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Smart Crop Prediction and Fertilizer Recommendation Based on ML and IoT

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Abstract- Agriculture depends on many factors such as soil nutrients, temperature, humidity, rainfall, soil type and crop characteristics. Selecting a suitable crop and applying the right fertilizer are important for obtaining good production. Traditionally, farmers mainly depend on previous experience, local knowledge and manual soil testing. These methods can be useful, but they may not provide the same result for different soil and weather conditions. In recent years, machine learning and Internet of Things technologies have been increasingly used to support agricultural decision-making. This literature review studies existing research related to crop prediction, fertilizer recommendation, machine learning, IoT-based monitoring and intelligent agricultural decision-support systems. Different machine learning algorithms such as Random Forest, Decision Tree, K-Nearest Neighbour, Support Vector Machine, XGBoost, CatBoost, Logistic Regression and ensemble methods have been applied in previous studies. IoT systems have also been developed using sensors and microcontrollers to collect soil and environmental information in real time. The reviewed studies show that machine learning can provide useful predictions when sufficient and relevant agricultural data are available, while IoT can help overcome the limitation of relying only on static datasets. However, several limitations are still present in existing systems. Some studies focus only on crop prediction, while others concentrate only on fertilizer recommendation. Many systems are evaluated using small or region-specific datasets, and real-time sensor integration is not always included. Explainability, fertilizer quantity optimization, climate variation and practical deployment also require further attention. Based on these observations, this review identifies the need for an integrated system that combines crop prediction, fertilizer recommendation, real-time IoT data and comparative machine learning evaluation. The proposed research direction is therefore focused on developing a practical smart farming system that can use soil and environmental parameters to predict a suitable crop and recommend an appropriate fertilizer.

Keywords— Smart Agriculture, Crop Prediction, Fertilizer Recommendation, Machine Learning, Internet of Things, Random Forest, IoT Sensors, Precision Agriculture.

I. INTRODUCTION

Agriculture is an important part of the economy and plays a major role in providing food and employment. The productivity of agriculture depends on several factors, including soil properties, nutrient availability, rainfall, temperature, humidity, water availability and crop selection. A wrong decision during crop selection or fertilizer application can affect crop growth and increase the cost of farming. Earlier agricultural recommendation systems mainly depended on soil testing, agricultural experts and predefined rules. For example, the earlier crop recommendation work by Rajak et al. used soil-specific attributes to recommend suitable crops and applied machine learning techniques for precision agriculture [1]. The study highlighted that crop selection needs to consider soil properties because different crops require different growing conditions. The authors also used an ensemble approach where multiple classifiers contributed to the final recommendation [1].Machine learning has provided another way of approaching this problem. Instead of depending completely on manually defined rules, machine learning models can learn relationships between agricultural parameters and crop classes from historical datasets. Parameters such as nitrogen, phosphorus, potassium, pH, rainfall, temperature and humidity are commonly used in crop recommendation studies.For example, Ashwitha and

Latha studied crop recommendation and yield estimation using agricultural data from Karnataka [2]. Their dataset contained 6730 records and included parameters such as temperature, pH, rainfall, nitrogen, phosphorus and potassium. Several machine learning algorithms were compared, and Random Forest obtained an accuracy of 99.94% for crop prediction in their experimental setup [2]. Fertilizer recommendation is another important part of precision agriculture. The amount and type of fertilizer required depend on soil nutrient levels, soil type and crop requirements. Khan et al. proposed an IoT-assisted context-aware fertilizer recommendation system using soil type, crop type and NPK-related information [3]. Nearest Neighbour. The work also considered real-time soil fertility information, showing how IoT can be combined with machine learning for fertilizer recommendation [3]. Recent research has moved towards combining multiple machine learning models. Sinha et al. presented a crop and fertilizer recommendation system based on stacking ensemble learning and explainable AI.

Their approach combined Random Forest, XGBoost and LSTM models and used Logistic Regression as a meta-model [4]. SHAP was also used to explain the contribution of different features to the prediction. IoT has further increased the practical possibilities of these systems. Sensors can collect information such as soil moisture, temperature and nutrient levels, while a microcontroller can transfer or process this information. Recent research has demonstrated IoT-based crop prediction using real-time sensor information, showing a movement from offline prediction towards field-level applications [5]. Therefore, the combination of ML and IoT provides an interesting direction for smart agriculture. ML can be used for prediction and recommendation, while IoT can provide current information from the agricultural environment. The purpose of this review is to study these approaches, compare their characteristics and identify the research gaps that can be addressed through the proposed system, Smart Crop Prediction and Fertilizer Recommendation Based on ML and IoT.

II. REVIEW OF EXISTING LITERATURE

1. Machine Learning for Crop Recommendation

Rajaket al. studied crop selection using machine learning techniques. The study used soil and agricultural parameters to identify suitable crops. The results showed that machine learning can help in selecting crops based on field conditions instead of depending only on traditional methods [1].

Ashwitha and Latha developed a crop recommendation and yield estimation system using agricultural data from Karnataka. Their dataset contained 6730 records with parameters such as temperature, humidity, rainfall, pH, nitrogen, phosphorus and potassium. Different machine learning algorithms were tested, and Random Forest gave the best crop recommendation accuracy of about 99.94% [2].

2. Machine Learning for Fertilizer Recommendation

Khan et al. proposed an IoT-assisted fertilizer recommendation system using soil type, crop type and NPK values. Logistic Regression, SVM, Gaussian Naive Bayes and KNN were tested for fertilizer prediction. The study showed that machine learning can be used to select suitable fertilizers according to soil fertility conditions [3]. Selvi and Poornima also worked on a soil-based fertilizer recommendation system. Their work shows the importance of considering soil properties when deciding fertilizer requirements [4].

3. IoT-Based Agricultural Monitoring

Basuelet al. developed an IoT-based plant monitoring system using ESP32-CAM. The system collected information such as NPK, temperature and soil moisture

The study used machine learning algorithms including Logistic Regression, Gaussian Naive Bayes, Support Vector Machine and K-for monitoring plant growth [5].

Sharafatet al. used IoT sensors and machine learning for real-time crop prediction. Their system used 3300 samples covering 22 crops and was implemented using Raspberry Pi and sensors. The study reported 95.9% accuracy for its stacking model on the IoT device [6].

4. Combined Crop and Fertilizer Recommendation

Musanaseet al. studied a data-driven system for crop and fertilizer recommendation using machine learning [7]. Reddy et al. proposed a precision farming system that used data analysis and machine learning for crop and fertilizer recommendation [8]. Sinhaet al. proposed a system using Random Forest, XGBoost and LSTM with a stacking approach for crop and fertilizer recommendation. SHAP was also used to understand the contribution of different input features to the prediction [9].

5. Recent Developments and Limitations

Pariaet al. proposed a hybrid machine learning system for crop and fertilizer recommendation and also considered explainability and real-time IoT data [10].

Ennajiet al. focused on site-specific fertilizer recommendation using machine learning and optimization [11]

III. COMPARATIVEANALYSISOFEXISTING STUDIES

Table 1: Comparative analysis of existing Crop Prediction and Fertilizer Recommendation.

Ref.	Author s/ Year	Main Contribution	Techique/Model
[1]	Rajak et al., 2017	Recommended suitable crops to improve crop yield.	Machine Learning
[2]	Ashwitha& Latha,2022	Recommended suitable crops and estimated crop yield.	RF, KNN, DT, SVM, XGBoost, ML
[3]	Khan et al.,2022	Developed a context-aware fertilizer recommendation system using soil fertility, crop and soil type.	IoT, LR, SVM, GNB, KNN
[4]	Sinha et al., 2025	Combined crop and fertilizer recommendation with explainable results.	RF, XGBoost, LSTM, Stacking, SHAP
[5]	Sharafat et al.,2025	Developed an IoT-based real-time crop prediction system.	IoT, ML/DL, sensor data
[6]	Ennaji et al., 2026	Provided site-specific fertilizer recommendations and considered fertilizer quantity.	ML, CatBoost, constrained optimization
[7]	Basuel& Fajardo, 2024	Monitored plant growth using IoT-based sensing.	ESP32-CAM, IoT, sensors
[8]	Reddy et al., 2024	Developed a data-driven crop and fertilizer recommendation system.	ML and data analysis
[9]	Rani et al.,2023	Developed an optimal crop selection system using agricultural and weather information.	ML, RF, LSTM/RNN
[10]	Hasan et al.,2023	Recommended suitable crops using ensemble learning.	Ensemble Machine Learning
[11]	Selvi&Poor nima,2021	Connected soil information with fertilizer recommendation and crop disease prediction.	Soil-based ML/DL
[12]	Bondre& Mahagaonk ar,2019	Predicted crop yield and recommended fertilizers.	Machine Learning
[13]	Musanase et al.,2023	Developed an integrated crop and fertilizer recommendation system.	Data analysis and ML
[14]	Mahale et al., 2024	Developed crop recommendation and forecasting for Maharashtra.	ML, LSTM

[15]	Priyanka et al., 2023	Developed an IoT-based crop recommendation system for smart agriculture.	IoT, ML, weather data
[16]	Bilal et al.,2023	Used ML for crop monitoring and improving crop quality and yield.	ML, crop monitoring
[17]	Manju et al.,2024	Developed real-time crop prediction using soil fertility information.	IoT, ML, soil sensors
[18]	NehaNiharika et al.,2023	Developed an IoT and ML-based crop recommendation system.	IoT, ML
[19]	Shams et al.,2024	Improved crop recommendation by explaining why a crop was recommended.	XAI, LIME, ML
[20]	Bhattacharya &Pandey,	Combined different data sources for crop 2024 and fertilizer recommendations.	Multimodal data fusion, NPK, moisture, images, geographical data.

IV. RESEARCH GAP

1. Treatment of Crop and Fertilizer Recommendation
Many earlier systems focus on only one task. Crop recommendation studies provide a suitable crop, while fertilizer studies provide a suitable fertilizer. Only a smaller number of recent studies attempt to combine both tasks [2], [3], [11], [13].

2. Limited Real-Time Data Integration
Several crop recommendation systems depend mainly on historical datasets. Although IoT-based studies have demonstrated real-time monitoring, complete integration of real-time soil and environmental data with both crop and fertilizer prediction is still limited [3], [12].

3. Dataset Limitations
The performance of a model depends strongly on the dataset used for training. Some studies use datasets collected from a particular region. For example, the real-time crop prediction study by Sharafatet al. used data from Habiganj District in Bangladesh [12]. Such regional datasets may not represent different soil and climatic conditions.

4. Limited Fertilizer Quantity Recommendation
A system that only predicts the fertilizer name may not fully support precision fertilizer management. Recent work has started considering fertilizer quantity and optimization, but this area still requires further development [14].

5. Explainability is Not Common in Older Systems
Traditional machine learning systems generally provide a predicted crop or fertilizer without clearly showing why that result was obtained. Recent studies have introduced SHAP and LIME to improve interpretability [11], [13]
.

6. Need for a Practical and Simple Farmer-Oriented System
Some research focuses mainly on model performance, while real-world agricultural systems also need easy data collection, understandable recommendations and simple user interaction. IoT-based deployment studies show progress in this direction [3], [12], [13].

V. MOTIVATION FOR THE PROPOSED SYSTEM

The main motivation for the proposed system comes from the problems found in existing agricultural decision-making methods. Crop selection is often based on previous experience, while fertilizer selection may be based on general recommendations. However, soil nutrient levels, temperature, humidity, moisture, pH and rainfall can vary between locations. Because of these differences, the same crop or fertilizer recommendation may not be suitable for every field.The reviewed studies show that machine learning can identify relationships between agricultural parameters and crop suitability [1], [2], [7]. Similarly, IoT can help in collecting soil and environmental information from the field [3], [4]. Combining these two technologies can therefore provide a more connected approach to agricultural decision making. Another reason for developing the proposed system is the need to consider both crop selection and fertilizer requirements. If only the crop is predicted, the farmer still needs to decide which fertilizer should be used. On the other hand, recommending fertilizer without considering the selected crop may also give incomplete information. A system that provides both recommendations can give the farmer a more useful decision-support output. The proposed system, "Smart Crop Prediction and Fertilizer Recommendation Based on ML and IoT," is therefore motivated by these observations. The system aims to collect or use parameters such as nitrogen, phosphorus, potassium, temperature, humidity, moisture, pH and rainfall. Machine learning models can then be used to predict a suitable crop, followed by fertilizer recommendation based on the available soil and crop information. The proposed work also takes motivation from recent research on real-time IoT crop prediction, ensemble learning and explainable AI [11]–[14]. At the same time, the system is intended to remain simple enough for practical implementation. The use of an ESP32 and sensors can provide a low-cost way of collecting field information, while the machine learning models can process the data and provide recommendations.

VI. CONCLUSION

The literature reviewed in this paper shows that machine learning and IoT have become useful technologies for smart and precision agriculture. Machine learning models such as Random Forest, Decision Tree, KNN, SVM, XGBoost and ensemble methods have been used for crop prediction, yield estimation and fertilizer recommendation. Among the reviewed studies, Random Forest has shown strong performance in several crop recommendation experiments [2], while other recent studies have explored stacking, explainable AI and optimization [11], [13], [14]. The literature also shows that IoT can improve agricultural systems by collecting soil and environmental information directly from the field. Khan et al. demonstrated the use of IoT-assisted soil fertility mapping for fertilizer recommendation [3], while Sharafatet al. showed the possibility of real-time crop prediction using an IoT device [12]. These studies indicate that real-time data can make agricultural recommendations more connected to actual field conditions. At the same time, some limitations are still present in existing systems. Many studies focus on only crop prediction or fertilizer recommendation, and some depend on region-specific datasets. Real-time sensing, fertilizer quantity estimation, explainability and practical deployment are also areas that need further attention. Recent studies are addressing some of these issues, but there is still scope for a simple integrated system. Based on these observations, the proposed work focuses on combining machine learning and IoT for both crop prediction and fertilizer recommendation. The system uses soil and environmental parameters to support crop selection and fertilizer decisions. The overall aim is to develop a practical decision-support system that can make agricultural recommendations using data rather than relying only on traditional methods.

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