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Soil Fertilizer Recommendation System using Soil Analysis and Cloud IoT Platform

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***Abstract*—**Accurate soil nutrient measurement is vital for modern agriculture as it directly impacts crop yield and quality. By precisely assessing soil nutrient levels, farmers can make well-informed decisions regarding fertilization, irrigation, and other management practices, leading to increased crop yields and improved sustainability. The proposed system utilizes an NPK sensor, DHT11 sensor, and soil moisture sensor to continuously monitor soil conditions in real-time. The collected data, including nutrient levels, temperature, humidity, and moisture, is analyzed and transmitted to a cloud platform (Arduino IoT Cloud.) for remote monitoring. By implementing this IoT solution, farmers can optimize their agricultural practices, enhance crop yields, reduce the usage of chemical fertilizers, and overcome challenges such as labor shortages and limited farming knowledge. Additionally, the proposed system offers the capability to recommend appropriate fertilizer according to the NPK values detected in the soil, providing farmers with accurate information and convenient access to insights through mobile application. This contributes to sustainable and efficient farming practices.

Keywords*—Nitrogen, Phosphorus, Potassium, NPK Sensor, soil nutrients, Mobile Application, fertilizer recommendation, soil analysis.*

1. Introduction

The Internet of Things (IoT) refers to the interconnectedness of physical systems, devices, and vehicles that are equipped with sensors, software, and network connectivity [1]. This connectivity enables the collection and exchange of data, allowing for remote sensing and control of various parameters. By integrating the physical world with computer-based systems, the IoT offers benefits such as enhanced efficiency, accuracy, and economic gains, while reducing the need for human intervention [2].

Accurate and precise soil analysis is of utmost importance in modern agriculture as it directly influences agricultural productivity and crop quality. To achieve optimal crop yields, farmers need to have a deep understanding of the nutrient composition in their soil. This is where IoT-powered soil monitoring systems play a crucial role. These systems utilize advanced technologies and sensors to continuously monitor and track soil characteristics, providing farmers with real-time information and insights.

One key component of soil fertility is the presence of nitrogen, phosphorus, and potassium, commonly referred to as NPK. The NPK sensor used in this system allows farmers to accurately measure and monitor the levels of these essential nutrients in the soil. By having access to this vital information, farmers can make informed decisions regarding fertilization practices. They can adjust the application of fertilizers based on the specific nutrient requirements of their crops, ensuring optimal growth and minimizing the risk of nutrient deficiencies or excesses.

The system includes the utilization of a DHT11 sensor to measure temperature and humidity, alongside a soil moisture sensor for evaluating soil moisture content, in addition to monitoring nutrient levels. These sensors provide valuable data that helps farmers understand the environmental conditions in which their crops are growing. By having real-time information on temperature, humidity, and soil moisture, farmers can make adjustments to irrigation schedules

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and optimize water usage, promoting efficient resource management and reducing the risk of water stress or waterlogging.

One of the significant advantages of the proposed IoT-based system is its ability to control a humidifier and a pump through a relay. By analyzing the data obtained from the humidity and soil moisture sensors, the system can automatically regulate the operation of the humidifier and pump. This ensures that the system ensures proper maintenance of moisture in both the soil and the surrounding environment. within the desired range for optimal plant growth. Maintaining appropriate humidity levels can mitigate plant stress, facilitate nutrient absorption, and enhance the overall well-being of crops.

By integrating these technologies and sensors into the agricultural practices, farmers can optimize their crop production, overcome labour challenges, and reduce costs associated with excessive fertilizer use. Moreover, by maintaining the right balance of nutrients and moisture in the soil, farmers can promote sustainable farming practices, minimize environmental impact, and contribute to the long-term health and productivity of their land.

In conclusion, the use of IoT-powered soil monitoring systems, including the NPK sensor, DHT11 sensor, and soil moisture sensor, offers valuable insights into soil characteristics and environmental conditions. Using this data, farmers can make well-informed choices regarding fertilization, irrigation, and overall crop management strategies. This system aims to empower farmers with accurate information, enhance agricultural productivity, and promote sustainable farming practices for a more efficient and environmentally friendly approach to agriculture.

2. Related Work

Various sensors are employed to monitor important parameters of soil including moisture, pH, temperature, humidity, and light reaching into the soil [3]. The data obtained from these sensors is then changed into a digital format using an Analog to Digital Converter (ADC). The collected data is transmitted to the cloud through a Raspberry Pi, enabling users to conveniently view and monitor the data on a mobile phone application or a web application. The data is then accessible and can be displayed on a laptop or mobile application. This system utilizes IoT technology to effectively oversee the comprehensive soil characteristics [4-5].

To ensure optimal crop productivity, the project incorporates the use of sensors to continuously measure and monitor crucial soil parameters, including pH level, soil moisture, temperature, and humidity. Designing of this system is to enhance soil fertility and improvise the quality of soil through the implementation of an optical transducer [6]. The levels of nitrogen, phosphorus, and potassium (NPK) are classified into three categories: low, medium, and high. Data acquisition is performed using an Arduino microcontroller, which converts the analog output into digital format for further processing.

In this project, a system is being developed that integrates a microcontroller-based device with an EC sensor, pH sensor, and color sensor [7]. The sensor readings are collected and wirelessly transmitted to a mobile application through Bluetooth serial communication. Furthermore, a proposed system utilizes artificial neural networks and image processing techniques to detect soil parameters and accurately determine the pH level [8]. The methodology employed in this system incorporates a color recognition method which focuses on creating a soil nutrient analyzer with the capability to determine pH levels. This analyzer incorporates various sensors to accurately measure soil nutrient levels and provide pH analysis.

3. Proposed Approach

The proposed approach is an IoT-powered soil monitoring solution for agriculture. It

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integrates sensors such as NPK, DHT11, and soil moisture sensors to collect real-time data on soil nutrient levels, temperature, humidity, and moisture. The collected data is analyzed and transmitted to a cloud platform (Arduino IoT Cloud.) for remote monitoring, providing farmers with insights to optimize fertilizer application, irrigation, and overall crop management.

Methodology

The primary objective of the proposed system is to monitor NPK values in the soil and suggest the fertilizers required based on the values collected. Fig. 1 depicts the block diagram illustrating the system architecture proposed in this system which incorporates the ESP32 microcontroller as the central processing unit. It employs various sensors including the NPK sensor, DHT11 sensor, and soil moisture sensor to collect real-time data on crucial soil parameters. The NPK sensor is interfaced with the microcontroller using a MAX485 TTL to RS485 module which can be observed in the fig. 2, circuit diagram of the proposed system.

The ESP32 microcontroller efficiently reads and processes the sensor data, extracting valuable insights regarding fertilizer requirements, soil moisture content, and environmental conditions like temperature and humidity. This processed information is then transmitted to the Cloud IoT (a service by Arduino.) through a Wi-Fi connection, enabling remote monitoring and analysis of the soil conditions for effective agricultural management.

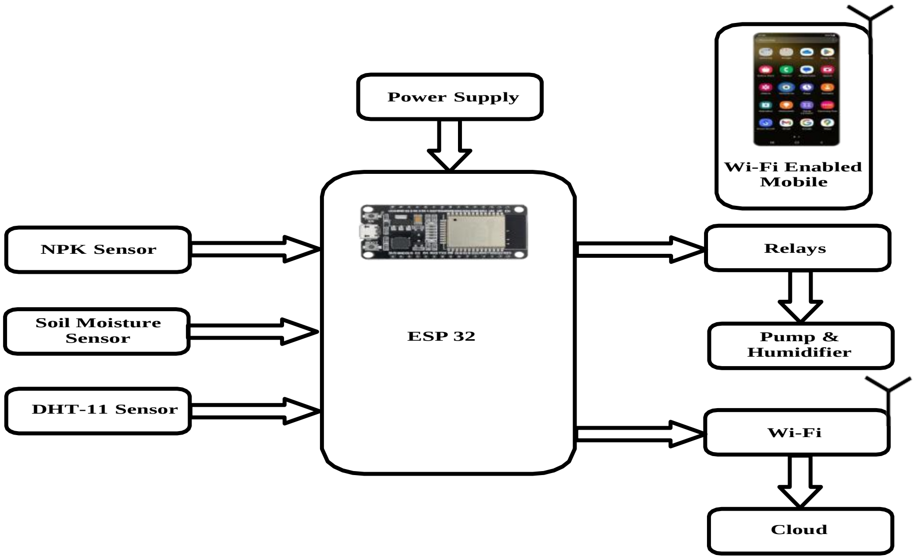

Fig 1. Illustration of block diagram of the Proposed System.

IoT Cloud, a service by Arduino, is a cloud-based platform provided by Arduino that enables developers to securely connect and manage their IoT devices and applications. It provides secure communication, data storage, and remote control capabilities. Developers can create custom dashboards to visualize real-time data from their devices, set up triggers and alerts, and remotely control device parameters.

NPK Sensor

NPK sensors play a key role in determining soil fertility by quantifying the concentrations of nitrogen, phosphorus, and potassium, which are essential elements in soil fertilization. By analyzing the nutrient concentrations in the soil, NPK sensors provide valuable information

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about potential deficiencies or excesses of these nutrients, enabling improved plant production. Assessing soil nutrient levels through NPK sensors allows farmers to make informed decisions about fertilization strategies, leading to optimized nutrient management and enhanced crop growth.

Fig 2. NPK Sensor

The employed sensor in the system operates without the need for chemical reagents and offers notable advantages such as high measurement accuracy, swift response speed, and wide compatibility with various microcontrollers. However, due to the presence of a Modbus Communication port on the sensor, direct connection to the microcontroller is not feasible. To facilitate the connection and enable communication between the sensor and the microcontroller, the utilization of a Modbus Module, such as the RS485/MAX485 module depicted in Fig.2, becomes necessary. The sensor is designed to operate within a voltage range of 9-24V while consuming minimal power. It achieves an impressive accuracy level within 2% and provides a fine resolution of 1 mg/kg (mg/l) for precise measurement of nitrogen, phosphorus, and potassium levels. The advancement of portable sensing technology has allowed many previously lab-based procedures for determining N, P, and K (nitrogen, phosphorus, and potassium) to cater to the dynamic nature of field measurements in agriculture, the system is designed to be adaptable for on-site applications., as mentioned in [9]. These portable sensing applications offer the potential for efficient and convenient nutrient analysis in agricultural settings. Table 1 presents the specifications of NPK sensor.

Table 1 Npk Sensor Specifications

Sensor Model	JXBS-3001-NPK-RS
Range	0-1999mg/kg
Accuracy	±2%F.s
Input Voltage	12V-24V DC
Output Signal	RS485

Soil Moisture Sensor

A soil moisture sensor gauges the soil's moisture content by employing resistive method. It typically consists of two metal electrodes embedded in the soil, and the moisture level affects the resistivity between the electrodes. As the soil moisture increases, the resistivity between the electrodes decreases. By measuring the resistance, the sensor can determine soil moisture content. These are commonly used in gardening, agricultural applications, and automated irrigation systems. According to [10], soil moisture sensors can offer immediate data on the moisture level within the root zone, enabling timely water application. Considering the variability in working principles among different soil moisture sensors and their dependence on

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soil type, It is crucial to consider the pros and cons of each sensor during the selection process, as mentioned in [11]. One notable advantage of these sensors is their ability to provide continuous near real-time measurements, which can be transmitted to irrigation managers through telemetry and accessed on computers or handheld communication devices, as highlighted in [12]. Table 2 provides the specifications of the soil moisture sensor.

Table 2 Soil Moisture Sensor Specifications

Sensor Model	FC28
Range	0-1023
Soil Probe Dimension	6cm×3cm
Input Voltage	3.3V – 5V
Output Signal	Analog

DHT - 11 Sensor

The DHT-11 sensor is utilized for measuring the temperature and humidity levels in the field. It is equipped with a reliable single-wire digital interface, making it suitable for integration into a variety of projects. The sensor operates within a moderate measurement range and provides a satisfactory level of accuracy, with temperature readings typically having a precision of around ±2°C and humidity measurements with an accuracy of approximately ±5%. According to the research referenced in [13], the optimal soil temperature for planting ranges between 18-24°C. It has been observed that higher soil temperatures can stimulate nitrogen mineralization by promoting microbial activity and accelerating the decomposition of organic matter in the soil. The specifications of DHT-11 sensor are given in Table 3.

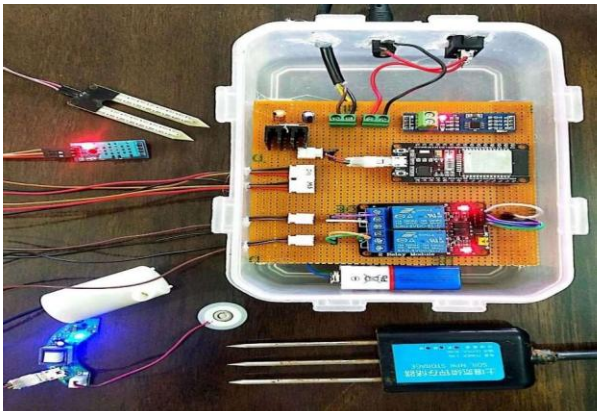
Table 3 DHT-11 Sensor Specifications

Sensor Model	DHT11
Range	20-90%RH 0-50°C
Humidity Accuricy	±5%RH
Temperature Accuricy	±2°C
Input Voltage	3.5V – 5.5V
Output Signal	Serial Data

Completed Prototype

The circuit is designed for the problem discussed and is implemented in various conditions to verify the working of the setup. Below are the steps for implementation of the proposed system. Overview of the project is given in the Fig. 3

Fig.3 Overview of the Proposed System.



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4. Results and Discussion

This chapter encompasses a detailed discussion of the results, including the presentation of calculations, statistical analyses, and interpretations. The findings are thoroughly examined and contextualized, contributing to a comprehensive understanding of the research outcomes.

Calculations

Let the area of the land covered be 1 hectare, The NPK sensor probe is typically inserted into the ground at a depth of 10 centimeters, density of the soil is given as 1200 kilogram per meter cube.

i. Area = 1ha = 10000 m^2
ii. Depth = 10 cm = 0.1 m
iii. Bulk Density (Density of soil) = 1200 kg/m^3

Volume = Area × Depth = 10000 × 0.1 = 1000 m^3
Mass = Volume × Density = 1000 × 1200 = 1200000 kg/ha.

Let the value of nitrogen obtained by NPK sensor be 67 mg/kg.
Then, for 1 ha → 67 × 1200000 = 80400000 mg = 80.4 kg/ha

These calculations are required as the use of mg/kg (milligrams per kilogram) is commonly used unit in soil measurements. It represents the concentration or content of a substance in the soil on a mass basis. However, the choice of units depends on the specific context and requirements of the analysis. While mg/kg may be suitable for discussing trace elements or contaminants in soil, kg/ha is often preferred for expressing nutrient levels or fertilizer application rates at an agricultural scale, providing a more practical and meaningful representation of quantities in relation to land area.

Crop nutrient needs and fertilizer recommendation based on NPK values

Crop nutrient needs refer to the specific requirements of essential NPK for optimal growth and development. These elements play crucial roles in various physiological processes of plants. By understanding the crop's nutrient needs and using NPK values as guidelines, the system can make informed decisions regarding fertilizer selection and application, thereby supporting healthy plant growth and maximizing crop productivity. The crops considered for analysis include Rice, Cotton, Maize, Turmeric, and Chillies as mentioned in Table 4.

Table 4 Optimum Values of NPK for various Crops

Name of Crop	**Nutrients**					
	Nitrogen		***Phosphorus***		***Potassium***	
	Min	***Max***	***Min***	***Max***	***Min***	***Max***
Rice	100	120	40	50	40	50
Cotton	120	150	60	80	60	80
Maize	120	150	60	80	40	60
Turmeric	60	90	60	80	60	80
Chillies	60	90	40	60	60	90

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Farmers commonly use several fertilizers to enhance crop productivity. The choice of fertilizers depends on the specific crop, soil type, and nutrient requirements. The selection of these fertilizers for the system is based on the farmers' familiarity and knowledge of these fertilizers, as they are well aware of their properties and know how to utilize them effectively which are:

- *Urea:* Urea is a nitrogen-based fertilizer and is extensively used in Telangana. It provides a quick supply of nitrogen to crops, promoting their growth and development.
- *Diammonium phosphate (DAP):* DAP is a widely used phosphorous-based fertilizer. It provides a high concentration of phosphorous, which is crucial for root development, flowering, and fruiting of plants.
- *Muriate of Potash (MOP):* MOP is a potassium-based fertilizer. It supplies potassium to crops, which is important for various physiological processes such as water regulation, disease resistance, and overall plant vigor.
- *Superphosphate:* Superphosphate is a phosphorous fertilizer, usually in the form of single superphosphate or triple superphosphate. It provides a readily available form of phosphorous to plants.
- *NPK Complex Fertilizers:* These fertilizers are composed of a blend of nitrogen (N), phosphorus (P), and potassium (K) in varying ratios. They are formulated to meet the specific nutrient requirements of different crops and are often preferred for their balanced nutrition.

Visual outputs displayed on Cloud IoT dashboard

The dashboard interface on the webpage of Arduino IoT cloud can be seen in the Fig.4 a and the Fig.4 b) Illustrates the appearance of the dashboard on the mobile application. Fig.5 Illustrates the graph of nitrogen values on IoT Cloud website. Fig.6 shows the graph of phosphorus values on IoT Cloud website. Fig.7 shows the graph of potassium values on IoT Cloud website. Fig.8 shows the communication of user with proposed system to check status on the mobile app dashboard. Fig. 9 shows the communication of user with proposed system to check analyzed data and fertilizer recommendation on the mobile app.

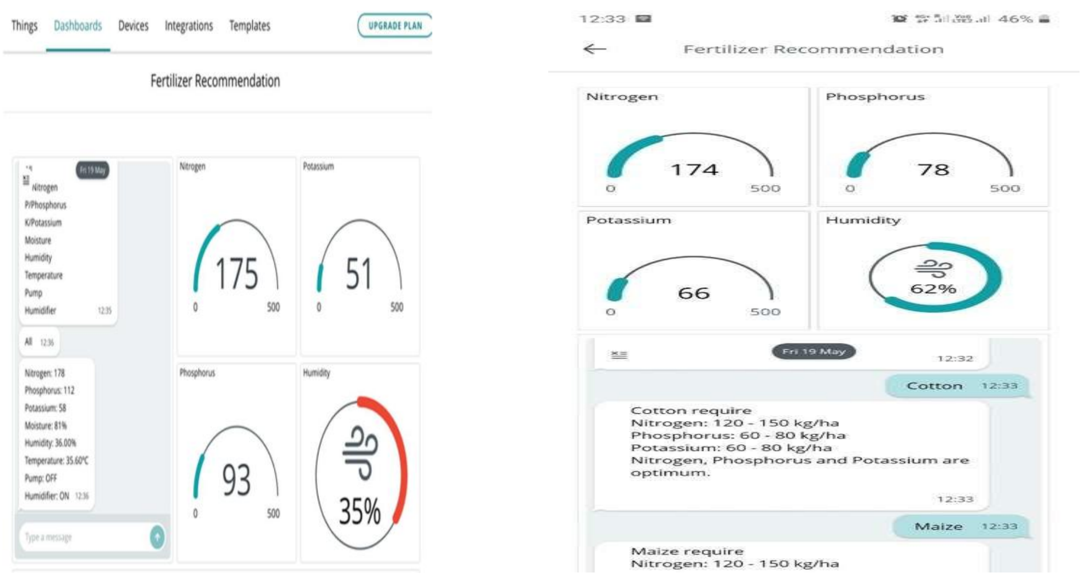

Fig 4. a)Web Dashboard.b) Mobile Dashboard.

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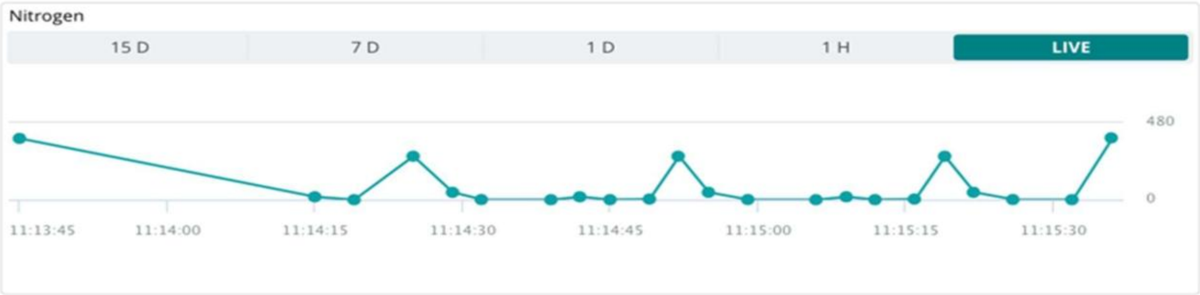

Fig 5 Nitrogen values on IoT Cloud.

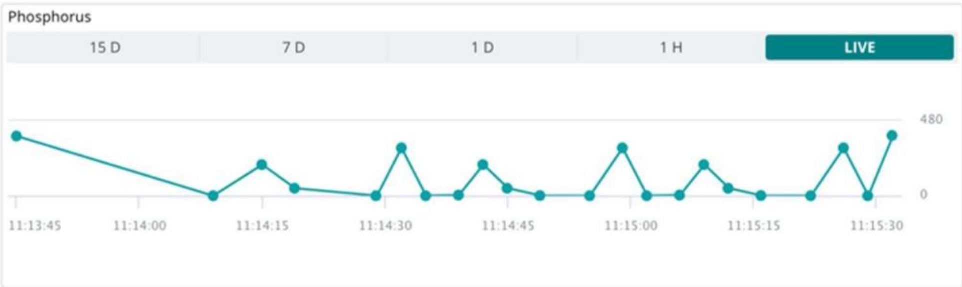

Fig 6. Phosphorus values on IoT Cloud.

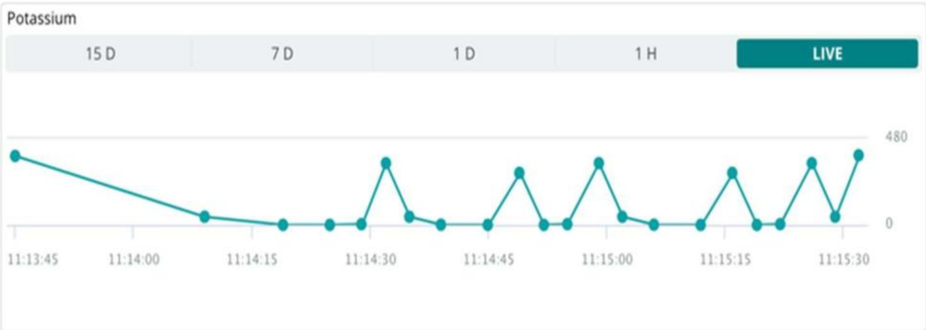

Fig 7 Potassium values on IoT Cloud.

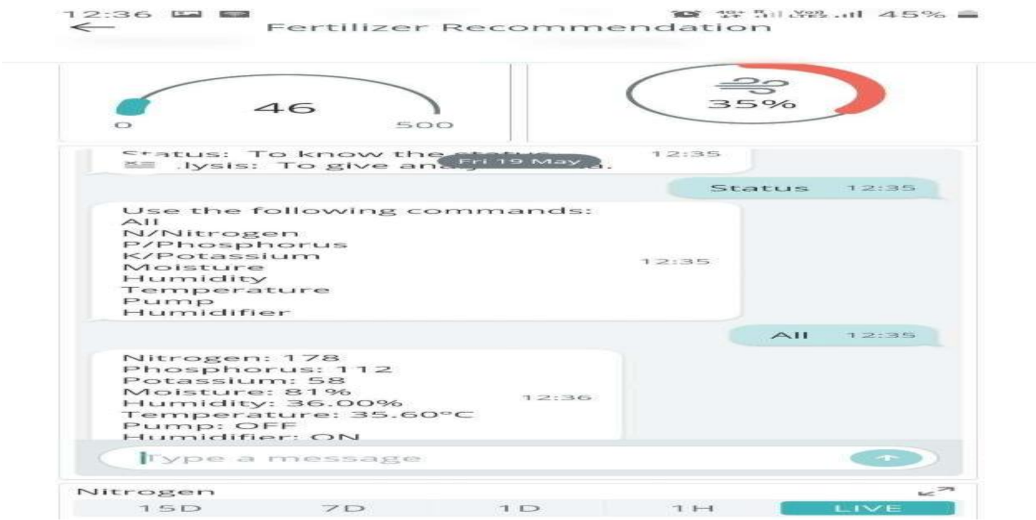

Fig 8 Checking Status.

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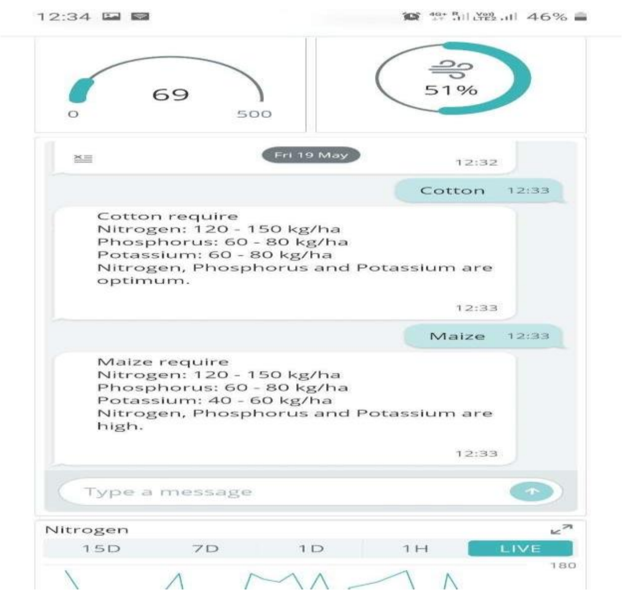

Fig 9. Checking Analyzed Data.

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5. Conclusion

The proposed system aims to develop a wireless soil monitoring system using sensors such as NPK, DHT11, and soil moisture sensors, which are connected to an ESP32 microcontroller. The collected and processed data, including fertilizer recommendations, soil moisture, temperature, and humidity, is transmitted to the Arduino IoT Cloud server, website, and mobile application. This cost-effective and portable system improves soil analysis accuracy, enhances agricultural productivity, and promotes sustainable farming practices. The Soil NPK sensor, compatible with various microcontroller boards, provides precise and quick measurements of nitrogen (N), phosphorus (P), and potassium (K). Overall, the system highlights the potential of wireless sensor networks in agriculture and the need for accessible solutions for small-scale farmers.

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