IoT Based Soil Parameter Analysis for Crop Recommendation

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Abstract - *In the evolving agricultural landscape, precision farming is revolutionizing crop cultivation with the aid of technology. This research focuses on the development of a soil parameter analysis device that uses Bluetooth technology to measure and transmit real-time data on essential soil properties such as temperature, moisture, pH, and nutrient content. The device offers personalized crop recommendations based on soil conditions, helping farmers optimize their resource use and improve crop yields. By integrating IoT principles with Bluetooth, the system provides an accessible and efficient solution for modern, sustainable farming.*

Key Words: **Soil Analysis, IoT, Bluetooth, Precision Agriculture, Real-time Data, Sensors, Sustainable Farming.**

1. INTRODUCTION

Agriculture faces numerous challenges such as soil degradation, water scarcity, and the effects of climate change. Precision farming, supported by Internet of Things (IoT) technologies, offers an innovative approach to address these challenges. This paper presents the development of a Bluetooth-based device for real-time soil parameter analysis. This device measures critical parameters such as soil moisture, soil temperature, pH, and N, P, K that provides crop recommendations based on the data collected by respective sensors.

In conventional soil testing method, number of soil samples are collected from the same field at different places. Then the collected soil samples are mixed then filtered and converted to a single fine soil sample. 10 grams of soil sample is tested on various equipment. These tests like electrical conductivity, pH, and flame photometry are carried out using various solutions. As this conventional method of soil testing takes more time to give precise results, IoT based soil parameter analysis device is developed. This device allows farmers to maximize their available resources and reduce the risk of crop failure. By utilizing Bluetooth for data transmission, the system ensures easy access to soil health information through a mobile application, empowering farmers to make informed decisions in crop management.

2. LITERATURE SURVEY

Poor soil fertility is a major challenge in Indian agriculture. This study uses chemical soil measurements to classify soil parameters such as organic carbon (OC), phosphorus pentoxide (P2O5P_2O_5P2O5), manganese (Mn), and iron (Fe), alongside soil pH, type, and nutrient content, to recommend fertilizers and suitable crops. Twenty machine learning classifiers, including Random Forest (RF), AdaBoost, and SVM, were evaluated. RF achieved the highest performance in six of ten classification problems, surpassing 90% accuracy in most cases. The results highlight the potential of ML models to save time and cost while offering reliable recommendations.[1]

Sensitivity and uncertainty analyses identify critical soil parameters for crop simulation models, enabling users to prioritize calibration efforts. This study focused on 15 soil input parameters of the Web Info Crop Wheat model under different stress conditions, including water deficit, high temperature, and their combination. Key findings showed that nutrient parameters like nitrate and organic carbon were most sensitive under potential and high-temperature stress, while soil moisture parameters such as clay percentage and field capacity were critical under water deficit conditions. Identifying sensitive soil parameters significantly improved model efficiency across various agro-climatic regions in India.[2]

This study presents an IoT-enabled soil nutrient classification and crop recommendation model (IoTSNA-CR) designed to assist farmers in precision agriculture. The model integrates sensors, cloud computing, and machine learning for real-time monitoring of soil parameters such as temperature, moisture, pH, and NPK values. Data collected via sensors are stored in Firebase cloud storage and accessed through an Android application for analysis using a multi-class support vector machine optimized with the fruit fly optimization method (MSVM-DAG-FFO). The proposed algorithm achieved high accuracy (0.973) compared to other methods like SVM and decision trees. The system provides cost-effective, user-friendly solutions for monitoring soil health, optimizing fertilizer use, and enhancing productivity.[3]

Tamil Nadu faces challenges in agriculture due to variable climatic conditions, necessitating modern technological interventions. This study highlights the use of machine learning techniques to develop models for predicting crop suitability, water and fertilizer requirements, and pest protection. By leveraging agricultural data and climatic factors, the system provides crop recommendations tailored to productivity and seasonal variations. Data analytics plays a crucial role in extracting insights from agricultural datasets, helping farmers optimize cultivation and management. This approach not only aids in overcoming climate-related uncertainties but also paves the way for more efficient and sustainable agriculture.[4]

This study explores the use of machine learning (ML) to analyse agricultural datasets, including soil nutrients (NPK), pH, and climatic variables (temperature, rainfall, and humidity), to recommend crops or nutrients for optimal production. Five ML models—SVM, XGBoost, Random Forest, KNN, and Decision Tree—were evaluated using data for 11 agricultural and 10 horticultural crops. Results showed that analysing datasets separately for agricultural and horticultural crops yielded better predictions. Among the models, XGBoost achieved the highest accuracy, with precision rates exceeding 98% for all crop categories. The study proposes a potential AI cloud-based interface for rapid, site-specific decision-making to enhance crop selection and fertilizer application.[5]

This paper examines the role of machine learning classifiers in solving agricultural challenges, particularly soil nutrient analysis and crop prediction. Various classifiers such as J48, Naive Bayes, k-NN, Random Forest, SVM, and JRip were compared for their effectiveness in predicting crops based on soil data, including parameters like pH, nitrogen, phosphorus, and potassium. Naive Bayes performed notably well for large datasets. The survey highlights the utility of ML models in aiding farmer decision-making for improved yield, soil quality assessment, and addressing plant diseases, contributing to sustainable agriculture practices.[6]

Spatial distributions of soil chemical properties are critical for site-specific management practices. This study analysed spatial patterns in two fields: one under a corn-soybean rotation with inorganic fertilizers and the other under a five-year crop rotation using organic nutrient sources. Soil properties like pH, exchangeable calcium, total organic carbon, and nitrogen showed strong spatial correlations in the inorganic field with a larger range (>182 m), while properties like phosphorus and magnesium in the organic field exhibited patchy distributions due to manure and sludge applications. These findings suggest that closer sampling grids are required for organic fields to improve data precision, whereas conventional fields can utilize coarser grids. The study emphasizes the importance of documenting long-term field management histories to optimize sampling strategies.[7]

This study reviewed optimization methods for identifying soil parameters, focusing on error functions, search strategies, and identification procedures. Five optimization techniques—genetic algorithms, particle swarm optimization, simulated annealing, differential evolution, and artificial bee colony algorithms—were compared using synthetic and real geotechnical tests. Differential evolution demonstrated the strongest search capability but slow convergence. To address this, an enhanced algorithm integrating the Nelder-Mead simplex method was developed, improving convergence speed while maintaining search reliability. The enhanced method successfully identified soil parameters, such as Mohr-Coulomb and ANICREEP, from pressure meter tests in sand and clay, showcasing its potential for geotechnical applications.[8]

Repeated wetting and drying cycles in soil lead to crack formation and the development of fracture networks. This study examined crack characteristics in alfalfa root-loess complexes during different growth periods and dry-wet cycles. It compared these with plain soil under both plant growth dry-wet cycles (PG-DWC) and extreme condition dry-wet cycles (EC-DWC). The presence of plant roots in the root-soil complex increased crack parameters (average width, rate, relative area, and length) compared to plain soil. Crack development was stable under PG-DWC but intensified with the number of cycles under EC-DWC. These findings highlight the dual role of plant roots in promoting crack formation while enhancing macro-mechanical soil properties, offering insights for designing vegetation-based slope protections.[9]

This review highlights in-field techniques for assessing soil properties such as pH, texture, carbon, and nitrogen levels, emphasizing methods for determining plant-available nutrients. Key tools include electromagnetic, conductivity-based, and electrochemical sensors. Soil spectroscopy and ion-specific electrodes provide reliable data on nutrients like phosphorus, potassium, and pH. Combining multi-sensor methods with data fusion has proven economically and practically viable. Challenges like sensor signal interference and certification as official analysis methods remain barriers to adoption. These advancements enable faster, more accurate soil evaluations, supporting precision agriculture practices.[10]

Static soil parameters often fail to capture the dynamic stress-strain responses observed during geotechnical construction. This study introduces an intelligent inversion method using a ResNet architecture to model soil behaviour. Deformation responses are processed via a BiLSTM network, with a ResNet mapping features to soil parameters. A novel input strategy enables static finite element method (FEM) analysis to simulate dynamic excavation scenarios, improving model accuracy. Validation using a foundation pit project in China demonstrated strong alignment between predicted and measured diaphragm wall displacements, underscoring the method's efficacy in quality control and problem prevention for geotechnical infrastructure.[11]

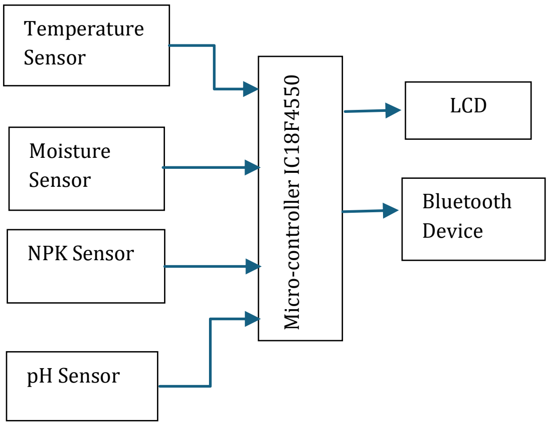
Agriculture heavily depends on soil fertility and moisture levels, with fertilizers recommended based on soil nutrient content. Traditional soil testing methods are time-intensive, leading many farmers to skip testing, resulting in declining soil health due to continuous monocropping. This study proposes an IoT-based system utilizing Wireless Sensor Networks (WSNs) for real-time monitoring of soil parameters such as moisture, pH, and temperature. The collected data is transmitted to the cloud and accessed through a mobile application, which also provides recommendations for fertilizer and water usage. This approach improves soil quality, ensures optimal crop growth, and promotes sustainable farming practices.[12]

This study examined the effects of different irrigation water qualities (groundwater, mixed water, canal water, and desalinized water) and fertigation levels on tuber yield in potatoes. While groundwater irrigation showed the lowest total yield, mixed water and desalinized water significantly enhanced tuber production. Notably, desalinized water was superior when soil salinity (EC1:2) exceeded 0.65 dS m^{-1}. Among potato varieties, 'Kufri Jyoti' outperformed others by 13–22% in yield under all irrigation conditions. Fertigation at 80% of the recommended NPK levels showed no significant yield reduction, offering cost savings and reduced environmental impact. The findings advocate optimizing water and nutrient use to improve yields in saline conditions while minimizing resource waste.[13]

3. METHODOLOGY

This device uses a set of sensors to collect data of soil moisture, soil temperature, pH, and nutrient levels (N, P, K). These sensors are connected to a microcontroller, which process and analyse the data and sends it via a Bluetooth module to a mobile device. A mobile application is used to display real-time soil parameters and provide crop recommendations based on the data collected. The Bluetooth-based design allows for easy, wireless data transmission over short distances, making the system portable and suitable for small to medium-sized farms.

3.1 Integrated System



3.2 Selection of Sensors

To measure the necessary soil parameters, several types of sensors were researched and selected based on their accuracy, cost-effectiveness, and compatibility with the microcontroller and Bluetooth module:

Temperature Sensor:

Thermistor plays a key role in measuring soil temperature, which is a critical factor in crop cultivation. A thermistor is a type of temperature-sensitive resistor, meaning its resistance changes significantly with temperature variations. Specifically, Negative Temperature Coefficient (NTC) thermistors, which are commonly used in soil temperature monitoring, decrease in resistance as the temperature rises.

Fig-2: Thermistor (NTC)

Soil Moisture Sensor:

The capacitive moisture sensor was chosen for its ability to accurately measure soil moisture levels by detecting changes in the dielectric permittivity of the soil. This sensor is preferred over resistive types due to its durability and resistance to corrosion.

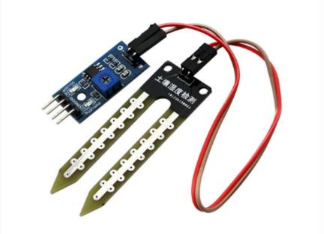


Fig-3: Moisture sensor (YL-69)

pH Sensor (YL-69):

An electrochemical soil pH sensor was selected to measure the acidity or alkalinity of the soil. This sensor is optimized for soil testing and provides precise pH readings critical for crop selection.

Fig-4: pH sensor

N, P, K Sensors:

This sensor is selected to measure the concentrations of Nitrogen (N), Phosphorus (P), and Potassium (K) in the soil. These sensors provide real-time nutrient analysis and can detect deficiencies in essential nutrients, helping to optimize fertilizer application.

Fig-5: NPK sensor

3.3 Data Processing

To develop a system that can accurately recommend crops based on soil conditions, data is collected from sensors and analysed using a microcontroller.

Table -1: Standard Soil Parameter values for Crop

Sr. No.	Crop	N (KG/HA*10)	P (KG/HA*10)	K (KG/HA*10)	Moisture (%)	Temperature (DEG C)	pH
1	Wheat	12	60	40	50-60	15-25	6.0-7.0
2	Rice	100	50	50	100(flooded)	20-35	5.0-6.5
3	Sugar cane	300	100	100	80-90	21-35	6.5-7.5
4	Cotton	90	45	45	50-60	21-27	6.0-7.5
5	Groundnut	25	50	75	60-80	21-30	6.0-7.5
6	Tomato	100	80	80	60-80	20-27	5.5-7.0
7	Onion	100	50	50	60-70	20-25	6.0-7.5
8	Chickpea	20	40	20	50-60	20-25	6.0-7.5
9	Turmeric	80	60	40	70-80	20-30	4.5-7.5
10	Banana	300	200	300	80-90	20-30	6.0-7.5
11	Maize	150	75	40	50-60	21-30	5.8-7.5
12	Brinjal	80	60	60	60-70	20-30	6.0-7.5
13	Soybean	20	60	40	70-80	15-30	6.0-7.5
14	Grape	70	50	100	60-70	25-30	6.0-7.5

The essential soil parameters influencing crop growth are identified as moisture content, pH levels, and nutrient concentrations, primarily focusing on Nitrogen (N), Phosphorus (P), and Potassium (K).

Ding cereals (e.g., wheat, maize), legumes (e.g., soybeans, peas), and vegetables (e.g., tomatoes, carrots) are compiled. For each crop, ranges of pH, moisture content, and nutrient levels were recorded from agricultural research studies and government publications.

The PIC18F4550 microcontroller was chosen due to its processing capability, which allows it to handle multiple sensor inputs simultaneously. A Bluetooth module (HC-05) was integrated to enable wireless communication between the sensor system and a mobile device, where the data will be displayed.

The sensors were installed at strategic points in the soil to measure moisture content, pH, and nutrient levels (N, P, K). Data was collected at regular intervals and transmitted to the microcontroller for processing.

After the soil data was analyzed, the system provided crop recommendations based on the following procedure:

The processed data was compared against the ideal conditions for various crops in the database. If the soil moisture, pH, and nutrient levels were within the acceptable range for a particular crop, that crop was suggested as suitable for cultivation.

3.4 User Interface and Crop Recommendations

The analyzed data and crop recommendations were transmitted via Bluetooth to a mobile application. The user interface of the app displayed a list of recommended crops along with suggestions for optimizing soil conditions (e.g., adding fertilizer to balance nutrient levels). Farmers could view this information in real-time, enabling informed decision-making.

4. IMPLEMENTATION

The soil monitoring system integrates hardware components and software to collect, process, and transmit data about soil conditions. At its core, a PIC18F4550 microcontroller manages data acquisition and control. Sensors for temperature, moisture, pH, and NPK levels are connected to the microcontroller, primarily through analog input pins. The system also includes an LCD module for displaying real-time data and a Bluetooth module for wireless communication with mobile devices. Signal conditioning circuits are used where necessary to ensure accurate sensor reading.

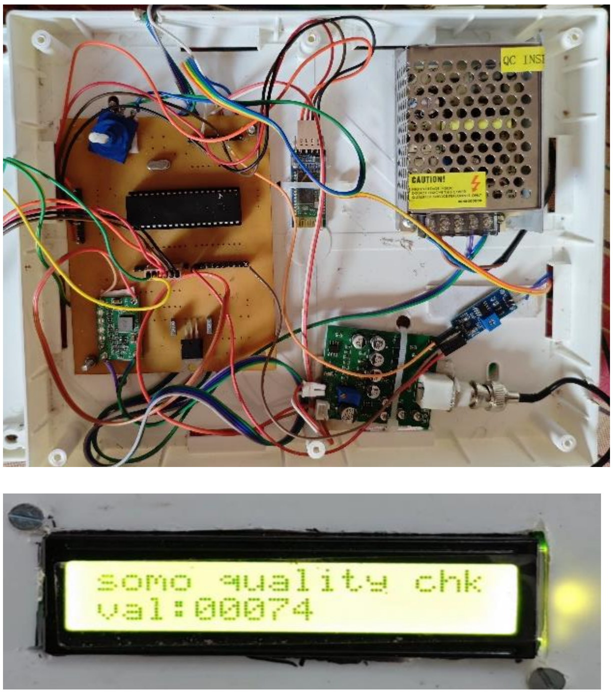


Fig-5: Hardware Implementation

The microcontroller is programmed using C in MikroC, leveraging its ADC modules to read sensor inputs and UART for Bluetooth communication. The software processes raw analog data into meaningful values, such as temperature in °C, moisture percentages, and pH levels. These readings are displayed on the LCD and sent via Bluetooth to a paired mobile device, which can display and store the data. A custom mobile application may enhance usability with features like trend visualization.

The Bluetooth module, configured through AT commands, ensures reliable wireless data transfer. Sensor calibration is crucial to maintain accuracy, using reference standards like buffer solutions for pH. The system undergoes testing to confirm sensor accuracy, data display, and Bluetooth communication functionality.

5. RESULTS

Initial testing has shown that the Bluetooth-enabled system effectively measures and transmits soil parameter data in real-time. The mobile application provides farmers with easy-to-understand insights on soil health and personalized crop recommendations. Field trials are planned to validate the system's performance in diverse agricultural environments, but early results suggest the device significantly improves decision-making related to irrigation, fertilization, and crop selection, leading to better resource management and higher crop yields.

Table -2: Results of Soil Parameter for Samples

Soil Samples	pH	Moisture	Temp.	N	K	P
Soil Sample1	5	59	30	12	17	39
Soil Sample2	5	66	23	11	12	42
Soil Sample3	4	54	33	11	11	56
Soil Sample4	6	76	24	10	11	34

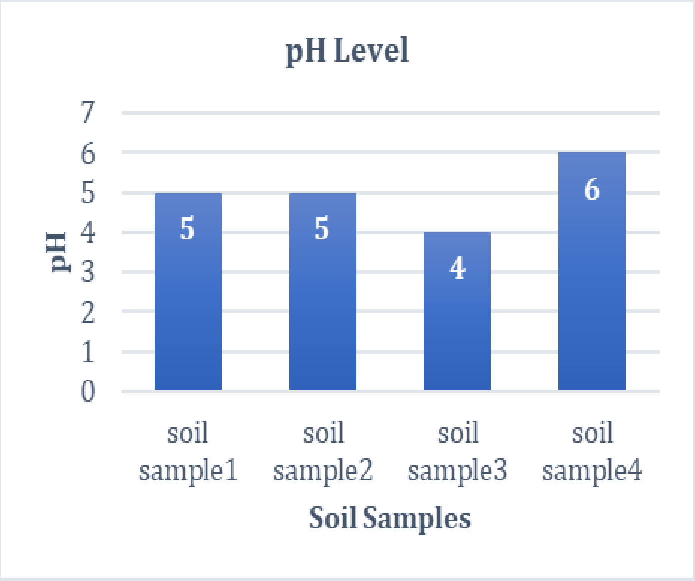


Chart-1: Soil sample v/s pH

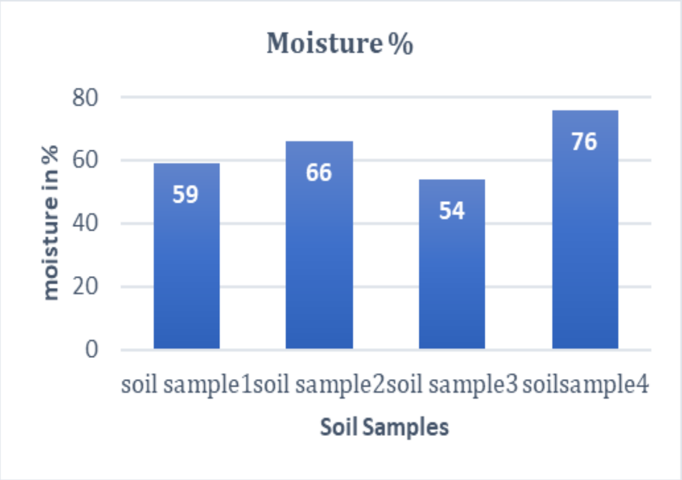


Chart-2: Soil sample v/s Moisture

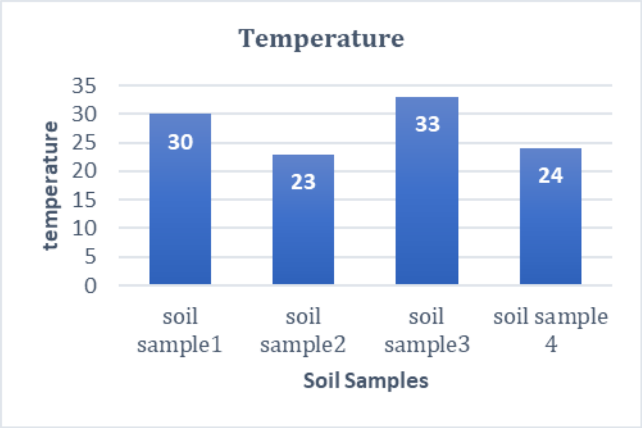


Chart-3: Soil sample v/s Temperature

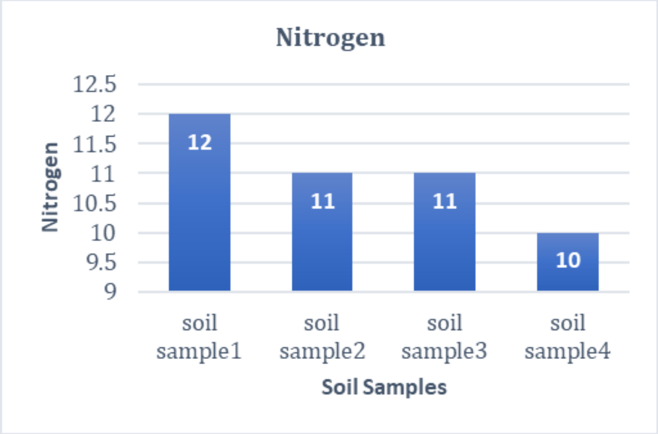


Chart-1: Soil sample v/s Nitrogen

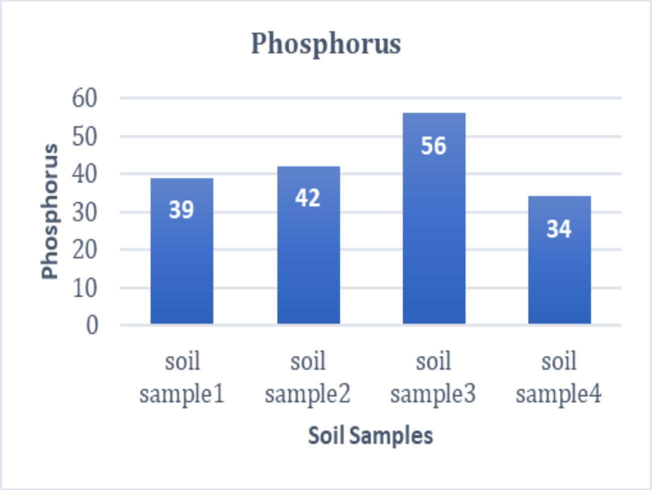


Chart-2: Soil sample v/s Phosphorus

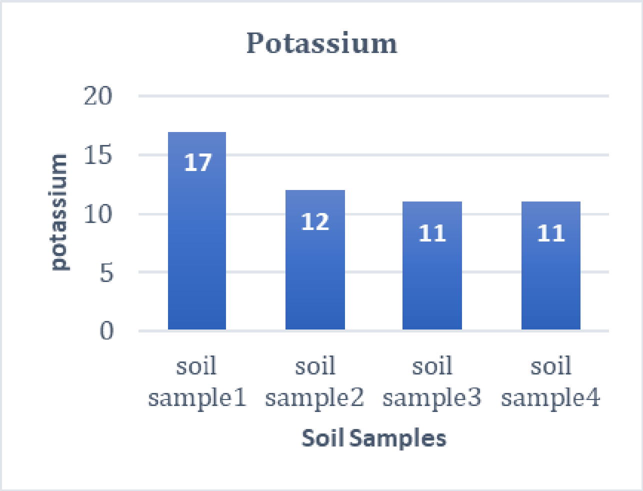


Chart-3: Soil sample v/s Potassium

The above samples show the analysis of various parameters in soil. It is observed that in samples 1 and 3, and according to our given dataset our system predicts this soil is suitable for cotton, wheat, and chickpea cultivation, Similarly, if we observe the second soil sample, we can see the increase in parameters like moisture and reduced temperature this soil is suitable for soybean, turmeric, banana, maize, grape crop cultivation. Observing the soil sample four according to the given dataset we can predict, that it is good for the cultivation of rice since it requires moderate temperature and very high moisture.

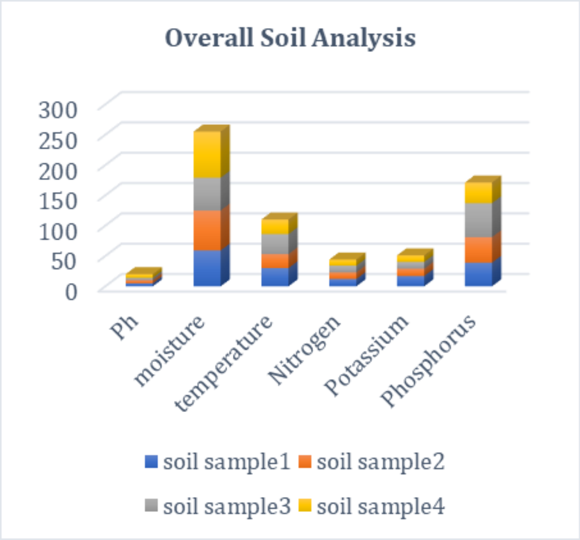


Chart-4: Overall Soil Analysis

This is the overall analysis of all four soil samples, as it depicts all four parameters of each soil sample. And according to this prediction, crops is done via a mobile application using Bluetooth. As per analysis the predictions for soil sample one and three are cotton, wheat, chickpea cultivation. Similarly for soil sample two, soybean, turmeric, banana, maize, grape crop cultivation. And soil sample four, is good for cultivation of rice.

6. CONCLUSIONS

IoT-based soil parameter analysis and crop recommendation system stands as a testament to the transformative power of technology in agriculture. By harnessing the potential of IoT and data analytics, this paper not only addresses the challenges faced by traditional farming methods but also charts a course towards a more sustainable, resilient, and productive future for global agriculture. As this technology continues to evolve and be embraced by the farming community, it holds the promise of ushering in a new era of precision agriculture, where data-driven decisions pave the way for increased food security, resource conservation, and environmental sustainability.

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