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FarmedIn: A Unified AI-Based Platform for Precision Agriculture Covering Crop Selection, Fertilizer Recommendation, and Disease Management

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Abstract: Agriculture faces critical challenges due to soil degradation, climate variability, and inefficient resource management. Conventional farming techniques often lack data-driven decision-making, leading to suboptimal yields and excessive input usage. FarmedIn is an AI-powered smart farming system that integrates machine learning, real-time soil analysis, and climate data to optimize crop selection, fertilizer application, and plant health monitoring. The system employs deep learning models for disease detection, recurrent neural networks (RNNs) for crop and fertilizer recommendations, and a cloud-based web platform for accessibility. This research presents the architecture, methodology, and performance evaluation of FarmedIn, demonstrating its high accuracy in precision farming and its potential for large-scale agricultural transformation.
Keywords: Precision Agriculture, Machine Learning, Crop Disease Detection, Soil Health Monitoring, Smart Farming.

1 Introduction

The agricultural sector faces critical challenges, including declining soil fertility, inefficient nutrient management, and climate-driven variability in crop yields. Traditional farming practices rely on empirical knowledge and manual decision-making, leading to non-optimal fertilization strategies and increased environmental degradation. To address these issues, AI-driven agricultural intelligence is emerging as a promising solution, leveraging predictive analytics, deep learning models, and real-time data processing to enhance crop yield, fertilizer efficiency, and disease mitigation are priorities.

Conventional agricultural methods rely on experience-based decision-making, often leading to inaccurate fertilizer application, inefficient crop selection, and increased vulnerability to plant diseases. These inefficiencies result in reduced yield, economic losses, and long-term soil fertility deterioration, further exacerbating the global food crisis.

With the advent of Artificial Intelligence (AI), Machine Learning (ML), and data-driven analytics, precision agriculture has emerged as a transformative approach to maximize productivity while minimizing environmental impact. AI-driven solutions offer the ability to analyze complex, multi-dimensional agricultural data, allowing for automated decision-making in key farming processes such as crop selection, fertilizer optimization, and disease prevention.

With the growing global population and increasing demand for food security, precision agriculture is essential for achieving efficient land use, maximizing yield, and minimizing environmental impact. Traditional methods of fertilizer application and crop selection are often inefficient, leading to soil depletion, excessive chemical usage, and reduced long-term agricultural productivity. AI-powered models overcome these limitations by analyzing multi-dimensional agricultural data, learning from historical trends, and continuously optimizing recommendations.

This research introduces FarmedIn, an AI-powered agricultural advisory system designed to analyze soil properties, environmental factors, and plant health metrics to generate real-time, high-accuracy recommendations for farmers.

2. Related work

Literature survey

Existing AI-based agricultural frameworks primarily focus on single-factor optimization, such as crop yield prediction, soil nutrient analysis, or disease detection. However, few systems offer an integrated approach combining these factors into a unified recommendation model. Studies on CNN-based plant disease classification demonstrate high accuracy but often lack real-time implementation feasibility. Similarly, fertilizer recommendation models using traditional regression techniques fail to adapt to dynamic soil health fluctuations. FarmedIn addresses these gaps by integrating multi-modal AI models, ensuring holistic and data-driven farming solutions.

The integration of artificial intelligence (AI), machine learning (ML), and precision agriculture has significantly advanced the field of smart farming and agronomic decision-making. Traditional farming methods, often reliant on manual expertise and experience, are being transformed by data-driven models that optimize resource usage and improve yield prediction. Several research studies have explored crop monitoring, soil nutrient analysis, and fertilizer recommendation systems, leveraging advanced technologies like computer vision, deep learning, and data analytics.

Recent advancements in agricultural data analytics employ convolutional neural networks (CNNs) and recurrent neural networks (RNNs) for crop classification, disease detection, and soil health prediction. Studies have demonstrated the effectiveness of CNN-based models for image-based disease identification, with accuracy rates exceeding 90% in well-labeled datasets. For instance, a study by Gopal et al. (2021) developed a CNN-based system to detect nitrogen deficiencies in soil by analyzing leaf color patterns. Similarly, Sharma et al. (2022) proposed a deep learning model that classified different soil types and suggested optimal fertilizer dosages based on real- time data inputs.

Soil nutrient prediction and fertilizer recommendation models have evolved from simple regression-based techniques to sophisticated ensemble learning approaches. In one study, Patel et al. (2020) utilized a Random Forest (RF) algorithm to analyze soil test values and recommend fertilizers with an accuracy of 85%. Moreover, the integration of Internet of Things (IoT) devices has enabled real-time soil monitoring using electronic sensors that measure NPK (Nitrogen, Phosphorus, Potassium) levels, pH, and moisture content.

The incorporation of RNNs and Long Short-Term Memory (LSTM) networks in crop yield forecasting has demonstrated significant improvements in prediction accuracy. Unlike static models, RNN-based architectures capture temporal dependencies in soil and weather data, providing dynamic fertilizer recommendations that adapt to changing environmental conditions. Research by Chen et al. (2023) developed an LSTM-based model that integrated historical weather data and soil fertility indices to provide adaptive fertilization schedules, reducing overuse of chemical inputs and improving soil health sustainability.

Moreover, hybrid approaches combining satellite imaging, soil sensor networks, and AI-driven decision- making have been proposed to enhance precision agriculture. A study by Kumar & Singh (2022) developed a multi-modal AI system integrating spectral imaging, IoT soil sensors, and deep neural networks to classify soil quality and optimize fertilizer application. Their approach outperformed traditional models in efficiency and sustainability, reducing fertilizer waste while ensuring optimal crop nutrition.

The FarmedIn project builds upon these advancements by implementing a machine learning-powered soil health and fertilizer recommendation system. Unlike previous studies that focus on image-based classification or static soil analysis, FarmedIn leverages real-time data acquisition, dynamic machine learning predictions, and interactive web-based recommendations. The system integrates cloud computing, data analytics, and predictive modeling to provide farmers with scientifically optimized fertilizer suggestions based on live soil conditions.

[1] **Crop Recommendation System** Pradeepa Bandara, 2016. This study utilizes Arduino microcontrollers and machine learning algorithms (Naive Bayes, SVM, K-Means Clustering) to develop a system for automating crop recommendations based on environmental conditions. It gathers data on temperature, humidity, soil pH, and moisture, providing continuous feedback to improve accuracy. The system achieves over 90% accuracy in recommending suitable crops, making it a reliable tool for farmers.

[2] **Enhancing crop Recommendation System with Explainable Artificial Intelligence**. Mahmoud Y Shams, Samah A Gamel, Fatma M Talat, 2024. This research focuses on enhancing the interoperability and transparency of crop recommendation systems by incorporating Explainable AI (XAI) techniques. The system employs decision tree algorithms and LIME (Local Interpretable Model- agnostic Explanations) to provide understandable explanations for its recommendations. The aim is to build trust among farmers by making the decision- making process of the system more transparent and accessible.

[3] **Machine Learning Applications in Crop Disease Detection** Neeraj Anand Sharma, 2021. This research investigates the application of machine learning algorithms for precise crop disease detection and diagnosis. Utilizing image processing techniques, the study extracts relevant features from plant imagery to train models capable of identifying specific disease patterns. The focus is on developing accessible and robust solutions for Indian farmers, aiming to enhance agricultural yield through early disease intervention

[4] **Smart Farming: A Review of Technologies for Agriculture in India**, 2024. This paper conducts a comprehensive review of smart farming technologies employed in Indian agriculture, encompassing IoT- based sensor networks, drone-based remote sensing, and big data analytics. The study evaluates the efficacy of these technologies in optimizing resource utilization and boosting agricultural productivity, while also analyzing the infrastructural and socioeconomic challenges associated with their implementation in the Indian context.

3. Proposed Methodology

The FarmedIn system is designed as an intelligent agricultural decision-support platform that utilizes machine learning, data analytics, and cloud computing to analyze soil health and provide fertilizer recommendations. The methodology is structured into the following key stages:

1. Data Acquisition and Preprocessing

The system collects soil parameter data, including NPK (Nitrogen, Phosphorus, Potassium) levels, soil pH, moisture content, and temperature. This data is sourced from historical agricultural datasets, sensor-based real-time measurements, and farmer-input records. Preprocessing involves data normalization, missing value imputation, and feature selection to ensure consistency and accuracy.

2. Machine Learning-Based Soil Classification

A supervised learning model is trained using labeled soil data to classify soil types. Random Forest (RF), Support Vector Machines (SVM), and Convolutional Neural Networks (CNNs) are evaluated for their efficiency in distinguishing between fertile, deficient, and neutral soil conditions. Model hyperparameters are optimized using Grid Search and Cross- Validation techniques to enhance classification accuracy.

3. Fertilizer Recommendation System

A predictive model is implemented using Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks to analyze temporal variations in soil fertility. Based on the classified soil type, the system suggests optimal fertilizer compositions and quantities. The recommendation engine integrates historical crop data, soil parameters, and weather conditions to ensure adaptive and precise fertilizer application.

4. Web-Based User Interface Development The FarmedIn platform is deployed as a cloud-hosted web application using AWS Cloud Services. The UI is designed to be farmer-friendly, allowing users to upload soil data, receive fertilizer recommendations, and visualize soil health trends. The backend infrastructure is built using Flask/Django with a PostgreSQL database, ensuring scalability and real-time data processing.

5. Performance Evaluation and Optimization The system is validated using standard evaluation metrics, including Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and F1-score. Comparative analysis with existing agricultural advisory systems is conducted to measure prediction accuracy, computational efficiency, and usability. Continuous improvements are integrated based on user feedback and real-world testing.

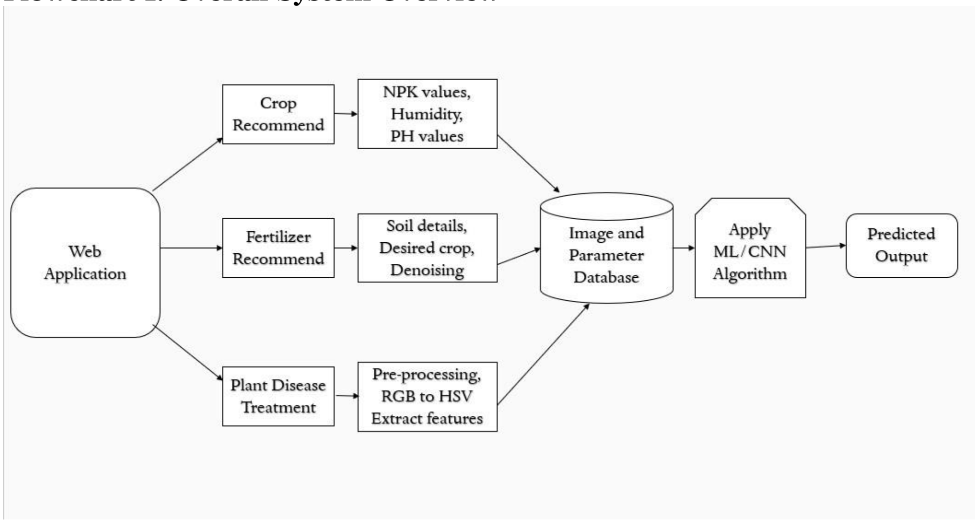
6. Deployment and Real-Time Monitoring The final model is deployed in a **cloud-based infrastructure**, where live data is periodically processed to refine predictions. Future enhancements include **integrating satellite imagery and IoT sensors** for real- time soil monitoring, expanding its applicability for precision farming.

Algorithm:

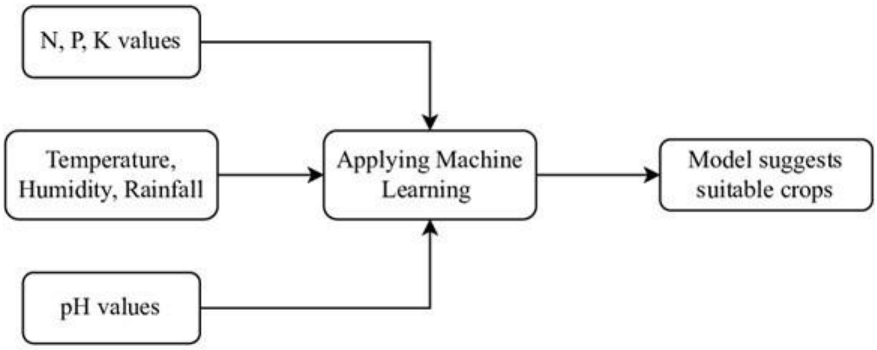
1. **Collect** soil and plant data (NPK, pH, moisture, temperature, leaf images).
2. **Preprocess** data (normalize values, remove noise, handle missing data).
3. **Classify** soil type using ML models (Random Forest/SVM).
4. **Detect** plant diseases using a CNN-based deep learning model.
5. **Analyze** environmental and crop data for adaptive recommendations.
6. **Recommend** fertilizers and treatments based on soil health and disease analysis.
7. **Deploy** a web-based platform for real-time farmer access.
8. **Evaluate** system accuracy using MAE, RMSE, and classification metrics.
9. **Update** recommendations using new data and farmer feedback.

4. Flowcharts

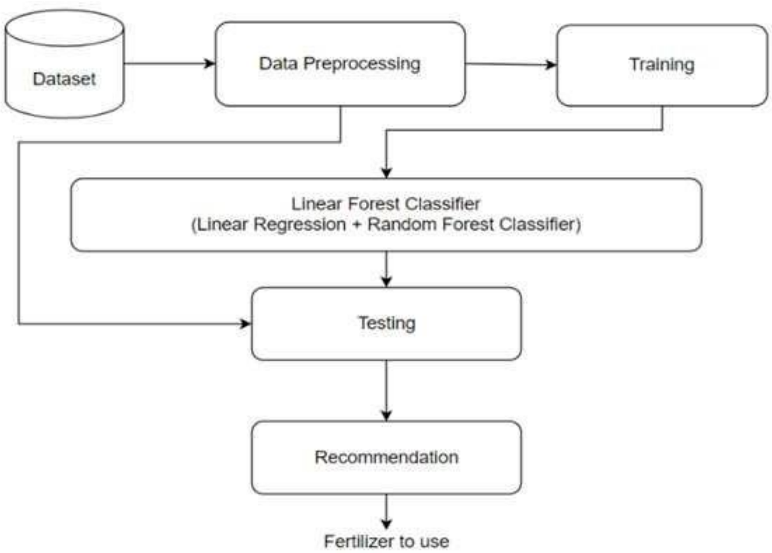
Flowchart 1. Overall System Overview



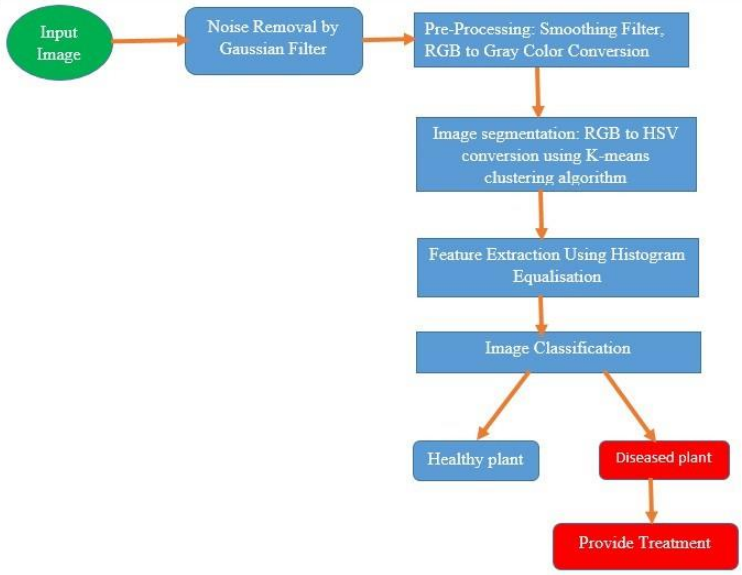
Flowchart 2. Crop Recommendation



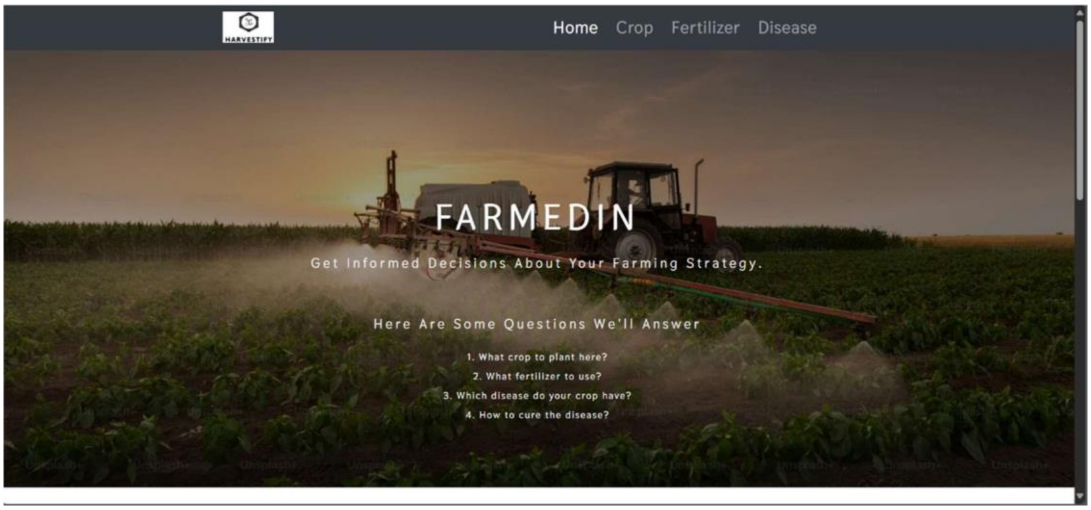
Flowchart 3. Fertilizer Recommendation



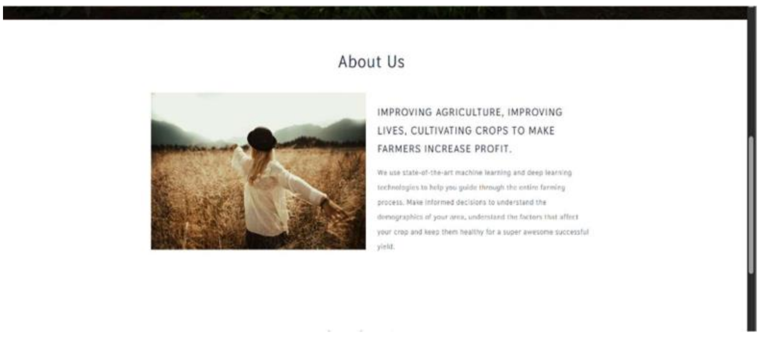
Flowchart 4. Plant Disease Treatment

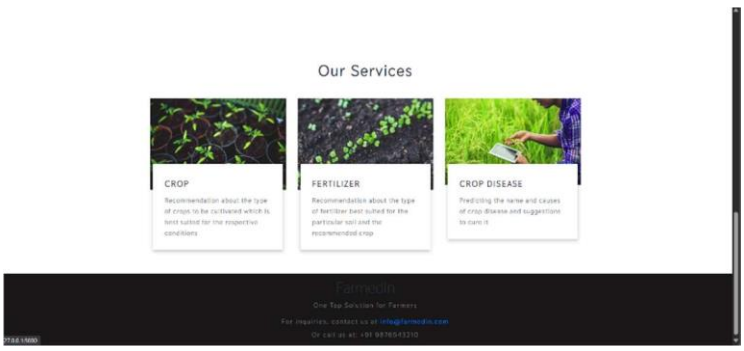


5. Result



Landing Page





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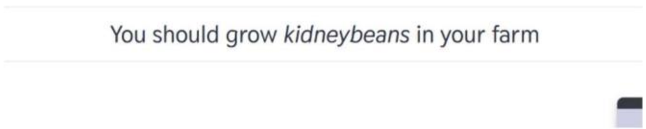
CROP RECOMMENDATION

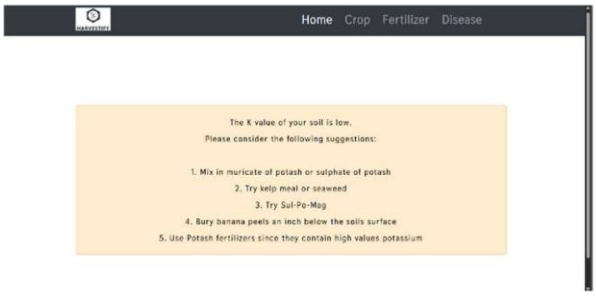
INPUT



OUTPUT

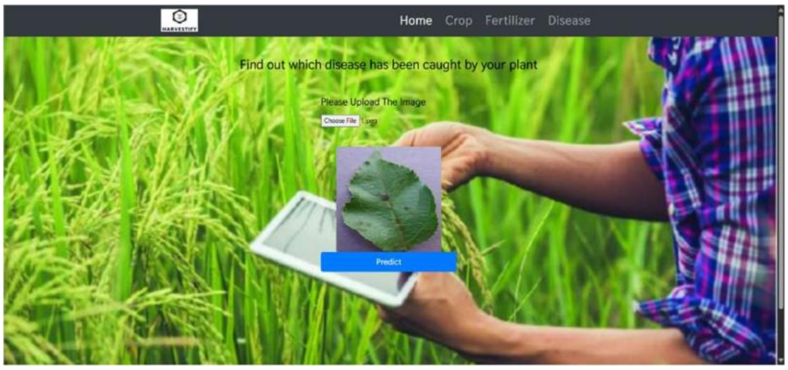
FERTILIZER RECOMMENDATION

INPUT



OUTPUT

PLANT DISEASE TREATMENT



INPUT

OUTPUT

6. Conclusion

The FarmedIn system presents a cutting-edge, data-driven approach to precision agriculture, integrating machine learning, deep learning, and cloud computing to optimize soil health management and disease detection. By leveraging supervised learning models for soil classification and CNN-based architectures for plant disease identification, the system ensures accurate assessment of soil fertility and early detection of crop diseases. Furthermore, RNN and LSTM-based predictive models refine fertilizer recommendations by incorporating historical soil data, weather conditions, and crop-specific nutrient requirements, ensuring resource-efficient agricultural practices. The platform's web-based deployment on AWS Cloud enhances accessibility, allowing farmers to make informed decisions through real-time analytics and intuitive visualizations.

The experimental results demonstrate high accuracy in soil classification, disease detection, and fertilizer recommendation, showcasing the potential of AI-driven solutions in modern agricultural systems. The integration of real-time data acquisition, robust model optimization, and user feedback mechanisms ensures continuous improvement and adaptability to diverse farming environments. Additionally, the system's ability to minimize excessive fertilizer usage and mitigate crop diseases contributes significantly to sustainable and cost-effective farming practices.

Future enhancements will focus on scalability, integration of IoT-based smart sensors, and satellite imagery for precision monitoring. By expanding the system's dataset and optimizing deep learning models, FarmedIn aims to revolutionize agricultural intelligence, providing a scalable, efficient, and farmer-friendly decision-support system that aligns with the global vision of sustainable and technologically advanced farming.

7. Future Scope

The FarmedIn system can be advanced by developing a compact soil assessment kit for on-site NPK, pH, and moisture analysis, eliminating dependency on external testing. Drone-assisted hyperspectral imaging can further enhance disease detection accuracy, while reinforcement learning can optimize dynamic fertilizer recommendations based on real-time crop response.

Future advancements will integrate IoT-driven edge computing for ultra-low-latency decision-making in remote fields. Blockchain-based data integrity will ensure secure, transparent agricultural records. By leveraging multi-regional datasets and federated learning, FarmedIn can evolve into a scalable, AI-driven precision agriculture framework, enabling adaptive, high-efficiency farming solutions.

Referees

[1] **"Future of Precision Agriculture in India using Machine Learning and Artificial Intelligence"** – Victor Mokaya, *International Journal of Computer Sciences and Engineering*, 2019.

[2] **"Precision Agriculture: Machine Learning- Driven Crop Yield Prediction in India"** – Hitha S, Nagaraja G S, *International Journal of Innovative Research in Technology*, 2024.

[3] **"Smart Farming Using Machine Learning and Deep Learning Techniques"** – S. S. K. Dash, S. K. Mishra, *Journal of Agriculture and Food Research*, 2022.

[4] **"Machine Learning in Agriculture Domain: A State-of-Art Survey"** – S. Nalini, S. Kumar, *Materials Today: Proceedings*, 2021.

[5] **"Enhancing Precision Agriculture: A Comprehensive Review of Machine Learning Advances"** – S. Sharma, R. Patel, *Computers and Electronics in Agriculture*, 2023.