Machine Learning Based Crop Recommendation System

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***Abstract*— In a country where conventional farming methods are still widely used and often result in small yields and little profit for farmers, our goal is to increase crop yields by presenting a range of farming techniques through a recommendation system for intelligent farming. This system uses a scientific method to forecast the best crops depending on a number of important factors, such as the nutrients in the soil. It pinpoints nutritional deficits in the soil for particular crops. Our system, which is implemented as a website, makes use of crop dataset that include parameters for temperature, rainfall, pH, and humidity. It then applies a variety of ML algorithms to make accurate and efficient crop recommendations, achieving impressive metrics such as accuracy of 96.08%, precision of 93%, and recall of 45%.**

Keywords—Crop, Fertilizer, Nitrogen, Potasium, Rainfall, Recommendation.

I. Introduction

A significant economic sector in India is agriculture for sustenance, but farmers often face challenges like debt and climate change, leading to suicides. Precision farming and machine learning offer solutions by recommending crop quality depending on factors such as soil nutrients and climatic conditions. This paper aims to predict crop production accuracy for various crops in India using unsupervised machine learning techniques include logistic regression, decision trees, support vector machines, and gaussian naïve bayes.[1] Crop selection is pivotal for farmers, impacting yields directly. Traditionally, expert consultation is sought, yet it's costly and time-consuming. Recommender Systems (RSs) offer an alternative, leveraging data to suggest suitable crops, akin to how Amazon recommends products. RSs' adoption in agriculture, however, lacks a standardized classification scheme, hindering development and adoption. Thus, this systematic literature review (SLR) aims to bridge this gap by identifying trends, techniques, input features, evaluation criteria, and challenges in Crop Recommendation (CR). Through unbiased analysis, it seeks to enhance decision-making in agriculture, helping farmers make knowledgeable crop decisions selections efficiently [2]. For farmers, choosing crops is crucial because it directly affects yields. Expert consultation is traditionally sought after, but it is expensive and time-consuming. As an alternative, recommender systems (RSs) use data to make recommendations for appropriate crops, much like Amazon does with product recommendations. However, the lack of a standardized classification scheme prevents the development and implementation of RSs in agriculture. In order to close this gap, this systematic literature review (SLR) identifies trends, methods, input characteristics, evaluation standards, and difficulties in crop recommendation (CR). It aims to improve agricultural decision-making by objective analysis, empowering farmers to choose crops with knowledge and efficiency. [3] The agricultural sector in African nations, employing two-thirds of the workforce, faces challenges from climate change, affecting crop yield prediction. While traditional statistical models are time-consuming, machine learning offers promise. Yet, the lack of transparency in machine learning models like Crop Recommendation Systems (CRS) hinders trust. To address this, the proposed XAI-CROP algorithm enhances transparency and interpretability, aiding farmers' decision-making. [4] Agriculture, a vital profession in India, faces challenges in adopting modern methods. To bridge the gap, this paper focuses on simpler parameters like district, rainfall, and temperature to aid farmers in predicting crop yield and selecting the right crop. By simplifying technical complexities, this approach aims to empower farmers and improve agricultural outcomes. [5] India's agriculture, employing 58% of the population and contributing 17% to GDP, faces challenges in crop selection due to diverse terrain and climate. Climate-smart practices and precision agriculture aim to address these challenges, utilizing deep learning techniques to develop crop suggestion systems customized for a given area. This research proposes an algorithm that optimizes crop selection according to terrain and climatic circumstances using graph convolution neural networks. [6] The agriculture sector in India faces challenges with declining harvest yields and uncertain crop choices due to climate vulnerability. In this study, an approachable recommender system, integrating machine learning algorithms to forecast harvest production and suggest optimal crop selection considering environmental and economic factors. By considering variables like precipitation, temperature, soil type, the model aims to enhance harvest yield and meet the country's food demand. [7] India's agricultural sector is vital to the livelihoods of over half the population, but challenges like farmer suicides and crop selection errors persist. Precision farming, aided by IoT technology, offers solutions by providing real-time data for improved decision-making. Machine learning models are employed to offer crop recommendations considering both economic and environmental factors, aiming to enhance

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agricultural sustainability and profitability. Recommendation systems analyse user data to predict their interests and suggest relevant items or services [8]. Initially focusing on ratings, they now incorporate diverse data sources for personalized recommendations. Widely used in e-commerce, entertainment, social media, and even healthcare, recommendation systems enhance user experience by providing tailored suggestions based on preferences and behaviour. Agriculture in India faces numerous challenges due to various factors like climate change, soil degradation, and natural disasters [9]. With agriculture being the foundation of the national economy, it's crucial to empower farmers with modern techniques and knowledge. Multi-criteria decision-making methods like DRSA and Shannon's Entropy aid in crop selection, while VIKOR method assists in ranking alternatives. Emerging approaches like soft set theory further enhance decision-making in agriculture, ensuring sustainable practices and improved yields. In order to estimate crop yields, machine learning analyses a variety of elements including soil, climate and agricultural method [10]. A literature review was conducted to identify gaps in existing research and gather insights. The goal of this review is to give a thorough introduction to machine learning applications in crop yield prediction, guiding future research and enhancing agricultural productivity [11].

II. LITERATURE SURVEY

Dighe et al. [12] evaluate a range of algorithms, including CHAID, KNN, Decision Tree, and Neural Network. It also explored the utilization of the Hadoop framework for intricate computations. Furthermore, the research delved into the application of ensemble models to elevate the precision of recommendations. The primary aim was to empower farmers with data-driven insights for optimizing crop yields and overall returns, particularly in regions where agriculture plays a central economic role.

Reddy et al. [13] introduced a crop recommendation system, employed an ensemble model that uses majority voting to combine several algorithm such as Random tree, CHAID, K-nearest neighbour and Naïve bayes. This system focused on suggesting the most appropriate crop choices rooted in soil parameters, emphasizing precision and speed. Moreover, it leveraged categorized images containing crucial information, such as weather data, crop yield, and regional crop statistics, enabling the forecasting of crop yields under distinct weather conditions.

Kanaga and Raja [14] explored into predictive crop modelling, emphasizing soil features, crop traits, and water resources. They investigated the impact of crucial nutrients like Phosphorus, Nitrogen, Magnesium, and Sulphur, employing a hybrid method that united Neural Networks and Image Processing. Clustering algorithms and the k-Nearest Neighbour technique unveiled concealed patterns within extensive datasets.

Attaluri et al. [15] highlighted India's agriculture-dependent economy, with 18% of its GDP attributed to the sector. Agriculture 4.0 incorporated modern technologies and precision farming techniques, employing advanced tools like data science and machine learning algorithms to discern factors contributing to profitable crop cultivation in India. These methods were applied to historical data from various government sources and publicly available datasets, culminating in a crop recommendation system aimed at enhancing farmers' economic well-being. Factors such as planting and harvesting costs, rainfall, crop demand, seed and fertilizer expenses, and crop yield were meticulously analyzed to yield more accurate predictions regarding crop profitability.

Kiruthika's and Kratika [16] proposed enhanced farming technology. They introduced an innovative approach that merged IDCSO and WLSTM with IoT technology for precise and expedited crop prediction, which considers climate and crop data. This method aimed to improved farming efficiency and accuracy, demonstrating its superiority over conventional systems in experimental results, offering a potential solution to India's agricultural challenges.

Amalia et al. [17] discussed techniques like Ridge Regression and Classifiers, using diverse datasets for improved accuracy. To maximize crop output and therefore help satisfy the nation's growing demand for food supplies, the proposed model allowed crop selection based on economic and environmental variables. The suggested model examined variables like State, District, area, and season to forecast the agricultural production. The optimal timing for applying fertilizers is also determined by the system.

Manjula and Narsimha [18] proposed a system that fostered communication among farmers, experts, and data sources to deliver customized recommendations for crop and fertilizer choices. Its goal was to boost crop yields and assist farmers in making knowledgeable choice regarding the best crops for their area. The system also offered strategies for agricultural practices and help in the selection of fertilizers and pesticides.

Desai et al. [19] variables are sowing seasons, geographical locations, and soil attributes were factored in to deliver tailored crop suggestions. Furthermore, the system forecasted the anticipated yield should recommended crop be cultivated. The objective of the study was to enhance agricultural methods and augment crop productivity in India.

Hasan et al. [20] research utilized data preprocessing and a group machine learning approach to forecast significant crop yields called k-nearest neighbour random forest ridge regression (KRR) exhibited superior predictive accuracy compared to traditional models, offering potential solutions to optimize crop production. Additionally, a recommender system aided in crop selection for specific land areas, benefiting both the agricultural sector and farmers.

Waldia [21] introduced and applying machine learning methods including gradient boosting, random forest, decision tree, KNN, and naïve bayes These algorithms were utilized in order to recommend which crops would be best suited for growing in various soil profiles.

Vivek et al. [22] identifies effective data mining algorithms were identified machine learning, specifically Multiple Linear Regression, was employed to predict the most suitable crops for optimal yields considering current environmental conditions. The study aimed to analyse soil data, categorize soil types, and predicts unexplored attributes through regression techniques, ultimately assisting farmers to choose the right crops for their land properties and environmental conditions.

Kadam et al.[23] introduced a recommendation system utilizing deep learning techniques and a vast dataset for evaluating soil conditions and other factors, ultimately delivering crop suggestions. It established a neural network-based crop recommendation model and evaluated its efficacy compared to conventional machine learning models.

Bandara et al. [24] aimed to deliver precise crop recommendations considering site-specific parameters and environmental factors. It made use of natural language processing, k-means clustering for unsupervised learning and machine learning methods including Naïve Bayes and Support Vector Machine.

Parikh et al. [25] study concentrated on crafting a predictive model. This model took into account diverse factors to propose the optimal crops for planting on a particular farm. The system's primary objective was to amplify agricultural productivity and efficiency, curbing resource wastage and affording farmers the advantage of data-driven crop selection, resulting in improved decision-making based on scientific principles.

Hingmire [26] harnessed machine learning, with a particular focus on the Random Forest algorithm, for crop prognostication. It acquired data along with vital variables like temperature, humidity, and moisture levels to enable precise crop growth predictions. The study entailed the creation of a web application, streamlining the collection of user-specific data such as temperature and soil conditions to initiate the crop forecasting procedure.

Omkar et al. [27] introduced a crop recommendation and prediction system. It utilized user-provided data encompassing moisture, pH, NPK values, temperature, and rainfall. The system leveraged supervised machine learning algorithms such as Logistics Regression, Random Forest, and Decision Trees to establish a predictive model, delivering customized crop recommendations to farmers.

Shinde et al. [28] explored crop analysis and prediction, essential to agricultural optimization. Using machine learning, the research evaluated seven distinct algorithms for forecasting appropriate crops depending on temperature and soil composition data, consistently achieving high accuracy levels. This technology had transformative potential for agriculture, enhancing crop yields, sustainability, and profitability across various scales. It addressed the demand for efficient, data-driven agricultural practices in a dynamic environment.

The author [29] presented a precision-oriented crop recommendation system that integrated Artificial Intelligence (AI) and an array of machine learning techniques. Utilizing a dataset with various variables, such as NPK levels, temperature, and humidity, the study applied methodologies like SMOTE to balance and optimize data for improved system performance. Significantly, Gradient Boosting and Gaussian Naive Bayes (GNB) demonstrated exceptional accuracy and precision, underscoring the capacity of AI and machine learning to improve crop selection and harvest quality in the context of Indian agriculture.

Kavya et al. [30] implemented sophisticated and sustainable production paradigms. The Crop Recommendation System championed the judicious selection of crops based on intricate soil compositions and meteorological variables, leveraging cutting-edge machine learning algorithms for precision. A comprehensive evaluation of model performance, encompassing K-Nearest Neighbors (KNN), Random Forests, and Decision Trees guided the discernment of optimal agricultural practices.

Roy and B.Bankotkar [31] discussed about issues like unsuitable crop selection for prevailing soil, weather, or water conditions, and limited agricultural expertise were exacerbated the problem. The proposed solution involved employing techniques like cooperative and content-based filtering, coupled with machine learning algorithms, to optimize crop selection and enhance agricultural productivity.

Tharun et al. [32] discussed that effective nutrient management was essential for optimal crop yields and sustainable agriculture. Conventional methods often lacked precision, leading to suboptimal fertilization and environmental harm. NPK sensor technology enabled real-time soil nutrient monitoring. Our system integrated NPK data, machine learning, and agronomic expertise for tailored fertilization recommendations, revolutionizing agriculture for enhanced productivity and environmental stewardship. Further research and field trials were crucial for validation and refinement.

Dubey et al. [33] proposed agricultural recommender system aimed to address this gap, offering tailored recommendations to minimize losses and maximize profits. By considering crucial parameters, it empowered farmers to make informed choices in crop selection, ultimately enhancing agricultural outcomes.

Sundaresan et al. [34] proposed a system that insufficiently favorable atmospheric conditions resulted in substantial annual crop losses, with India experiencing losses exceeding 11 billion dollars. The study integrated IoT and machine learning technologies to create an advanced agricultural system, unifying crop selection, autonomous watering, and fertilizer recommendation processes for eight crucial crops. A machine learning-powered crop recommendation system factored nitrogen, phosphorous, potassium, pH, and weather data; a fertilizer recommendation method was based on crop type and current soil nutrient levels; and an automated irrigation system incorporated real-time soil moisture levels and weather forecasts. The paper presented successful system implementations, supported by simulation outcomes.

Kamatchi et al. [35] addresses the intricate task of integrating meteorological and climatic data into agricultural decision-making processes. It acknowledges the abundance of available weather and climate information, emphasizing the imperative of incorporating natural factors into decision models. Meteorological data, specifically climatic information, proves crucial for effective agricultural planning. Additionally, the paper introduces Artificial Neural Networks, highlighting their dual capacity for data analysis and learning. It presents a predictive analysis for determining the most suitable crops under specific weather conditions and proposes a hybrid recommender system, combining case-based reasoning with collaborative filtering. The new aspect of the model is how it analyzes agriculture data at the district level to anticipate weather and suggest crops while taking into account each district's own agricultural tendencies.

Samuel et al. [36] agriculture, fundamental to the Indian economy, provided raw materials for diverse sectors. However, its share of the economy had waned to under 15% due to burgeoning industrial and service sectors. Escalating population exacerbated the challenge of meeting growing demands. Climate change further impacted crop yields. The research addressed precise crop prediction, vital for farmer income and enhanced production. It employed supervised learning classification techniques, focusing on optimal feature selection for accurate crop suitability prognosis based on soil and environmental factors, constituting a pivotal contribution to agricultural advancement.

Rajesh et al. [37] innovation drove a nation's competitiveness and economic growth. Software played a pivotal role in sustainable agriculture, offering farmers crucial insights on crop management. Sensors monitored soil conditions, contributing to a model that provided tailored crop recommendations based on factors like crop details, soil composition, and weather conditions. Machine learning algorithms, including Linear Regression, Random Forest, and Decision Tree, were applied. Experimental data from the Indian Chamber of Food and Agriculture were analyzed for accuracy metrics, revealing Linear Regression's superior performance with a precision of 66%, demonstrating efficiency in model development.

TABLE I. COMPARISION OF LITREATURE REVIEW

Work Done	Technology Used	Results	Limitation	Research Gap
This paper proposed methodology combines IDCSO, WLSTM and IoT to provides crop recommendations to Indian farmers by improving productivity based on soil characteristics and addresses the India's agricultural challenges.(1)	IDCSO, WLSTM and IoT.	This project is evaluated using MATLAB. It has accuracy of 92.68%, precision of 90.88 and recall of 91.98, it also reduces execution time from 250.47 seconds to 241.05 seconds.	Data Quality, Computational resources, Dependency on External Factors, Integration, Validation and Adaptation.	Scalability, Generalizability, User Feedback, Comparative Studies.
This paper explores the challenges faced by Indian farmers. It predicts crop yields based on the locations and seasons. It aims to assist farmers in making informed decisions.(2)	Ridge Regression, Classifier, Dataset Utilization, Accuracy Improvement, Decision Support.	This project evaluates metrics providing insights into their effectiveness in crop recommendation, achieving an accuracy of 65.05%.	Data Availability, Model Complexity, Regional Specificity, Data overfitting, User Adoption, External factors.	Exploration of Advanced Techniques, Integration with Real-time Data, Economic and Social Implications, Long-term Sustainability and Scalability.
This paper predicts the crop based on historical soil data and weather forecasts. It enhances traditional farming recommendations and it utilize past agricultural data to recommend crops and fertilizer to increase crop yield.	Linear Regression, Data analysis techniques, Application development and0020Database management.	This project aims to assist Indian farmers in maximizing crop yield, by achieving an accuracy of 80% and the precision of 0.80. The future work will focus on enhancing yield prediction with a larger dataset.	Reliance on historical data, Cost estimation, Adoption Challenge, Scalability issues, Limitations of filtering approaches.	Data availability,Validation and Testing, User adoption and usability, Long term Impact assessment.
This paper implemented precision agriculture in India for selecting suitable crops. It utilized soil database, soil testing lab data for ensemble modelling to achieve accurate crop recommendation,with high efficiency.(4)	Support Vector Machine algorithm, Artificial Neural Networks, Ensemble Modelling techniques (like majority voting), Soil testing lab dataset integration and analysis.	This project enhance productivity, mitigate soil degradation, minimize chemical usage and achieve an accuracy of 82%. It focuses on implementing yield prediction models to further improve	Small farm size, Data availability, Technological Accessibility, Accuracy, Research and Development needs.	Validation and Scalability, Socio-economic factors, Inadequate Data availability, Limited investigation.

Work Done	Technology Used	Results	Limitation	Research Gap
		farming outcomes.		
This paper includes researched various algorithms for developing a recommendation system in smart farming. The use of ensembles models and Hadoop framework for improved accuracy and efficiency in yield maximization.(5)	CHAID, IBK, Decision tree, Neural network, C4.5, KNN, LAD, SVM, Hadoop framework, Naïve bayes,	This project emphasizes the need for further research in agriculture to enhance accuracy. The consideration of additional parameters like investment, labour, and land size is crucial for farmer-centric profitability.	Technology Accessibility and Adoption Challenges, Soil pollution, Infertility concerns, Industrialization And land Use Changes Impact.	Lack of comprehensive evaluation, Insufficient focus on Small-scale farming practices.
This paper developed a crop recommendation system leveraging ML algorithms to account for climatic factors and soil conditions. Its aim is to assist Indian farmers to mitigate financial losses due to incorrect crop choices due to climatic changes.(6)	Machine Learning Algorithm, Data analysis, GUI, Modelling techniques, Integration of Parameters.	This project aims to empower Indian. Farmers with modern tools. It secures and accessible, machine learning enables continual evolution and weather pattern identification, supported by an intuitive GUI and achieve an accuracy of 99%.	Limited data availability, Dependency on weather forecast, Variable Environmental conditions, Complexity of factors.	Lack of comprehensive Data sets, Limited focus on regional Specificities, Need for enhanced Scalability and accessibility.
This project aims is to minimize losses and maximize profits by using ML and working with various dataset.(7)	Machine learning algorithms, HTML, CSS, JS , Flask framework, Dataset preparation, Prediction Process Improvement.	In this project the input data is captured through HTML forms and uses HTTP POST method to send data. In this project it achieves an accuracy of 96.3%.	Weather variability, Model generalization, User interface complexity, Dependency on Input parameters.	Integration of Real-time weather data, Incorporating soil health parameters.
This paper utilizes ML algorithms to aid farmers in selecting suitable crop based on soil.(8)	Python, ML libraries, Scikit-learn, Flask framework.	In this project Gradient boosting yielded the accuracy at 98.18%, surpassing others such as KNN, Decision tree, Naïve Bayes and Random Forest.	Soil data accessibility, Historical data reliability, Complexity of soil relationship, Considerations of external factors.	Dynamic crop-specific models, Farmer feedback mechanisms, Scalability and Accessibility Challenges.
This paper used technological advancements, to classify soil and predict untested traits benefiting farmers in crop selection for better yields.(9)	Data Mining, Machine Learning Algorithms, Integration, Software tools, Database Management.	This project emphasizes the importance of soil suitability and involves integrating crop recommendations with weather forecasting for better agricultural outcomes.	Uncertainty in weather forecasting, Lack of adoption by traditional farmers, Economic constraints for implementation, Complexity in model interpretation.	Limited studies on soil data mining, Need for further investigation into crop prediction accuracy, Scope of evaluating the impact of precision agriculture techniques, Lack of comprehensive analysis.
This paper uses Deep learning algorithms for crop recommendations. Its performance compared to traditional ML models which optimize crop selection based on soil and other parameters.(10)	Deep Learning algorithm, Fully connected MLP architecture.	This project achieves the highest overall performance, indicating its effectiveness by achieving and accuracy of 99% in crop recommendation system based on the given conditions.	Data quantity, Biases in the dataset, Resources requirements, Influence of unconsidered factors, Interpretability, Transparency, Adoption.	Underutilization of Agricultural data, Absence of deep learning, Challenges of multiple parameters, Inadequate performance.

Work Done	Technology Used	Results	Limitation	Research Gap
This paper provides automating crop selection based on the environmental factors. It uses integrated recommendation system and sentiment analysis for precise crop recommendation in Sri Lanka. It can be used to predict crops for both types of land i.. e, domestic and farming land. (11)	Arduino microcontrollers, ML techniques, Unsupervised learning (K-means), NLP, AI.	This project suggests optimal crops, achieving over 92% accuracy. It also recommends four crop types tailored to the land conditions. It enables user feedback.	Reliance on environmental factors, Dependency, Data availability, Limited scope.	Integration, Testing and validation, Current challenges.
This paper provides automating crop selection based on the environmental factors. It uses integrated recommendation system and sentiment analysis for precise crop recommendation in Sri Lanka. It can be used to predict crops for both types of land i.. e, domestic and farming land. (12)	Arduino microcontrollers, ML techniques, Unsupervised learning (K-means), NLP, AI.	This project suggests optimal crops, achieving over 92% accuracy. It also recommends four crop types tailored to the land conditions. It enables user feedback.	Reliance on environmental factors, Dependency, Data availability, Limited scope.	Integration, Testing and validation, Current challenges.
This paper implemented ML techniques, it recognizes the significance of climate and soil attributes in crop cultivation, addressing the challenge of increasing crop production by using advanced technology. (13)	ML algorithms, Web development, Database management, Data processing, Python libraries.	This project rates comprises three key steps: data organization, Dataset testing, Data analysis.it ensures efficient processing and analysis and facilitate yield rate predictions for decision-making through which it has achieved 99.7% accuracy.	Data availability, Soil variability, Model complexity, Accessibility, Adoption.	Limited historical data, Farmer feedback, Generalizability, Scalability, Real-time monitoring.

III. PROPOSED METHODOLOGY

This research aims to apply the crop selecting approach so that it may help solve various agricultural and farmer problems. A method of data analytics is suggested to update the pace of agricultural output. It benefits the Indian economy. Since there are various soil types, the ranking system is used to predict crop quality.

This allows for the identification of the rate of high-quality and low-quality crops. Using many classifiers, the group of classifiers creates a path for making superior predictions.
To choose the classifier outcome, decision-making essentially involves a rating process. An ensemble of classifiers, including decision trees and random forests, is used in this study. Furthermore,

$$ni_j = w_j C_j - w_{left(j)} C_{left(j)} - w_{right(j)} C_{right(j)}$$

ni sub(j) = importance of node j's.
w sub(j) is the sample reading node j's weighted number.
c sub(j) = node j's impurity value.
left(j) = child node from left split on node j.
right(j) = child node from right split on node j.

$$fi_i = \frac{\sum j{:}\, node\ j\ splits\ on\ feature\ i\ ni_j}{\sum_{k \in all\ nodes} ni_k}$$

fi sub(i) = the significance of the attributes i.
ni sub(j) = node j's si

A. Dataset

The crop suggestion dataset is available here https://www.kaggle.com/datasets/atharvaingle/crop-recommendation-dataset?resource=download. Several factors that affect crop output and rainfall in a particular area are included in the crop recommendation dataset for this study.

The variables temperature, humidity, pH, precipitation, potassium (K), nitrogen (N), phosphorus (P), and label are all included in the crop recommendation dataset.
The crop recommendation system flowchart encompasses several crucial stages. It commences with data collection, where diverse datasets related to soil attributes, climate conditions, and rainfall are gathered. Subsequently, data preprocessing ensures the data is cleaned and formatted for analysis. The partitioning stage divides the data into training and testing sets, facilitating model development and evaluation, respectively. Training data is then utilized to construct models using Support Vector Machines (SVM), decision trees, and random forests algorithms. These models are trained to forecast crop yields based on the collected data inputs.

B. Flowchart

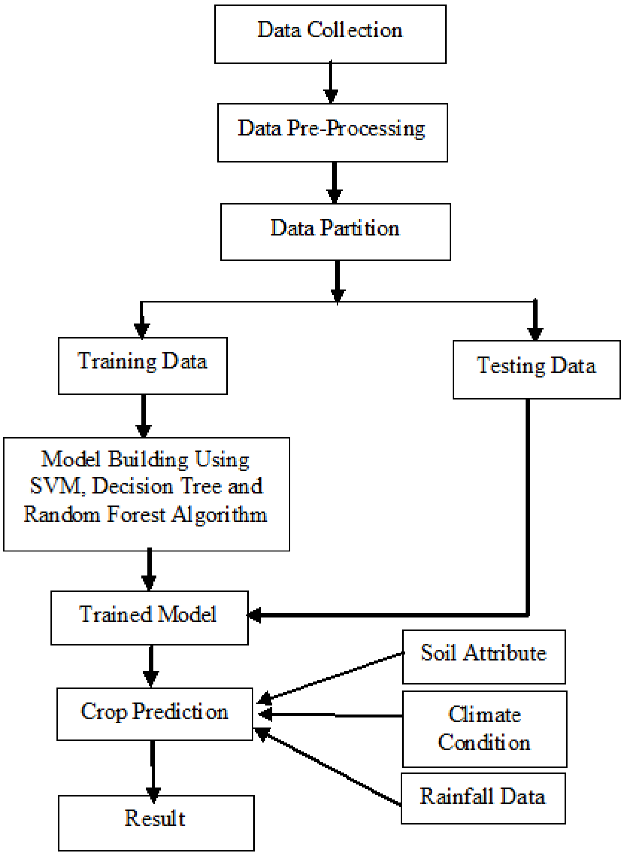

Fig. 1. Flowchart of Crop Recommendation System

Following model training, the system employs the trained models to predict crop outcomes using soil attributes, climate conditions, and rainfall data. Finally, the system generates recommendations for suitable crops based on these predictions. This iterative process not only aids in optimizing crop selection but also enhances agricultural decision-making by leveraging data-driven insights. By seamlessly integrating data analysis and machine learning techniques, the crop recommendation system streamlines the agricultural planning process, enabling farmers to make informed decisions to maximize yields and mitigate risks.

C. Classification Techniques

1) Support Vector Machine –

With the help of support vectors, we create hyperplane. The hyperplane thus generated has two support vectors each on either side of the hyperplane. The support vectors are nothing but lines that is drawn passing through two data points on either side, which is closest to hyperplane.

2) Decision Tree –

A structured system is used to evaluate aspects of agriculture, like soil quality, climate and crop features. By making decisions step by step they categorize crops according to these factors giving farmers personalized suggestions, on what crops to grow in their surroundings boosting output. Decision trees effectively sort crops based on how they match conditions by analyzing different criteria helping farmers choose wisely for better harvests.

3) Random Forest Algorithm -

A collection of decision trees is used by random forest to suggest the crops, for farming conditions. Each tree is trained on sets of data incorporating soil type, environmental factors and past yields. By combining predictions, from these trees Random Forest offers dependable suggestions customized to suit farming environments.

IV. Result

A. Accuracy

Integration of additional data sources: Incorporating data from diverse sources such as weather forecasts, satellite imagery, and historical crop yield data can enhance the accuracy and relevance of the recommendations.

Accuracy refers to how close a set of measurements are to a goal. Precision is how close those measurements are to each other but not necessarily to the target measurement.

To assess a crop recommendation system's accuracy, you need data showing recommended crops and their actual results. First, split the data into training and testing sets. Train the model using the training set, then evaluate its performance using the test set. Compare the recommended crops to the actual outcomes in the test set. Accuracy is determined by dividing the number of correct recommendations by the total recommendations made. This gives a percentage reflecting how often the model's suggestions align with real outcomes.

Accuracy expression:

$$\text{Accuracy} = \text{Correct Prediction} / \text{Total Prediction} \quad (1)$$

B. Precision:

To determine precision in a crop recommendation system, focus on the accuracy of the recommendations. Calculate the number of true positives (correct recommendations) and false positives (incorrect recommendations). Precision is then computed by dividing the number of true positives by the sum of true positives and false positives. This ratio indicates the system's capability to offer relevant suggestions.

Precision expression:

$$\text{Precision} = \text{True Positives} / (\text{True Positives} + \text{False Positives})$$

C. Recall-

To determine recall in a crop recommendation system, assess how well it identifies all relevant recommendations. Calculate the number of true positives (correct recommendations) and false negatives (missed recommendations). Recall is then computed by dividing the number of true positives by the sum of true positives and false negatives. This ratio reflects the system's capability to capture all relevant suggestions.

Recall expression:

Recall = True Positives / (True Positives + False Negatives)

TABLE II. COMPARINF EXISTING AND PROPOSED SYSTEM VALUES

Methods	Accuracy	Precision	Recall
Recommendation System Based on Deep Learning [16]	92.68%	0.908	0.919
Deep Learning-based Enhancing Agricultural Productivity[38]	90%	0.942	0.91
IOT-BASED professional crop recommendation system[39]	91%	0.91	0.84
Proposed Model	96.88%	0.93	0.92

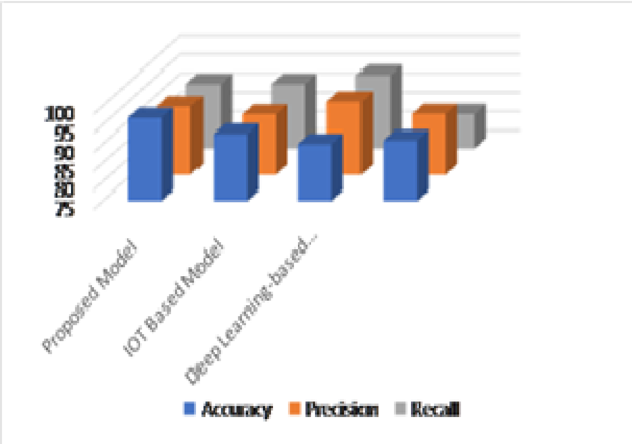

Fig. 2 COMPARISON OF DIFFERENT MODEL

V. CONCLUSION AND FUTURE WORK

Agriculture is key to our country's economy, so even the smallest investment done in this sector has a tremendous effect on our country altogether. Therefore, we need to be more serious about it. Due to the lack of scientific knowledge about different factors affecting crops, the farmers of our country tend to face a lot of challenges in selecting the right crops to grow. Hence, face a loss in their profit, due to less productivity. But our system will provide them with a ray of hope to grow crops which will earn them at most profit. The quality as well as quantity of their production will increase exponentially. Also, it will also help them in maintaining nutrients content in the soil. Both the quantity and quality will be increased.

Future improvements to the dataset through the addition of more attributes will be our main goal. Furthermore, we want to create a strong model that can detect the precise disease that is harming the crop in addition to differentiating between healthy and infected crop leaves. In addition, we want to develop a mobile app and user-friendly website specifically for farmers, with features like email and SMS notifications. For improved functionality, we plan to combine the Crop-Yield Prediction and Crop Prediction models into a single platform.

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