JURNAL TEKNOLOGI DAN OPEN SOURCE
Vol. 9, No. 1, June 2026, pp. 357~369
e-ISSN: 2622-1659, accredited Four Grade by Kemenristekdikti, Decree No: 152/E/KPT/2023
DOI: https://doi.org/10.36378/jtos.v9i1.5760

An IoT-Based Model for Monitoring Soil pH, Temperature, and Moisture to Support Precision Agriculture

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Article Info

Article history:

Received 05 01, 2026
Revised 06 11, 2026
Accepted 06 24, 2026

Keywords:

Internet of Things
Precision agriculture
Soil monitoring
ESP32 NodeMCU
Web dashboard

ABSTRACT

Manual measurement of soil pH, temperature, and moisture often produces fragmented field data that are difficult to use for periodic land monitoring. This study developed an Internet of Things-based prototype for monitoring soil conditions to support precision agriculture. The system integrated a soil pH sensor, a waterproof DS18B20 soil temperature sensor, a soil moisture sensor, an ESP32 NodeMCU, Wi-Fi communication, data storage, and a web-based dashboard. The research followed a prototype development model covering requirement analysis, system design, hardware and software implementation, testing, evaluation, and refinement. Field testing was conducted from February to April 2026 at 08:00, 12:00, and 16:00. The results showed that soil pH ranged from 6.47 to 6.70 with an average of 6.58, soil temperature ranged from 21.30°C to 28.61°C with an average of 24.57°C, and soil moisture ranged from 73.67% to 90.00% with an average of 87.71%. Functional testing indicated that the prototype could read, transmit, store, and visualize soil data through the dashboard during operation. The proposed model is feasible as an early-stage monitoring system for data-driven soil management, although future accuracy validation with calibrated instruments is still required.

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1. Introduction

Soil condition is a basic requirement for productive agriculture because crop growth depends on the chemical and physical environment around the root zone. Soil pH affects nutrient availability, while soil temperature and moisture influence biological activity, water uptake, and daily crop stress. In practice, farmers often measure these variables manually, irregularly, and only when visible crop problems appear. This work pattern creates a data gap because land managers cannot easily review the direction of soil change over time.

The need for more frequent and structured field information has encouraged the adoption of Internet of Things (IoT) technology in agriculture. IoT allows sensors, microcontrollers, wireless networks, databases, and dashboards to operate as one monitoring system. Previous studies have shown that IoT can support soil fertility monitoring [2], soil pH and moisture observation [3], crop-specific soil monitoring [4], long-range soil monitoring using LoRa [5], and precision irrigation [11]. Wider reviews also confirm the role of IoT in smart farming, wireless sensor networks, and sustainable agriculture [12] [14].

Despite these developments, several practical gaps remain. Many prototypes focus on one or two parameters, use dashboards only as supporting interfaces, or report implementation results without adequate field-based monitoring summaries. A soil monitoring model for precision agriculture should not only connect sensors to a microcontroller. It should also record time-based data, visualize trends, and provide evidence that the system can support periodic field monitoring for descriptive analysis.

This study addresses that gap by developing an IoT-based model that integrates soil pH, soil temperature, and soil moisture monitoring in a web dashboard. The prototype uses ESP32 NodeMCU as the main controller and stores historical data for later review. The study contributes a field-tested monitoring model, a structured prototype workflow, descriptive monitoring results, and an explicit discussion of system boundaries. The contribution is positioned on prototype integration and functional feasibility, not on absolute sensor accuracy or automated agronomic decision-making. The research questions are how to design the prototype, how to implement the data flow from sensor to dashboard, and how the system performs during field testing.

2. Research Method

2.1. Research Design

This research used an engineering research approach because the main objective was to build and evaluate a working technological prototype. The development followed a prototype model. The work started with requirement analysis, continued with system design, hardware and software implementation, functional testing, evaluation, and system refinement. This model was selected because IoT-based systems usually require direct adjustment after sensors, power supply, communication, and dashboard functions are tested in real conditions [23].

The field test was conducted on agricultural land from February to April 2026. Observations were collected at three daily time points: morning, midday, and late afternoon. The measured variables were soil pH, soil temperature, and soil moisture. The dataset contained 36 observations. Each observation included date, time, pH, temperature, moisture, and soil status.

2.2. Hardware, Software, and System Architecture

The hardware consisted of a soil pH sensor, a waterproof DS18B20 soil temperature sensor, a soil moisture sensor, ESP32 NodeMCU, connecting cables, a control box, and a power supply. The software consisted of a microcontroller program for reading and sending sensor data, a web dashboard for visualization, a table-based data storage feature, and a manual input or device-connection form used during testing and integration. The dashboard displayed numeric values, graphs, historical records, and device status.

Table 1. Main system components and their functions

No	Component	Function in the system
1	Soil pH sensor	Reads the acidity level of the soil medium and provides the pH variable for dashboard classification.
2	Waterproof DS18B20 sensor	Measures soil temperature at the observation point and supports daily temperature pattern analysis.
3	Soil moisture sensor	Measures water content indication in the soil and supports moisture trend monitoring.
4	ESP32 NodeMCU	Acts as the main controller for reading sensor signals, processing values, and sending data through Wi-Fi connectivity.
5	Web dashboard and data table	Displays recent values, graphs, device identity, historical records, manual input, and CSV download.
6	Power supply and control box	Supports device operation and organizes the circuit during field implementation.

The configuration in Table 1 shows that the prototype was built as a complete monitoring pipeline rather than a standalone sensor reader. Each component had a specific role in the flow from field measurement to data documentation. This structure was important because the main target of the study was not only to obtain sensor values, but also to make those values accessible and reviewable through a dashboard.

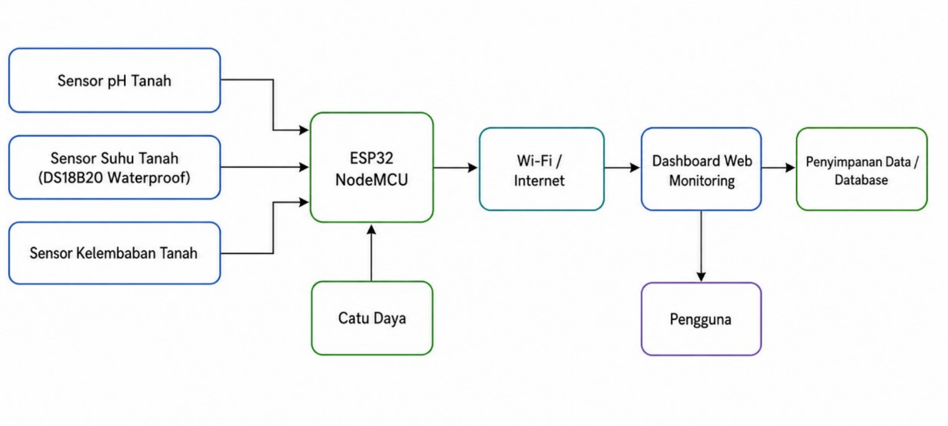


Figure 1. Block diagram of the IoT-based soil monitoring system

As shown in Figure 1, the sensors served as data input components, while ESP32 NodeMCU functioned as the processing and communication unit. After the sensor values were read, ESP32 sent the data through Wi-Fi or internet connectivity to the dashboard and database. Users could then review current values and historical records through the web interface. This architecture was designed to support monitoring rather than automatic control. Therefore, irrigation, fertilization, liming, and actuator control were outside the scope of this study.

2.3. Data Flow and Dashboard Mechanism

The data flow started when the soil pH, temperature, and moisture sensors read field conditions at the observation point. The ESP32 NodeMCU then received the sensor values, converted them into monitoring variables, and sent them through the configured internet connection to the dashboard environment. The dashboard displayed the newest reading, stored historical data, and allowed users to inspect changes through graphs and tables. This flow was designed to support periodic field monitoring, not automatic control.

Each monitoring entry was stored as a structured record containing timestamp, node identity, soil pH, soil temperature, soil moisture, and the dashboard status label. These records were shown in a historical table and could be exported in CSV format for further analysis. This storage mechanism made the dashboard useful not only as a display interface, but also as a simple documentation tool for reviewing soil condition changes over time.

The system boundary was defined clearly to avoid overclaiming the prototype function. The prototype did not activate irrigation, fertilization, liming, or other actuators. It also did not use artificial intelligence to recommend crop treatment. Therefore, the evaluation focused on the ability of the system to read, transmit, store, visualize, and export monitoring data.

2.4. Sensor Stabilization and pH Status Classification

Before field observation, the sensors were checked through repeated readings to ensure that values could appear consistently on the device and dashboard. This procedure was used as an initial functional calibration and stabilization step. The pH status in the dashboard was treated as a practical field category. Because the observed pH values were concentrated around the neutral zone, the article uses the term near-neutral rather than making a detailed fertilizer recommendation. Absolute accuracy testing against calibrated laboratory instruments was outside the main scope and is stated as a limitation of the study.

Table 2. Practical pH status rule used in the dashboard

pH range	**Dashboard status**	**Interpretation boundary**
< 6.40	Acidic	Requires further agronomic interpretation before treatment.
6.40-7.00	Near-neutral	Used as the dashboard category for the observed field readings.
> 7.00	Alkaline tendency	Requires further validation and agronomic interpretation.

This classification was used only to help users read the dashboard quickly. It should not replace laboratory soil testing or crop-specific agronomic analysis because soil management decisions depend on crop type, organic matter, nutrient status, rainfall, and field history [6], [7]. In this article, the near-neutral category is an operational dashboard label based on general soil reaction concepts, not a fertilizer recommendation.

2.5. Testing and Data Analysis

System testing covered hardware, software, connectivity, data storage, dashboard visualization, and stability of readings. Hardware testing checked whether every sensor could read values and whether ESP32 could process and transmit the data. Software testing used a black-box approach to verify login, dashboard display, graphs, table records, manual input, CSV export, and logout. Data analysis used descriptive statistics, including minimum value, maximum value, mean, standard deviation, and coefficient of variation. Because this study focused on prototype feasibility, absolute accuracy testing against calibrated laboratory instruments was not treated as the main evaluation target.

Accordingly, this study should be read as a functional feasibility study. The evaluation measured whether the integrated prototype could perform the expected monitoring tasks, while instrument-level accuracy validation was reserved for future work. This distinction is important because a working IoT pipeline does not automatically prove that every sensor has laboratory-grade accuracy.

3. Result and Discussion

3.1. Prototype Implementation

The proposed system was implemented as a field prototype placed directly on agricultural soil. The sensor probes were positioned in the soil medium, while the ESP32 NodeMCU and supporting circuit were protected inside a control box. This arrangement allowed the system to read soil pH, temperature, and moisture at the test location while keeping the main electronic components more organized during operation.

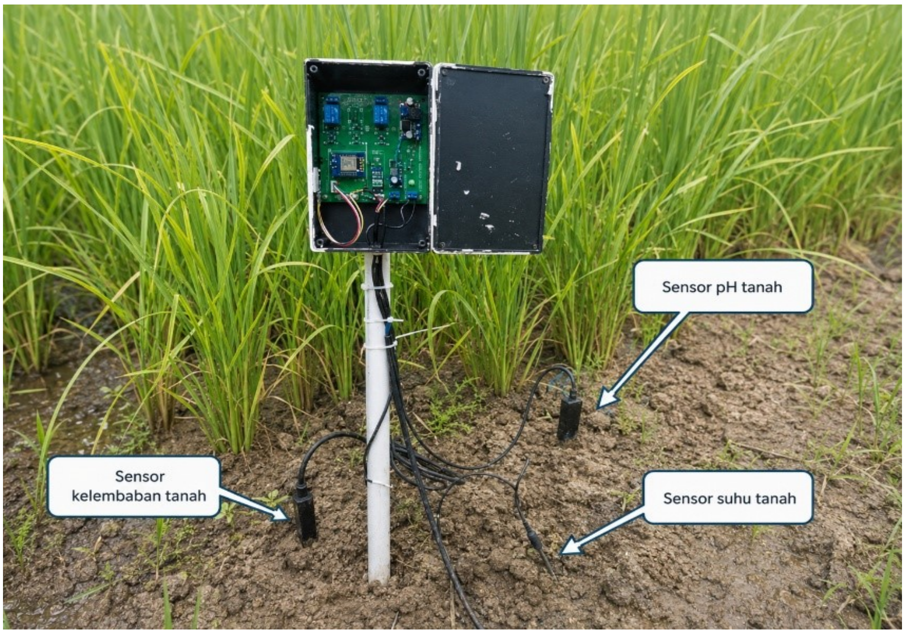
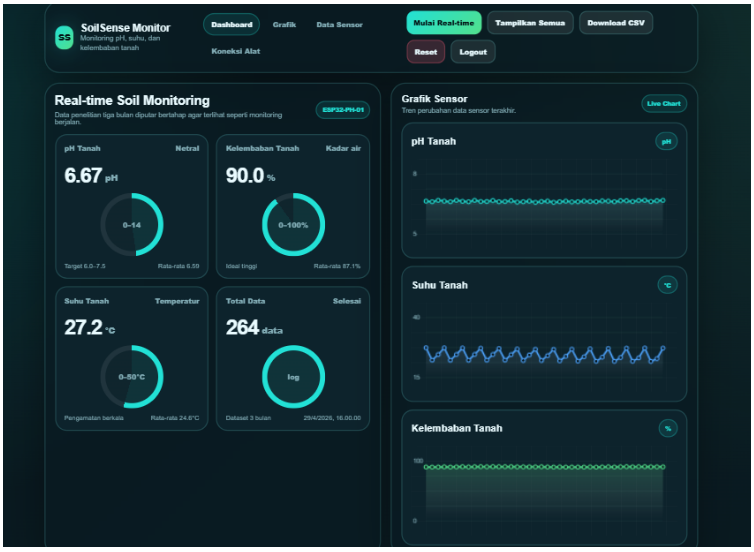


Figure 2. Hardware implementation of the soil monitoring prototype

Figure 2 shows that the prototype was not limited to a conceptual diagram. The physical device was assembled and tested in a real field setting. This is important because soil monitoring systems often face practical issues that do not appear in a laboratory layout, such as cable placement, sensor position, field exposure, and communication reliability. The implementation confirmed that the main components could be connected into a single operational unit.

3.2. Web Dashboard Implementation

The web dashboard was developed to make the monitoring results easier to read and store. It displayed the latest soil pH, soil temperature, soil moisture, total data, and node information. The dashboard also included graphs to support visual interpretation of changing values. The use of a dashboard is important because raw sensor readings are rarely useful for users if they are not organized into accessible information.



Real-time Soil Monitoring

Data penelitian tiga bulan diputar bertahap agar terlihat seperti monitoring berjalan.

pH Tanah — Netral — 6.67 pH — Target 6.0–7.5 — Rata-rata 6.59

Kelembaban Tanah — Kadar air — 90.0 % — Ideal tinggi — Rata-rata 87.1%

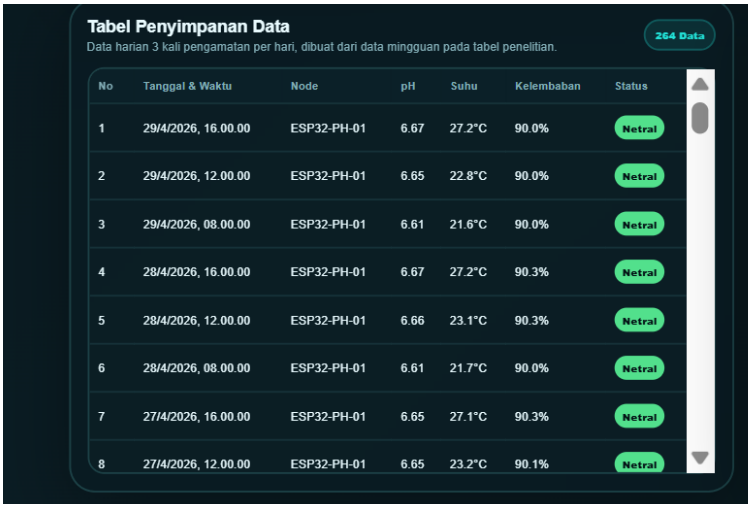
Suhu Tanah — Temperatur — 27.2 °C — Pengamatan berkala — Rata-rata 24.6°C

Total Data — Selesai — 264 data — Dataset 3 bulan — 29/4/2026, 16.00.00

Grafik Sensor

Tren perubahan data sensor terakhir.

Figure 3. Main dashboard display for soil monitoring



Tabel Penyimpanan Data

Data harian 3 kali pengamatan per hari, dibuat dari data mingguan pada tabel penelitian.

No	Tanggal & Waktu	Node	pH	Suhu	Kelembaban	Status
1	29/4/2026, 16.00.00	ESP32-PH-01	6.67	27.2°C	90.0%	Netral
2	29/4/2026, 12.00.00	ESP32-PH-01	6.65	22.8°C	90.0%	Netral
3	29/4/2026, 08.00.00	ESP32-PH-01	6.61	21.6°C	90.0%	Netral
4	28/4/2026, 16.00.00	ESP32-PH-01	6.67	27.2°C	90.3%	Netral
5	28/4/2026, 12.00.00	ESP32-PH-01	6.66	23.1°C	90.3%	Netral
6	28/4/2026, 08.00.00	ESP32-PH-01	6.61	21.7°C	90.0%	Netral
7	27/4/2026, 16.00.00	ESP32-PH-01	6.65	27.1°C	90.3%	Netral
8	27/4/2026, 12.00.00	ESP32-PH-01	6.65	23.2°C	90.1%	Netral

Figure 4. Historical data table on the monitoring dashboard

Input Manual / Koneksi Alat

Masukkan data sensor untuk uji tambahan.

Node: ESP32-PH-01

pH: 6,58

Suhu: 24,57

Kelembaban: 87,71

Figure 5. Manual input and device connection interface

Figures 3 to 5 indicate that the dashboard functioned as both a visualization interface and a data management tool. The historical table helped document readings by time, device node, and sensor values. The manual input or device-connection feature supported testing, simulation, and integration with ESP32. This structure strengthens the monitoring model because users can inspect both current readings and previous records without opening the microcontroller environment.

3.3. Overall Monitoring Results

The prototype produced 36 monitoring records during the field test. Table 3 presents the complete monitoring dataset. The results show that the system successfully recorded all three parameters at different observation times. The status column classified the pH values as near-neutral because the readings remained in a narrow range around neutral soil reaction.

Table 3. Overall field monitoring results

No	Date	Time	pH	Temp. (°C)	Moist. (%)	Status
1	01-02-2026	08:00	6.48	21.50	90.00	Near-neutral
2	01-02-2026	12:00	6.50	23.20	90.00	Near-neutral
3	01-02-2026	16:00	6.47	27.10	90.00	Near-neutral
4	08-02-2026	08:00	6.52	21.30	90.00	Near-neutral
5	08-02-2026	12:00	6.55	23.50	90.00	Near-neutral
6	08-02-2026	16:00	6.51	27.40	90.00	Near-neutral
7	15-02-2026	08:00	6.53	21.80	90.00	Near-neutral
8	15-02-2026	12:00	6.56	24.00	90.00	Near-neutral
9	15-02-2026	16:00	6.54	27.60	90.00	Near-neutral
10	22-02-2026	08:00	6.55	21.90	90.00	Near-neutral
11	22-02-2026	12:00	6.58	24.20	90.00	Near-neutral
12	22-02-2026	16:00	6.56	27.80	90.00	Near-neutral
13	01-03-2026	08:00	6.57	22.10	88.00	Near-neutral
14	01-03-2026	12:00	6.60	24.30	88.00	Near-neutral
15	01-03-2026	16:00	6.58	28.00	88.00	Near-neutral
16	08-03-2026	08:00	6.60	22.00	87.00	Near-neutral
17	08-03-2026	12:00	6.62	24.50	87.00	Near-neutral
18	08-03-2026	16:00	6.61	28.20	87.00	Near-neutral
19	15-03-2026	08:00	6.61	22.20	85.00	Near-neutral
20	15-03-2026	12:00	6.64	24.70	85.00	Near-neutral
21	15-03-2026	16:00	6.62	28.40	85.00	Near-neutral
22	22-03-2026	08:00	6.60	22.30	83.00	Near-neutral
23	22-03-2026	12:00	6.63	24.90	83.00	Near-neutral
24	22-03-2026	16:00	6.61	28.60	83.00	Near-neutral
25	01-04-2026	08:00	6.52	22.04	73.67	Near-neutral
26	01-04-2026	12:00	6.59	23.34	79.81	Near-neutral
27	01-04-2026	16:00	6.55	28.61	85.02	Near-neutral
28	15-04-2026	08:00	6.61	22.36	90.00	Near-neutral
29	15-04-2026	12:00	6.70	24.67	90.00	Near-neutral
30	15-04-2026	16:00	6.65	27.47	90.00	Near-neutral
31	22-04-2026	08:00	6.60	22.00	90.00	Near-neutral
32	22-04-2026	12:00	6.63	24.29	90.00	Near-neutral
33	22-04-2026	16:00	6.57	26.67	90.00	Near-neutral
34	29-04-2026	08:00	6.61	21.62	90.00	Near-neutral
35	29-04-2026	12:00	6.65	22.77	90.00	Near-neutral
36	29-04-2026	16:00	6.67	27.16	90.00	Near-neutral

The pH values ranged from 6.47 to 6.70 and were interpreted as near-neutral for dashboard reading purposes. This small range indicates stable soil reaction during the monitoring period. Soil temperature showed a wider daily pattern because morning values were generally lower than midday and late afternoon values. Soil moisture stayed high for most observations, although a short decline appeared in early April. These variations show that the prototype could capture both stable and changing parameters.

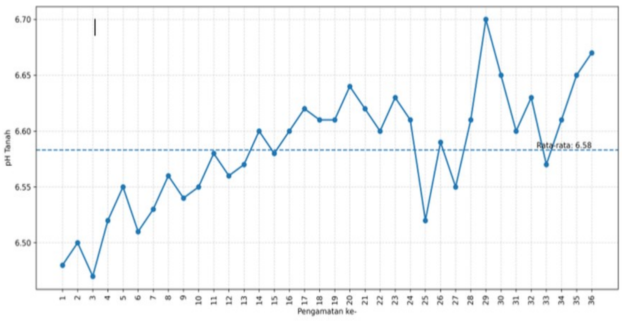
3.4. Descriptive Statistical Analysis

Table 4. Descriptive statistics of monitoring results

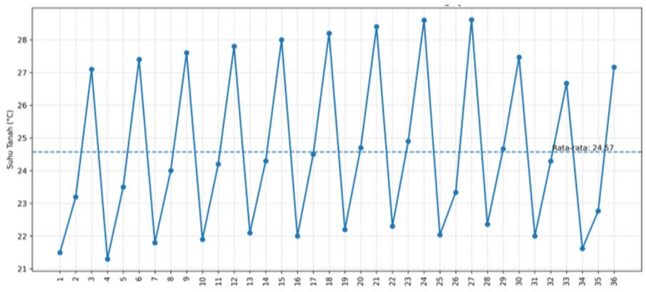
No	Parameter	n	Min-Max	Mean	SD	CV	Interpretation
1	Soil pH	36	6.47-6.70	6.58	0.05	0.81%	Stable and near-neutral
2	Soil temperature (°C)	36	21.30-28.61	24.57	2.50	10.19%	Fluctuated by observation time
3	Soil moisture (%)	36	73.67-90.00	87.71	3.65	4.17%	High, with a temporary decrease

Table 4 shows that soil pH had the lowest coefficient of variation, only 0.81%. This value supports the visual interpretation that pH was stable during the test. Soil temperature had the highest coefficient of variation, 10.19%, because it changed with the time of observation. This result is reasonable because the soil received different environmental exposure between morning, midday, and late afternoon. Soil moisture had a coefficient of variation of 4.17%, which suggests that the moisture condition was still relatively stable despite a temporary decrease.

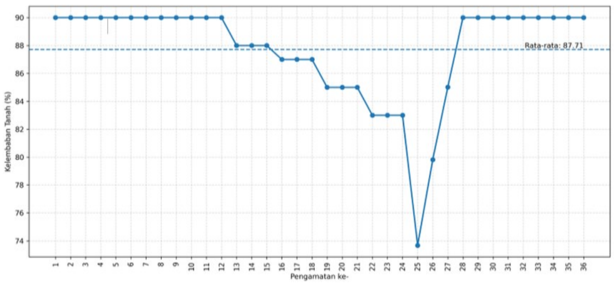
3.5. Trend Visualization



(a) Soil pH



(b) Soil temperature



(c) Soil moisture

Figure 6. Trend visualization of soil pH, temperature, and moisture

Figure 6 strengthens the interpretation from Table 4. The pH curve moves within a narrow interval and does not show abnormal jumps. The temperature curve forms a repeated fluctuation that follows daily observation time. The moisture curve remains high but drops during several observations before returning to 90%. This pattern demonstrates why multi-parameter monitoring is more informative than a single sensor reading. Stable pH alone does not describe the whole field condition because temperature and moisture still change across time.

The results also show the practical value of historical monitoring. A farmer or land manager can use the dashboard to see whether soil variables are stable, rising, falling, or temporarily abnormal. In this study, the early April moisture decline would be easier to notice through recorded trends than through occasional manual measurement. This is the basic logic of precision agriculture: decisions should begin with timely and documented field data rather than isolated observation.

3.6. Functional Validation

Table 5. System validation and accuracy limitations

Validation aspect	Observed indicator	Result	Note
Initial pH sensor calibration	Sensor reading before field use	The sensor displayed stable pH values	Further comparison with a standard pH meter is required
Reading consistency	Changes in pH, temperature, and moisture during observation	No unreasonable extreme spike was found	Consistency supports prototype feasibility
System integration	Data transmission from sensors to ESP32 and dashboard	Data appeared on the dashboard during functional testing	Performance depends on Wi-Fi quality
Data storage	Historical monitoring data	Records were stored and available for analysis	Supports periodic land documentation

Table 5 confirms that the prototype met the functional requirements of the study. The sensors could produce readable data, the ESP32 could process and send the values, and the dashboard could store and display monitoring records. However, the validation scope must be interpreted carefully. The test confirmed functional feasibility and reading stability, not absolute measurement accuracy. A future version should compare the sensor outputs with calibrated soil instruments to quantify error, bias, and acceptable tolerance.

3.7. Hardware and Software Testing

Table 6. Hardware functional testing results

No	Tested component	Testing result	Conclusion
1	Soil pH sensor	The pH value was read within 6.47-6.70	Operated as expected
2	Soil temperature sensor	The temperature value was read within 21.30°C-28.61°C	Operated as expected
3	Soil moisture sensor	The moisture value was read within 73.67%-90.00%	Operated as expected
4	ESP32 NodeMCU	Sensor data could be processed and sent	Worked as main controller
5	Local display	Sensor data could be shown on the device	Worked as local display
6	Wi-Fi/Internet	Data could be sent to the dashboard	Connection worked according to function
7	Hardware integration	All components could be connected	Hardware system followed the design

Table 7. Software black-box testing results

No	Tested feature	Testing result	Conclusion
1	Login page	The system accepted username and password	Operated as expected

No	Tested feature	Testing result	Conclusion
2	Monitoring dashboard	pH, temperature, and moisture data were displayed	Operated as expected
3	Sensor graphs	Graphs showed changes in sensor data	Operated as expected
4	Monitoring data table	Sensor data appeared in tabular form	Operated as expected
5	Manual input/device connection	The system accepted sensor data input	Operated as expected
6	Data storage	Monitoring data were stored as history	Operated as expected
7	Download data	Data could be downloaded in CSV format	Operated as expected
8	Logout	The system could exit the dashboard	Operated as expected

Tables 6 and 7 show that the system worked as an integrated monitoring prototype. The hardware could read and send sensor values, while the software could display, store, and export the data. These findings are relevant because the value of IoT monitoring does not come from a sensor alone. It comes from the complete data pipeline: sensing, processing, transmission, storage, visualization, and user access.

3.8. Comparative Discussion

The main finding of this study is that an ESP32-based IoT system can provide structured monitoring of soil pH, temperature, and moisture through a web dashboard. The field results indicate that the prototype is suitable for early-stage soil condition monitoring. The pH readings were stable and remained near-neutral, while temperature and moisture showed observable temporal variation. These results support previous work that positioned IoT as a practical technology for smart farming and data-based land management [12] [25].

Table 8. Comparison with related IoT-based agricultural monitoring studies

Study	Main focus	Position of the present study
Lestari et al. [3]	IoT prototype for soil pH and moisture monitoring	This study adds soil temperature, historical dashboard records, trend visualization, and explicit prototype limitations.
Barki et al. [4]	Soil moisture and pH monitoring for tomato plants	The previous work is crop-specific, while this study presents a general three-parameter soil monitoring model for early precision agriculture support.
Rilangi and Iqbal [5]	LoRa-based pH and soil moisture monitoring	The previous work highlights long-range communication, while this study focuses on ESP32, Wi-Fi, dashboard storage, and field-data documentation.
Sumarsono et al. [22]	IoT webserver, Android, and machine learning for soil pH	The previous work extends toward intelligent analysis, while this study limits the scope to functional prototype integration and multi-parameter monitoring.
Westari and Ilman [26]	ESP32-based automatic watering using moisture and DHT22 sensors	The previous work includes automation, while this study separates monitoring from actuator control to keep the prototype claim testable.

Table 8 clarifies the novelty position of the article. The proposed system does not claim to outperform long-range, mobile, automated, or machine-learning-based systems. Its contribution lies in combining three soil variables, web dashboard visualization, historical data storage, periodic field observation, and a clear functional validation scope in one early-stage monitoring model. This comparison leads to the final prototype outcome, where the strength of the model is evaluated from the completeness of the monitoring workflow rather than from sensor accuracy claims alone.

Compared with related studies summarized in Table 8, the integration of three soil parameters gives the proposed model a broader monitoring function than systems that focus only on soil moisture or only on pH. Soil pH indicates chemical reaction, soil temperature reflects thermal changes in the root environment, and soil moisture describes water availability. When the three parameters are presented together, users obtain a more complete picture of field condition. This is useful for precision agriculture because soil management decisions often require more than one indicator.

The dashboard also improves the usefulness of the prototype. Without visualization and historical storage, sensor readings would remain temporary values. The dashboard converts these readings into records that can be compared across time. This function is important for farmers, students, and researchers who need practical evidence before deciding whether to irrigate, evaluate soil treatment, or conduct further testing.

Nevertheless, the system is still a prototype and should not be interpreted as a final decision-making tool. The absence of calibrated instrument comparison limits the claim of measurement accuracy. The system was also tested at one agricultural location, so the results cannot represent all soil types, crop conditions, or network environments. In addition, the system only performs monitoring. Automatic irrigation, liming, fertilization, mobile notification, and predictive analysis were not implemented in this study. These limitations do not reduce the prototype function, but they define the boundary of what the present system can validly claim.

3.9. Final Prototype Outcome

The final outcome of the study is a functional IoT-based soil monitoring prototype that integrates sensing, data transmission, storage, visualization, and export features in one workflow. The result does not position the prototype as a final agronomic decision tool, but as a field monitoring model that can document soil condition data more systematically than manual observation.

Table 9. Final outcome of the prototype evaluation

Aspect	Final result	Interpretation
Monitoring variables	Soil pH, soil temperature, and soil moisture were recorded at 36 observation points.	The prototype covered three basic soil condition indicators.
Main field result	Mean pH = 6.58, mean temperature = 24.57°C, and mean moisture = 87.71%.	The monitored soil was near-neutral, with temperature fluctuation and high moisture.
System function	Sensor data could be read, sent, stored, displayed, and exported through the dashboard.	The prototype met the functional monitoring objective.
Scientific boundary	Sensor readings were not compared with calibrated laboratory instruments.	The result supports feasibility, not absolute measurement accuracy.

Table 9 summarizes the final result of the prototype evaluation. The system fulfilled the research objective because it produced a working monitoring pipeline from field measurement to dashboard documentation. The most important finding is not only the range of soil values, but also the ability of the prototype to organize periodic field data into readable and reusable records. This final result supports the article contribution as an early-stage precision agriculture monitoring model.

3.10. Interpretation of Monitoring Results

The monitoring results indicate that the prototype was able to document different soil condition patterns during the field test. Soil pH showed the most stable pattern, with a narrow range between 6.47 and 6.70 and a low coefficient of variation. This condition supports the interpretation that the soil reaction at the observation site was relatively stable and near-neutral during the monitoring period. However, this interpretation should be limited to dashboard-based field observation because the pH sensor readings were not compared with a calibrated laboratory instrument.

Soil temperature showed a wider variation than soil pH. This pattern was expected because temperature readings were collected at three different observation times: morning, midday, and late afternoon. The repeated increase and decrease in the temperature trend shows that the system could capture temporal changes in the field environment. Soil moisture also remained high in most observations, although a temporary decline was recorded in early April. This decline is important because it shows the usefulness of historical data storage. Without stored records and trend visualization, temporary changes in soil moisture would be more difficult to identify through manual observation alone.

These findings strengthen the role of the proposed prototype as an early monitoring model for precision agriculture. The system does not directly recommend irrigation, fertilization, or liming treatment. Instead, it provides structured field data that can support further interpretation by farmers, researchers, or agricultural officers. Therefore, the main value of the prototype lies in its ability to transform periodic sensor readings into documented information that can be reviewed over time.

3.11. Limitations and Future Work

Several limitations should be considered before the prototype is used as a wider decision-support tool. First, the field test used 36 periodic observations from one agricultural location, so the results describe prototype feasibility rather than a complete representation of different soil types, seasons, or crop systems. Second, the study did not record network latency as a separate variable. Therefore, the dashboard display should be interpreted as successful operational visualization during functional testing, not as a measured real-time performance value in seconds. Third, the sensor outputs were not compared with calibrated laboratory instruments, so the study cannot claim absolute measurement accuracy.

Future studies should validate pH, temperature, and moisture readings against standard instruments and calculate error values such as mean absolute error or percentage error. The monitoring period should also be extended, and the prototype should be tested under different soil textures, rainfall conditions, crop stages, and network environments. Further development can add threshold-based alerts, mobile access, power-consumption analysis, weatherproof housing tests, and automatic control for irrigation or liming after the monitoring accuracy has been verified.

4. Conclusion

This study developed an IoT-based prototype for monitoring soil pH, soil temperature, and soil moisture to support precision agriculture. The system integrated soil sensors, ESP32 NodeMCU, Wi-Fi communication, data storage, and a web dashboard. The prototype could read, transmit, store, export, and visualize soil condition data through the dashboard during functional testing. Field testing from February to April 2026 produced 36 observations. Soil pH ranged from 6.47 to 6.70 with an average of 6.58, soil temperature ranged from 21.30°C to 28.61°C with an average of 24.57°C, and soil moisture ranged from 73.67% to 90.00% with an average of 87.71%.

The results indicate that the proposed model is feasible as an early-stage monitoring system for data-driven soil management. The dashboard makes readings easier to access, review, document, and export. The system can therefore support preliminary precision agriculture practices by providing more structured soil information than manual and irregular measurement. However, the prototype should be interpreted as a functional monitoring model rather than a final agronomic decision tool. Future studies should compare sensor readings with calibrated instruments, test the system in wider and more diverse fields, extend the monitoring period, measure transmission delay, add automatic alerts, and integrate control functions only after sensor accuracy and field durability have been validated.

Acknowledgement

The author thanks the Department of Informatics Engineering, Faculty of Business Technology and Science, Universitas Dharma Wacana, for academic support during the preparation of this study. The author also acknowledges all parties who supported field testing and prototype documentation.

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