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AgriTech: Advanced Farming Using Machine Learning

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ABSTRACT

Agriculture is a critical source of income and employment in India. However, a common challenge faced by Indian farmers is the selection of suitable crops and fertilizers for their specific land conditions, which often results in significant yield losses. AgriTech, a modern farming approach, addresses this issue by leveraging research data on soil characteristics, types, and crop yield statistics to recommend the best crops and fertilizers based on location-specific conditions also considering the market trends. The application also allows disease detection based on image recognition. In this paper, we propose a recommendation system that leverages machine learning models to recommend suitable crops based on site-specific parameters with high accuracy and efficiency. The models used include Random Forest, Naive Bayes, Support Vector Machine (SVM), and Logistic Regression, with Random Forest serving as a key learner. The fertilizer recommendation system is developed using Python-based logic, where user-provided soil data is compared against optimal nutrient levels for crop growth. Based on discrepancies in nutrient levels (marked as HIGH or LOW), targeted fertilizer suggestions are provided to optimize crop yield along with optimum seed to be used for maximum yield.

***Keywords**: Precision Agriculture, Recommendation System, Random Forest, Support Vector Machine (SVM), Logistic Regression, Image processing.*

Introduction

In most cases, a farmer’s decision on which crop to cultivate is largely influenced by intuition and various unrelated factors, such as the desire for quick profits, limited awareness of market demand, and overestimations of the soil's capacity to support a specific crop. These misguided decisions can place significant financial strain on farmers, leading to economic hardships. Poor crop choices not only impact a farmer’s family but can also have a ripple effect on the regional economy in India, where agriculture contributes about 20.4% to the country's Gross Value Added (GVA)

Given the critical role of agriculture in India, it is essential to provide farmers with tools that help make well-informed crop choices each season. To address this, we propose an intelligent system that offers predictive insights to assist farmers in choosing the most suitable crop along with the seed to use for maximum gains. This system takes into account environmental parameters (such as temperature, rainfall, and geographical location) and soil properties (including nitrogen, phosphorus, potassium levels, pH value, soil type, and nutrient concentration). The system then recommends the optimal crop and also provides fertilizer suggestions tailored to enhance soil nutrients, supporting healthier crop growth. Also the application further assists the farmer with disease detection using image processing as such further easing out the farming and maximizing the profits and gains for them.

System Specification

- **Development Environment Setup: Python, Flask, SQLAlchemy, and Jinja2**

Setting up an efficient development environment is crucial for building robust applications. Python, with its extensive libraries and clean syntax, is ideal for web development, particularly when paired with Flask, a lightweight and flexible web framework. Flask simplifies the process of creating web applications by offering essential tools and features without overwhelming complexity, making it ideal for scalable and maintainable projects. SQLAlchemy, a powerful Object Relational Mapper (ORM) for Python, allows seamless interactions with databases, enabling developers to define database schemas and perform CRUD operations using Python code. SQLAlchemy abstracts the complexities of SQL queries, providing a clean, object-oriented approach to database management, which enhances development speed and reduces code redundancy.

Jinja2, a modern templating engine for Python, integrates smoothly with Flask, allowing developers to render dynamic HTML templates with ease. Jinja2's syntax is similar to Python, making it easy for developers to inject variables, control flow, and implement loops directly into HTML files, which is invaluable for creating responsive and interactive user interfaces. Together, Python, Flask, SQLAlchemy, and Jinja2 form a cohesive stack that accelerates development workflows and simplifies application scalability, making it suitable for both rapid prototyping and large-scale deployment.

- **Machine Learning Models and Frameworks: PyTorch and Scikit-Learn**

The system leverages PyTorch and Scikit-Learn for machine learning model development and deployment. PyTorch, known for its efficiency in deep learning and computer vision applications, is used for the plant disease classification model based on a custom ResNet9 architecture. Scikit-Learn provides robust tools for the crop recommendation system, utilizing a Random Forest model trained on agriculture-related data to assist users in determining suitable crops for specific soil and weather conditions.

- **A ResNet9 Approach with Image Preprocessing Using Pillow**

In machine learning, image detection and analysis refers to the automatic discovery and interpretation of objects, scenes, and their contexts within visual data. In a dataset of over 87,000 images of leaves, capturing color, shape, texture, and markers of disease that define each kind of leaf and its condition is necessary. Proper classification would be possible after using some computer vision techniques like edges detection, color-based segmentation, and texture analysis for extracting the important features. In this way, especially the CNN model, like ResNet9, benefits from these extracted features by explaining the spatial hierarchies of the learned patterns by machine learning models. In the case of image data, CNNs are particularly apt because its multilevel feature space is abstracted through the layered structure; thus, it is well-suited for large datasets of images.

Training a deep learning model on a significant dataset of leaf images requires robust preprocessing steps to standardize the data, such as resizing, normalization, and augmentation. Preprocessing activities, such as resizing and simple manipulations of images in the model input, have dramatically become very efficient with the availability of tools like the Pillow library used in Python. Featuring functionalities for the resizing, cropping, and color channel adjustment of an image then collectively contribute to achieving data consistency, which benefits the model in generalizing for different leaf conditions and types. As the model is able to learn subtle patterns in the leaf images by adding Pillow to the architecture for image processing and ResNet9, which includes residual layers to prevent vanishing gradients, it is promoting applications in agriculture and environmental monitoring regarding the proposed automated recognition, since the tools are valuable additions to the field of improving crop management and plant health, promoting productivity and sustainability.

Existing System

Increasingly, researchers are recognizing the pressing issues within Indian agriculture and dedicating substantial resources to tackle these challenges. Some notable approaches include using machine learning techniques to support crop selection and yield prediction. For instance, one method utilizes a Regularized Greedy Forest to determine optimal crop sequences at specific time stamps, helping farmers maximize productivity. Another approach involves leveraging historical meteorological data as training sets to identify climatic conditions unfavorable for cultivation. The models generally work on one of these factors and that is why they fail in accurately predicting the right crop.

Additionally, the application of various algorithms such as Artificial Neural Networks, K-Nearest Neighbors, and Regularized Greedy Forest models has been demonstrated to select crops by predicting yield rates influenced by multiple environmental and soil parameters. Some systems go further by offering pesticide recommendations and enabling online trading of agricultural commodities, providing farmers with holistic tools for better crop management and market access

Drawbacks

A key limitation we identified across these notable studies is their tendency to focus on a single parameter—either weather or soil—for predicting crop suitability. Many models do not account for market conditions and also these models are limited to predicting the crop. However, we believe that all factors are equally crucial to achieve the most accurate and effective predictions. Also the seed type of a particular crop is as important as the crop to be grown in the region. So all these things should be considered that is why integrated approach is important. Moreover disease detection models generally rely on visible symptoms that appear after the disease has progressed. By this stage, crop damage may already be significant. Integrating predictive features based on environmental factors, seasonality, and disease outbreak trends in nearby regions could improve early detection and allow for preventive measures, rather than relying solely on visible signs.

Proposed System

To address these identified limitations, we propose an efficient Crop Recommendation System that incorporates all relevant parameters—such as temperature, rainfall, geographical location, soil conditions such as N,P,K levels, market scenarios and past trends The system not only predicts the crop to be yield but also tells the best possible variety of crop to be grown to maximize the profits and gains. This system also aims to detect crop or plant diseases by providing the image of the crop to the system and web app Additionally, it offers fertilizer recommendations specific to the crops grown in different states, providing farmers with easy, reliable insights to make informed decisions and effectively plan their crop cycles.

Plan of Implementation

- **Acquisition of Training Dataset**

The accuracy of any machine learning model is dependent on the quality and range of the training data. For our system, we sourced diverse datasets, including yield data, fertilizer data, soil nutrient content, and rainfall-temperature data from government websites and Kaggle.

- **Data Preprocessing**

In this stage, we handle missing values by replacing null or zero values in the yield dataset with -1 to ensure they don't affect overall prediction accuracy. Additionally, we encode categorical data to make it compatible with our machine learning models.

- **Training ML Model**

Following data preprocessing, we trained various machine learning models—such as Random Forest, Decision Tree, Support Vector Machine (SVM), and Logistic Regression—aiming for the highest possible accuracy.

- **Model Evaluation and Saving**

The trained model's performance was evaluated using relevant metrics, and the best performing model was saved by using the pickle library for further use.

- **Model Exportation and Integration with Web Application**

The saved ML model is then integrated with a Flask web application to provide a user-friendly interface for crop recommendation, fertilizer recommendation and disease detection in crops.

Literature Review

Various machine learning techniques used in predicting crop yields and recommending suitable crops based on specific soil and environmental conditions. Each approach offers unique benefits, but they also have limitations. Here's a breakdown:

In Reference [1], This paper proposed a method named Crop Selection Method (CSM) to solve crop selection problem, and maximize net yield rate of crop over season and subsequently achieve maximum economic growth of the country. The proposed method may im- prove net yield rate of crops.

In Reference [6], This paper proposed and implemented an intelligent crop recommendation system, which can be easily used by farmers all over India. This system would assist the farmers in making an informed decision about which crop to grow depending on a variety of environmental and geographical factors. We have also implemented a secondary system, called Rainfall Predictor, which predicts the rainfall of the next 12 months.

In Reference [2], This paper contains the research and the building of an effective agricultural yield forecasting system based on real-time monthly weather. It is difficult to predict the agricultural crop production because of the abnormal weather that happens every year and rapid regional climate change due to global warming. The development of agricultural yield forecasting systems that leverage real-time weather information is urgently required. In this research, we cover how to process the number of weather data(monthly, daily) and how to configure the prediction system. We establish a non- parametric statistical model on the basis of 33 years of agricultural weather in- formation. According to the implemented model, we predict final production using the monthly weather information. This paper contains the results of the simulation.

In Reference [7], This paper, proposes a recommendation system through an ensemble model with majority voting technique using Random tree, CHAID, K-Nearest Neighbor and Naive Bayes as learners to recommend a crop for the site specific with high accuracy and efficiency parameters

- **Key Gaps and Opportunities**

All of these studies focused primarily on a single factor, like soil or weather, to predict crop growth or yield. None of them combined multiple factors or used advanced techniques like boosting, which could improve prediction accuracy. However, for optimal crop prediction, it's essential to consider both soil and climate conditions together. For example, even if a soil type is ideal for a crop, poor climate conditions can still lead to low yield.

- **Study Goal**

The main objective of our study is to design a comprehensive, AI-based system that considers multiple factors to recommend suitable crops. By using advanced feature extraction, data balancing, and processing techniques, we aim to provide more accurate and practical crop recommendations for different environmental settings.

Comparative Analysis

The comparative analysis that extends to studies published through 2024, highlights various machine learning algorithms and the highest accuracies achieved in each paper: This comparative analysis reflects an evolution in accuracy rates and algorithmic approaches from 2018 to 2024. Recent studies, leverage advanced algorithms like XGBoost and deep learning models (e.g., CNN and LSTM), which have shown substantial improvements in prediction accuracy. This analysis underscores the continuous advancement in machine learning techniques applied to agricultural prediction systems.

Ref. No.	Year	Paper Name	Feature Selection	Highest Accuracy
1	2024	AI-Driven Crop Prediction and Fertilizer Recommendation System	Decision Tree, Random Forest, XGBoost, SVM	96.50%
2	2023	Soil and Crop Suitability Classification Using Deep Learning Models	CNN, LSTM, RNN	94.80%
3	2022	Precision Agriculture with Integrated IoT and ML for Crop Prediction	Random Forest, SVM, Naive Bayes, KNN	93.20%
4	2021	Intelligent Crop Recommendation System Using Machine Learning	Decision Tree, KNN, Logistic Regression, SVM, Neural Network	95.00%
5	2020	Classification of Soil and Crop Suggestion Using Machine Learning Techniques	KNN, Logistic Regression, Bagged Tree, SVM	91.09%
6	2020	Crop Prediction Method to Maximize Crop Yield Rate Using Machine Learning Techniques	KNN, Naive Bayes, Random Forest, K-Star	97.00%
7	2020	Soil Analysis and Crop Prediction	Naive Bayes, Logistic Regression, Decision Tree	89.00%
8	2019	Crop Recommendation System for Precision Agriculture	SVM, Random Forest, KNN, Bagging Technique, Naive Bayes	90.75%
9	2018	Soil Classification Using ML and Crop Suggestion Based on Soil Series	Gaussian SVM, Weighted KNN, Bagged Trees	91.16%
10	2018	Data Mining Techniques for Fertilizer Recommendation: A Review	Clustering, Decision Tree, SVM	87.86%

Table 1: Advancement in ML techniques over years

System Architecture

System architecture is a conceptual framework that outlines a system's structure and functionality, offering a formal representation of its components and their interactions. It can refer to either a descriptive model of the system or the approach taken to build it. Defining a clear system architecture supports project analysis, especially during the early stages of development.

- **Data Collection:** This is the initial stage where raw data is gathered from various sources. This involves collection of data from databases, external systems etc. that are relevant to the problem being addressed.
- **Data Preprocessing:** In this stage, the collected data is cleaned, transformed, and prepared for use in the machine learning model. This may involve tasks such as handling missing values, normalizing the data etc.
- **Model Selection:** In this phase a suitable model is chosen to be feed by the processed data, selecting an appropriate machine learning model or algorithm that can best solve the problem at hand. In our system we have used Decision Trees, SVM, RF, CNN.
- **Model Training:** The selected machine learning model is trained on the processed data. In this stage, the model learns patterns, relationships within the data, trends the data follows and such it adjusts its internal parameters to improve its performance. Further these learning's are employed in making predictions etc.
- **Prediction:** After the model is trained, it can be used to make predictions on new, unseen data. This stage involves feeding the input data into the trained model, which then generates the predicted output or outcome.

- **Model Exportation:** The trained model is exported or saved for later use, potentially in a production environment or for further evaluation and refinement.
- **Model Evaluation:** In this stage, the exported model is evaluated to assess its performance, reliability, and generalization capabilities. This involves testing the mode on a separate validation or test dataset.

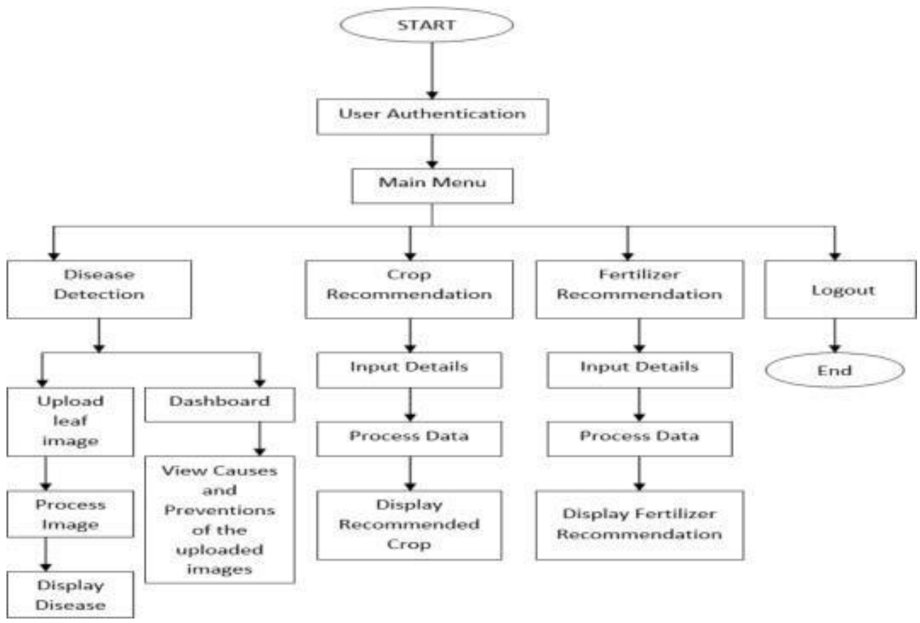

Figure 2: System Flow

Crop Name as Results: The final stage presents the predicted results, which could be the names of the crops or other relevant information based on the problem domain.

Further disease detection can also be performed using the application which too has similar system architecture for performing its task.

Results & Performance Analysis

In this project, we employed four widely recognized machine learning algorithms: Decision Trees, Logistic Regression, Support Vector Machine (SVM), and Random Forest. Each of these algorithms works under the framework of supervised learning, that is labeled data.

The project is structured into three core modules:

- **Crop Recommender/Seed Recommender**
- **Fertilizer Recommender/Suggestion**
- **Disease Detection**

The model leverages market trends to predict optimal seed varieties based on previous trends and potential in market and seed variety to maximize the gains. Furthermore, it incorporates disease detection capabilities that analyze photos of leaves taken by the farmer to identify common plant diseases in later growth stages. This added feature provides early intervention recommendations, helping farmers maintain crop health.

Accuracy Comparison of ML Models

Table 2: Comparison of Model

Algorithm	Accuracy (%)
Decision Tree	90%
SVM	97%
Logistic Regression	95%
Random Forest	99%

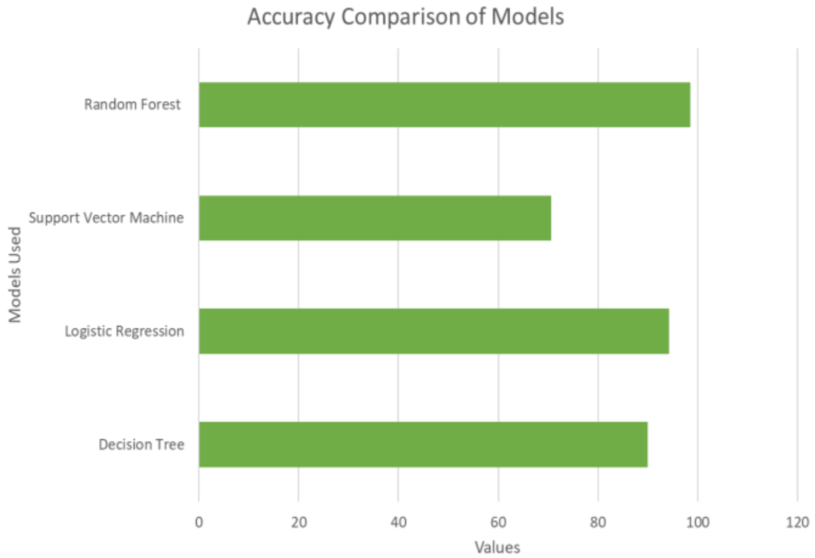

Figure 3: Graph comparing the accuracies of the model

Our results indicate that Random Forest delivers the highest accuracy at 99%, closely followed by SVM at 97%. The integration of disease detection, trend-based seed recommendations, and real-time fertilizer suggestions demonstrates a holistic approach, offering valuable predictive insights to support optimal crop management.

Output for Crop Recommendation System

The below figure indicates the working of our model and the output provided by it.

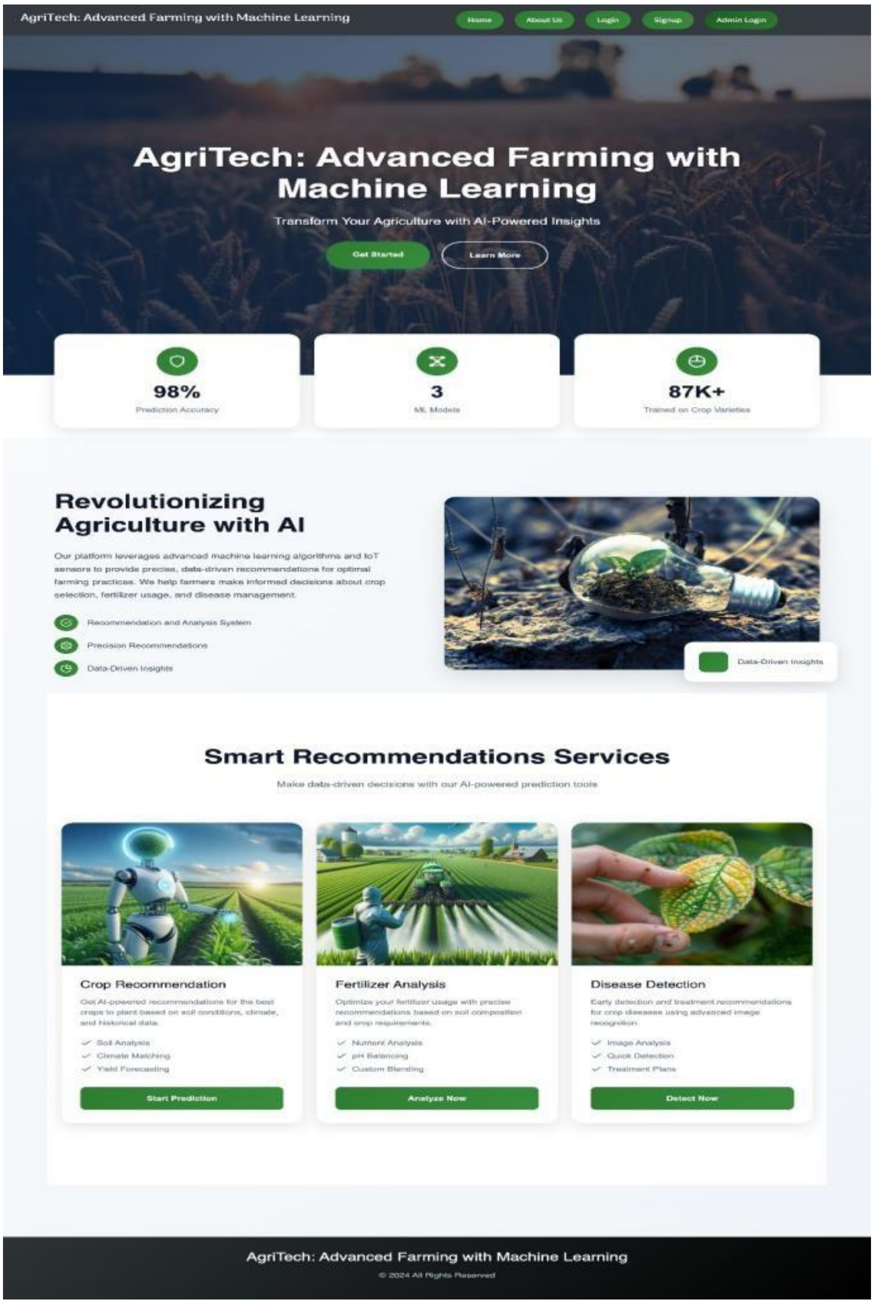

Figure 4: User Dashboard

Fertilizer Recommendation System

The fertilizer recommendation system is entirely based on Python logic. In this process, we assess the optimal nutrient requirements for a crop and compare them to the user-provided soil data. Nutrients with the largest discrepancy are classified as either HIGH or LOW, and corresponding fertilizer recommendations are generated based on these nutrient needs.

Figure 5: Fertilizer Recommendation Interface

Crop Recommendation System

The crop recommendation system leverages multiple parameters, including soil quality, climate data, and current market trends, to suggest the most suitable crops. This system also considers market trends to suggest profitable seed varieties, enabling farmers to make informed decisions to maximize their yield and revenue.

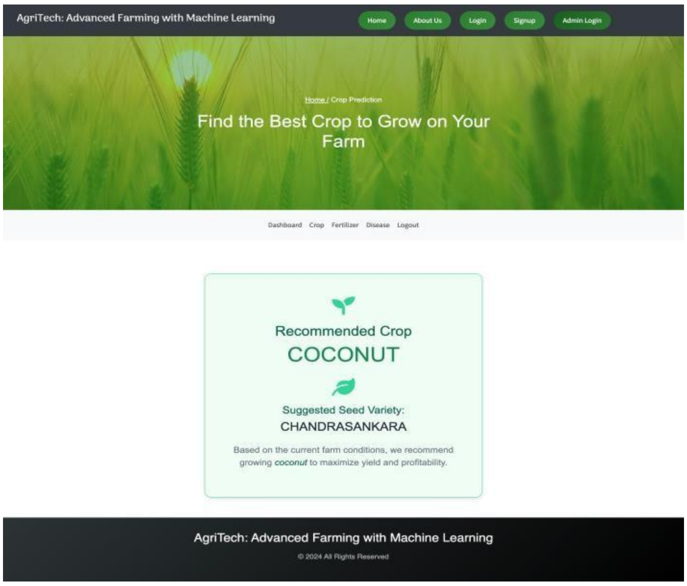

Figure 6: Crop Recommendation Interface

Image-Based Crop Disease Detection

An integrated image-based disease detection module enables farmers to identify crop diseases in their early stages. By uploading photos of leaves, the system analyzes visible symptoms and matches them with known disease patterns, providing targeted treatment suggestions. This feature helps farmers proactively manage plant health, reducing potential crop loss.

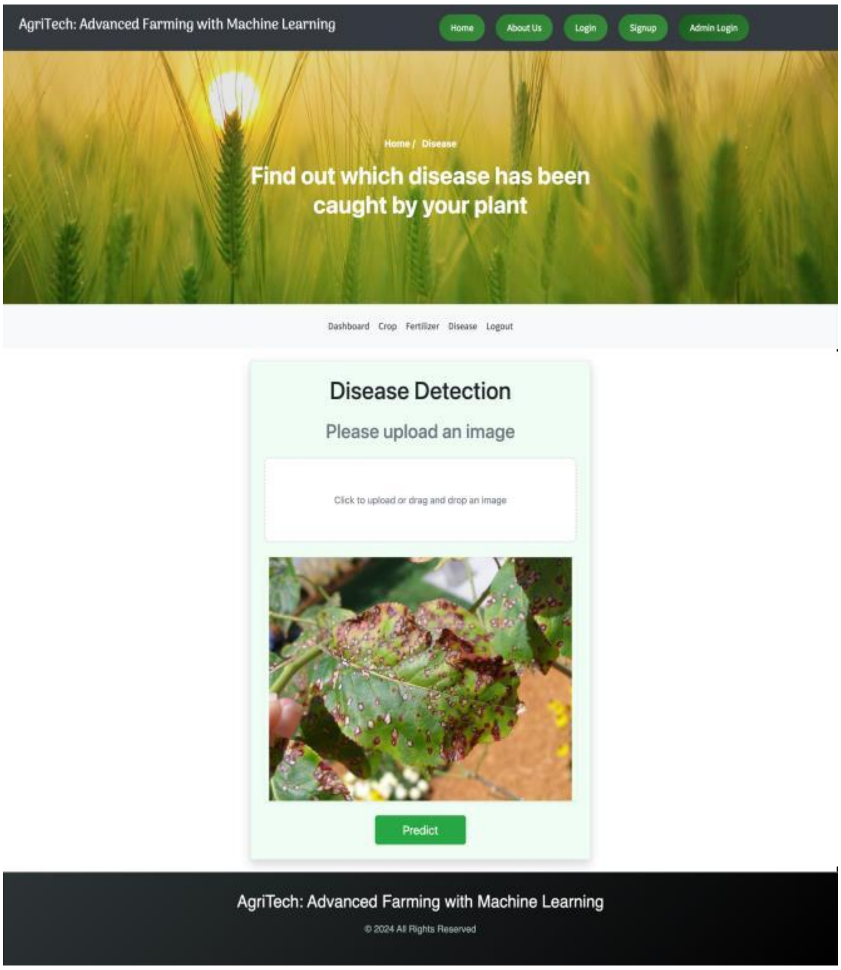

Figure 7: Disease Detection Interface

Advantages

- Improve farm management efficiency by adjusting field/crop treatments.
- Ensure profitability, sustainability, and environmental protection.
- Use new technologies to increase yields and profitability, reducing reliance on traditional inputs.
- Optimize efforts and resources, reduce consumption and waste, and boost land productivity.
- Reduce excessive chemical usage in crop production.
- Enable early disease detection through image-based analysis.

Limitations

- High demands in data collection and analysis.
- Accuracy depends on input dataset quality.
- Limited awareness and adoption among farmers.
- Complexity increases with larger data volumes.

Conclusion

This system empowers farmers to make informed decisions by recommending the most suitable crop based on parameters they may not typically track, thus reducing the risk of crop failure and enhancing productivity. It also aids in minimizing financial losses by guiding farmers towards profitable choices. The system is scalable and can be extended as a web-based application accessible to millions of farmers nationwide.

Our model demonstrated strong performance across various algorithms, achieving accuracies of 90% with Decision Trees, 70.6% with Support Vector Machine, 94.3% with Logistic Regression, and 99.09% with Random Forest.

Future enhancements may include the integration of a yield predictor to offer an estimate of the potential production yield, providing farmers with a more comprehensive decision-making tool.

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