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An IoT-based Real-Time Soil Monitoring with Commentary on the Crop Fertilization System

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Abstract:

This study emphasizes the importance of an iterative, improvement-based soil quality monitoring system. Improving our ability to detect and avoid soil desertification requires a plan to sustain and enhance these biological systems over the long run. Predicting soil health and providing a comprehensive, real-time understanding of soil conditions across any given region requires accurate monitoring of key soil characteristics, including temperature, moisture, pH, and nutrient levels (NPK). Because of this, cutting-edge technical solutions must be implemented to increase the crop yield. Plants rely on NPK (Nitrogen, Phosphorus, and Potassium) for vital nutrients that promote healthy development, strong roots, and general well-being. However, the availability of these nutrients depends on soil pH. Careful examination of the soil is required before planting any crop. The proposed system can monitor soil pH, NPK, Temperature, and Humidity.

Farmers can ascertain the appropriateness of management using this method. The Arduino initializes all peripherals, such as the LCD, RS485 modules, serial communication ports, and sensor libraries, when the system is powered on, enabling continuous data collection. Monitored data can be viewed on the LCD on the spot, and it is collected in the cloud in parallel via an IoT module. In this article, soil samples from Thiruvallur district, collected from many terrestrial and terrace gardens and from the main seven places, are tested using the proposed soil monitoring hardware, and the data are stored in the cloud using IoT for future Work on implementing AI-based prediction methods. Profitable crops and mainstays make up the bulk of Thiruvallur's agrarian output. A soil EC value below 1.0 dS/m indicates that the soil is not exposed to salt. For the most part, Thiruvallur soils are suitable for planting. Soil testing is essential before planting any crop. Soil testing helps farmers identify which crops will thrive in a given area and creates a personalized fertilization strategy.

Keywords: Soil Characteristics, Real-time soil nutrients, Thiruvallur District, Crops, and fertilizer.

1. Introduction

The expansion and improvement of any nation's economy is closely tied to agriculture. Climate change has had a devastating effect on agricultural output. Hence, a plethora of cutting-edge technologies are being developed to implement smart agriculture, which can adapt to changing weather conditions and enhance both the quantity and quality of agricultural goods (1). This article suggests one such approach. The developed technique is an innovative, easy-to-understand approach to implementing smart agriculture using the Internet of Things. The suggested method involves automating soil moisture regulation and remotely monitoring critical soil parameters using a software and hardware combination. In the southern state of Tamil Nadu, Tiruvallur is a fast-developing district (2). The agricultural sector in Tiruvallur district plays an important role in India's food security by meeting demand for paddy, rice, pulses, and vegetables through the use of sophisticated, high-yielding farming techniques. Industrial farming and the export of valuable horticultural products make this area an economic and food security boon to India. Water for irrigation in this region comes mostly from the monsoon, with some help from tanks and rivers such as the Kosathalayar, Adyar, and Cooum in the south (3).

The northern and western areas of Tiruvallur district, which are closer to Chennai, have more farmland and are therefore more heavily used for agricultural purposes (4). Nearly 47% of the district's employment is involved in agriculture. Rice, often known as paddy, is the most widely farmed food crop in the Thiruvallur district, occupying more than 7 out of 10 hectares (5). Groundnuts take up over 20% of the arable land, right behind peanuts. The blocks of Minjur, Sholavaram, Ponneri, Ellapuram, and Tiruvallur are well-known for their paddy fields and green gram crops (6).

The main sources of black gram and sugarcane are the Tiruthani, Tiruvalangadu, RK Pet, and Pallipat blocks. The net cultivated area of the district is around 89,383 hectares, with paddy taking up more than 101,000 hectares of that over the multi-season cycle(7).

The other states rely on Tamil Nadu as a main supplier of food grains. When it comes to groundnuts, maize, cumbu, and oil seeds, Tamil Nadu is unrivaled. Following cereals, coconut, and rice, it ranks second(8). The soil types found in the research region are clay loam, salty coastal alluvium, and red sandy loam, and are ideal for growing rice and other plants (9). In the research region, 70% of the land is used for rice cultivation, while 30% is devoted to horticulture(10). Much of the region's wealth comes from farming, which employs more than 80% of the locals (11).

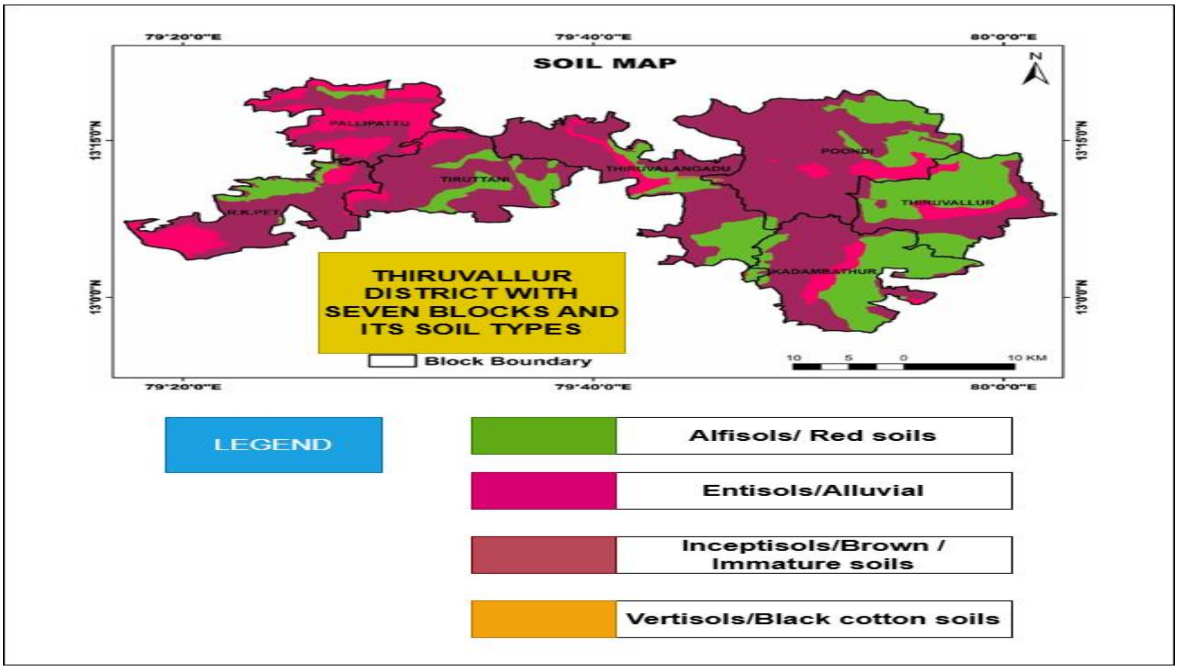

Figure 1: Thiruvallur District main blocks, Soil types

As shown in Figure 1, spanning 1557.07 sq km, the Thiruvallur district is a prominent district in Tamil Nadu. Since the land-use conditions in this area make it vulnerable to floods and droughts, and since more than 70% of the population relies on agriculture. The seven blocks that make up the district's rural area are RK Pet, Pallipattu, Tituttani, Thiruvalangadu, Poondi, Kadambathur, and Thiruvallur. The study region is bordered to the north by Andhra Pradesh, to the south by the Chennai district, to the east by Poondi and the Vellore district, and to the west by the Bay of Bengal. The research area spans 1557.07 square kilometers and is located between the longitudes of 79°17′34.8″ and 80°2′34.8″ to the east and the latitudes of 13°20′31.2″ and 12°56′27.6″ to the north (12).

A variety of processes, including transpiration, nutrient transport, photosynthesis, and temperature regulation, are heavily influenced by leaf humidity. Stomatal opening, water stress prevention, and optimal mineral and water flow from roots to leaves are all supported by optimal leaf humidity. Additionally, it aids in predicting disease incidence and enhancing crop quality and output. Humidity, temperature, and NPK levels are crucial for plants to grow to their full potential. The rates of photosynthetic reactions, root development, and seed germination are all controlled by temperature. Plant growth slows, and production reduces when temperatures are too high or too low. Plant transpiration loss and disease transmission are both affected by Humidity. Low Humidity promotes wilting, whereas high Humidity might worsen fungal infections. The three most essential soil nutrients are nitrogen (N), phosphorus (P), and Potassium (K). Phosphorus promotes root and flower development, whereas Potassium increases a plant's resistance to disease and increases the area of its leaves. Consequently, when conditions are ideal for temperature, Humidity, and NPK levels, crop development is optimal, yield is increased, and fertilizer waste is avoided. The quantity of soluble salts in the soil water is the primary determinant of the electrical conductivity (EC). This crucial soil metric indicates how well the soil conducts electricity. Ionic forms of nitrogen, Potassium, calcium, and magnesium are included in these soluble salts, which are vital plant nutrients. Consequently, EC is a popular tool for measuring soil salinity and total nutrient availability. Soils with low electrical conductivity (EC) values are not very salty. Still, soils with high EC values are quite salty, limiting the amount of water plants can take in through their roots and ultimately reducing their yield.

Factors such as weather, soil pH, soil moisture, leaf humidity, and dust pollution significantly impact farming in the Thiruvallur district (13). Crop development and yield are affected by factors such as mildly acidic soils, hot summer temperatures, uneven soil moisture, and a lack of available nitrogen (14). Hail on plants regulates transpiration and disease incidence, whereas dust on leaves inhibits photosynthesis(15). The future of farming in the area depends on monitoring and controlling these variables (16).

The main objectives of this research are as follows.

- The importance of soil nutrients, soil pH, soil temperature, and Humidity, leaf humidity, and dust monitoring in agriculture, and their uses, has been discussed.
- The main blocks of the Tiruvallur district, with their respective soil types and characteristics, are discussed.
- Thiruvallur District, Tamil Nadu, is suggested here for the real-time monitoring of soil parameters in terrestrial gardens and farmland, as tabulated in the results and discussion. This article has the following structure, as shown in Figure 2.

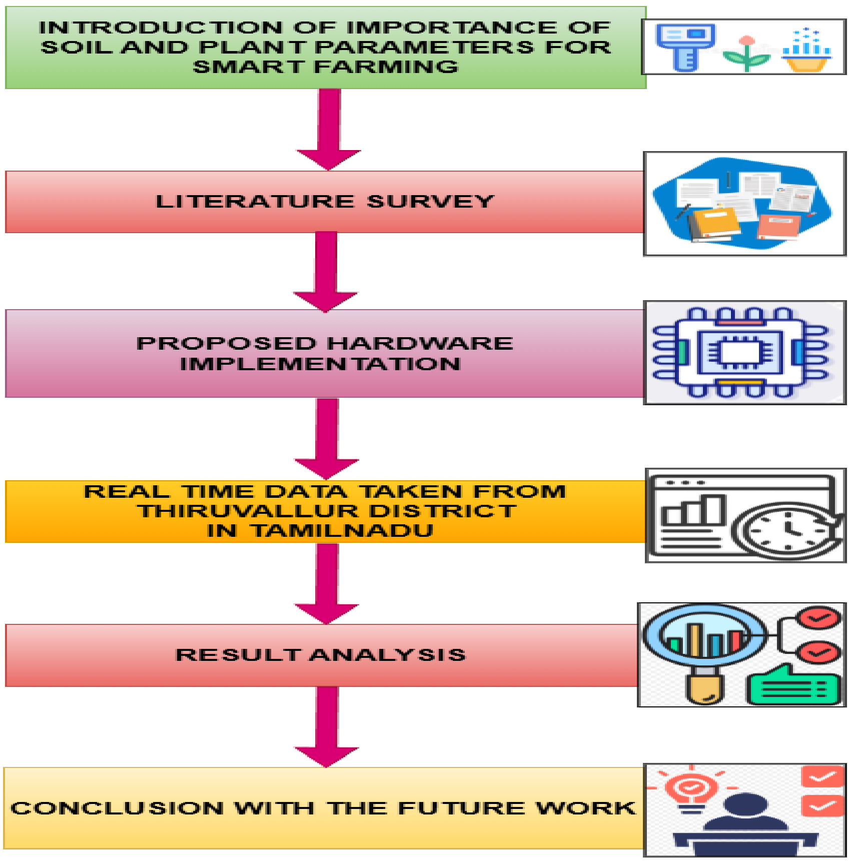

Figure 2: Flowchart of the article structure

2. Literature survey

Postolache, S., et al presented (2023) IoT-Based Systems for Soil Nutrients Assessment in Horticulture. Researchers introduce a horticulture farm information system that leverages various sensing capabilities, the Internet of Things, and a mobile app. Also included is a synopsis of the many methods and tools available for determining soil fertility. We address the difficulties identified in the literature and in the field as we discuss the outcomes of a botanical garden that mimics the variety of environments and plants found on a horticulture farm. Research like this gives horticulture growers a leg up in managing their resources, both theoretically and practically(17).

Pace, R. et al. (2025). Artificial intelligence in soil microbiome analysis: A potential application in predicting and enhancing soil health—a review. A crucial step in creating sustainable agriculture is characterizing and preserving soil biological health. Soil microbiota data can be used to build models that monitor and predict soil health. Researchers reviewed all the studies that have used Artificial Intelligence (AI) approaches to do this. Furthermore, we explored the potential of using Decision Support Systems (DSSs) powered by AI to utilize microorganisms better to improve soil fertility and health(18).

Valentina-Daniela B. et al. (2025) presented an Advanced Autonomous System for Monitoring Soil Parameters. The purpose of this paper is to lay out all the necessary steps for creating a soil quality monitoring system that can be used in a laboratory setting. The methodologies used were the implementation of the data acquisition infrastructure, sensor calibration, and sensor deployment(19).

Senapaty, M. K., et al. (2023). IoT-Enabled Soil Nutrient Analysis and Crop Recommendation Model for Precision Agriculture. An optimized-cost sensing system was built using several sensors, including an Arduino UNO board, soil temperature and moisture sensors, a pH and water level indicator, a GPS and color sensors, and so on. Our ability to measure Humidity, temperature, water level, soil NPK color values, date, time, longitude, and latitude was made possible by this sensory system. Firebase Cloud Storage was used to store all acquired data. Then, a farmer might periodically access and analyze data stored in the Firebase cloud service using an Android app. A new strategy was discovered in this study by combining several types of algorithms(20).

Biswas, S. (2018) presented A remotely operated Soil Monitoring System: An Internet of Things (IoT) Application. This article investigates an Arduino-based, GSM-networked soil monitoring system. Data on the aforementioned parameters is collected by the Arduino-attached sensors, which then communicate with the client's mobile device via GSM network and deliver an SMS message. First, the data will serve as a repository for soil data that may be used in studies focusing on the soil health of a specific area. Eventually, it will give national soil health data(21).

Wu et al. (2023) reported an Internet-of-Things-based multiple-sensor monitoring system for soil information diagnosis using a smartphone. A new approach to soil data prediction was investigated simultaneously using the DQN reinforcement learning algorithm. The DQN Bi-OS-P prediction model was created by combining a weighted bidirectional long short-term memory with an online sequential extreme learning machine and parallel extreme machine learning. To accurately diagnose soil conditions, the suggested data-gathering system collected time-series soil data at regular intervals over an extended period. Compared to previous approaches, the DQN Bi-OS-P minimized RMSE, MAE, and MAPE and increased R2 by 0.1%(22).

Reljić, M., et al. (2023). Advanced continuous monitoring system—tools for water resource management and a decision support system in a salt-affected delta. This article discusses the most up-to-date automated continuous water quality monitoring systems. Our personal experience in deploying a similar system in the Neretva River Delta along the Adriatic coast of Croatia is also incorporated. The installed system monitors several soil and meteorological factors, as well as water parameters such as temperature, pH, EC, TDS, and DO. Data is made available to different parties through a database and an online site at high frequency. Models for predicting water quality characteristics and for guiding future management may be developed from large datasets collected through continuous monitoring(23).

Islam, M. R., et al. (2023) presented a Machine-Learning-Enabled IoT system for soil nutrient monitoring and crop recommendations. This study presents a novel Internet of Things (IoT) device that uses machine learning to track soil nutrient levels and provide precise planting recommendations. Soil composition, moisture, temperature, and nutrient levels can be monitored in real time using the FC-28, DHT11, and JXBS-3001 sensors integrated into the device. The MQTT protocol is used to transfer the gathered data to a server. To provide personalized suggestions based on crop needs and soil nutrient levels, machine learning algorithms analyze collected data and generate a list of potential high-yielding crops, the names of fertilizers, and the amounts to apply. In addition, the database tracks the fertilizers and treatments applied to the field during production(24).

Nadporozhskaya, M., et al. (2022). Recent advances in chemical sensors for soil analysis: a review. An overview is provided of the principles of operation, advantages and disadvantages of chemical sensors used in soil analysis, and specific uses of single-sensor and multi-sensor systems for evaluating pollutants, primary plant nutrition components, and other significant soil parameters (such as pH, moisture content, salinity, exhaled gases, etc.) during the last twenty years, with a focus on the most recent five years (2017–2021)(25).

Based on these reviewed papers, the proposed methodology has been designed to monitor the soil nutrients.

3. Proposed methodology

The proposed methodology helps quickly identify soil nutrient measurements. The traditional methodology has taken many days to determine nutrient levels. Here, an Arduino Mega 2560 is used for Internet of Things automation.

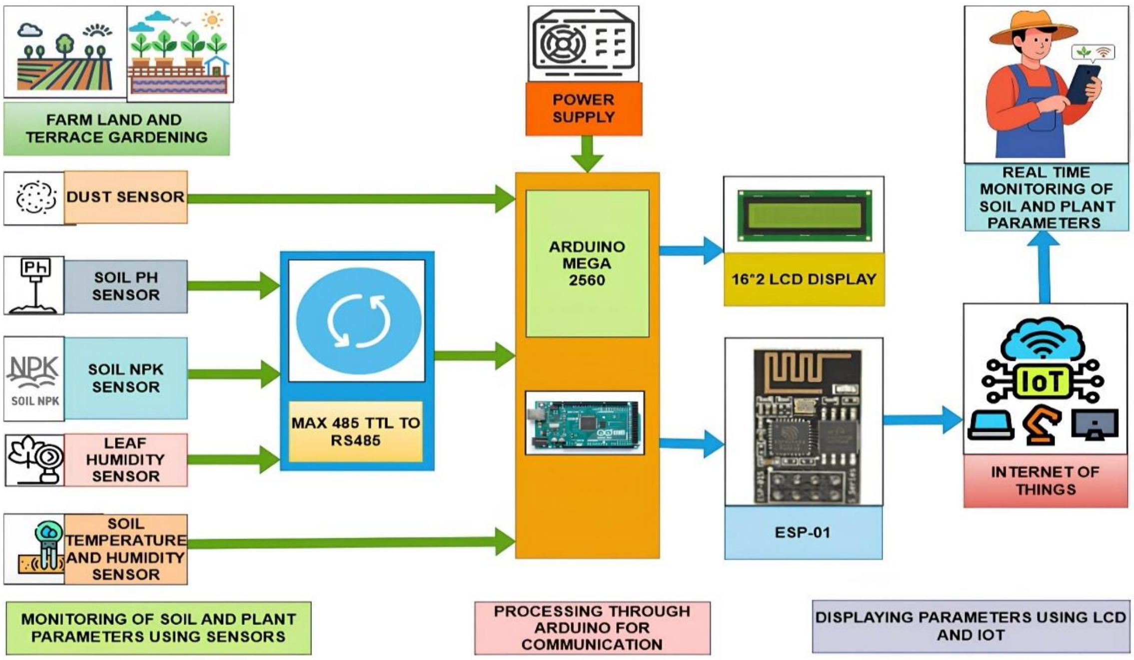

Figure 3. Modelling of IoT-Based Soil Nutrients Monitoring Proposed Work

As shown in Figure 3, the Arduino Mega 2560 is the system's CPU. For real-time soil condition, temperature, Humidity, dust level, and plant health data, it interfaces with environmental and soil-based sensors. Data is sent and monitored locally and remotely via a Wi-Fi module and display device. The ground-based regulated power source powers all sensors and modules. While most sensors receive 5V from the Arduino Mega, the ESP-01 Wi-Fi module requires 3.3V. All peripherals, including the LCD, RS485 modules, serial communication ports, and sensor libraries, are initialized by the Arduino upon powering the system for continuous data collection. Arduino Mega supports soil NPK, pH, and leaf humidity sensors using MAX485 TTL-to-RS485 modules. These Modbus-enabled sensors communicate over differential RS485 lines (A and B). The Arduino communicates Modbus inquiry commands via its hardware serial ports, and MAX485 modules convert TTL serial data to RS485 signals. Use the direction control pins (DE and RE) to switch transmission and reception modes for a reliable two-way connection with each sensor. Data on soil water and dust concentration are provided via analog voltages from moisture and dust sensors, respectively. The Arduino's analog input pins receive this data. The analog-to-digital converter (ADC) on the Arduino digitizes these voltages, which are then calibrated and mapped to coincide with data from the surrounding environment. The digital input ports of the Arduino Mega can communicate with DHT22 sensors over a single-wire digital interface. The sensor periodically sends accurate temperature and humidity readings to the Arduino, which it uses for environmental monitoring and analysis. For engineering purposes, such as converting temperature, Humidity, soil moisture, dust density, pH, and nutrient content readings, Arduino filters out background noise and analyzes all sensor outputs. Only reliable data values are presented and transferred by using validation logic and threshold checks.

4. Result and Discussion

Soil samples were collected from the Thiruvallur district blocks and analyzed using the proposed methodology, as discussed in the following results and discussion. Plants need a specific ratio of nutrients or minerals (45%), organic matter (5%), air (25%), and water (25%) to produce crops of sufficient quality and health. Good crop production, healthy crop development, and appropriate crop selection all depend on soil nutrients. Growing food for humans and other animals is known as agriculture. All plants require plenty of water, air, and sunlight. The necessary data may be obtained by measuring the various features. Soil NPK measurements can help maintain track of all these necessary nutrients. NPK analyses indicate the appropriate nutrient levels. Along with research, nutrient availability, and real needs can be estimated using NPK and pH testing. Here, the terrace garden plants in Thiruvallur district are being sampled, tested with hardware, and the sensor outputs are displayed and saved in the cloud for future use.

Figure.4: Different soil samples collected from Thiruvallur district gardens

The different soil samples taken from the garden are shown in Figure 4. Here, garden soil samples from Maduravoyal, Nerkundram, Velappanchavadi, and Thiruvallur are shown. Nearly 150 samples from the garden have been collected, and the readings have been tabulated in the cloud.

Figure 5. Hardware Implementation of IoT-Based Soil Nutrients Monitoring System – Sensors all inserted into the soil, and reading of nutrients displayed

As shown in Figure 5, NPK, pH, and Temperature and Humidity sensors are inserted into the soil to monitor actual nutrient levels, which are displayed on an LCD. Every two minutes, the next reading is collected via an IoT device.

Figure 6. Hardware Implementation of IoT-Based Soil Nutrients Monitoring system, also checking the pollution, leaf wet, and temperature.

As shown in figure 6, the leaf and dust sensors are located to monitor leaf wetness and temperature values along with dust values. Continuous monitoring of these values is loaded in the cloud. The following tables (1, 2, and 3) show the soil test data from Thiruvallur district.

Table 1: Tested Soil data from Thiruvallur district terrestrial garden blocks of soil moisture, temperature, and Humidity

Date with Time	Soil Moisture (%)	DHT22 Temperature (°C)	DHT22 Humidity (%RH)
10-03-2026 9.26	78	30	69.1
10-03-2026 9.24	78	30	69.3
10-03-2026 9.12	81	30.5	69
10-03-2026 8.55	80	30.2	70.8
07-02-2026 16.29	88	30.1	66.3
07-02-2026 16.27	90	30.1	66.2
07-02-2026 11.54	58	29	67.9
07-02-2026 11.52	58	28.9	67.9
07-02-2026 11.40	60	28.9	70
07-02-2026 11.39	61	28.9	70.3
07-02-2026 11.01	75	28.6	72.4
07-02-2026 10.59	100	28.6	72.2
07-02-2026 10.57	100	28.6	72.5
24-01-2026 19.53	79	27.3	82
24-01-2026 19.52	100	27.3	82
08-01-2026 18.13	72	30.1	75
08-01-2026 18.08	0	30.1	73.3
08-01-2026 14.17	95	29.9	57.1
29-12-2025 15.03	100	31.5	58.3

In the table, soil moisture is monitored based on soil water availability. Soil moisture value varies from 0 to 100%. Temperature varies from 27.3 to 31.5 degrees Celsius, and Humidity varies from 58.3 to 82 RH.

Table 2: Tested Soil data from the Thiruvallur district terrestrial garden of N, P, and K

Date with Time	Nitrogen (N in PPM)	Phosphorus (Pin PPM)	Potassium (K in PPM)
10-03-2026 9.26	11	15	31
10-03-2026 9.24	11	15	31
10-03-2026 9.12	10	15	30
10-03-2026 8.55	3	5	10
07-02-2026 16.29	3	4	9
07-02-2026 16.27	5	8	16

07-02-2026 11.54	13	18	37
07-02-2026 11.52	13	18	37
07-02-2026 11.40	13	18	37
07-02-2026 11.39	13	18	37
07-02-2026 11.01	11	16	33
07-02-2026 10.59	6	9	18
07-02-2026 10.57	6	9	18
07-02-2026 10.53	6	9	18
24-01-2026 19.53	7	10	20
24-01-2026 19.52	6	9	18
08-01-2026 17.47	2	3	7
08-01-2026 17.46	3	4	8
08-01-2026 17.45	1	1	3

Macro-nutrient values of Nitrogen, Phosphorus, and Potassium vary drastically, as shown in Table 2. Here, continuous crop planting leads to NPK deficiency in pot soil as well as in farm land. Nitrogen values are very low compared to those of Phosphorus and Potassium.

Table. 3 Tested Soil data from Thiruvallur district terrestrial garden blocks of soil PH, leaf temperature, and dust level

Date with Time	Leaf Temperature °C)	Dust Level (µg/m³)	Soil pH (pH)
10-03-2026 9.26	27.8	89.4	3.9
10-03-2026 9.24	27.8	97.8	3.9
10-03-2026 9.12	28.2	96.9	4
10-03-2026 8.55	28.1	97.8	8.6
07-02-2026 6.29	27.6	89.4	5.2
07-02-2026 16.27	27.6	85.3	5.5
07-02-2026 11.54	26.5	77	6
07-02-2026 11.52	26.5	68.7	5.9
07-02-2026 11.40	26.5	77.8	5.6
07-02-2026 11.39	26.5	79.5	5.6
07-02-2026 11.01	26.5	83.6	3.6
07-02-2026 10.59	26.5	82.8	5.9
07-02-2026 10.57	26.4	86.1	5.8
24-01-2026 19.53	0	96.9	3
24-01-2026 19.52	0	103.6	3

08-01-2026 18.13	0	96.9	3
08-01-2026 18.08	27.8	75.3	9
08-01-2026 14.17	25.6	60.4	5.8
29-12-2025 15.03	25.3	98.6	3.3

As shown in the table.3 leaf temperature varies between 25 and 28 degrees Celsius. Dust levels also vary from 60 to 110 micrograms per meter. Soil pH varies from acidic to slightly alkaline (3 to 8).Real-time soil data is uploaded through the Internet of Things to the cloud, and it is used for AI to predict the future value and recommend the fertilizer and crop for the current data. As shown in Figure 7 real-time sensed data is stored in the cloud. Useful data can be downloaded as a CSV file.

S.No	Date	Soil Moisture (%)	DHT22_Temperature (°C)	DHT22_Humidity (%RH)	Nitrogen (N) in ppm	Phosphorus (P) in ppm	Potassium (K) in ppm	Leaf Temperature (°C)	Leaf Wet (g/kg)	Dust Level(µg/m³)	Soil pH (pH)
1	2026-03-10 09:26:19	78	30	69.1	11	15	31	27.8	0	89.4	3.9
2	2026-03-10 09:24:19	78	29.9	69.3	11	15	31	27.8	0	97.8	3.9
3	2026-03-10 09:23:18	78	29.9	69.5	11	15	31	27.8	0	84.5	3.9
4	2026-03-10 09:21:16	78	29.9	69.8	11	15	31	27.8	0	88.6	3.9
5	2026-03-10 09:19:15	79	30	69.9	11	15	31	27.9	0	95.3	3.9
6	2026-03-10 09:17:15	79	30	69.7	11	15	30	28	0	93.6	3.9
7	2026-03-10 09:16:13	79	30.1	69.6	10	15	30	28	0	91.9	3.9
8	2026-03-10 09:14:12	80	30.3	69.5	10	15	30	28.1	0	114.4	3.9
9	2026-03-10 09:12:10	81	30.5	69	10	15	30	28.2	0	96.9	4
10	2026-03-10 09:10:08	81	30.5	69.1	10	15	30	28.2	0	99.4	4.1
11	2026-03-10 09:08:07	82	30.5	69.2	10	14	29	28.1	0	135.1	4.4

359	2026-01-08 10:23:18	82	28.5	65.4	4	6	12	24	26.4	57.9	3.2
360	2026-01-08 10:15:29	59	27.7	67.2	0	0	0	0	0	212.4	0
361	2025-12-29 15:14:36	36	30	61.9	10	14	28	25.8	43.8	114.4	4.2
362	2025-12-29 15:13:36	40	30	61.1	10	14	28	25.7	43.8	87.8	4.1
363	2025-12-29 15:12:34	45	30.1	61.3	10	14	28	25.7	43.8	89.4	4
364	2025-12-29 15:11:34	49	30.1	61.3	9	13	27	25.7	43.7	82.8	3.9
365	2025-12-29 15:10:33	53	30.2	61.1	9	13	27	25.7	41.8	91.1	3.9
366	2025-12-29 15:09:33	58	30.2	61.4	9	13	27	25.6	0	82.8	4.9
367	2025-12-29 15:08:32	97	30.2	61.4	9	13	27	25.6	43	80.3	3.5
368	2025-12-29 15:07:32	99	30.2	62	9	13	27	25.5	42.8	95.3	3.6
369	2025-12-29 15:05:24	100	30.8	59.7	6	8	17	25.4	43.1	100.2	3.3
370	2025-12-29 15:04:23	100	31.1	58.9	6	8	17	25.4	43.2	93.6	3.3
371	2025-12-29 15:03:23	100	31.5	58.3	6	8	17	25.3	43.2	98.6	3.3
372	2025-12-29 15:02:23	100	32	57.2	6	8	17	25.3	43.2	84.5	3.6
373	2025-12-29 14:47:55	100	0	0	6	8	17	25.7	41.9	100.2	3.7

Figure 7: Real-time sensed data stored in the cloud.

Measurement of soil nutrients, water absorption, and environmental pollution is shown and recorded. According to the data, the graph of the stored data is as follows.

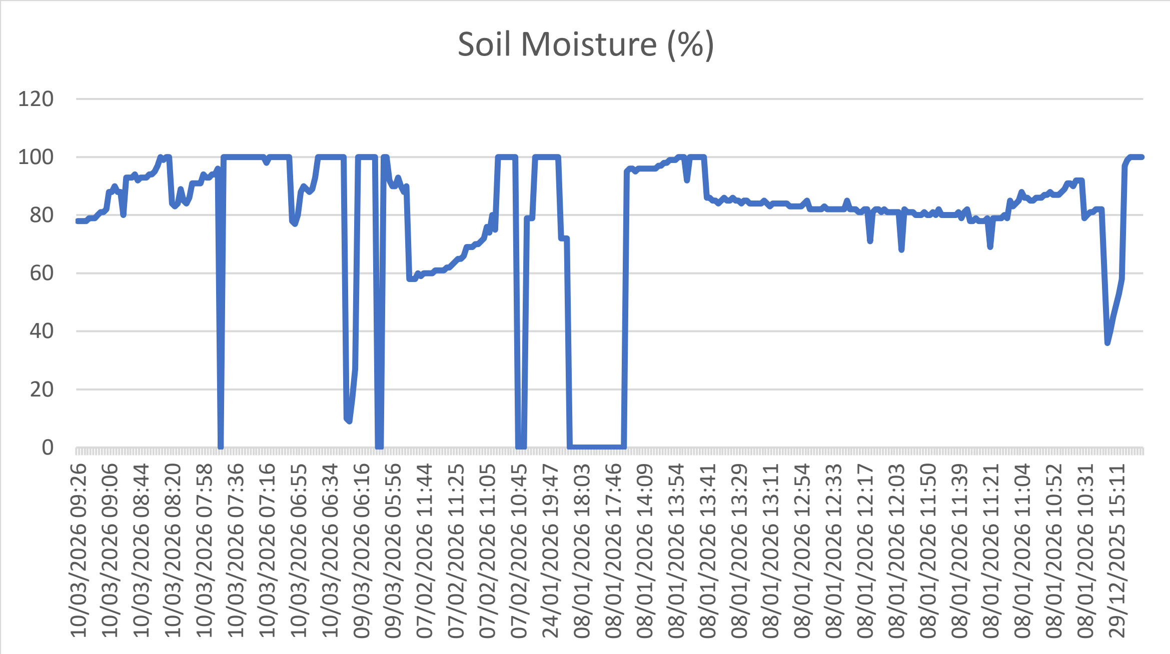

Figure 8. Measurement of Soil moisture level for the Thiruvallur district

Figure.8. Soil moisture shows that the moisture in the soil found in the higher strata is a scarce but crucial resource for plant growth, ecological harmony, and agricultural productivity. Here, the graph shows normality and sufficient water at all times. Soil moisture is more than 50% and, when it falls below 10%, automatic irrigation can be implemented using smart farming.

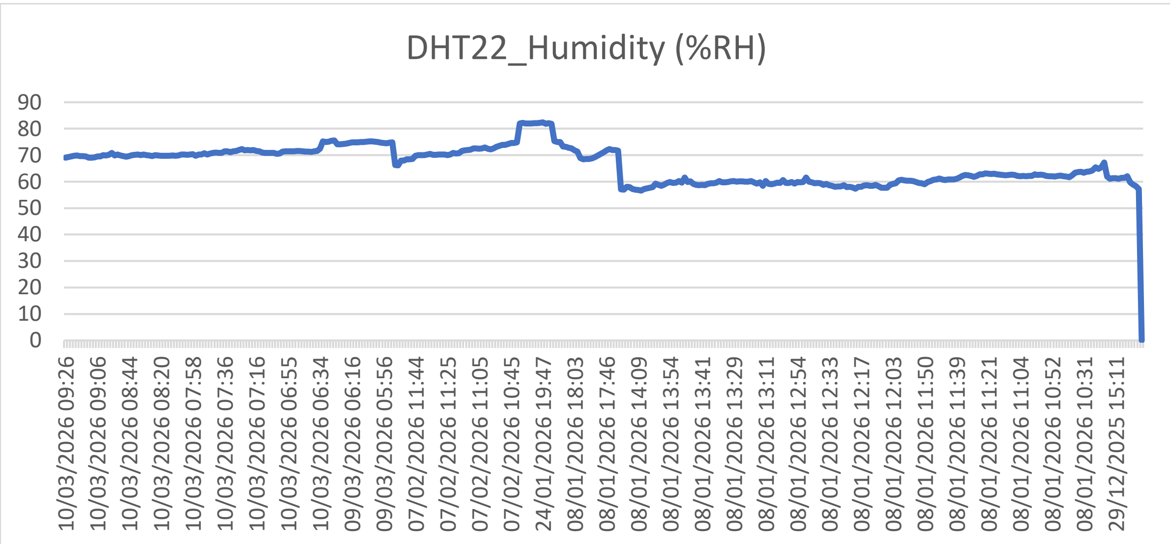

Figure 9. Measurement of Soil Humidity level for Thiruvallur district

Figure 9, Soil Humidity shows water comprises 75-95% of plant tissue, making soil humidity (moisture) essential for plant life, nutrient absorption, and ecological well-being as a whole. An overabundance of water can lead to compaction, while a deficiency of water restricts development; on the other hand, sufficient moisture avoids root asphyxiation. The graph shows the normal distribution of soil humidity.

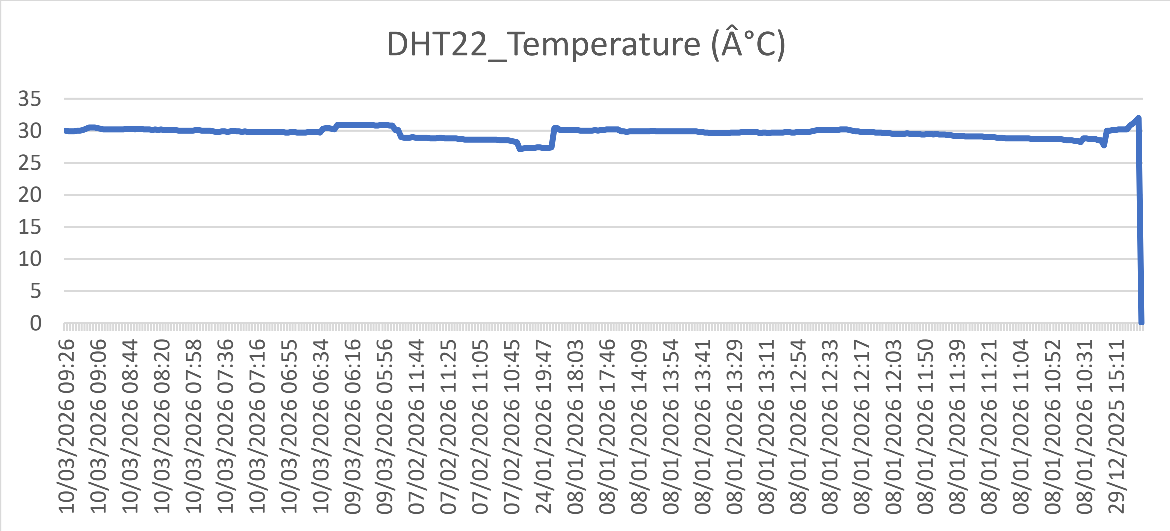

Figure 10. Measurement of Soil temperature level for the Thiruvallur district

Figure.10. Soil temperature shows that seed germination, nutrient uptake, root development, and microbial activity are all controlled by soil temperature, which is an important but sometimes disregarded component in agricultural and ecological contexts. By regulating nutrient availability (e.g., through nitrogen fixation), setting ideal planting periods, and accelerating decomposition, it directly influences crop performance.

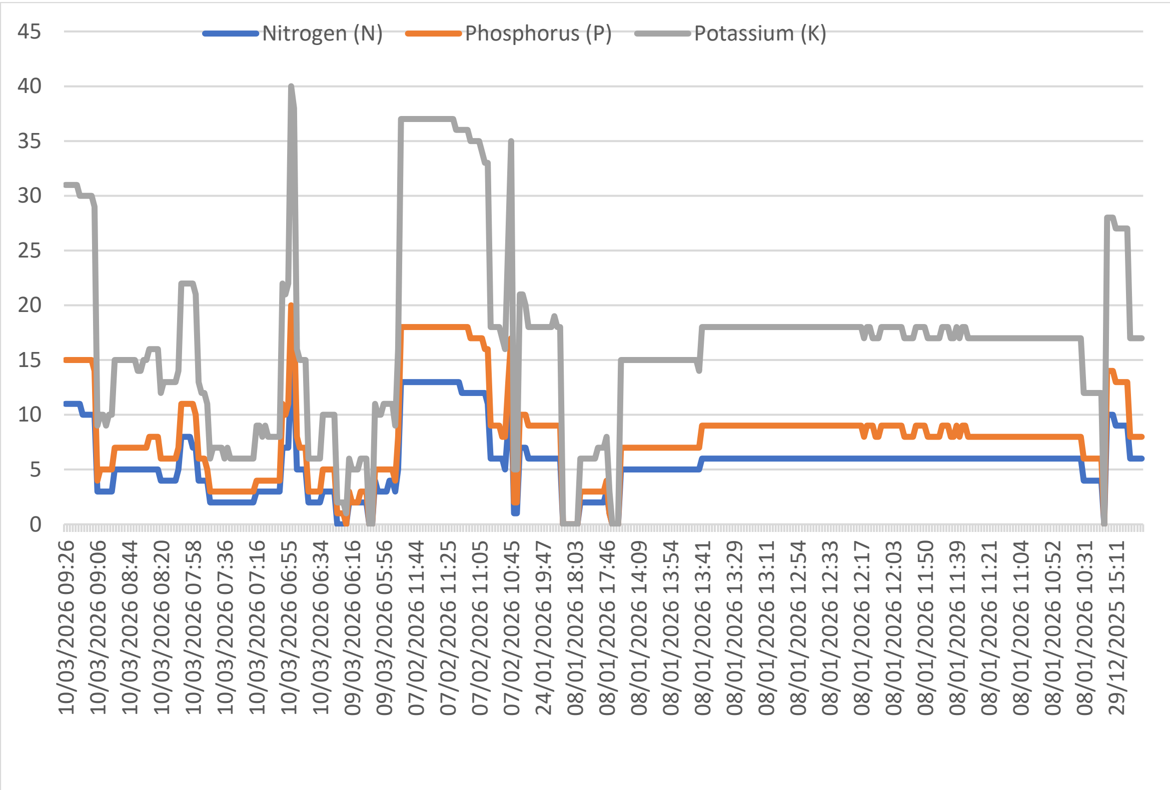

Figure 11. Measurement of Soil NPK level for Thiruvallur district

Figure.11 shows that Soil NPK—Nitrogen (N), Phosphorus (P), and Potassium (K)—are the primary macronutrients vital for plant health, driving photosynthesis, root development, and disease resistance. Here, Potassium (K) is higher than nitrogen and phosphorus, as shown.

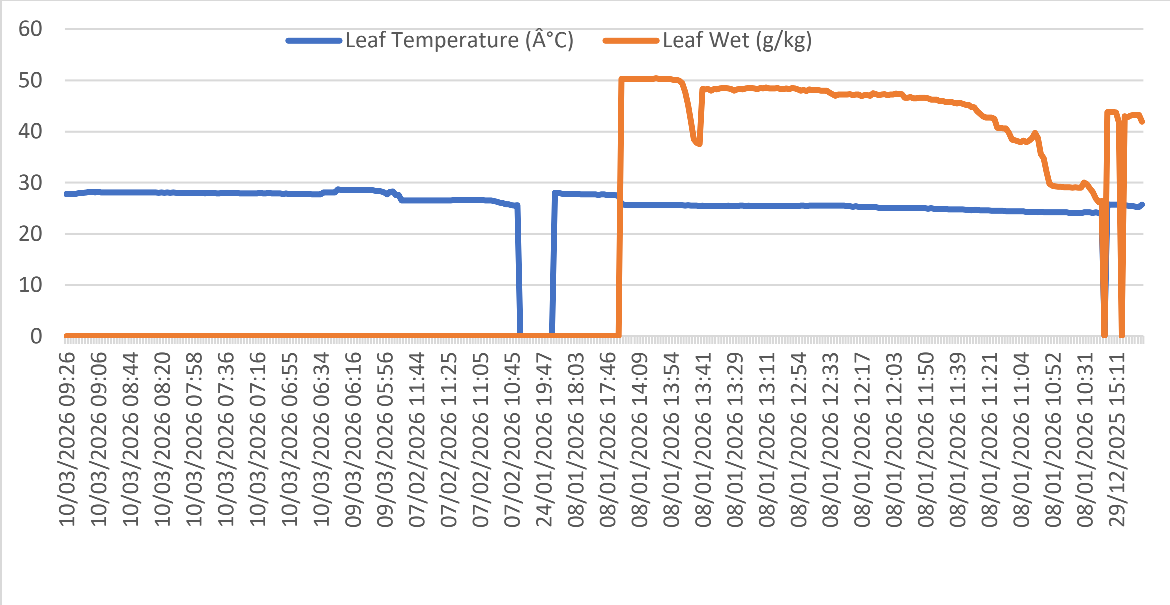

Figure 12. Measurement of leaf temperature and wet level for Thiruvallur district

As shown in Figure 12, the physiological processes of plants, including photosynthesis, transpiration, respiration, and enzyme activity, are strongly influenced by leaf temperature. Not only does it indicate hydraulic state and energy balance, but it also differs from air temperature, which influences carbon assimilation rates and overall plant survival under heat stress. As a result, it serves as a main stress indicator

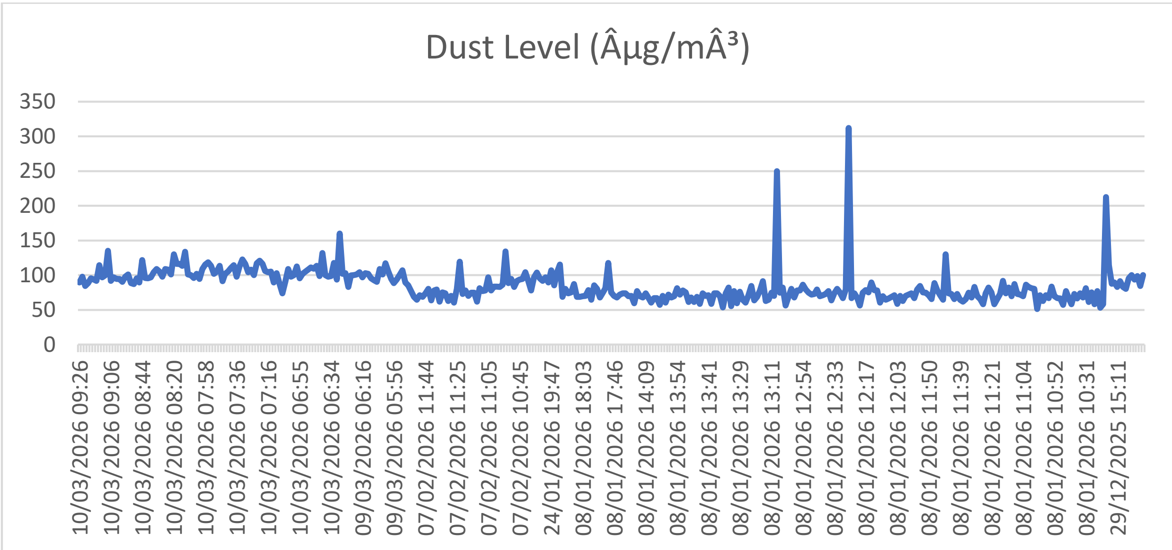

Figure 13. Measurement of the dust level of the environment for the Thiruvallur district

Agriculturalists place a premium on environmental dust levels, as they pose a serious risk to crop yields while also providing certain soil nutrients in some areas. Clogged stomata, which hinder respiration, photosynthesis, and transpiration due to dust on leaves, can lead to heat stress and stunt overall development. The dust level is maximum at 300 ug/m, and a moderately high level of 80 to 150 ug/m is present in the environment, as shown in Figure 13.

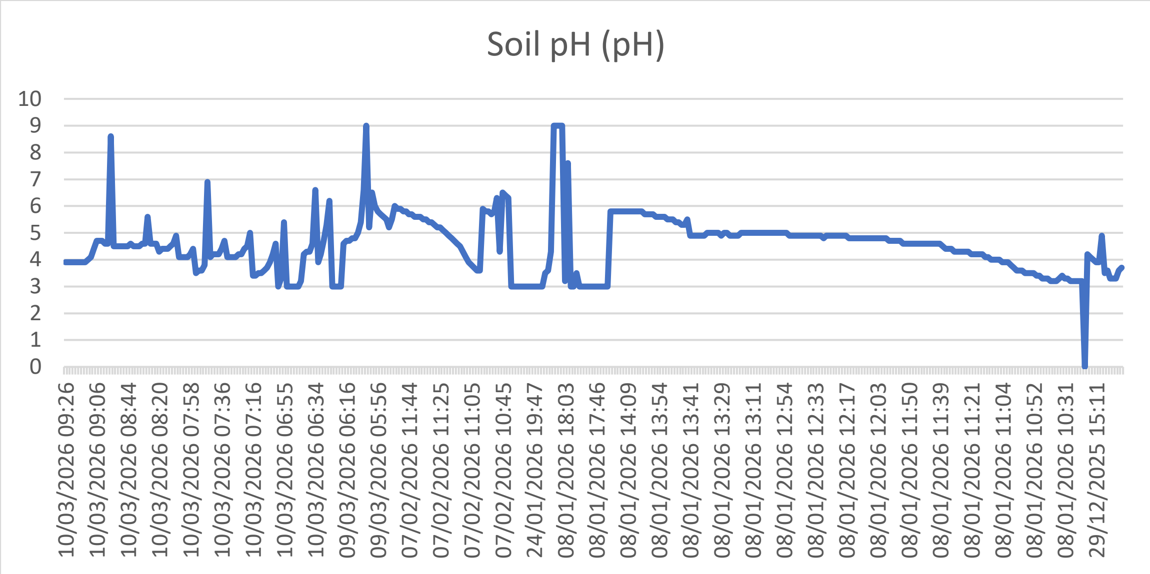

Figure 14. Measurement of soil PH for Thiruvallur district

Figure 14: Soil pH shows that fertilizer absorption is best achieved within an ideal pH range of 6.0 to 7.5. Still, nutrient deficiencies or toxicity can cause plants to become stunted and yellow at an incorrect pH. Here, based on pH variation, the soil is more acidic.

Using the proposed hardware, soil samples from farmland in Thiruvallur district have been collected, and key soil parameters such as pH, EC, and NPK have been analyzed to determine soil type across seven blocks in Thiruvallur. Soil types found in areas and their suitable crops are shown in Table No. 4. Seven blocks in Thiruvallur District and their nutrient ranges are shown in Table No. 5.

Table. No. 4: Soil type found in areas and its suitable crops

The Sort of Soil and its Alternative Name	**Reproductive health**	**Maximum Absorbency of Water**	**Situated in**	**Approved Harvests**
Alfisols/ Red soils	Medium	Medium	Parts of Tiruvallur, Poondi, Kadambathur, Tiruttani	Groundnut Pulses Millets Cotton Vegetables
Vertisols/ Black cotton soils	High	Very High	Small pockets near Kadambathur & interior blocks	Cotton Paddy Sugarcane Sorghum
Entisols/ Alluvial / Young	Low	Low	Pallipattu, R.K. Pet, parts of Tiruvallur	Paddy Vegetables Sugarcane

soils				
Inceptisols/ Brown / Immature soils	Medium	Medium	Tiruttani, Thiruvallangadu, Poondi, Kadambathur	Paddy Sugarcane, Groundnut, Maize Pulses

As shown in Table 4, Red soils have medium water-absorbability and fertility characteristics, and they are found in parts of Tiruvallur, Poondi, Tiruttani, and Kadambattur. Brown immature soil also has the same soil characteristics and is placed like Red soil, suitable for cropland, Gardens, etc. Black cotton soil in Kadambattur has high fertility and absorbability(26).

Table 5 The nutrient range in seven areas in Thiruvallur District:

Areas	**Most Prevalent Soil Type**	**pH Scale**	**Soil Reaction Name (as per pH)**	**Measurement of Electrical Conductivity (dS/m)**	**Level of Nutrients (N-P-K)**
Pallipattu	Entisols And Alfisols	6.5 – 7.5	Mildly acidic to balanced	0.2 – 0.6	N: Low, P: Medium, K: Medium
Tiruttani	Inceptisols and Alfisols	6.5 – 7.2	Mildly acidic to balanced	0.2 – 0.6	N: Medium, P: Medium, K: Medium
Thiruvallangadu	Inceptisols	6.8 – 7.4	Neutral	0.2 – 0.7	N: Medium, P: Medium, K: Medium–High
Poondi	Inceptisols and Alfisols	7.0 – 7.8	Neutral to moderately alkaline	0.6 – 1.5	N: Medium, P: Medium, K: High
Tiruvallur	Alfisols and Entisols	6.5 – 7.5	Mildly acidic to balanced	0.3 – 0.8	N: Medium, P: Medium, K: Medium
RK Pet	Entisols	6.8 – 7.8	Balanced to slightly acidic	0.3 – 0.8	N: Low, P: Low-Medium, K: Medium
Kadambathur	Inceptisols and Vertisols	7.2 – 8.2	Slightly to moderately alkaline	0.5 – 1.2	N:Low–Medium, P: Medium, K: High

As shown in Table 5, Thiruvallur district has good pH and Electrical conductivity, but nitrogen is lower than phosphorus and Potassium. Even in terrace and terrestrial gardens, soil NPK has similar characteristics. The following Table 6 shows the overall averages for soil NPK, pH, and EC in Thiruvallur district[27].

Table 6 Values in Parts Per Million (Thiruvallur – Overall Average)

values set	kg/ha Range	Converted ppm Range	Status
Nitrogen (N)	178 – 295 kg/ha	**90 – 150 ppm**	Low to Medium
Phosphorus (P_2O_5)	9.8 – 24.9 kg/ha	**5 – 12.5 ppm**	Medium
Potassium (K_2O)	199 – 399 kg/ha	**100 – 200 ppm**	Medium to High
pH	6.4 – 8.1		Slightly acidic to slightly alkaline
EC (Electrical Conductivity)	0.2 – 0.8 dS/m		Non-saline (safe for crops)

As shown in table 6, the pH has neutral value range of 6.5 to7.5 means ,it has the sufficient micronutrients of Iron(Fe), Zinc(Zn), Manganese(Mn), Copper(Cu), Boron(B), Molybdenum (Mo), Chlorine (Cl). Although pH changes ,it will show slight variation in the range of micronutrients.

Based on real-time soil testing, the proposed methodology collects all data in the cloud. It uses machine learning to predict the appropriate crop and fertilizer based on soil data, as shown in Tables 7 and 8, as future Work.

Table. No. 7 Crop recommendation for the NPK level

NITROGEN(N)	PHOSPHORUS(P)	POTTASIUM(K)	HARVEST
N: 100–150 kg/ha Suitable when soil N is Medium–High	P_2O_5: 39–61 kg/ha	K_2O: 39–59kg/ha	Paddy (Rice)
N: 249–299 kg/ha	P_2O_5: 99–124 kg/ha	K_2O: 100–150 kg/ha	Sugarcane
N: 39–59 kg/ha	P_2O_5: 19–29 kg/ha	K_2O: 19–29 kg/ha	Ragi
N: 19–29 kg/ha	P_2O_5: 39–59 kg/ha	K_2O: 39–49 kg/ha	Groundnut
N: 119–179 kg/ha	P_2O_5: 59–74 kg/ha	K_2O: 39–59 kg/ha	Maize

Table.no 8.Fertilizer recommendation system for the crops

Harvest	Essential Nutrients	Application of fertiliser	The amount (kg/ha)
PADDY	Nitrogen: 120 kg/ha	Urea	260 kg
	Phosphorus	Di-Ammonium	130 kg

	Pentoxide:60 kg/ha	Phosphate(DAP)	
	Potassium Oxide: 60 kg/ha	Muriate of Potash(MOP)	100 kg
MAIZE	Nitrogen: 150 kg/ha	Urea	300 kg
	Phosphorus Pentoxide: 70 kg/ha	Di-Ammonium Phosphate(DAP)	150 kg
	Potassium Oxide: 50 kg/ha	Muriate of Potash(MOP)	80 kg
GROUNDNUT	Nitrogen: 25 kg/ha	Usually no extra Urea is needed	
	Phosphorus Pentoxide: 50 kg/ha	Di-Ammonium Phosphate(DAP)	110 kg
	Potassium Oxide: 40 kg/ha	Muriate of Potash(MOP)	65 kg

5.Conclusion and Future Work

Results in precision agriculture have been promising when using a novel ML-enabled system that combines Internet of Things (IoT) technology, sensor data collection, and machine learning algorithms. Expensive, complicated, and time-consuming, traditional laboratory procedures yield precise soil nutrient assessments. Technological progress in information and communication technology has led to the development of electronic instruments that can potentially assess various soil properties more quickly. We provide a synopsis of recent developments in soil fertility measurement methods and tools. Here, nearly 150 soil samples from the Thiruvallur district were collected and tested using the proposed system. The results were saved in the cloud for future Work, including the implementation of an ML algorithm to generate predicted data for crop selection and fertilizer recommendations. Here, the terrace garden pot plant's essential nutrients are found immediately within the PPM range; it shows very low NPK values because the plant needs 40 to 80 PPM Nitrogen, 20 to 40 PPM Phosphorus, and 40 to 80 PPM Potassium for good crop yield. Using our proposed methodology, soil characteristics can be viewed directly and deficiencies identified immediately with the limits. urther, the future Work on fertilizer recommendations is provided based on low nutrient values. Here, the terrestrial garden and farm land values for NPK and pH are compared, and the results clearly show that the Nitrogen is low in both values.Continuous paddy farming results in mostly low nitrogen levels (90-150ppm), which means nitrogen fertilizer is frequently needed. The phosphorus (P) level is usually medium (5-12ppm), which is sufficient for the majority of crops upon maintenance dosing. Medium to high levels of Potassium (100-200ppm), particularly in clay soils, are ideal for growing sugarcane and paddy. A neutral to slightly alkaline soil (6.5-8.0) characterizes most of the area.A soil EC value below 1.0 dS/m indicates that the soil is not exposed to salt.For the most part, Thiruvallur soils are suitable for planting. Present management approaches have resulted in soil in the Thiruvallur district that is around 60% efficient (moderate fertility) for agricultural production.Soil testing is a must before planting any crop. Soil testing helps farmers identify which crops will thrive in a given area and creates a personalized fertilization strategy.

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