

EXPLORING IoT AND MACHINE LEARNING INTEGRATION FOR SOIL NUTRIENTS MONITORING AND CROP RECOMMENDATION: A SURVEY

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ABSTRACT

The integration of Internet of Things (IoT) and machine learning (ML) technology has the capacity to transform agriculture via the improvement of precision agricultural methods. This survey paper explores the integration of IoT and ML in the field of soil nutrient monitoring and crop recommendation systems. In the context of crop recommendation systems and soil nutrient monitoring, this paper explores the integration of IoT and ML. Its goal is to provide a thorough overview of the most recent developments, applications, challenges, and potential future directions. IoT sensors collect and give immediate soil health information, while ML algorithms analyses this data to suggest nutrient deficits and recommend the most suitable crops. The paper reviews the progress made in sensor technology and machine learning applications, highlighting the advantages they provide to precision farming. This integration promises to enhance agricultural productivity and sustainability through datadriven decision-making and resource optimization. At the end research gaps are discussed, along with future research directions.

KEYWORDS

Precision Agriculture, IoT Sensors, Machine Learning, Soil Nutrient Monitoring, Crop Recommendation Systems.

1. INTRODUCTION

The agricultural field is the most prominent and is undergoing fast transformation, driven by technology innovations that seek to improve production and sustainability. With the ongoing increase in the world population, there is a growing need for agricultural techniques that are both efficient and sustainable. Conventional approaches of monitoring soil nutrient levels and managing crops frequently fail to adequately meet the complex and ever-changing requirements of contemporary agriculture. To address this discrepancy, the advancements of IoT and ML presents a transformative method. One of the notable breakthroughs is the integration of IoT with ML technology, which is considered as a groundbreaking approach. The IoT facilitates the gathering of data in realtime by using a network of sensors that observe different soil characteristics, such as moisture levels, pH levels, temperature, and nutrient concentrations. Continuous monitoring enables farmers to promptly get insights into soil health, allowing for quick and accurate actions.

Machine learning enhances IoT by providing robust tools for data analysis and predictive modelling. ML algorithms can analyse the extensive data produced by IoT sensors to recognise trends, identify deviations, and provide precise forecasts on soil nutrient deficits and the most suitable crop selections. Machine learning algorithms have the ability to analyse large volumes of data produced by IoT sensors, revealing hidden patterns and trends that may not be immediately obvious.

By using predictive analytics and pattern recognition, ML provides a practical and useful information, such as the most effective schedules for fertilisation, methods for crop rotation, and early alerts for possible soil deficiencies. The integration of IoT and ML improves the accuracy of soil nutrient management and facilitates the creation of customised crop recommendations. The integration of IoT with ML has the capacity to transform soil nutrient management and crop recommendation systems, resulting in enhanced decision-making, optimised resource utilisation, and refined agricultural production.

The aim of the presented survey paper is to provide a thorough and comprehensive examination of the present status of research and development in this particular sector. This paper analyses the structure and operation of integrated IoT and ML systems. It explores the challenges and potential future scope in the field of precision agriculture.

Rest of the paper is organised as follows: Section II discusses about the background and related work to IoT and ML in agriculture sector. Section III presents the identified research gaps. Section IV describes the future direction for further investigation in precision agriculture by highlighting the scope of integrated IoT and ML technologies together. Section V provides the conclusion with key findings from presented literature survey.

2. LITERATURE REVIEW

In recent years, there has been significant study on the combination of IoT and ML for the purpose of monitoring soil nutrients and providing crop recommendations. This literature review examines prominent research and advancement in this multidisciplinary domain, emphasising notable contributions, approaches, and discoveries.

2.1. IoT-Based Soil Monitoring Systems

IoT-based systems for soil monitoring have gained traction due to the ability to provide real-time data. Researchers such as [1][2] have developed advanced sensor networks to measure soil moisture, temperature, pH, and nutrient levels. Their systems utilize wireless sensor networks (WSNs) and communication protocols to transmit data to centralized platforms. In [3] authors continuously measured variables at the agro-field. The implemented work provides the development and testing of IoT based smartphones platform with IoT, DSS and Real-time data. Authors in [4] implemented the automated remote field monitoring system and provides the visualization in the cloud with LoRaWAN and Real-time data. [5] introduced a low-cost, energy-efficient IoT sensor system for precision agriculture, which significantly improved the accuracy of soil condition assessments.

2.2. Machine Learning for Data Analysis

Machine Learning techniques have been applied to analyse the vast amounts of data generated by IoT sensors. Studies in [6] proposes the Soil Classification based on micronutrients. Soil classification result in accuracy of 94 % with ELM and Private dataset. In [7] explored the crop

recommendation for predictive accuracy of soil health and crop yield forecasts. Their work highlighted the potential of ML to uncover complex relationships between soil parameters and crop performance. Crop recommendation were predicted in accuracy of 98.22 % with MLP and Kaggle dataset. Authors in [8] implemented the system to aid the farmer in developing a platform that provides recommendations for crops. Results shows that crop recommendation by Random forest achieved 97.18 % accuracy with RF and Kaggle dataset.

2.3. Integration Challenges and Solutions

Integrating IoT and ML in agriculture involves several challenges, including data management, system interoperability, and scalability. Authors in [9], proposed the solution to provide consistent and up-to-date agricultural data and field updates to assist farmers. The proposed mode achieved the accuracy of 97.3 % with MSVMDAG-FFO and own dataset. In [10], discussed the implementation using RFC and one's own dataset, crop recommendation achieved 99% accuracy. Also discussed the novel approaches to improve data accuracy and consistency. In [11], worked on crop selection with SCS and dataset from Pakistan achieved accuracy 97.4 %. Along with that addressed issues of system integration and interoperability, recommending standardized protocols and frameworks for seamless communication between IoT devices and ML models. In [12], authors has a system with an Arduino board, an Amazon Web Service, and a set of sensors. To analyse and visualise data, they made use of mobile applications, cloud computing, and machine learning techniques. This system makes it possible to ascertain the minerals that are present in the soil and prescribe the appropriate amount of fertiliser. Crop recommendation and soil nutrient monitoring are made more comprehensive by the combination of IoT and ML technology[13-21].

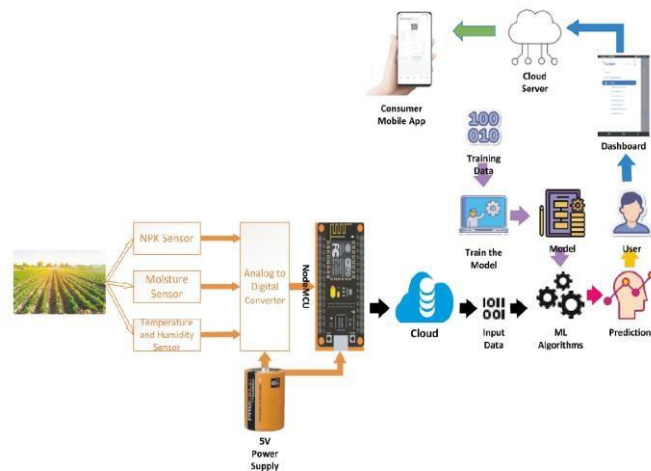


Fig. 1:Methodology framework for soil nutrients monitoring and crop recommendation using an advanced ML-Enabled IoT system [1].

Figure 1, shows framework having the integration of ML and IoT. The suggested framework in [1] uses three sensors—JXBS-3001, FC-28, and DHT11—to measure soil nutrient concentrations (NPK), moisture, humidity, and temperature in the agricultural field. The NodeMCU sends gathered data to a remote server via MQTT for processing. These sensors give real-time data to the suggested machine learning algorithm for using data to recommend planting schedules, crop kinds, and fertilisation strategies. This helps farmers choose crops and boost output. In addition, soil monitoring assures the health and safety of harvested product, and implanted sensors analyse food nutritional content, pesticide residues, and hazardous

pollutants. The framework's User-Friendly Mobile App lets farmers remotely monitor and manage their agricultural activities with seamless device and data access.

Table 1 shows a brief review provided on the related work for soil nutrients monitoring and crop recommendation with the Machine learning enabled IoT system.

3. RESEARCH GAPS

After extensive literature survey the following gaps are identified in soil nutrients monitoring and crop recommendation:

- *Labor-intensive and subjective soil nutrient analysis:*

Conventional techniques for analysing soil nutrients and recommending crops frequently depend on labour-intensive, subjective evaluations.

- *Inefficient resource utilization:*

Ineffective resource management and fertiliser application choices can result in lower yields and inefficient use of resources.

Table 1: Summary of Existing Literature Survey

Sr. No.	Authors	Year	Problem Statement	ML-IoT Enabled	Solution
1	Md Reazul Islam et al [1]	2023	The integration of IoT and machine learning algorithms to monitor soil nutrients and recommend crops.	Yes	Innovative ML-enabled monitoring and recommendation system with IoT device and Real-time data.
2	S.J. Ramson et al [2]	2021	Soil health monitoring in UpToDate manner.	No	Development and testing of a low cost (5667 USD) monitoring system with IoT and Real-time data.
3	S.V. Gaikwad et al [3]	2021	Continuously measures variables at the agrofield.	No	Develop and test the smartphones platform with IoT, DSS and Real-time data.
4	B.M. Zerihun et al [4]	2022	A system that monitors fields remotely using automation.	No	Visualization in the cloud with LoRaWAN and Realtime data.
5	V. Shukla et al [5]	2022	Soil monitoring system.	No	Identify soil type effectively and use IoT and real-time data to visually represent related information.

Sr. No.	Authors	Year	Problem Statement	ML-IoT Enabled	Solution
6	T. Blesslin Sheeba et al [6]	2022	Soil Classification based on micronutrients.	Yes	Soil classification result in accuracy of 94 % with ELM and Private dataset.
7	K. Bakthavatchalam et al [7]	2022	Crop recommendation.	Yes	Crop recommendation were predicted in accuracy of 98.22 % with MLP and Kaggle dataset.
8	Thilakarathne NN et al [8]	2022	To create a platform for crop recommendations in order to help farmers.	No	Crop recommendation by Random forest achieved 97.18 % accuracy with RF and Kaggle dataset.
9	Senapaty MK et al [9]	2023	To regularly provide farmers with up-to-date crop and field information.	Yes	The proposed mode achieved the accuracy of 97.3 % with MSVMDAG-FFO and own dataset.
10	S. Sundaresan et al [10]	2023	Crop Recommendation system.	Yes	Using RFC and one's own dataset, crop recommendation achieved 99% accuracy.
11	A. Ikram et al [11]	2022	Correct Selection of Crop.	Yes	Crop selection with SCS and dataset from Pakistan achieved accuracy 97.4 %

- *Lack of real-time monitoring and decision-making:*

Conventional farming methods frequently lack the ability to monitor and make decisions in real time.

- *Limited access to crop quality assessment:*

Information concerning the quality of the crops that consumers eat is frequently not readily available to them.

- *Fragmented solutions and high costs:*

High costs and fragmented solutions are common problems with current IoT-based soil monitoring systems.

4. FUTURE DIRECTION

- **Enhanced Sensor Technology:** The creation of more sophisticated, affordable sensors with increased precision and extended battery life will enhance realtime data gathering and minimize upkeep needs.

- **Data Integration and Management:** Enhancing techniques for merging data from various IoT devices and making sure that data management systems are strong will improve the accuracy and breadth of the information gathered.
- **Advanced Machine Learning Algorithms:** More advanced machine learning (ML) algorithm research, such as deep learning and reinforcement learning, may increase prediction accuracy and yield more useful information for crop recommendations and soil management.
- **Edge Computing:** Especially in remote agricultural areas, integrating edge computing into local data processing on IoT devices can improve real-time analytics, lower latency, and increase system responsiveness.
- **Interoperability Standards:** Standardized frameworks and protocols for ML models and IoT devices will enable smooth communication and integration between various platforms and systems.
- **Explainability and Transparency:** Improving ML models' interpretability will help farmers make better decisions by making results easier to comprehend and apply.
- **Scalability and Cost-Effectiveness:** Small and medium-sized farms will be able to afford more sophisticated IoT-ML systems thanks to research into scalable and economical solutions, which will encourage wider adoption.
- **Integration with Recent Technologies:** To further improve the capabilities and uses of IoT-ML systems in agriculture, new technologies like blockchain for data security and augmented reality (AR) for visualization should be investigated.

5. CONCLUSION

The combination of IoT and Machine Learning is a significant development in the field of soil nutrient monitoring and crop recommendation. Through the utilization of real-time data collection using IoT technology and advanced analytics through ML, the collaboration provides substantial enhancements in precision agriculture, specifically in the areas of soil management and crop yield. Despite the persistent obstacles of data integration, system interoperability, and algorithmic complexity, continuous research and technological advancements offer hope for conquering these challenges. Developments in sensor technology, data management, and machine learning algorithms will enhance agricultural practices, promoting sustainability and efficiency in precision farming.

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