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Leveraging Ensemble Learning Techniques for Efficient Fertilizer Recommendation

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ABSTRACTS

Agricultural productivity plays a critical role in improving crop yields, and the suitable use of fertilizers plays a significant role in enhancing crop yield. Traditional fertilizer recommendation approaches often rely on generalized strategies that may not account for discrepancies in soil properties, climatic conditions. To address this limitation, we proposed an intelligent Fertilizer Recommendation System (FRS) using an Ensemble Learning method. This system integrates multiple ensemble learning models, such as Bagging, AdaBoost, GBoosting, Extra Trees, and CatBoost to enhance recommendation accuracy. The ensemble model is trained on soil parameters (N) nitrogen (P) phosphorus, (K) potassium, and moisture to recommend the optimal fertilizer type in Andhra Pradesh region, India. The result shows that all ensemble models utilized were effective, and CatBoost model has achieved 94.78% with highest accuracy, when compared with the other ensemble models.

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Keywords / Kata Kunci — ***Ensemble Learning; Agriculture; Fertilizer; Recommendation System; NPK; moisture***

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1. INTRODUCTION

Agriculture plays a vital role in Indian food security, and optimizing crop yields is important to meet the demands of an increasing population. One of the most critical issues influencing agricultural production is soil fertility, which is achieved through the suitable application of fertilizers. However, excessive or incorrect fertilizer use can lead to environmental dilapidation, soil nutrient imbalance, and increased farming costs. Traditionally fertilizer recommendation methods rely on empirical knowledge methods, which may not effectively account for complex interactions among soil nutrients conditions, and crop requirements. Therefore, the development of an intelligent and precise fertilizer recommendation system is necessary to assist farmers in making informed decisions. This research explores the implementation of ensemble learning techniques in building an efficient and accurate fertilizer recommendation system. Nowadays Machine learning-based approaches have emerged as powerful tools for predictive modeling in agriculture. Ensemble learning techniques leverage multiple machine learning algorithms to improve prediction accuracy and generalization, reducing the likelihood of errors associated with individual models. By integrating various classifiers, the ensemble method enhances the robustness and reliability of fertilizer recommendations, ensuring optimal nutrient application for different soil types and crops. (Gao et al., 2023). The proposed fertilizer recommendation system incorporates multiple machine learning algorithms, including Random Forest (RF), Gradient Boosting Machine (GBM), eXtreme Gradient Boosting (XGBoost), and Adaptive Boosting (AdaBoost). These models are trained on diverse soil dataset which include essential parameters such as nitrogen (N), phosphorus (P), potassium (K), moisture content. (Vijender Reddy et al., 2024). The proposed "Precision Agriculture" model uses machine learning to classify soil samples and recommend suitable crops along with optimal NPK fertilizer ratios. It helps farmers make informed decisions to improve soil fertility and support sustainable farming. (Huy Cuong et al., 2022). This research developed a recommender system for farmers using tree-based data structures. The proposed model integrates the YOLO (You Only Look Once) algorithm within a convolutional neural network (CNN) framework and utilizes a similarity tree to compute and evaluate data similarity, enhancing the accuracy and relevance of recommendations. (Khan et al., 2022). The authors proposed a machine learning-based fertilizer recommendation approach that leverages real-time soil fertility data captured through an IoT-enabled soil mapping system. The integration of IoT architecture allows for dynamic, context-aware analysis, enhancing the accuracy and relevance of fertilizer recommendations tailored to current soil conditions. (Basava, 2024). This study investigates the use of artificial intelligence (AI) to optimize fertilizer application through intelligent, data-driven recommendations. By combining machine learning algorithms with detailed soil and crop datasets, a predictive model was developed to deliver precise fertilizer dosage tailored to specific field conditions, enhancing both efficiency and sustainability in agricultural practices.

1.1. Motivation

According to (K and Kumar, 2024). Soil is a vital natural resource that supports the production of food, fiber, and timber, making it fundamental to human survival and societal development. It plays a crucial role in sustaining livelihoods and supports various industries. Beyond its role in agriculture, soil serves multiple essential functions it contributes to productivity, acts as a natural filter, provides a habitat for organisms, supplies raw materials, and serves as a reservoir for ecological and genetic resources

Accordingly, (Zahra et al., 2025). Advancements in artificial intelligence (AI) and machine learning (ML) are set to transform precision farming by enabling data-driven agricultural practices. These technologies will facilitate highly specific and accurate recommendations for crops and fertilizers by analyzing complex interactions among soil properties, climatic conditions, and historical yield data. Fertilizer Association of India revealed that. Total fertilizer products consumed in (2023-24) approximately 64.84 million metric tons (MT), marking a 1.6% increase from previous year. Figure 1 shows the different categories of fertilizer consumed.

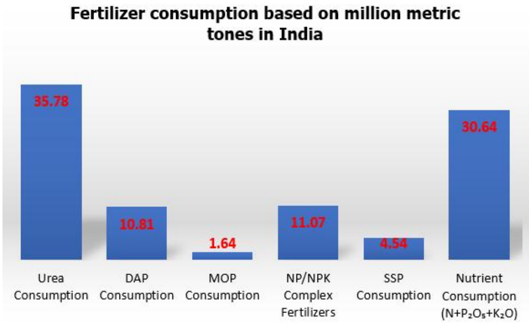

FIG 1. Indian fertilizer consumption statistic.

Global fertilizer consumption is projected to rise by 2% in FY 2024, reaching 195.4 million tones (Mt). Specifically, nitrogen (N) use is expected to grow by 2% to 111.6 Mt, phosphorus (P_2O_5) by 2% to 47.1 Mt, and potassium (K_2O) by 3% to 36.7 Mt.

To address this challenge, we proposed the development of an advanced fertilizer recommendation system based on ensemble learning techniques. The model is trained on comprehensive datasets from the Indian Institute of Soil Science (IISS), incorporating key soil parameters such as nitrogen (N), phosphorus (P), potassium (K), and moisture levels. By leveraging the predictive strength of ensemble algorithms, the system aims to support farmers in selecting the most suitable fertilizer types tailored to their specific soil nutrient profiles. This data-driven approach enhances precision in fertilizer application and promotes efficient, sustainable agricultural practices.

1.2. Contributions of the proposed study

- We proposed a soil fertility evaluation approach designed to address the limitations of traditional soil fertility assessment methods.
- The study proposes a precise fertilizer recommendation system based on an ensemble learning technique to enhance decision-making in soil nutrient management.
- The study evaluates and compares the performance of existing systems against the proposed ensemble learning-based approach.

2. LITERATURE REVIEW

This section offers a comprehensive review of existing research on fertilizer recommendation systems, highlighting the important contributions made by several notable studies. (Ngo et al., 2023). The authors proposed an Electronic Agricultural Record (EAR) system that consolidates disparate agricultural datasets into a unified structure. To store and manage this large-scale agricultural data, we developed a data warehouse architecture utilizing Hive and Elasticsearch. (Abera et al., 2022). This proposed approach employed a Random Forest machine learning model to capture the relationship between key nutrients nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) and wheat yield. The model accounted for approximately 83%, 82%, 47%, and 69% of the variance in yield under N, P, K, and S omission treatments, respectively, demonstrating consistent performance across both training and testing datasets. As expected, for N and P omission scenarios, nutrient application rate emerged as the most influential predictor, followed by soil organic carbon and soil pH. In contrast, for K and S omission, climatic variables, along with nutrient rates, played a more prominent role in explaining yield variability. (Gao et al., 2023).

This study introduces an innovative model that integrates machine learning (ML) techniques with swarm intelligence-based optimization to address the aforementioned challenges. Using historical data for maize, rice, and soybean, three ML algorithms Random Forest (RF), Extreme Random Tree (ERT), and Extreme Gradient Boosting (XGBoost) were evaluated for their effectiveness in crop yield prediction. These models were then coupled with the Cuckoo Search Algorithm (CSA) to develop the Prime Fertilization Decision Model (FDM), designed to identify optimal fertilization strategies. (Sajindra et al., 2024). In this study, a deep learning model was developed to predict soil nitrogen, phosphorus, and potassium (NPK) levels based on plant growth characteristics, including plant height, leaf count, and average leaf area. To train the model, weekly observations of cabbage plant growth traits were collected alongside corresponding measurements of soil NPK content from the surrounding area. (Huy Cuong et al., 2022). This proposed model integrates the You Only Look Once (YOLO) algorithm within a Convolutional Neural Network (CNN) framework and incorporates a similarity tree for enhanced similarity computation. Through experiments conducted on 400 samples and evaluation using metrics such as precision, accuracy, and positive predictive value (PPV), the results demonstrate the model's feasibility and superior performance compared to existing state-of-the-art approaches. (Tanaka et al., 2024). This study quantifies the uncertainty associated with applying machine learning methods to model the impact of fertilizer application on site-specific crop yield response. Using real-world on-farm precision experimental data, the analysis evaluates how different machine learning algorithms and covariate selection strategies influence the prediction of yield and the economically optimal input rate (EOIR). (Melasagare et al., 2024). This research article employs machine learning models, including regression and classification algorithms, to uncover patterns and correlations within agricultural data. By accurately predicting crop nutrient requirements based on historical and real-time data, the model enhances resource efficiency and minimizes environmental impact in fertilizer recommendations. This approach not only improves crop yield and quality but also addresses key sustainability challenges by reducing excessive fertilizer use. (M et al., 2022). This proposed paper developed a model to detect nutrient deficiencies in rice plants, an ensemble averaging strategy was implemented using transfer learning techniques. The approach leveraged five pre-trained deep learning architectures Xception, InceptionV3, ResNet50, MobileNet, and VGG16 to enhance classification accuracy and robustness. (Escorcia-Gutierrez et al., 2022).

This paper proposes the design of an intelligent soil nutrient and pH classification system using a Weighted Voting Ensemble Deep Learning (ISNpHC-WVE) technique. The ISNpHC-WVE model is developed to accurately classify the presence and levels of key soil nutrients and pH, enhancing soil assessment capabilities. (Thorat et al., 2023). This paper presents a system that integrates the Transition Probability Function (TPF) and Convolutional Neural Network (CNN) to process pest images in both discrete and continuous forms for targeted insecticide recommendation. The proposed approach addresses two key aspects of precision agriculture: automated pest identification and corresponding insecticide suggestion through machine vision and deep learning. In parallel, soil nutrient analysis is performed using an NPK sensor, which informs fertilizer recommendations based on the detected nutrient levels. (Khan et al., 2022). The proposed context-aware fertilizer recommendation system is implemented using four machine learning models: Logistic Regression (LR), Support Vector Machine (SVM), Gaussian Naïve Bayes (GNB), and K-Nearest Neighbor (KNN). Performance evaluation indicates that the GNB model outperforms the others in terms of accuracy within the given context. (Praynlin, n.d.). This study presents a customized recommendation system that leverages machine learning algorithms to support farmers in selecting suitable crops and determining optimal fertilizer application rates, tailored to their specific soil and weather conditions. (Bhola and Kumar, 2024). This research introduces a unified framework**,** ML-CSFR, that uses machine learning to assist with crop selection and fertilizer recommendation. It first employs Artificial Neural Networks (ANN) to identify suitable crops based on local conditions, then uses XGBoost (XGB) to recommend optimal fertilizers based on soil and environmental data. (Patel* and B. Patel, 2023). In this research, the authors proposed AgriRec, a machine learning-based algorithm for crop and fertilizer recommendation. The crop prediction model considers factors such as soil properties, water availability, farm size, and the minimum support price (MSP) of crops to recommend suitable crops for different seasons. Additionally, the authors introduced a complementary mechanism that analyzes soil characteristics, crop type, and fertilizer attributes to determine the optimal fertilizer combination for a given soil-crop pair. (Dhal et al., 2022). This paper evaluates various linear and non-linear algorithms trained on relatively small datasets using Bolstered error estimation techniques, aiming to identify the most effective method for nutrient regulation in hydroponic systems. Through repeated testing, the Semi-Bolstered Resubstitution Error estimation method, combined with a Linear Support Vector Machine (SVM) classifier and a penalty parameter set to one, was found to deliver the best performance. (Basava, 2024). This study investigates the use of artificial intelligence (AI) to optimize fertilizer application through intelligent, data-driven recommendations. By integrating machine learning algorithms with detailed soil and crop data, a predictive model was developed to deliver precise fertilizer dosage recommendations tailored to specific field conditions. (Vijender Reddy et al., 2024). The proposed machine learning-based model, "Precision Agriculture," is designed to predict suitable crops based on the classification of soil samples and recommend appropriate fertilizers to enhance soil fertility. By leveraging this model, farmers can make informed decisions about crop selection aligned with soil type and determine the optimal nitrogen–phosphorus–potassium (NPK) fertilizer ratios to support healthy crop growth. (Tkatek et al., 2023). The researchers developed, evaluated, and compared several prediction models including K-Nearest Neighbor (KNN), Linear Support Vector Machine (SVM), Naive Bayes (NB) classifier, Decision Tree (DT) regressor, Random Forest (RF) regressor, and eXtreme Gradient Boosting (XGBoost) to predict optimal fertilization strategies for potato cultivation. (Bhosale et al., n.d.). In this paper the authors utilizes the of integration of IoT technology, a Gaussian Naïve Bayes (GNB)-based machine learning model, NodeMCU for data transmission, and ThingSpeak for real-time data visualization represents a cutting-edge approach in precision agriculture. This system empowers farmers to efficiently monitor, analyze, and optimize their agricultural practices in a cost-effective and environmentally sustainable way. (Sunandini et al., 2024). The paper proposes an IoT-based system that uses sensors to monitor soil and environmental conditions (NPK levels, pH, temperature, humidity, rainfall) and sends the data to the cloud via a wireless network. Machine learning algorithms analyze this data to recommend the most suitable crops, helping farmers improve productivity. (León Chilito et al., 2025). The study uses the CRISP-DM methodology to develop a Fertilizer Recommender System (FRS) for coffee crops. It involves identifying key production factors, collecting and processing agroclimatic data, and building a Case-Based Reasoning (CBR) model to recommend tailored nitrogen, phosphorus, and potassium doses. Expert feedback was used to evaluate the system's effectiveness. (K and Kumar, 2024). This study introduces an Ensemble Machine Learning–based Crop and Fertilizer Recommendation System (EML–CFRS) aimed at maximizing agricultural productivity while promoting the efficient use of mineral resources. The system is developed using a dataset sourced from the Kaggle repository, enabling the evaluation and comparison of multiple machine learning algorithms for accurate crop and fertilizer recommendations. (D N and Choudhary, 2024). This paper presents a fertilizer and nutrient recommendation system that incorporates a novel feature selection methodology. The study compares two implementation scenarios one with feature ranking and selection, and one without to demonstrate the impact of feature selection on the system's performance. (Radočaj et al., 2022). The authors explore the application of both conventional and modern prediction techniques in precision fertilization by integrating agronomic factors with spatial interpolation and machine learning. While traditional methods have long been foundational in soil prediction, their effectiveness has diminished in recent years due to the growing complexity and scale of agricultural data. (Bouni et al., 2022). Finally, the authors proposed a deep reinforcement learning (DRL)-based crop classification system aimed at enhancing precision agriculture and addressing the decision-making challenges faced by farmers. By leveraging DRL, the system intelligently filters suboptimal crop choices and promotes optimal selections, thereby improving overall agricultural productivity. they evaluated the performance of the proposed recommendation system against several conventional machine learning algorithms, including Random Tree, Naive Bayes, and K-Nearest Neighbor, demonstrating its superior accuracy in site-specific crop selection

TABLE 1. Related Works

Reference	Dataset	Techniques used	Performance	Limitations
(Abera et al., 2022)	Terra climate data	DT	0.78%	Fertilization of wheat crop only
(M et al., 2022)	Kaggle dataset	InceptionV3	92.23%	Detecting rice plant nutrient deficiency
(Thorat et al., 2023)	Kaggle dataset	TPF-CNN	90.11&	Limited to only five categories of pest
(Khan et al., 2022)	department of agronomy Islamia University Bahawalpur (IUB) Pakistan	Machine Learning and IoT	93.10%	Conventional ML model were used
(Bhola and Kumar, 2024)	Kaggle dataset	ANN and ML	93.66%	Generalized dataset were used
(Patel* and B. Patel, 2023)	Gujarat regional dataset	Machine learning	92.11%	Four (4) categories of fertilizer were used
(Basava, 2024)	Not mention	DNN	92.89%	Conventional ML model were used
(Vijender Reddy et al., 2024)	Kaggle dataset	SVM	91.99%	Conventional ML model
(Tkatek et al., 2023)	900 field experiments from Kaggle	K-NN	89.54%	Limited to a single fertilization for potato crop
(Bhosale et al., n.d.)	IoT sensor dataset	ML and IoT	93.23%	Conventional ML model were used
(D N and Choudhary, 2024)		SVM	91.80%	Conventional ML model were used

Research Gap

Despite significant advancements technology in fertilizer recommendation systems, previous studies have largely overlooked the potential of ensemble learning techniques to enhance prediction accuracy and system robustness. Most existing models rely on single machine learning algorithm, which may not fully capture the complexity and variability of real-world agricultural data. This limitation highlights the need for more comprehensive models that integrate multiple machine learning algorithms to improve performance across diverse soil conditions.

3. Materials and Methods

The primary innovation of this study lies in the development of a novel ensemble learning-based fertilizer recommendation system, specifically tailored to the soil conditions of Andhra Pradesh. Leveraging a high-quality dataset obtained from the Indian Institute of Soil Science, Bhopal, the proposed system aims to deliver highly accurate and context-sensitive fertilizer recommendations. The methodology integrates advanced machine learning algorithms, by utilizing multiple models including Bagging, AdaBoost, GBoosting, Extra Trees and CatBoost classifier to enhance predictive performance. These models are engineered with robust features to support intelligent decision-making for fertilizer management. Figure 2 illustrates the overall architecture of the proposed recommendation framework.

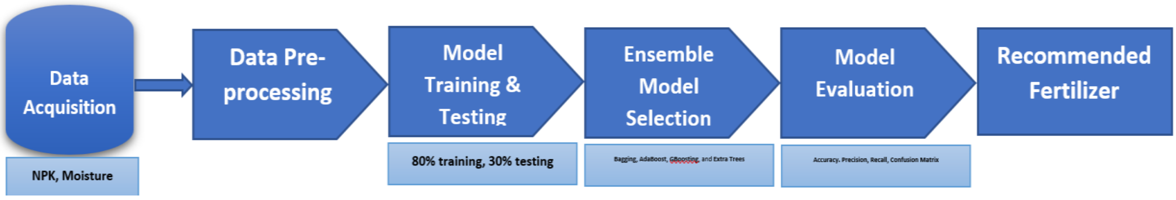

Fig 2. fertilizer recommendation system model.

3.1. Dataset Acquisition

The researchers begin by collecting data from the Indian Institute of Soil Science, Bhopal. This dataset contains detailed information on agricultural parameters, including soil properties and moisture levels. The dataset comprises 2199 entries collected from all major towns across Andhra Pradesh, India, covering 9 different fertilizer varieties.

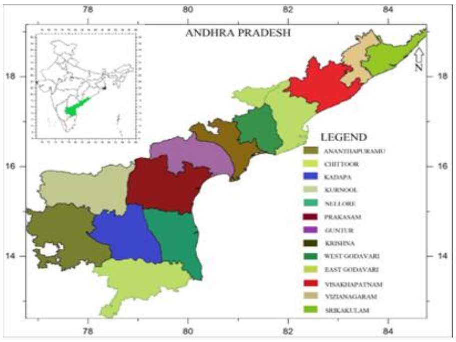

Fig 3. Study area from which soil and moisture were derived. i.e.. Andhra Pradesh..

```
df.tail()
```

	N	P	K	moisture	label
2195	107	34	32	177.774507	13:0:46 NPK
2196	99	15	27	127.924610	13:0:46 NPK
2197	118	33	30	173.322839	13:0:46 NPK
2198	117	32	34	127.175293	13:0:46 NPK
2199	104	18	30	140.937041	13:0:46 NPK

Fig 4. sample of soil features dataset

3.2. Data Pre-processing

The collected soil and moisture data are first preprocessed, which involves cleaning, structuring, and converting the raw data into a format that can be effectively utilized by machine learning algorithms.

3.3. Model Training & Testing

The refined dataset is subsequently utilized to train and evaluate multiple machine learning models. In the training phase, the models identify and learn underlying patterns and correlations within the data. During testing, their effectiveness is assessed using unseen data to measure their accuracy, robustness, and ability to generalize. This process is crucial for ensuring that the models can provide reliable predictions in practical agricultural applications.

3.4. Model Selection

After the training and testing phases, the most effective machine learning models are selected based on key evaluation metrics, including accuracy, precision, recall and confusion matrix. These selected models exhibit high predictive performance and reliability, making them well-suited for providing accurate mixed-crop recommendations across diverse soil and moisture conditions.

3.5. Model Evaluation

The selected machine learning models undergo comprehensive evaluation using standard performance metrics such as accuracy, precision, recall, and confusion matrix analysis. This evaluation ensures that the models are not only effective on the training dataset but also capable of generalizing well to new, unseen data confirming their reliability for practical agricultural applications and decision-making.

1. Accuracy is a key performance metric in machine learning that measures the ratio of correct predictions to the total number of predictions made by a model. It reflects how frequently the model accurately classifies or forecasts outcomes.

$$\text{Accuracy} = \frac{\text{True Positives (TP)+True Negatives (TN)}}{\text{TP+TN+FP+FN}} \quad (1)$$

2. Precision is a machine learning evaluation metric that assesses the correctness of positive predictions. It indicates the proportion of predicted positive instances that are truly positive, reflecting how reliable the model is when it predicts a positive outcome.

$$\text{Precision} = \frac{\text{True Positives (TP)}}{\text{True Positives (TP)+False Positives (FP)}} \quad (2)$$

3. Recall also referred to as sensitivity or the true positive rate, is a machine learning metric that evaluates how effectively a model identifies all relevant positive cases within a dataset. It reflects the model's ability to detect actual positives without missing any.

$$\text{Recall} = \frac{\text{True Positives (TP)}}{\text{True Positives (TP)+False Negatives (FN)}} \quad (3)$$

4. Confusion Matrix is a tabular representation used to assess the performance of a classification model by comparing its predicted outputs with the actual class labels. It offers a comprehensive summary of both correct and incorrect predictions across all classes, helping to identify where the model performs well and where it makes errors.

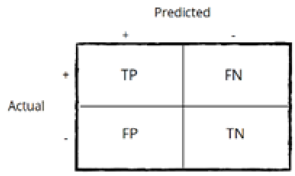

FIG 5. Confusion Matrix

3.6. Fertilizer Recommendation System

Recommended Fertilizer that can be applied into the individual farmer's soil

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Algorithm – fertilizer recommendation system

Step 1: Collection of the dataset
(Regional dataset)
Step 2: Perform Data-preprocessing
(Data cleaning, replacing missing values, feature selection, and engineering)
Step 3: Model Training and Testing
(Split the data into 80% for training and 20% for testing)
Step 4: Building Hybrid Models
(Bagging, AdaBoost, GBoosting, Extra Trees, CatBoost)
Step 5: Model Performance Evaluation
(Accuracy, Precision, Recall, Confusion Matrix)
Step 6: Recommended Fertilizer

Machine learning is a branch of artificial intelligence that centers on creating algorithms and statistical models that allow computers to learn from data and make informed decisions or predictions without the need for explicit programming for each individual task (Tanaka et al., 2024).

Supervised Learning is a machine learning approach where models are trained on a labeled dataset, meaning each *input* is associated with a known output. The model learns to map inputs to outputs, enabling it to accurately predict results for new, previously unseen data (Melasagare et al., 2024).

Unsupervised Learning is a machine learning technique where the model is trained on data without predefined labels or target values. Its primary aim is to uncover hidden patterns, structures, or groupings in the data without any external supervision or guidance (Thorat et al., 2023).

Reinforcement Learning is a machine learning approach in which an agent learns to make optimal decisions by interacting with an environment, receiving rewards or penalties in response to its actions. Through trial and error, the agent gradually improves its strategy to maximize cumulative rewards over time (Khan et al., 2022)**.**

4. RESULTS

The results of our proposed ensemble-based fertilizer recommendation system utilizing Bagging, AdaBoost, Gradient Boosting, Extra Trees, and the CatBoost classifiers demonstrate superior performance, achieving a peak accuracy of 94.78%.

These ensemble machine learning models were evaluated using multiple performance metrics, as detailed in Table 1 shown, which presents their accuracy, precision, and recall scores. The recommended ensemble model delivers personalized fertilizer recommendation by analyzing the specific soil nutrient and moisture of individual farmlands. This tailored approach enhances fertilizer suitability and diversity, ultimately contributing to improved agricultural productivity and increased economic returns for farmers across Andhra Pradesh, India.

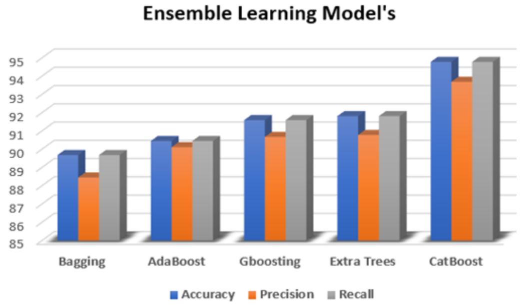

FIG 6. Fertilizer Recommendation Model's Performance Chart

TABLE 1. Ensemble models for fertilizer recommendation performance metrics

Ensemble Models	Accuracy	Precision	Recall
Bagging	89.68%	88.45%	89.68%
AdaBoost	90.45%	90.11%	90.45%
Gboosting	91.59%	90.67%	91.59%
Extra Trees	91.81%	90.78%	91.81%
CatBoost	94.78%	93.69%	94.78%

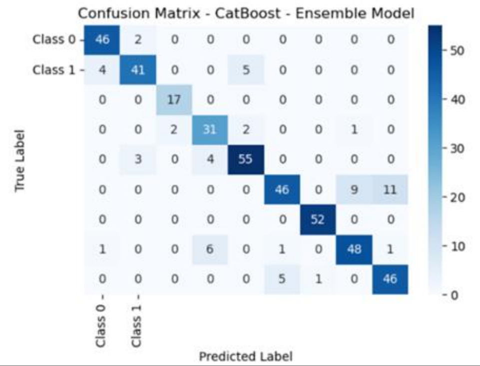

FIG 7. Ensemble Fertilizer Recommendation Confusion Matrix of CatBoost Classifier

The Table 2 and Figure 6 present a comparison analysis of the performance of various existing models and the proposed model, detailing their respective accuracy levels. Notably, the CatBoost classifier model demonstrated superior performance, achieving the highest accuracy among all the models assessed.

TABLE 2. Accuracy comparison for all existing models and the proposed model

Reference	Algorithms	Accuracy
(Thorat et al., 2023)	Inception-3	92.23%
(Khan et al., 2022)	TPF-CNN	90.11%
(Bhola and Kumar, 2024)	DT	93.10%
(Patel* and B. Patel, 2023)	LR	93.66%
(Basava, 2024)	K-NN	92.11%
(Vijender Reddy et al., 2024)	DNN	92.89%
(Tkatek et al., 2023)	SVM	91.99%
(Bhosale et al., n.d.)	DT	89.54%
(D N and Choudhary, 2024)	LR	93.23%
(Ngo et al., 2023)	SVM	91.80%
Proposed Work	**CatBoost**	94.78%

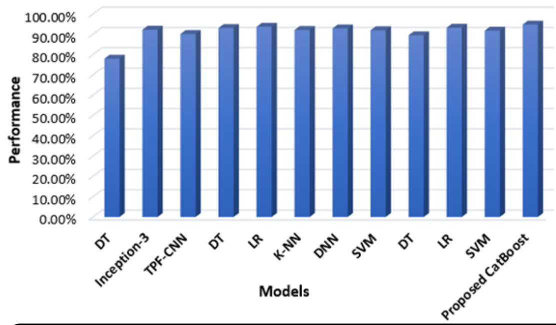

FIG 8. Performance comparison between the proposed model existing models

5. DISCUSSION

The findings of this proposed study highlight the effectiveness of ensemble learning algorithms in tackling complex, real-world classification of fertilizer application challenges based on individual farm soil nutrients such as nitrogen (N), phosphorous (P), potassium (K), and moisture. By harnessing diverse features and managing high-dimensional data, the proposed system demonstrated superior performance compared to existing conventional machine learning techniques. Especially, the CatBoost classifier emerged as the most effective model, achieving an accuracy of 94.78% and outperforming other ensemble methods such as Bagging, AdaBoost, Gradient Boosting, and Extra Trees in terms of accuracy, resilience, and generalization to unseen data.

These results underscore the potential of ensemble-based approaches in advancing precision agriculture. The success of CatBoost classifier in particular suggests that the frameworks capable of handling categorical variables and overfitting control are well-suited for agricultural decision support systems. This study offers valuable insights into how such technologies can be applied to improve fertilizer recommendations, minimize resource wastage, and contribute to enhancing food security on a global scale.

6. CONCLUSION

This study proposed an ensemble learning-based fertilizer recommendation system designed to enhance nutrient application by analyzing key soil characteristics. The model, which integrates a variety of ensemble algorithms including Bagging, AdaBoost, Gradient Boosting, Extra Trees, and CatBoost classifier achieved a high predictive accuracy of 94.78%, outperforming the other methods in both reliability and adaptability. The findings highlight the effectiveness of ensemble techniques in managing the complexity and collection of agricultural datasets. Such intelligent systems can empower farmers with precise, data-driven fertilizer recommendations, thereby improving crop yields, minimizing resource wastage, and supporting sustainable agricultural development. Future work may focus on integrating real-time data using IoT sensor and deploying the system on mobile platforms to increase practical accessibility for farmers.

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REFERENSI

[1] Abera, W., Tamene, L., Tesfaye, K., Jiménez, D., Dorado, H., Erkossa, T., Kihara, J., Ahmed, J.S., Amede, T., Ramirez-Villegas, J., 2022. A data-mining approach for developing site-specific fertilizer response functions across the wheat-growing environments in Ethiopia. Exp. Agric. 58, e9. https://doi.org/10.1017/S0014479722000047

[2] Basava, C., 2024. Optimizing fertilizer usage in agriculture with AI Driven Recommendations 21.

[3] Bhola, A., Kumar, P., 2024. ML-CSFR: A Unified Crop Selection and Fertilizer Recommendation Framework based on Machine Learning. Scalable Comput. Pract. Exp. 25, 4111–4127. https://doi.org/10.12694/scpe.v25i5.2599

[4] Bhosale, D.R.S., Kakad, M.T.P., Kakad, K.C., n.d. Smart Crop Prediction and Fertilizer Recommendation using Machine Learning.

[5] Bouni, M., Hssina, B., Douzi, K., Douzi, S., 2022. Towards an Efficient Recommender Systems in Smart Agriculture: A deep reinforcement learning approach. Procedia Comput. Sci. 203, 825–830. https://doi.org/10.1016/j.procs.2022.07.124

[6] D N, V., Choudhary, S., 2024. The new machine learning feature selection method used in fertilizer recommendation. Bull. Electr. Eng. Inform. 13, 3455–3462. https://doi.org/10.11591/eei.v13i5.7198

[7] Dhal, S.B., Bagavathiannan, M., Braga-Neto, U., Kalafatis, S., 2022. Nutrient optimization for plant growth in Aquaponic irrigation using Machine Learning for small training datasets. Artif. Intell. Agric. 6, 68–76. https://doi.org/10.1016/j.aiia.2022.05.001

[8] Durai, S.K.S., Shamili, M.D., 2022. Smart farming using Machine Learning and Deep Learning techniques. Decis. Anal. J. 3, 100041. https://doi.org/10.1016/j.dajour.2022.100041

[9] Escorcia-Gutierrez, J., Gamarra, M., Soto-Diaz, R., Pérez, M., Madera, N., Mansour, R.F., 2022. Intelligent Agricultural Modelling of Soil Nutrients and pH Classification Using Ensemble Deep Learning Techniques. Agriculture 12, 977. https://doi.org/10.3390/agriculture12070977

[10] Gao, J., Zeng, W., Ren, Z., Ao, C., Lei, G., Gaiser, T., Srivastava, A.K., 2023. A Fertilization Decision Model for Maize, Rice, and Soybean Based on Machine Learning and Swarm Intelligent Search Algorithms. Agronomy 13, 1400. https://doi.org/10.3390/agronomy13051400

[11] Huy Cuong, N.H., Trinh, T.H., Nguyen, D.-H., Bui, T.K., Kiet, T.A., Ho, P.H., Thuy, N.T., 2022. An approach based on deep learning that recommends fertilizers and pesticides for agriculture recommendation. Int. J. Electr. Comput. Eng. IJECE 12, 5580. https://doi.org/10.11591/ijece.v12i5.pp5580-5588

[12] K, K.D., Kumar, J.P., 2024. Sustainable Food Development Based on Ensemble Machine Learning Assisted Crop and Fertilizer Recommendation System. J. Mach. Comput. 317–326. https://doi.org/10.53759/7669/jmc202404030

[13] Khan, A.A., Faheem, M., Bashir, R.N., Wechtaisong, C., Abbas, M.Z., 2022. Internet of Things (IoT) Assisted Context Aware Fertilizer Recommendation. IEEE Access 10, 129505–129519. https://doi.org/10.1109/ACCESS.2022.3228160

[14] León Chilito, E.D., Casanova Olaya, J.F., Corrales, J.C., Figueroa, C., 2025. Sustainability-driven fertilizer recommender system for coffee crops using case-based reasoning approach. Front. Sustain. Food Syst. 8, 1445795. https://doi.org/10.3389/fsufs.2024.1445795

[15] M, S., Vallabhaneni, R.S., Vasireddy, T., Polavarpu, D., 2022. Deep Ensemble Mobile Application for Recommendation of Fertilizer Based on Nutrient Deficiency in Rice Plants Using Transfer Learning Models. Int. J. Interact. Mob. Technol. IJIM 16, 100–112. https://doi.org/10.3991/ijim.v16i16.31497

[16] Melasagare, S.M., Gawade, S., Narvekar, P., Pandit, S., 2024. Crop And Fertilizer RecommendationUsing Machine Learning 9.

[17] Ngo, V.M., Duong, T.-V.T., Nguyen, T.-B.-T., Dang, C.N., Conlan, O., 2023. A big data smart agricultural system: recommending optimum fertilisers for crops. Int. J. Inf. Technol. 15, 249–265. https://doi.org/10.1007/s41870-022-01150-1

[18] Patel*, K., B. Patel, H., 2023. Multi-criteria Agriculture Recommendation System using Machine Learning for Crop and Fertilizesrs Prediction. Curr. Agric. Res. J. 11, 137–149. https://doi.org/10.12944/CARJ.11.1.12

[19] Praynlin, E., n.d. Machine Learning Approach for Crop and Fertilizer Recommendation.

[20] Radočaj, D., Jurišić, M., Gašparović, M., 2022. The Role of Remote Sensing Data and Methods in a Modern Approach to Fertilization in Precision Agriculture. Remote Sens. 14, 778. https://doi.org/10.3390/rs14030778

[21] Sajindra, H., Abekoon, T., Jayakody, J.A.D.C.A., Rathnayake, U., 2024. A novel deep learning model to predict the soil nutrient levels (N, P, and K) in cabbage cultivation. Smart Agric. Technol. 7, 100395. https://doi.org/10.1016/j.atech.2023.100395

[22] Sunandini, M., Deepiga, R., Gokulapriya, A., 2024. SMART SOIL FERTILIZER MONITORING AND CROP RECOMMENDATION SYSTEM BY USING IOT AND MACHINE LEARNING TECHNOLOGY 06.

[23] Tanaka, T.S.T., Heuvelink, G.B.M., Mieno, T., Bullock, D.S., 2024. Can machine learning models provide accurate fertilizer recommendations? Precis. Agric. 25, 1839–1856. https://doi.org/10.1007/s11119-024-10136-x

[24] H. Amnur, Y. Syanurdi, R. Idmayanti, and A. Erianda, “Developing Online Learning Applications for People with Hearing Impairment,” JOIV : Int. J. Inform. Visualization, vol. 5, no. 1, pp. 32–38, Mar. 2021, doi: 10.30630/joiv.5.1.457.

[25] Thorat, T., Patle, B.K., Kashyap, S.K., 2023. Intelligent insecticide and fertilizer recommendation system based on TPF-CNN for smart farming. Smart Agric. Technol. 3, 100114. https://doi.org/10.1016/j.atech.2022.100114

[26] Tkatek, S., Amassmir, S., Belmzoukia, A., Abouchabaka, J., 2023. Predictive fertilization models for potato crops using machine learning techniques in Moroccan Gharb region. Int. J. Electr. Comput. Eng. IJECE 13, 5942. https://doi.org/10.11591/ijece.v13i5.pp5942-5950

[27] Vijender Reddy, G., Venkata Krishna Reddy, M., Spandana, K., Subbarayudu, Y., Albawi, A., Chandrashekar, R., Singla, A., Praveen, 2024. Precision farming practices with data-driven analysis and machine learning-based crop and fertiliser recommendation system. E3S Web Conf. 507, 01078. https://doi.org/10.1051/e3sconf/202450701078

[28] Zahra, S., Sharma, S., Kumar, S., 2025. The Agri-IQ Revolution: Crop and Fertilizer Recommendations Tailored by Nature. https://doi.org/10.20944/preprints202503.0376.v1