IADSS: Integrated Agricultural Decision Support System Using Machine Learning

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Abstract. Agriculture, the backbone of the Indian economy, stands as a cornerstone in the livelihoods of millions, contributing significantly to the economy, providing jobs, and fulfilling the country's food needs. Despite its vital role, the sector faces challenges like inadequate access to real-time weather forecasts, inadequate water management, inaccurate fertilization practices, and a lack of data-driven insights for crop management that inhibit its growth and efficiency. This paper presents a novel solution, the Integrated Agricultural Decision Support System (IADSS), incorporating agricultural practices with machine learning capabilities to establish a comprehensive platform tailored for farmers. By employing advanced meteorological data and state-of-the-art algorithms, this approach delivers accurate, location-specific weather predictions, boosting well-informed decisions regarding planting, irrigation, and harvesting. IADSS surpasses weather forecasting; it extends its utility by delivering guidance on crop selection based on historical data and predicting optimal fertilizers using machine learning models. The proactive features of the system delegate farmers to adopt preventive measures, reducing the need for chemical interventions and promoting sustainable agriculture. Accessible through smartphones, tablets, and computers, the user-friendly web application furnishes farmers with data-driven insights for crop cultivation and fertilizer management. Ultimately, this initiative aims to improve global agricultural productivity, sustainability, and resilience in a changing climate. The research shows commitment to elevating farmers' livelihoods worldwide by providing necessary tools for success in an ever-evolving agricultural landscape.

Keywords: Crop prediction · Fertilizer Recommendation · Weather Forecast · Machine Learning · Deep Learning

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1 Introduction

The Integrated Agricultural Decision Support System (IADSS) represents a pioneering advancement in agricultural technology aimed at addressing the multifaceted challenges faced by modern farmers. By seamlessly integrating cutting-edge technological capabilities with the intricate demands of contemporary agriculture, IADSS serves as a comprehensive solution provider for farmers worldwide.

At its core, IADSS consolidates three critical components: weather forecasting, crop prediction, and personalized fertilizer recommendations. Weather forecasting within IADSS is not just about providing generic weather updates; rather, it offers location-specific forecasts tailored to individual farms. This precision enables farmers to make informed decisions regarding crucial agricultural activities such as planting, irrigation, and harvesting. By leveraging real-time weather data and advanced modeling techniques, IADSS empowers farmers to mitigate risks associated with adverse weather conditions, ultimately safeguarding their yields and livelihoods.

The crop prediction module of IADSS is equally transformative. Drawing upon historical data, predictive analytics, and machine learning algorithms, this component assists farmers in selecting the most suitable crops for their specific environmental conditions. By analyzing factors such as soil quality, climate patterns, and historical yield data [1], IADSS provides farmers with actionable insights into which crops are likely to thrive on their farms [2]. This predictive capability not only optimizes agricultural productivity but also enhances farmers' ability to adapt to changing environmental conditions, thereby fostering resilience in the face of uncertainty.

Additionally, IADSS offers personalized fertilizer recommendations tailored to the unique needs of each farm. By integrating soil test results, crop preferences, and environmental factors, this component helps farmers optimize fertilizer usage, minimize waste, and reduce environmental impact. Moreover, by promoting sustainable farming practices, IADSS contributes to the long-term health of agricultural ecosystems and communities.

The motivation behind IADSS stems from the urgent need to address the pressing challenges confronting modern agriculture. Climate uncertainties, characterized by erratic weather patterns and shifting climatic conditions, pose a significant threat to global food security. In response, IADSS aims to empower farmers with the tools and knowledge needed to navigate these uncertainties effectively. By providing accurate, real-time weather forecasts, facilitating informed crop selection, and promoting sustainable agricultural practices, IADSS enables farmers to mitigate risks, optimize productivity, and enhance the resilience of agricultural systems.

In essence, IADSS represents a paradigm shift in farming practices, where data-driven insights and technological innovations converge to empower farmers and reshape the agricultural landscape. By bridging the gap between technology and agriculture [3], IADSS holds the potential to revolutionize the way farming is conducted, ushering in a new era of productivity, sustainability, and resilience in agriculture.

2 Literature Survey

The literature survey examines diverse applications of machine learning and data-driven techniques in agriculture, aiming to revolutionize traditional farming procedures. The research employs algorithms like Decision Trees, Naive Bayes, and Random Forest to predict crop yields, offer fertilizer recommendations, and aid crop selection decisions. Integrating advanced technologies, including sensors, IoT, and mobile applications, emphasizes a commitment to empower farmers, enhance productivity, and address challenges in the agricultural landscape. This comprehensive study aims to contribute to the prosperity of farmers, optimize agricultural developments, and highlight the critical role of data science in shaping the future of agriculture.

The study [4] predicts the selection of crops for planting by employing soil data gathered from sensors. The analysis employs decision tree-supervised machine learning algorithms, including Naive Bayes' theorem, Random Forest, and Decision Tree. The prediction of crop yield incorporates forecasting elements such as temperature, humidity, and rainfall. Additionally, the forecast of crop yield based on soil moisture involves assessing factors like NPK (Nitrogen, Phosphorous, and Potassium) and pH values using a variety of sensors.

The paper [5] proposes a user-friendly yield prediction system for Indian farmers, addressing the challenge of low crop yields compared to international standards, which contributes to issues like farmer suicides. The system, accessible through a mobile application, utilizes GPS for user location and allows input of area and soil type. Various machine learning algorithms are employed to predict crop yield or suggest the most profitable crops. Random Forest demonstrated the highest accuracy at 95%. The system also advises on optimal fertilizer application timing, aiming to enhance crop yield. Future work includes dataset updates for accurate predictions, process automation, and integrating fertilizer recommendations based on soil and climate analysis.

The paper [6] proposes a machine learning solution, specifically the Naive Bayes Gaussian classifier with boosting algorithm, to assist beginner farmers in predicting and optimizing crop yields amid unpredictable climatic changes. The system collects seed data with key parameters and develops an Android application for easy input. The research aims to provide accurate crop predictions, helping farmers with limited knowledge. Future enhancements include fertilizer suggestions, cropland guidelines, and crop health monitoring, contributing to a sustainable agricultural future. In recent years, the unpredictable changes in weather patterns have sparked various debates. Indonesia, being an agricultural nation with a significant portion of its population dependent on agriculture for their livelihoods, is experiencing tangible consequences, such as crop failures. The root cause can be traced back to the persistent use of traditional cropping patterns across generations, ignoring the impact of climate change and environmental factors. Recognizing the need for technological advancements in agriculture, this study seeks to leverage government-owned data to assist farmers by offering recommendations for suitable food crops.

The research employs a data classification technique utilizing the Naïve Bayes algorithm to generate recommendations for types of food plants. Data for the study is sourced from the Provincial Office of DI. Yogyakarta, focusing on parameters such as weather conditions, yields, and selling prices across four districts in the province. Data selection and cleaning processes are crucial to identify attributes influencing the recommendation outcomes. The WEKA tool is employed to assess Naïve Bayes' performance on the dataset, utilizing the cross-validation method for data validation. The results demonstrate an accuracy of 85.71%, demonstrating the suitability of Naïve Bayes for generating recommendations on crop types.

Furthermore, the study assesses Naïve Bayes' performance through sensitivity (0.857) and specificity (0.862) as validation measures, reinforcing its significance for the dataset. The consistency of Naïve Bayes is supported by a Kappa Statistics value of 0.8084. Additionally, the study estimates the method's error rate during classification and the time taken for the process.

The research outlined in paper [7] presents a crop recommendation system that employs machine learning techniques, considering key factors such as nitrogen (N), phosphorus (P), potassium (K), and humidity to propose the optimal crop for a given location. The study examines multiple algorithms, including KNN, Decision Tree, Random Forest, and SVM. After thoroughly analyzing their accuracy levels, the researchers implemented the Random Forest algorithm.

The chosen Random Forest algorithm enables training on large datasets, and the effectiveness of the recommendation system is assessed using an accuracy score as a performance metric. This approach allows for a thorough evaluation of crop recommendations, considering various environmental and soil-related characteristics for more accurate and reliable results.

The paper [8] presents machine learning and crop simulation techniques advances. While crop simulation strives to model agricultural processes, machine learning (ML) concentrates on forecasting by determining relationships between input and response variables. The complexities introduced by various factors, such as weather and soil conditions, pose challenges for farmers in crop cultivation. Accurate crop yield forecasts are essential for developing effective agricultural and food policies at both regional and international levels.

The proposed solution in this paper integrates two machine learning algorithms to enhance agriculture by predicting crop yield and offering fertilizer recommendations. What sets this approach apart is its innovative use of Random Forest and Logistic Regression algorithms for system implementation. This model stands out as an example of a hybrid ML approach designed to address the challenges mentioned earlier and potentially increase crop yield. Notably, the script enables users to predict the most suitable crop based on basic information like soil characteristics and weather conditions, showcasing a practical application of machine learning in agriculture.

The paper [9] suggests the incorporation of advanced technologies, specifically advanced sensors coupled with the Internet of Things (IoT), as a means to enhance agricultural production and mitigate economic losses. Global studies have successfully illustrated the impact of integrated IoT-smart sensors in monitoring crucial environmental factors for crop growth, including moisture, humidity, temperature, and soil composition. Furthermore, automated sensors are employed to measure greenhouse gases such as carbon dioxide and methane.

The integration of IoT-smart sensors into agriculture, often referred to as smart farming, facilitates the measurement of nitrogen content in soil. This information is valuable for farmers in determining the appropriate amount of fertilizers needed for their farmlands. By leveraging these advanced technologies, farmers can make informed decisions based on real-time data, leading to improved crop management practices and potentially higher yields.

The paper [10] proposes a decision tree supervised machine learning model to address key issues in agriculture planning, specifically focusing on soil moisture for crop yield prediction. Recognizing the economic impact of modern farming, the research highlights the importance of factors like soil nutrients, crop prediction, and monitoring. The model considers parameters such as temperature, humidity, and pH values, using various sensors for accurate predictions. The proposed system aids farmers in deciding the type of crop based on soil moisture values, contributing to economic growth and maximizing crop yield. The extension of this work includes automatic detection of crop yield by incorporating additional parameters like weather forecast and soil testing for improved agricultural outcomes.

This paper [11] introduces a comprehensive approach to addressing the economic significance of agriculture in India by proposing an advanced system for crop yield and fertilizer prediction. Utilizing data mining and machine learning, the study analyzes past weather and technological factors to accurately forecast future crop yield. The Random Forest regression model is employed for precise crop yield predictions, while the Decision Tree algorithm forecasts fertilizer requirements. The user interface, developed with Tkinter, allows users to input critical factors like state, district, year, season, crop, and area, enhancing accessibility for accurate predictions. Notably, the Random Forest Regression model demonstrates superior accuracy compared to other algorithms. The proposed system aims to empower agronomists, farmers, and policymakers, offering insights to maximize crop yield and optimize fertilizer use, thereby contributing to overall economic growth. The user-friendly interface promotes accessibility, and future enhancements, including the development of a mobile application, are suggested for more effective utilization.

The paper [12] introduces a comprehensive strategy for addressing the pivotal role of agriculture in India's socio-economic landscape, with a focus on optimizing crop productivity. Understanding the challenges faced by farmers in predicting yields amidst environmental fluctuations, the study employs deep learning algorithms like CNN, alongside machine learning models such as SVM, Naive Bayes, Random Forest, and XG Boost. Utilizing two datasets for fertilizer prediction and crop recommendation, the paper advocates for an ensemble technique to enhance prediction accuracy. The study's primary goal is to empower farmers by providing insights into crop production, disease prediction, fertilizer recommendations, and optimal crop choices. Notably, the paper underscores the accuracy of algorithms like Random Forest and CNN, comparing favorably with previous techniques. Additionally, it outlines the development of front-end and back-end frameworks using React JS and Django, facilitating user-friendly applications for farmers. The ultimate aim is to contribute to the prosperity of both farmers and the nation's agricultural output, with future plans to integrate cutting-edge features and expand datasets with new qualities.

This paper [13] underscores the significance of agriculture in India's economy and the challenges posed by natural calamities, often leading to financial losses for farmers and unfortunate outcomes like suicides. The study proposes an intelligent crop recommendation system employing machine learning algorithms to address this. The system aims to guide farmers in making informed decisions about crop selection based on critical parameters like Nitrogen, phosphorus, Potassium, pH Value, Humidity, Temperature, and Rainfall. The research expects increased productivity, profitability, and overall economic well-being, highlighting the vital role of data science in optimizing crop predictions and planning.

3 Materials and Methods

3.1 Proposed System

The proposed Integrated Agricultural Decision Support System (IADSS) enables farmers to select crops, make fertilizer recommendations, and forecast weather. IADSS uses historical and current data on soil, weather, and crops to train a machine learning model called a random forest, which predicts the best crop and fertilizer for a given location and crop also uses an external API to get real-time weather information for the user's location, which is detected by GPS or manual input. IADSS aims to improve agricultural productivity and sustainability by providing farmers with precise and personalized insights.

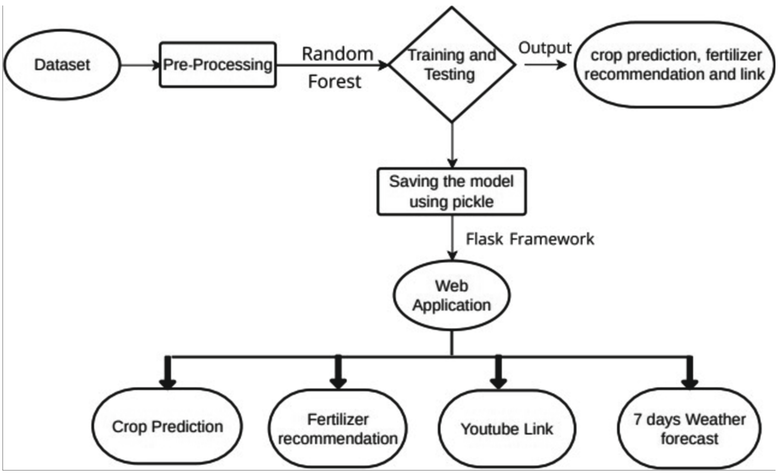

Fig. 1. Architecture of the proposed model.

The IADSS architecture in Fig. 1 reflects a holistic approach, combining agriculture, machine learning algorithms and web concepts to create an effective and user- friendly solution for enhancing resilience and prosperity of farming communities on a global scale.

3.2 Dataset

The Dataset is a publicly available dataset containing 4514 variations that aims at providing a clear picture of Crops and Fertilizer to be used to increase productivity. The features of dataset are: District Name, Soil color, Nitrogen, Phosphorus, Potassium, pH, Rainfall, Temperature, Crop, and Fertilizer. This data frame consists of eleven factors in which District Name, Soil color, Nitrogen, Phosphorus, Potassium, pH, Rainfall, Temperature are input parameters and Crop, Fertilizer, Link are output target values, which are trained by various ML techniques to predict the crop and the fertilizer which should be used for better yield of a crop and a link which provides details about the crop. Dataset is taken from Kaggle named Crop and Fertilizer and few modifications were done based on our requirements. The detailed description of dataset is given in Table 1.

Table 1. Features and their description.

S. No	Feature	Description
1	District Name	The name of the district where the data was collected
2	Soil color	Color or type of soil
3	Nitrogen	Quantity of nitrogen present in the soil (measurement unit is not specified)
4	Phosphorus	Quantity of phosphorus in the soil
5	Potassium	Quantity of potassium in the soil
6	pH	pH level of the soil
7	Rainfall	Amount of rainfall in the region (measurement unit is not specified generally in mm)
8	Temperature	Temperature in the region (measurement unit is not specified generally in Celsius)
9	Crop	Type of crop being cultivated
10	Fertilizer	Type of fertilizer recommended for the crop
11	Link	Link to a video or resource related to the crop (YouTube link provided)

3.3 Data Pre-processing

In this stage the data set is pre-processed i.e. handling missing data, null values, duplicate values, then Encoding of features named District Name & Soil color is done through Label Encoder to convert categorical values into numeric values for prediction. Later after the prediction of the result is done, values are to be converted back to their original values for next predictions. So, this back conversion to original values of features District Name & Soil color is done through inverse function. This process made us train the data easily for predictions.

3.4 Classifiers

After Pre-Processing phase, the dataset is trained using various ML algorithms such as Decision Trees, Random Forests, SVM, and Naive Bayes.

Random Forest Classifier. Random Forest is an ensemble learning technique [14] known for its high accuracy in classification and regression tasks. Constructing multiple decision trees during training and aggregating their predictions effectively minimizes over fitting. This algorithm excels in addressing large datasets with diverse features, requiring minimal preprocessing steps. It considers feature importance for better interpretability and efficiently manages unbalanced data, providing balanced class probabilities. Its versatility is prominent in applications ranging from customer churn prediction to bioinformatics. The advantages of high accuracy, resistance to over fitting, extensive dataset handling, feature importance assessment, and efficiency with unbalanced data make Random Forest a powerful and widely-used tool in the machine learning landscape.

Decision Tree Classifier. Decision Tree is a powerful supervised learning tool proficient at handling classification and regression challenges, though it is often favored for classification [15]. Its intuitive tree structure, featuring decision nodes for dataset features and leaves for results, ensures easy interpretability, making it accessible to non-experts. Outstanding benefits include its ability to seamlessly address numerical and categorical data, requiring minimal preprocessing, and its inherent feature selection capability, assisting in identifying crucial factors influencing decisions. Decision Trees find adaptable applications in medical diagnosis, marketing analytics, fault diagnosis systems, and environmental sciences, exhibiting their adaptability and effectiveness across disciplines.

Support Vector Machine. Support Vector Machine (SVM) [16] is a widely used supervised learning algorithm primarily applied to classification tasks in machine learning. It aims to create an optimal decision boundary, a hyper plane that effectively segregates n-dimensional space into distinct classes. To construct this hyper plane, SVM identifies crucial extreme points, termed support vectors. The algorithm has two main types: Linear SVM, suitable for linearly separable data classifiable by a straight line, and Non-linear SVM, designed for data that requires a more complex, non-linear decision boundary. In essence, SVM excels in creating robust decision boundaries for effective classification in both linearly and non-linearly separable datasets.

Naive Bayes Classifier. Naıve Bayes [17] is a supervised learning algorithm rooted in Bayes' theorem, predominantly employed for solving classification problems, especially in text classification with high-dimensional datasets. Recognized for its simplicity and effectiveness, Naıve Bayes is a probabilistic classifier, making predictions based on the probability of an object belonging to a certain class. It finds application in diverse tasks such as spam filtration, sentiment analysis, and article classification. Advantages include its speed, simplicity, applicability to both binary and multi-class classifications, and superior performance in multi-class predictions. However, its main drawback lies in the assumption of feature independence, limiting its ability to learn relationships between features. In essence, Naıve Bayes is a fast and efficient choice for classification tasks, particularly well-suited for text-related applications.

4 Results Discussion and Deployment

We trained the model using four prominent ML algorithms: RF, DT, SVM, and NB are employed. These algorithms are evaluated based on key performance metrics, including accuracy, F1 score, recall, and precision. Among all Random Forest Classifier and Decision Tree Classifier have higher accuracy and performance compare to other algorithms. After rigorous testing, we found Random Forest to be the most effective, and we used'pickle' to save and integrate the model into a web application, which predicts both crop and fertilizer based on soil parameters and weather conditions and provides a link of crop information,with integration of weather forecast. This ensures farmers have a reliable tool for informed crop decisions based on real-time conditions. Figure 2 represents the graphical representation of all algorithms comparison. Table 2 represents the metrics values of all algorithms.

Table 2. Performance evaluation of various classifiers.

Algorithm	Accuracy (In %)	F1 Score (In %)	Precision (In %)	Recall (In %)
Random Forest	100	100	100	100
Decision Tree	100	100	100	100
SVM	59.9114	56.8678	59.9114	57.415
Naive Bayes	77.9623	77.3655	77.9623	81.643

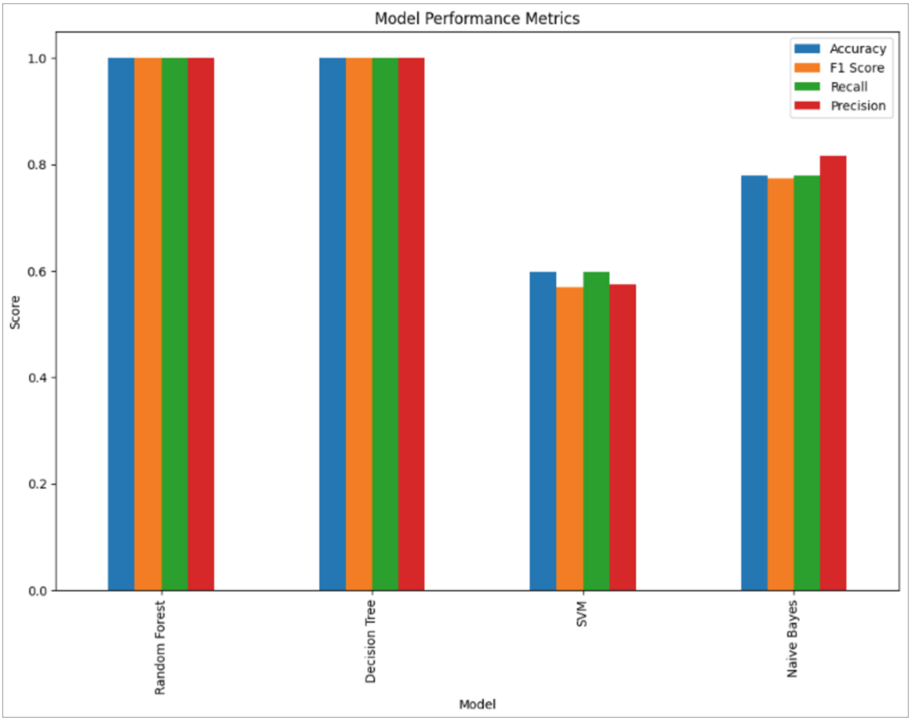

Fig. 2. Comparison of various classifiers.

4.1 Development of the Application

We trained the machine learning model using various algorithms such as Decision Trees, Random Forests, SVM, and Naive Bayes. After rigorous testing, we found Random Forest and Decision Tree to be more effective among them. Then we used Random Forest and'pickle' to save and integrate the model into the web application. We started developing the user-friendly web application using Flak Framework by deploying the saved trained model which was done through pickle along with the label encoder's files. It is integrated with the model and also OpenWeatherMap for 7-day's Weather forecast module which is automatic GPS and location specific based with dynamic background change. When User inputs the values of soil parameters and location-specific weather conditions the model predicts the crop based on the inputs with image and recommends crop-specific fertilizer with image to user along with a link of the crop details integrated with a 7-day weather forecast with dynamic background changes.

The following figures represents the inputs and outputs of the application. Figure 3 shows the user input format. For the given input the crop predicted i.e. wheat is shown in Fig. 4 and fertilizer recommended i.e. NPK is shown in Fig. 5. Figure 6 is the output predictions of recommended crop, fertilizer and weather forecasts for different places.

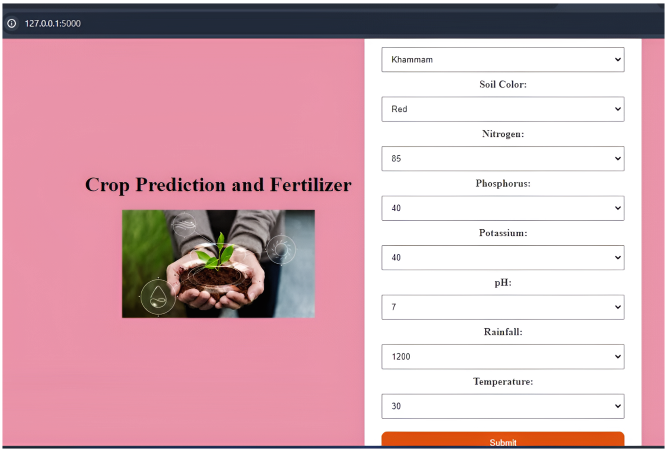

Fig. 3. Web Output taking input values

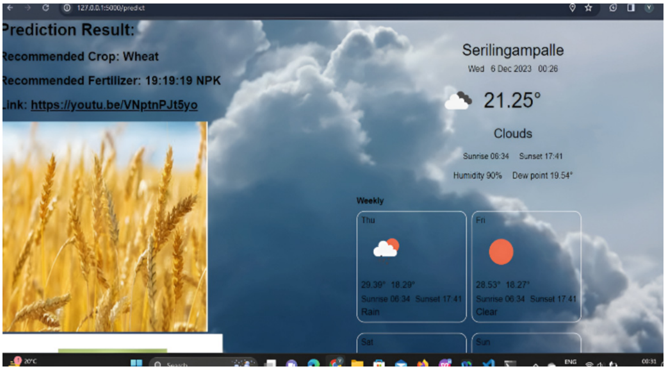

Fig. 4. Output Representing Wheat Crop

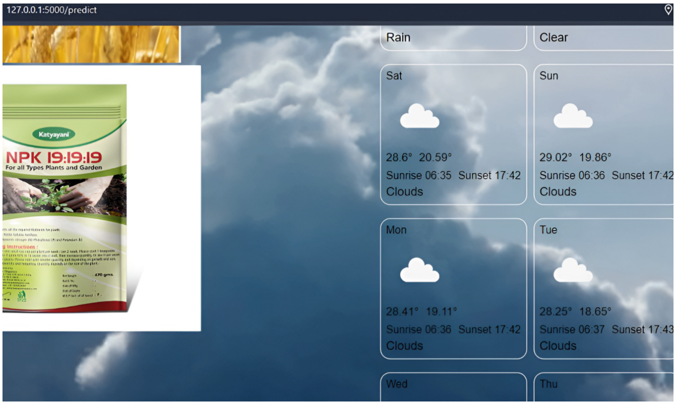

Fig. 5. Output Representing NPK Fertilizer

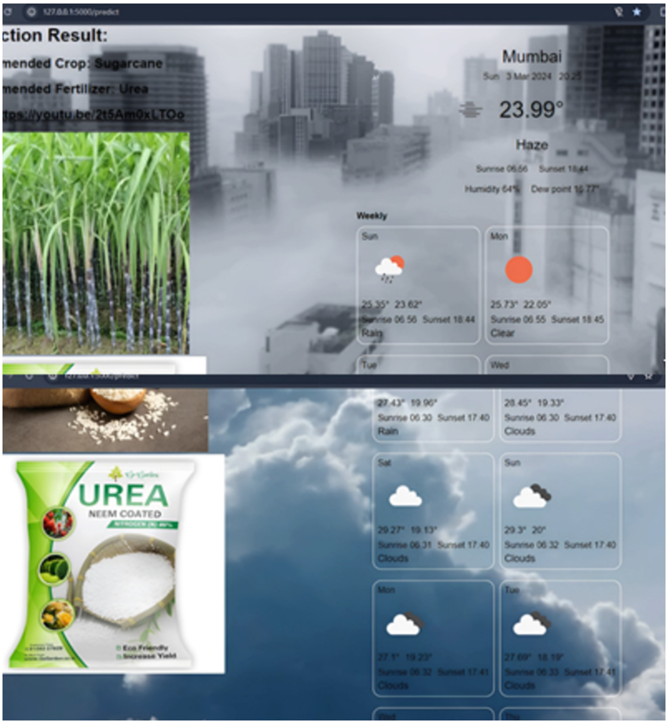

Fig. 6. Recommended crop, fertilizer and weather forecasts for different places.

5 Conclusion

The Integrated Agricultural Decision Support System using machine learning (IADSS) proposed in this work offers a groundbreaking solution to the challenges hindering the agricultural sector in India and globally. By integrating advanced meteorological data and machine learning algorithms, IADSS provides precise, location-specific weather forecasts, empowering farmers to make informed decisions on planting, irrigating, and harvesting. The system goes beyond weather forecasting, offering insights into crop selection and optimal fertilizers, promoting sustainable practices, and reducing reliance on chemical interventions. Accessible through smartphones and computers, IADSS promises to enhance global agricultural productivity, sustainability, and resilience, ultimately improving the livelihoods of farmers worldwide in the face of a changing climate.

In the future, IADSS envisions significant advancements, focusing on enhancing predictive capabilities, leveraging advanced data analytics, and integrating cutting-edge IoT devices for real-time monitoring. These developments aim to provide more accurate forecasts, covering various crucial agricultural factors such as weather patterns, pest outbreaks, crop yields, and market demands. The integration of advanced data analytics and IoT devices seeks to optimize decision-making for farmers, fostering efficiency, sustainability, and resilience in the agricultural sector globally.

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