Smart Crop Advisory System for Sustainable Seed Cultivation

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***Abstract*—Sustainable agricultural development requires accurate decision-making in seed selection and fertilizer management based on soil health conditions. In many regions, farmers rely on traditional practices that do not consider field-level variability, leading to reduced productivity and soil degradation. This paper presents a Smart Crop Advisory System for Sustainable Seed Cultivation, designed to recommend suitable seed varieties and optimal fertilizer usage using machine learning techniques. The system analyzes soil parameters such as nitrogen, phosphorus, potassium, organic carbon, electrical conductivity, soil pH, and micronutrients including zinc, iron, manganese, copper, boron, and sulphur, along with environmental factors like rainfall, temperature, and humidity. Multiple supervised learning algorithms, including Random Forest, Support Vector Machine, Extreme Gradient Boosting, Artificial Neural Network, and hybrid ensemble models, are implemented and evaluated using performance metrics such as accuracy, precision, recall, and F1-score. The comparative analysis identifies the most reliable model for prediction. The proposed system provides region-specific recommendations for crops such as rice, jowar, bajra, and wheat, ensuring improved yield, efficient fertilizer utilization, and sustainable soil management.**

***Index Terms*—Smart Agriculture, Crop Advisory System, Machine Learning, Soil Analysis, Seed Recommendation, Fertilizer Prediction, Support Vector Machine, Artificial Neural Network, Ensemble Learning**

I. INTRODUCTION

Agriculture plays a vital role in ensuring food security and supporting the economic stability of countries like India. However, increasing population pressure, shrinking cultivable land, and declining soil fertility have made sustainable agricultural practices more critical than ever. One of the major challenges faced by farmers is the selection of suitable seeds and the application of appropriate fertilizers based on actual soil conditions. In many cases, these decisions are guided by traditional practices or generalized recommendations, which often fail to consider field-level variability. This leads to nutrient imbalance, reduced crop productivity, and long-term soil degradation.Recent advancements in data-driven agriculture have introduced the use of machine learning techniques for crop prediction, soil classification, and fertilizer recommendation. Various supervised learning algorithms have been successfully applied to improve decision-making in agriculture by analyzing complex relationships between soil properties, environmental factors, and crop performance. Techniques such as Support Vector Machines, Artificial Neural Networks, and ensemble learning models have demonstrated significant potential in enhancing prediction accuracy and automation. However, most existing systems primarily focus on general crop recommendation or disease detection, with limited emphasis on seed-specific suitability based on localized soil conditions.The Satara region of Maharashtra exhibits significant variability in soil fertility parameters, including macronutrients such as nitrogen, phosphorus, and potassium, as well as micronutrients like zinc, iron, manganese, copper, boron, and sulphur. Additionally, environmental factors such as rainfall, temperature, and humidity further influence crop growth and productivity. Crops commonly cultivated in this region, including rice, jowar, bajra, and wheat, require specific nutrient conditions for optimal growth. The absence of a scientific, region-specific advisory system often results in inefficient fertilizer usage and suboptimal crop selection.To address these challenges, this paper proposes a Smart Crop Advisory System for Sustainable Seed Cultivation that leverages machine learning techniques to provide data-driven recommendations.

II. PROPOSED SYSTEM

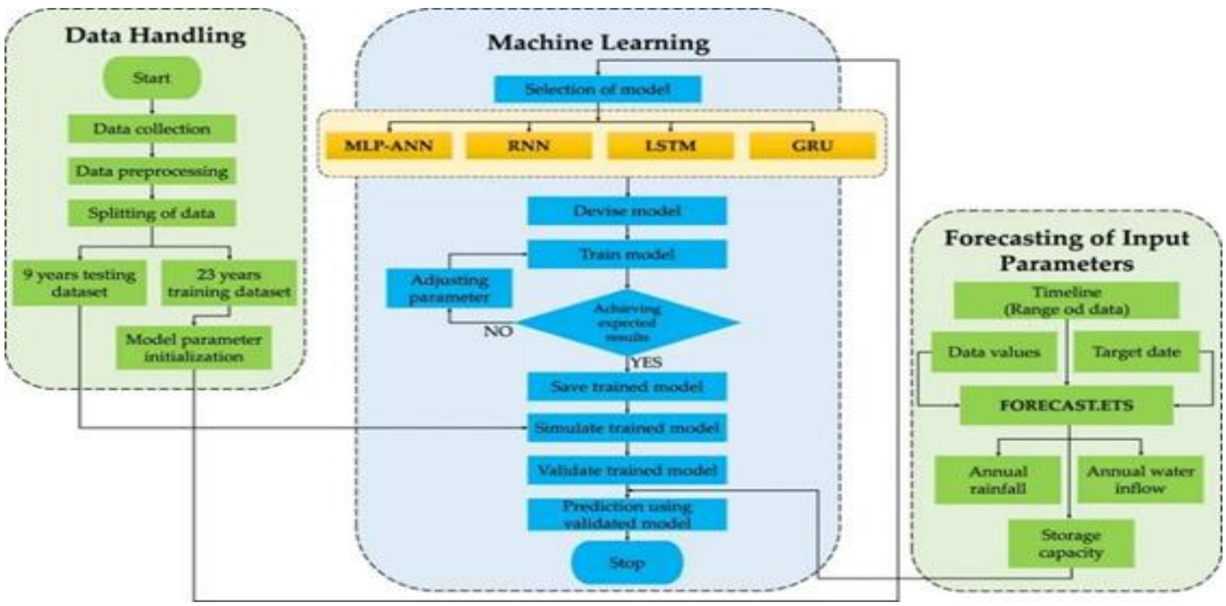

Fig. 1 Architecture Diagram of the recommended system

III. OVERVIEW OF THE PROPOSED SYSTEM

The proposed Smart Crop Advisory System is a machine learning-based decision support framework designed to assist farmers in selecting suitable seeds and optimizing fertilizer usage based on soil and environmental conditions. The system utilizes a structured dataset consisting of key soil parameters such as nitrogen, phosphorus, potassium, organic carbon, electrical conductivity, and soil pH, along with micronutrients including zinc, iron, manganese,
copper, boron, and sulphur. In addition, environmental factors such as rainfall, temperature, and humidity are incorporated to improve prediction accuracy.

The system follows a systematic workflow beginning with data collection and preprocessing, where raw agricultural data is cleaned, normalized, and transformed into a structured format. The processed dataset is then divided into training and testing sets to develop predictive models. Multiple supervised machine learning algorithms, including Support Vector Machine, Artificial Neural Network, Extreme Gradient Boosting, and hybrid ensemble methods, are applied to analyze the relationship between soil properties and crop suitability.

Based on the trained models, the system predicts the most appropriate seed among crops such as rice, jowar, bajra, and wheat, and provides fertilizer recommendations by identifying nutrient deficiencies. The final output enables farmers to make data-driven decisions, improving crop productivity, reducing input costs, and promoting sustainable agricultural practices.

IV. LITERATURE SURVEY

➢ SURVEY OF EXISTING SYSTEM

The most common existing system we have seen are :

[1] Amrutha et al. (2016) propose an automated system designed for detecting soil nutrients and dispensing fertilizers. The system integrates sensing mechanisms with automated fertilizer delivery. The study focuses on detecting soil nutrient levels and dispensing required fertilizer quantities accordingly. The system relies on embedded sensors to measure key soil parameters and uses control logic to release fertilizers in

measured amounts. This work highlights the importance of real-time soil analysis for efficient nutrient management and reduction of manual intervention in farming practices. However, the approach mainly emphasizes hardware automation rather than predictive modeling or data-driven crop selection. In relation to the present project, this study supports the need for accurate soil parameter analysis, which forms the foundation for machine learning-based seed and fertilizer recommendation in the Satara region.

[2] Mirhoseini Nejad et al. (2023) develop a multispectral crop yield prediction method using three-dimensional Convolutional Neural Networks together with attention-driven Convolutional LSTM techniques. The research utilizes spatial and temporal agricultural data collected from remote sensing platforms to enhance yield forecasting accuracy. By combining spectral bands with temporal patterns, the model captures seasonal crop behavior and environmental variations. Although the focus is on yield prediction using remote sensing data, the study demonstrates that deep learning models are capable of recognizing intricate nonlinear relationships present in agricultural datasets. This supports the adoption of advanced machine learning techniques in the proposed seed advisory system where soil and environmental attributes influence cultivation outcomes.

[3] Devi Priya et al. (2023) introduce an ensemble-based system designed to recommend suitable crops and fertilizers while also predicting leaf diseases. The study integrates multiple classification methods such as Decision Trees, Support Vector Machines, and Neural Networks to improve the overall accuracy of the recommendations. The use of an ensemble technique results in better prediction performance than individual models by reducing variance and enhancing robustness.

The integration of disease identification with nutrient advisory creates a more comprehensive agricultural support system. This directly relates to the current project, where multiple supervised learning algorithms are compared to identify the best model for seed and fertilizer recommendation based on soil data.

[4] Mishra (2023) presented a machine learning-based approach for detecting and predicting nutrient deficiencies in crops. The study emphasizes analyzing soil and plant parameters to identify specific nutrient shortages such as nitrogen, phosphorus, and potassium deficiencies. The proposed system assists farmers in applying corrective measures before visible symptoms severely affect crop growth. The findings highlight the importance of nutrient level monitoring for balanced fertilizer application and sustainable soil management. This aligns with the present work, which uses soil macro and micronutrient data to recommend suitable seeds and fertilizers for improved productivity.

[5] Sudhir et al. (2023) focus on the detection of the severity of plant diseases along with suitable fertilizer suggestions by applying deep learning techniques. The research combines disease classification models with nutrient management strategies to support crop health improvement. By utilizing image-based disease detection and linking it with fertilizer suggestions, the study presents an integrated agricultural advisory framework. While the primary emphasis is on disease detection, the study demonstrates how integrated systems can improve agricultural decision-making. The present project extends this concept by concentrating on seed suitability and soil-based fertilizer prediction for specific crops cultivated in the region.

[6] Rama Devi et al. (2023) introduce a fertilizer prediction model built using machine learning approaches. The study examines different predictive methods such as Random Forest, Logistic Regression, and Gradient Boosting to determine fertilizer requirements using soil and crop-related data. The comparison of model performance emphasizes the need to choose a suitable algorithm for higher prediction accuracy. This work reinforces the importance of comparative algorithm analysis, which is also adopted in the current project to select the most accurate model for seed and fertilizer advisory.

[7] Narayana and Saxena (2023) develop an online crop diagnosis system using both machine learning and deep learning techniques. The system provides advisory support for crop health management through a digital interface. It assists farmers by diagnosing plant diseases and suggesting remedial measures. Although the focus is on disease diagnosis, the study demonstrates the feasibility of

intelligent agricultural advisory platforms that can operate in real time. This supports the implementation of a localized advisory system for seed cultivation in the Satara region where timely recommendations are essential.

[8] Kulkarni et al. (2022) present a framework for soil classification, crop recommendation, and fertilizer prediction using soil series data. The study uses soil characteristics including texture, structure, and nutrient composition to recommend suitable crops and fertilizers. The framework emphasizes the importance of soil taxonomy in agricultural planning. This research closely relates to the proposed system, as it highlights the importance of soil-based crop suitability analysis. The present work further refines this approach by focusing on seed-level recommendation specific to rice, jowar, bajra, and wheat cultivated in the region.

[9] Raja et al. (2022) examine crop prediction by considering environmental parameters along with feature selection techniques and multiple classification methods. The results show that selecting relevant features helps improve the accuracy of classification and reduces computational complexity. By identifying the most influential environmental parameters, the predictive model becomes more efficient and interpretable. This insight is relevant to the current project, where soil parameters such as nitrogen, phosphorus, potassium, pH, and micronutrients are analyzed carefully for optimal seed prediction.

[10] Rani et al. (2022) developed an automated framework for predicting crop diseases and fertilizer requirements using Convolutional Neural Networks. The study utilizes deep learning models for agricultural forecasting tasks and demonstrates their capability in handling complex agricultural datasets. Although the study focuses more on disease detection, it confirms the effectiveness of neural networks in agricultural applications. This supports the inclusion of artificial neural networks in the proposed advisory system to enhance prediction performance.

V. METHODOLOGY

The proposed system follows a structured machine learning-based approach for predicting suitable seeds and fertilizer recommendations. The methodology consists of three major modules: Data Processing Module, Prediction Module, and Recommendation Module, as illustrated in

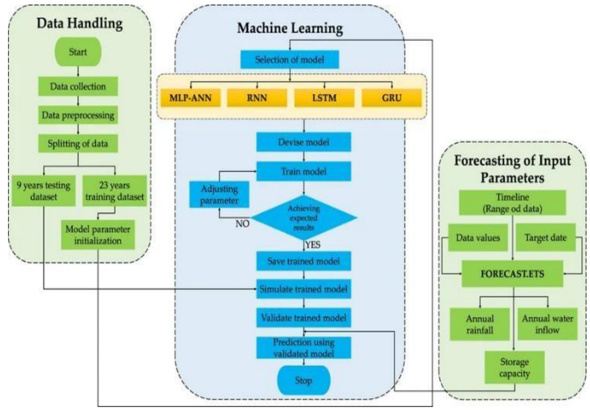

Fig. 2 (Process Flow).

The system begins with collecting soil and environmental data, followed by preprocessing to improve data quality. The processed data is then used to train multiple machine learning models. Based on the trained models, predictions are generated for suitable crops and fertilizer requirements.

A. Data Processing Module

This module focuses on preparing agricultural data for machine learning analysis. The dataset includes soil parameters such as nitrogen, phosphorus, potassium, organic carbon, electrical conductivity, soil pH, and micronutrients, along with environmental factors like rainfall, temperature, and humidity.

The preprocessing stage involves:

1. Handling missing values and removing inconsistencies
2. Feature scaling and normalization
3. Splitting dataset into training and testing sets

These steps ensure that the data is structured and suitable for accurate model training.

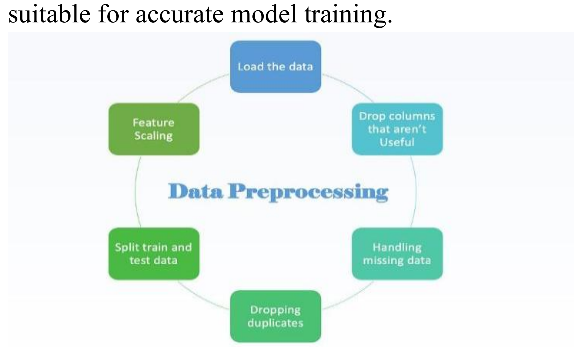

Fig. 3: Data Preprocessing Workflow

B. Prediction Module

This module performs the core predictive analysis using machine learning algorithms. Multiple supervised learning techniques are implemented, including:

- Support Vector Machine (SVM) for classification
- Artificial Neural Network (ANN) for capturing nonlinear relationships
- Extreme Gradient Boosting (XGBoost) for high accuracy
- Hybrid Ensemble Model for combining multiple predictions

The models are trained using the prepared dataset and evaluated using performance metrics such as accuracy, precision, recall, and F1-score. The best-performing model is selected for final prediction.

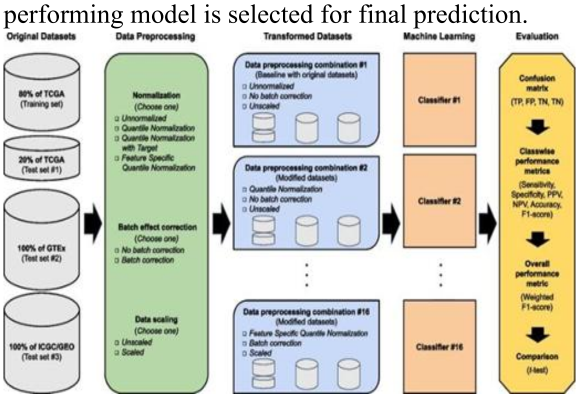

Fig. 4: Model Development and Training

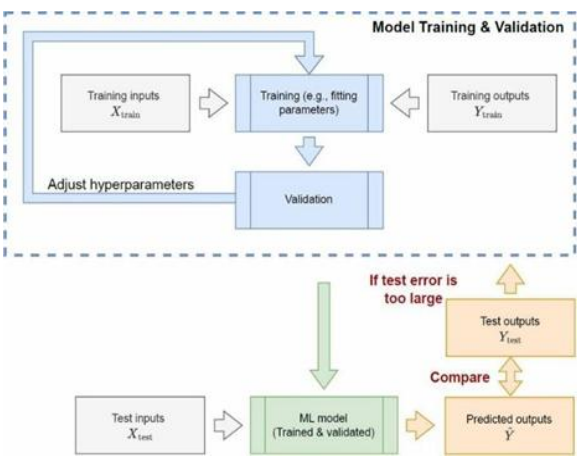

Fig. 5: Prediction Module Workflow

C. Recommendation Module

This module generates final outputs based on prediction results. The system recommends:

- Suitable crops such as rice, jowar, bajra, and wheat
- Fertilizer requirements based on nutrient deficiencies
- Expected yield insights based on soil and climate conditions

The output is presented in a user-friendly format, enabling farmers to make informed decisions regarding cultivation and resource management.

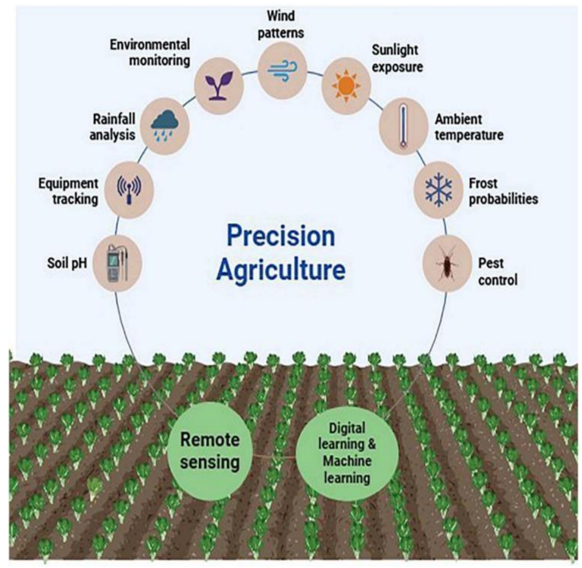

Fig. 6: System Output and Recommendation Flow

VI RESULTS

The proposed Smart Crop Advisory System was evaluated using multiple machine learning algorithms to identify the most accurate model for crop and fertilizer prediction. The dataset includes soil parameters such as Nitrogen (N), Phosphorus (P), Potassium (K), Organic Carbon, Electrical Conductivity, soil pH, and micronutrients, along with environmental factors like rainfall, temperature, and humidity. The dataset was divided into training and testing sets to ensure reliable evaluation.

Among the implemented models, CatBoost achieved the highest accuracy, followed by the Hybrid Ensemble Model and Artificial Neural Network **(ANN)**. Models such as Support Vector Machine (SVM) and Random Forest also produced satisfactory results but with comparatively lower accuracy. The superior performance of CatBoost is due to its ability to handle complex relationships and feature interactions effectively.

The results highlight that soil nutrients, especially nitrogen, phosphorus, potassium, and pH, are key factors influencing crop suitability. The system successfully predicts suitable crops such as rice, jowar, bajra, and wheat, and provides fertilizer recommendations based on detected nutrient deficiencies.

System Output

The system generates user-friendly output that includes:

- Predicted suitable crop based on soil and environmental data
- Recommended fertilizers to balance nutrient deficiencies
- Soil health insights for better decision-making

For example, if the soil has low nitrogen and optimal pH, the system may recommend:

- Crop: Wheat
- Fertilizer: Nitrogen-based fertilizers (e.g., urea)

This output enables farmers to make data-driven decisions, improving productivity and reducing unnecessary fertilizer usage.

Comparative analysis confirms that ensemble and boosting techniques outperform individual models in accuracy and consistency. The graphical results further validate the effectiveness of the proposed system in sustainable agriculture.

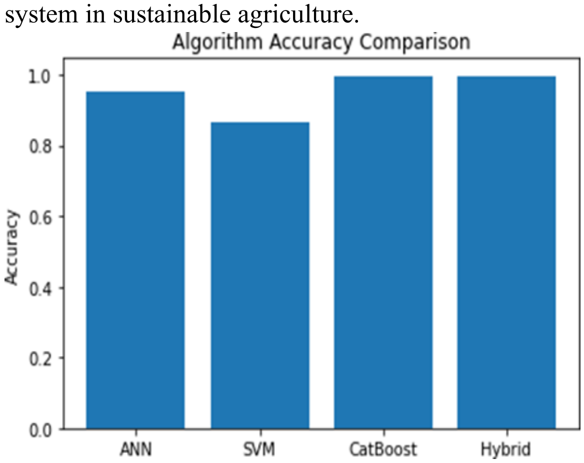

Figure 1: Conclusion of Results

VII. CONCLUSIONS

This paper presents a Smart Crop Advisory System for Sustainable Seed Cultivation that utilizes machine learning techniques to assist farmers in selecting suitable crops and optimizing fertilizer usage based on soil and environmental conditions. The system analyzes key soil parameters, including macronutrients and micronutrients, along with climatic factors such as rainfall, temperature, and humidity, to generate accurate and data-driven recommendations. Multiple machine learning algorithms were implemented and evaluated, including Support Vector Machine, Random Forest, Artificial Neural Network, Extreme Gradient Boosting, and CatBoost. Among these, CatBoost demonstrated the highest prediction accuracy, followed by hybrid ensemble approaches, indicating the effectiveness of boosting techniques in handling complex agricultural datasets.The system successfully predicts appropriate crops such as rice, jowar, bajra, and wheat, and provides fertilizer recommendations based on nutrient deficiencies. This helps in improving crop yield, reducing excessive fertilizer usage, and maintaining soil health.Overall, the proposed system contributes to sustainable agriculture by enabling informed decision-making and efficient resource utilization. Future work can focus on integrating real-time IoT-based soil data and expanding the system to support a wider range of crops and geographic regions.

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