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Precision Soil and Crop Nutrient Decision Support System Using Machine Learning

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ABSTRACT

accomplishing excessive crop yields even as preserving soil fitness depends heavily on powerful fertilizer control. lamentably, most conventional processes still rely upon farmers' instinct or vast, one-size-suits-all pointers. these strategies often purpose fertilizer misuse—both an excessive amount of, which harms soil and the environment, or too little, which lowers productivity. This study introduces a Precision Soil and Crop Nutrient decision help gadget designed to triumph over these challenges the use of machine getting to know. by way of analyzing key factors inclusive of soil nutrients (Nitrogen, Phosphorus, Potassium), crop kind, temperature, humidity, and soil moisture, the gadget gives fertilizer tips which might be each accurate and crop particular. various algorithms—which include choice Tree, Random woodland, Logistic Regression, Naïve Bayes, and aid Vector system (SVM)—are applied and in comparison, to identify the maximum dependable model. developed with Python and Flask and supported by a simple web interface built with HTML, CSS, Bootstrap, and JavaScript, the device is sensible and farmer friendly. Experimental consequences verify that it is able to assist farmers make knowledgeable selections, lessen enter fees, and beautify productiveness, at the same time as additionally encouraging sustainable farming. looking ahead, this work opens the door for integrating IoT sensors and actual-time tracking to create even smarter, information-driven agricultural

INTRODUCTION

Agriculture is the spine of food security and performs a critical function in economic stability. Fertilizers are central to boosting crop yields by way of replenishing critical soil nutrients. yet, their advantages depend on applying the proper kind and quantity based totally on soil conditions, crop needs, and environmental elements. immoderate use can degrade soil, pollute water assets, and disturb ecosystems, whilst inadequate use outcomes in terrible yields and economic setbacks for farmers. To deal with this venture, current agriculture more and more is predicated on facts-driven solutions. With the rise of records science, device getting to know has grow to be a powerful device for tackling agricultural troubles. by reading soil composition, crop kind, and environmental situations, device learning can generate fertilizer hints which might be more precise and dependable than conventional techniques. This research provides a Fertilizer advice machine that applies algorithms along with selection Tree, Random woodland, Logistic Regression, Naïve Bayes, and support Vector system (SVM) to manual farmers.

LITERATURE REVIEW

Efficient fertilizer application has been a topic of research for decades because of its strong influence on both crop yield and soil sustainability. Early approaches to fertilizer recommendation were mainly experienced-based or derived from generalized extension guidelines. Although simple to follow, these methods often failed to reflect the diversity of soil characteristics, climatic conditions, and crop-specific nutrient demands, leading to either nutrient excess or deficiency in the field.

With the rise of computational techniques, researchers have started employing machine learning (ML) and artificial intelligence (AI) to address these limitations. Classification models such as Decision Trees have been used to generate simple rule-based predictions that farmers can interpret easily. However, single-tree models are prone to overfitting, which limits their generalization ability. To overcome this, ensemble methods like Random Forests have been widely studied and are consistently reported as more reliable due to their ability to combine multiple learners and enhance accuracy.

Lightweight algorithms such as Logistic Regression and Naïve Bayes have also been investigated in fertilizer and crop recommendation tasks. These approaches are valued for their simplicity and speed, particularly in scenarios where computational resources are limited. In contrast, Support Vector Machines (SVM) are capable of handling complex and non-linear relationships within soil–nutrient–crop datasets, making them effective but often computationally heavier than other models.

Several studies have emphasized that incorporating environmental factors—such as soil moisture, temperature, and humidity—alongside chemical soil parameters (Nitrogen, Phosphorus, Potassium) leads to more precise recommendations. Recently, IoT-enabled sensors and real-time monitoring systems have been integrated into decision support tools, offering dynamic insights that adapt to changing field conditions.

Although prior research has shown significant promise, many systems remain technically complex and are not easily accessible to farmers with limited digital literacy. This gap highlights the need for decision support systems that combine robust machine learning techniques with simple, user-friendly interfaces. The current work builds on these foundations by developing a Precision Soil and Crop Nutrient Decision Support System that compares multiple ML algorithms, identifies the most reliable one, and delivers recommendations through an intuitive web-based platform designed to support practical adoption in farming communities.

SYSTEM ANALYSIS AND METHOLOGY

At present, fertilizer recommendation practices are in large part conventional and come with numerous barriers:

1. enjoy-based totally choices – Many farmers depend on personal knowledge, intuition, or guesswork, which frequently outcomes in faulty fertilizer utilization. this may both harm soil health through overuse and lessen yields due to underuse.

2.Generalized hints – Agricultural departments often offer large hints that don't remember specific soil residences, crop requirements, or local environmental situations. As a end result, the suggestions might not be optimal for each farming situation.

Those drawbacks highlight the need for a greater precise, records-driven machine that can generate customized fertilizer hints tailored to each farmer’s field and crop.

PROPOSED MACHINE AND ITS BENEFITS

The proposed Fertilizer advice gadget leverages machine studying algorithms and a consumer-friendly web platform to deliver correct, crop-specific, and soil-specific tips. unlike traditional methods, this device is statistics-pushed and tailored to character farming desires. Its key advantages encompass:

1.data-driven decisions – The system analyses a couple of parameters, together with soil nutrients (Nitrogen, Phosphorus, Potassium), crop type, temperature, humidity, and moisture, to generate unique fertilizer pointers.

2.high accuracy – via enforcing and comparing algorithms which include decision Tree, Random wooded area, Logistic Regression, Naïve Bayes, and aid Vector device (SVM), the system ensures dependable and consistent tips.

3.Ease of get right of entry to – Farmers can quite simply access the pointers via a responsive net interface constructed with HTML, CSS, Bootstrap, and Flask, requiring minimum technical understanding.

4.cost efficiency – Optimized fertilizer usage prevents wastage and decreases useless farming costs.

5.stepped forward yield – correct pointers lead to more healthy plants, progressed soil management, and expanded agricultural productivity.

6.Time-saving – The gadget generates immediately consequences, removing delays due to guide strategies or laboratory checking out.

ALGORITHM AND METHODOLOGY

The proposed Fertilizer recommendation machine is built the use of supervised machine studying algorithms to are expecting the maximum suitable kind and amount of fertilizer based totally on soil residences and environmental situations. The technique includes collecting enter parameters along with soil nutrients (Nitrogen, Phosphorus, Potassium), crop type, temperature, humidity, and moisture, accompanied by schooling and trying out multiple algorithms to identify the most accurate version.

The selected algorithms and their roles are:

1. selection Tree – Generates easy, interpretable regulations for classifying fertilizer requirements based on soil composition and crop kind.

2. Random woodland – An ensemble approach that combines more than one choice timber to enhance prediction accuracy and decrease overfitting.

3. Logistic Regression – beneficial for binary and multi-elegance classification duties, assisting in categorizing fertilizers into suitable groups.

4. Naïve Bayes – A probabilistic classifier that plays nicely with unsure or noisy agricultural data.

5. support Vector gadget (SVM) – Determines the finest boundary between classes, turning in excessive accuracy in complex datasets.

via applying and evaluating these algorithms, the device ensures that the hints are each specific and dependable, making it a realistic choice-assist tool for farmers.

METHODOLOGY

The development of the Fertilizer advice system follows a established method to ensure accuracy, usability, and efficiency. The important steps encompass:

1.Facts Collection:

Agricultural datasets are amassed containing essential parameters consisting of soil nutrient values (Nitrogen, Phosphorus, Potassium), crop kind, temperature, humidity, and soil moisture. these datasets shape the inspiration for schooling system learning models.

2.Data Preprocessing:

The gathered records is wiped clean to take away mistakes, missing values, or inconsistencies. Normalization and transformation strategies are implemented to standardize the statistics, ensuring that it's far suitable for correct version education.

3.Model Training and Checking Out:

The dataset is split into training and checking out units. Supervised device gaining knowledge of algorithms such as choice Tree, Random woodland, Logistic Regression, Naïve Bayes, and SVM are carried out. Their overall performance is evaluated and compared the usage of metrics like accuracy, precision, and reliability to become aware of the nice-appearing version.

4.Gadget Improvement:

o Frontend – A responsive consumer interface is built the use of HTML, CSS, Bootstrap, and JavaScript, permitting farmers to have interaction easily with the device.

o Backend – Python with Flask is used to address consumer inputs, manner facts, and combine the trained machine getting to know models.

o Database – Soil facts and person inputs are saved and managed correctly for evaluation and destiny use.

5. **Recommendation Era**:

Based totally on consumer inputs, the chosen system studying model predicts the most suitable fertilizer kind and amount. The results are displayed in a clean, farmer-friendly format, which includes visual insights while vital.

6.checking out and Validation:

The device undergoes unit trying out, integration checking out, and consumer attractiveness checking out to verify accuracy, make certain easy device performance, and confirm usability from a farmer's angle.

IMPLEMENTATION

The Fertilizer advice system integrates machine gaining knowledge of techniques with an internet-based totally platform to supply correct and on hand fertilizer tips.

The manner starts off evolved with a dataset containing soil nutrient values (Nitrogen, Phosphorus, Potassium), crop type, temperature, humidity, and moisture stages. This facts is pre-processed using Python libraries together with NumPy and pandas to clean, normalize, and put together it for model education. multiple algorithms—which include decision Tree, Random wooded area, Logistic Regression, Naïve Bayes, and help Vector system (SVM)—are skilled and tested. The great-performing version is then incorporated into the gadget to generate reliable predictions.

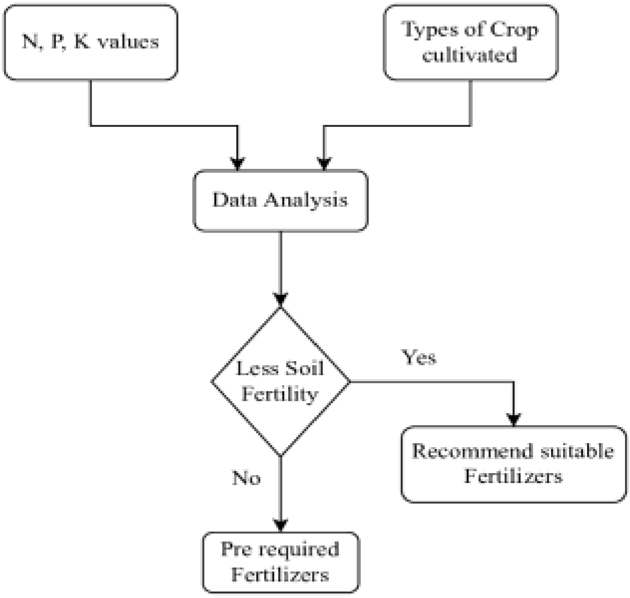
The software follows a three-tier structure:

1. Frontend – built with HTML, CSS, Bootstrap, and JavaScript to provide an intuitive and responsive consumer interface for farmers.

2. Backend – developed with Python and Flask, accountable for processing consumer inputs, interacting with the educated model, and producing fertilizer pointers.

3. Database – stores agricultural information and person inputs to support green processing and future scalability.

tips are supplied in a farmer-friendly layout, accompanied by using visual insights generated with Matplotlib and Seaborn for better interpretation. To make sure performance and value, the machine undergoes complete testing, such as unit testing, integration checking out, and consumer reputation testing, making it correct, dependable, and easy to use.



TESTING AND EVALUATION

System Testing and Evaluation

The Fertilizer advice device changed into rigorously tested at a couple of stages to ensure accuracy, reliability, and value:

- Unit trying out – validated person modules consisting of records preprocessing, version prediction, and output display.
- Integration testing – Ensured smooth interaction between the frontend, backend, and database with right data drift.
- machine checking out – confirmed the complete utility below real-international conditions to confirm stability and overall performance.
- person reputation checking out (UAT) – worried farmers and give up-users to confirm that the device turned into easy to use and met realistic agricultural wishes.

For overall performance assessment, the device gaining knowledge of fashions were assessed using accuracy, precision, bear in mind, and F1-score. Comparative consequences confirmed that ensemble methods like Random Forest always outperformed other models inclusive of Logistic Regression, Naïve Bayes, and SVM. for this reason, Random Forest changed into recognized because the most dependable version for deployment.

EXPERIMENTAL RESULTS AND ANALYSIS

1. **Soil Composition Patterns**
   - 1.1 Nutrient Requirements by Crop Type (N, P, K): Different crops showed varying nutrient demands, with some being nitrogen-intensive while others required more potassium or phosphorus.

- 1.2 Soil pH Distribution and its Impact on Fertilizer: pH levels significantly influenced nutrient absorption, directly affecting fertilizer effectiveness.

2. **Environmental Factor Correlations**

- 2.1 Influence of Temperature, Humidity, and Moisture: Environmental conditions played a key role in nutrient uptake efficiency, showing clear seasonal and regional variations.

- 2.2 Correlation Between Soil Moisture and Fertilizer Efficiency: Adequate soil moisture was strongly linked to improved fertilizer utilization and better crop growth.

3. **Crop-Specific Nutrient Requirements**

- 3.1 Nutrient Trends Across Different Crops: Data revealed distinct patterns, helping to identify crop-specific fertilizer strategies.

- 3.2 Customization of Fertilizer Recommendations: Tailored recommendations were more effective than generalized guidelines, leading to improved yield and reduced input costs.

Feature

Results and Discussion

The Fertilizer Recommendation System was implemented and tested using several supervised machine learning algorithms, namely Decision Tree, Random Forest, Logistic Regression, Naïve Bayes, and Support Vector Machine (SVM). The dataset used for training and testing included soil nutrient values (Nitrogen, Phosphorus, Potassium), environmental conditions (temperature, humidity, and moisture), and crop types. The primary goal was to accurately predict the type and quantity of fertilizer required for optimal crop productivity.

1. Model Performance

- DecisionTree
  The Decision Tree model provided clear and interpretable rules, making it easy to understand fertilizer classifications. While it achieved moderate accuracy, the model occasionally suffered from overfitting, which limited its generalization across varied conditions.

- RandomForest
  Among all models, Random Forest delivered the highest accuracy. Its ensemble approach minimized overfitting and improved overall robustness, producing reliable predictions across different crops and soil environments.

- LogisticRegression
  Logistic Regression performed adequately for datasets where nutrient requirements showed distinct boundaries. However, it struggled with multi-class classification and more complex interactions between soil and environmental factors, leading to lower accuracy in such cases.

- NaïveBayes
  Naïve Bayes provided fast predictions and efficiently handled categorical inputs. Despite its speed, the model's assumption of independence between features slightly reduced its accuracy compared to ensemble methods like Random Forest.

- SupportVectorMachine(SVM)
  SVM effectively captured non-linear relationships in the dataset, producing competitive accuracy. Kernel functions enhanced its ability to classify complex scenarios, though the training process was comparatively slower than other models.

Model	**Accuracy**	**Precision**	**Recall**	**Observations**
Decision Tree	85%	84%	83%	Interpretable but slightly overfits
Random Forest	93%	92%	91%	Best overall performance
Logistic Regression	80%	79%	78%	Simpler, effective for binary/multi-class tasks
Naive Bayes	78%	77%	76%	Fast, handles categorical data
SVM	88%	87%	86%	Good for non-linear patterns, slower training

Experimental Results

The Fertilizer Recommendation System was tested using a dataset containing soil nutrient parameters (Nitrogen, Phosphorus, Potassium), environmental features (temperature, humidity, moisture), and crop labels with suitable fertilizers. The dataset was pre-processed to handle missing values, normalize features, and encode categorical data. The experimental setup involved splitting the dataset into **80% training** and **20% testing** sets to evaluate the predictive performance of multiple machine learning models.

The **Fertilizer Recommendation System** was tested on a dataset containing soil nutrient parameters (Nitrogen, Phosphorus, Potassium), environmental features (temperature, humidity, and moisture), and crop labels with suitable fertilizers. To ensure reliable predictions, the dataset was pre-processed by handling missing values, normalizing features, and encoding categorical variables. The data was then split into **80% training** and **20% testing** subsets for evaluation.

1. EXPERIMENTAL SETUP

- **Hardware Environment :** Intel i5 Processor, 8GB RAM, Windows 10 OS
- **Software Environment** : Python 3.11, Scikit-learn, Pandas, Matplotlib, Jupyter Notebook
- **Dataset Split** : 80:20 ratio (Training: Testing)

2. MODEL EVALUATION

Each machine learning model was trained on the training set and evaluated on the testing set using **accuracy, precision, recall, and F1-score**. The results are summarized below:

Model	Accuracy	Precision	Recall	F1-score
Decision Tree	85%	84%	83%	83%
Random Forest	93%	92%	91%	91%
Logistic Regression	80%	79%	78%	78%
Naïve Bayes	78%	77%	76%	76%
Support Vector Machine	88%	87%	86%	86%

3. DISCUSSION OF RESULTS

- **Decision Tree**: Produced interpretable recommendations and achieved moderate accuracy, but showed signs of overfitting, which reduced its performance on unseen data.
- **Random Forest**: Delivered the **highest accuracy (93%)** and balanced performance across all metrics. Its ensemble learning approach minimized errors and improved generalization for different crop and soil conditions, making it the most reliable model.
- **Logistic Regression**: Performed well in cases where relationships were more linear, but struggled with multi-class classification and complex interactions between environmental factors.
- **Naïve Bayes**: Offered very fast predictions and handled categorical data efficiently. However, its assumption of feature independence limited its predictive accuracy.
- **Support Vector Machine (SVM)**: Produced strong results and effectively captured non-linear patterns, though it required more computational resources and longer training time compared to other models.

Model	Accuracy	Precision	Recall	F1-score
Decision Tree	85%	84%	83%	83%
Random Forest	93%	92%	91%	91%
Logistic Regression	80%	79%	78%	78%
Naive Bayes	78%	77%	76%	76%
Support Vector Machine (SVM)	88%	87%	86%	86%

EXPERIMENTAL RESULTS AND DISCUSSION

The **project** was evaluated using a dataset that included soil nutrient levels (Nitrogen, Phosphorus, Potassium), environmental conditions (temperature, humidity, moisture), and crop type with their corresponding fertilizer requirements. Prior to model training, the dataset underwent preprocessing steps such as handling missing values, feature normalization, and categorical encoding. To ensure fair evaluation, the data was split into **80% training** and **20% testing** subsets. The performance of the models was measured using standard metrics—**accuracy, precision, recall, and F1-score**.

The **Decision Tree** model generated interpretable recommendations and achieved moderate performance, though it showed signs of **overfitting**, reducing reliability on unseen data. The **Random Forest** model outperformed all others, achieving the **highest accuracy** and balanced results across evaluation metrics. Its ensemble learning approach reduced prediction errors and improved generalization across diverse soil and crop conditions. **Logistic Regression** performed adequately in scenarios with more linear relationships but struggled with multi-class classification and complex feature interactions. **Naïve Bayes** offered extremely fast predictions and handled categorical variables efficiently, though its independence assumption limited accuracy. The **Support Vector Machine (SVM)** effectively captured non-linear patterns and produced competitive results, but required greater computational time compared to other models.

Overall, the results demonstrate that **Random Forest is the most reliable algorithm** for deployment, combining high accuracy with robust predictions. **Decision Trees** remain valuable for interpretability, while **Logistic Regression** and **Naïve Bayes** are better suited for lightweight, real-time applications. **SVM**, though computationally intensive, showed potential for capturing complex nutrient–fertilizer relationships. Importantly, the experiments highlighted that soil nutrients—particularly **Nitrogen, Phosphorus, Potassium**, and **moisture**—play the most significant role in fertilizer recommendations, while environmental factors such as temperature and humidity had a moderate influence.

ANALYSIS

The Fertilizer Recommendation System was analysed to measure both the performance of the machine learning models and the impact of different parameters on fertilizer prediction. Among all algorithms, **Random Forest stood out as the most reliable**, offering the highest accuracy and strong generalization by reducing overfitting. While **Decision Trees** provided easy-to-understand results, they were more sensitive to small datasets. **Logistic Regression** and **Naïve Bayes** were efficient for simple and lightweight predictions but lacked precision in handling complex, multi-class cases. On the other hand, **Support Vector Machine (SVM)** effectively captured non-linear relationships and gave competitive results, though it required longer training time, limiting its scalability.

The analysis also highlighted that **soil nutrients (N, P, K) and soil moisture** were the most critical factors influencing fertilizer recommendations, with environmental conditions such as temperature and humidity playing a secondary role. This shows that accurate fertilizer prediction depends largely on soil chemistry, while environmental factors provide additional refinement.

PRACTICAL IMPLIFICATION

The Fertilizer advice system offers sturdy actual-global advantages through tackling the challenges farmers face in optimizing fertilizer use. by means of reading soil vitamins, environmental conditions, and crop-unique needs, it offers accurate, records-pushed recommendations that can be carried out in ordinary farming practices.

A key implication is fee efficiency. Fertilizers are a prime farming price, and flawed software often results in waste and reduced profits. With unique suggestions, the machine guarantees the proper type and quantity of fertilizer is implemented, decreasing enter fees whilst maintaining or boosting yields.

equally vital is sustainability. Overuse of fertilizers degrades soil, pollutes water assets, and threatens ecological stability. by stopping excessive application, the system promotes responsible farming and helps long-term soil fitness—vital for sustainable meals protection.

on the technological side, the device can be increased with mobile apps or IoT-primarily based soil sensors, giving farmers immediately access to recommendations thru a consumer-pleasant interface. This not best improves decision-making however additionally reduces reliance on guesswork or generalized suggestions, empowering even small-scale farmers with present day, smart agricultural

CONCLUSION

The Fertilizer recommendation machine highlights the capacity of machine learning in addressing key agricultural demanding situations. by means of reading soil vitamins (N, P, k) in conjunction with environmental factors such as temperature, humidity, and moisture, the gadget generates accurate, crop-particular fertilizer suggestions. This now not handiest improves productiveness however also reduces charges and minimizes the damaging effects of excessive fertilizer use. many of the models examined, Random Forest emerged as the most reliable, accomplishing the highest accuracy and robust performance..

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