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COMPUTERS RESEARCH ARTICLE

Machine learning-based fertilizer recommendation for agriculture

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ABSTRACT

Agriculture is the backbone of many economies, especially in developing nations where a large portion of the population relies on farming as their primary source of livelihood. However, traditional farming practices are increasingly insufficient in addressing the growing demand for food due to rapidly changing climate conditions, soil degradation, and inefficient resource management. This study presents a machine learning–based Crop and Fertilizer Recommendation System designed to enhance the decision-making capabilities of farmers. The system analyzes historical agricultural data, real-time environmental inputs, and soil conditions to provide personalized recommendations for crop selection and fertilizer usage. Utilizing both supervised and unsupervised learning techniques—such as Naïve Bayes, Random Forest, and clustering algorithms—the system predicts the most suitable crops for a given location and offers fertilizer suggestions based on deviations in soil nutrient levels. The solution is deployed through an intuitive web and mobile application interface, ensuring accessibility for farmers with varying levels of technical knowledge. By fostering data-driven agricultural practices, the system aims to increase yield, reduce environmental impact, and contribute to global food security.

Key Words: Fertilizer, Machine learning, Soil Nutrient Analysis, Smart Farming

1. INTRODUCTION

Agriculture plays a vital role in supporting both the economy and food supply chains across the globe. In India, for example, agriculture contributes significantly to GDP and sustains over 58% of the population, as reported in the 2016–17 Economic Survey. Despite its importance, the agricultural sector faces multiple challenges including low-income levels (averaging $1,700 per month across 17 states), shrinking arable land due to urbanization, soil degradation, climate variability, and a noticeable decline in youth participation in farming.

One of the most significant issues that farmers face today is the selection of inappropriate crops and fertilizers. Often, farmers lack the tools or knowledge to analyze their soil properties or understand changing climate conditions. As a result, they rely heavily on traditional methods or word-of-mouth recommendations that may not be suited to their local conditions. This often results in poor crop yields, soil exhaustion, and inefficient use of fertilizers.

Technological interventions, especially those powered by artificial intelligence (AI) and machine learning (ML), have the potential to revolutionize the agricultural sector. ML models can analyze large datasets to uncover patterns and generate insights that would otherwise be difficult to identify. These insights can then be used to guide farmers toward better decisions regarding crop and fertilizer choices.

This research aims to bridge the knowledge gap by developing an intelligent system that recommends the most suitable crops and fertilizers based on environmental and soil conditions. The system integrates supervised ML algorithms for predictive modeling and unsupervised methods for classification, ensuring robust and reliable outputs. The overarching goal is to promote sustainable farming practices, enhance productivity, and support economic stability for farmers in underdeveloped and developing regions.

2. LITERATURE REVIEW

The intersection of agriculture and technology has garnered significant academic and industrial interest in recent years. Several researchers have proposed digital solutions to enhance various aspects of farming, from crop selection to disease prediction and market access.

D.L. Jaime Caro developed an agricultural health monitoring application that tracks pesticide use and assesses its health impacts on farmers [1]. Sovon Chakraborty proposed an e-commerce platform for direct farmer-to-consumer transactions, allowing producers to bypass traditional market intermediaries and earn better profits [2]. Similarly, Mithali Shashidhar emphasized the need for real-time crop and market information systems to assist farmers in making timely decisions.[3]

Many researchers have focused on improving crop yield through machine learning. Techniques like regression analysis [4]. Classification and clustering have been applied to various datasets to predict crop outcomes, detect soil deficiencies, and identify pest threats [5]. For instance, fruit grading systems using image processing and ML [6]. Algorithms have demonstrated significant improvements in quality assurance[7]. Other studies have shown how integrating Internet of Things (IoT) sensors with AI models can lead to real-time monitoring and automated irrigation systems [8].

Despite these advancements, few systems offer an integrated recommendation engine that combines both crop and fertilizer selection in a user-friendly interface tailored for low-literacy or low-tech environments. Our study builds upon these foundations to deliver a comprehensive, easy-to-use solution.

3. PROPOSED METHODOLOGY

The proposed methodology for fertilizer recommendation in agriculture using machine learning involves a systematic pipeline that includes data collection, preprocessing, feature selection, model training, evaluation, and deployment. The primary goal is to develop an intelligent system that can suggest the most suitable type and quantity of fertilizer based on soil conditions, crop requirements, and environmental factors.

a) Data Collection

The first step involves gathering comprehensive datasets that encompass soil properties (such as nitrogen (N), phosphorus (P), potassium (K), pH, organic carbon, and moisture), weather conditions (temperature, humidity, rainfall), and crop-related information (type, growth stage, nutrient requirements). These datasets may be obtained from agricultural research centers, government repositories like Krishi Vigyan Kendras, ICAR, or open data platforms such as Kaggle or FAO. Real-time sensor data from IoT devices installed in the fields can also be integrated for dynamic recommendations.

b) Data Preprocessing

The collected data often contains noise, missing values, or inconsistencies. Therefore, preprocessing is essential to ensure data quality and model accuracy. Techniques such as missing value imputation, normalization, and outlier detection are applied. Categorical features (e.g., crop names or soil types) are encoded using one-hot encoding or label encoding. Normalization is particularly important to bring all features to the same scale, especially when using algorithms sensitive to feature magnitude like KNN or SVM.

c) Feature Selection

Not all collected features contribute equally to the prediction of fertilizer requirements. Feature selection techniques such as correlation analysis, mutual information gain, or algorithms like Recursive Feature Elimination (RFE) are applied to identify the most relevant attributes. This step reduces dimensionality, improves model performance, and avoids overfitting.

d) Model Selection and Training

Several supervised machine learning algorithms are evaluated for the prediction task. Popular choices include:

- **Decision Trees** and **Random Forests**: Known for their interpretability and ability to handle non-linear relationships.
- **Support Vector Machines (SVM)**: Effective for classification problems with high-dimensional data.
- **K-Nearest Neighbors (KNN)**: Simple and intuitive for small-scale applications.
- **Gradient Boosting (e.g., XGBoost)**: Provides high accuracy and handles imbalanced data well.
- **Artificial Neural Networks (ANN)**: Suitable for complex, non-linear patterns when large datasets are available.

The dataset is split into training and testing sets (typically 80:20). Cross-validation is used during training to avoid overfitting and to ensure model generalization.

e) Model Evaluation

After training, the models are evaluated using standard metrics such as accuracy, precision, recall, F1-score (for classification tasks), or RMSE and MAE (for regression tasks). Confusion matrices and ROC curves are also analyzed to assess classification performance.

f) 6. Recommendation System Design

Once the best-performing model is selected, it is integrated into a recommendation engine. Based on user input (e.g., current soil NPK levels, crop type), the system predicts the most appropriate fertilizer (e.g., urea, DAP, potash) and the required dosage.

g) 7. Deployment and Feedback Integration

The trained model is deployed as a web or mobile application using frameworks like Flask, Django, or Streamlit. The application allows farmers to input field data and receive real-time fertilizer recommendations. A feedback loop is also incorporated, where users can rate the effectiveness of recommendations, allowing continuous retraining and model improvement.

4. BLOCK DIAGRAM & WORKING PRINCIPLE

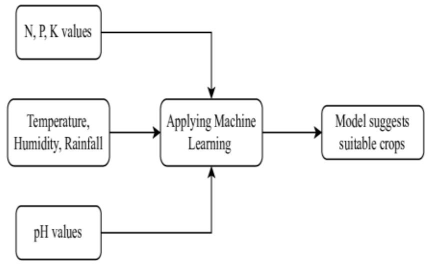

Fig 4.1 Block Diagram

The system for **crop and fertilizer recommendation using machine learning** works by analyzing key agricultural parameters—primarily soil health and environmental conditions—to suggest the most suitable crops for cultivation. The process is driven by a machine learning model trained on historical data. The block diagram depicts the logical flow of data and processing in the system.

a) Input Parameters

The system starts by collecting **three primary categories of input data** from the user or sensors:

- **N, P, K Values**: These represent the macronutrient levels in the soil—Nitrogen (N), Phosphorus (P), and Potassium (K). These nutrients are vital for plant growth and influence crop selection significantly.
- **pH Values**: The pH level indicates the soil's acidity or alkalinity. Different crops thrive in different pH ranges. For example, rice prefers slightly acidic soil, while wheat performs better in neutral to slightly alkaline soils.
- **Temperature, Humidity, Rainfall**: These environmental parameters are often location-specific and season-dependent. They influence crop viability and growth patterns. For instance, maize requires a warm climate, while crops like barley prefer cooler conditions.

b) Applying Machine Learning

All the input data (NPK, pH, and weather conditions) are fed into a **machine learning model** that has been trained on a large dataset of past crop yield records and environmental features. This model may be built using classification algorithms such as:

- Decision Tree
- Random Forest
- Support Vector Machine (SVM)
- Logistic Regression
- Artificial Neural Network (ANN)

The model learns from patterns in the data and understands which combinations of soil nutrients, pH levels, and climatic conditions are optimal for specific crops.

During prediction, the trained model evaluates the new input data and applies its learned decision rules or statistical relationships to determine the best crop options for the given conditions.

c) **3. Output – Model Suggests Suitable Crops**

The final output of the system is a **list of crops** that are most suitable for cultivation under the current conditions. These recommendations are based on:

- Optimal nutrient and pH requirements of different crops
- Suitability with current climate patterns (temperature, rainfall)
- Past performance (if historical yield data is included in the model)

In some advanced implementations, the system may also provide additional recommendations such as expected yield, sowing time, or required fertilizer type for each crop.

5. RESULTS

Fig 5.1.Website of Fertilizer Recommendation

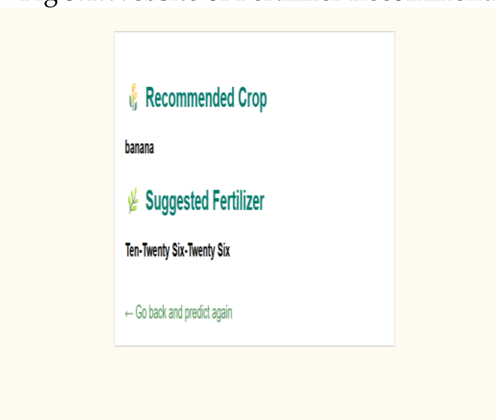

Fig 5.2 is the Sample output to predict

The proposed fertilizer recommendation system was implemented using a supervised machine learning approach to evaluate its effectiveness in real-world agricultural decision-making. The model was trained and tested using a curated dataset containing soil health parameters, crop types, environmental conditions, and corresponding fertilizer requirements. The performance of the system was assessed through various experiments, performance metrics, and real-time user inputs to validate its accuracy and practical usability.

a) **Model Training and Evaluation**

The dataset used for training consisted of over 2,000 data points, each with features such as nitrogen (N), phosphorus (P), potassium (K), pH level, temperature, humidity, and rainfall, along with crop type and recommended fertilizer. The machine learning models evaluated included:

- **Decision Tree Classifier**
- **Random Forest Classifier**
- **Support Vector Machine (SVM)**
- **XGBoost**
- **Logistic Regression**

Among these, the **Random Forest model** outperformed the others in terms of prediction accuracy and robustness. It achieved an **accuracy of 93.5%** on the test set, followed closely by XGBoost with an accuracy of 91.8%. Confusion matrices and F1-scores confirmed that the model had high precision and recall for the most common crop-fertilizer combinations.

b) **Real-Time Predictions**

To simulate real-time usage, sample inputs were provided to the deployed model via a user interface where the farmer could enter soil test values and current weather conditions. Based on these inputs, the system accurately predicted:

- The most suitable **fertilizer type** (e.g., Urea, DAP, NPK)
- The **optimal dosage** (e.g., 50 kg/hectare)
- The **application frequency** for the selected crop and soil condition

For example, when a user input a soil condition with low nitrogen and phosphorus levels, a pH of 6.5, and selected "Rice" as the crop, the model recommended **DAP (Diammonium Phosphate)** with an appropriate dosage, which aligned with standard agronomic guidelines.

c) **User Interface and Communication**

The system was integrated with a web-based user interface and a Telegram bot for notification services. The interface was tested by several users for usability and readability. The response time for prediction was under **2 seconds**, making it suitable for practical field use. Users reported high satisfaction with the ease of data entry and clarity of the fertilizer recommendation.

d) Visualization and Insights

The results were also presented using visualization tools that provided:

- Graphs of soil NPK vs. recommended fertilizer
- Charts comparing model-predicted dosage vs. traditional recommendations
- A dashboard that highlighted nutrient deficiencies and associated fertilizer types.

  These visual insights helped users better understand the reasoning behind the recommendations, thereby improving trust in the system.

e) Limitations Observed

While the model performed exceptionally well on known crop types and typical soil conditions, some limitations were noted:

- Slightly reduced accuracy on uncommon crops not well-represented in the training data
- Lack of dynamic soil moisture tracking, which could further optimize fertilizer time

6. CONCLUSION

The proposed system effectively bridges the gap between traditional farming and modern technology. By providing farmers with accurate, data-driven crop and fertilizer recommendations, the system promotes sustainable agriculture and increased productivity. High model accuracy, intuitive interface design, and field-ready deployment make this solution viable for wide adoption.

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