6	18:23:59	18:23:57	2
7	32	7	33.4	50.3	18:24:24	18:24:18	6
8	31	7	33.4	50.1	18:26:32	18:26:28	4
9	32	7	33.4	50.1	18:27:58	18:27:55	3
10	31	7	33.4	49.8	18:28:05	18:28:00	5
11	31	7	33.5	49.6	18:29:07	18:29:04	3
12	31	7	33.6	49.6	18:30:03	18:30:00	3
13	32	7	33.6	49.7	18:31:10	18:31:06	4
14	32	7	33.6	49.7	18:32:11	18:32:05	6
15	32	7	33.6	49.6	18:33:05	18:33:01	4
16	32	7	33.6	49.6	18:34:27	18:34:24	3
17	31	7	33.7	49.6	18:35:30	18:35:26	4
18	32	7	33.7	49.5	18:36:26	18:36:23	3
Average RT							**4**

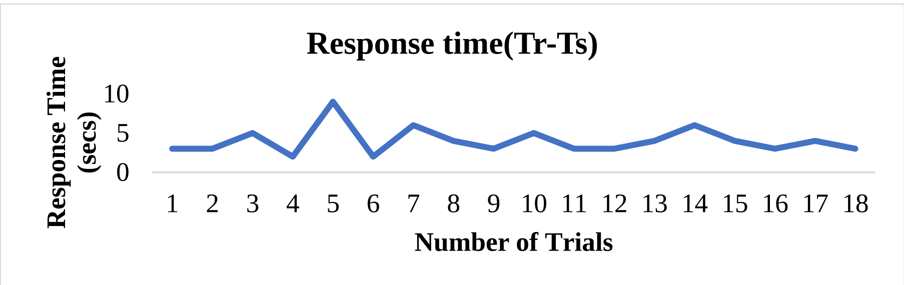

Figure 5: Graph for the Response time of the System

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4.1 Accuracy Evaluation

Three days' worth of tests were carried out regularly: morning, afternoon, and night. The temperature and humidity levels from the system were recorded and compared with the weather forecast figures for the temperature and humidity of that particular time. Table 4 shows the results obtained.

As shown in Table 4, sensor readings revealed a significant difference in the result. An average error of 2.52 and an average percentage error of 8.20% was discovered. This is potentially due to time lags from the weather forecast models. Weather conditions can change rapidly, and the sensor may not be able to capture up-to-date information at a specific moment. Figure 6 compares the temperature sensor readings of the proposed system and the weather forecast readings. The two lines in the graph are similar, which show the accuracy of the proposed sensor-based DAS. Also, the graph reveals some significant differences between the weather forecast data and the proposed sensor-based DAS data, which might result from the position placement of the temperature sensor.

Table 4: Comparison of proposed systems temperature readings with temperature weather forecast readings.

Day	Period	Temp (°c)	Temp weather forecast (°C)	|Error|	|%Error|
First	10:00am	24.0	30.0	6.00	20.00
	3:00pm	31.0	36.0	5.00	13.89
	9:00pm	31.8	31.6	0.16	0.51
Second	10:00am	27.3	29.0	1.70	5.86
	3:00pm	32.8	35.0	2.20	6.29
	9:00pm	29.4	29.5	0.10	0.34
Third	10:00am	28.2	24.0	4.20	17.50
	3:00 pm	33.2	36.0	2.80	7.78
	9:00 pm	30.5	31.0	0.50	1.61

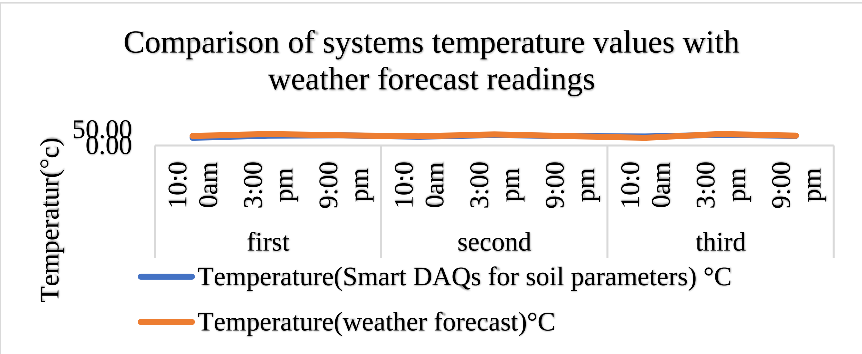

Figure 6: Graph for Comparison of systems temperature values with weather forecast readings.

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As shown in Table 5, an average error of 3.92 and an average percentage error of 5.08% were estimated from the proposed system reading for humidity and weather forecast data. Figure 7 plots the percentage humidity reading of the proposed system and the weather forecast reading. The difference in the plot is due to time lags from the weather forecast models. Weather conditions can change rapidly, and the sensor may not be able to capture up-to-date information at a specific moment. Another reason might be the position placement of the sensor.

Table 5: Comparison of systems humidity sensor with weather forecast readings for humidity.

Day	Period	Humidity (%)	Humidity (weather forecast %)	|Error|	|% Error|
First	10:00 am	80	83.8	3.79	4.52
	3:00 pm	60	63.3	3.32	5.24
	9:00 pm	65	71.0	6.00	8.45
Second	10:00 am	73	79.9	6.85	8.58
	3:00 pm	66	67.9	1.90	2.80
	9:00 pm	74	74.4	0.44	0.59
Third	10:00 am	74	74.4	0.40	0.54
	3:00 pm	67	68.5	1.54	2.25
	9:00 pm	75	86.0	11.00	12.79

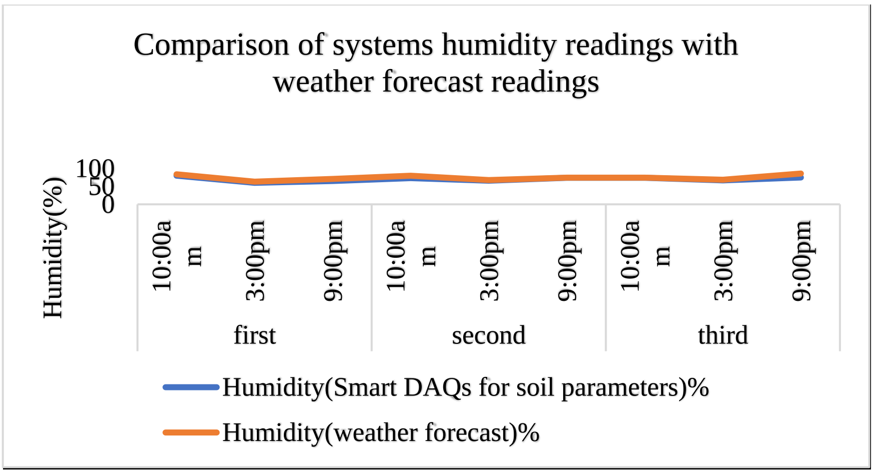

Figure 7: Graph for Comparison of systems humidity readings with weather forecast readings.

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5 Conclusion

Human supervision and control of farming operations have proven inefficient as humans are prone to many errors, fatigue, and forgetfulness. Also, agriculture production is greatly hampered by ongoing climate change; hence, there is a need for a sensor-based data acquisition system for soil parameters. Some crops cannot grow or bear fruit in places where the climate is not conducive to their development. Moreover, some existing DASs for soil parameters give inaccurate measurements due to the sensors' lack of proper calibration, resulting in significant errors in the measured values. The effect of calibration on the accuracy of soil pH measurements is essential for accurate pH measurements. All these challenges make it difficult to assess soil conditions accurately and can lead to problems such as crop failures, poor resource management, and decreased crop yields. To address these difficulties, this study developed an efficient and precise means of data collection to enable users to make better decisions. The developed sensor-based DAS for soil parameters was used to collect soil pH, moisture, temperature, and humidity from a farm site. Sensors are calibrated using known pH, moisture, and temperature values for specific crops, aiding farmers in making well-informed choices on the best crops to grow and the best times to plant. The performance evaluation of the developed system was carried out using response time and accuracy. The results revealed that the system response time was 4 seconds, and the percentage error for temperature and humidity readings compared to weather forecast readings was 8.20% and 5.08%, respectively. The results show that the proposed system can provide accurate and reliable measurements of soil parameters and can be easily deployed and operated by small-scale farmers. The system can help bridge the technology gap in precision agriculture and promote the adoption of sustainable farming practices. The future direction of this study is to integrate real-time actions such as irrigation systems in the proposed system. Moreover, incorporating renewable energy, such as solar systems, for adequate power supply for the proposed system is another future direction.

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