
A Multi-Modular AI Approach to Sustainable Agriculture: Integrating Predictive Analytics for Crop Selection and Nutrient Optimization

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Abstract

Agriculture remains the backbone of rural livelihoods, with 60% to 70% of the population depending on it. However, farmers often face challenges in making informed decisions due to time constraints, lack of expertise, and limited access to real-time information. This paper explores a comprehensive, web-based decision support system which enables farmers to make real-time predictions and recommendations dependent on the environmental and soil factors such as Nitrogen (N), Phosphorus (P), Potassium (K), pH, temperature, humidity, soil moisture, and rainfall. The application is going to be an Ensemble Model, based on Majority Voting Mechanism, to be applied in crop recommendation and also a Fertilizer Dictionary to provide better fertilizer recommendations. The system based on the Kaggle dataset employs a Sequential Convolutional Neural Network (CNN) for identification of pests. It analyzes market trends for recent past history, historical prices, and provides insights into keeping crops healthy through monitoring in real-time. The application also has an inventory management system that ensures the availability of resources. From crop selection to optimal fertilizer usage to pest control, it promises farmers data-driven insights into increasing productivity in their agricultural outputs with minimal operational risks, offering support for sustainable farming as well.

Keywords

Precision Agriculture, Machine Learning, Crop Recommendation, Fertilizer Optimization, Pest Management, Ensemble Learning, Convolutional Neural Networks, Decision Support System, Market Trends Analysis, Inventory Management.

1. INTRODUCTION

Agriculture is an important sector of the Indian economy, and the area accounts for approximately 18% of the country's Gross Domestic Product as well as provides for almost 60% of the population. Yet, the farmers face severe stresses in the forms of little or late information, low resources, and less desirable implications of effects due to climatic change on crop yields. These cases are even more challenging by the recent unusual environmental changes and the complexity of modern agricultural activities. Traditionally, a farmer depends on his experience and, in general, sporadic expert advice on crop choice, fertilization, and pest management. However, the availability of experts is often meager and has not allowed the farmer to make proper decisions on his farm leading to low productivity, high costs, and financial instability [1].

Recent technological advances in machine learning (ML) and artificial intelligence (AI) open up new prospects to transform precision agriculture. These technologies determine data-driven understanding; hence, they empower farmers with maximum utilization of available resources and optimal crop yields. In applying such crucial factors as soil nutrients (Nitrogen, Phosphorus, Potassium), pH, temperature, humidity, and rainfall, ML models can make recommendations to the farmer for crop selection and fertilizer application much more precisely. Precision agriculture enables farmers to adapt to constantly shifting environmental conditions and improve their agricultural efficiency, thus reducing risks imposed on them by unpredictable weather patterns and other extraneous factors.

This paper focuses on a web-based decision support system that allows farmers to make decision support in crop selection, fertilizer use, pest management, and prediction of plant diseases. This paper uses an Ensemble Model with a Majority Voting Mechanism for crop recommendation, a Fertilizer Dictionary for the best fertilizers to be recommended, and a Sequential CNN for pest identification through image analysis. Also, it has a plant disease prediction sub-feature that is able to detect possible diseases early by its image recognition technique. This makes it possible to intervene at the right time. It integrates real-time market trends, weather data, and inventory management for full well-rounded solutions. This improves agricultural productivity while promoting sustainability.

2. LITERATURE REVIEW

Vishwash Tatarwal et al [1], is engaged in the use of help for the ARIMA modeling for forecasting soybean prices for farmers to make the right decision on planting times and risk management. The authors worked on the historical data available through Agmarknet.gov.in while strictly ensuring that the used data is absolutely stationary on checking through Augmented Dickey-Fuller Test. However, such a model predicted the trends for the period between 2004 and 2017 but raised two serious problems: it is based on history and relies on assumptions that are proven incorrect quite often. Jeerawan Saelao and Nopporn Patcharaprakiti [2], tries to understand the trend of the rainfall in Sansai District, Thailand, with a time series analysis of the period from 1993 to 2012 in support of irrigation planning. The research has determined an upward trend for the rainfall during the months between January and October and had presented a predictive model to be apt for the subsequent five years. The reliance on history may perhaps not have disclosed the present climate changes, and the research was constrained to just one district. Rok Rupnik et al. [3], is a presentation of the AgroDSS, which is data analysis-related decision support to improve precision agriculture. It permits farmers to upload data and use predictive modeling to inform their decisions. This is used in a case study on pest dynamics. Still, several disadvantages here are the quality of data, user engagement, and also adaptation to another agricultural context. Authors [4], who define SIDSS as a machine learning-based optimization system of irrigation management, in which real-time data input from soil sensors and weather stations would optimize irrigation at better accuracy, are H. Navarro-Hellin et al. The application may suffer at the vagaries of sensor data quality and will be crop-specific, reducing the generalizability of the system; moreover, it is not applicable without technical knowledge on implementation.

Nidhi H. Kulkarni et al. [5] discusses crop recommendation using ensemble techniques of different models from machine learning: that outputs are highly accurate for cropping patterns for farmers according to soil and climatic attributes. Promising technique; though its effectiveness depends on the quality of the data available in the system and may not account for all external factors that affect growth, which, therefore, restricts its use. Shilpa Mangesh Pande et al. [6] also proposed crop recommender system based on machine learning for Indian farmers that achieved an accuracy rate of 95%. Historical crop data is analyzed and followed by processing using different algorithms in making recommendations to the farmer. Since there is a high cost of maintenance, there is dependence on the quality of data available, and further, only fertilizer application timing was provided without specifying fertilizer types. Authors in [7], 'Smart Crop Recommendation System' for Indian farmers, proposed a crop recommendation system which considers soil and environmental factors in search of yield optimization. The methodology adopted by the system is preprocessing data and applying machine learning algorithms that predict the sustainability of crops. The limitation is that it relies on the quality of the data and the rise in environmental conditions might be missed. It requires technical knowledge to be effective.

Rhia Trogo et al [8], proposed a decision support system for Isabela, Philippines yellow corn farmers based on crop simulation models that may help farmers get worthwhile insights from practicing farming activities. As it is supposed to provide agricultural information to many people without requiring them to develop technical skills for that purpose, it needs improvement, especially by incorporating market price data.

Thomas van Klompenburg and Ayalew Kassahun [9], reviewed application of machine learning in predicting crop yield and noted that ANN is the most popular algorithm applied, featuring temperature and rainfall. Analysis points to complexity in yield prediction; however, shows promise from machine learning for accuracy improvement. Hakan Erden [10], said Turkey has constructed its Agricultural Inventory Management System by using real-time data collection for monitoring its agricultural assets. With its capacity to provide reliable data for monitoring and planning, the system supports national policies by applying live databases and OLAP systems for proper agricultural statistics.

3. METHODOLOGY

The methodology for developing the web-based application designed to assist farmers with crop selection, fertilizer application, pest management, and plant disease prediction involves systematic data collection, model development, and implementation processes. This section outlines each component in detail.

3.1. Data Collection

Data collection was critical in establishing a reliable foundation for the application. Various datasets were compiled from primary sources, including:

3.1.1. Soil Nutrient Levels:

- Nitrogen (N): Obtained as a ratio of nitrogen content in soil, which is crucial in plant growing and development.
- Phosphorus (P): Gathered as a ratio of phosphorus content, which is very basic to root development and flowering.
- Potassium (K): As potassium concentration, which is also essential for water functioning and activation of enzymes.

3.1.2. Environmental Factors:

- Temperature: As degree Celsius in order to study the impact on crop growth
- Humidity: Percent relative humidity was developed to calculate the amount of moisture present in the surrounding atmosphere.
- Soil pH: Soil pH was recorded to determine its alkalinity or acidity and how it influences the nutrient availability.
- Rainfall: Measured in milli meters, rainfall data was crucial for understanding water availability for crops.

	A	B	C	D	E	F	G	H
1	N	P	K	temperatu	humidity	ph	rainfall	label
2	90	42	43	20.87974	82.00274	6.502985	202.9355	rice
3	85	58	41	21.77046	80.31964	7.038096	226.6555	rice
4	60	55	44	23.00446	82.32076	7.840207	263.9642	rice
5	74	35	40	26.4911	80.15836	6.980401	242.864	rice
6	78	42	42	20.13017	81.60487	7.628473	262.7173	rice
7	69	37	42	23.05805	83.37012	7.073454	251.055	rice
8	69	55	38	22.70884	82.63941	5.700806	271.3249	rice
9	94	53	40	20.27774	82.89409	5.718627	241.9742	rice
10	89	54	38	24.51588	83.53522	6.685346	230.4462	rice
11	68	58	38	23.22397	83.03323	6.336254	221.2092	rice
12	91	53	40	26.52724	81.41754	5.386168	264.6149	rice

Figure 1. Crop and Fertilizer Recommendation Dataset

3.1.3. Historical Crop Yield Data:

The historical data collected for yield prediction includes:

- *State*: The state from where the crop data is gathered.
- *District*: The particular district where the crop was cultivated.
- *Crop*: The kind of crop (for instance, Arecanut, Wheat, Rice, etc.)
- *Crop Year*: The year during which the crop was grown
- *Season*: The season when the cultivation takes place, for example, Kharif, Rabi, Autumn, or Summer.
- *Area*: Area under cultivation measured in hectares
- *Production*: The overall crop production in tons.
- *Yield*: The output in tons per hectare is the central point for forecasting.

	A	B	C	D	E	F	G	H
1	State	District	Crop	Crop_Year	Season	Area	Production	Yield
2	Andaman and Nicobar Island	NICOBARS	Arecanut	2007	Kharif	2439.6	3415	1.4
3	Andaman and Nicobar Island	NICOBARS	Arecanut	2007	Rabi	1626.4	2277	1.4
4	Andaman and Nicobar Island	NICOBARS	Arecanut	2008	Autumn	4147	3060	0.74
5	Andaman and Nicobar Island	NICOBARS	Arecanut	2008	Summer	4147	2660	0.64
6	Andaman and Nicobar Island	NICOBARS	Arecanut	2009	Autumn	4153	3120	0.75
7	Andaman and Nicobar Island	NICOBARS	Arecanut	2009	Summer	4153	2080	0.5
8	Andaman and Nicobar Island	NICOBARS	Arecanut	2000	Kharif	1254	2000	1.59
9	Andaman and Nicobar Island	NICOBARS	Arecanut	2001	Kharif	1254	2061	1.64
10	Andaman and Nicobar Island	NICOBARS	Arecanut	2002	Whole Year	1258	2083	1.66
11	Andaman and Nicobar Island	NICOBARS	Arecanut	2003	Whole Year	1261	1525	1.21
12	Andaman and Nicobar Island	NICOBARS	Arecanut	2004	Whole Year	1264.7	806	0.64

Figure 2. Crop Yield Dataset

3.1.4. *Fertilizer Dictionary*: A comprehensive dataset was created that links specific crops with their nutrient requirements. This dictionary included:

- *Nutrient Ratios*: The required N, P, and K ratios for each crop, which guided fertilizer recommendations.

3.1.5. *Plant Disease Classification*: The dataset for plant disease prediction comprised labeled images of various plant diseases, including:

- Healthy Plants: Images of healthy crops were included for accurate classification.
- Diseased Plants: Specific diseases such as Late Blight in tomatoes and Huanglongbing in oranges were represented, with a focus on 35 distinct disease categories.

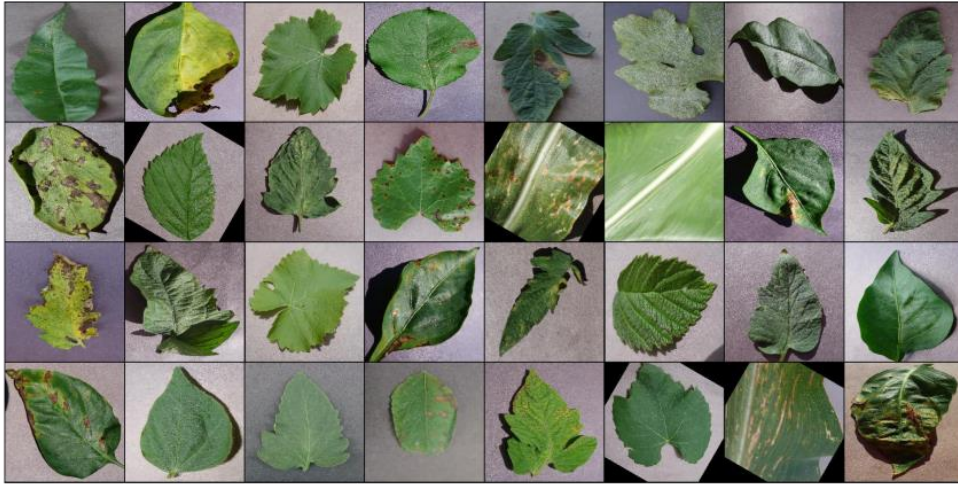


Figure 3. Diseased Plants Leaf Dataset

3.2. System Architecture

The flow diagram (provided) illustrates the key components of the system. It is divided into three modules, each responsible for specific agricultural decision-making tasks:

- *Krishi Bhavishya (Future Farming)*: This module predicts crop yield by integrating data on weather forecasts and real time market prices.
- *Krishi Rakshak (Crop Protection)*: Focuses on crop disease prediction and disease management solutions, incorporating a ResNet9 model for identifying crop diseases through image analysis.
- *Krishi Niyojak (Farm Planning)*: Manages farm inventory, including storage of crops, fertilizers, and seeds, while providing investment and best selling point analysis.

3.3. Crop Prediction and Yield Estimation

Random Forest Model:

- A Random Forest model was used to predict optimal crop choices based on environmental conditions, such as soil health and weather data. A history-based model of crop yield is fitted in and this model predicts crop yield based on the assessment of such features as temperature, rainfall, and the composition of the soil.
- Integration of real-time crop price monitoring and profit analysis into this model makes sure that farmers would make the right decisions concerning which crops to plant.
- Forecasting Yield: For every crop that a farmer will select, the amount of yields that may be produced is predicted using the Random Forest model to guide farmers in return estimation of every crop to them.

3.4. Disease Prediction using ResNet9

ResNet9 for Image-based Disease Identification:

- The ResNet9 architecture was selected for the plant disease detection. This deep learning architecture feeds image inputs to crops so that the diseases can be diagnosed through its symptoms.
- This worked on a labeled dataset of images from plants with several convolutional layers to draw out the features, identify the symptoms patterns of diseases, and learn in the right way.
- Disease Management Solutions: The system provides disease management techniques based on the identified disease, such as pesticide recommendations and application instructions to farmers.

3.5. Fertilizer Recommendation System

- *Fertilizer Dictionary*: The fertilizer recommendation engine was integrated in the system for the NPK ratio according to crop type and the soil nutrient levels. Thus, a proper amount of nutrients needed for growth is applied by farmers.

3.6. Real-time Monitoring and Support Services

- *Weather Forecasting and Market Tracking*: The system integrates weather forecasting to give the farmer up-to-date information on the state of the weather. It, therefore, aids in timely planting and harvesting decisions. The platform tracks crop price real time and gives profit analysis based on predicted yields and helps farmers decide when to sell their produce at the most profitable time.
 - *Inventory Management*: The inventory management module keeps track of stored crops, fertilizers, and seeds; therefore, farmers have adequate supplies at hand so they would be able to know the appropriate time to sell their crop depending on prevailing market conditions.

3.7. System Implementation and Deployment

- *Web-based Application*: The system was deployed as a web-based application that can be accessed through mobile devices, making it possible for rural farmers to operate the system without high-tech infrastructure.
User Training and Support: For easiness in operating the system, trainings were offered to farmers on how to use it, read recommendations, and implement the insights given.

4. PROPOSED SYSTEM

The proposed system is an integrated web-based application aimed at aiding the farmers to make right choices in crop selection, fertilizer application, pest management, and predicting plant disease. It will be based on advanced data analytics and machine learning techniques to help the farmers make real-time, action-able insights according to their demand.

Key Components of the Proposed System:

4.1. System Components

There are three main modules that form the system, which can be observed from the flowchart below:

- *Krishi Bhavishya (Crop Forecasting)*: This module focuses on crop prediction and estimation of yield. It predicts crops best suited to a farm according to weather conditions and soil health with respect to market trends. The algorithm used here is the Random Forest model, which, having been trained on historical crop data, suggests optimal crops to plant and, based on environmental factors, produces an estimate of the projected yield.
 - *Krishi Rakshak (Crop Protection)*: This module offers the prevention of diseases in crops. Then, the farmers upload images of infected plants and use them in the ResNet9 model to determine the prevailing diseases.
-

Then, the system feeds back the measures and remedies available for prevention and thus enables timely intervention by the farmers.

- *Krishi Niyojak (Farm Planning)*: It allows a farmer to manage the inventory of crops, seeds, and fertilizers. Besides this, it offers the facility of investment analysis, suggesting the best time to the farmer for crop purchase and sale, and optimizes the input cost.

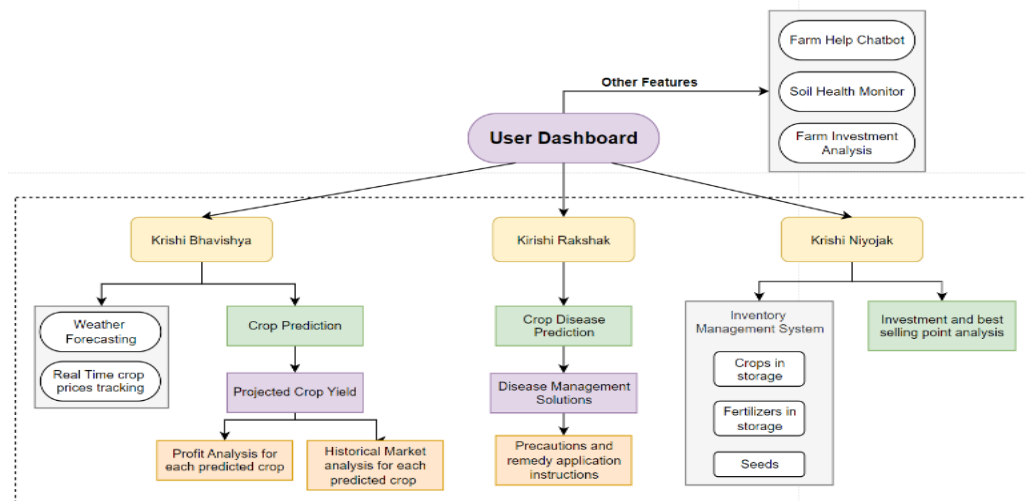


Figure 4. Flowchart of the proposed system

4.2. Machine Learning Models

- *Random Forest for Crop Prediction*: This model takes environmental information, such as the content of soil NPK, temperature, humidity, and real-time market prices, and suggests the crops to be cultivated. It provides estimated yield predictions as well. This way, decisions from farmers will be based on facts.
- *ResNet9 for Disease Detection*: ResNet9 is a model used in the area of plant disease detection from images. This allows farmers to get notified about any issues with the plants early in the season and suggests some treatments and prevention methods.

4.3. Real-time Features

- *Weather Forecasting*: It has linked meteorological data to ensure that the farmers are allowed to see real time reports and planting and harvesting schedules.
- *Crop Market Price Tracking*: It tracks the crops market price in real time, helping them to know when to sell their produce so that it brings maximum profit.
- *Farm Help Chatbot*: The system features include a chatbot who advises farmers on common issues and furthermore discusses matters such as soil health, pattern of pest management, and even general farming queries.
- *Soil Health Monitor*: This will measure the nutrient content in the soil and provides a set of recommendations to improve the quality of the soil through application of proper fertilizers.

4.4. User Interface and Accessibility

The system is designed to be user-friendly and accessible through mobile devices, even with farmers who don't have a highly technical background can use the system effectively. Training and supporting services are provided to farmers to utilize the system to the fullest with its available features.

5. RESULTS AND ANALYSIS

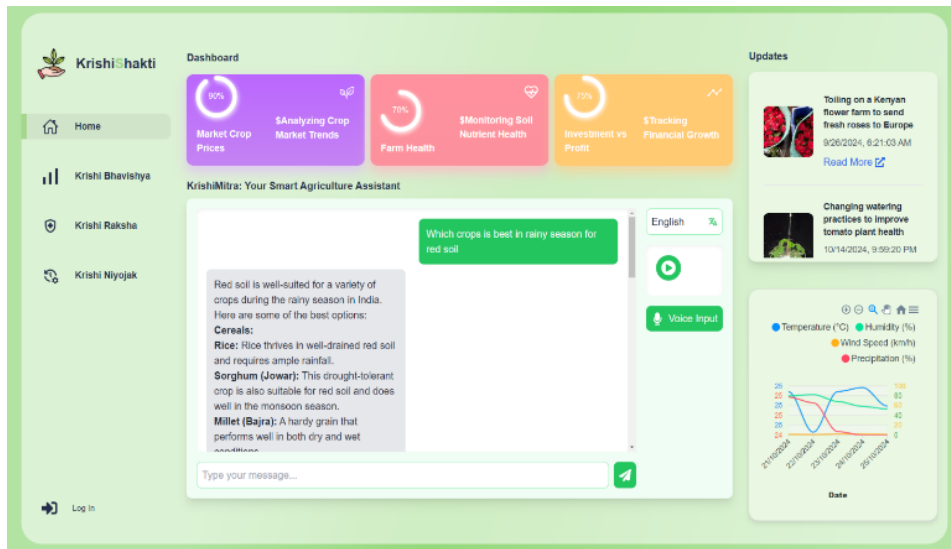


Figure 5. Home Page of the KrishiShakti

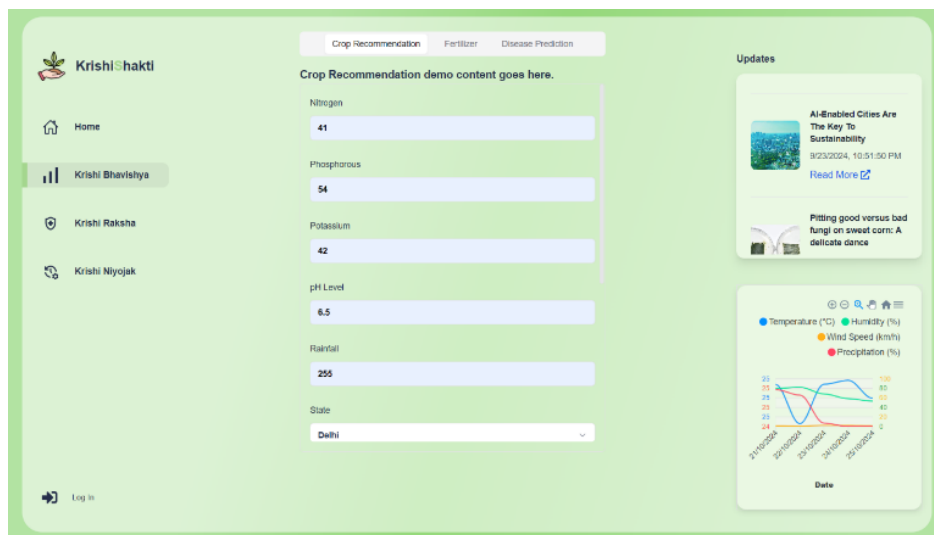


Figure 6. Crop Recommendation Window



Figure 7. Recommended Crops

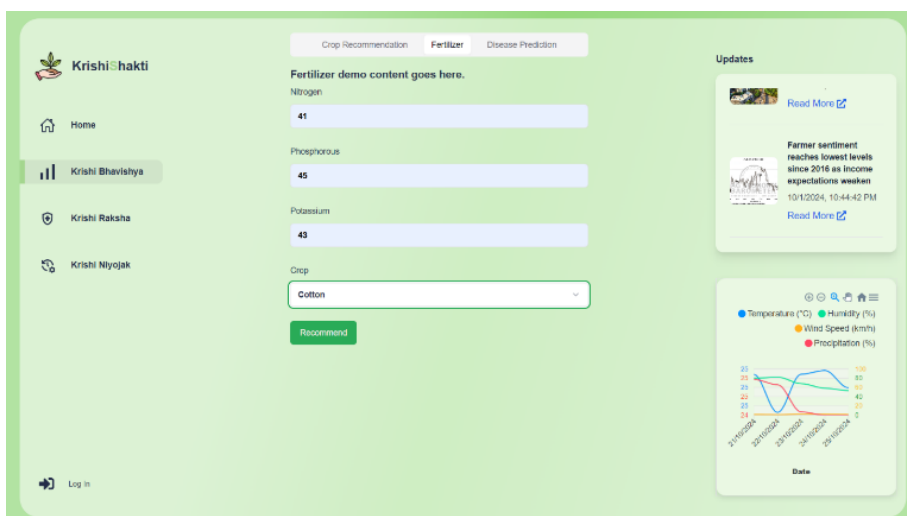


Figure 8. Fertilizer Recommendation Window

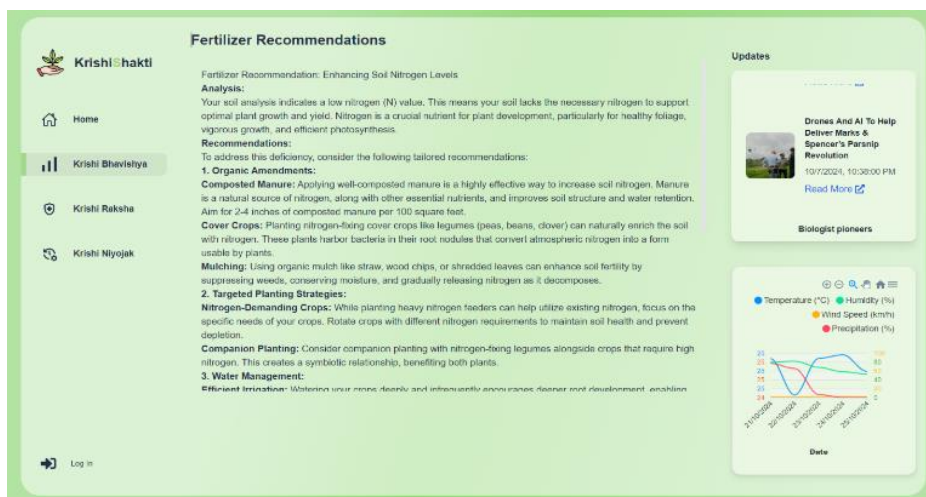


Figure 9. Recommendation of Fertilizers

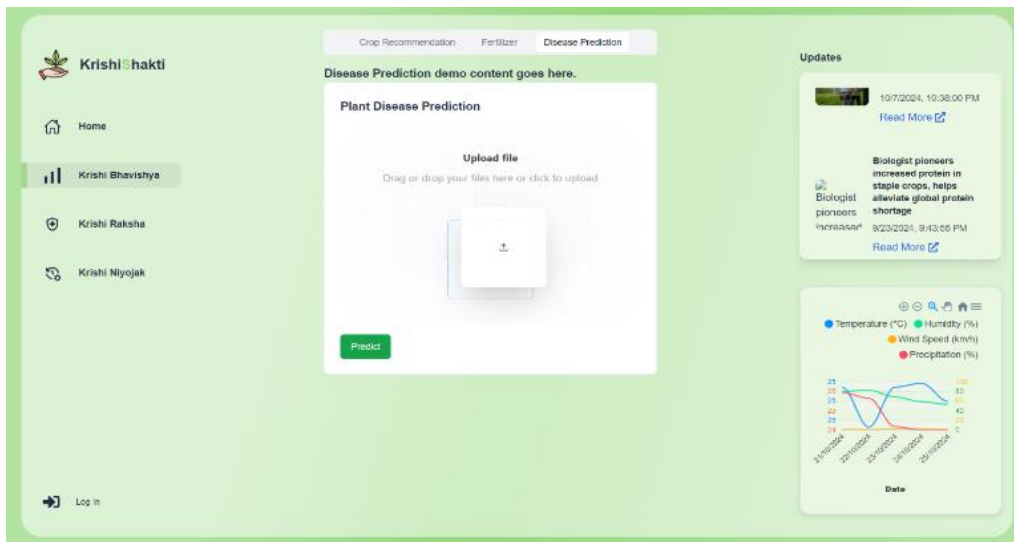


Figure 10. Diagnosis of Plants Disease

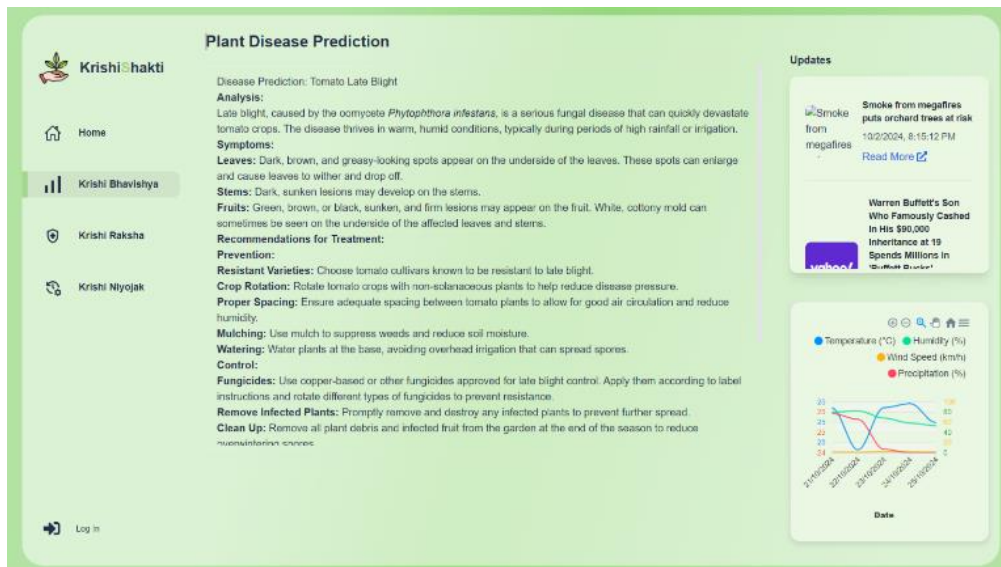


Figure 11. Result of Diagnosis and Recommendation

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RF's Accuracy is: 0.990909090909091
      precision    recall  f1-score   support

   apple         1.00      1.00      1.00        13
   banana         1.00      1.00      1.00        17
  blackgram         0.94      1.00      0.97        16
  chickpea         1.00      1.00      1.00        21
   coconut         1.00      1.00      1.00        21
   coffee         1.00      1.00      1.00        22
   cotton         1.00      1.00      1.00        20
   grapes         1.00      1.00      1.00        18
    jute          0.90      1.00      0.95        28
 kidneybeans       1.00      1.00      1.00        14
   lentil         1.00      1.00      1.00        23
   maize         1.00      1.00      1.00        21
   mango         1.00      1.00      1.00        26
  mothbeans        1.00      0.95      0.97        19
  mungbean         1.00      1.00      1.00        24
 muskmelon         1.00      1.00      1.00        23
   orange         1.00      1.00      1.00        29
   papaya         1.00      1.00      1.00        19
 pigeonpeas        1.00      1.00      1.00        18
 pomegranate       1.00      1.00      1.00        17
    rice          1.00      0.81      0.90        16
 watermelon        1.00      1.00      1.00        15
...
 accuracy                   0.99        440
 macro avg                   0.99      0.99      0.99        440
 weighted avg                 0.99      0.99      0.99        440

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Figure 12. Classification Report of Crop Recommendation model

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Random Forest MSE: 14534268384281.896
Random Forest MAE: 141149.8842820532
Random Forest R-squared: 0.9655846605787191

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Figure 13. Mean Squared Error, Mean Absolute Error and R-squared

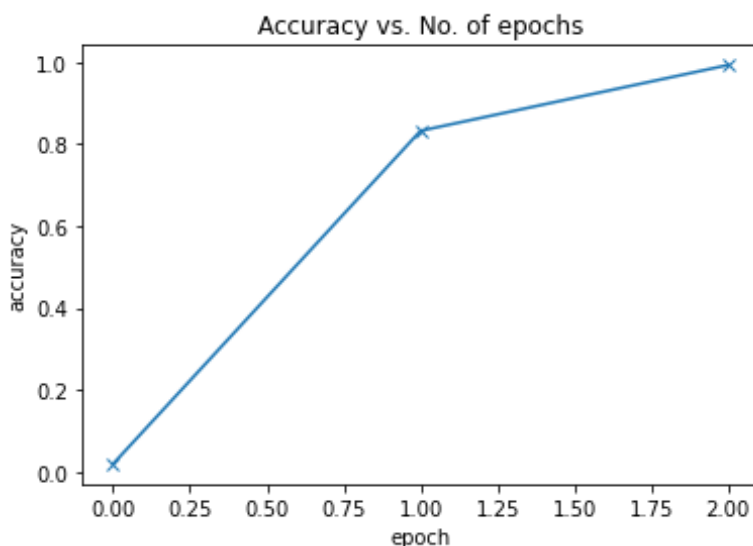


Figure 14. Accuracy vs Number of Epochs of Disease Prediction model

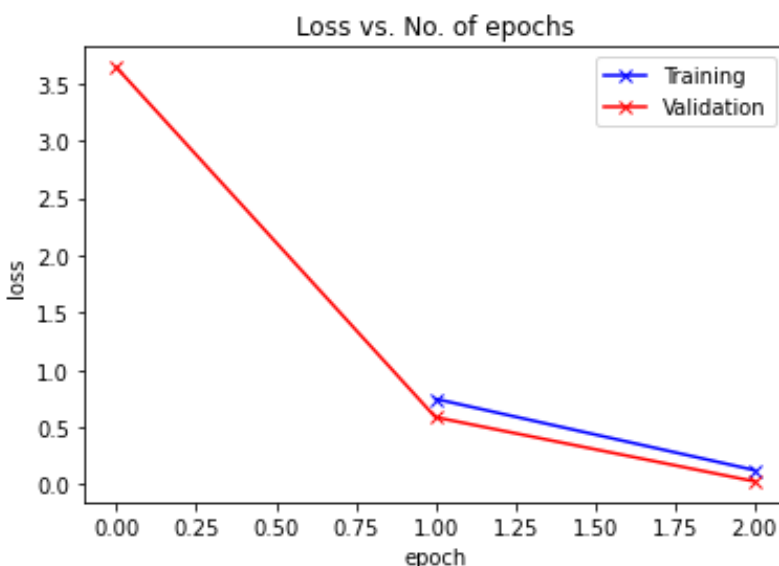


Figure 15. Loss vs Number of Epochs of Disease Prediction model.

6. CONCLUSION

This research paper explored the development of an integrated web-based decision support system that aims to provide data-informed insights in machine learning models for improving agricultural productivity. Environmental factors, such as NPK levels in the soil, pH, temperature, and rainfall, could be considered along with real-time market trends and historical crop yield data in order to provide an overall correct recommendation pertaining to the prediction of crop and yield using a Random Forest model. The incorporation of a ResNet9 deep learning model for pest and disease identification further supports farmers in timely decision-making to protect their crops. Additionally, the system's Fertilizer Dictionary ensures the optimization of nutrient application, while the inventory management module helps farmers track and manage their resources effectively. Through real-time weather forecasting, crop market price tracking, and mobile accessibility, the system addresses the critical challenges faced by farmers, such as unpredictable environmental conditions,

limited access to expert advice, and market volatility. Overall, this platform empowers farmers with actionable insights, reducing operational risks, improving resource management, and contributing to sustainable farming practices. The proposed system showcases the potential of technology and AI in revolutionizing agriculture, ensuring that farmers can make informed decisions, increase their yields, and improve their economic stability.

REFERENCES

- [1] Vishwash Tetarwal, Kavya Dashora, Dharamaraja Selvamuthu, “Predictive Analysis of Market trends in Agriculture using ML/AI Techniques”, 2024, IEEE Applied Sensing Conference (APSCON)
- [2] Jeerawan Saclao, Nopporn Patchaaprakiti, “A rainfall trend analysis for agriculture irrigation system management case study: Sansai district – Chiangmai province”, 2015, International Conference on Science and Technology (TICST)
- [3] Rok Rupnik, Matjaz Kukar, Petar Vracar, Domen Kosir, Darko Pevec Zoran Bosnic, “AgroDSS: A decision support system for agriculture and farming”, Computers and Electronics in Agriculture, Volume 161, 2019, Pages 260-271, ISSN 0168-1699
- [4] H. Navarro-Hellín, J. Martínez-del-Rincon, R. Domingo-Miguel, F. Soto-Valles, R. Torres-Sánchez, “A decision support system for managing irrigation in agriculture, Computers and Electronics in Agriculture”, Volume 124, 2016, Pages 121-131, ISSN 0168-1699
- [5] N. H. Kulkarni, G. N. Srinivasan, B. M. Sagar and N. K. Cauvery, “Improving Crop Productivity Through A Crop Recommendation System Using Ensembling Technique,” 2018 3rd International Conference on Computational Systems and Information Technology for Sustainable Solutions (CSITSS), Bengaluru, India, 2018, pp. 114-119, doi: 10.1109/CSITSS.2018.8768790.
- [6] S. M. PANDE, P. K. RAMESH, A. ANMOL, B. R. AISHWARYA, K. ROHILLA and K. SHAURYA, “Crop Recommender System Using Machine Learning Approach,” 2021 5th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 2021, pp. 1066-1071, doi: 10.1109/ICCMC51019.2021.9418351.
- [7] P. A. S. Chakraborty, A. Kumar and O. R. Pooniwala, “Intelligent Crop Recommendation System using Machine Learning,” 2021 5th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 2021, pp. 843-848, doi: 10.1109/ICCMC51019.2021.9418375.
- [8] R. L. Trogo, G. L. A. Lorenzo, J. S. Binarao, and J. C. Aliac, “A decision support system for yellow corn farmers in Isabela, Philippines based on crop simulation models,” *Int. J. Adv. Trends Comput. Sci. Eng.*, vol. 9, no. 3, pp. 3144–3150, 2020.
- [9] T. van Klompenburg, A. Kassahun, and C. Catal, “Crop yield prediction using machine learning: A systematic literature review,” *Comput. Electron. Agric.*, vol. 177, p. 105709, Oct. 2020, doi: 10.1016/j.compag.2020.
- [10] H. Erden, “Agricultural Inventory Management System of Turkey,” in *Proc. 7th Int. Conf. Agric. Stat. (ICAS VII)*, Rome, Italy, 2016, pp. 1–12.