iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.70432

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Fertilizer Prediction Using Machine Learning

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Abstract: Fertilizer application is an important aspect of sustainable agriculture, having a direct influence on crop yield and soil health. Yet, if not used correctly, fertilizers can have negative environmental impacts and reduced productivity. This study seeks to create a machine learning model for precise fertilizer prediction, utilizing a Random Forest algorithm. The model takes into account key agricultural parameters, such as temperature, humidity, soil moisture, soil type, crop type, and the levels of nitrogen, potassium, and phosphorus, as well as pH levels. Utilizing a strong dataset, our Random Forest-based model scored an accuracy of 95%, proving its potential to assist farmers in choosing the best fertilizer for a given condition. This not only optimizes fertilizer usage but also encourages sustainable agriculture by reducing the environmental footprint. The findings of this research highlight the importance of incorporating machine learning in precision agriculture to boost productivity and ecological balance.
Keywords: Fertilizer Prediction, Random Forest Algorithm, Precision Agriculture, Soil Parameters, Sustainable Farming

I. INTRODUCTION

The agricultural sector is the backbone of any country's economic strength and a crucial factor in food security for the increasing population worldwide. Even though it is crucial, conventional agricultural practices tend to depend on word-of-mouth criticism and individual experience in making choices about planting crops and applying fertilizers. Though helpful, such methods are often not effective in delivering maximum results, resulting in economic losses and decreased productivity. To address these challenges, there is a pressing need to transition from conventional methods to data-driven, technology-enabled precision agriculture.

The conventional methods usually lack important considerations like the soil composition, watering needs of crops, land capability, and climate patterns, all of which have a substantial bearing on crop production. Recent technological innovations like big data, machine learning, and image processing through digital tools provide game-changing solutions to enhance agricultural processes. These technologies have been extensively used in many sectors, such as e-commerce, medicine, and entertainment, to support decision-making through recommendation systems. In farming, they have great potential to enhance crop choice, pest control, and fertilization by processing enormous amounts of information.

Machine learning, in specific, offers a strong paradigm for addressing intricate agricultural issues through the processing of past data and providing customized, evidence-based advice.

Digital image processing allows data like land and crop images to be processed to detect diseases, quantify soil nutrients, and evaluate growth patterns. These approaches enable farmers to make informed choices regarding fertilizers, pesticides, and crop rotation to ensure sustainability and productivity.

The main challenge is the absence of personalized advice for farmers to deal with such important issues as water shortages, soil erosion, pest outbreaks, and resource availability. Current systems do not typically incorporate multiple variables like soil characteristics, precipitation, temperature, and humidity into their suggestions, resulting in less-than-optimal results.

In order to overcome the drawbacks of these methods, we created a machine learning-based fertilizer prediction system based on the Random Forest algorithm. Based on the analysis of parameters such as soil type, crop type, temperature, humidity, and nutrient levels, our system provides accurate fertilizer recommendations with 95% accuracy. Our system not only increases agricultural efficiency but also overcomes age-old problems in the industry, which will lead to a technologically equipped and sustainable future for farming

II. LITERATURE SURVEY

[1] The paper titled "IoT Based Smart Black Box System" presents a novel approach to enhancing vehicle safety and accident investigation. The proposed system utilizes sensors, Zigbee communication, and the PLX-DAQ module to create a smart black box that records vehicle data and transmits accident details to nearby hospitals, traffic control centers, and emergency services.

The system leverages IoT technology to provide real-time location data, ensuring immediate medical attention in remote or unpopulated areas where accident reporting is otherwise challenging. By integrating Arduino, GSM, and a web tracking feature, this system offers a comprehensive solution for accident analysis, improving response time and facilitating efficient investigations.

[2] Researchers developed AgriRec, a machine learning-based recommendation system that suggests the best crops and fertilizers based on soil properties, water levels, farm size, and crop prices. Tested on 5000 land samples in Gujarat, AgriRec achieved 95.85% accuracy in crop prediction and 92.11% accuracy in fertilizer recommendation, outperforming existing methods by four times.

[3] This research introduces a machine learning-based system for recommending fertilizers and predicting crop yields. By analyzing soil, weather, and crop data, the model uses Gradient Boosting Machines to suggest the best fertilizer type and quantity for optimal crop growth. Achieving an accuracy of 86.5%, this method outperforms traditional approaches in both precision and efficiency. By guiding farmers with accurate recommendations, this system aims to improve productivity, reduce fertilizer costs, and promote sustainable agricultural practices..

[5] This paper introduces a decision-support tool for precision nitrogen (N) management in corn fields using satellite imagery and the APSIM crop model. The tool integrates soil maps and vegetation index data to create management zones and recommend variable-rate N fertilization. Tested on a 66 ha corn field in Illinois, the tool effectively recommended sidedress N rates between 60 to 120 kg/ha, improving yields up to 110 kg/ha before benefits plateaued. Results highlight the importance of soil properties and organic matter in optimizing N recommendations, offering a promising solution for precision agriculture.

[15] This paper reviews progress in developing fertilizer recommendations for rice-based systems in sub-Saharan Africa (SSA). Despite rice being a key crop, SSA farmers use only 5–9 kg/ha of fertilizer, far less than Latin America and Asia. Efficient fertilizer management is crucial for improving rice yields, but challenges arise due to diverse ecologies, fertilizer costs, and market limitations. The paper highlights new decision-support tools and modeling approaches as promising strategies for better fertilizer management in SSA's varied rice systems.

[16] This paper explores the use of machine learning to improve crop recommendation, helping farmers choose the best crops based on soil and climate conditions. Traditionally, this relied on expert knowledge, which was time-consuming and labor-intensive. With the world's population expected to reach 9.7 billion by 2050, sustainable food production is crucial. The proposed system uses seven machine learning algorithms to predict suitable crops, achieving an impressive accuracy of up to 99.5%. This approach aims to boost crop yields, sustainability, and farmer profitability, offering a powerful tool for modern agriculture.

[20] This paper highlights the need for automation in agriculture to improve productivity and address labor shortages. Developing agricultural robots can simplify tasks like fertilizing, watering, drilling, and seeding, making farming more efficient. Given India's heavy reliance on agriculture, these robots can significantly boost crop performance and economic growth. The authors emphasize that modern mechanisms, advanced algorithms, and new technologies can overcome existing challenges in robot design. By adopting such innovations, smart farming can enhance productivity and ensure food security for the growing population.

[21] This paper discusses how integrating machine learning with crop prediction techniques has greatly improved agricultural productivity. By combining three different algorithms using an ensemble technique, the system enhances prediction accuracy and minimizes errors in crop yield forecasting. The study highlights how information technology is transforming agriculture, enabling farmers to make better decisions and achieve consistent crop production levels. This approach helps improve efficiency in the agricultural sector, ensuring more reliable and optimized outcomes.

[25] This paper highlights the role of precision agriculture in improving crop productivity, especially in India's Ramtek region. Farmers often struggle with low yields due to planting crops unsuitable for their soil. To address this, the proposed system uses an ensemble model combining Random Tree, CHAID, K-Nearest Neighbor, and Naive Bayes algorithms. By analyzing soil characteristics, soil types, and crop yield data, the system recommends the most suitable crops with high accuracy. This approach enhances productivity, improves resource efficiency, and helps farmers make informed decisions for better yields.

[10] This research explores the use of machine learning, specifically the Random Forest algorithm, to predict the best fertilizers for improving crop yields. By analyzing data related to soil conditions, environmental factors, and past agricultural outcomes, the model effectively recommends suitable fertilizers with high accuracy. This approach aims to support farmers, especially in rural areas, by providing precise fertilizer suggestions that enhance productivity while minimizing environmental impact. The study demonstrates Random Forest’s superior performance compared to other models like Linear Regression and K-Nearest Neighbors, achieving over 99% accuracy in fertilizer prediction.

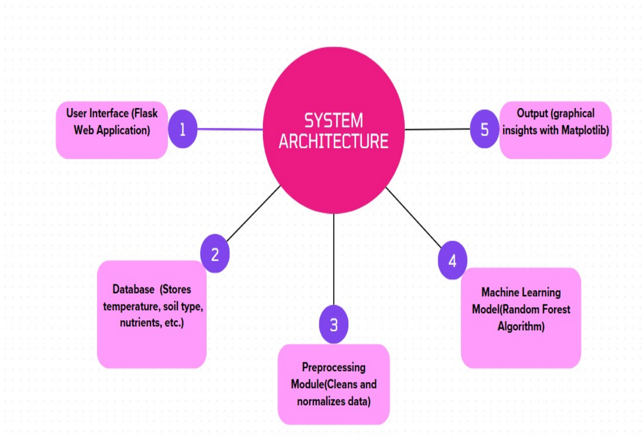
[13] Agriculture plays a crucial role in India's economy, yet farmers often face challenges in optimizing fertilizer and pesticide usage. This paper introduces a smart farming solution that combines Machine Learning (ML) and Internet of Things (IoT) to predict the appropriate type and quantity of fertilizers and pesticides based on soil type and crop requirements.

By analyzing soil conditions using IoT sensors and employing ML algorithms like K-Nearest Neighbors (KNN), Naive Bayes, and Linear Support Vector Classifier (SVC), the system helps farmers make informed decisions. The KNN model performed best with an accuracy of 81.45%, ensuring better crop health, reduced wastage, and improved yields. This innovative approach empowers farmers with data-driven insights, ultimately contributing to sustainable agriculture.

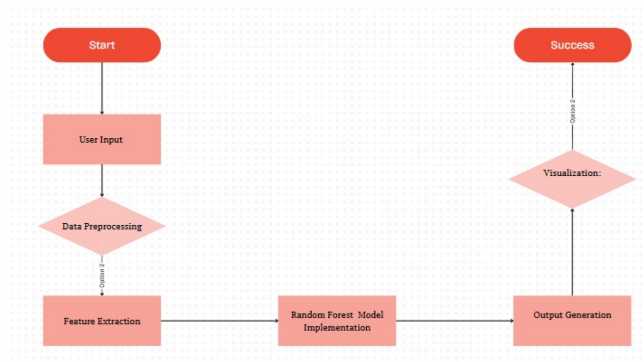
[4] This study presents an effective crop selection system using the Random Forest algorithm to improve crop yield predictions. The model leverages extensive datasets on weather conditions, soil moisture, and agricultural patterns to suggest optimal crop choices. By analyzing large-scale data from various sources, the Random Forest algorithm outperformed traditional methods like Multiple Linear Regression in accuracy and efficiency. The system's robust prediction capabilities aim to help farmers make better decisions regarding crop selection, improving productivity and profitability. Future enhancements will explore advanced machine learning techniques for even faster and more accurate predictions.

III. PROPOSED SYSTEM

A. System Architecture



B. Flowchart



Mathematical Derivations for Random Forest Classifier

1) Majority Voting in Random Forest:

In a Random Forest classifier, the final decision is made based on the majority voting mechanism among multiple decision trees

- *Step1: Individual Tree Prediction*

Each decision tree in the ensemble makes an independent prediction. Let hi(X) represent the prediction of the i-th tree for an input X:

$hi(X) = k$, where $k \in \{1, 2, \ldots, K\}$

where k is the predicted class label from the set of possible classes.

- *Step 2: Indicator Function*

To count how many times each class k is predicted, we define an indicator function ⊮ as follows:

$$\nVdash(h_i(X) = k) = \begin{cases} 1, & \text{if } h_i(X) = k \\ 0, & \text{otherwise} \end{cases}$$

This function returns 1 when the i-th tree predicts class k, and 0 otherwise.

- *Step 3: Counting Votes for Each Class*

The total votes for class k is calculated as:

$$V_k = \sum_{i=1}^{N} \nVdash(h_i(X) = k)$$

where: - N is the total number of decision trees. - hi(X) represents the predicted class of the i-th tree. - ⊮(hi(X) = k) is an indicator function that returns 1 if the i-th tree predicts class k, and 0 otherwise.

- *Step 4: Majority Voting Decision*

The final predicted class ˆy is the class with the highest vote count:

$$\hat{y} = \arg\max_k \sum_{i=1}^{N} \nVdash(h_i(X) = k)$$

where: - arg max selects the class k with the highest number of votes. - ⊮(hi(X) = k) is the indicator function returning 1 if hi(X) = k, and 0 otherwise. - N is the total number of decision trees.

2) Derivation of Accuracy Formula

Accuracy is a performance metric for classification models and is defined as:

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Total Predictions}} \times 100$$

- *Step 1: Definition of Correct Predictions*

The total number of correctly predicted instances is given by:

Correct Predictions = T P + T N

where: - True Positives (TP): The number of positive instances correctly classified. - True Negatives (TN): The number of negative instances correctly classified.

- *Step 2: Total Predictions*

The total number of samples is given by:

Total Predictions = T P + F P + F N + T

N where: - False Positives (FP): The number of negative instances incorrectly classified as positive. - False Negatives (FN): The number of positive instances incorrectly classified as negative.

- *Step 3: Deriving Accuracy Formula*

Accuracy is defined as the fraction of correct predictions over the total number of predictions:

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Total Predictions}}$$

Substituting values:

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

where: - T P = True Positives - False Positives (FP): Negative instances incorrectly classified as positive. - False Negatives (FN): Positive instances incorrectly classified as negative.

Final Expression for Accuracy :

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

where: - T P = True Positives - T N = True Negatives - F P = False Positives - F N = False Negatives

IV. METHODOLOGY

A. Tools and Frameworks

The system was implemented with Python (version 3.6.2) as the primary programming language and Flask used to develop the user interface. Crucial Python packages, such as NumPy, Pandas, Matplotlib, and Scikit-learn, were used to manipulate data, visualize data, and implement machine learning. Logical programming was adopted to apply machine learning models in a way that did not wholly depend on native frameworks, keeping it flexible and customizable.

B. Modules Implemented

Dataset Upload: A dataset of 1500 rows with seven primary parameters (temperature, humidity, moisture, soil type, crop type, nitrogen, phosphorus, potassium) was uploaded.
Feature Extraction: Key features were extracted from the dataset to identify influential parameters for fertilizer recommendations.
Model Training: Machine learning models were trained on a quality-controlled dataset to determine prediction accuracy.
Accuracy and Loss Analysis: Visualization of the model accuracy and loss graphs for assessing performance.
Dynamic Input Testing: An easy-to-use interface was created for dynamic input to forecast fertilizers using real-time user-input values

C. Data Collection

The basis of this project is the development of a comprehensive dataset that includes historical crop data, soil characteristics, weather patterns, and nutrient content. This information was carefully collected from credible sources, with emphasis on the determinants of fertilizer needs. A strong dataset allows the machine learning model to provide accurate predictions and suggestions

D. Data Preparation

Prior to training, the data collected was preprocessed to make it model-ready. The preprocessing step had two important steps:

- *Data Exploration:* A thorough examination of the dataset was done to find patterns, correlations, and outliers. Missing values and outliers were identified and marked.

- *Data Preprocessing:* Missing values were filled and outliers were handled. Data was normalized and standardized to ensure consistency and reliability, followed by correlation analysis to establish interdependencies between variables.

E. Data Analysis

Data analysis was pivotal in preprocessing the dataset to make it model-ready. Methods like cluster analysis, normalization, and statistical analyses were used to enhance the dataset and align it with the selected machine learning models. This step guaranteed that the data characteristics suited the prediction criteria

F. Model Training

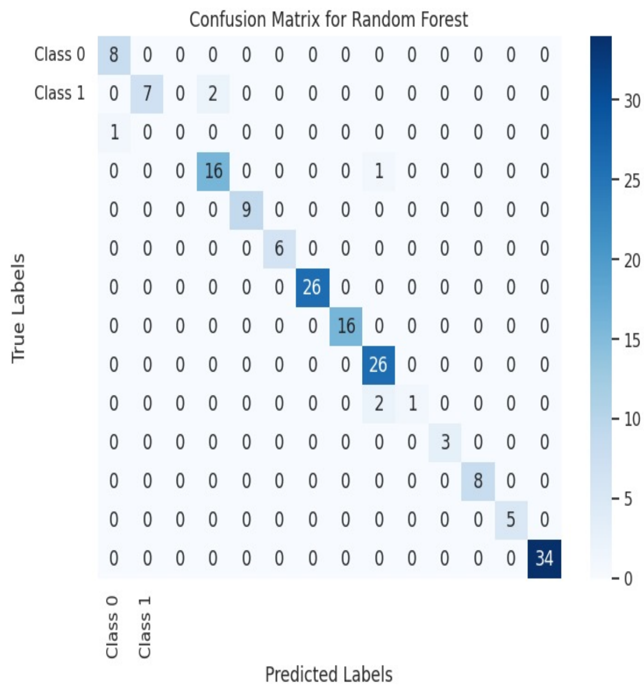
Random Forest algorithm was used for model training because of its strong ability to handle complex data and high prediction accuracy. The model was trained on the cleaned dataset so that it could learn the input parameter-fertilizer recommendation relationships. The model hyperparameters were tuned using grid search to improve performance.

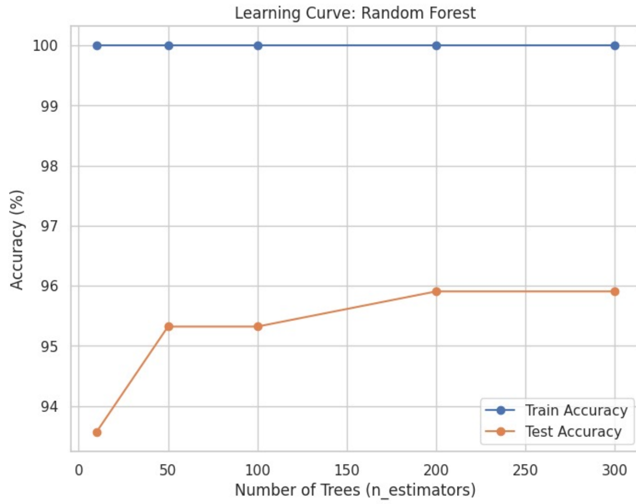
G. Model Evaluation

After training, the model was validated on a subset of the dataset to check its accuracy. The validation process included measuring precision and recall metrics and inspecting accuracy and loss plots. The Random Forest algorithm had a remarkable accuracy of 95%, which highlights its capability to predict appropriate fertilizers from input parameters.

V. WORKING

1) *User Interaction:* The system begins with user interaction through a web interface built using Flask. Farmers or users input the required parameters, including temperature, humidity, soil moisture, soil type, crop type, and nutrient levels (nitrogen, phosphorus, and potassium).
2) *Data Processing:* Once the inputs are provided, the system validates and preprocesses them to ensure they match the format and scale used during the model's training. Data normalization and scaling ensure that the inputs align with the trained model's expectations.
3) *Machine Learning Model:* The system uses a Random Forest machine learning algorithm, trained on a dataset of 1,500 rows containing historical data. This data includes information on environmental conditions, soil properties, and fertilizer recommendations. The Random Forest model analyzes the input features and applies its ensemble of decision trees to predict the most suitable fertilizer for the specified conditions.





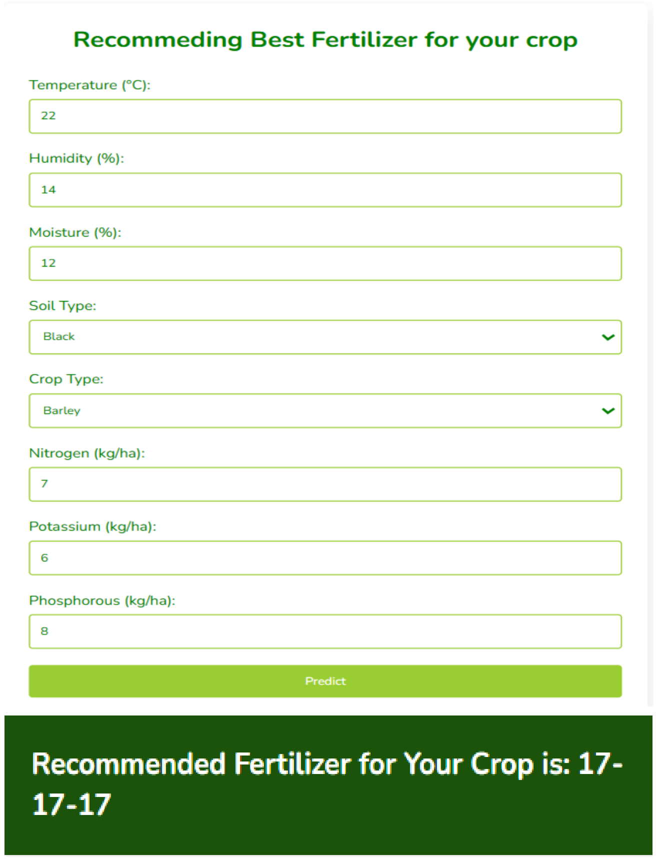
4) *Prediction Generation:* The trained model processes the input data and generates a prediction for the recommended fertilizer. It also provides an accuracy score that represents the confidence level of the recommendation.
5) *Output Display:* The predicted fertilizer recommendation, along with supplementary information such as potential accuracy and suggested quantities, is displayed to the user through the Flask interface. The output is presented in an easy-to-understand format, ensuring that users without technical knowledge can readily apply the recommendation.
6) *Graphical Insights:* The system also generates graphs using Matplotlib to visualize the relationship between parameters, such as nutrient levels and fertilizer recommendations. This aids users in understanding the underlying patterns in the data.
7) *Testing and Validation:* After training, the model was tested using a subset of data not seen during training to validate its performance. The model achieved an accuracy of 95%, indicating its reliability in providing precise recommendations

VI. RESULT

1) *Forecasted Fertilizer Recommendations:*

The main deliverable of the project is the projection of the most appropriate fertilizer depending on user-input parameters like temperature, humidity, moisture, type of soil, type of crop, and nutrient content (nitrogen, phosphorus, potassium).

The system provides these suggestions dynamically and with high precision to ensure that farmers are able to make informed choices to maximize crop yield.

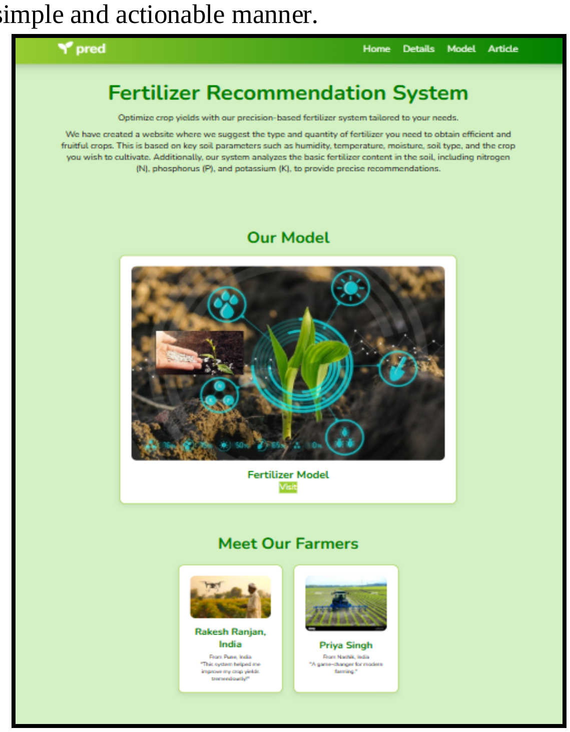


2) Web Interface Features:

The user interface based on Flask is user-friendly and interactive. It enables users to:

Enter real-time agricultural parameters for fertilizer prediction.

See results in real time, presented in a simple and actionable manner.



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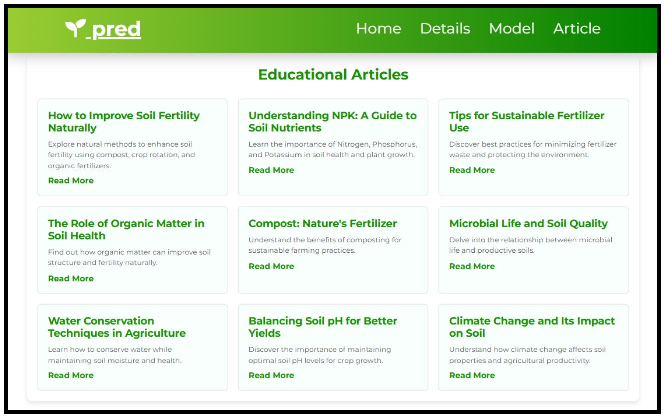
3) Educational Resources:

The site carries articles on topics such as fertilizers, containing informative content regarding their use, kinds, and advantages.
Such resources seek to inform users, particularly farmers, on sustainable agricultural practices and why nutrient management matters in agriculture.



4) Historical Insights on Fertilizers:

A special webpage on the website gives the history of fertilizers, following their development and role in contemporary agriculture.
This feature not only enriches the user's knowledge but also highlights the role of fertilizers in addressing global food security challenges.

5) Data Visualization:

The site uses graphs and charts to show data relationships, e.g., the effect of soil nutrients and environmental conditions on fertilizer needs.
These visualizations improve the knowledge of data-based farming methods.

6) More Efficient Farming:

The system simplifies the decision-making process, minimizing guesswork and allowing users to maximize fertilizer use efficiently.
It supports sustainability through encouraging optimal nutrient management.

VII. CONCLUSION

In summary, the system created in this project effectively applies machine learning algorithms, Random Forest in this case, to make precision and efficient fertilizer recommendations depending on various environmental and soil parameters. The capacity of the system to use historical data in conjunction with its simple-to-use interface created with Python and Flask provides a realistic solution for farmers to maximize their crop harvests. Attaining an accuracy rate of 95% showcases the capabilities of machine learning to improve agricultural activities. The project not only identifies the significance of data-driven decision-making but also paves the way for subsequent innovations in smart agriculture. With additional enhancements, including the addition of real-time data and extended parameter sets, this system can be a crucial tool for sustainable agriculture, promoting enhanced crop yield with reduced environmental consequence from fertilizer usage.

VIII. ACKNOWLEDGMENT

We would like to express our deepest gratitude to Vishwakarma Institute of Technology for giving us the opportunity to work on this research project. We are particularly thankful to our esteemed professor, Prof. Bhagwan Thorat, whose exceptional knowledge and expertise in Agriculture have guided us throughout this journey. His unwavering support, insightful suggestions, and constant encouragement have been invaluable to the successful completion of this project.

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