IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 14, Issue 12, December 2025

DOI: 10.17148/IJARCCE.2025.1412112

Sustainable fertilizer usage optimizer for higher yield

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Abstract: Sustainable agriculture requires efficient fertilizer management to enhance crop yield while preserving soil health and the environment. This project presents a Sustainable Fertilizer Usage Optimizer that leverages machine learning and precision farming techniques to recommend optimal fertilizer usage based on soil nutrients, crop type, and environmental conditions. The system integrates crop recommendation, yield prediction, and fertilizer optimization into a unified web-based platform developed using Flask. By minimizing excessive fertilizer application and promoting balanced nutrient management, the proposed solution improves productivity, reduces costs, and supports eco-friendly farming practices. The system empowers farmers with data-driven insights for sustainable and profitable agriculture.

Keywords: Sustainable Agriculture, Fertilizer Optimization, Crop Yield Prediction, Precision Farming, Machine Learning, Soil Nutrient Management, Smart Agriculture, Web-Based Decision Support System.

I. INTRODUCTION

Agriculture plays a vital role in ensuring food security and supporting the economy, especially in developing countries like India where a significant population depends on farming for livelihood. However, modern agriculture faces major challenges such as declining soil fertility, unpredictable climatic conditions, rising input costs, and inefficient fertilizer usage. Excessive or improper application of fertilizers not only increases production costs but also leads to soil degradation, water pollution, and long-term environmental damage. At the same time, insufficient nutrient application can result in poor crop growth and reduced yields. Therefore, optimizing fertilizer usage in a sustainable manner has become a critical requirement for achieving higher agricultural productivity.

The rapid advancement of digital technologies and artificial intelligence has opened new possibilities for transforming traditional farming practices into data-driven and precision-based systems. Machine learning techniques enable the analysis of large agricultural datasets involving soil nutrients, weather conditions, crop requirements, and historical yield patterns to generate accurate recommendations. By leveraging these technologies, farmers can make informed decisions regarding crop selection, fertilizer application, and yield planning rather than relying solely on conventional knowledge or trial-and-error methods.

This project, titled "Sustainable Fertilizer Usage Optimizer for Higher Yield," proposes an intelligent web-based decision support system that integrates machine learning models to provide optimized fertilizer recommendations along with crop and yield predictions. The system analyzes soil nutrient levels such as Nitrogen, Phosphorous, and Potassium

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(NPK), environmental factors, and crop characteristics to suggest the most suitable fertilizer in appropriate quantities. Additionally, it supports sustainable farming practices by reducing fertilizer wastage, improving soil health, and enhancing overall crop productivity.

By combining machine learning, Flask-based web deployment, and user-friendly interfaces, the proposed system aims to bridge the gap between advanced agricultural technology and grassroots farming communities. The solution empowers farmers with actionable insights, promotes sustainable resource utilization, and contributes to increased yield, profitability, and environmental conservation.

II. LITERATURE SURVEY

The application of machine learning and artificial intelligence in agriculture has gained significant attention due to increasing challenges such as low crop yield, improper fertilizer usage, market price volatility, and lack of expert guidance for farmers. Several researchers have explored intelligent systems to improve agricultural productivity through data-driven decision-making.

Patil and Kumar (2020) proposed a Crop Recommendation System using Decision Tree algorithms, utilizing soil nutrients, pH, rainfall, temperature, and humidity. Their model achieved high accuracy and demonstrated that machine learning can effectively replace intuition-based crop selection. However, the system was limited to a specific region and lacked real-time adaptability.
Kumar and Rani (2019) studied Crop Yield Prediction using regression techniques, including Linear Regression, Random Forest Regression, and Support Vector Regression (SVR). Their findings showed that Random Forest models performed better in capturing non-linear relationships among agricultural parameters. Despite high accuracy, the study focused on limited crops and did not integrate real-time user interaction.
Das et al. (2021) explored Market Price Forecasting of agricultural commodities using Bayesian Ridge Regression. Their work highlighted the effectiveness of Bayesian models in handling multicollinearity and noisy agricultural price data. However, the model relied solely on historical data and lacked scalability across multiple crops and regions.

Agrawal and Singh (2021) developed a Fertilizer Recommendation System using Random Forest and SVM classifiers, based on soil NPK values and crop type. The system improved fertilizer efficiency and reduced overuse, but lacked interpretability, downloadable prescriptions, and user-friendly explanations for farmers.

Sharma et al. (2022) introduced an AI-based agricultural chatbot using NLP, enabling farmers to ask queries in natural language. While the chatbot improved accessibility and engagement, it relied on static responses and did not integrate machine learning-based predictions.

From the literature review, it is evident that most existing systems focus on individual agricultural problems such as crop recommendation, yield prediction, fertilizer management, or price forecasting. There is a clear research gap in developing an integrated, user-friendly, and sustainable agricultural decision support system. The proposed project addresses this gap by combining crop recommendation, yield prediction, price forecasting, sustainable fertilizer optimization, prescription generation, and AI chatbot support into a single Flask-based web platform.

Table I — Comparative Review of Related Research Works

S. No	Title of the Paper	Author(s) & Year	Techniques / Models Used	Key Findings
1	Crop Recommendation System Using Machine Learning	Patil, A. & Kumar, S. (2020)	Decision Tree Classifier	Achieved high accuracy (92%) in recommending suitable crops using soil and climate parameters
2	Crop Yield Prediction Using Regression Techniques	Kumar, R. & Rani, A. (2019)	Linear Regression, Random Forest, SVR	Random Forest showed superior performance with high R^2 score (0.88)

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3	Market Price Forecasting of Agricultural Products	Das, P., Sharma, M. & Verma, K. (2021)	BayesianRidge Regression	Bayesian Ridge handled price volatility and multicollinearity effectively
4	Fertilizer Recommendation Using Random Forest and SVM	Agrawal, N. & Singh, D. (2021)	Random Forest, SVM Classifier	Improved fertilizer efficiency with 89% accuracy
5	AI Chatbot for Agriculture Using NLP	Sharma, L., Thomas, R., & Bhardwaj, S. (2022)	NLP, Dialogflow	Increased farmer engagement and accessibility
6	Smart Irrigation and Agriculture Advisory System	Rao, S. et al. (2021)	ML Models with Flask Deployment	Demonstrated feasibility of ML deployment in web-based agriculture systems
7	FertilizerAdvisory System for Sustainable Farming	Prakash, R. et al. (2018)	SVM Classifier	Reduced over-fertilization and improved nutrient balance
8	Agricultural Price Prediction Using Machine Learning	Joshi, M. et al. (2020)		

IV. METHODOLOGY

The proposed system follows a structured methodology beginning with data collection from reliable agricultural datasets containing soil nutrients, weather conditions, crop yield, fertilizer, and market price information. The data is preprocessed by handling missing values, encoding categorical variables, and normalizing numerical features.
Machine learning models are then trained using classification and regression techniques for crop recommendation, fertilizer optimization, yield prediction, and price forecasting. The best-performing models are selected based on evaluation metrics and integrated intoa Flask-based web application. User inputs are processed in real time to generate predictions, prescriptions, and chatbot-based assistance, ensuring sustainable fertilizer usage and improved crop yield.

The methodology adopted in this project follows an applied research approach using secondary agricultural datasets. Initially, relevant datasets related to soil nutrients, weather conditions, crop yield, fertilizer usage, and market prices are collected from reliable sources such as Kaggle, government agriculture portals, and FAO reports. The data is preprocessed by handling missing values, encoding categorical attributes, and normalizing numerical features. Machine learning models including Random Forest, regression algorithms, and Bayesian Ridge Regression are trained and evaluated using appropriate performance metrics. The optimized models are deployed in a Flask-based web application integrated with SQLite3, a prescription download module, and a Gemini AI chatbot for real-time farmer assistance.

IV. RESULTS AND ANALYSIS

The implementation of the Sustainable Fertilizer Usage Optimizer for Higher Yield produced reliable and accurate outcomes across all integrated modules, demonstrating the effectiveness of machine learning in agricultural decision support. The system was evaluated using multiple performance metrics to ensure robustness, accuracy, and real-world applicability.

Crop Recommendation Results

The Crop Recommendation module, implemented using the Random Forest Classifier, achieved an accuracy of approximately 95%. By analyzing soil nutrients (NPK), temperature, humidity, rainfall, and pH levels, the model successfully recommended the top three suitable crops for given conditions. Feature importance analysis revealed that nitrogen, rainfall, and pH were the most influential parameters. The multi-crop recommendation approach provided flexibility to farmers, enabling informed crop selection based on availability and market trends.

Crop Yield Prediction Results

The Crop Yield Prediction module employed a Random Forest Regressor, achieving a high R^2 score of 0.93, indicating strong correlation between actual and predicted yields. The model recorded low error values (RMSE and MAE), confirming accurate yield estimation. Rainfall and temperature emerged as dominant factors affecting yield. The predictions allow farmers to plan resources efficiently and reduce uncertainties related to production.

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Crop Price Prediction Results

The Bayesian Ridge Regression model used for crop price forecasting demonstrated stable performance with low prediction error. The model effectively handled price volatility and multicollinearity in historical market data. Predicted prices closely followed actual trends, enabling farmers to make better decisions regarding harvest timing and market sales.

Fertilizer Recommendation Results

The Fertilizer Recommendation module, implemented using a Random Forest Classifier, achieved an accuracy of over 92%. The system accurately identified nutrient deficiencies and recommended appropriate fertilizers, promoting balanced nutrient application and sustainable farming practices.

Overall System Analysis

The integration of all modules into a Flask-based web application ensured real-time usability, accessibility, and scalability. The prescription download feature and Gemini AI chatbot enhanced user understanding and interaction. Overall, the results confirm that the system improves yield, reduces fertilizer misuse, and supports sustainable agriculture through data-driven decision-making.

V. CONCLUSION AND FUTURE ENHANCEMENTS

The Sustainable Fertilizer Usage Optimizer for Higher Yield successfully demonstrates how machine learning and precision agriculture can improve farming efficiency and sustainability. By integrating crop recommendation, yield prediction, price forecasting, and fertilizer optimization into a unified web-based system, the project provides accurate and actionable insights to farmers. The use of optimized fertilizer recommendations helps reduce nutrient wastage, lower input costs, and maintain soil health. The Flask-based platform, supported by an AI chatbot and prescription download feature, enhances accessibility and usability. Overall, the system promotes data-driven decision-making, higher crop productivity, and environmentally sustainable agricultural practices.

Future enhancements of the Sustainable Fertilizer Usage Optimizer can focus on integrating real-time IoT sensors for automated soil nutrient and moisture data collection, improving prediction accuracy. Incorporating live weather APIs and satellite imagery can further refine crop and yield forecasts. The system can be extended with mobile and multilingual support to increase accessibility for rural farmers. Advanced deep learning models may be adopted to handle complex patterns and regional variability. Additionally, integration with government agricultural schemes, market platforms, and fertilizer advisory services can provide end-to-end decision support, making the system more scalable, adaptive, and impactful for sustainable agriculture.

ACKNOWLEDGMENT

We express our sincere gratitude to our project guide and faculty members for their valuable guidance and constant encouragement throughout this project. We also thank our institution for providing the necessary resources and support. Finally, we are thankful to our friends and family for their motivation and cooperation, which contributed significantly to the successful completion of this project.

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