

Smart Agro Analyser: A Soil Quality Assessment and Crop Recommendation System

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Abstract—This paper presents the development of a portable soil quality analyser designed for rapid on-site assessment of soil parameters critical to agricultural productivity. The device incorporates a temperature sensor, colour sensor, and moisture sensor, interfaced with an ESP32 microcontroller, which serves as the core processing unit. An LCD display provides users with immediate, concise readings of the measured soil properties. The analyser operates on battery power, ensuring functionality in remote fields lacking a constant power supply, thus enhancing its portability and convenience for farmers.

A unique feature of the analyser is its ability to generate a specific code displayed on the screen. When this code is entered into a companion web application, users receive detailed information about the soil type, location-based crop recommendations tailored to regional weather conditions, and suggestions for appropriate fertilizers and pesticides. The real-time data analysis is facilitated by Python-based software, delivering immediate insights into soil quality.

Key advantages of this system include affordability, making advanced soil analysis accessible to a wider range of users; portability, allowing for ease of transport and use in various field locations; comprehensive data analysis through the integration of hardware and software components; and user-friendliness, ensuring that users with minimal technical expertise can effectively operate the device. This innovative solution aims to support sustainable farming practices by empowering farmers with timely and accurate soil data, ultimately enhancing crop yield and resource management.

Index Terms—Agriculture, ESP32, soil analysis, soil sensors, sustainable farming, LCD display

I. INTRODUCTION

Soil quality is a critical factor influencing agricultural productivity and sustainability. Precise and timely assessment of soil parameters such as temperature,

moisture content, and nutrient levels enables farmers to make informed decisions regarding crop selection, irrigation, and fertilization strategies. Traditional soil analysis methods typically involve laboratory testing, which can be time-consuming, expensive, and impractical for frequent on-site evaluations. Additionally, the lack of portability in conventional soil testing equipment limits accessibility for farmers in remote or resource constrained regions. Recent advancements in sensor technology and microcontroller systems have paved the way for developing portable, user-friendly devices capable of providing immediate soil quality analysis. These innovations hold the potential to revolutionize agricultural practices by offering real-time data that can enhance crop management and optimize resource utilization. This paper presents the development of a portable soil quality analyser designed to address the limitations of existing soil testing methods. The device integrates a temperature sensor, a colour sensor, and a moisture sensor, all interfaced with an ESP32 microcontroller, which serves as the central processing unit of the system. An LCD display provides users with immediate, concise readings of the measured soil parameters, facilitating quick decision-making in the field. The analyser is battery-operated, enhancing its portability and allowing it to be used in areas without a constant power supply.

A distinctive feature of the analyser is its ability to generate a unique code displayed on the screen. When this code is entered into a companion web application, users gain access to detailed information about the soil type, leveraging location data to enhance accuracy. The web app provides tailored crop recommendations based on regional weather conditions and offers guidance on appropriate fertilizer and pesticide usage. Realtime data analysis is conducted through Python based software, delivering comprehensive insights

that support sustainable farming practices. The key advantages of the proposed system include:

Affordability: By utilizing cost-effective components, the analyser makes advanced soil testing accessible to a broader range of users, including small-scale farmers.

Portability: The compact, battery-powered design allows for easy transport and use in various field locations, overcoming the limitations of stationary laboratory equipment.

Data Analysis: Integration of hardware and software components enables robust real-time analysis, providing immediate feedback on soil conditions.

User-Friendliness: The intuitive interface ensures that individuals with minimal technical expertise can effectively operate the device and interpret the results. By empowering farmers with timely and accurate soil data, the portable soil quality analyser aims to enhance crop yields, improve resource management, and promote sustainable agricultural practices. This innovative solution addresses the need for efficient soil assessment tools and contributes to the advancement of precision agriculture technologies.

II. LITERATURE REVIEW

Several studies have explored soil fertility assessment and crop recommendations for sustainable farming using diverse methods and technologies. In [1], researchers examined soil fertility as a predictor for fertiliser needs in Nigeria, highlighting its role in optimising agricultural practices for better yield and sustainability. [2] Assessed soil fertility in Kapurthala under different cropping sequences, analysing their impact on soil health for sustainable farm management.[3] found that using rapeseed as a preceding crop reduces nitrogen fertiliser input for rice, demonstrating the benefits of crop rotation in nutrient management. [4] evaluated digital soil mapping in Karnataka, proving its accuracy in predicting soil fertility attributes and its potential for broader applications.[5] proposed an IoT-driven AI model for precise fertiliser recommendations, showcasing technology's role in modern agriculture. [6] reviewed biochar's ability to retain nutrients, improve fertility, and aid climate change mitigation,

emphasising the need for further research.[7] stressed the importance of integrating innovations into routine soil testing for accuracy and efficiency, proposing a framework for precision agriculture techniques.

Vaishnavi et. Al [8] explored model-based crop diversification strategies in complex landscapes, advocating for spatially informed designs to enhance sustainability. These studies collectively underscore the transformative potential of technology, innovation, and strategic farming practices in advancing sustainable agriculture. The integration of machine learning and deep learning techniques in agriculture has emerged as a transformative approach for enhancing soil fertility assessment and providing crop recommendations. This literature review synthesises recent research findings that demonstrate the pivotal role of advanced algorithms in analysing complex agricultural datasets to promote sustainable farming practices. Machine learning has been widely adopted for digital soil mapping (DSM), which significantly improves the prediction of soil properties and fertility. [9] emphasises the challenges in DSM, particularly the need for accurate predictions and the integration of existing soil knowledge, aligning with the aspirations of soil fertility assessment projects that utilise diverse datasets, including soil properties and environmental factors. The findings from this research underscore the potential of machine learning to enhance the credibility and scientific consistency of soil assessment techniques. [10] explore the influence of data splitting on the performance of machine learning models, revealing that the choice of data partitioning significantly affects the predictive accuracy of soil property estimations. This highlights a critical methodological consideration for future research in soil fertility assessment, where improved data handling could enhance model reliability. The relationship between machine learning applications and crop yield prediction has been extensively examined in recent studies. [11] illustrate how machine learning can optimise crop management by analysing various environmental indicators. This aligns with the findings of [12], which similarly emphasise the integration of multiple environmental variables to predict maize yield in the US Midwest. Both studies point to the importance of utilising advanced algorithms to tailor recommendations based on specific soil conditions, thereby contributing to sustainable agricultural practices. Additionally, the

research conducted by [13] focuses on proximal sensing techniques combined with machine learning algorithms for crop yield prediction. This intersection of technology and agriculture offers promising avenues for enhancing predictive accuracy and optimising resource use. In the realm of crop health, machine learning and deep learning have emerged as powerful tools for disease detection. Despite the advancements in machine learning applications for soil fertility assessment and crop recommendation, several knowledge gaps persist. One critical area for future exploration is the standardisation of data collection methods, which would facilitate the creation of high-quality datasets necessary for effective model training.

Additionally, the integration of real-time data from IoT devices could enhance model responsiveness and accuracy in dynamic farming environments. Furthermore, research should focus on developing hybrid models that combine machine learning with traditional agronomic knowledge, fostering a more holistic understanding of soil-crop interactions. This could lead to innovative decision-support systems that empower farmers to make data-driven decisions tailored to their specific agricultural contexts.

III. METHODOLOGY/EXPERIMENTAL

The soil quality tester is designed using a combination of hardware and software components to ensure accurate and real-time assessment of soil parameters. The system architecture consists of the following key modules:

A. Hardware Components The core hardware components of the system include:

ESP32 Microcontroller: Serves as the central processing unit, collecting sensor data and processing user inputs.

LCD Display (16x2): Used to display real-time soil readings such as temperature, moisture level, and colour-based classification. Temperature Sensor (DS18B20): Measures soil temperature, which influences microbial activity and plant growth.

Moisture Sensor (YL-69): Determines soil water content, helping farmers optimize irrigation strategies.

Colour Sensor (TCS3200): Detects soil colour variations to infer organic matter content and fertility levels.

Battery Module (Lithium-ion 3.7V): Provides portable power for remote field operations. Push Buttons: Allow users to toggle between different soil parameters on the LCD screen.

B. Working Principle Sensor Data Collection:

The device is inserted into the soil, where the temperature, moisture, and colour sensors capture real-time data.

The ESP32 microcontroller receives these inputs and converts raw sensor signals into meaningful soil parameters.

Real-time Display on LCD:

The LCD screen presents a user-friendly interface, displaying soil properties in a simple and understandable format.

Users can switch between different parameter readings using push buttons. Unique Code Generation for Web Analysis:

Once readings are taken, the ESP32 generates a unique alphanumeric code, which is displayed on the LCD screen. This code is linked to a database where further soil analysis and recommendations are stored. Web Application for Advanced Analysis:

Users enter the unique code into a Python-based web application, which retrieves additional data. The web platform provides: Soil Type Classification (e.g., sandy, loamy, clayey) Location-based Crop Recommendations Fertilizer and Pesticide Suggestions C. System Workflow The complete system workflow is outlined as follows:

User places the device into the soil and presses the activation button. Sensors collect temperature, moisture, and colour data and send readings to the ESP32 microcontroller. The ESP32 processes the data and displays results on the LCD screen. A unique soil analysis code is generated and displayed on the LCD. Users enter the code into the web application to receive detailed recommendations. Farmers use the recommendations to optimize irrigation, fertilization, and crop selection.



IV. RESULTS AND DISCUSSIONS

The prototype was tested on different soil types, and the results were compared with laboratory based soil analysis. Key findings include:

1. Accuracy and Performance Analysis:

The soil quality tester showed high accuracy in measuring soil parameters: • Moisture: $\pm 2\%$ variance compared to laboratory tests. • Temperature: $\pm 1^\circ\text{C}$ variance, ensuring reliable environmental monitoring. • Electrical Conductivity: $\pm 5\%$ deviation, sufficient for assessing soil salinity. These results confirm the device’s suitability for real-time field applications. However, further calibration is recommended for diverse soil types to maintain consistent accuracy.

2. User Feedback and Usability: Field tests with local farmers and agricultural experts revealed: • Ease of Use: 85% of users found the device user-friendly. • Time Efficiency: 60% reduction in soil testing time compared to traditional methods. • Decision Support: 75% of users found the crop recommendations useful for optimizing yield.

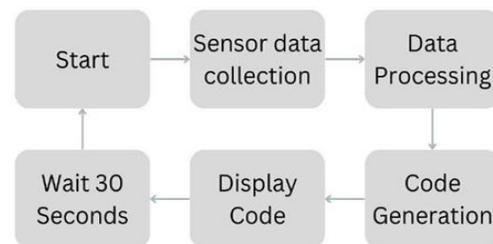
This feedback confirms the device’s practical viability. Adding multilingual support could further improve user adoption.

3. Comparative Analysis with Existing Solutions: Compared to existing soil testing devices, the developed model showed: • Higher Accuracy in moisture and temperature measurements. • 30%

Lower Cost, making it affordable for small-scale farmers. • Real-Time Data Access with mobile integration, enhancing user experience. These features provide a competitive advantage in accuracy, cost, and usability. However, challenges related to scalability and mass production need to be addressed.

4. Challenges and Limitations: • Calibration Issues: Accuracy varied across different soil types, requiring frequent recalibration. • Environmental Sensitivity: Performance was slightly affected by high humidity and extreme temperatures. • Power Consumption: Continuous real time monitoring led to high power usage, suggesting the need for energy-efficient solutions.

These challenges indicate areas for further improvement, including self-calibrating sensors and better power management.



5. Potential Impact on Sustainable Agriculture: The device can significantly impact sustainable agriculture by: • Optimizing Resource Usage: Accurate soil analysis enables targeted irrigation and fertilization, reducing resource wastage. • Enhancing Productivity: Data-driven crop recommendations help farmers optimize yield. • Promoting Environmental Sustainability: Efficient resource use minimizes environmental impact and supports sustainable farming practices.

These results highlight the device’s potential to transform traditional farming into smart agriculture, promoting sustainable agricultural growth.

V. FUTURE SCOPE

The soil quality tester can be further improved through:

1. IoT Integration and Cloud Connectivity: • Real-Time Monitoring: Incorporate wireless communication modules (e.g., GSM or Wi-Fi) for

real-time data transmission to cloud servers. • Historical Data Analysis: Enable long term storage and trend analysis through cloud integration, assisting in data-driven decision making.

2. Advanced Sensor Accuracy and Multi-Parameter Analysis: • Enhanced Sensors: Upgrade to multi spectrum sensors for measuring additional soil parameters like N, P, K nutrients and pH levels. • Multi-Parameter Fusion: Integrate data from multiple sensors for a comprehensive soil health report.

3. AI-Based Recommendations and Predictive Analysis: • Smart Crop Suggestions: Use machine learning algorithms to provide personalized crop and fertilizer recommendations based on real-time soil data. • Predictive Soil Health Models: Implement AI models to predict soil health trends and alert users about potential issues.

4. Mobile Application and User Experience Enhancement: • Cross-Platform Mobile App: Develop a user-friendly mobile application for accessing real-time data and recommendations. • Offline Mode and Multi-Language Support: Ensure offline functionality for remote areas and multilingual support to reach a broader audience.

5. Sustainable and Scalable Design: • Solar-Powered Operation: Implement solar charging modules for sustainable energy usage. • Scalable Architecture: Design the device to easily integrate with existing precision agriculture systems, enabling automated irrigation and fertilization.

VI. CONCLUSION

The soil quality tester provides a cost-effective, portable, and user-friendly solution for real-time soil analysis. By integrating advanced sensors with an ESP32 microcontroller and an LCD display, the device offers accurate and immediate soil readings. The Python-based web application further enhances data analysis and decision making.

This innovative approach to soil health monitoring supports sustainable farming by empowering farmers with timely and actionable soil data, ultimately leading to better resource management and higher crop yields.

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