Smart soil parameters monitoring and crop recommendation Using NPK Sensor: A Review

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Abstract

Farming acting a key part in confirming food safety and maintainable growth, yet soil health management remains a persistent challenge due to the lack of timely and accurate information. Traditional soil testing methods are slow and labor-intensive, making it difficult for farmers to make knowledgeable decisions about crop choice and fertilizer use. To address this issue, a Smart Soil Monitoring and Crop Recommendation System has been developed using NPK sensors and an ESP32 microcontroller. The system continuously measures key soil nutrients—Nitrogen (N), Phosphorus(P), and Potassium (K)—and transmits actual data to a cloud platform for processing and analysis. A machine learning–based recommendation model then suggests suitable crops and optimal fertilizer application strategies. The frontend dashboard, built with React.js and TypeScript, provides interactive visualizations of soil health and crop recommendations, while the backend, powered by Python FastAPI and PostgreSQL, ensures efficient data management and analysis. This system allows farmers to make data-driven decisions, refining crop yields, reducing fertilizer wastage, and promoting sustainable agricultural practices. The combination of IoT and AI skills in this project demonstrates a significant step toward precision farming and enhanced source operation.

***Key words*:** Precision agriculture, IoT, NPK sensors, Machine learning, Graph neural network, Soil monitoring, Crop recommendation.

Agriculture is the foundation of many economies and is essential for confirming food safety and sustainable development. The productivity of agriculture largely depends on the strength and fertility of the soil, which directly affects crop growth and yield. However, in many regions, soil health is often neglected due to a lack of awareness, insufficient monitoring, and the limitations of old soil testing procedures. Conventional testing processes are slow, costly, and need research laboratory analysis, which leads to delays in obtaining results and hinders timely decision-making for farmers.

To overcome these challenges, the implementation of current skills such as the Internet of Things (IoT) and Artificial Intelligence (AI) has become gradually significant in precision farming. IoT-based systems allow actual information assembly
and monitoring of vital soil parameters such as nitrogen (N), phosphorus (P), and potassium (K) levels, as well as temperature and moisture. These technologies help farmers gain instant insights into soil conditions, improving fertilizer management, crop selection, and overall productivity.

This project, Smart Soil Monitoring and Crop Recommendation System, is designed to provide farmers with actual soil nutrient data using NPK sensors integrated with an ESP32 microcontroller. The collected information is communicated to a cloud based stage for analysis, where a machine learning model processes the information to recommend suitable crops and fertilizer applications. By providing accurate, data driven insights, the system aims to allow farmers to make up-to-date results, improve crop yield, lessen resource wastage, and
help maintainable agricultural practices. In essence, this project demonstrates how combining IoT and AI technologies can revolutionize traditional farming by enabling intelligent soil management and fostering a transition toward precision and sustainable agriculture.

Review of Literature

Prakhar Austin Mohan, Amrender Singh,et.al,have been proposed IoT-based Crop Recommendation System using NPK Sensor to help the farmers for crop selection and better crop yield .IoT-based NPK systems utilize sensors to measure soil nutrient levels, enabling decisions on fertilizer application and crop selection. These systems provide valuable insights for precision agriculture, promoting sustainable farming practices. A study on IoT-based soil fertility analyzers using NPK sensors demonstrated the potential of these systems in measuring soil nutrient levels based on that it provides detail fertilizer application. This system is useful for crop commendation by using machine learning algorithm integration with IoT technology [1].

Sehrish Munawar Cheema a,∗, Ivan Miguel Pires b,∗,et.al, have been proposed AIoT based soil nutrient analysis and recommendation system for crops using machine learning. A clever system using sensors and cloud services to track soil and weather—measuring pH, NPK levels, temperature, humidity, and rainfall. It used real-time sensor data along with historical information to power its machine learning models. Five classifiers were compared: Decision Tree + AdaBoost, Random Forest, KNN, Decision Tree, and SVM. The best performers were Decision Tree + AdaBoost (98% accuracy), Random Forest (97%), and KNN (96%), followed by DT (93%) and SVM (92%).This system helps farmers get accurate, personalized crop recommendations based on actual field conditions.By combining IoT, AI, and cloud tools, it supports precision agriculture boosting yields, cutting waste, and improving resource use. Overall, it shows how modern tech can help farming become smarter and more sustainable[2].

L. Lenin Kumar, M. Srivani, Md. Tabassum Nishath, et.al,have been proposed to the Monitoring of Soil Nutrients Using Soil NPK
Sensor and Arduino. Indian soils are typically low in nitrogen and phosphorus but rich in potassium, making precise nutrient

monitoring essential. Plants require 17 elements for growth,among this 14 absorbed from soil and 3 from air and water with NPK being the primary macronutrients: nitrogen boosts leaf development, phosphorus help root and flower development, and potassium supports stem strength also overall growth. The researchers collected four soil samples and compared sensor readings with lab results, showing close alignment: Nitrogen (30 vs. 55), Phosphorus (6 vs. 6.6), and Potassium (72 vs. 82.2). The findings demonstrate the system's accuracy and practicality for real-time nutrient monitoring. It offers an effective, low-cost solution for farmers to manage fertilizer use and enhance crop productivity.[3]

Haroon Ali Khan, Farooq Shah, and Sher Shah,et.al,have been presents an IoT-based soil health monitoring system designed to measure key parameters like moisture, pH, temperature, and NPK nutrients in real time. It highlights the disadvantages of old soil testing devices and shows in what way IoT can provide automated, remote, and cost effective monitoring. The authors describe system design, sensor integration with Arduino/ESP32, and data transmission to cloud platforms like ThingSpeak. Results confirm successful real-time data collection and visualization of soil parameters. The study emphasizes improved decision-making for irrigation and fertilization, contributing to precision agriculture. Overall, the work demonstrates a practical and sustainable approach to enhancing crop productivity and resource efficiency [4].

P.STELLA
MARRY, S.ANANDHARAJ,et.al have been proposed Crop Recommendation system and soil health monitoring. A smart agricultural system that recommends crops based on real time soil and climate data. Using sensors for moisture, temperature, humidity, and NPK levels, it collects field data efficiently. The system applies machine learning, particularly the Random Forest algorithm, to predict the best crops for improved yield. Integration with Arduino and MATLAB enables real time monitoring and automation. Smart greenhouses further optimize growth by controlling environmental conditions. Farmers can access insights remotely, improving decision-making. The goal is to boost productivity, reduce waste, and support sustainable farming practices.[5]

P.Ayesha Barvin and T.Sampradeepraj have been proposed crop recommendation system based on soil and environmental factor using graph convolution neural network to present a comparative study of two graph based machine learning model like GCN and GNN for crop recommendation. In india their is 58% population are belongs to an agriculture industry and also contributes 17% to the GDP.It highlights how machine learning is being applied in agriculture for crop selection.An aim to enhance planning and productivity in developing country.GCN model for crop recommendation gives 98% accuracy rate.It portrays GCN as the leading and most effective solution for modern crop management.[6]

Sai Tharun Reddy Jajala, Akash Thalari, ,et.al,have been proposed to the Sustainable Crop Recommendation System Using Soil NPK Sensor. To developing harvesting system using NPK sensors,where as data collected from this sensors (Nitrogen, Phosphorus, and Potassium) and this combined with machine learning techniques. Researcher aim is to advice farmers to in learnt informed choices by recommending crops that are most suitable for exact soil nutrient .The system will begin with data collection, real-time readings from NPK sensors. Once the soil nutrient data is accurately obtained and processed, it will be send to machine learning models skilled to recognize patterns and relationships between soil nutrients and crop performance. These models will then be used to recommend the best yields for given soil situations, thus enabling farmers to grow crops with higher chances of success, better yields, and reduced risk of failure due to lower nutrient.This leading to improved agricultural productivity.[7]

Bharadwaj.Cheruv,Dr.S. Bhargavi Latha,et. al,have been Discussed the IoT-based smart farming system using NPK sensors and machine learning for real-time monitoring and crop recommendation. The system uses sensors to measure soil nutrients (Nitrogen, Phosphorous, Potassium), temperature, humidity, too moisture. Data is transmitted via the NodeMCU ESP8266 module to the Thingspeak platform and studied using a Random Forest classifier trained on a crop recommendation dataset. The data is analyzed using a Random Forest machine learning model to recommend to most suitable crop. The Flask-based user interface enables farmers to track conditions and receive crop suggestions. The model achieved 95.09% accuracy, aiding in efficient resource use and better crop decisions [8]

KALAIVAANI V1 ,THARIKAA SRINITHI A B2 ,et.al,have been proposed smart soil monitoring system using low-power IoT sensors to track moisture, temperature, pH, and nutrients. It's a clear statement of how present data supports farmers improve yields and also conserve resources. smart soil monitoring system using IoT, STM32 microcontrollers, and LoRaWAN helps farmers check soil health in real time. It reduces manual work, improves crop growth, and supports eco-friendly farming by using data to manage resources better. The wireless tech, and apps like Node-RED help automate farming and improve irrigation through digital tools. sensors connected to an STM32 microcontroller and LoRaWAN send real time soil data (like pH, moisture, nutrients) to the cloud and display it on a Node-RED web portal [9].

Purnawarman Musa ,Herik Sugeru,et.al,have been proposed wireless sensor network for precision agriculture to integrate WSN in agriculture, to monitor plant macronutrients specifically nitrogen (N), phosphorus (P), and potassium(K).It emphasizes importance of precision agriculture enhancing productivity and efficiency. An 8.47% error rate was found, when comparing sensor data with lab result which is acceptable.Their are some technologies are used for better result in crop recommendation like Zigbee, xStream, LoRa are well suited for peer-to peek communication. WSN system is autonomously collect and transmit data to a central note. Enabling farmer to make decision based on current condition of land or soil.WSN system help to enhance crop productivity and sustainability by using NPK sensor.[10]

Dinesh B. Bhoyar1 , Amey Naik2, et.al, have been suggested PH and NPK Sensor Based Soil Testing System. It explains that traditional lab testing of soil is costly, time consuming, and not easily accessible to farmers in remote areas. The proposed system uses sensors connected to an Arduino board to measure soil nutrients quickly. The collected data is then analyzed with MATLAB software, which suggests the most suitable crops. This makes soil testing faster, cheaper, and more convenient compared to chemical methods. The system aims to improve farming practices by giving accurate soil health data and helping farmers make better crop choices[11].

Ms.Niveditha JV, Mr.Pramodh SP, et.al, have been proposed development and testing of soil NPK sensing gadget. SoilNPK sensing gadgets are developed to provide farmers with quick, on site measurement of soil nutrient level, reducing the need for time consuming laboratory testing. Development involves selecting suitable sensors(optical, electrochemical or colorimetric),designing an electronics system with a microcontroller and building a durable, potatle device. Testing convers field trials in different soil types, validation against standard lab methods and assessment of environmental factor like PH, moisture and temperature. The final gadget aims to be accurate, cost effective and easy to use, enabling better

fertilizer management and improving crop yields.[12]

R. Pallavi Reddy, B. Vinitha,et.al, have been proposed Crop Monitoring and Recommendation System using Machine Learning and IOT can help farmers by giving them real-time advice on crop care, making farming smarter and more productive. Smart farming uses soil sensors to track moisture, pH, and nutrient levels in real time, so farmers don't guess about watering or fertilizing. IoT tools help farmers know exactly when and how much to water or fertilize their crops, which saves water, money, and time. This approach also sends alerts for soil dryness or pest risk, helping farmers act fast. The soil health matters nutrients like nitrogen, phosphorus, potassium and proper pH help plants grow well, and soils differ across India (alluvial, black, etc.) with crops suited to each type. The goal is to build an Android app that uses soil data to recommend crops, irrigation, fertilizer amounts, yield forecasting, and price estimates all to help Indian farmers be resource efficient and productive[13].

Karad S. C.1 and Mundhe S. S.2 ,et.al, have been suggested Smart NPK Soil Sensor: Step towards Precision crop production the publication explains NPK soil sensors designed for Indian farms, where soil, weather, and crop types differ across Zaid, Kharif, and Rabi seasons. The sensors measure how much nitrogen, phosphorus, and potassium (N,P,K) in soil, helping farmers apply exactly the right amount of fertilizer. This improves crop size, health, and yield while preventing environmental harm. Plus, by linking sensor data on nutrients, moisture, and irrigation to mobile apps, Farmers get real-time info to apply the exact right amount of fertilizer and water, helping improve crop health and yields without wasting resources [14].

Rahul Adhikary, Suvra Jyoti Choudhury,et.al,have been proposed to the Real-Time Soil Nutrient Monitoring Using NPK Sensors to Enhancing Precision Agriculture. Excessive fertilizer use in conventional farming leads to financial waste and environmental damage. NPK sensors offer a solution by providing real-time soil nutrient data, enabling precise fertilizer application and reducing runoff and leaching. The soil NPK sensor precisely monitors nitrogen, phosphorus, and potassium levels with ±2%FS accuracy and ≤1s response time. Field tests using Arduino Nano and NPK sensors in five Odisha locations showed the sensor consistently underestimated nutrient levels by 10% for nitrogen, 12% for phosphorus, and 9% for potassium compared to lab results. The variations remained within acceptable limits, proving the sensor's reliability and suitability for practical agricultural applications. Resercher results show that neural network (NN) outperform traditional methods in accuracy and adaptability, making them ideal for real-time, scalable integration into smart agriculture systems.[15]

Methodology

The proposed Smart Soil Monitoring and Crop Recommendation System follows a five-step methodology integrating IoT and machine learning. First, the system design and architecture include sensors, a microcontroller, cloud communication, and a user interface for real-time soil data monitoring. Second, the hardware implementation involves using an NPK sensor to measure soil nutrients and an ESP32 microcontroller to collect and transmit data to the cloud. Third, the software system implementation uses Python FastAPI for background processing, PostgreSQL for data storing, and a React.js dashboard for visualizing results. Fourth, during data processing and crop recommendation, the system analyzes sensor data using machine learning algorithms to identify suitable crops and nourishment needs. Finally, the system workflow integrates sensing, transmission, analysis, and display, providing farmers with accurate, fact-based crop recommendations for improved productivity and sustainable farming.

COMPARATIVE ANALYSIS

Study	Technology Used	Focus Area	Accuracy	Scalability
Kumar et al. (2024)[3]	Arduino + NPK Sensor	Real-time soil nutrients	85%	Moderate
Niveditha et al. (2021)[12]	ESP32 + Multi-sensor	NPK, Moisture, Temp	88%	High
P.Ayesha Barvin (2023) [6]	GCN & GNN models	AI-based crop recommendation	98%	Very High

Conclusion

The Smart Soil Monitoring and Crop Recommendation System provides an innovative and practical solution to the challenges faced in modern agriculture. By integrating IoT, sensors, and machine learning, the system enables real-time monitoring of essential soil nutrients such as nitrogen, phosphorus, and potassium (NPK), helping farmers make informed decisions about crop selection and fertilizer application. The use of NPK sensors and the ESP32 microcontroller ensures accurate and continuous data collection, while cloud-based analysis and AI driven recommendations support precision farming.

This system not only enhances crop productivity but also promotes sustainable agricultural practices by minimizing fertilizer wastage and reducing environmental impact. Through data-driven insights, farmers can optimize resource use, improve soil health, and increase overall efficiency.

The project demonstrates how technology can transform traditional farming into a smart, efficient, and environmentally responsible process, paving the way toward a more sustainable and productive future for agriculture.

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