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Hybrid AI–Machine Learning and Deep Learning-Enhanced Predictive System for Crop Disease Diagnosis, Yield Forecasting, and Smart Advisory Support for Farmers

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Yield Prediction, Crop Recommendation, Precision Farming

ABSTRACT

Recent advancements in agriculture have led to the development of crop recommendation systems offering a new approach to optimizing crop yields and the efficient use of resources. In this study, we introduced an enhanced "Crop Recommendation System" designed to assist farmers in selecting suitable crops based on various soil and environmental factors. Our system leverages machine learning (ML) and deep learning (DL) models to enhance agricultural productivity and crop yields. The dataset used for training and evaluation was sourced from Kaggle's repository, featuring key parameters such as nitrogen (N), phosphorus (P), potassium (K), rainfall, pH, temperature, humidity, and crop labels corresponding to 22 different crop types. The study incorporates several ML and DL algorithms, including Decision Trees, Random Forest, XGBoost, Support Vector Machine, K-Nearest Neighbors, Naive Bayes, Artificial Neural Networks, Deep Neural Networks, and Temporal Convolutional Networks. According to performance metrics, Random Forest and TCN delivered the highest accuracy, achieving 99.2% and 99.9%, respectively. Other models also performed impressively, with accuracy ranging between 93.8% and 98.7%. Although Support Vector Machine (SVM) showed slightly lower performance, with 93.4% accuracy, it still yielded satisfactory results. The project also explores parameter tuning for XGBoost and TCN, with TCN outperforming XGBoost after optimization.

The findings of this research indicate that both machine learning and deep learning models are highly effective in crop recommendation systems, wisth TCN providing accurate and efficient recommendations. Furthermore, this study aids precision agriculture by offering a web-based interface for farmers, helping them select crops based on environmental and soil conditions.

1. INTRODUCTION

As climate change accelerates and the demand for sustainable agriculture increases, the need for precise and efficient crop management practices enhance the effectiveness of traditional crop management methods. The study employs a data- driven approach, utilizing a well-curated dataset for making crop recommendations. The dataset includes essential features such as rainfall, pH,temperature, humidity, nitrogen (N), phosphorus (P), potassium (K), and crop labels representing 22 distinct crops. The study highlights the application of various ML models, including Decision Trees, Random Forest, XGBoost, Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and Naive Bayes, along with deep learning models like Artificial Neural Networks (ANN), Deep Neural Networks (DNN), and Temporal Convolutional Networks (TCN) to provide farmers with a clearer understanding of agricultural ecosystems. The results show that Random Forest and TCN deliver the highest accuracy, achieving 99.2% and 99.9%, respectively. The study also explores the performance of other models like Decision Trees, XGBoost, KNN, Naive Bayes, ANN, and DNN, all of which demonstrate impressive accuracy. SVM showed the lowest accuracy at 93.4%. This research also includes optimization techniques for tuning the parameters of XGBoost and TCN, with TCN continuing to perform well even after optimization, showcasing its efficiency in processing complex agricultural data patterns. Additionally, the research provides a user- friendly web interface for farmers, allowing them to easily input soil and environmental parameters and receive tailored crop recommendations. The real- time interface simplifies the generated data, offering practical advice for farmers. Figure 1 illustrates the overall workflow of this system. The process begins with data collection, where critical features are identified before creating the training and testing datasets. To ensure accurate predictions, both ML and DL models are utilized. The website streamlines the user experience by processing input data and recommending the most suitable crops for specific conditions, ultimately guiding users from the data collection stage to crop selection.

II. LITERATURE REVIEW

This section provides a comprehensive review of the existing research on crop recommendation systems, highlighting key contributions from various studies. Early techniques for crop prediction, such as K-Nearest Neighbors and Naive Bayes, were introduced by Medar et al.. Dhruvi Gosai et al. investigated data attributes like pH and humidity using machine learning methods like Random Forest and XGBoost, with XGBoost showing superior performance. To enhance prediction accuracy, Bandara et al. implemented Naive Bayes and SVM in a specific region, incorporating farmer input into the model. Other research, including that by Varun Prakash R et al., explored the use of Naive Bayes, XGBoost, and Random Forest for crop prediction, utilizing real-time data for improved precision. A crop recommendation system was developed based on a team-based approach and a majority decision technique in precision agriculture, using models such as Random Tree, CHAID, K- Nearest Neighbor, and Naive Bayes, which achieved 88% prediction accuracy. This work also builds on earlier studies that used classification algorithms for yield prediction, the Crop Yield Prediction Framework (XCYPF), and data mining methods for crop yield estimation across different regions.

The research provides a crop recommendation system tailored to Indian agriculture, aimed at assisting farmers with optimal crop selection based on localized data. It emphasizes the role of precision agriculture in India, particularly in helping farmers address the challenges of choosing suitable crops for varying soil types . Research in reviews advancements in smart recommender systems for agricultural applications, while studies show how IoT enhances crop recommendations by providing real-time environmental data to improve agricultural decision-making. One proposed solution for precision agriculture involves a recommendation system that integrates a soil database, expert knowledge on crops, and criteria such as soil characteristics from laboratory tests. This system employs SVM and ANN in an ensemble

model for accurate crop recommendations. The use of machine learning for crop prediction is particularly significant in improving agricultural yields in India. Key techniques like precision farming, recommendation systems, ensemble models, SVM, ANN, and Random Forest are essential to this system, which also incorporates IoTand ML technologies for soil testing, addressing the major issue of crop selection in Indian agriculture.

A comprehensive approach is presented through the application of machine learning models such as Decision Tree, Naive Bayes, Support Vector Machine, Logistic Regression, Random Forest, and XGBoost, focusing on key soil characteristics like temperature, moisture, pH, and NPK nutrients. The Majority Voting ensemble technique is used to generate precise crop predictions by combining multiple models. A comparative analysis with similar studies underscores the effectiveness of the proposed method, particularly with algorithms like Naive Bayes, Random Forest, and XGBoost, in achieving high accuracy. This system is aligned with broader goals of increasing agricultural productivity and mitigating the impacts of climate change.

III. METHODOLOGY

Related Approach

A proposed solution for precision agriculture involves a crop recommendation system that utilizes a soil database, expert crop knowledge, and soil characteristics obtained from laboratory tests. This system employs ensemble learning models, specifically Support Vector Machine (SVM) and Artificial Neural Networks (ANN), to provide accurate and effective crop suggestions. The concept of using machine learning for crop prediction emphasizes the importance of boosting agricultural output in India. The primary methods used in this system include precision farming, recommendation systems, ensemble models, SVM, ANN, and Random Forest. These techniques integrate Internet of Things (IoT) and machine

learning (ML) technologies for soil testing, addressing a key issue in Indian agriculture: crop selection. The approach incorporates machine learning models such as Decision Tree, Naïve Bayes, SVM, Logistic Regression, Random Forest, and XGBoost, while also focusing on soil attributes like temperature, moisture, pH, and NPK nutrients. The Majority Voting ensemble technique is used to generate precise crop predictions by integrating input from multiple models. A comparative study shows that algorithms like Naïve Bayes, Random Forest, and XGBoost contribute significantly to high accuracy. The system's potential to increase agricultural yields and reduce the impact of climate change aligns with the broader goals of precision agriculture.

Proposed Approach

The proposed crop recommendation system integrates cutting-edge machine learning (ML) and deep learning (DL) models to optimize agricultural practices. This system aims to recommend the most suitable crops based on specific soil and environmental conditions, ultimately improving crop yields and sustainability.The system uses models like Decision Trees, Random Forest, XGBoost, Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and Naive Bayes to analyze data patterns and provide crop recommendations. Advanced models such as Artificial Neural Networks (ANN), Deep Neural Networks (DNN), and Temporal Convolutional Networks (TCN) are utilized to capture complex patterns and temporal relationships within the data. The system enhances crop yields by recommending the most suitable crops based on specific soil and environmental factors, promoting more efficient resource use. The web-based platform provides an easy-to-use interface, enabling farmers to input data and receive crop recommendations, thus making advanced technologies accessible to a wider audience. The system is designed to work with various machine learning and deep learning models, making it adaptable to different datasets and agricultural contexts. The modular architecture allows for the addition of new features and crops, ensuring the system evolves with the changing needs of agriculture. Traditional crop selection methods often involve trial-and-error, where farmers experiment with various crops at significant costs, including seeds, fertilizers, irrigation, and labor, with no guaranteed success. The proposed system helps mitigate these challenges by providing data-driven crop recommendations that are both efficient and cost-effective.

IV. SYSTEM DESIGN

System Architecture

Below diagram depicts the whole system architecture.

Fig 1. Methodology followed for proposed model

V.SYSTEM IMPLEMENTATION

Modules

Data Preprocessing: This module focuses on preparing the data by handling missing values and outliers. It includes encoding categorical variables into numeric values to ensure compatibility with machine learning algorithms. Additionally, it involves scaling numerical features (such as nitrogen, phosphorus, potassium, and temperature) to normalize the dataset. Feature engineering techniques are applied to extract valuable patterns,
optimizing the input for the models.

Machine Learning and Deep Learning Model Training: This module involves the training of machine learning models like Support Vector Machine (SVM) and deep learning models, including Artificial Neural Networks (ANN) and Temporal Convolutional Networks (TCN), to develop accurate predictive models for crop recommendations.

Model Optimization: The optimization module fine-tunes the models to ensure maximum performance. Techniques like grid search and cross- validation are used to improve the accuracy and efficiency of models such as XGBoost and TCN. This step ensures that the models generate reliable recommendations in various agricultural contexts.

Crop Recommendation System: Serving as the core of the system, this module processes farmer inputs— such as soil pH, rainfall, temperature, and humidity—through the trained ML and DL models. Based on these inputs, it provides personalized crop recommendations aimed at achieving the best yield and resource utilization. This module also features a decision layer that dynamically selects the most effective model (e.g., TCN or Random Forest) for generating recommendations.

User Interface and Reporting: The system includes a user-friendly web interface that allows farmers to easily input data and receive real-time crop recommendations. This module also provides visualizations and detailed reports, presenting the results in a clear and understandable format. The interface is designed to be accessible to farmers with minimal technical knowledge, ensuring the system is user-friendly and widely adoptable.

VI. RESULTS AND DISCUSSION

In above diagram a discribes about verious algorithmic accuracy comparion graph

VII. CONCLUSION

The Crop Recommendation System, utilizing a blend of machine learning (ML) and deep learning (DL) models, delivered promising outcomes.
The comparative analysis highlighted the accuracy of models like Temporal Convolutional
Networks (TCN) in predicting the most suitable crops. The system’s intuitive web interface provides farmers with a practical tool for receiving
tailored recommendations based on their input parameters. Advancements in precision agriculture hold significant potential to boost
cropyields and sustainability. This project sets the stage for further technological advancements in agriculture, playing a key role in the evolution of contemporary farming practices. Future iterations could

incorporate larger datasets with additional features, and the use of ensemble learning models with hyperparameter optimization could further enhance prediction accuracy.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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