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Smart Crop Recommendation and Yield Prediction System Using Machine Learning

G. V. S. Sriram[1], Y. M. Mahalakshmi Kondalamma[2], S. Mounika Divya Sri[3], T. Srinivasa Rao[4], V. Chaitanya Ganesh[5]

Author Affiliations

1. Assistant Professor, Dept. of CSE, D.N.R. COLLEGE OF ENGINEERING & TECHNOLOGY, Balusumudi, Bhimavaram – 534 202, W.G. Dist., A.P., India.

2,3,4,5 Student, Dept. of CSE, D.N.R. COLLEGE OF ENGINEERING & TECHNOLOGY, Balusumudi, Bhimavaram – 534 202, W.G. Dist., A.P., India.

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ABSTRACT

Our project, Smart Crop Recommendation and Yield Prediction System Using Machine Learning, is developed to address the key limitations of traditional agricultural decision-making practices. Existing approaches primarily rely on farmer experience, regional advisories, and static guidelines that lack personalization, accuracy, and real-time adaptability. Farmers struggle to determine the most suitable crops for their specific soil and environmental conditions, leading to poor crop selection, resource wastage, and reduced productivity. To overcome these challenges, the proposed system leverages advanced Machine Learning algorithms — specifically Light Gradient Boosting Machine (LightGBM) and Random Forest — to analyze soil parameters (Nitrogen, Phosphorus, Potassium, and pH) and environmental factors (temperature, humidity, and rainfall), providing accurate and data-driven crop recommendations. The system performs multi-class classification on structured agricultural datasets and incorporates feature importance analysis to improve transparency. It is deployed through a Streamlit-based interactive web application, allowing users to input values and receive real-time crop recommendations instantly. The system provides a practical and accessible solution for farmers, agricultural researchers, and policymakers, enabling informed decision-making, optimized resource utilization, and promotion of sustainable farming practices.

Key words: Precision Agriculture, Crop Recommendation, Machine Learning, LightGBM, Random Forest, Multi-Class Classification, Feature Importance, Streamlit, Predictive Modeling, Soil Nutrients, Soil pH, Temperature, Humidity, Rainfall, Decision Support System

1. INTRODUCTION

1.1 Brief Information

Agriculture plays a crucial role in the economic development of many countries, especially in developing nations like India, where a significant portion of the population depends on farming for their livelihood. However, agricultural productivity is highly influenced by multiple factors such as soil nutrients, climatic conditions, and environmental variations. Traditional farming practices often rely on experience, intuition, and generalized knowledge, which may lead to inefficient crop selection and reduced yield.

To address these challenges, the proposed system titled "Smart Crop Recommendation and Yield Prediction System Using Machine Learning" is developed as an intelligent decision-support system that leverages Machine Learning (ML) techniques for precision agriculture. The system analyzes key soil parameters such as Nitrogen (N), Phosphorus (P), Potassium (K), and pH, along with environmental factors including temperature, humidity, and rainfall. These inputs are processed using advanced machine learning algorithms such as Light Gradient Boosting Machine (LightGBM) and Random Forest, which are well-suited for handling structured agricultural data and capturing complex relationships between input features and crop suitability.

The application is implemented using Python and deployed through a Streamlit-based web interface, providing an interactive and user-friendly platform. Users can input environmental and soil conditions and receive real-time crop recommendations. By integrating machine learning, data analytics, and an intuitive interface, the system enables data-driven decision-making, improves agricultural productivity, reduces risks of crop failure, and promotes sustainable farming practices.

1.2 Purpose

The primary purpose of the Smart Crop Recommendation and Yield Prediction System is to transform traditional agriculture into a data-driven and intelligent decision-making process. The system aims to assist farmers, agricultural researchers, and policymakers in selecting the most suitable crop and estimating its potential yield based on soil and environmental conditions. The system is designed to:

- Recommend the most suitable crop based on soil nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), and pH value
- Predict expected crop yield using environmental parameters like temperature, humidity, and rainfall
- Enable real-time decision-making through an interactive and user-friendly web interface
- Reduce dependency on traditional guesswork and improve accuracy in crop selection
- Optimize the use of resources such as water, fertilizers, and land
- Support sustainable agriculture by promoting crops best suited to local conditions

By integrating Machine Learning with an intuitive interface, the system ensures that users not only receive predictions but also gain meaningful insights into agricultural planning. The ultimate goal is to enhance productivity, minimize risks, and contribute to the development of smart and sustainable farming practices.

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1.3 Motivation

Agriculture plays a vital role in India's economy, yet many farmers struggle to choose the right crops due to unpredictable weather, varying soil conditions, and lack of proper technological support. Traditional decision-making methods often result in low productivity and financial losses. With the advancement of Machine Learning, there is an opportunity to improve farming practices by using data-driven approaches. This project is motivated by the need to assist farmers in selecting suitable crops and predicting yields based on factors like soil nutrients, climate, and historical data. By developing a smart crop recommendation and yield prediction system, the aim is to enhance productivity, reduce risks, and promote sustainable agriculture.

1.4 Problem Statement

Agriculture is the backbone of the Indian economy and plays a vital role in ensuring food security and employment. However, farmers today face numerous challenges such as unpredictable climatic conditions, soil degradation, improper crop selection, and lack of access to modern technological tools. These issues often lead to reduced crop productivity, financial losses, and inefficient use of agricultural resources. Traditionally, farmers rely on experience, local knowledge, and general guidelines to decide which crops to cultivate. While these methods have been followed for generations, they are not sufficient in today's dynamic environmental conditions.

The major problems include:

- Lack of a centralized platform for data-driven crop selection
- Limited opportunities for real-time prediction and analysis of soil and environmental conditions
- Absence of personalized crop recommendations tailored to individual farm conditions
- Difficulty in identifying the most productive crop for given soil and climate parameters
- Time-consuming and unorganized agricultural decision-making methods

This project aims to address these challenges by developing a Smart Crop Recommendation and Yield Prediction System Using Machine Learning. The application provides structured decision support, real-time predictions, and AI-based recommendations to guide farmers effectively, improving crop selection, productivity, and sustainable resource utilization.

2. LITERATURE SURVEY

2.1 Introduction

Agriculture is one of the most important sectors that supports human life and the economy. With the increase in population, there is a growing need for higher crop production and efficient farming methods. Traditional farming practices are not always sufficient to meet these demands due to changing environmental conditions and limited resources. In recent years, Machine Learning has emerged as a powerful tool in agriculture for improving decision-making and productivity. It helps in analyzing large amounts of data such as soil nutrients, weather conditions, and crop patterns. This literature survey examines existing research related to crop recommendation, yield prediction, and ML-based agricultural systems, providing a foundation for the proposed system.

2.2 Machine Learning in Agriculture

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Machine Learning plays an important role in agriculture by improving crop production and decision-making. Jeong et al. [1] demonstrated that ML models can effectively predict crop yield using environmental and historical data, establishing a strong foundation for data-driven agriculture. Liakos et al. [2] provided a comprehensive review explaining that ML supports precision agriculture by analyzing factors like soil nutrients, temperature, and rainfall to give accurate recommendations. Their study highlighted ML's potential to improve productivity and reduce farming risks through intelligent, automated decision support.

2.3 Crop Yield Prediction Using Machine Learning

Crop yield prediction is an important application of Machine Learning in agriculture that helps farmers estimate production before harvesting. According to Jeong et al. [1], ML models use historical and environmental data to predict crop yield accurately. Van Klompenburg et al. [3] conducted a systematic literature review on crop yield prediction using machine learning, identifying that ensemble algorithms such as Random Forest and gradient boosting methods consistently achieve high predictive accuracy on structured agricultural datasets. Kuradusenge et al. [4] further confirmed these findings through a case study on Irish Potato and Maize, showing that ML-based yield prediction significantly supports planning of resources like water, fertilizers, and labor.

2.4 Soil Analysis and Nutrient Assessment

Soil analysis is an important aspect of agriculture that helps in determining the quality and fertility of soil. Liakos et al. [2] demonstrated that ML models can effectively analyze soil nutrients and improve crop productivity. Key parameters such as Nitrogen, Phosphorus, Potassium, and pH value are essential for determining crop suitability. Ranjan et al. [6] examined AI applications in soil and crop management, establishing that machine learning algorithms process soil composition data to recommend suitable crops, reducing manual soil testing efforts while improving farming decisions. These systems contribute to efficient use of fertilizers and water, supporting sustainable agriculture.

2.5 Crop Recommendation Systems

Crop recommendation systems use Machine Learning techniques to suggest the most suitable crops based on soil and environmental conditions. Kamble et al. [5] showed that ML models analyzing soil nutrients and weather data provide accurate recommendations that improve farming efficiency and resource utilization. Algorithms like Decision Tree, Random Forest, and LightGBM are commonly employed in such systems. Xu et al. [7] explored smart farm architectures incorporating recommendation logic, emphasizing modular system design, which aligns with the architecture of scalable agricultural decision-support platforms. These systems reduce dependency on traditional guesswork and help farmers adopt modern practices.

2.6 AI and Remote Sensing in Crop Monitoring

Recent advancements in AI and remote sensing have expanded the capabilities of crop monitoring systems. Oré et al. [8] demonstrated how drone-based remote sensing can monitor crop growth effectively, generating insights into plant health and environmental stress. Moysiadis et al. [9] proposed a cloud-based web application for smart farming, integrating sensor data and ML models to provide scalable agricultural solutions. These studies demonstrate how AI integration with sensor technologies can significantly improve the accuracy of crop recommendations by incorporating real-time field conditions.

2.7 Research Gaps Identified from Literature

Based on the reviewed literature, several research gaps are identified:

- Limited integration of ML personalization with real-time soil and environmental data — most existing systems use static or offline datasets [1], [2]
- Lack of unified platforms combining crop recommendation and yield prediction in a single accessible interface [3], [4]
- Insufficient focus on user-friendly deployment for non-technical agricultural users such as farmers [5], [9]
- Need for scalable, lightweight architectures suitable for rural and resource-limited environments [7], [9]
- Most studies focus only on prediction accuracy without providing interactive, real-time decision support tools [1], [3]
- Requirement for execution-based validation and feature importance analysis to improve model interpretability [2], [6]

These gaps highlight the necessity for a comprehensive crop recommendation system that integrates AI-driven guidance with an accessible, interactive deployment environment.

2.8 Relevance of Literature to the Proposed System

The proposed Smart Crop Recommendation and Yield Prediction System builds upon existing research by:

- Applying ML-based yield prediction principles using ensemble learning [1], [3], [4]
- Leveraging soil nutrient analysis and feature-driven modeling techniques [2], [6]
- Incorporating high-performance classification models — Random Forest and LightGBM [3], [5]
- Utilizing smart farm and modular system architectural concepts [7], [9]
- Addressing the gap in user-friendly, accessible deployment through Streamlit web interface [2], [5]
- Incorporating feature importance analysis to bridge the interpretability gap identified in literature [2], [6]

By synthesizing these research contributions, the proposed system offers a novel and practical solution to modern agricultural decision-making challenges, directly addressing the identified gaps.

3. PROPOSED SYSTEM

The proposed system introduces a Smart Crop Recommendation and Yield Prediction System Using Machine Learning to improve the existing agricultural decision-making process. This system reduces dependency on multiple platforms and traditional methods by providing a single, user-friendly solution for crop analysis, prediction, and evaluation. It enhances efficiency and builds user confidence by offering real-time crop recommendations and instant feedback without the need for external consultation tools.

The system utilizes Machine Learning techniques — specifically Light Gradient Boosting Machine (LightGBM) and Random Forest — along with performance analysis mechanisms to create an interactive and personalized agricultural decision environment. The ML-driven components analyze soil parameters

(N, P, K, pH) and environmental conditions (temperature, humidity, rainfall) to recommend suitable crops and predict expected yield. The system processes data through a structured pipeline of collection, preprocessing, feature analysis, model training, and result visualization, ensuring accurate and reliable outputs.

This approach makes the preparation process more structured, adaptive, and effective, ultimately improving crop selection accuracy, resource optimization, and overall agricultural productivity. The system is implemented using Python and deployed through a Streamlit-based web application, providing a simple and accessible interface suitable for both technical and non-technical users including farmers, researchers, and agricultural policymakers.

Advantages of Proposed System

- Real-time crop recommendations based on soil and environmental parameters
- High-accuracy predictions using LightGBM and Random Forest algorithms
- AI-based personalized crop selection tailored to specific input conditions
- Feature importance analysis for transparent, interpretable model outputs
- Interactive Streamlit-based interface accessible to non-technical users
- Scalable and adaptable architecture for different agricultural regions

4. SYSTEM ARCHITECTURE

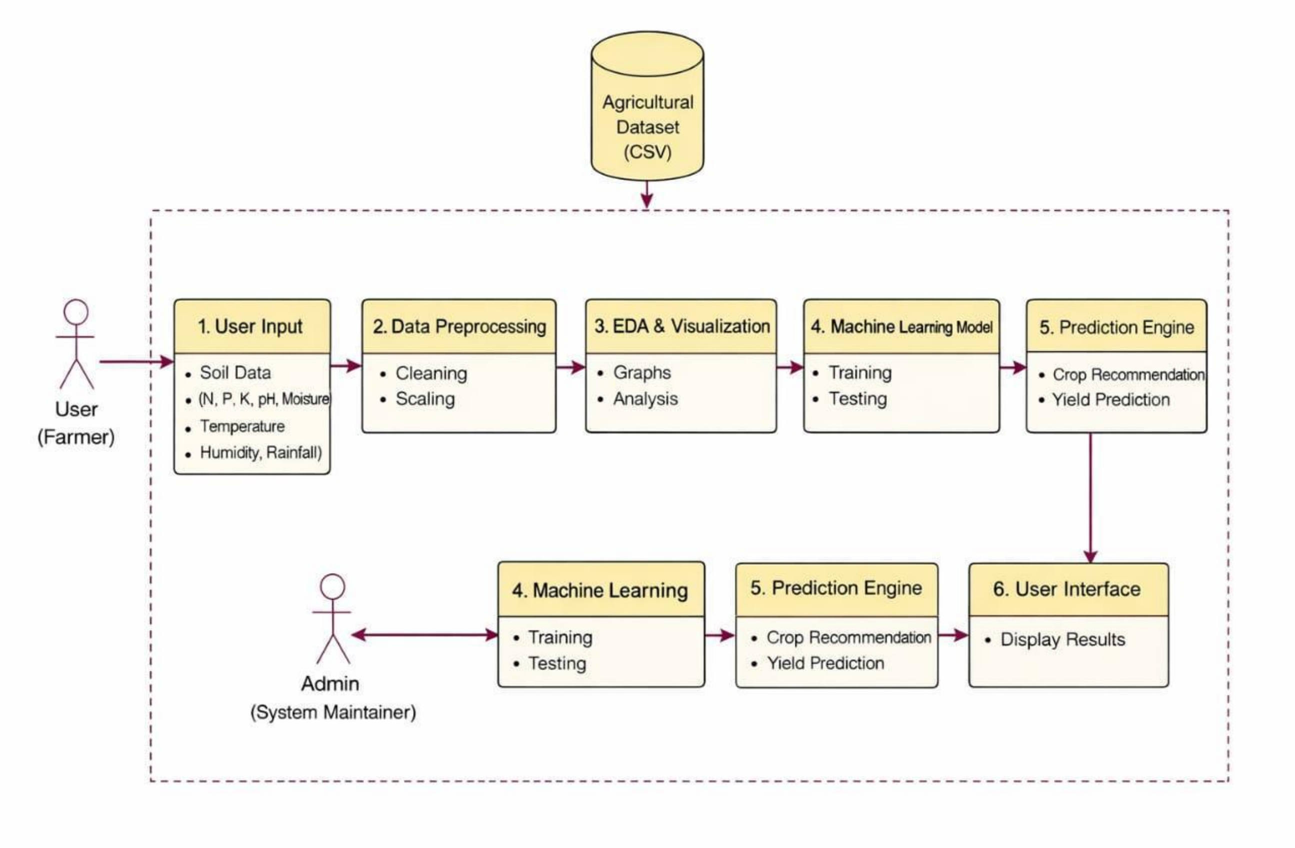

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Fig 1: *System Architecture*

The system architecture of the Smart Crop Recommendation and Yield Prediction System using Machine Learning represents the overall structure and workflow of the system. It defines how data flows through different modules, how processing is performed, and how predictions are generated and presented to the user. The proposed system follows a modular and layered architecture consisting of data collection, preprocessing, machine learning modeling, and user interaction components.

The architecture flow is as follows: [User Input] → [Data Preprocessing] → [Feature Analysis] → [ML Model] → [Prediction] → [Result Display]. The Data Input Layer collects soil parameters (N, P, K, pH) and environmental conditions (temperature, humidity, rainfall) through the Streamlit interface. The Data Preprocessing Layer handles missing values, normalization, and formatting. The Feature Analysis Layer identifies the most influential parameters using importance scores from LightGBM and Random Forest. The Machine Learning Model Layer performs classification using the trained model, and the Result Display Layer presents the recommended crop along with descriptive insights through the interactive interface.

4.1 Use Case Diagram

A Use Case Diagram in the Unified Modeling Language (UML) is a behavioral diagram that provides a high-level representation of the functionalities of a system by illustrating the interaction between users (actors) and the system's features (use cases). In the Smart Crop Recommendation System, the primary actors are the Farmer (User) and the Admin. The Farmer interacts with functionalities such as entering soil and weather parameters, submitting data for analysis, viewing crop recommendations, and checking yield predictions. The Admin manages the system by maintaining datasets, updating machine learning models, and monitoring system performance.

The main purpose of this diagram is to clearly show which system functions are performed for each actor and how different features are connected. It helps in capturing and organizing system requirements in a simple and understandable way during the analysis phase, ensuring smooth interaction between users and the system.

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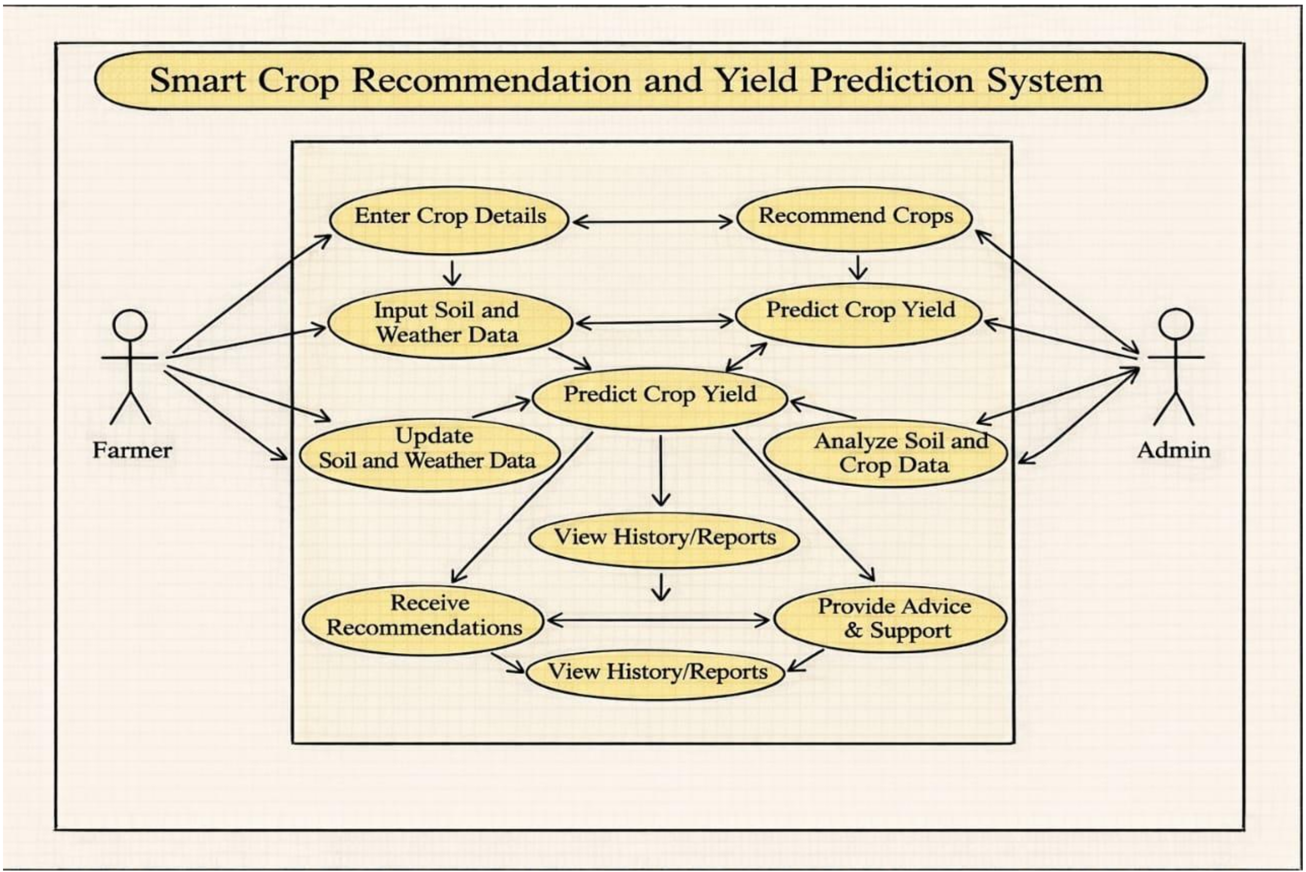


Fig 2: *Use Case Diagram*

4.2 Class Diagram

A Class Diagram in the Unified Modeling Language (UML) is a type of structural diagram that represents the static structure of a system by showing its classes, attributes, methods, and the relationships between them. In the Smart Crop Recommendation and Yield Prediction System, the class diagram illustrates the key classes: User and Admin. The User class contains attributes such as userId and name, and methods including enterCropDetails(), inputSoilAndWeatherData(), getRecommendations(), viewYieldPrediction(), and viewHistoryReports(). The Admin class includes adminId and name as attributes, and methods such as preprocessData(), updateDataset(), trainModel(), getYieldPrediction(), and monitorSystem().

The relationship between these classes ensures smooth system functionality. The User provides input data that is processed and analyzed by the Admin module to generate accurate crop recommendations and yield predictions. The class diagram serves as a blueprint for developers to implement the system effectively and maintain consistency throughout the development process.

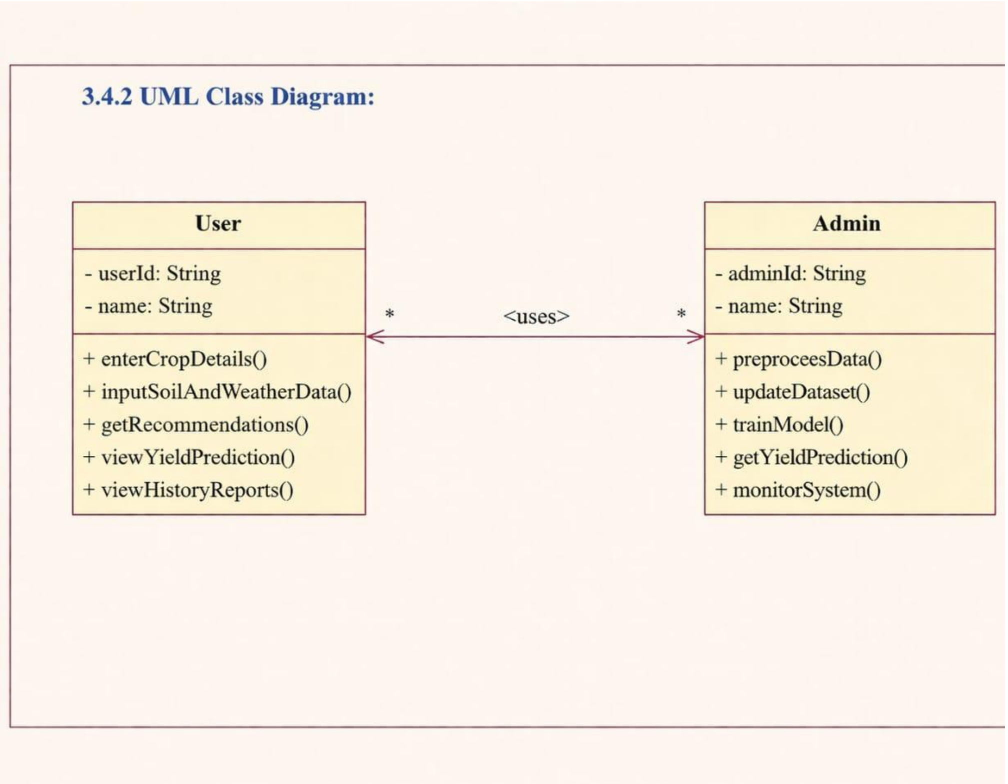
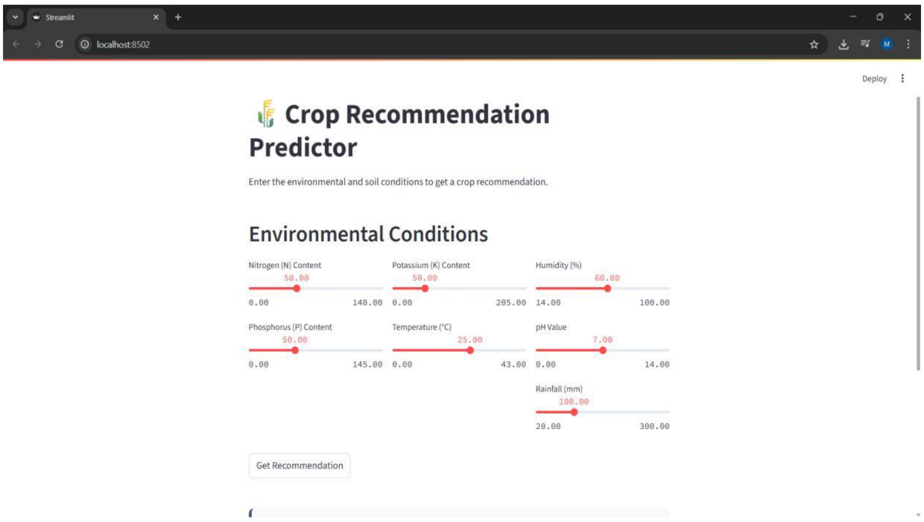


Fig 3: *Class Diagram*

5. RESULTS

5.1 USER INPUT INTERFACE



5.2 INPUT INTERFACE WITH APPLICATION INFORMATION

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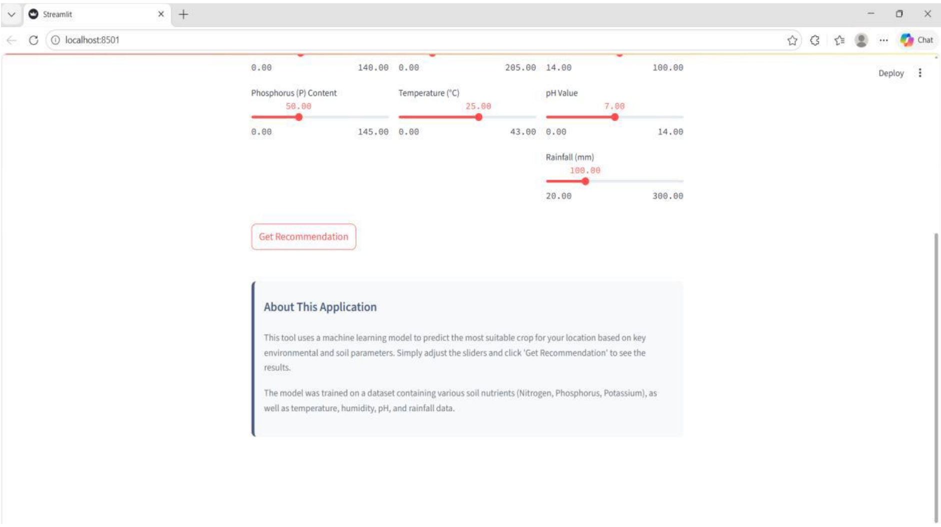

The primary objective of this project was to design and develop a Smart Crop Recommendation and Yield Prediction System Using Machine Learning that addresses the shortcomings of traditional agricultural decision-making methods. With the increasing need for precision agriculture and data-driven farming, there is a growing demand for systems that provide accurate, personalized, and accessible crop recommendations. This project successfully fulfills these requirements by integrating modern web technologies, Machine Learning algorithms (LightGBM and Random Forest), and an interactive Streamlit-based deployment within a unified system. The trained model achieves a high prediction accuracy of approximately 98%, demonstrating reliable performance for real-world agricultural applications.

5.3 ENVIRONMENTAL PARAMETERS INPUT DASHBOARD

6. CONCLUSION

The Crop Recommendation System project successfully demonstrates the effective use of Machine Learning techniques in the field of agriculture. The system is designed to assist farmers and users in selecting the most suitable crop based on important environmental and soil parameters such as nitrogen, phosphorus, potassium levels, temperature, humidity, pH, and rainfall.

The application integrates various stages including data collection, preprocessing, exploratory data analysis, model training, and prediction into a single platform. By using the Random Forest algorithm, the system analyzes agricultural data and provides accurate crop recommendations, helping users make informed decisions.

The implementation of data visualization techniques enables users to better understand patterns and relationships within the dataset. Graphs and charts make it easier to interpret data, which improves the overall usability of the system.

The use of the Streamlit framework provides a simple and user-friendly interface, allowing users to upload datasets, view insights, and get crop predictions easily.

Overall, the system offers an efficient data-driven solution for agriculture, helping improve crop selection, productivity, and decision-making

7. FUTURE SCOPE

The future scope of the Smart Crop Recommendation and Yield Prediction System defines the functional boundaries and potential extensions of the application. While the current system successfully delivers accurate crop recommendations and yield predictions through a user-friendly interface, several enhancements can be incorporated in future iterations to further improve system capabilities and real-world applicability:

- Integration with real-time weather APIs (e.g., OpenWeatherMap) for live environmental data
- Incorporation of IoT-based soil sensors for automated real-time soil parameter collection
- Implementation of advanced deep learning models to further improve prediction accuracy
- Cloud-based deployment (AWS, Heroku, Streamlit Cloud) for scalability and broader accessibility
- Development of a mobile application for improved accessibility among rural farming communities
- Addition of disease detection and pest management modules using image recognition
- Include historical yield records and trend analysis for long-term farm planning
- Introduce company-specific or region-specific crop modules for targeted agricultural guidance
- Implement Explainable AI (XAI) techniques to improve model transparency and user trust
- Enable multi-language support to make the platform accessible to farmers across different regions

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