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Design and Development of a Compact Soil Conditioning Kit for Assessing Key Soil Quality Parameters in Agriculture

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Abstract

Plant development and agricultural production are largely dependent on soil health, which includes a variety of physical, chemical, and biological elements that have a direct impact on plant life. Robust plant development depends on healthy soils because they promote beneficial microbial populations, assist nutrient cycling, and improve water retention. Therefore, assessing soil quality is crucial for agriculture, and sustainable growth. Although recent technological developments, especially in the areas of Internet of Things (IoT) and deep learning, have improved soil quality monitoring, problems like cost, real-time data and reliability still exist. The present paper presents a simple, compact, inexpensive and reliable IoT based solution which enable real-time monitoring of soil parameters such as nitrogen, phosphorous, potassium, humidity and temperature. The data collected by the monitoring system is then transmitted to a mobile app, where it can be analyzed and interpreted in real-time. The mobile application analyzes the data to recommend the best crops for the particular soil conditions in addition to offering comprehensive insights into soil health. The software may suggest crops that are most likely to flourish in a given area by evaluating the pH, nutrient levels, and other characteristics of the soil. This increases agricultural yields and encourages sustainable farming methods. Data-driven crop suggestions combined with soil monitoring might empower farmers, save costs, and improve agricultural practices for increased environmental sustainability and production.

Keywords: Soil health, Real time data, NPK, Sustainable agriculture, Agricultural productivity

Introduction

Plant development and productivity are greatly influenced by the condition of the soil since it affects water retention, nutrient availability, and general plant vigor. Degraded soils can result in low crop yields, pest problems, and a greater need for chemical fertilizers, which worsen the condition of the soil [1]. For sustainable agriculture and the security of the world's food supply, soil health must be maintained. Among the methods farmers employ to enhance soil health are crop rotation [2], cover crops [3], and the application of organic amendments such as manure and compost. According to the study by [2], crop rotation, the use of nitrogen fertilizer, and the inclusion of crop residue all have a beneficial effect on soil fertility. While nitrogen fertilizers raised the overall nitrogen content by 5%–10%, crop rotations such as "velvet beans-maize" and "soybeans-maize" enhanced soil fertility by 10%–15%. Crop residues also increased soil pH and total nitrogen by 1% to 5%. Restoring soil fertility, improving structure, and increasing microbial activity are the goals of these techniques. Soil testing is essential to sustainable farming, nevertheless, because it helps determine the soil's present state and any particular weaknesses. Physical, chemical, and biological markers like pH, organic matter content, nutrient levels [4], soil texture [5], and microbial diversity [6] are commonly used to evaluate the health of soil. Although soil health cannot be measured in and of itself, Janzen et al. [7] contended that proxy variables (like SOM), land functions (like food quality, water quality, and climate mitigation), and societal values (like aesthetics, equity, and well-being) can all be used as "illuminating indicators" to view soil characteristics. However, neither one sign nor a set of indicators can offer a thorough assessment of the overall health of the soil system. Lewandowski et al. (Lewandowski A, Zumwinkle M, Fish A. Assessing the Soil System: A Review of Soil Quality Literature, Minnesota Department of Agriculture, Energy and

Sustainable Agriculture Program. Minnesota Department of Agriculture, St. Paul, MN (1999).) claim that soil health offers an overall fitness for performing ecosystem activities, reacting to external stressors, and implementing agricultural treatments including fertilizer application, tillage, and irrigation. Since soils are home to countless microorganisms, they constitute a living system in this sense, and as such, the variety of the soil microbiome determines the health of the soil. Cutting-edge methods for comprehending soil ecosystems include spectroscopic and genetic analysis [8]. However, traditional soil testing frequently calls for certain tools and knowledge. Some farmers depend on government programs or community initiatives to gain access to soil testing, which is carried out by private laboratories, research organizations, and agricultural extension agencies. In order to help policy-making and environmental conservation initiatives, agronomists and environmental scientists also participate in assessments of soil health.

The cost of soil testing varies greatly based on how complex the study is. Small-scale farmers may be deterred from performing routine testing by the procedure's lengthy turnaround time (more than a week) and frequent requirement to travel to urban labs. Conventional soil testing techniques can be laborious, and farmers who require quick information for planting or fertilization decisions may find delays in results troublesome. The need for quick and inexpensive soil health monitoring techniques is rising in response to these issues. Because they bridge the gap between conventional laboratory tests, portable soil testing instruments present a possible answer. Crop productivity is directly impacted by soil fertility, making it essential for sustainable agriculture. In order to maximize crop yield, farmers use soil analysis to identify the needed fertilizers and their dosages. Despite being the most widely used technique for analyzing soil, chemical analysis can be expensive, time-consuming, and labor-intensive. Linking soil characteristics and behavior is a key function of the soil-water retention curve (SWRC) in unsaturated soil mechanics. One of the main variables affecting the SWRC has been shown to be temperature. To maximize water use efficiency, it is crucial to comprehend how soil moisture impacts crop growth, particularly as crops modify root growth in response to environmental factors.

Plant growth depends on soil nutrients including potassium, phosphorus, and nitrogen (NPK) [9]. Potassium is important in plant homeostasis and metabolic processes, phosphorus is involved in nucleic acids and membrane lipids, and nitrogen is essential for the formation of amino acids and nucleic acids. Although the soil must contain these nutrients, leaching, volatilization, or low soil concentrations might decrease their availability, necessitating fertilizer applications 10]. However, nutritional imbalances may result from overfertilization. Soil depth also affects the its quality by altering its microbial characteristics [11]. Soil samples should be collected at a consistent depth to guarantee accurate results. Unreliable results may arise from inconsistent sampling, such as the use of wedge-shaped or surface-only samples. Proper sampling tools, including hand probes or automated probes, should be used to gather soil from the correct depth for accurate analysis.

In this work, we present the development of a cost-effective soil health monitoring device designed to measure critical parameters such as NPK levels, soil temperature, and humidity. The collected data is seamlessly transmitted to a smartphone for real-time access. Furthermore, the measured parameters are analyzed using a machine learning algorithm to recommend the most suitable crop for the given soil conditions. This innovative approach aims to optimize agricultural productivity by providing precise and data-driven insights into soil health.in

Methodology

The methodology for developing the soil health monitoring device was divided into three distinct phases, encompassing nutrient analysis, device design, and data visualization through a mobile application.

1. In the first phase, a comprehensive study of soil nutrients essential for plant growth was conducted.
2. Research was undertaken to identify suitable sensors for detecting soil nutrients. Since no single sensor could measure all the nutrients, multiple sensors were integrated to provide a comprehensive nutrient analysis.
3. In the second phase, the device design and circuitry for sensor integration were completed.
4. By the end of the second phase, the device was fully operational, capable of detecting all key soil nutrients and displaying the results to the user.

5. In the third phase, a mobile application was developed to display the data collected by the device. This application features a user-friendly interface for convenient monitoring of soil nutrient levels.

System development and data acquisition

The present IoT-based project utilizes an Arduino board as the central controller, interfaced with multiple sensors, including a soil moisture sensor, a soil temperature sensor, and an NPK sensor. These sensors are embedded into the soil to measure key properties such as temperature, moisture content, and nutrient levels. Comparators and converters facilitate communication between the sensors and the Arduino, ensuring that sensor readings are processed in a compatible format. The Arduino board processes this data, analyzing the values received to determine the nutrient composition of the soil by comparing the readings to predefined thresholds. The system outputs the nutrient levels, offering precise insights into soil health.

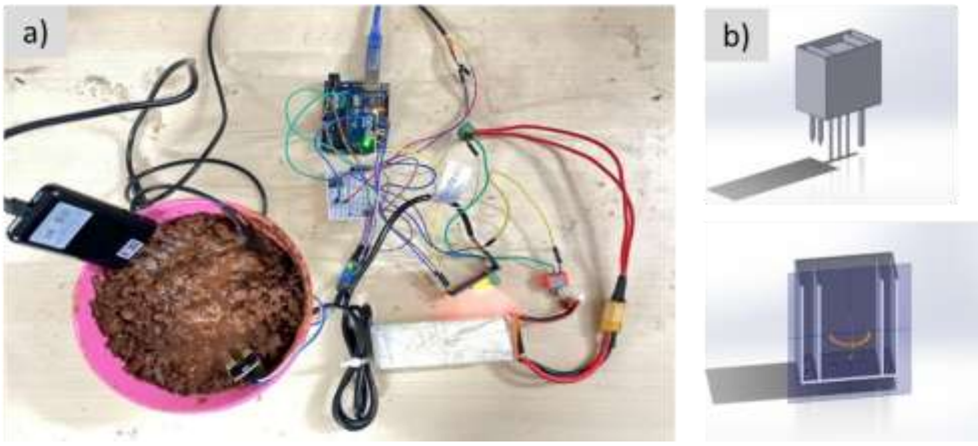

Fig. 1 The cost effective soil test facility – (a) sensors and circuitry and (b) isometric and sectional view of the casing for the sensors.

Integrating IoT capabilities, the project enables wireless data transmission and storage, allowing real-time monitoring and remote access to soil nutrient information. This facilitates timely interventions and supports the optimization of agricultural practices. By leveraging the functionality of Arduino and advanced sensors, the project delivers an automated, cost-effective, and comprehensive solution for soil nutrient analysis.

In designing a soil testing device using SolidWorks 2022, we adopted a structured, step-by-step approach. Initially, individual components for the moisture, temperature, and NPK sensors were modeled to ensure precise representation and compatibility with the device's functional requirements. These sensor components were carefully designed and optimized for seamless integration.

Subsequently, the sensors were assembled within an ergonomic enclosure, with careful attention to their positioning and alignment to ensure optimal performance. A custom casing was also designed to house the Arduino Uno and breadboard, integrating them cohesively within the overall sensor unit. The design process prioritized minimizing the device's size without compromising its functionality or user-friendliness.

The final outcome was a compact and portable sensor unit, suitable for convenient field use. The integration of multiple sensors and the Arduino Uno within a single enclosure enhances the device’s efficiency, delivering accurate and comprehensive soil data analysis. This design achieves a practical and user-centric solution for soil testing, combining accuracy, portability, and ease of use.

The circuit design for the soil testing device, which included NPK, temperature, and soil moisture sensors, was developed using KiCAD, an open-source software platform. KiCAD's extensive built-in components library played a pivotal role in the design process. The library provided pre-designed components for NPK, temperature, and soil moisture sensors, significantly simplifying the circuit design workflow.

Leveraging KiCAD's intuitive interface, we seamlessly integrated these sensors into the circuit design. The software facilitated precise placement of the sensors and the establishment of the necessary electrical connections. With KiCAD's powerful design tools and features, we ensured that the circuit design was robust, efficient, and well-suited for accurate soil testing.

Overall, KiCAD and its built-in components library provided the essential resources to create a comprehensive circuit design for the soil testing device. This enabled the effective integration of NPK, temperature, and soil moisture sensors, allowing the device to analyze soil properties accurately. By utilizing KiCAD, we were able to design a circuit that met the specific requirements of the soil testing application, ensuring precise and reliable measurements for agricultural and environmental purposes.

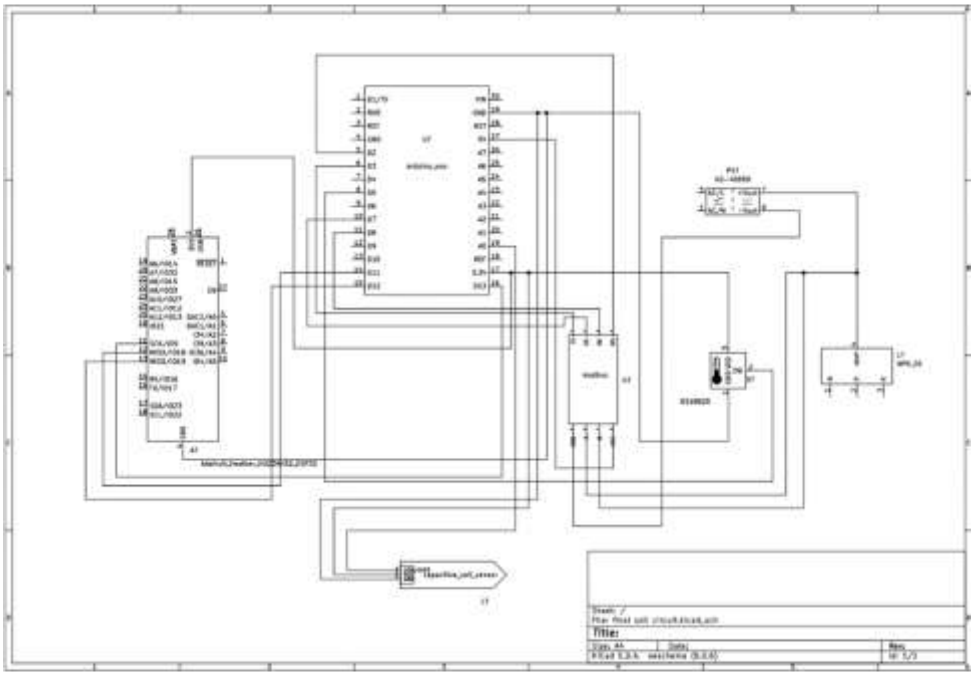

Fig. 2 KiCAD diagram for the soil test circuitry

RESULTS AND DISCUSSIONS

A mobile application, *Soil Health*, was developed to display the measured quantities of soil nutrients. The app provides a user-friendly interface for visualizing and displaying the levels of nitrogen, phosphorus, potassium, temperature, and humidity in soil samples. By leveraging the app's functionalities, users can easily access and monitor these essential parameters for optimal plant growth. The app enables users to view real-time data and measurements, offering valuable insights into soil health.

The *Soil Health* app aims to empower users by providing critical information about the nutrient and environmental conditions affecting soil health. With this information, users can make informed decisions regarding fertilizer application, watering schedules, and other plant care practices. Ultimately, the app facilitates improved plant management and contributes to successful and sustainable agricultural practices.

Fig. 3 Sample display of mobile app integrated with soil test setup

Soil Sample Analysis:

1. **Soil Sample 1**: Collected near the Boys Hostel at St. Joseph Engineering College.

Results obtained –

Nitrogen (N): 273 kg/ha Phosphorus (P): 73 kg/ha Potassium (K): 197 kg/ha Humidity: 34% Temperature: 26°C	Suggested Crops: Pineapple, Sweet Potato, Garlic, Ginger, Turmeric.

2. **Soil Sample 2**: Collected from the St. Joseph Engineering College ground.

Results obtained –

Nitrogen (N): 176 kg/ha Phosphorus (P): 124 kg/ha Potassium (K): 152 kg/ha Humidity: 37% Temperature: 27°C	Suggested Crops: Tomato, Onion, Celery, Bell Pepper.

3. **Soil Sample 3**: Collected from the Pachanady Dumping Yard.

Results obtained –

Nitrogen (N): 73 kg/ha Phosphorus (P): 24 kg/ha Potassium (K): 71 kg/ha Humidity: 42% Temperature: 25℃	Suggested Crops: Mango, Papaya, Lemon, Guava, Jackfruit. Observation: The soil sample collected from the landfill area exhibited significantly lower levels of NPK nutrients, indicating poor soil health.

By providing real-time analysis and tailored crop recommendations, the *Soil Health* app serves as a practical tool for improving soil management and optimizing agricultural outcomes.

CONCLUSION

Soil nutrient testing results provide valuable insights into the nutrient levels and overall suitability of the soil for plant growth, guiding farmers in making informed decisions for optimal crop cultivation. It is essential to have a reliable and efficient soil nutrient testing device that can accurately analyze and assess the nutrient levels in soil samples. The application of real-time data for soil conditioning addresses these challenges by using efficient and reliable sensors, which provide useful information about soil health through a mobile application.

As technology continues to advance, we can expect to see even more innovative tools, like the soil nutrient testing device, emerge, paving the way for a more sustainable and prosperous future for all. In the future, the accuracy of the soil testing device can be further improved by integrating sensors with higher precision, leading to more reliable and detailed results. Additionally, incorporating advanced methods such as spectrophotometry could enhance the device's efficiency and expand its capabilities to detect a wider range of soil nutrients, providing a more comprehensive analysis. Furthermore, the system could be integrated with an automated irrigation feature, where water levels are monitored, and irrigation is triggered based on real-time soil moisture data. This would optimize water usage, promote sustainability, and contribute to more efficient agricultural practices.

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