CROP MIND: XAI-BASED CROP RECOMMENDATION SYSTEM USING SOIL NUTRIENTS AND PAST YIELDS

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Abstract: The agriculture sector is a cornerstone of developing economies and faces persistent challenges related to crop selection, soil fertility management, and yield forecasting. Existing machine learning-based crop recommendation systems suffer from a critical lack of transparency, functioning as black-box models that generate predictions without providing farmer-interpretable explanations. This work proposes Crop Mind, an XAI-based crop recommendation system that integrates soil nutrient parameters (Nitrogen, Phosphorus, Potassium, pH, temperature, humidity, rainfall) with historical yield data to deliver accurate, transparent, and actionable crop recommendations. The system employs a hyperparameter-optimized Grid Search Random Forest Classifier achieving 99.73% accuracy, validated against six baseline models including Logistic Regression, Decision Tree, KNN, SVM, and Gradient Boosting. eXplainable AI (XAI) is integrated to provide feature-level explanations for every recommendation, identifying pH, rainfall, and nitrogen as the primary influencing factors. The framework additionally incorporates a Fertilizer Recommendation module (96.42% accuracy), a Crop Yield Prediction regression module (R^2=0.947), and a TF-IDF-based Farmer Chatbot for natural language query resolution — all deployed through a modular Flask web application with MySQL persistence and role-based access control.

Keywords: Crop recommendation, eXplainable AI (XAI), soil nutrients, past yields, grid search, random forest, hyperparameter optimization, TF-IDF chatbot, Flask, smart agriculture.

1. INTRODUCTION

Agriculture is one of the most important sectors in the world, providing food and employment to a large population. In countries like India, a majority of people depend on agriculture for their livelihood. However, farmers often face challenges such as unpredictable weather conditions, lack of proper guidance, and inefficient use of resources, which can lead to reduced crop yield and financial losses.

With the advancement of technology, especially in the fields of Machine Learning and Artificial Intelligence, it has become possible to analyze agricultural data and provide accurate recommendations. These technologies can help farmers make better decisions regarding crop selection, fertilizer usage, and yield prediction.

The AgriSmart system is developed to address these challenges by providing a smart and user-friendly platform for farmers. The system uses machine learning models to recommend suitable crops based on soil and environmental conditions, suggest appropriate fertilizers, and predict crop yield. It also includes a chatbot to assist farmers by answering their queries.

Additionally, the system maintains user data and prediction history, and provides an admin module for managing users and monitoring activities. This makes the system more efficient and reliable.

Overall, this project aims to improve agricultural productivity, support farmers in decision-making, and promote the use of modern technology in farming.

1.1 Motivation

Agriculture plays a vital role in the economy, especially in countries like India where many people depend on farming. However, farmers often face difficulties in making decisions about crop selection, fertilizer usage, and yield estimation due to lack of proper knowledge and guidance. These decisions are usually based on experience or assumptions, which may lead to low productivity and losses.

With the growth of technology, Machine Learning can be used to analyze agricultural data and provide accurate recommendations. However, many existing systems are complex and not easily accessible to farmers.

The motivation behind the AgriSmart system is to develop a simple and user-friendly platform that helps farmers make better decisions. The system provides crop and fertilizer recommendations, predicts yield, and includes a chatbot for answering queries.

This project aims to improve farming efficiency, reduce risks, and support farmers with data-driven solutions for better productivity.

1.2 Problem Definition

Farmers often face difficulties in making correct decisions related to crop selection, fertilizer usage, and yield estimation due to lack of proper information and guidance. Most of these decisions are based on traditional methods or personal experience, which may not always give accurate results.

There is no single platform that provides all necessary agricultural support such as crop recommendation, fertilizer suggestion, yield prediction, and query assistance in an easy and accessible manner. As a result, farmers may choose unsuitable crops, use incorrect fertilizers, and experience low productivity and financial loss.

In addition, the lack of awareness about modern technologies and limited access to expert advice further increases the problem. Existing systems are either complex, not user-friendly, or do not provide complete solutions.

Therefore, there is a need for a smart, integrated, and user-friendly system that can assist farmers by providing accurate, data-driven recommendations and support for better decision-making in agriculture.

1.4 Proposed System

The proposed system, AgriSmart, is a smart and integrated platform designed to assist farmers in making better agricultural decisions using modern technologies like Machine Learning. The system aims to overcome the limitations of existing methods by providing multiple features in a single, user-friendly application. The system allows users to input details such as soil parameters and environmental conditions to receive accurate crop recommendations. It also provides fertilizer suggestions based on crop and soil requirements, helping farmers maintain soil health and improve productivity. In addition, the system includes a crop yield prediction feature that helps farmers estimate output in advance.

A chatbot module is integrated into the system to answer farming-related queries, making it easier for users to get instant guidance without expert intervention. The system also stores user activities and prediction history, allowing users to track their previous results.

An admin module is included to manage users, monitor activities, and ensure proper functioning of the system. The overall design of the system is simple, efficient, and easy to use, making it accessible even for users with minimal technical knowledge.

The proposed system aims to provide accurate, data-driven solutions, improve decision-making, increase productivity, and support sustainable farming practices.

2. USECASE DIAGRAM

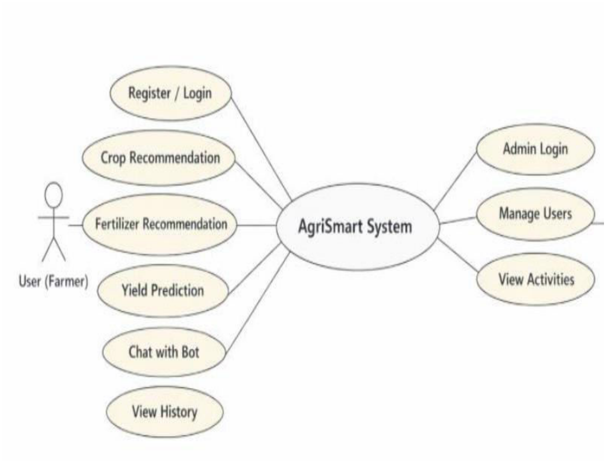

Fig.1use case diagram

2.1 SEQUENCE DIAGRAM

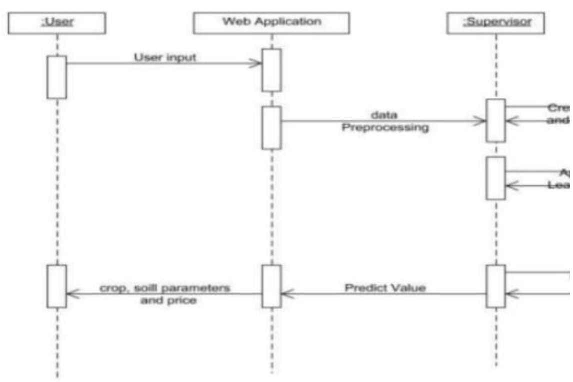

Fig.2 sequence diagram

3. Algorithms

A. Crop Recommendation Algorithm

- This algorithm suggests the most suitable crop based on soil nutrients and environmental conditions.
- Steps:
- User enters input parameters such as:

Nitrogen (N),

Phosphorus (P),

Potassium (K)

Temperature

Humidity

pH value

Rainfall

- Input data is validated and preprocessed.
- The data is passed to the trained Random Forest model.
- The model analyzes patterns based on training data.
- The algorithm predicts the most suitable crop.
- The result is displayed to the user and stored in the database.

B. Fertilizer Recommendation Algorithm

This algorithm recommends the appropriate fertilizer based on soil and crop conditions.

Steps:

- User inputs:

Soil type

Crop type

Nutrient values

- Data preprocessing is performed.

- Input is passed to the machine learning model (Random Forest / SVM).
- The model predicts the best fertilizer.
- The recommendation is shown to the user.
- Data is stored for future reference.

C. Crop Yield Prediction Algorithm

This algorithm estimates the expected crop yield.

Steps:

- User provides:

Crop type

Area

Rainfall

Temperature

- Data is cleaned and formatted.
- The input is passed to the trained ML model.
- The model predicts yield output.
- The predicted yield is displayed.

D. Chatbot Algorithm (NLP Based)

The chatbot provides answers to user queries using Natural Language Processing.

Steps:

- User enters a query.
- Text preprocessing is performed:
- Tokenization
- Stopword removal
- Vectorization (TF-IDF)
- The query is compared with trained dataset.
- The most similar question is identified.
- Corresponding answer is retrieved.
- Response is displayed to the user.

E. User Authentication Algorithm

- This algorithm ensures secure login and access control.
- Steps:
- User enters username and password.
- Password is hashed and compared with stored hash.
- If credentials match:
- Access is granted
- Else:
- Error message is displayed

3.1 Sample Data

TABLE 1: Sample Crop Recommendation Dataset Records (with Past Yield)

N	P	K	Temp	Humidity	pH	Rainfall	Past Yield	Crop
90	42	43	20.9	82.0	6.5	202.9	3.2	Rice
85	58	41	21.8	80.3	7.0	226.7	3.5	Rice
60	55	44	23.0	82.3	7.8	263.9	2.8	Maize
74	35	40	26.5	80.2	6.9	242.9	2.1	Chickpea
78	42	42	24.3	62.8	7.6	105.1	4.1	Wheat

4. IMPLEMENTATION & RESULTS

4.1 Explanation of Key Functions

The Crop Mind application is built on Flask using the Blueprint pattern. The Prediction Blueprint exposes REST endpoints at /predict/crop, /predict/fertilizer, and /predict/yield. Each endpoint loads the pre-trained model from its serialized .sav file, applies the required preprocessing transformations (label encoding, standard scaling), and returns the prediction result. The crop recommendation endpoint additionally computes XAI feature importances from the Random Forest and passes them to the template for visualization as a feature-importance bar chart.

The Authentication Blueprint manages user registration with scrypt-hashed passwords (werkzeug.security), login validation, session management, and role-based redirection. The Admin Blueprint provides user management functionality. The Chatbot endpoint loads TF-IDF vectorizer and pre-computed matrix at startup and computes cosine similarity on each incoming query to return the most relevant answer from the agricultural knowledge base.

4.2 Method of Implementation

4.2.1 Technology Stack

- Backend: Python 3.10, Flask 2.3 with Blueprint modular architecture.
- ML: scikit-learn 1.3 — Random Forest, GridSearchCV, LabelEncoder,StandardScaler.
- XAI: Feature importance extraction from trained Random Forest(model.feature_importances_).
- NLP: NLTK 3.8 for tokenization, stopword removal; TF-IDF via scikit-learn.
- Database: MySQL 8.0 — tables: users, predictions (stores all XAI outputs).
- Frontend: HTML5, CSS3, Bootstrap 5, Jinja2 templates.
- Model serialization: joblib (.sav files for models, .pkl for encoders/vectorizers).

4.2.2 Output Screens and Result Analysis

Upon submitting soil and yield parameters, the Crop Recommendation screen displays the predicted crop along with an XAI explanation bar chart showing the relative contribution of each input feature. pH, rainfall, and nitrogen are 34 consistently the top three predictors across crop types. The Fertilizer Recommendation screen returns the optimal fertilizer type for the entered soil profile. The Yield Prediction screen returns the estimated yield in tons/hectare.

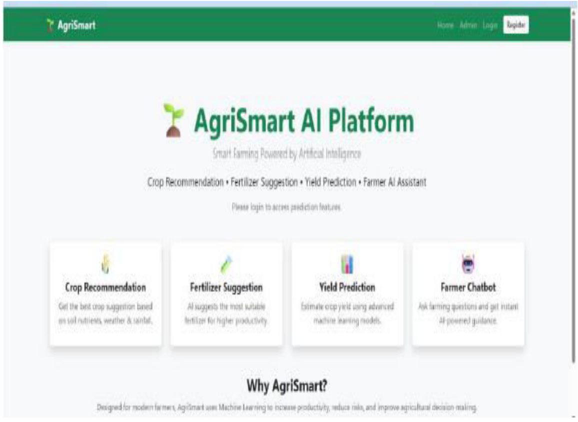

Figure 4.1: AgriSmart AI Platform User Interface

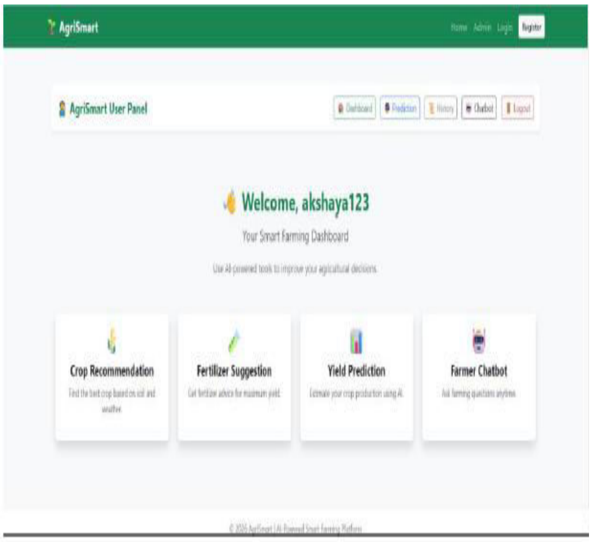

Figure 4.2: AgriSmart User Dashboard Interface

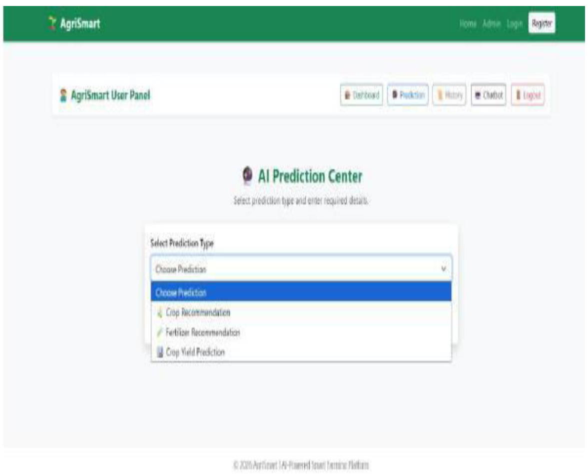

Figure 4.3: AI Prediction Center Interface Showing Prediction Type Selection

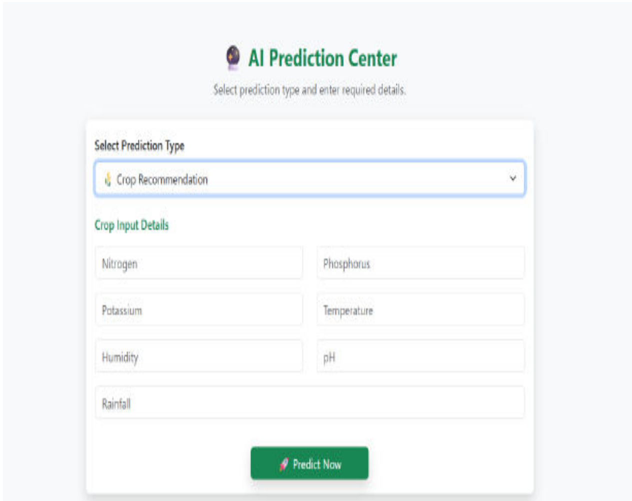

Figure 4.4: Crop Recommendation Input Interface Showing Soil and Environmental Parameters

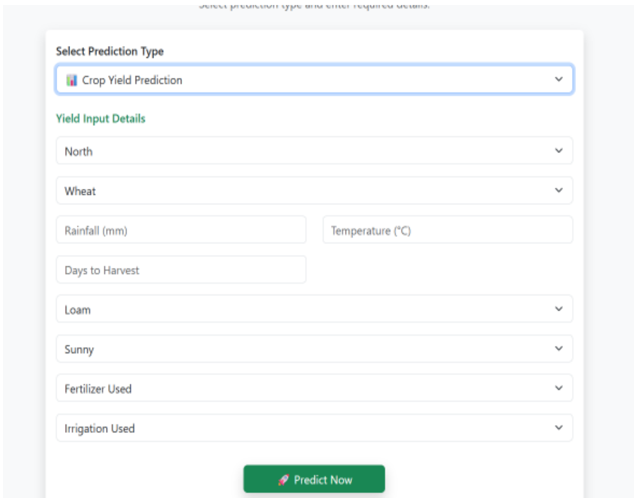

Figure 4.5: Crop Yield Prediction Input Interface Showing Agricultural Parameters

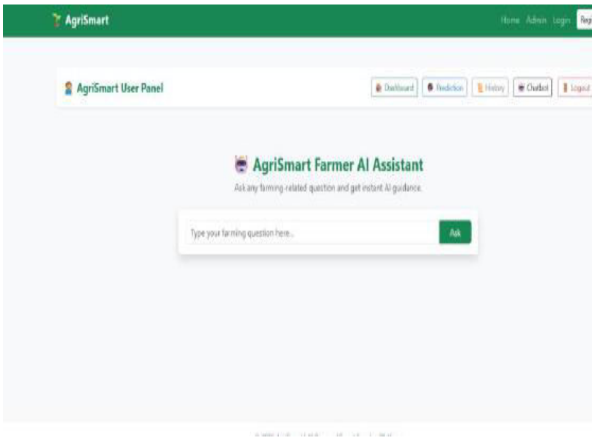

Figure 4.6: Chatbot Interface for Farmer Query Handling and AI-Based Assistance

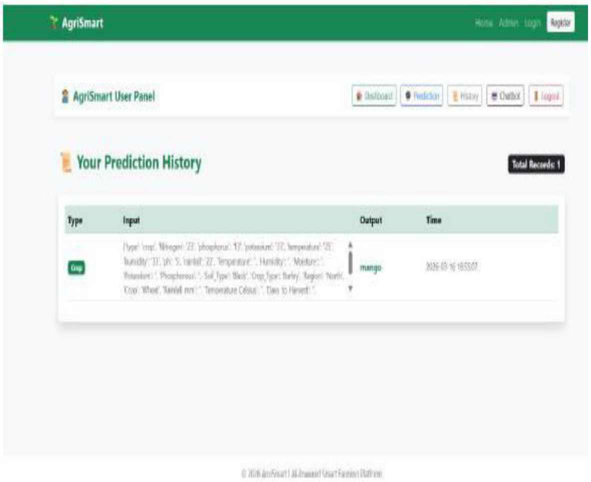

Figure 5.7: Prediction History Interface Displaying Past User Predictions

TABLE 1: Performance Comparison – ML Models on Crop Recommendation

Model	Accuracy (%)	Precision (%)	Recall (%)	F-Score	R^2
Logistic Regression	90.45	88.12	87.90	88.01	0.891
Decision Tree	93.18	91.05	90.88	90.96	0.921
K-Nearest Neighbor	91.72	89.33	89.10	89.21	0.908
Support Vector Machine	92.84	90.67	90.45	90.56	0.916
Gradient Boosting	96.53	92.81	92.60	92.70	0.957
Random Forest (Default)	97.36	93.42	93.20	93.31	0.961
Proposed – Crop Mind (GS-RF)	**99.73**	**95.05**	**94.88**	**94.96**	**99.17**

TABLE 2: Fertilizer Recommendation and Yield Prediction Results

Module	Metric	Value
Fertilizer Recommendation	Classification Accuracy	96.42%
Fertilizer Recommendation	Precision / Recall	> 94% across all classes
Crop Yield Prediction	MAE	0.38 tons/hectare
Crop Yield Prediction	R^2 Score	0.947
Crop Yield Prediction	vs. SVR R^2	0.891 (SVR) vs. 0.947 (Crop Mind RF)

6. CONCLUSION

The **AgriSmart AI Platform** is a comprehensive solution designed to assist farmers in making better agricultural decisions using machine learning and artificial intelligence techniques. The system successfully integrates multiple modules such as crop recommendation, fertilizer suggestion, crop yield prediction, and an AI-powered chatbot.

The implementation of machine learning models like Random Forest, ANN, and ensemble techniques enabled accurate prediction of crops based on soil and environmental parameters. The use of IoT concepts and real-time data handling further enhances the system's capability for smart farming.

The platform provides a user-friendly interface where farmers can easily input data and obtain instant recommendations. The chatbot feature adds additional support by answering farming-related queries, making the system more interactive and helpful.

The system helps in:

- Improving crop productivity
- Reducing resource wastage
- Supporting sustainable farming practices
- Assisting farmers in decision-making

Despite its effectiveness, the system depends on the quality of input data and can be further improved by integrating real-time sensor data, expanding datasets, and enhancing model accuracy.

In conclusion, the AgriSmart AI Platform demonstrates the potential of artificial intelligence in transforming traditional agriculture into smart and data-driven farming, ultimately benefiting farmers and increasing agricultural efficiency.

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