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Fertilizer Recommendation for Agriculture using Machine Learning

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Abstract

Ineffective fertilizer use frequently reduces agricultural output by degrading soil, increasing expenses and producing less-than-ideal crop yields. Conventional fertilizer application techniques focus on broad guidelines and ignore particular soil and environmental circumstances, leading to deficiencies in nutrients and resource waste. This study suggests a machine learning-based fertilizer recommendation system that offers precise, data-driven recommendations based on specific agricultural conditions in order to address this problem. Utilizing exploratory data analysis (EDA) and processing techniques the system analyzes important variables like temperature, humidity, moisture, crop kind soil type and vital macronutrients like potassium, phosphorus and nitrogen to guarantee high-quality input. After testing several classifiers such as Random Forest (which overfits at 100%) and KNN (93.4%), a Decision Tree Classifier with an accuracy of 99.78% is used as the final model. Farmers can enter soil and environmental characteristics in real time to receive accurate fertilizer recommendations instantaneously thanks to the system's integration with a Streamlit-based user interface. This technology supports efficient and healthy farming by optimizing the use of fertilizers, increasing crop production, decreasing nutrient waste and encouraging sustainable agricultural practices.

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Introduction

In order to maximize crop productivity, fertilizer application is a critical component of agriculture, which is essential to global food security. However, using fertilizer incorrectly results in pollution of the environment, high expenses, and soil damage [1]. Farmers sometimes depend on conventional practices or broad guidelines that ignore particular soil types, crop needs and weather circumstances. Nutrient imbalances brought on by this carelessness lower farming methods' sustainability and productivity. Advanced technologies like Machine Learning (ML) are being investigated to give data-driven, intelligent solutions for fertilizer consumption optimization in order to address these issues.

Current systems for recommending fertilizer usually rely on predetermined rules or professional judgments, which might not always be appropriate for a range of soil and climate circumstances. Certain systems rely on rule-based methodologies or simple statistical models that are unable to adjust to the ever-changing environment [2]. Furthermore, choosing fertilizers by hand is inefficient and frequently results in either an excessive or insufficient application of nutrients, which has an impact on crop productivity and health. Although technology and smart farming solutions have been introduced in recent years many of them lack high precision, real-time flexibility and user-friendly interfaces that would allow farmers to make well-informed decisions based on weather and soil conditions.

By creating a machine learning-based fertilizer recommendation system, this research aims to close the gap between traditional farming methods and contemporary technological developments. This method can evaluate a variety of environmental factors including soil type, temperature, humidity and nutrient content by utilizing Decision Tree Classification to generate precise and personalized fertilizer recommendations. Farmers may enter real-time data and get accurate recommendations instantaneously thanks to the integration of a Streamlit-based user interface. This promotes effective resource use, lowers fertilizer waste, and increases agricultural output overall. By providing farmers with data-driven insights this project seeks to increase crop productivity and advance sustainable farming methods [3].

Related Work

This section provides a review of existing approaches, highlighting their advantages and limitations.

Musanase *et al*. proposes [4] a combined crop and fertilizer suggestion system for Rwandan agricultural that optimizes practices. The system makes individualized fertilizer recommendations using a rule-based methodology and predicts crop growth characteristics using a neural network model. By fusing computational intelligence and domain expertise the system achieves 97% accuracy, significantly advancing precision agriculture.

Khan *et al*. through IoT-assisted fertility of the soil mapping, the study suggests a machine learning-based fertilizer prescription methodology that takes into account the current soil fertility situation [5]. By taking into account the current context of crop kind, soil fertility levels, and soil type, this method increases the precision of the fertilizer system of recommendations. To evaluate the accuracy of IoT-assisted fertility mapping, the technique is applied in actual agricultural areas. Gaussian Naïve Bayes, K-Nearest Neighbor, Support Vector Machine and Logistic Regression are among the machine learning algorithms whose performance is assessed; the GNB model yields the most accurate findings.

Thorat *et al*. in order to control excess fertilizer and pesticides in agriculture [6], this research proposes a dual operator strategy that uses a Convolution Neural Network (CNN) and Transition Probability Function (TPF). The system uses a soil NPK sensor to analyze soil nutrients and combines machine vision and CNN for pest detection and insecticide recommendation. For insecticide and fertilizer recommendations, the approach produces on-the-spot findings in 10 and 80 seconds, respectively. With an accuracy of above 90%, the system performs better than other clever techniques.

Proposed Method

By offering precise, data-driven fertilizer recommendations the suggested methodology aims to create a machine learning-based fertilizer suggestion system that maximizes agricultural productivity. Data gathering is the first step in the process which includes important agricultural parameters including temperature, humidity, wetness, crop type, soil type and vital macronutrients (potassium, phosphorus, and nitrogen). The data is subjected to preparation methods, such as standardization using standard scaler and handling missing values as well as exploratory data analysis (EDA). To provide a strong model evaluation the dataset is divided into 80% training and 20% testing. After testing several machine learning models, the Decision Tree Classifier was chosen as the final model because of its excellent accuracy and generalization capacity with an accuracy of 99.78%. Other models are also assessed including KNN (93.4% accuracy) and Random Forest (100% accuracy, although overfits). In order to improve crop output and encourage sustainable farming methods the system is finally incorporated into a streamlit-based interface which allows farmers to enter current agricultural circumstances and receive accurate fertilizer recommendations.

- **Developing an intelligent fertilizer recommendation System:** Create a system based on machine learning that evaluates a variety of soil and environmental factors to offer precise, data-driven suggestions for fertilizer for various crops and soil types.
- **Enhancing agricultural productivity with machine Learning:** Optimize fertilizer application using Decision Tree Classifiers and other models to maximize crop yields and improve resource efficiency.
- **Improving data preprocessing and feature engineering:** To guarantee high-quality data for efficient model training, use standard scaler for feature scaling, exploratory data analysis (EDA), missing value management and categorical encoding.
- **Comparative analysis of machine learning models:** To find the best model for fertilizer recommendation, compare several classification algorithms such as Decision Tree, Random Forest and KNN.
- **Building a real-time user interface for farmers:** Provide a user interface (UI) based on Streamlit that enables farmers to enter current environmental and soil parameters and get immediate, customized fertilizer recommendations.
- **Ensuring sustainable and eco-friendly farming practices:** Reduce fertilizer waste and environmental damage by suggesting the right amounts of fertilizer and avoiding abuse, which can degrade soil health.

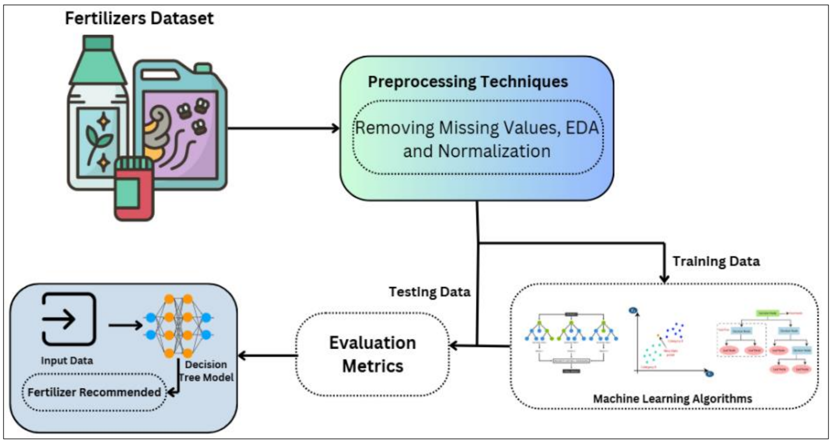

Fig 1: Architecture of Fertilizer Recommendation System using Machine Learning

Decision tree classifier:
A supervised learning technique called the Decision Tree Classifier creates a tree-like structure by iteratively dividing the dataset into smaller subsets according to feature requirements [7]. It manages both categorical and numerical information effectively and is quite interpretable. It was selected as the final model for this project because of its 99.78% accuracy, which balanced generalization and performance. Using learnt decision rules, the model efficiently evaluates environmental and soil characteristics to select the optimal fertilizer.

Random forest classifier:
In order to increase accuracy and decrease overfitting, the Random Forest Classifier is a method of ensemble learning that constructs several decision trees and averages their predictions [8]. It was discovered to be overfitting that is, it memorized the data rather than extrapolating well to unknown inputs despite achieving 100% accuracy on the training and testing datasets. In spite of this, it is still a strong and reliable classifier that provides excellent accuracy in challenging classification tasks, which makes it helpful when overfitting can be managed.

K-Nearest Neighbors (KNN) classifier:
A non-parametric in instance-based learning technique called the KNN Classifier uses the majority class of its K-nearest neighbors in the feature space to categorize new data points [9]. Its accuracy of 93.4% showed a great capacity to generalize without overfitting, although being lower than that of Decision Tree and Random Forest. KNN is less effective than tree-based models in this application [10] because it needs to compute distances for each new prediction which makes it computationally costly for large datasets.

Results and Discussion
The accuracy, generalizability and appropriateness of machine-learning algorithms for real-time suggestions for fertilizers were used to assess their performance [10]. With an accuracy of 99.78%, the Decision Tree Classifier was the best-performing model and was ultimately selected for deployment. By effectively learning decisions from environmental and soil-related data, this model showed great classification capabilities and ensured high precision in recommending fertilizers. Although the Random Forest Classifier achieved 100% accuracy, it showed overfitting, which means that instead of generalizing to unknown inputs, it memorized trends in the training data. Although it did well on the dataset, its lack of generalizability raised questions about how useful it would be in real-world situations. However, although being less accurate than the Decision Tree model, the K-Nearest Neighbors (KNN) Classification demonstrated its capacity to generalize effectively without overfitting, achieving 93.4% accuracy. However, it was less appropriate for real-time forecasts due to its processing inefficiency for large-scale applications.

The preprocessing of information and feature engineering were important components of the study that had a big impact on model performance. The accuracy of the model was enhanced using exploratory data analysis (EDA) and preparation methods include handling values that are missing, encoding categorical variables, and normalizing numerical features with standard scaler. Effective model evaluation was ensured by the 80-20 train-test split, which also prevented data leaking and produced accurate performance measures. The Decision Tree model's feature importance analysis showed that the most important parameters in fertilizer selection were nitrogen, phosphorous, and potassium, followed by soil type and moisture level. This result validates the model's decision-making process and strengthens its practical reliability because it is consistent with agronomic knowledge. Farmers could enter soil and environmental factors and obtain immediate, customized fertilizer recommendations thanks to the model's deployment via a Streamlit-based user interface (UI), which allowed for real-time user input.

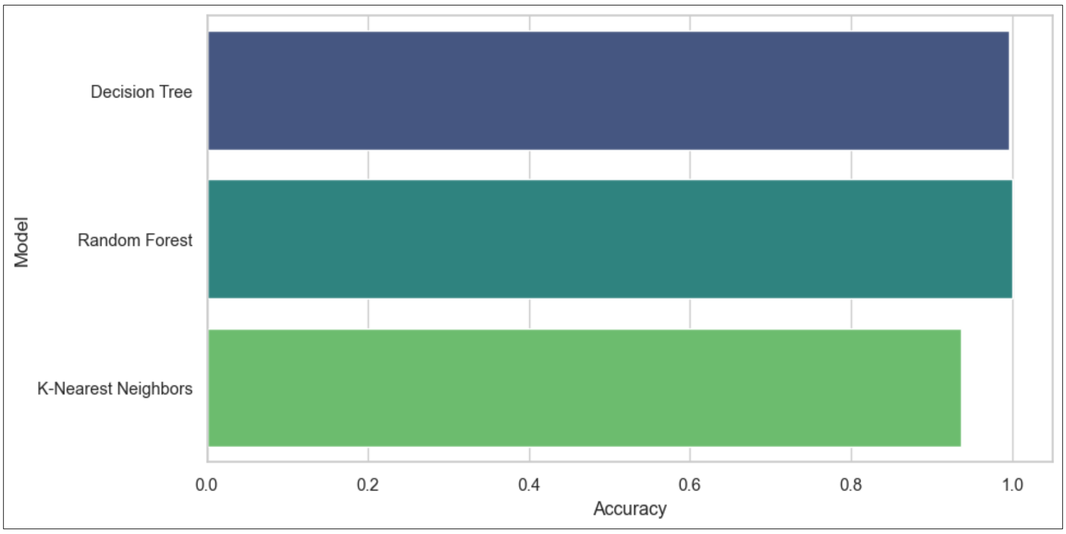

Fig 2: Accuracy of Different Models

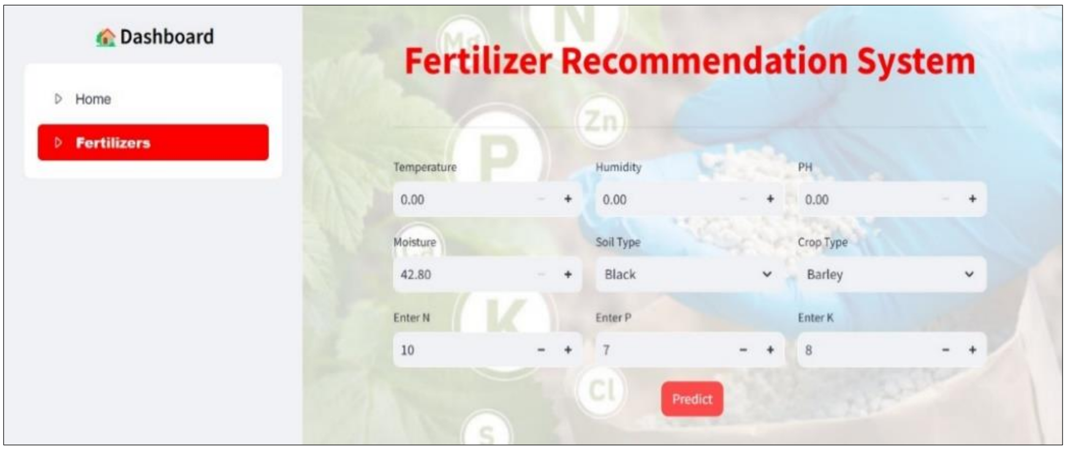

Fig 3: Predictions Page

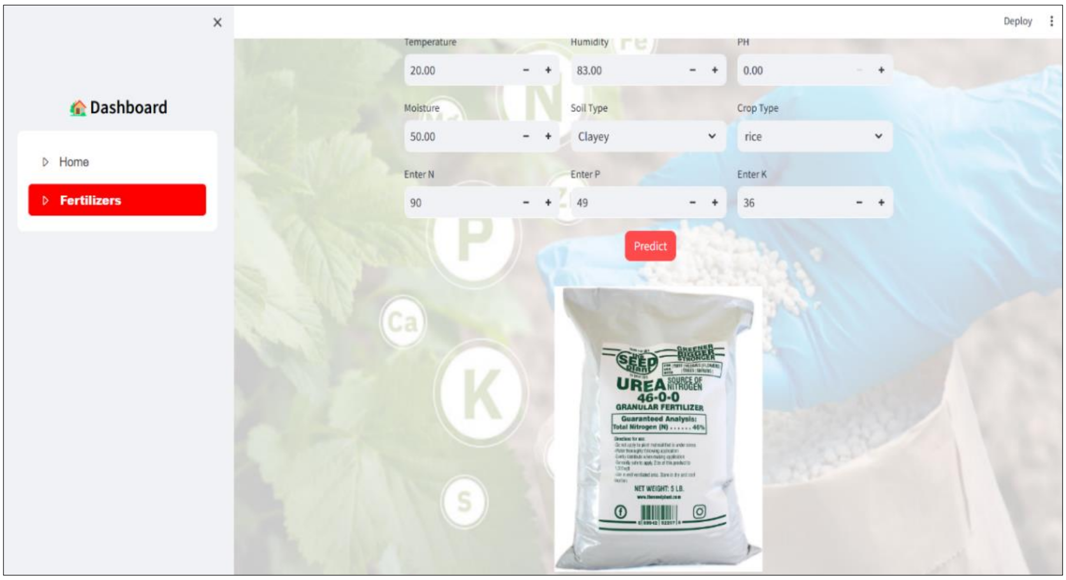

Fig 4: Fertilizer Prediction Page

From an agricultural standpoint, the suggested solution connects traditional farming methods with cutting-edge AI-powered precision farming. Improved crop output, cost savings, and sustainable farming are all facilitated by reducing fertilizer waste and guaranteeing precise nutrient application. By offering specialized solutions suited to particular soil and crop circumstances, this strategy greatly increases agricultural efficiency when compared to conventional techniques that rely on general advice. In order to improve the accuracy of the model, the study also points to the possibility of additional developments, such as using satellite imagery, real-time weather updates, or Internet of Things-based soil sensors. Furthermore, using ensemble methods or **deep learning models

Conclusion

This study introduces a machine learning-based fertilizer suggestion system that optimizes agricultural output by utilizing soil and environmental characteristics to generate precise, data-driven fertilizer recommendations. The Decision Tree Classifier was chosen as the final model after a number of models were evaluated; it achieved 99.78% accuracy, while Random Forest (100%) showed overfitting and KNN (93.4%) was computationally costly. In order to guarantee high-quality input, the system combines EDA, data preparation, and feature engineering. This allows for accurate recommendations for fertilizer through a Streamlit-based user interface for real-time user involvement. This method provides individualized insights based on particular agricultural conditions, increasing crop production, reducing fertilizer waste, and advancing sustainable farming. The study bridges the gap between smart agriculture and traditional farming methods by highlighting the significance of artificial intelligence (AI) in contemporary farming. To further increase the system's accuracy and versatility, future research will concentrate on integrating deep learning models, IoT-based soil detectors and real-time weather updates.

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