International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

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Generative AI based Fertilizer and Pesticide Recommendation System for Farmers

G. Kalaiselvi [1, *], M. Nisha [2], M. Rudhra [2] and V. Shrivaishnavi [2]

[1] Assistant Professor, Department of Computer Science and Engineering, Anjalai Ammal Mahalingam Engineering College, Kovilvenni, Tamil Nadu, India.

[2] UG Student, Department of Computer Science and Engineering, Anjalai Ammal Mahalingam Engineering College, Kovilvenni, Tamil Nadu, India.

International Journal of Science and Research Archive, 2025, 15(02), 1536–1546

Publication history: Received on 19 April 2025; revised on 25 May 2025; accepted on 27 May 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.2.1498

Abstract

Agriculture is the backbone of the Indian economy, with 60% - 70% of the Indian people relying on agriculture for livelihood. Limited education and awareness hinder farmers from understanding the effects of improper fertilizer and pesticide use, leading them to heavily rely on agricultural experts. However, this expert advice often meets fewer of the farmer's specific needs, such as soil quality, weather conditions, or crop health. Due to the inadequate fulfillment of farmer's specific requirements from the experts, it results in inefficiencies, excessive use of fertilizers and pesticides, and harmful effects on the environment. With the aid of Generative Artificial Intelligence, the farmers get recommendation on fertilizers and pesticides for the crops and know which crops are best to grow on their land.

Generative AI based fertilizer and pesticide recommendation system generate the real-time prediction that analyzes environmental and soil factors like Nitrogen (N), pH, Organic Matter, Microbial activity which recommends the fertilizer by using XGBoost and pesticide recommendation based on the image analysis of the crop affected by pest using Inception V3. When providing inputs on the web interface, the system recommends, what fertilizer to be used and helpful for identification of the pest and prescribe the appropriate dosage of pesticide. Additionally, farmers can contact directly through the GPT-4o-mini service for quick help.

Keywords: Fertilizer Recommendation; Pest Detection; Pesticide Management Recommendation; Xgboost; Inception V3; AI Chatbot For Agriculture**.**

1. Introduction

Agriculture has always been at the forefront of human innovation, evolving continuously to meet the demands of growing populations and changing environmental conditions. One of the critical aspects of modern agricultural practices is the effective use of fertilizers . Fertilizers are essential for enhancing soil fertility and ensuring high crop yields. However, improper and excessive use of fertilizers can lead to several issues, including nutrient runoff, soil degradation, and environmental pollution. This necessitates the development of strategies that optimize fertilizer usage to achieve maximum crop productivity while minimizing negative environmental impacts. Traditional fertilizer management practices often rely on general guidelines that do not account for the specific needs of individual fields or crops. These conventional methods can lead to either under-fertilization or over-fertilization, both of which are harmful to crop health and environmental sustainability. Under-fertilization can result in poor crop yields and nutrient deficiencies, while over-fertilization can cause nutrient leaching, water contamination, and increased greenhouse gas emissions.

Generative AI-driven fertilizer optimization addresses these challenges by utilizing large datasets, including historical agricultural records, soil health indicators, crop performance data, and real-time environmental

* Corresponding author: G. Kalaiselvi

conditions. Machine learning algorithms can analyze these datasets to identify patterns and correlations that inform precise fertilizer application rates tailored to specific field conditions.

The AI-powered solution uses the XGBoost algorithm to predict soil fertility by analyzing important factors such as pH, nitrogen, phosphorus and potassium level. This allows farmers to understand their state of land and make informed decisions on necessary treatments.

The proposed model benefits from the InceptionV3 model to analyze crop images and detect signs of the disease. When an illness is detected, the system provides action rich recommendations on how to manage and recover from this problem, which are able to take timely measures for farmers to reduce losses and protect their crops. It also gives real-time tips on how to use fertilizers and pesticides in the best way, using the latest data. Farmers can get these suggestions easily through simple apps or chatbots using GPT-4o-mini, so they can make quick and smart decisions. Machine learning and deep learning, the smart agricultural assistant helps farmers reduce costs, improve crop health and promote more sustainable agricultural practices. It provides an effective way to handle fertilizers and pesticides in favour of both farmers and the environment.

The integration of Gen AI in fertilizer management offers several advantages:

- Informed Decision Making: AI systems can process huge amount of data and generate insights that are beyond human capabilities. This leads to more informed and accurate fertilizer recommendations.
- Environmental Sustainability: By optimizing fertilizer use, AI reduces the risk of nutrient runoff and soil degradation, contributing to environmental conservation efforts.
- Cost Efficiency: Accuracy in fertilizer application translates to cost savings for farmers, as it reduces waste and ensures that resources are used effectively.

Generative AI-based web application designed to support farmers with real-time fertilizer and pesticide recommendation. These can be done by integrating machine learning models such as XGBoost and Inception V3 with environmental and soil data. It also supports regional languages like Tamil to improve accessibility. Experimental results demonstrate that the Generative AI system increases crop yield, reducing fertilizer overuse, and promoting sustainable farming.

2. Literature Review

The Application of Smart Agriculture [1] enhanced the food security in the context of the global population's growth. It consider the use of deep learning in agriculture, particularly the application of CNN, RNN and SVM. Based on the analysis, Decision Tree performed most effectively in terms of accuracy for crop and fertilizer prediction. Time series based Random Forest algorithm [2] for the prediction of optimal nutrient requirements considering rainfall patterns and crop health. It consider soil type, crop growth and weather in order to optimally use fertilizer for increasing yield. Modern approaches for crop and fertilizer recommendations include pest management and soil health management [3]. Using mobile application or website, farmers can submit photo of their crops which are processed through CNN to detect the disease. Using data analytics and machine learning, proposed a system [4] that predicts seasonal fertilizer requirements by analyzing weather conditions, soil characteristics and crop yield data. The Leaf Color Chart(LCC) [5] which was developed by IRRI and PhilRice, assist farmers in using nitrogen effectively by indicating nitrogen status. Findings indicated that LCC adoption optimized fertilizer and pesticide applications while keeping crops healthy.

AI based approach for optimizing the fertilizer usage [6] by analyzing soil, crop and environmental data. It offers field-specific fertilizer recommendations, reducing usage and cost by the predictive model while improving crop yields. Smart farming [7] based on the technologies such as IoT, weather monitoring and robotics, is crucial to supply increasing global food needs sustainably. Understanding the current condition of agriculture and latest trends in technology are essential for a seamless transition into Agriculture 4.0. The machine learning based system [8] for personalized crop and fertilizer recommendations using regression and classification algorithms. It consider soil type, crop growth and weather in order to optimally use fertilizer for increasing yield. Machine learning [9] is transforming agriculture by combining ICT with conventional farming to implement smart and precision agriculture. Systems such as drones and autonomous vehicle improve precision in agricultural operations. Machine learning and deep learning models like SVM, Random Forest, VGG16 and ResNet50 [10] are highly accurate in detecting crop diseases. This research emphasizes the importance of well-balanced, high-quality datasets and robust evaluation metrics for successful real-word agriculture use.

A new approach for recommending pesticides and their application [11] based on the automation of crop disease detection through image classification. Using mobile application or website, farmers can submit photo of their crops which are processed through CNN to detect the disease. Soil Health Card scheme [12] which was introduced in 2015, assist farmers in managing the nutrients properly. This program is designed to increase crop yields while maintaining long-term soil health. AI technologies such as machine learning and deep learning [13] are being used increasingly to detect and predict plant diseases as a response to major agricultural challenges such as climate change. It offers insights into AI based solution and current research trends. AI and sensor technology for pest control, fertilizer application [14] in agriculture which use TPF - CNN for pest identification and soil NPK sensors for fertilizer recommendations. This system identifies the pests with 90% accuracy and delivers recommendations. Advancements in Agriculture [15] use the advanced technologies such as deep learning, drones and robotics for efficient plant disease detection in agriculture. Among the 198 studies examined from 2021 – 2023, particularly deep learning techniques, utilized the Plant Village dataset and show superior performance compared to other methods

3. System Architecture

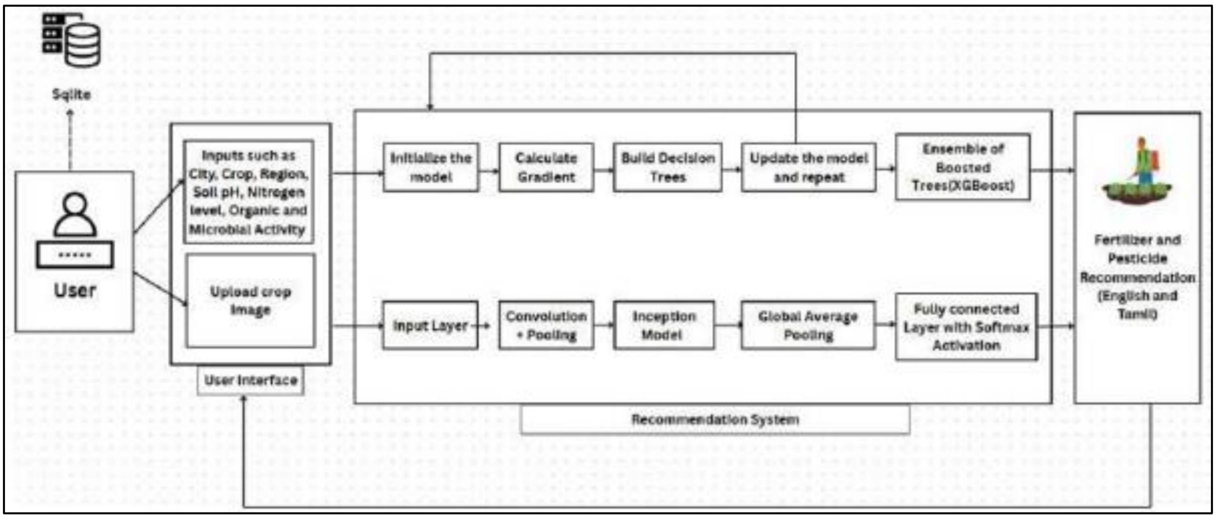

Figure 1 System Architecture

Figure 1 shows the system architecture of the proposed Generative AI-based fertilizer and pesticide recommendation system. It is a interactive web-application developed using the Flask framework, designed to assist farmers in making informed agricultural decisions. The system includes multiple integrated modules, all accessible after a simple user authentication process.

XGBoost is used as a core algorithm for fertilizer recommendation, which aims to predict the optimal type and fertilizer volume based on inputs such as crop types, soil NPK levels, pH, organic matter, microbial activity and location. XGBoost is ideal due to its high accuracy, speed and ability to handle structured, missing and unbalanced data. It works by building an ensemble of decision trees that learn from previous errors to improve predictions. Integrated in flask backend, trained model processes the user input through an API and gives actionable recommendations including fertilizer types, dosage and time, which is presented to the user through a favorable web interface. This ensures that farmers receive accurate, real -time guidance that increases yield, reduces waste, and supports sustainable farming practices.

Inception V3 is used in the Pest Detection Module to analyze images of crop leaves uploaded by farmers and accurately detect signs of pest affected or disease. When a farmer submits a crop image, It is preprocessed using libraries like OpenCV and PIL resized to 299x299 pixels, normalized, and formatted for the model. Inception V3 then extracts complex visual features through its inception modules, which apply multiple convolutional filters in parallel to capture lesions, color changes, and texture patterns. The model, fine-tuned on a agricultural dataset, classifies the image into predefined pest or disease categories and returns the predicted label, confidence score, and severity level. Based on the output, the system provides actionable recommendations such as pesticide type, dosage, method of application, and preventive measures. This trained model is deployed in the Flask backend, integrated through an API endpoint that processes uploaded images and returns results in real time to the frontend interface.

The module allows farmers to make quick, informed decisions, reducing crop loss, minimizing unnecessary pesticide use, and supporting sustainable farming practices through accurate and early pest detection.

Additionally, the system features a Bilingual Chatbot Module built on GPT-4o-mini, enabling Tamil and English communication via voice or text to answer user queries on agriculture, fertilizer, pest control, and weather. The backend also incorporates OpenCV for image preprocessing and integrates weather APIs like OpenWeatherMap for real-time environmental data, making the platform an intelligent and farmer-friendly decision support system.

4. Results and Discussion

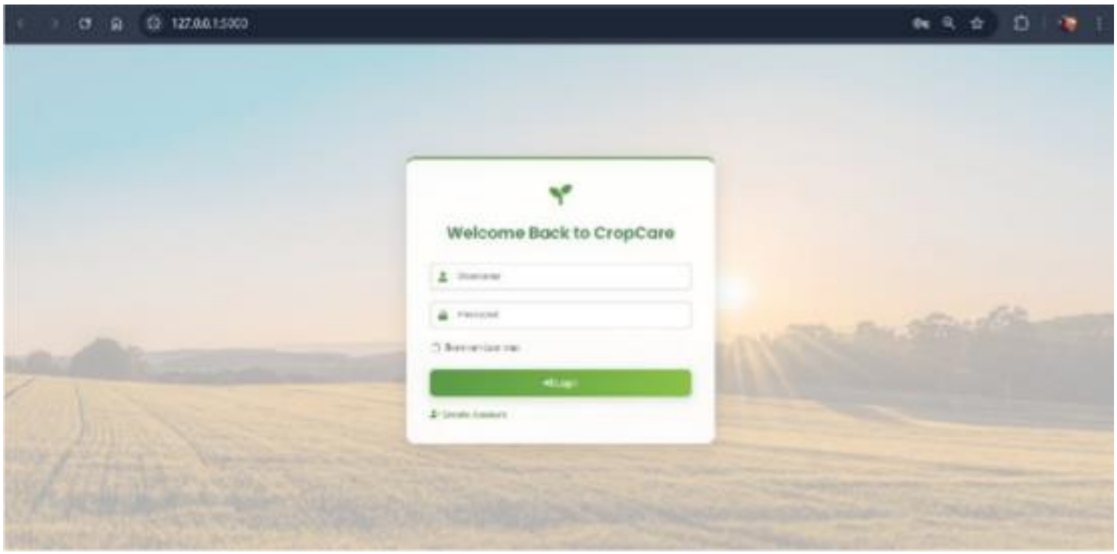

Figure 2 Login Page

Figure 2 shows the login screen of the fertilizer recommendation system. Farmers can log in using their username and password or create a new account. After login, they can access features like crop suggestion, fertilizer advice, pest detection, and chatbot support.

Figure 3 Home Page

Figure 3 shows the homepage of the application. It shows smart farming tools such as fertilizer recommendation, pest detection, and an AI-powered Agri Chatbot. The platform helps farmers improve productivity and take informed decisions using Generative AI technology.

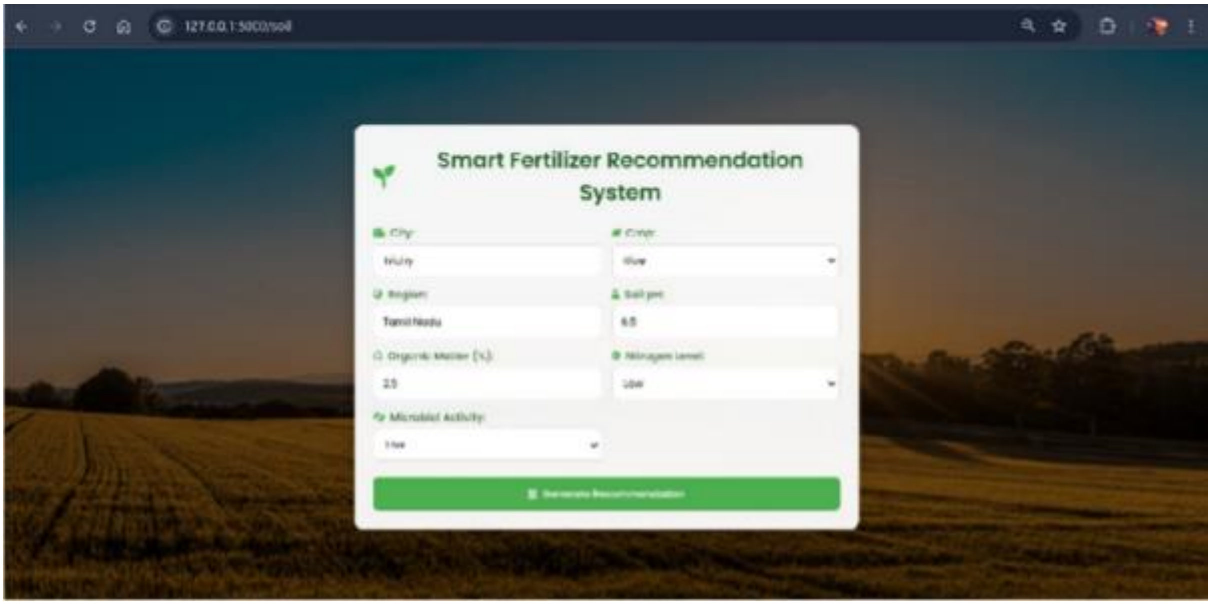

Figure 4 Smart Fertilizer Recommendation System

Figure 4 displays the user input form of the Fertilizer Recommendation System. Farmers can enter details such as city, region, crop type, soil pH, organic matter, nitrogen level, and microbial activity. It also provides an option to use a webcam to detect leaf color. Based on these inputs, the system utilizes the XGBoost algorithm to analyze the data and generates fertilizer recommendations.

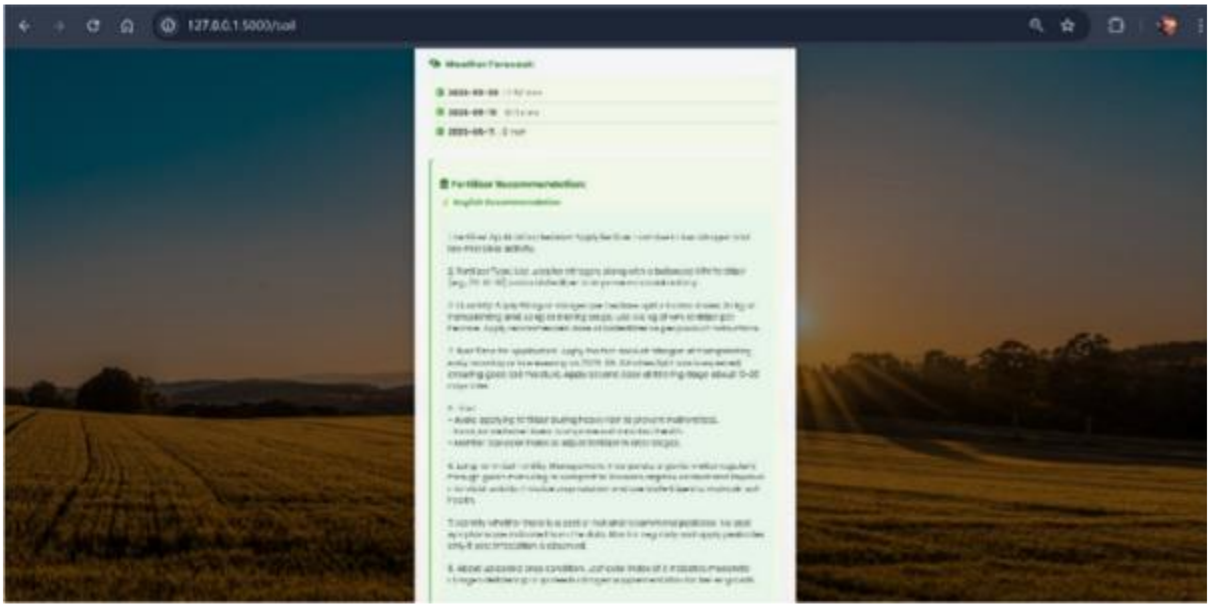

Figure 5 English Recommendation

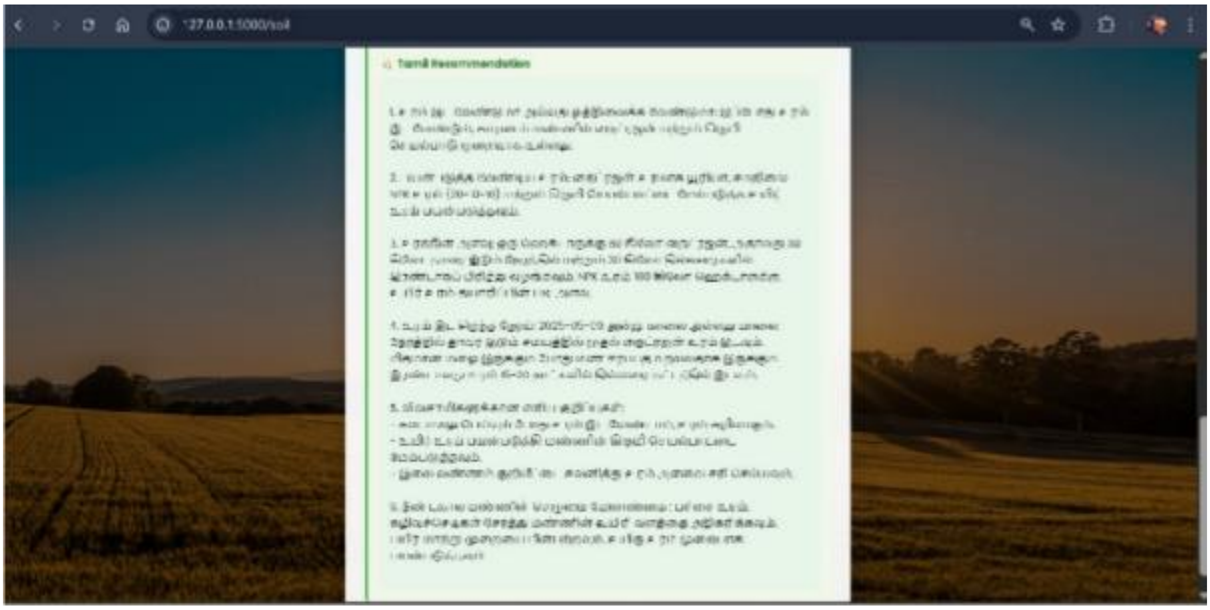

Figure 6 Tamil Recommendation

Figure 5 and 6 provides a detailed weather forecast and personalized fertilizer guidance based on upcoming rainfall and soil data. The recommendation includes the type, quantity, and timing of fertilizer application, along with tips for improving soil health. The recommendations are presented in both English and Tamil, enabling farmers to make informed decisions in their preferred language.

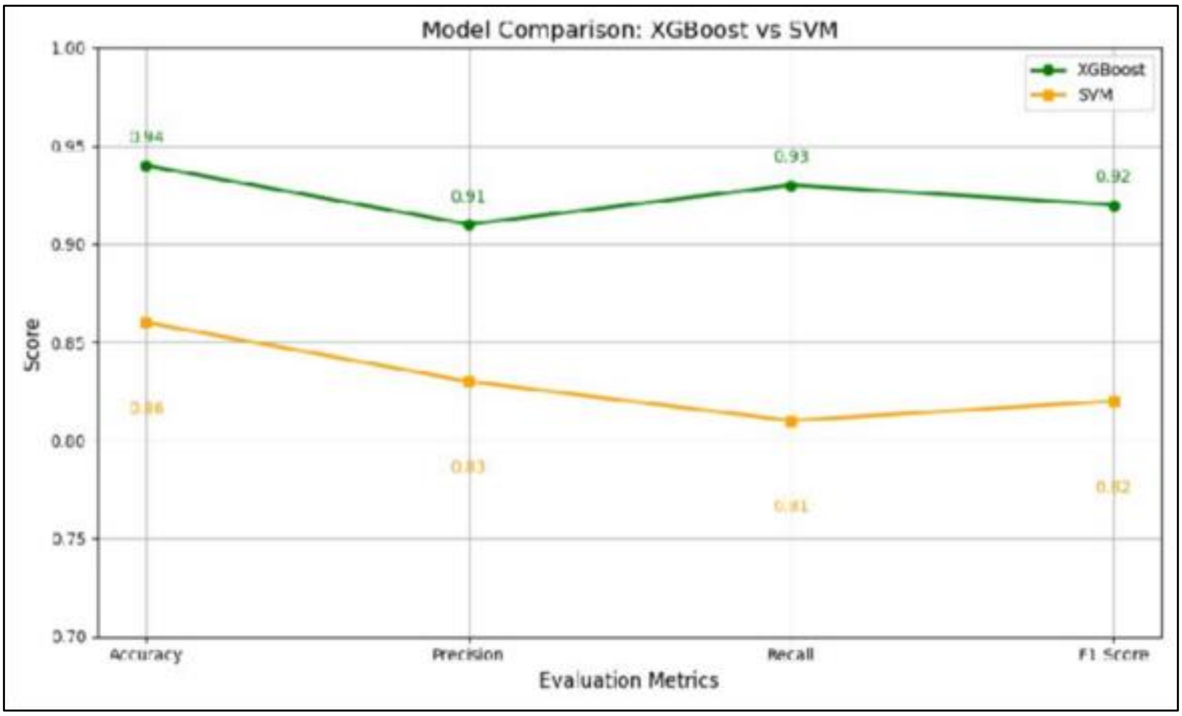

Figure 7 Model Comparison:XGBoost vs SVM

Figure 7 presents a comparative performance analysis between two machine learning models XGBoost and SVM based on four key evaluation metrics. In the context of our project, it is used to validate the selection of XGBoost for the Fertilizer Recommendation feature. The graph shows that XGBoost consistently better performance than SVM across all metrics, achieving an accuracy of 0.94 compared to 0.86 for SVM, a precision of 0.91 versus 0.83, a recall of 0.93 against 0.81, and an F1-score of 0.92 compared to 0.82. These results shows that XGBoost is not only more reliable overall but also better at correctly identifying the right fertilizer with fewer false positives and missed recommendations. High recall and Accuracy values are especially crucial for our use case, ensuring that fertilizer suggestions are accurate and actionable.

Table 1 Evaluation Metrics for Fertilizer Recommendation

Metric	XGBoost	SVM
Accuracy	0.94	0.86
Precision	0.91	0.83
Recall	0.93	0.81
F1 Score	0.92	0.82

Table 1 compares the performance of XGBoost and SVM using four key metrics to evaluate their effectiveness in the Fertilizer Recommendation feature. XGBoost clearly demonstrates stronger performance than SVM, achieving an accuracy of 0.94 compared to 0.86, a precision of 0.91 versus 0.83, a recall of 0.93 in contrast to 0.81, and an F1 score of 0.92 compared to 0.82.

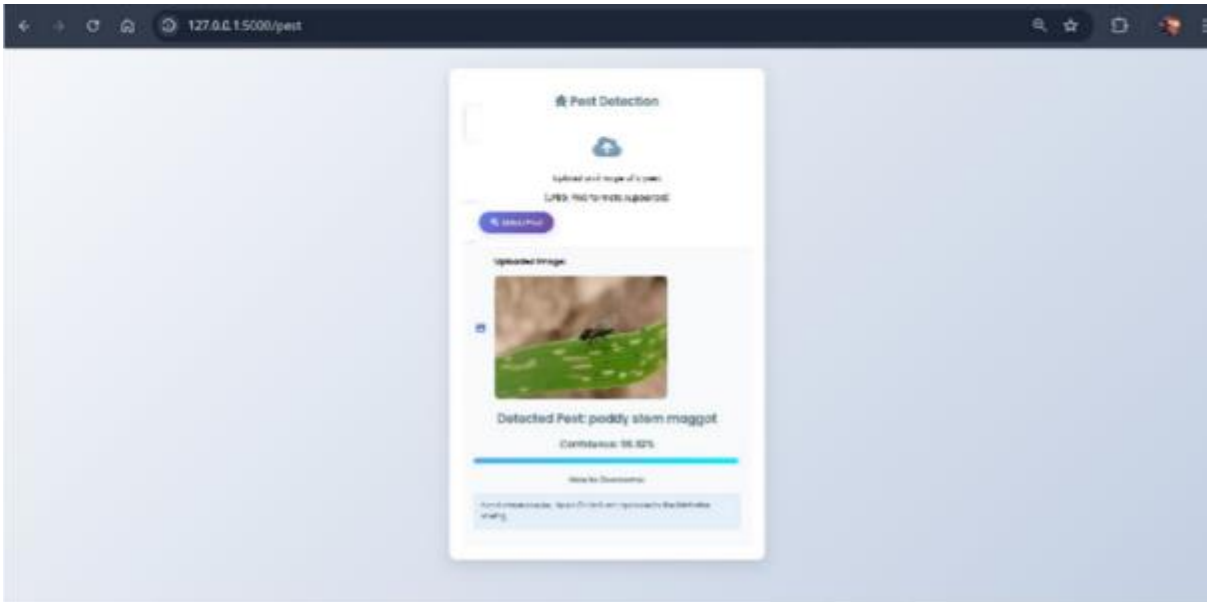

Figure 8 Pesticide Recommendation

Figure 8 illustrates the Pest Detection feature of the system. Users can upload a pest image(in JPEG or PNG format), which identifies the pest with high confidence. It also provides suitable control measures. The detection can be done by the InceptionV3 deep learning algorithm, ensuring accurate pest classification.

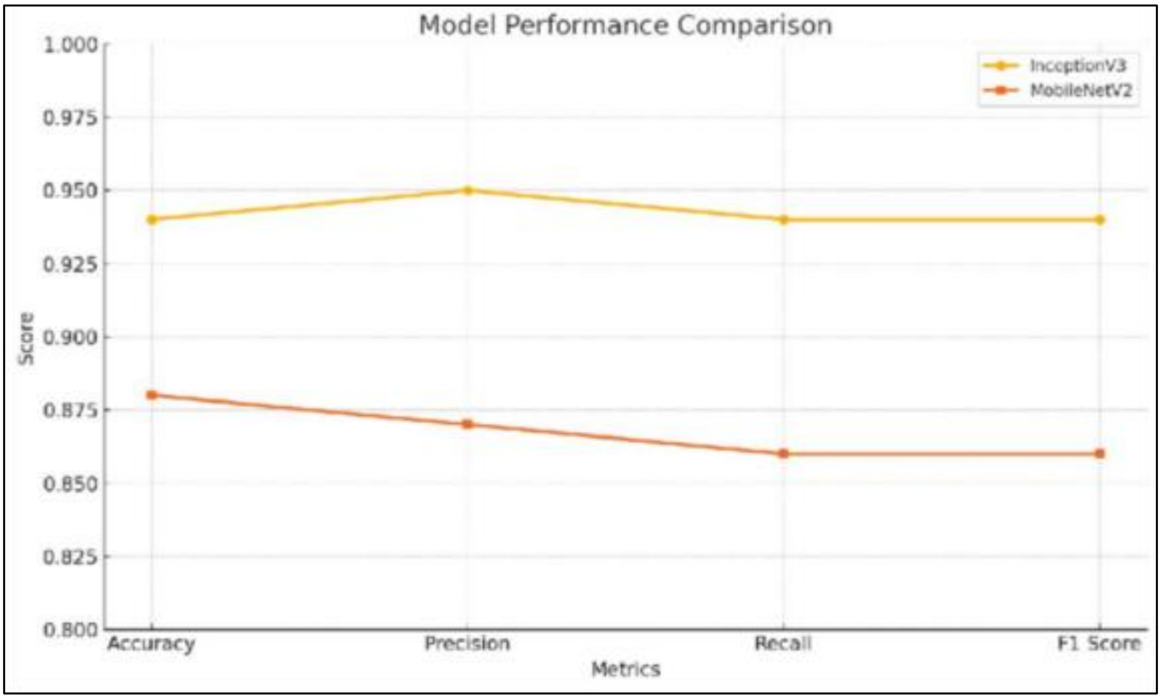

Figure 9 Model Comparison: Inception V3 vs MobileNetV2

Figure 9 visually compares the performance of InceptionV3 and MobileNetV2 models based on four evaluation metrics used in the Pest Detection Module. InceptionV3 consistently scores higher across all metrics, with the highest value in precision (0.95) and equally strong performance in accuracy, recall, and F1 score (around 0.93–0.94). In contrast, MobileNetV2 shows lower scores in each metric, with its best being accuracy at 0.88 and slightly declining performance across the remaining metrics. This comparison clearly shows that InceptionV3 is the more effective and reliable model for pest detection, offering better prediction accuracy and minimizing errors in our system.

Table 2 Evaluation Metrics for Pest Detection

Metric	Inception V3	Mobile Net V2
Accuracy	0.93	0.88
Precision	0.95	0.87
Recall	0.94	0.86
F1 Score	0.93	0.86

Table 2 represents the evaluation metrics for the Pest Detection feature, comparing the performance of Inception V3 and MobileNetV2. Inception V3 achieves higher scores across all metrics, with an accuracy of 0.93, precision of 0.95, recall of 0.94, and F1 score of 0.93, while MobileNetV2 scores lower in each category. These results indicate that Inception V3 is more effective at correctly identifying pest-infected crops, reducing false predictions and making it the preferred model for pest detection in our system.

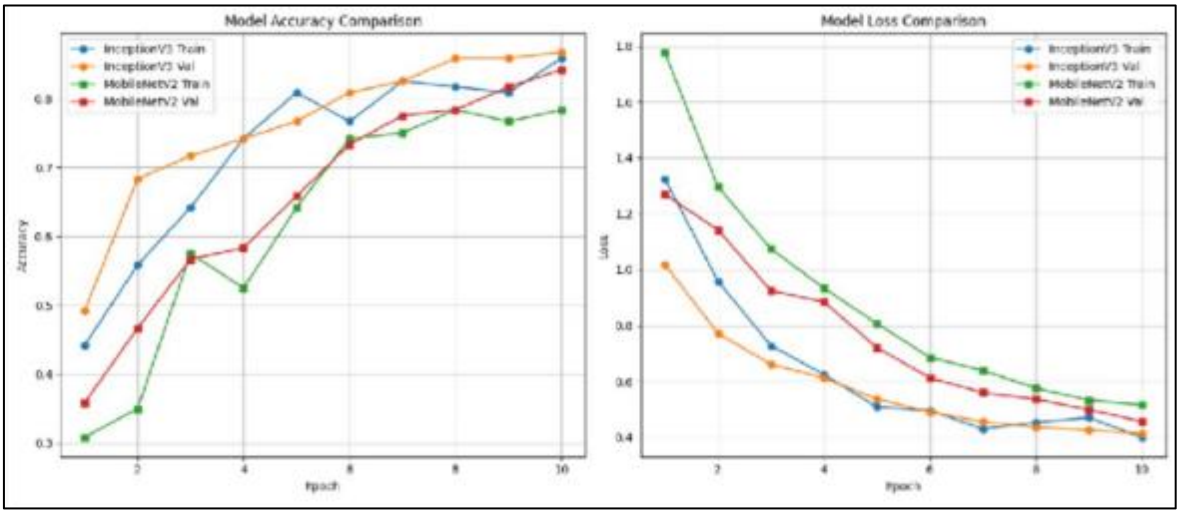

Figure 10 Performance Comparison of InceptionV3 and MobileNetV2 Models (Accuracy & Loss over Epochs)

Figure 10 shows comparison between two deep learning models InceptionV3 and MobileNetV2 used in Pest Detection feature, based on their training and validation performance over 10 epochs. The left graph compares model accuracy, where InceptionV3 consistently better performance than MobileNetV2, achieving a validation accuracy of approximately 0.86, while MobileNetV2 reaches only around 0.79. This indicates that InceptionV3 is more effective at correctly identifying pest-infected leaves. The right graph compares loss, which represents the models prediction error. InceptionV3 shows a steady decline in loss from around 1.0 to 0.4, while MobileNetV2 starts higher at 1.8 and reduces to about 0.5, which shows slower learning and higher error. These results ensure that InceptionV3 is better in both accuracy and efficiency, making it the correct choice for reliable and early pest detection in our system.

Table 3 Accuracy table for Pest Detection

Epoch	Inception V3 Train	InceptionV3 validation	MobileNet V2 Train	MobileNet V2 validation
1	0.44	0.49	0.31	0.36
2	0.56	0.68	0.35	0.47
3	0.65	0.71	0.58	0.57
4	0.74	0.73	0.53	0.58
5	0.81	0.74	0.65	0.66
6	0.76	0.81	0.74	0.74
7	0.83	0.83	0.75	0.77
8	0.82	0.86	0.78	0.78
9	0.81	0.86	0.76	0.82
10	0.84	0.87	0.78	0.85

Table 3 shows the training and validation accuracy over 10 epochs for two deep learning models, Inception V3 and MobileNet V2, used in the Pest Detection feature. Inception V3 consistently achieves higher accuracy throughout the training process, starting at 0.44 (train) and 0.49 (validation) in epoch 1 and reaching up to 0.84 (train) and 0.87 (validation) by epoch 10. In contrast, MobileNet V2 starts lower at 0.31 (train) and 0.36 (validation) and progresses to 0.78 (train) and 0.85 (validation) by the final epoch. These results shows that Inception V3 learns faster, generalizes better, making it the more accurate and better model for pest detection in our system.

Table 4 Loss table for Pest Detection

Epoch	Inception V3 Train	InceptionV3 validation	MobileNet V2 Train	MobileNet V2 validation
1	1.32	1.02	1.78	1.28
2	0.95	0.77	1.30	1.14
3	0.72	0.66	1.08	0.93
4	0.63	0.62	0.93	0.89
5	0.51	0.54	0.80	0.72
6	0.48	0.50	0.69	0.60
7	0.43	0.46	0.64	0.56
8	0.46	0.43	0.58	0.54
9	0.44	0.42	0.54	0.50
10	0.40	0.41	0.52	0.46

Table 4 represents the training and validation loss values over 10 epochs for Inception V3 and MobileNet V2 in the Pest Detection feature. Lower loss shows better model performance with few prediction errors. Inception V3 shows a correct and significant reduction in both training and validation loss, starting at 1.32 and 1.02 respectively in epoch 1, and decreasing to 0.40 (train) and 0.41 (validation) by epoch 10. In comparison, MobileNet V2 begins with higher loss values of 1.78 (train) and 1.28 (validation), and ends at 0.52 (train) and 0.46 (validation). These results suggest that Inception V3 not only learns quick but also maintains lower error rates, making it a more accurate and efficient model for pest detection in our system.

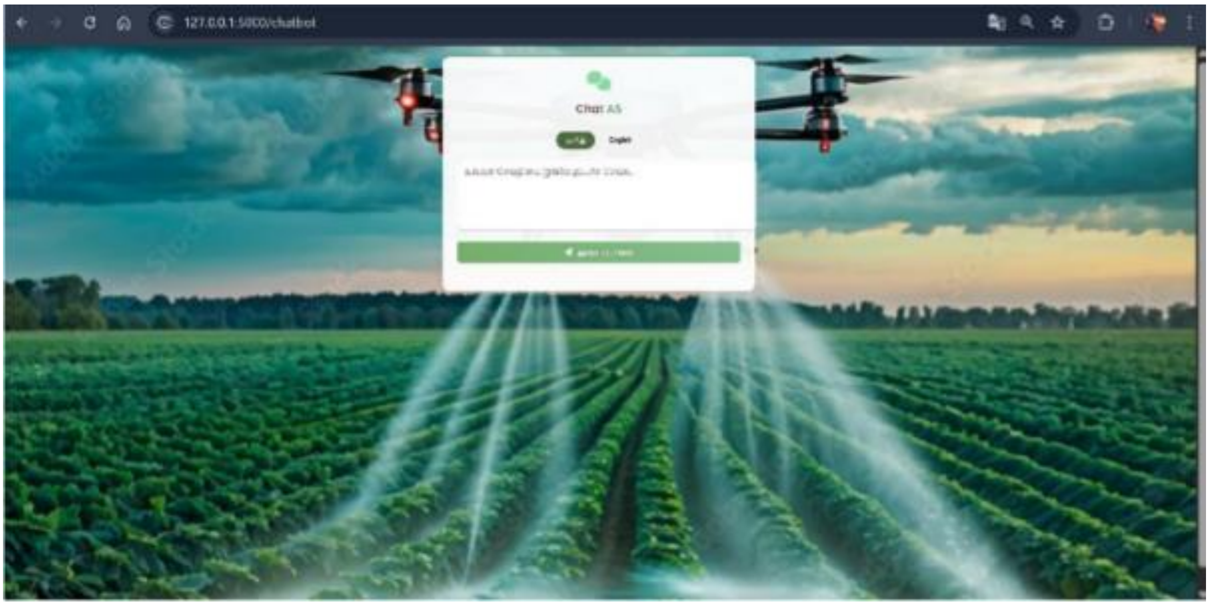

Figure 11 Agri Chatbot

Figure 11 illustrates the Agri Chatbot, designed to provide instant, intelligent support to farmers. The chatbot answers queries related to crop selection, fertilizer usage, pest management, and weather information in a user-friendly manner. It is powered by OpenAI's GPT-4o-mini model, enabling it to understand and respond accurately in both English and Tamil. This makes agricultural guidance more accessible and personalized for local farmers.

5. Conclusion

The Generative AI-Based Fertilizer and Pesticide Recommendation System offering real-time recommendations for soil health, fertilizer usage, and pest management. Additionally, the GPT-4o-mini chatbot, available in both English and

Tamil, offers farmers convenient access to personalized advice, enhancing their decision-making processes. By utilizing the XGBoost algorithm for accurate soil fertility predictions and the InceptionV3 algorithm for crop disease detection. When compared to Support Vector Algorithm, XGBoost gives higher accuracy, with an accuracy rate of 94%, and providing faster, more reliable predictions. Inception V3 outperforms MobileNetV2 by offering deeper network architecture and better feature extraction, achieving an accuracy 95% whereas standard MobileNetV2 achieves 88%. In the future, adding voice-based recommendations would make the system even easier. Developing a mobile application would also help farmers access these services at any time.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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