A J Journal of Engineering and Management
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SoilIQ: Intelligent Soil Health Testing and Crop Suggestion Using IOT And Computer Vision

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A R T I C L E I N F O

Keywords:
Precision Agriculture
Colorimetric Analysis
Real-time Monitoring
Agricultural Automation

A B S T R A C T

The health of soil constitutes an important aspect of farming products because it directly affects the crop yield, resource use, and sustainability in the long-term. Nonetheless, traditional soil analysis. It is not often that methods are time- consuming and not labor-intensive. state that they tend to be professionally interpreted, which renders them less practical and applicable. inaccessible to farmers. It is a complete-integrated project. soil analysis system providing the real-time understanding of the most important parameters. like moisture content, PH level, and composition of nutrients, including NPK. Colorimetric analysis- detection of nutrients is carried out by connection to a camera module, and moisture is detected. capacitive sensing is used as well as pH is measured with calibrated. glass electrodes. This device is designed on a Raspberry Pi 3. processor, which is a local data collector and processer of the sensor data. then delivering the output to a web-based service. Informed Agri-decision can be undertaken because the gadget is able to eliminate. manual intervention and furnished instant, correct. reporting. It minimizes the use of conventional tests in labs. and gives farmers a small, data-driven device to support them. embrace precision farming. The system will also enlighten farmers. so as to have time to practice optimum irrigation and fertilization policies. that will prevent waste of resources and enhance farm produce. On the Crop recommendation is also a module of web interface. that indicates possible crops as far as the profile under analysis is concerned. Concisely, the innovation will enable more efficient soil diagnostics. increases sustainable agricultural activities, and leads to. By increasing more developed agricultural methods it can global food security. technology available to the consumer.

1. Introduction

Soil health is one of the most important foundations of successful agriculture because it directly affects crop productivity, fertilizer efficiency, irrigation planning, and the long-term sustainability of farming systems. Farmers depend on proper soil conditions to achieve better crop yield and reduce unnecessary resource wastage. However, traditional soil testing methods are usually expensive, time-consuming, and dependent on laboratory infrastructure and expert interpretation. These limitations make soil testing inaccessible for many farmers, especially those in rural and small-scale farming environments. Modern agriculture requires fast and accurate decision-making based on real-time field conditions. Precision agriculture has therefore become an important approach where technology is used to monitor soil conditions and improve farming decisions. Recent developments in embedded systems, IoT platforms, sensor integration, and computer vision have made it possible to create portable and automated soil diagnostic systems. Several research works provide the foundation for this project. Wu et al. [1] developed an IoT-based soil monitoring system integrating multiple sensors with a smartphone application. Their system measures soil temperature, moisture, and electrical conductivity and demonstrates the practical feasibility of mobile-integrated agricultural diagnostics and real-time field monitoring. Nussbaum et al. [2] proposed improvements in pH glass electrodes using constant potential coulometry at zero current, which increased sensitivity and reduced noise in high-impedance systems. Naumann et al. [3] further emphasized the importance of calibration in pH measurement and recommended multi-point calibration to improve accuracy and traceability. Vaidya et al. [4] developed a real-time soil fertility analyzer using sensor data and data mining algorithms for crop prediction. Their work supports the crop recommendation module used in this project. Razaq et al. [5] reviewed various soil moisture measuring techniques and highlighted the effectiveness of capacitive sensors for sustainable land and water management. Similarly, Pandit et al. [6] discussed soil moisture estimation methods and their importance in irrigation water allocation and crop planning. Jain et al. [7] proposed a sensor-based model for predicting soil nutrients (NPK) using the TCS3200 color sensor and RGB value analysis. This work closely aligns with the colorimetric nutrient detection module of the present system. Automated soil testing devices for soil pH estimation have also shown the importance of microcontroller-based solutions in simplifying soil diagnostics [8].Tommaselli [9] highlighted the growing importance of image processing in modern agriculture using RGB, multispectral, and hyperspectral imaging systems for monitoring crop health and improving agricultural decisions. Cuevas et al. [10] explained digital image processing techniques such as image subtraction, thresholding, binarization, and convolutional filtering, which are useful for nutrient detection through image analysis Kumar et al. [11] reviewed Artificial Intelligence and Machine Learning applications in soil analysis and explained how predictive modeling and remote sensing improve the speed and accuracy of soil diagnostics. Mansoor et al. [12] discussed IoT-enabled smart sensors in precision agriculture and explained how cloud computing, big data, and AI help deliver real-time agricultural insights. These studies strongly support the development of an integrated soil health monitoring and crop recommendation system. This project, titled SoilIQ: Intelligent Soil Health Testing and Crop Suggestion Using IoT and Computer Vision, is developed to address these challenges by creating a compact, low-cost, and automated soil testing device using Raspberry Pi 3, capacitive moisture sensors, pH glass electrodes, and camera-based NPK analysis. The system provides real-time soil diagnostics through a web-based interface and also recommends suitable crops based on the soil profile. The major objectives of this project are to construct and implement a portable soil testing device, enable real-time monitoring of moisture, pH, and nutrient levels, reduce dependency on laboratory-based testing, and promote sustainable farming practices through better irrigation and fertilization decisions. By minimizing manual intervention and making soil testing more accessible, the system helps farmers adopt data-driven precision agriculture methods.

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DOI: https://doi.org/10.5281/zenodo.20073450
Received 15 April 2026; Received in revised form 28 April 2026; Accepted 03 May 2026, Available online 07 May 2026

2. Methodology and Implementation

The methodology of the SoilIQ system includes both hardware and software components working together for soil data collection, processing, visualization, and crop recommendation. The entire system is designed to provide real-time soil analysis in a compact and efficient form suitable for agricultural use.The hardware section uses Raspberry Pi 3 as the main processing unit. It acts as the controller for collecting sensor data, processing information, and communicating with the software interface. Analog sensors are connected through an ADC (Analog-to-Digital Converter) to enable accurate data acquisition. The capacitive moisture sensor is used to measure the water content of the soil. It works by detecting changes in the dielectric properties of the soil and provides stable moisture readings after insertion into the sample. The pH glass electrode is used to measure soil acidity. Since pH measurement requires high accuracy, the electrode is calibrated using a two-point calibration process with standard buffer solutions. Soil is mixed with distilled water, and the electrode is immersed until a stable pH reading is obtained.
For NPK nutrient detection, a camera module is connected to the Raspberry Pi. Soil samples are mixed with chemical reagents that produce different color reactions depending on Nitrogen (N), Phosphorus (P), and Potassium (K) concentrations. These images are captured and processed using colorimetric analysis techniques. The software stack is developed using HTML and CSS in Visual Studio Code and functions as a web-based interface for displaying soil reports and crop recommendations. Sensor data from the hardware module is transmitted to the backend using APIs, allowing real-time updates on the web interface. Crop recommendation is generated using a Kaggle dataset that maps soil parameters to suitable crops. Based on user input and measured soil conditions, the backend filters and displays the most appropriate crop suggestions. The system is designed in a modular format so that future improvements such as mobile applications, multilingual support, advanced analytics, and additional sensors can be added easily

1. User requirements

The SoilIQ system is developed to meet the practical needs of farmers, especially those working in rural and small-scale agricultural environments where access to laboratory testing facilities is limited. The first major requirement is low-cost soil testing. Farmers need an affordable solution that can provide accurate soil analysis without expensive laboratory services. The system must therefore be compact, economical, and easy to maintain. Real-time monitoring is another important requirement. Farmers need immediate information about soil moisture, pH, and nutrient levels so that they can make quick decisions regarding irrigation, fertilization, and crop selection. Ease of use is also essential because many users may not have advanced technical knowledge. The web interface must be simple, clear, and understandable so that soil reports and recommendations can be interpreted easily without expert assistance. Portability is required so that the system can be used directly in agricultural fields rather than requiring soil samples to be sent to laboratories. This improves convenience and saves time. Crop recommendation support is another user need. Farmers require guidance on selecting the most suitable crop based on the current soil condition. The system must provide practical recommendations using reliable datasets. Finally, scalability and future improvements are important user requirements. The system should support future features such as mobile application access, multilingual support, weather integration, geolocation services, solar-powered deployment, and advanced machine learning models for improved agricultural intelligence

2. Block Diagram of Dispenser

The block diagram of the SoilIQ system shows the complete process of soil testing and crop recommendation. First, the soil sample is taken for analysis of three important parameters: moisture content, pH value, and NPK (Nitrogen, Phosphorus, and Potassium) nutrient levels. The moisture sensor is directly inserted into the soil sample to measure the water content present in the soil. It helps farmers understand irrigation needs and maintain proper water levels for crop growth. For pH measurement, the soil sample is mixed with distilled water to form a soil solution. The pH electrode is then placed into this mixture to measure the acidity or alkalinity of the soil. Proper pH balance is necessary because it affects nutrient absorption and crop productivity. For NPK analysis, the soil sample is mixed with chemical reagents that produce color changes based on nutrient concentration. A camera module captures the image of the treated sample, and image processing techniques are used to identify the Nitrogen, Phosphorus, and Potassium levels. The outputs from the moisture sensor and pH electrode are analog signals, so they are connected to an ADC (Analog-to-Digital Converter), which converts them into digital signals. These digital values, along with the camera input, are sent to the Raspberry Pi 3, which acts as the main processing unit of the system. The Raspberry Pi processes all sensor data, performs analysis, and sends the results to the web server through API communication. The web server displays real-time soil reports and crop recommendations through a simple web interface. This helps farmers make better decisions regarding irrigation, fertilization, and crop selection using accurate and real-time soil information.

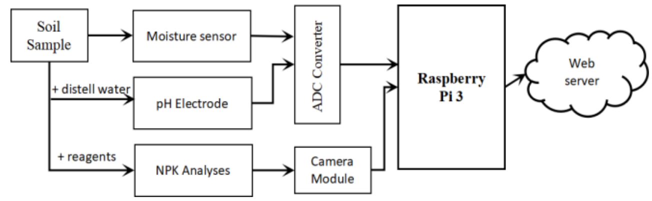

Fig. 1. Block diagram of the system.

Results and Discussions

The SoilIQ system was successfully implemented and tested for real-time soil analysis and crop recommendation. The hardware and software modules worked together effectively to provide accurate monitoring of soil moisture, pH value, and crop suggestions through a web-based interface. The moisture sensor produced stable readings and accurately reflected changes in soil water content. This helped in identifying irrigation requirements and showed that the capacitive sensor is suitable for real-time field monitoring. The pH sensor was calibrated using standard buffer solutions and provided reliable results for different soil samples. The readings were consistent and helped determine the acidity and alkalinity of the soil, which is important for nutrient absorption and crop growth. The moisture and pH values were successfully transmitted from the Raspberry Pi to the web server using API communication. The frontend interface displayed the values clearly in real time, making the system easy to use even for farmers with limited technical knowledge.

The HTML and CSS-based webpage was responsive, simple, and user-friendly. The crop recommendation module was developed using a Kaggle dataset that maps soil parameters to suitable crops. Based on the user input and sensor readings, the system successfully filtered and displayed the most appropriate crop suggestions. This helps farmers make better decisions regarding crop selection and improves productivity. The NPK detection module using camera-based colorimetric analysis was partially implemented. Soil samples treated with chemical reagents showed visible color changes based on nutrient concentration. The Raspberry Pi camera successfully captured these images for further image processing. Although full optimization of the NPK analysis is still under development, the initial testing showed promising results for future improvement. Overall, the system demonstrated reliable sensor performance, smooth hardware-software integration, and effective real-time reporting. It reduced dependency on traditional laboratory testing and provided a low-cost, portable solution for precision agriculture. Future improvements in NPK image processing, region-specific crop datasets, and mobile support can further enhance the system performance and practical usability.

Fig. 2. User interface

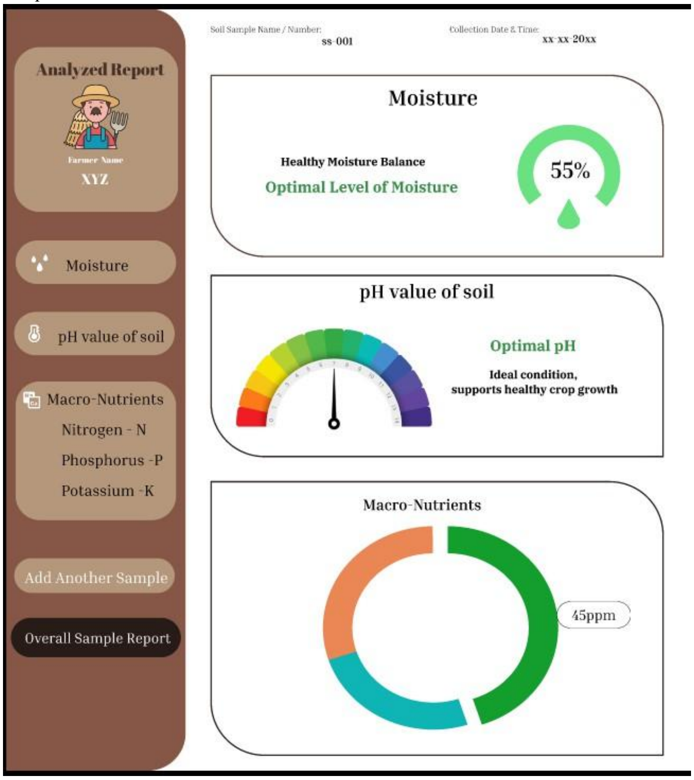

Fig. 3 Moisture and pH Integration

Fig. 4. Crop Recommendation based on user data

6. Conclusion

This endeavor therefore shows that a low- can be viable. cost, soil analysis system and built in sensor-based data. web- based reporting and acquisition. By coupling a Raspberry Pi 3 and capacitive moisture sensor and calibrated pH. The system has glass electrode as inputs and real-time as in- for. information about the state of soil. The web interface built with HTML and CSS enables the farmers to see the soil. crop recommendations and reports of curated datasets. Laboratory testing can be minimized and at the same time, it can offer. farmers who have easy access to data-driven decisions. Sensors Sensor calibration was a problem during development. ADC integration, and providing the assurance of data relay. The NPK analysis module will be in developmental stages. applying colorimetric image processing and shall be refined. with optimisation of algorithm and sample testing

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