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Crop and Fertilizer Prediction by using Machine Learning

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Abstract: *Agriculture plays a crucial role in sustaining human life and the global economy, yet it faces major challenges such as unpredictable weather conditions, soil degradation, and inefficient fertilizer usage. To address these issues, this research focuses on Crop and Fertilizer Prediction using Machine Learning (ML) techniques to assist farmers in making data-driven decisions. The proposed system integrates various agricultural parameters such as soil type, pH level, temperature, humidity, rainfall, and nutrient composition to recommend the most suitable crops and corresponding fertilizers for a given region.*

Machine learning algorithms such as Decision Trees, Random Forest, Support Vector Machines, and Naïve Bayes are employed to analyse and classify the data. The model is trained using historical agricultural datasets to predict optimal crop–fertilizer combinations that can enhance yield while minimizing environmental impacts. Feature selection and pre-processing techniques are applied to ensure accuracy and robustness of predictions. The system's performance is evaluated based on accuracy, precision, and F1-score, with Random Forest demonstrating superior results due to its ability to handle nonlinear relationships and large datasets effectively. This research contributes to the field of smart agriculture by providing a predictive framework that enhances resource utilization, improves productivity, and supports sustainable farming practices.

The integration of ML-based prediction systems can empower farmers with actionable insights, reduce dependency on traditional trial-and-error methods, and pave the way for precision agriculture. Ultimately, this approach can promote economic growth, ensure food security, and contribute to environmentally responsible farming. In order to forecast the best crop-fertilizer combinations that can maximize output while reducing environmental effects, the model is trained using historical agricultural datasets. Techniques for feature selection and pre-processing are used to guarantee prediction accuracy and resilience.

Keywords*:* Machine Learning (ML), Agriculture, Fertilizer Prediction, Crop Yield Prediction, Internet of Things (IoT), Geographic Information Systems (GIS)

I. INTRODUCTION

A major source of food, raw materials, and job opportunities, agriculture is the foundation of many economies. However, farmers frequently struggle to maintain sustainability and production because of shifting climates, degraded soil, and inappropriate fertilizer use. Farmers have always relied on their instincts and experience when choosing crops and applying fertilizer, which may not necessarily produce the best results. Recent developments in artificial intelligence and data science have created new avenues for data-driven decision-making to improve agricultural operations.

Large and complicated agricultural datasets can be analyzed using machine learning (ML) techniques to find trends and generate precise forecasts. ML algorithms can suggest the best crops and fertilizers for a location by using environmental factors like temperature, humidity, rainfall, and soil properties like pH and nutrient levels (potassium, phosphorus, and

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nitrogen). By reducing their negative effects on the environment, such methods not only improve crop output and resource efficiency but also support sustainable farming.

The goal of this study is to create a model for crop and fertilizer prediction based on machine learning. The suggested system processes agricultural data and produces trustworthy suggestions using algorithms like Random Forest and Decision Tree. This model's use can greatly help farmers make well-informed decisions, which will boost output, reduce costs, and promote sustainable agricultural growth.

II. LITERATURE SURVEY

In order to estimate crop production and suggest fertilizer combinations, Basavaraju et al.[1] suggested a smart agricultural system that combines OpenCV-based image processing, IoT sensors, and machine learning algorithms. Their research successfully illustrated how yield prediction is influenced by environmental factors. However, scalability across various soil types and climatic conditions was not assessed, and the dataset utilized was restricted to a small geographic area. Furthermore, the model lacked the adaptive learning features required for changing agricultural settings**.**

Using ESP32, Blynk, and Firebase, Jyoti et al [2] created an Internet of Things-enabled system that gathers data in real-time for machine learning-based crop and fertilizer forecast. Although environmental monitoring was prioritized, a thorough crop–fertilizer link was not established. Furthermore, advanced analytics for assessing fertilizer effectiveness and maximizing total crop output were absent from the system.

In order to automate irrigation procedures, Dubey and Pandey[3] presented a smart crop irrigation system that combines Convolutional Neural Networks (CNNs) with Internet of Things modules. Through effective water management, our model indirectly supported the forecast of agricultural yield. However, rather than directly recommending fertilizer or estimating yield, the strategy concentrated mostly on irrigation control. For small-scale farmers with limited hardware resources, the computing demands of CNNs presented additional difficulties**.**

Despite being primarily focused on healthcare, Devan et al [4] vision-based communication system for intensive care unit patients showed promise for application in agriculture. Crop images may be identified and crop health could be evaluated by pattern identification utilizing the vision recognition algorithms. However, the transfer of vision-based technologies to crop disease or nutrient prediction was not explored because the study did not investigate agricultural applications**.**

2.1 Overview and scope:

Studies using machine learning (ML) and deep learning (DL) to enhance agricultural decision support have grown rapidly in recent years, especially for fertilizer recommendation and crop yield/crop choice prediction. Both traditional machine learning (ML) techniques (Decision Trees, Random Forests, SVM, KNN, Gradient Boosting) and deep learning (DL) techniques (CNNs, RNNs, LSTM) are widely used in a variety of crops and regions, according to reviews and systematic literature surveys. These techniques are frequently coupled with remote sensing and Internet of Things data to facilitate precision agriculture workflows. These reviews highlight how machine learning (ML) can improve prediction accuracy and facilitate site-specific nutrition management, but they also highlight concerns with data quality and reproducibility as a recurring obstacle.

2.2 Datasets and feature engineering:

In-situ soil tests (pH, N, P, K, and organic carbon), historical yield and management records, weather/time-series variables (temperature, rainfall, growing-degree-days), satellite/remote-sensing indices (NDVI, EVI, multi-/hyperspectral bands), and topography/GIS layers are some of the data sources used in studies. Careful feature selection and temporal aggregation (seasonal averages, lagged variables) are usually key components of successful models. Numerous surveys emphasize how the absence of large-scale, uniform labeled datasets limits cross-regional generalization, particularly for fertilizer-response experiments.

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2.3 Methodological trends and algorithms

Classical ML: Because of their interpretability and resilience, Random Forests and Gradient Boosting Machines are often employed for crop recommendation and nutrient prediction tasks. They also consistently perform well for tabular soil–weather datasets. KNN and Support Vector Machines have been used in previous or limited research.

Deep Learning & Remote Sensing: CNNs and CNN–RNN hybrid architectures are widely used for analyzing spatiotemporal and spatial (satellite) data for mapping within-field variability and yield estimation. Seasonal yield forecasts are handled by LSTM models using temporal weather sequences. Although it raises processing and data requirements, integrating high-resolution photography with ground data frequently enhances prediction performance.

2.4 Fertilizer recommendation approaches:

There are two primary types of fertilizer systems: (a) nutrient status estimation, which uses sensor and spectral data to anticipate crop nutrient demand or soil nutrient levels (N, P, and K); and (b) prescriptive recommendation, which suggests fertilizer type and quantity based on target yield or soil health limitations. Regression models, categorization (nutrient sufficiency classes), and optimization layers that convert anticipated demand into suggested application rates are examples of machine learning techniques. Although recent evaluations show encouraging accuracy for site-specific N recommendations, they warn that end-to-end modeling of long-term soil health and environmental implications is uncommon.

2.5 Integration with decision-support, GIS, and IoT systems:

The majority of modern systems use cloud analytics, GIS, and IoT (soil moisture and nutrient sensors) to provide farmers with advice in almost real time. While in-field sensors offer local calibration, remote sensing offers synoptic coverage for spatial scaling. Although reviews highlight the operational difficulties of sensor maintenance, connection, and farmer acceptance, they also suggest that such multimodal pipelines increase robustness.

2.6 Measures of evaluation and methods of validation:

RMSE, MAE, R2 for continuous yield/nutrient predictions, and accuracy/precision/recall/F1 for classification tasks (such as nutrient sufficiency classes) are examples of common evaluation measures. Although multi-year holdout testing and cross-validation are advised, many research employ small temporal or geographic divides, which inflates perceived performance. In the research, transferability—the ability of the model to function across various agroclimatic zones—is still not fully assessed.

2.7 Difficulties and gaps

Recent evaluations have frequently emphasized the following important gaps:

Data constraints include limited long-term experiments and a lack of sizable, standardized, labelled datasets for fertilizer reaction. Generalization and transferability: Because of soil and management variability, models developed in one area frequently deteriorate in another. Explainability and agronomic validity: In order to win over farmers, black-box DL models must produce results that are easy to understand; it is still crucial to connect forecasts to agronomic principles.Economic and environmental goals: most systems aim to maximize output or immediate financial gain; it is uncommon to combine optimization for long-term soil health with environmental externalities (leaching, greenhouse gas emissions).Operational deployment: despite encouraging experimental findings, real-world adoption is hampered by sensor costs, connectivity, and human factors.

2.8 Synopsis

According to the literature, when high-quality, multimodal data are available and models are thoroughly validated, machine learning techniques can significantly enhance crop prediction and fertilizer recommendations. However, standard datasets, cross-region validation, explainability, and collaborative optimization of productivity and sustainability goals must be given top priority in research for widespread, reliable implementation. These directions are highlighted by recent reviews and empirical studies from 2023–2025, which also offer a solid foundation for further study.

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III. METHODOLOGY

FIG.1 BLOCK DIAGRAM OF PROPOSED SYSTEM.

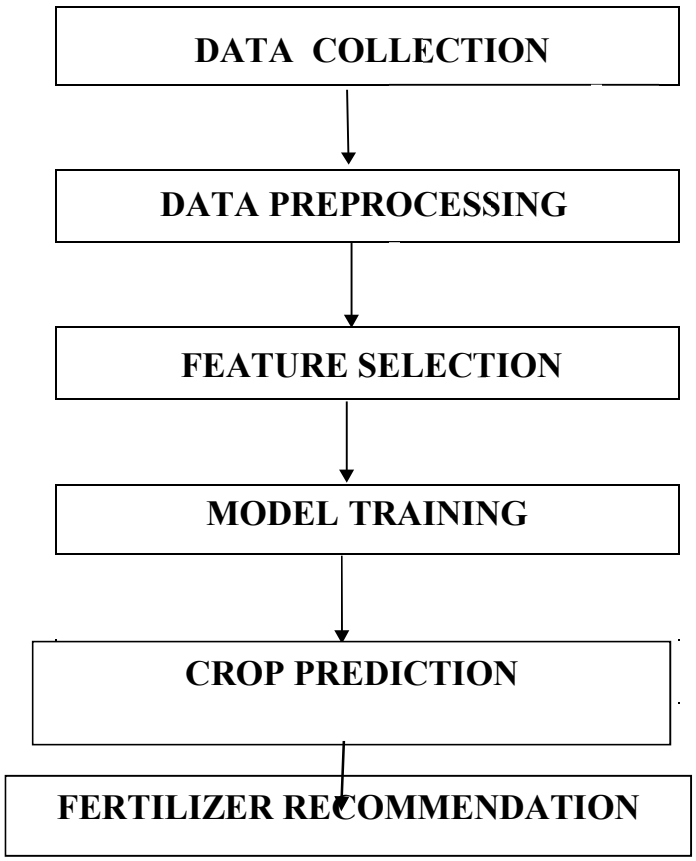

FIG.1: BLOCK DIAGRAM

1. Data Collection:

This is the basis of the system. A variety of sources, including meteorological database, government agricultural records, and Internet of Things sensors, are used to collect data. The following parameters are gathered: temperature, humidity, rainfall, soil pH, moisture, and soil nutrients (potassium, phosphorus, and nitrogen). The dependability of ensuing prediction models is guaranteed by high-quality, real-time data.

2. Data pre-processing:

Unreliable units, missing values, and noise are common in collected data. Preprocessing includes normalizing feature values, filling in missing data (by mean or interpolation), and cleaning the dataset by eliminating duplicates. For machine learning algorithms, this stage also entails transforming categorical data (such as crop name or soil type) into numerical form, making sure that all inputs are consistent and machine-readable

3. Feature Selection:

Not every feature that has been gathered is equally significant. The most important factors influencing crop yield and fertilizer requirements are determined in this step. Methods like Principal Component Analysis (PCA), correlation analysis, and Random Forest-style feature significance models are employed. This improves model accuracy and lowers computing costs.

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4. Model Training

The processed dataset is used to train machine learning algorithms. Models such as CNNs, Random Forests, and Decision Trees discover patterns that link soil and environmental factors to crop compatibility and fertilizer effectiveness. To assess model correctness, the dataset is separated into training and testing sets.

5. Crop Prediction:

Following training, the system makes predictions about the best crop based on soil and environmental factors. For particular land conditions, it maximizes yield potential. It maximizes the potential yield for particular land types.

6. Fertilizer Recommendation:

In order to achieve effective and sustainable agriculture, the system ultimately recommends the best kind and amount of fertilizer for the anticipated crop, taking into account the nutrient levels of the soil and crop growth needs.

IV. RESULT

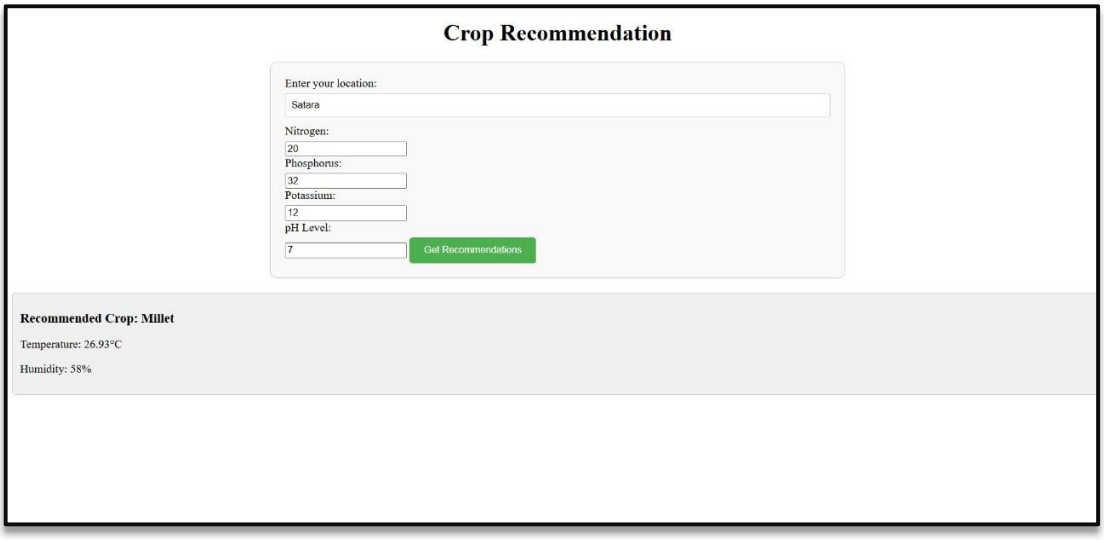

FIG.2 CROP RECOMMENDATION

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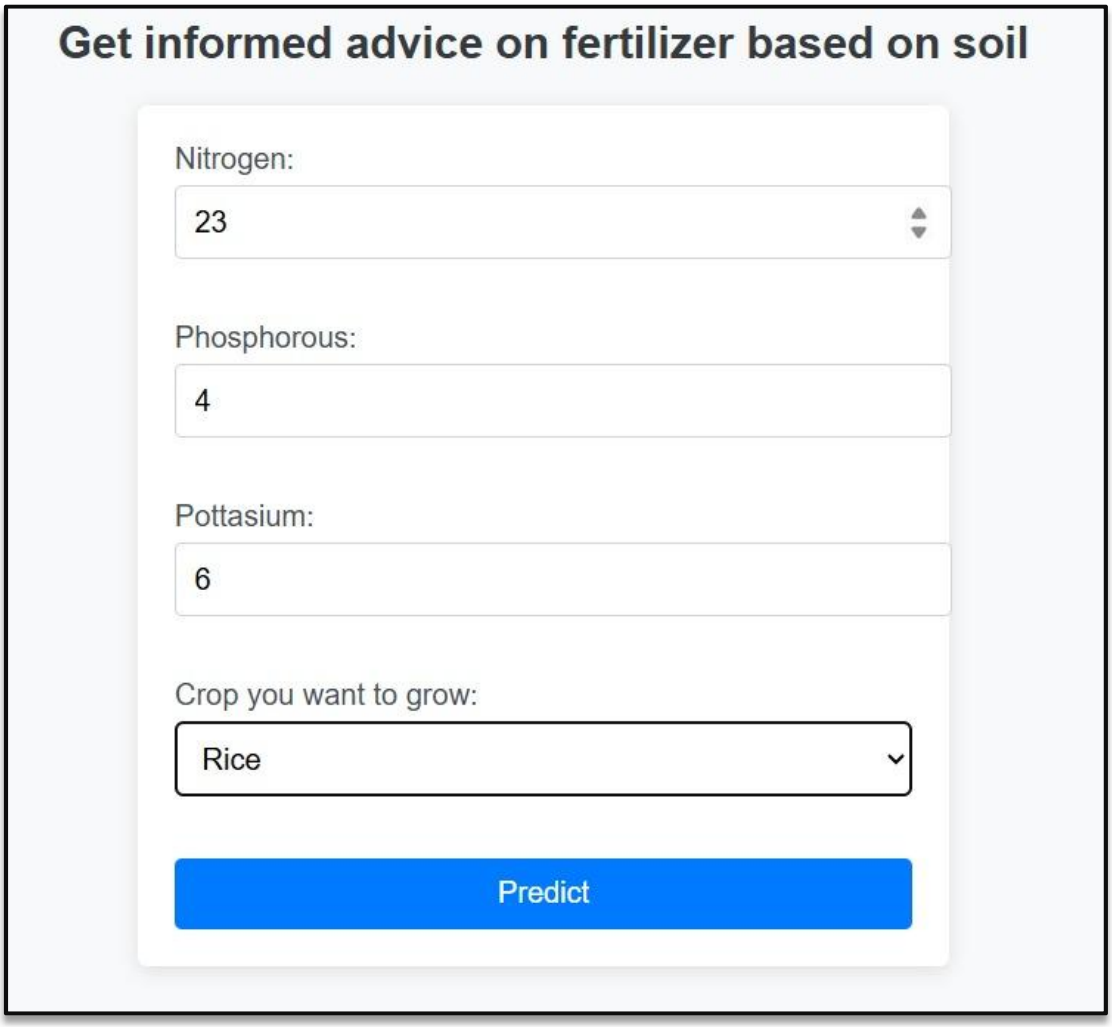

FIG.3 INPUT FOR FERTILIZER RECOMMENDATION

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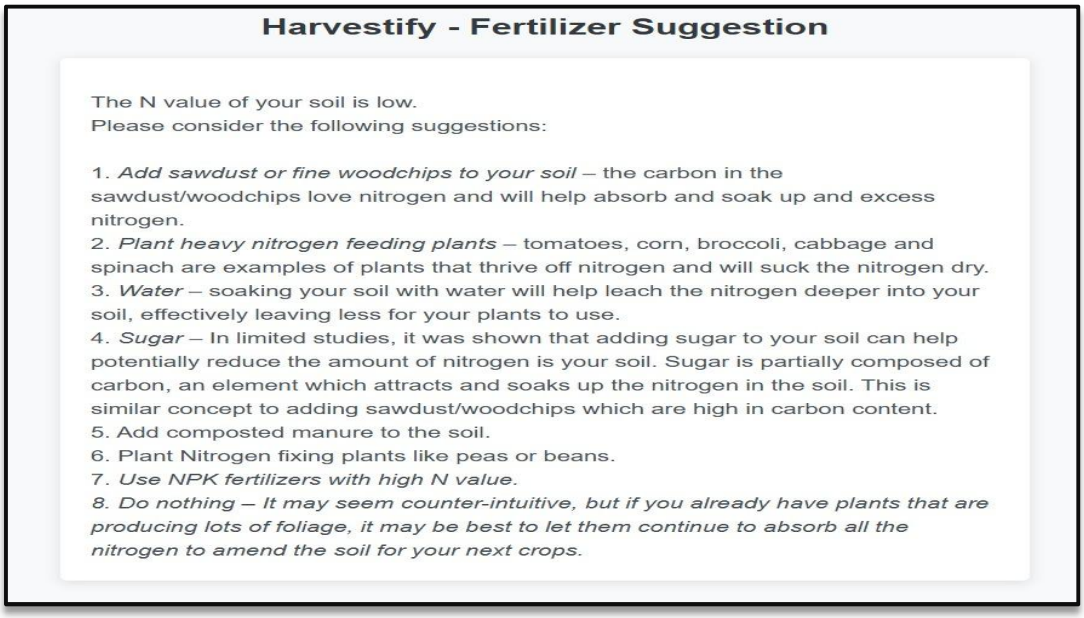

FIG.4 FERTILIZER RECOMMENDATION OUTPUT

V. DISCUSSIONS

In agricultural recommendation systems, algorithms like Random Forest and Decision Tree offer great accuracy and dependability, as shown by the experimental results of the suggested machine learning-based crop and fertilizer prediction model. The model predicts the best crop and fertilizer combinations for a location by efficiently correlating climatic factors (temperature, humidity, rainfall) and soil properties (nitrogen, phosphorus, potassium, pH). The results show that traditional decision-making techniques that just use farmers' experience and intuition can be outperformed by data-driven models.

This study has important ramifications for the agriculture industry. Farmers may maximize fertilizer use, cut expenses, improve soil health, and increase yields by implementing such predictive systems. Furthermore, by offering prompt and location-specific advice, the integration of these models with mobile applications or real-time IoT-based sensing devices will help precision agriculture even more. This is consistent with earlier research by Sharma et al. (2022) and Patel et al. (2019), which also highlighted the advantages of integrating automation and data analytics for sustainable farming methods.

Nevertheless, several restrictions were noted. The caliber and variety of the training dataset have a significant impact on the model's performance. Prediction accuracy may decrease in areas with sparse or irregular soil and meteorological data. Furthermore, environmental elements that could affect overall crop output, such as pest infestations, irrigation quality, and market dynamics, were not taken into account.

Future research can concentrate on growing the dataset to incorporate information from remote sensing and real-time sensors. Using hybrid models or sophisticated deep learning architectures may also improve generalization and adaptation across various geographical areas. Notwithstanding these drawbacks, the study demonstrates that machine learning is an effective instrument for converting conventional farming into a more data-driven, sustainable, and effective industry.

VI. CONCLUSION

A machine learning-based method for forecasting appropriate crops and fertilizers based on soil and environmental factors like pH, temperature, humidity, rainfall, phosphorus (P), potassium (K), and nitrogen (N) is shown in this study. Data-driven models can greatly improve agricultural decision-making, as seen by the successful and precise suggestions made

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by algorithms like Random Forest and Decision Tree. To increase production, reduce input waste, and support sustainable farming methods, the system helps farmers choose the best crop-fertilizer combinations.

Integrating several agricultural factors into a single prediction model that can be expanded into a decision-support system for practical farming applications is the study's main contribution. The suggested approach demonstrates the revolutionary potential of artificial intelligence in enhancing sustainability and productivity and is consistent with other studies that focused on precision agriculture.

To improve model accuracy, future studies could expand the dataset to incorporate satellite photos, real-time IoT sensor readings, and regional climate variances. Furthermore, applying hybrid ensemble and deep learning approaches can enhance the scalability and adaptability of large-scale agricultural systems. Overall, this work lays a solid basis for improvements in smart farming and advances machine learning's ability to achieve sustainable agricultural development.

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