An AI-Driven Multi-Sensor Soil Analytics System with Crop Recommendation

Dhaval J. Devikar
dhavaldevikar09@gmail.com

Dr. M.V. Lande
milind.jdiet@gmail.com

Mrs. Sarita I. Bansod
sarubansod@gmail.com

Ms. Minakshi B. Manalwar
siddhamminakshi@gmail.com

Abhijit A. Khandre
abhijeetkhandre2007@gmail.com

Yash S. Shriramjawar
yashshriramojwar@gmail.com

Suhani B. Palikondawar
suhanipalikondawar@gmail.com

Dhanashri G. Atram
dhanashriatram01@gmail.com

Department Of Computer Engineering Government Polytechnic Gadchiroli, Maharashtra, India

---***---

Abstract— Agricultural productivity largely depends on soil quality and environmental factors that influence crop growth, which often leads to inefficient irrigation, unsuitable crop selection, and reduced yield. To address these challenges, this paper proposes an artificial intelligence based multi sensor soil analytics system for intelligent agricultural decision support. The proposed system continuously collects important soil and environmental parameters. such as soil moisture, temperature, humidity, pH, and nutrient levels using an integrated sensing framework. The collected sensor data is processed by the microcontroller and displayed through a monitoring interface for analysis. A machine learning model is employed to analyze the multi sensor data and evaluate soil conditions, predict irrigation requirements, and recommend suitable crops. Experimental results indicate that the proposed system improves precision farming by enabling data driven decisions, optimizing resource utilization, and supporting sustainable agricultural practices. For example, chickpea was identified as a suitable crop for the tested soil conditions.

Keywords— Artificial intelligence, Internet of Things, Soil health monitoring, Crop prediction, Precision agriculture, Machine learning

I. INTRODUCTION

Crop production strongly relies on soil characteristics and environmental conditions, yet traditional farming methods rely mainly on manual observation and experience-based decisions. Such practices often lead to inefficient irrigation, improper crop selection, and reduced agricultural productivity.

With increasing climate variability and resource constraints, there is a growing need for intelligent and data- driven farming solutions.

Advances in Artificial Intelligence (AI) and Internet of Things (IoT) technologies now allow real-time monitoring and analysis of agricultural environments. This paper presents an AI-Driven Multi-Sensor Soil Analytics System with Crop Prediction that integrates soil moisture, temperature, humidity, light intensity, and soil pH sensors using a low-powered IoT- enabled microcontroller platform.

A machine learning model processes the multi- sensor data to evaluate soil condition, determine irrigation requirements, and recommend suitable crops. By transforming raw sensor data into actionable insights, the proposed system supports precision farming, improves crop yield, and promotes sustainable agricultural practices.

Agricultural productivity is strongly influenced by soil health, environmental conditions, and nutrient availability. In many farming practices, decisions related to crop selection and fertilizer usage are still based on traditional knowledge or periodic manual soil testing. Such approaches are time-consuming, location-dependent, and often fail to capture dynamic variations in soil conditions. As a result, improper crop selection and inefficient fertilizer application can lead to reduced yield and long-term soil degradation.

This work presents an AI-driven multi-sensor soil analytics system that integrates soil moisture, temperature and humidity, pH, and NPK sensors with a wireless microcontroller platform. The proposed system analyses real-time soil data to recommend suitable crops and appropriate fertilizers for improving soil fertility

II. LITERATURE SURVEY

II.I. TABLE I

No.	Authors	Year	Key Findings
1.	Priya, R., Kumar, M., and Singh, A.	2020	Machine learning models improve crop recommend-ation accuracy
2.	Sharma, P. and Verma, R.	2021	Soil pH and NPK analysis enables efficient fertilizer management
3.	FAO and National Research Council	2022	Emphasizes sustainable and climate resilient agriculture
4.	Meena, D., Joshi, S., and Patel, K.	2023	AI based IoT systems provide real time decision support
5.	Zhang, Y., Liu, H., and Chen, X.	2024	Deep learning improves soil and crop prediction accuracy

III. PROPOSED MODEL

The proposed system is an AI-driven, multi- sensor soil analytics and crop recommendation model designed to assist farmers in making informed agricultural decisions. The model integrates IoT-based sensing, wireless communication, and machine learning for intelligent soil analysis.

The system consists of multiple sensors, including soil moisture, temperature and humidity and pH sensors, which are interfaced with an ESP32 microcontroller. These sensors continuously monitor soil and environmental parameters in real time. The collected sensor data is analyzed using a machine learning model implemented within the system.

A machine learning model is trained using historical sensor data and agronomic thresholds to classify soil conditions and predict irrigation requirements. Based on moisture level, temperature stress, light availability, and soil pH, the system analyses soil suitability and recommends appropriate crops for cultivation. The model also identifies potential yield risk and soil stress conditions. The processed results are presented through a user-friendly interface, enabling farmers to understand soil health and receive actionable recommendations. This proposed model aims to enhance precision farming, reduce resource wastage, and improve crop productivity through intelligent automation.
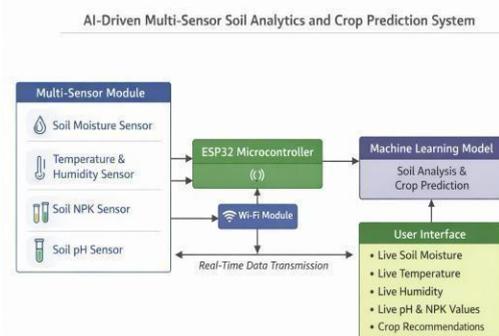

Fig. 1. Block diagram of the proposed AI-driven multi-sensor soil analytics and crop prediction system.

IV. WORK DESCRIPTION

This paper presents an AI-driven multi- sensor soil analytics and crop prediction system designed to support smart agriculture. Using an ESP32 microcontroller, the system collects real-time soil parameters including moisture, temperature, humidity, pH, and NPK nutrient levels. The sensor data is transmitted wirelessly and processed using machine learning algorithms to analyse soil health. Based on the analysed conditions, the system provides accurate crop recommendations and suggests suitable fertilizers to improve soil fertility. A user interface displays live sensor readings and AI-based insights, enabling farmers to make informed decisions, optimize crop yield, reduce resource wastage, and promote sustainable farming practices.

V. HARDWARE DESCRIPTION

V.I. ESP32 Microcontroller

Fig. 2. ESP32 WROOM 32D microcontroller.

The ESP32 microcontroller acts as the central control unit of the system. It is responsible for acquiring sensor data, performing basic preprocessing, and transmitting the information to the monitoring interface using built-in Wi-Fi connectivity.

V.II. Capacitive Soil Moisture Sensor :

Fig. 3. Capacitive soil moisture sensor.

A capacitive soil moisture sensor measures the amount of water present in soil by detecting changes in capacitance. Unlike resistive moisture sensors, this sensor operates on the principle of capacitance variation, where changes in soil moisture alter the dielectric constant between the sensor electrodes. This method reduces the effect of soil salinity and minimizes corrosion, making the sensor suitable for long-term field deployment.

V.III. Soil pH Sensor :

Fig. 4. Soil pH sensor.

The soil pH sensor determines whether the soil is acidic, neutral, or alkaline, which is a critical parameter influencing nutrient availability, microbial activity, and overall crop productivity. Soil pH directly affects the solubility of essential nutrients such as nitrogen, phosphorus, and potassium, thereby impacting plant growth and yield. Based on the measured pH value, the system can identify whether the soil condition is acidic, neutral, or alkaline.

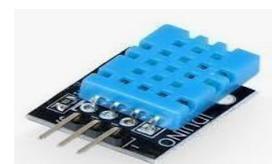### V.IV. Temperature and Humidity Sensor (DHT11)

Fig. 5. DHT11 temperature and humidity sensor The DHT11 sensor monitors environmental temperature and humidity levels around the crop field that directly affect crop growth, soil moisture retention, and evapotranspiration rates. Temperature variations influence plant metabolic activity, while relative humidity impacts water loss from soil and plant surfaces. Continuous monitoring of these parameters is essential for effective irrigation planning and crop health management.
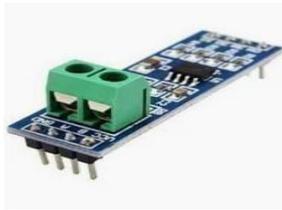
V.V. Max485 Modbus module:

Fig. 6. MAX485 Modbus module.

The MAX485 module is used to enable RS-485 based Modbus communication for reliable, long-distance, and noise-resistant data transmission in agricultural monitoring systems.

V.VI. NPK Sensor :

Fig. 7. NPK sensor.

The NPK sensor is used to measure the concentration of essential soil nutrients, namely Nitrogen (N), Phosphorus (P), and Potassium (K), which are vital for plant growth and crop productivity.

V.VII. L298n Motor Driver

Fig. 8. L298N motor driver.

The L298N motor driver is used to control the movement of DC motors in the rover system. It allows bidirectional motor control and supports speed and direction regulation through control signals from the microcontroller.

VI. SOFTWARE

The Arduino Integrated Development Environment (IDE) is used for developing, compiling, and uploading firmware to the microcontroller used in the proposed system. It provides a simple and user-friendly programming interface based on C and C++ languages, making it suitable for rapid prototyping and embedded system development.

The IDE supports serial communication, which is utilized for debugging, sensor data monitoring, and real-time analysis during system testing. In the proposed system, the Arduino IDE is used to program the ESP32 microcontroller for sensor data acquisition and processing. The system reads soil parameters such as moisture, temperature, humidity, pH, and NPK values and analyzes them to generate crop recommendations.

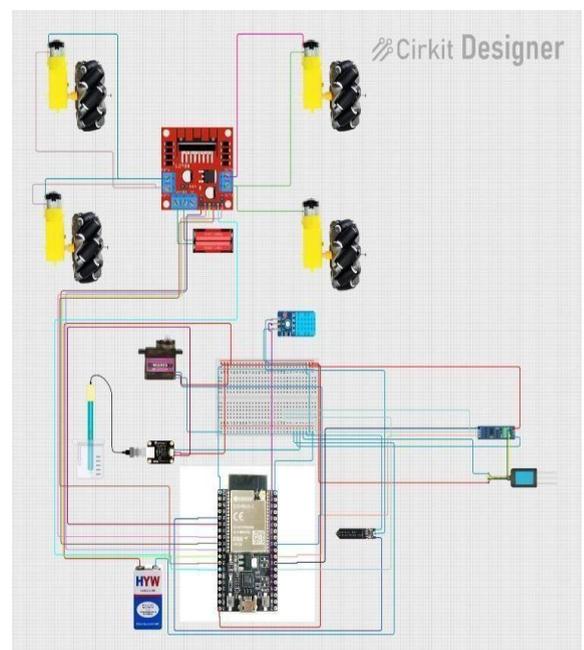Fig. 9. Arduino IDE

VI.I. HARDWARE CONNECTION

Fig. 10. Hardware Connection

VI.II. COMPLETE HARDWARE SETUP

(a)

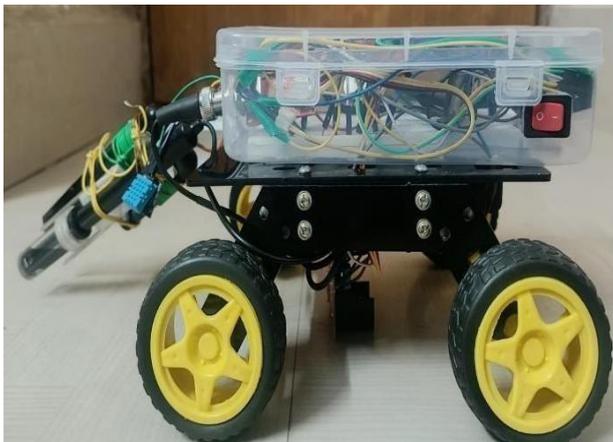

Fig. 11. Hardware configuration

(b)

Fig. 12. Hardware configuration

VII. SOIL SAMPLE TESTING

VII.I. TESTING SOIL SAMPLE 1

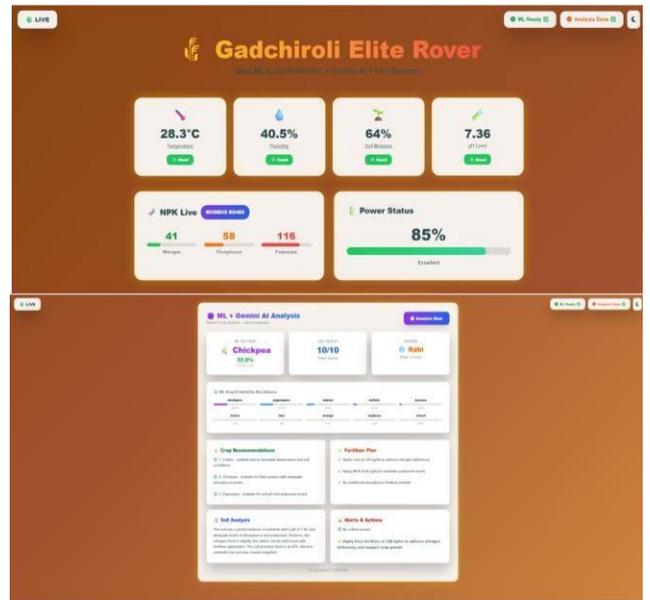Fig. 13. Soil sample I testing setup.

VII.II. Result

Fig. 14. Soil sample I testing results.

VII.III. TESTING SOIL SAMPLE 2

Fig. 15. Soil sample II testing setup.
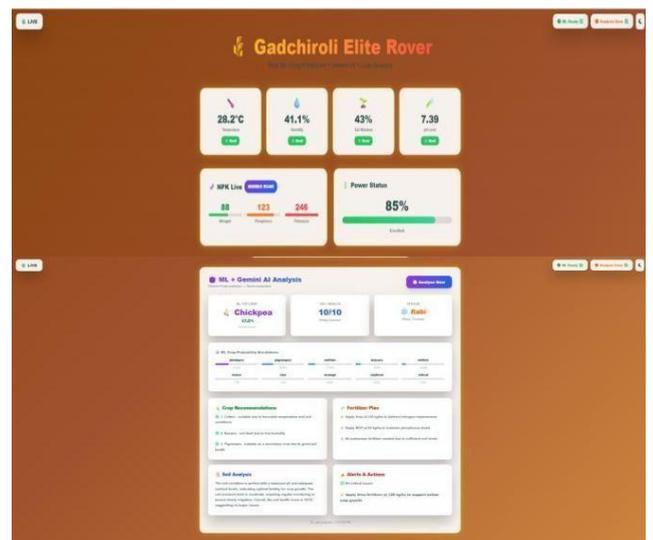
VII.IV. RESULT

Fig. 16. Soil sample II testing results.

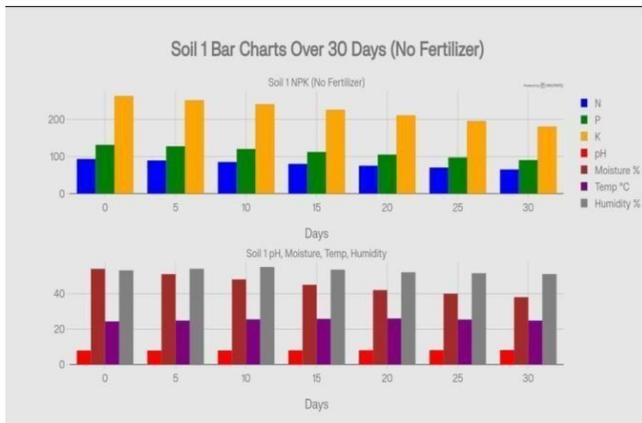## VII.V. SOIL1 SENSORS OVER 30 DAYS (NO FERTILIZER)

Fig. 17. Soil 1 (Channa, no fertilizer): NPK depletion, moisture decline over 30 days.
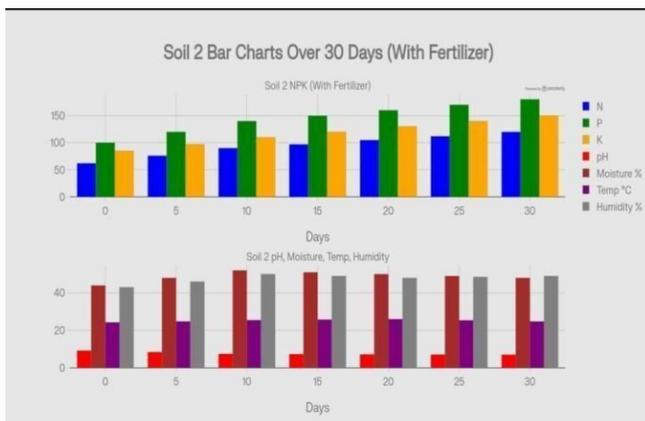
VII.VI SOIL 2 SENSORS OVER 30 DAYS (WITH FERTILIZER)

Fig. 18. Soil 2 (Channa, +fertilizer): Nutrient enrichment, pH normalization, faster growth.

VIII.   Advantages

• Real-time soil health monitoring

• Accurate crop recommendation using AI

• Reduces fertilizer and water wastage

• Low-cost and farmer-friendly system

• Improves crop yield and soil fertility

• Wireless and remote monitoring

• Minimizes human error in decision-making

IX.   FEATURES

• Live soil moisture monitoring

• Temperature and humidity sensing

• Real-time soil pH measurement

• NPK (Nitrogen, Phosphorus, Potassium) analysis

• AI-based crop recommendation

• Fertilizer suggestion for soil improvement

• Simple and interactive user interface

X.   APPLICATION

• Smart agriculture systems

• Precision farming

• Soil testing laboratories (portable)

• Greenhouses and polyhouses

• Research and agricultural institutes

• Small and large-scale farms

XI.   CONCLUSION

This study presents the development and implementation of an AI-based multi-sensor soil monitoring and crop recommendation system. By integrating soil moisture, temperature and humidity, soil pH, and NPK sensors with a wireless microcontroller, the system enables real- time monitoring of critical soil parameters. The collected data is processed and analyzed to generate suitable crop recommendations and fertilizer suggestions, supporting informed agricultural decision-making. The system reduces dependency on traditional trial-and-error farming practices and promotes efficient soil utilization. Experimental testing confirms reliable sensor performance, stable wireless data transmission, and meaningful AI- based predictions under practical conditions. Due to its low cost, modular design, and scalability, the proposed system is well suited for small and medium-scale farmers. Future enhancements may include advanced machine learning models, mobile application integration, and long-term field deployment to further improve accuracy and usability in precision agriculture.

XII. REFERENCES

[1] Institute of Electrical and Electronics Engineers, "IoT-Based Smart Agriculture Monitoring System," IEEE International Conference on Communication and Electronics Systems, 2019.

[2] IEEE Access, "Machine Learning Techniques for Smart Agriculture: A Review," vol. 8, pp. 2019–2030, 2020.

[3] Computers and Electronics in Agriculture, "Artificial Intelligence Applications in Precision Agriculture," vol. 178, 2020.

[4] Sensors, "IoT-Based Soil Monitoring Systems for Smart Farming," vol. 20, no. 18, 2020.

[5] Food and Agriculture Organization, "Digital Technologies in Agriculture and Rural Areas," FAO Report, 2020.

[6] International Journal of Agricultural Science and Research, "Soil Nutrient Monitoring Using NPK Sensors in Precision Farming," 2021.

[7] Agricultural Water Management, "Smart Irrigation Systems Using IoT and Sensor Networks," vol. 245, 2021.

[8] International Journal of Scientific and Engineering Research, "ESP32 Based Smart Agriculture Monitoring System," vol. 12, no. 4, 2021.

[9] Espressif Systems, "ESP32 Technical Reference Manual," 2022.

[10] Indian Council of Agricultural Research, "Soil Health Monitoring and Crop Productivity," ICAR Agricultural Research Report, 2022.

[11] International Journal of Advanced Computer Science and Applications, "Machine Learning Based Crop Yield Prediction Using Environmental Parameters," vol. 13, no. 6, 2022.

[12] IEEE Internet of Things Journal, "AI-Enabled Smart Farming Systems Using Sensor Networks," 2023.

[13] Journal of Precision Agriculture, "Multi- Sensor Soil Monitoring Systems for Precision Farming," vol. 24, 2023.

[14] World Bank, "Digital Agriculture and Smart Farming Technologies," World Bank Report, 2023.

[15] Sensors, "Wireless Sensor Networks for Soil Monitoring in Agriculture," 2023.

[16] IEEE Access, "Deep Learning Techniques for Crop Yield Prediction," 2023.

[17] International Society of Precision Agriculture, "Precision Agriculture Technologies for Soil and Crop Monitoring," 2024.

[18] Computers and Electronics in Agriculture, "AI-Driven Crop Prediction Models Using Soil and Climate Data," 2024.

[19] United Nations, "Smart Agriculture for Sustainable Food Production," 2024.