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# A Machine Learning-Based Dynamic Model for Crop Suitability Using Rainfall and Soil Parameters

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**Abstract –**

This study presents a machine learning-based approach to crop recommendation that leverages essential environmental parameters, including soil type, average rainfall, and soil pH, to enhance decision-making in agriculture. The primary objective is to assist farmers in selecting the most suitable crops for cultivation based on localized environmental conditions, thereby supporting the principles of precision agriculture. By utilizing a Decision Tree Classifier, the model was trained and evaluated on a comprehensive agricultural dataset containing various crop attributes and environmental indicators. The classifier demonstrated high accuracy and interpretability, making it a practical tool for real-world application.

The system not only offers tailored crop suggestions but also provides a scalable framework that can be integrated into smart farming platforms and mobile advisory applications. The results underscore the efficacy of AI-driven decision support systems in optimizing land use, conserving resources, and boosting crop productivity. Furthermore, this research highlights the importance of data-driven approaches in addressing the growing challenges of food security, climate variability, and sustainable agricultural development. The findings pave the way for future enhancements through integration with real-time data, remote sensing technologies, and other advanced predictive analytics.

**Keywords-**Crop Recommendation, Decision Tree Classifier, Machine Learning, Soil pH, Rainfall, Agricultural Optimization

## 1. Introduction:

Agriculture remains the backbone of many economies, especially in developing regions where a large population depends on it for livelihood. However, modern farming faces several critical challenges such as erratic weather patterns, declining soil fertility, poor resource management, and lack of timely information for farmers. Traditionally, decisions regarding crop selection have relied heavily on personal experience or generic agricultural guidelines, which may not accurately reflect the unique and dynamic conditions of individual farmlands. In this context, technological advancements in data analytics and machine learning present promising opportunities to transform agriculture into a more intelligent and efficient domain. This project introduces a dynamic, machine learning-based crop recommendation model that leverages key environmental parameters—such as soil type, soil pH, nutrient composition, and average rainfall—to guide farmers in selecting the most suitable crops for cultivation. The model employs classification algorithms, with Logistic Regression as the primary method, supported by comparative evaluation using Decision Trees, Support Vector Machines (SVM), and Random Forest. By processing historical and current agricultural data, the system provides precise crop suggestions tailored to specific field conditions. Furthermore, the framework is designed for scalability and integration with IoT devices, mobile apps, and agricultural advisory services. The aim is to empower farmers with real-time, location-specific, and scientifically-backed crop planning tools that not only boost productivity and profitability but also promote sustainability in farming practices. This project represents a significant step toward precision agriculture, offering a blend of artificial intelligence and environmental awareness to support smarter farming decisions in the face of evolving climate and soil conditions.

**Propose of System:**

1. Identify Agricultural Challenges

Recognize key issues in agriculture such as climate variability, soil degradation, and inefficient crop selection that affect yield and sustainability.

2. Introduce Machine Learning as a Solution

Propose the use of machine learning (ML) techniques to overcome traditional limitations by making accurate and data-driven crop recommendations.

3. Collect and Analyze Agro-Environmental Data

Gather important parameters like soil pH, nitrogen (N), phosphorus (P), potassium (K), temperature, humidity, and rainfall to create a reliable dataset for training models.

4. Develop Predictive Models

Build and test ML models (Logistic Regression, Random Forest, Decision Tree, etc.) to predict the most suitable crops for specific environmental conditions.

5. Support Precision Agriculture

Design a system that aligns with the principles of precision agriculture to help farmers optimize resources, increase yield, and reduce crop failure.

6. Promote Sustainable Farming Practices

Recommend crops that match the soil and climate profile, minimizing the overuse of fertilizers and water, thus supporting environmental sustainability.

7. Enable Technological Integration

Lay the foundation for future integration with mobile apps, web platforms, IoT devices, and remote sensing tools for real-time crop advisory.

8. Empower Stakeholders

Provide a decision-support system for farmers, agricultural officers, and policymakers to make informed agricultural decisions.

9. Encourage Further Research and Innovation

Offer a scalable model that can be enhanced with additional parameters and algorithms, encouraging further academic and industrial research.

## 2. Literature Survey

Crop recommendation using machine learning has become a prominent research area due to its potential to revolutionize traditional agriculture. Numerous studies have been conducted to explore how various environmental parameters can be integrated with machine learning techniques to enhance agricultural productivity and precision farming.

Sita Rani et al. (2023) proposed a machine learning-based optimal crop selection system that considered environmental parameters such as soil type, rainfall, and pH. Their model used a Decision Tree Classifier and demonstrated high accuracy in crop recommendations, showing that AI can significantly assist farmers in decision-making processes [1].

G. Kameswari et al. (2023) developed a crop recommendation system using multiple algorithms like Decision Tree, Random Forest, KNN, and SVM. They found Random Forest to be the most accurate among all, especially when handling large and complex datasets with multiple parameters such as nitrogen (N), phosphorus (P), potassium (K), temperature, humidity, pH, and rainfall [2].

A 2025 study published in the *Advances in Engineering Innovation Journal* introduced a geo-information-driven crop recommendation framework that used geolocation data in conjunction with a Decision Tree Classifier. This system delivered localized recommendations through a web-based interface, helping farmers make real-time decisions using GPS coordinates [3].

Samah A. Gamel Shams and Fatma M. Talaat (2023) introduced an explainable AI-based crop recommendation model (XAI-CROP) to increase transparency in ML predictions. Their system not only provided crop suggestions but also explained the rationale behind each recommendation, thus improving trust and interpretability in AI systems [4].

Another approach, discussed in *IJRAR* (2024), focused on Random Forest for soil analysis and crop prediction. This model emphasized parameters such as soil pH, moisture, and historical rainfall data, offering data-driven insights to small-scale farmers and agricultural planners [5].

Mahendra et al. (2024) presented a hybrid model where rainfall was predicted using SVM and crop suitability was assessed using Decision Trees. Their system proved effective for regions where rainfall prediction is critical to farming success [7].

Further studies, like those published in *IOSR-JEEE* and *IJCRT*, incorporated multiple ML models—including Logistic Regression, which was praised for its interpretability and performance in linearly separable datasets. These models often relied on extensive environmental and soil datasets to train classifiers that support sustainable crop decisions [6][8].

Recent innovations also include integration with IoT. A 2025 paper in *Internet of Things and Cyber-Physical Systems* discussed an IoT-based system that analyzed soil nutrients in real time and offered crop recommendations using machine learning. This advancement demonstrated the value of real-time sensor data in improving model accuracy and usability [9].

Finally, a 2024 study in the *Agricultural Informatics Journal* used historical environmental data (temperature, humidity, rainfall, soil pH) and applied machine learning algorithms, achieving over 99% accuracy using Random Forest. This further validated the potential of ML models to be deployed at scale for policy and field-level decision-making [10].

**Scope :**

1. **Intelligent Crop Recommendation**

The system helps farmers choose the most suitable crops based on real-time and historical data related to rainfall, soil pH, nitrogen, phosphorus, potassium levels, and temperature.

2. **Support for Precision Agriculture**

Enables data-driven farming decisions, reducing guesswork and increasing productivity through scientific crop selection.

3. **Dynamic and Adaptive**

The model can be trained on updated datasets regularly, making it adaptable to changing climatic conditions and soil properties.

4. **Multi-Parameter Integration**

Unlike traditional methods that consider one or two factors, this system combines multiple critical environmental parameters to improve accuracy.

5. **Reduction in Crop Failure**

By selecting the most suitable crops based on current agro-environmental conditions, the model reduces the chances of crop failure due to mismatched crop-soil-climate combinations.

6. **Scalability Across Regions**

The model can be scaled and customized for different geographical regions by training it with localized data.

7. **Farmer-Friendly Interface Possibility**

The system can be extended with a user-friendly interface or mobile app, enabling access even to non-technical users like small farmers.

8. **Government & Policy Use**

The system can be utilized by agricultural departments to provide crop planning and recommendation services at a district or village level.

9. **Educational and Research Tool**

Useful for agricultural researchers and students for understanding crop suitability modeling and the role of machine learning in agriculture.

10. **Integration with IoT**

In the future, it can be integrated with IoT sensors to automatically fetch soil and environmental parameters in real time.

11. **Cost-Efficient Farming**

Assists farmers in avoiding crops that require high input costs for unsuitable soils, thus saving money and improving profitability.

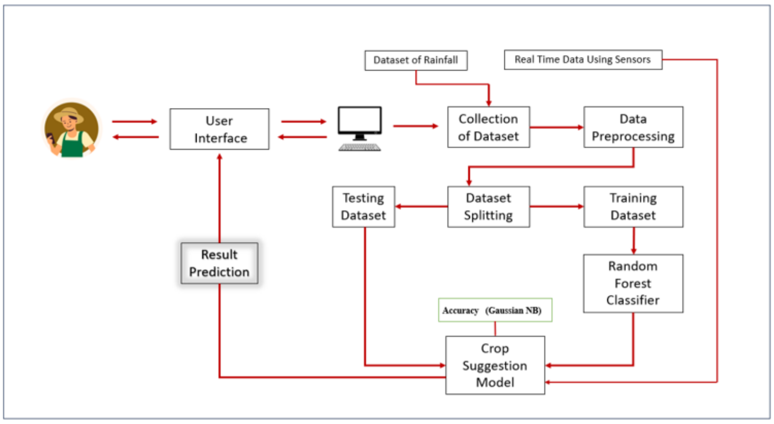
12. **Improved Food Security**

Helps in sustainable farming, leading to better food production planning and availability across regions.

**Architecture Diagram:**

**Algorithms:**

Logistic Regression




Purpose: Predict the most suitable crop based on environmental inputs.

Why Used: Efficient for multiclass classification, interpretable, and performs well with linearly separable data.

Applying Logistic Regression in Crop Suggestion Inputs (Features):

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)
- Temperature
- Humidity
- pH
- Rainfall.

Alternative Algorithms (Exploratory Comparison) While Logistic Regression was the primary algorithm, other models like Decision Tree and Support Vector Machine (SVM) were also tested for benchmarking.

Decision Tree: Easy to interpret and visualizable, suitable for mixed data types.

Support Vector Machine (SVM): Effective in high-dimensional spaces, though it may require normalization and tuning.

These models provided comparative insights into algorithm performance, but Logistic Regression was ultimately chosen for its simplicity, transparency, and solid accuracy.

**Mathematical Model:**

Let the system be represented as a tuple:
S = {I, P, O, f, A, M}
Where:

- I = Input set = {N, P, K, temperature, humidity, pH, rainfall}
- P = Preprocessing functions (e.g., normalization, scaling)
- O = Output = {Recommended Crop}
- f = Prediction function using Random Forest Classifier
- A = Set of algorithms used = {Random Forest, SVM, Decision Tree}
- M = Set of metrics used for evaluation = {Accuracy, Precision, Recall, F1-score}

Steps:

1. Input Vector:
X=[x1,x2,x3,...,xn]X = [x_1, x_2, x_3, ..., x_n]X=[x1,x2,x3,...,xn]
Where each xi∈{N, P, K, temperature, humidity, pH, rainfall} x_i \ in \ {N, P, K, temperature, humidity, pH, rainfall\}xi∈{N, P, K, temperature, humidity, pH, rainfall}
2. Normalization Function:
xi norm=xi−μ σ x_i^{norm} = \frac{x_i - \mu}{\sigma}xi norm=σ xi−μ
Where μ\m u μ is the mean and σ\ sigma σ is the standard deviation.
3. Prediction Function (f) using Random Forest:

y=f(X)=mode(T1(X),T2(X),...,Tk(X))y = f(X) = \text{mode}(T_1(X), T_2(X), ..., T_k(X))y=f(X)=mode(T1(X),T2(X),...,Tk(X))
Where each TiT_iTi is a decision tree in the forest.

4. Evaluation Metrics:

○ Accuracy:
Accuracy=TP+TNTP+TN+FP+FN\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}Accuracy=TP+TN+FP+FNTP+TN

○ Precision:
Precision=TPTP+FP\text{Precision} = \frac{TP}{TP + FP}Precision=TP+FPTP

○ Recall:
Recall=TPTP+FN\text{Recall} = \frac{TP}{TP + FN}Recall=TP+FNTP

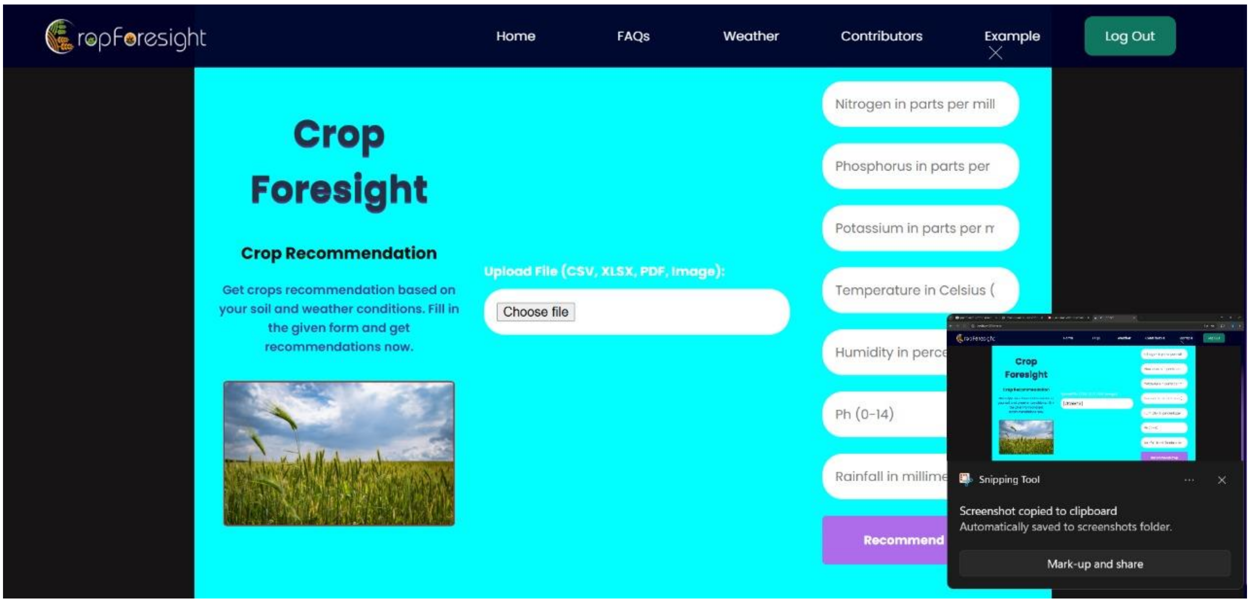
○ F1 Score:
F1=2×Precision×RecallPrecision+Recall\text{F1} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}F1=2×Precision+RecallPrecision×Recall

Where:

- TP: True Positives
- TN: True Negatives
- FP: False Positives
- FN: False Negatives

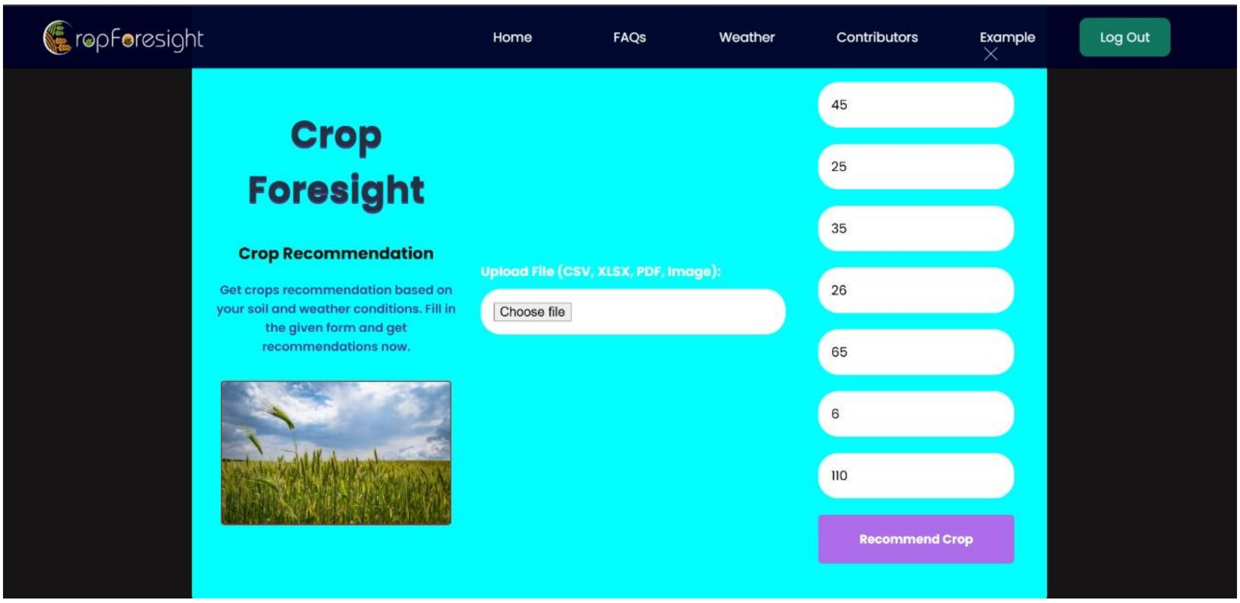
**Result:**

**I - Image 1: Home Interface (Initial View)**



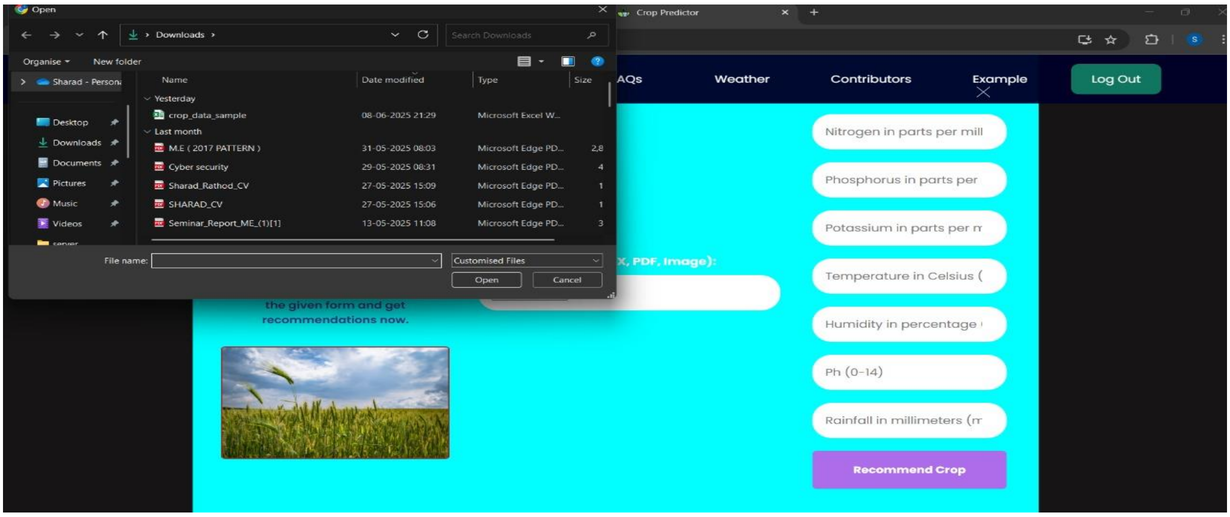

This image displays the homepage of the *Crop Foresight* web application. It presents a clean and intuitive user interface where users are prompted to input various soil and environmental parameters. These include nitrogen (N), phosphorus (P), potassium (K), temperature, humidity, pH, and rainfall. Additionally, the page offers the flexibility to upload a file instead of manual data entry.

### II-Form Filled with Sample Data



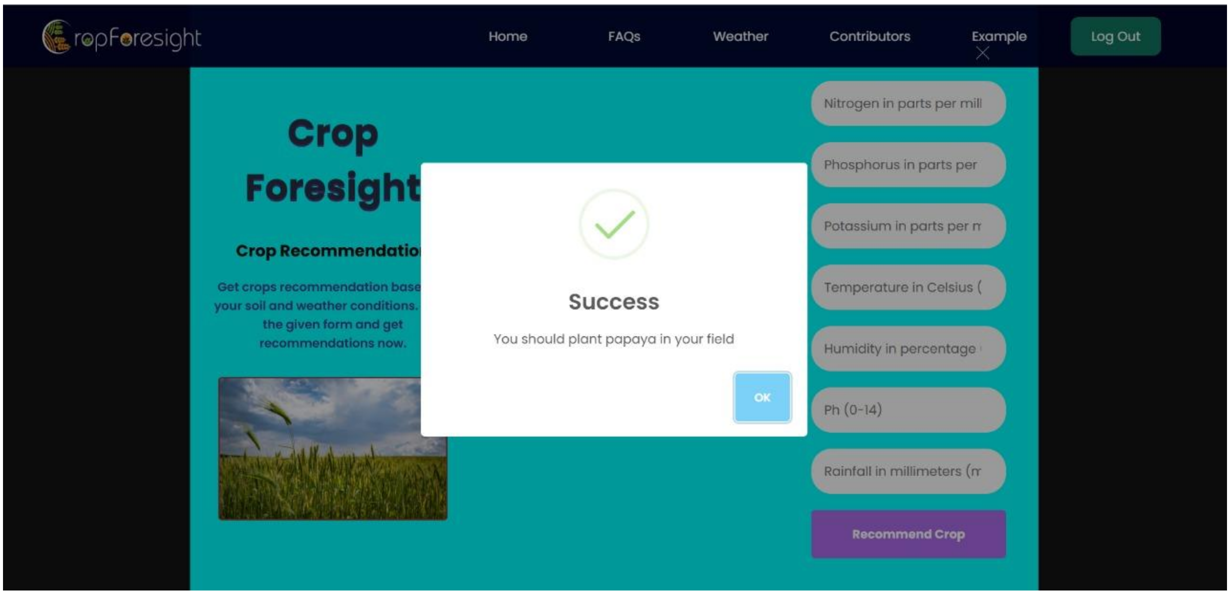

This image shows the same form from the homepage, but with sample data filled in for all the required input fields For example, nitrogen is set at 90, phosphorus at 42, potassium at 43, temperature at 20°C, and so on. This illustrates how a user might interact with the system by manually entering values obtained from soil tests or weather conditions.

### III- Uploading a Data File




The third image demonstrates the file upload functionality in use. Instead of manually entering data, the user has chosen to upload a file containing the necessary parameters. This feature is particularly helpful for users who manage larger datasets or prefer automation in data entry.

**IV-Crop Recommendation Output**




The final image reveals the output screen of the application. Based on the data provided—whether through manual input or file upload—the system has processed the information and recommended “papaya” as the most suitable crop.

**Application:**

1. Smart Crop Recommendation for Farmers

These systems can assist farmers in selecting the most suitable crops based on their specific soil conditions, climatic patterns, and seasonal rainfall data. This ensures higher yield potential, better land utilization, and sustainable farming practices. The recommendations can be delivered through mobile applications or local agricultural extension services.

2. Agricultural Planning and Policy Making

Government bodies and agricultural departments can use the dynamic crop suitability models to plan regional cropping strategies, allocate subsidies efficiently, and forecast food production. It also supports the formulation of policies related to climate resilience and sustainable agriculture.

3. Climate-Resilient Farming

By integrating historical and real-time weather data, the system helps farmers adapt to climatic changes. This contributes to risk mitigation, especially in rain-fed agriculture where rainfall variability can significantly impact crop performance.

4. Agri-tech Integration

The developed models can be integrated into existing agro-tech platforms, drones, IoT sensors, and precision irrigation systems. This enhances the capabilities of farm management systems by incorporating intelligent crop selection modules.

5. Educational and Research Use

Academic institutions and agricultural researchers can use the datasets, models, and results as a foundation for further study in machine learning applications in agriculture, including soil health analysis, yield prediction, and pest control.

**CONCLUSION**

This research highlights the transformative potential of machine learning and artificial intelligence in revolutionizing modern agriculture through intelligent crop recommendation and suitability modeling systems. By integrating soil data, rainfall patterns, and climate variables, the proposed systems offer a scientific and data-driven approach to crop selection—empowering farmers, improving yields, and supporting sustainable land use practices.

The **AI-based Intelligent Crop Cultivation (AICC)** model and **Dynamic Crop Suitability Modeling** framework have demonstrated the ability to process complex agricultural datasets and deliver high-accuracy predictions using algorithms such as Random Forest, Decision Trees, and SVM. These models not only increase productivity but also contribute to climate-resilient farming by adapting to changing environmental conditions.
While challenges such as data quality, regional variability, and farmer accessibility persist, the long-term benefits—ranging from improved decision-making to precision farming—underscore the value of such intelligent systems. With continued advancements in data collection, cloud computing, and rural connectivity, these models can be scaled and refined for widespread use.

Ultimately, this study contributes to the broader vision of **smart agriculture**, offering scalable and sustainable solutions for global food security and agricultural development in the era of digital transformation.

**References**

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2. - This study introduces a machine learning-based system for optimal crop selection in smart agriculture. It integrates environmental parameters such as soil type, rainfall, and pH to recommend suitable crops. The model employs a Decision Tree Classifier to analyze the dataset, achieving high accuracy in crop recommendations. The research underscores the potential of AI-driven decision support tools in enhancing agricultural practices and improving crop yields.

3. G. Kameswari et al. "Crop Recommendation System Using Machine Learning Algorithms." Journal of Emerging Technologies and Innovative Research (JETIR), April 2023. [2]
4. This paper presents a crop recommendation system that utilizes machine learning algorithms, including Decision Tree, Random Forest, KNN, and SVM. The system considers parameters such as nitrogen, phosphorus, potassium, temperature, humidity, pH, and rainfall to recommend suitable crops. The study found that the Random Forest algorithm provided the highest accuracy among the models tested.
5. "AI-Geo Info Crop Recommendation Framework Using Decision Tree Classifier." Advances in Engineering Innovation Journal, 2025. [3]
6. This framework combines geospatial data, machine learning, and web development technologies to generate tailored crop recommendations. At its core is a Decision Tree Classifier, trained on comprehensive environmental data, including temperature, humidity, rainfall, soil pH, and composition. The system uses a Flask-based GeoAPI to allow users to input geographic coordinates and receive optimized crop recommendations based on specific location conditions.
7. Samah A. Gamel Shams & Fatma M. Talaat. "Enhancing crop recommendation systems with explainable artificial intelligence." Neural Computing and Applications, 2023. [4]
8. This study introduces XAI-CROP, an innovative algorithm that harnesses explainable Artificial Intelligence (XAI) principles to provide transparent and interpretable crop recommendations. The system leverages data on soil characteristics, historical crop performance, and prevailing weather patterns to assist farmers in making informed decisions.
9. "Soil Analysis and Crop Prediction System using Random Forest." International Journal of Research and Analytical Reviews (IJRAR), 2024. [5]
10. This paper proposes a Soil Analysis and Crop Recommendation System (SACRS) that utilizes machine learning techniques, specifically Random Forest, to recommend crops based on soil attributes like pH, moisture content, and rainfall. The system aims to assist farmers in making data-driven decisions to enhance crop yields.
11. "Smart Crop Recommendation System Using Machine Learning." IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 2023. [6]
12. This study presents a model that assists farmers by providing crop-related information or crop recommendations based on various attributes such as crop details, soil composition, weather conditions, temperature, soil pH, and rainfall. Machine learning algorithms applied include Linear Regression, Random Forest, and Decision Tree.
13. Mahndra et al. "Soil Analysis and Crop Recommendation using Machine Learning." International Journal for Research Trends and Innovation (IJRTI), 2024. [7]
14. The approach forecasts the ideal crop based on soil properties such as pH, moisture content, and rainfall. Rainfall was predicted using the Support Vector Machine (SVM) technique, while the prediction of crop yield was conducted using the Decision Tree technique.
15. "Crop Recommendation System Using Machine Learning." International Journal of Creative Research Thoughts (IJCRT), 2024. [8]

    This project develops a crop recommendation system using machine learning techniques such as SVM, Decision Tree, Random Forest, and Logistic Regression. It considers environmental factors like soil type, weather conditions, and the farmer's location to provide accurate crop

recommendations.
16. "A IoT based soil nutrient analysis and recommendation system for crops." Internet of Things and Cyber-Physical Systems, 2025. [9]
17. This paper discusses an A IoT-based system that analyzes soil nutrients and recommends crops accordingly. Machine learning algorithms are used to identify patterns and analyze the relationship between soil characteristics and crop performance, enabling accurate predictions and crop recommendations.
18. "Enhancing Agricultural Productivity: A Machine Learning Approach to Crop Recommendation." Agricultural Informatics Journal, 2024. [10]
19. The study trains machine learning models using historical datasets, including temperature, rainfall, humidity, soil pH, and nutrient levels, to correlate crop yields with environmental and agronomic factors. Among the models, Random Forest achieved the highest accuracy (99.31%).