

Literature Review on Crop and Fertilizer Prediction by using Machine Learning

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Abstract: *The agriculture industry has undergone a transformation thanks to the quick development of methods based on machine learning (ML), which allow for data-driven decision-making to increase crop output and sustainability. The latest advancements, techniques, and uses of predictive machine learning models in agricultural and fertilizer prediction are examined in this review paper.*

In order to predict the best crops based on soil characteristics, climatic conditions, and geographic features, the study looks at a variety of supervised and unsupervised algorithms, including Decision Trees, Random Trees, Support Vector Machines (SVM), neural network methods (ANN), and ensemble approaches. The study also highlights machine learning (ML)-based fertilizer suggestion engines that analyse crop needs, soil fertility, and environmental conditions to enhance nutrient management.

The advantages and disadvantages of present techniques, such as problems with data quality, choosing features, and model interpretability, are shown through comparative examination of several models and datasets from the body of existing literature. The integration of machine learning (ML) with Internet of Things (IoT), remote sensing, and Geographic Information Systems (GIS) to accomplish precision agriculture is highlighted in the paper's conclusion, along with potential avenues for future study to create prediction systems for farmers that are sustainable, scalable, and explicable..

Keywords: Machine Learning (ML), Agriculture, Fertilizer Prediction, Crop Yield Prediction, , Internet of Things (IoT), Geographic Information Systems (GIS)

I. INTRODUCTION

The majority of developing economies are based on agriculture, which is also essential to maintaining global food security. Farmers still have to deal with issues like erratic weather patterns, degraded soil, incorrect fertilizer application, and restricted access to real-time data, though. Poor crop yields and unsuitable farming methods are frequently the results of these problems. The incorporation of cutting-edge technology like artificial intelligence (AI) and machine learning (ML) has created new opportunities in recent years to turn conventional farming into a precision-driven, data-driven industry.

Large and complicated agricultural datasets, such as soil characteristics, crop history, weather conditions, and fertilizer composition, can be analyzed using machine learning to produce precise and useful forecasts. Based on soil and environmental factors, crop forecasting techniques help farmers choose which crops are best to grow in a given area, and fertilizer prediction models help them choose the right kind and amount of fertilizer to use in order to maximize yield without endangering the ecosystem. For such predictive tasks, a variety of machine learning algorithms, including Decision Trees, Random Forests, Support Vector Machines (SVM), Artificial Neural Networks (ANN), and K-Nearest Neighbors (KNN), have proven to be useful.

The purpose of this review paper is to provide an overview of current research and approaches in machine learning-based crop and fertilizer prediction. The datasets utilized, feature selection strategies, algorithmic approaches, assessment measures, and the incorporation of machine learning (ML) with remote sensing and Internet of Things (IoT) technologies



are all covered. It also draws attention to the difficulties and potential paths for creating sustainable and intelligent agricultural decision-support systems. This research aims to show how machine learning may greatly increase production, decrease resource waste, and support the long-term objective of sustainable agriculture by examining current developments.

II. LITERATURE SURVEY

In order to estimate crop production and suggest fertilizer combinations, Basavaraju et al.[1] suggested a smart agricultural system that combines OpenCV-based image processing, IoT sensors, and machine learning algorithms. Their research successfully illustrated how yield prediction is influenced by environmental factors. However, scalability across various soil types and climatic conditions was not assessed, and the dataset utilized was restricted to a small geographic area. Furthermore, the model lacked the adaptive learning features required for changing agricultural settings.

Using ESP32, Blynk, and Firebase, Jyoti et al [2] created an Internet of Things-enabled system that gathers data in real-time for machine learning-based crop and fertilizer forecast. Although environmental monitoring was prioritized, a thorough crop–fertilizer link was not established. Furthermore, advanced analytics for assessing fertilizer effectiveness and maximizing total crop output were absent from the system.

In order to automate irrigation procedures, Dubey and Pandey [3] presented a smart crop irrigation system that combines Convolutional Neural Networks (CNNs) with Internet of Things modules. Through effective water management, our model indirectly supported the forecast of agricultural yield. However, rather than directly recommending fertilizer or estimating yield, the strategy concentrated mostly on irrigation control. For small-scale farmers with limited hardware resources, the computing demands of CNNs presented additional difficulties.

Despite being primarily focused on healthcare, Devan et al [4] vision-based communication system for intensive care unit patients showed promise for application in agriculture. Crop images may be identified and crop health could be evaluated by pattern identification utilizing the vision recognition algorithms. However, the transfer of vision-based technologies to crop disease or nutrient prediction was not explored because the study did not investigate agricultural applications.

2.1 Overview and scope

Studies using machine learning (ML) and deep learning (DL) to enhance agricultural decision support have grown rapidly in recent years, especially for fertilizer recommendation and crop yield/crop choice prediction. Both traditional machine learning (ML) techniques (Decision Trees, Random Forests, SVM, KNN, Gradient Boosting) and deep learning (DL) techniques (CNNs, RNNs, LSTM) are widely used in a variety of crops and regions, according to reviews and systematic literature surveys. These techniques are frequently coupled with remote sensing and Internet of Things data to facilitate precision agriculture workflows. These reviews highlight how machine learning (ML) can improve prediction accuracy and facilitate site-specific nutrition management, but they also highlight concerns with data quality and reproducibility as a recurring obstacle.

2.2 Datasets and feature engineering:

In-situ soil tests (pH, N, P, K, and organic carbon), historical yield and management records, weather/time-series variables (temperature, rainfall, growing-degree-days), satellite/remote-sensing indices (NDVI, EVI, multi-/hyperspectral bands), and topography/GIS layers are some of the data sources used in studies. Careful feature selection and temporal aggregation (seasonal averages, lagged variables) are usually key components of successful models. Numerous surveys emphasize how the absence of large-scale, uniform labeled datasets limits cross-regional generalization, particularly for fertilizer-response experiments.

2.3 Methodological trends and algorithms

Classical ML: Because of their interpretability and resilience, Random Forests and Gradient Boosting Machines are often employed for crop recommendation and nutrient prediction tasks. They also consistently perform well for tabular soil–weather datasets. KNN and Support Vector Machines have been used in previous or limited research.



Deep Learning & Remote Sensing: CNNs and CNN–RNN hybrid architectures are widely used for analysing spatiotemporal and spatial (satellite) data for mapping within-field variability and yield estimation. Seasonal yield forecasts are handled by LSTM models using temporal weather sequences. Although it raises processing and data requirements, integrating high-resolution photography with ground data frequently enhances prediction performance.

2.4 Fertilizer recommendation approaches:

There are two primary types of fertilizer systems: (a) nutrient status estimation, which uses sensor and spectral data to anticipate crop nutrient demand or soil nutrient levels (N, P, and K); and (b) prescriptive recommendation, which suggests fertilizer type and quantity based on target yield or soil health limitations. Regression models, categorization (nutrient sufficiency classes), and optimization layers that convert anticipated demand into suggested application rates are examples of machine learning techniques. Although recent evaluations show encouraging accuracy for site-specific N recommendations, they warn that end-to-end modelling of long-term soil health and environmental implications is uncommon.

2.5 Integration with decision-support, GIS, and IoT systems:

The majority of modern systems use cloud analytics, GIS, and IoT (soil moisture and nutrient sensors) to provide farmers with advice in almost real time. While in-field sensors offer local calibration, remote sensing offers synoptic coverage for spatial scaling. Although reviews highlight the operational difficulties of sensor maintenance, connection, and farmer acceptance, they also suggest that such multimodal pipelines increase robustness.

2.6 Measures of evaluation and methods of validation:

RMSE, MAE, R2 for continuous yield/nutrient predictions, and accuracy/precision/recall/F1 for classification tasks (such as nutrient sufficiency classes) are examples of common evaluation measures. Although multi-year holdout testing and cross-validation are advised, many research employ small temporal or geographic divides, which inflates perceived performance. In the research, transferability—the ability of the model to function across various agroclimatic zones—is still not fully assessed.

2.7 Difficulties and gaps:

Recent evaluations have frequently emphasized the following important gaps:

Data constraints include limited long-term experiments and a lack of sizable, standardized, labelled datasets for fertilizer reaction. Generalization and transferability: Because of soil and management variability, models developed in one area frequently deteriorate in another. Explainability and agronomic validity: In order to win over farmers, black-box DL models must produce results that are easy to understand; it is still crucial to connect forecasts to agronomic principles. Economic and environmental goals: most systems aim to maximize output or immediate financial gain; it is uncommon to combine optimization for long-term soil health with environmental externalities (leaching, greenhouse gas emissions). Operational deployment: despite encouraging experimental findings, real-world adoption is hampered by sensor costs, connectivity, and human factors.

2.8 Synopsis

According to the literature, when high-quality, multimodal data are available and models are thoroughly validated, machine learning techniques can significantly enhance crop prediction and fertilizer recommendations. However, standard datasets, cross-region validation, explainability, and collaborative optimization of productivity and sustainability goals must be given top priority in research for widespread, reliable implementation. These directions are highlighted by recent reviews and empirical studies from 2023–2025, which also offer a solid foundation for further study.



TABLE 1: SUMMARY OF AUTHORS AND THEIR RESEARCH METHOD

Sr. No.	Author(s)	Year	Research Paper Name	Research Method	Research Gap
1	Basavaraju, N.M., Mahadevaswamy, U.B., & Mallikarjunaswamy, S	2024	Design and Implementation of Crop Yield Prediction and Fertilizer Utilization Using IoT and Machine Learning in Smart Agriculture Systems	Used IoT sensors and machine learning algorithms integrated with OpenCV-based image processing for predicting crop yield and suggesting suitable fertilizer combinations based on environmental parameters..	Dataset was limited to a small region; scalability to multiple soil types and climatic conditions was not tested. The model lacked adaptive learning for diverse agricultural scenarios.
2	Jyoti A.	2024	Applications For Crop Prediction And Fertilizer Suggestion Using ML Technique	Implemented an IoT-based monitoring system using ESP32, Blynk, and Firebase for collecting real-time environmental data and applying ML models for crop and fertilizer prediction.	Focused mainly on environmental monitoring rather than comprehensive crop-fertilizer correlation. The system lacked data analytics for fertilizer efficiency and yield optimization..
3	Dubey K, Pandey D	2024	A smart crop irrigation	Utilized Convolutional Neural Network (CNN)-based vision analysis and IoT modules to automate irrigation and indirectly support crop yield prediction.	The approach emphasized irrigation management rather than direct fertilizer prediction or yield forecasting. Computational complexity limited its use for small-scale farmers..
4	Devan K.P, Swetha.B, Uma Smruhi.	2022	Vision-Based Communication System for ICU Patients	Although focused on healthcare, the vision-based technique can be adapted to agriculture for recognizing crop images and predicting health through pattern recognition.	The study lacked agricultural data applications; transfer of vision-based techniques to crop image recognition for disease and nutrient prediction was unexplored.
5	Bondre,D.A.	2023	Emergency Gesture Detection Framework Using Deep CNNs for Healthcare	Used deep CNN models for real-time recognition and alerting systems—techniques adaptable for identifying crop stress and disease signs in agriculture.	Focused only on emergency signals in healthcare; did not extend CNN application to agricultural data like soil health, crop type, or fertilizer mapping.
6	THORAT,P.B	2023	Affordable IoT Health Monitoring Using ESP32 and Firebase	Developed an affordable IoT setup using ESP32 and cloud connectivity to continuously collect sensor data—principles suitable for low-cost agricultural data acquisition.	Lacked AI and predictive modeling for decision support. Did not include agricultural or fertilizer optimization features using machine learning.



III. PROPOSED METHODOLOGY

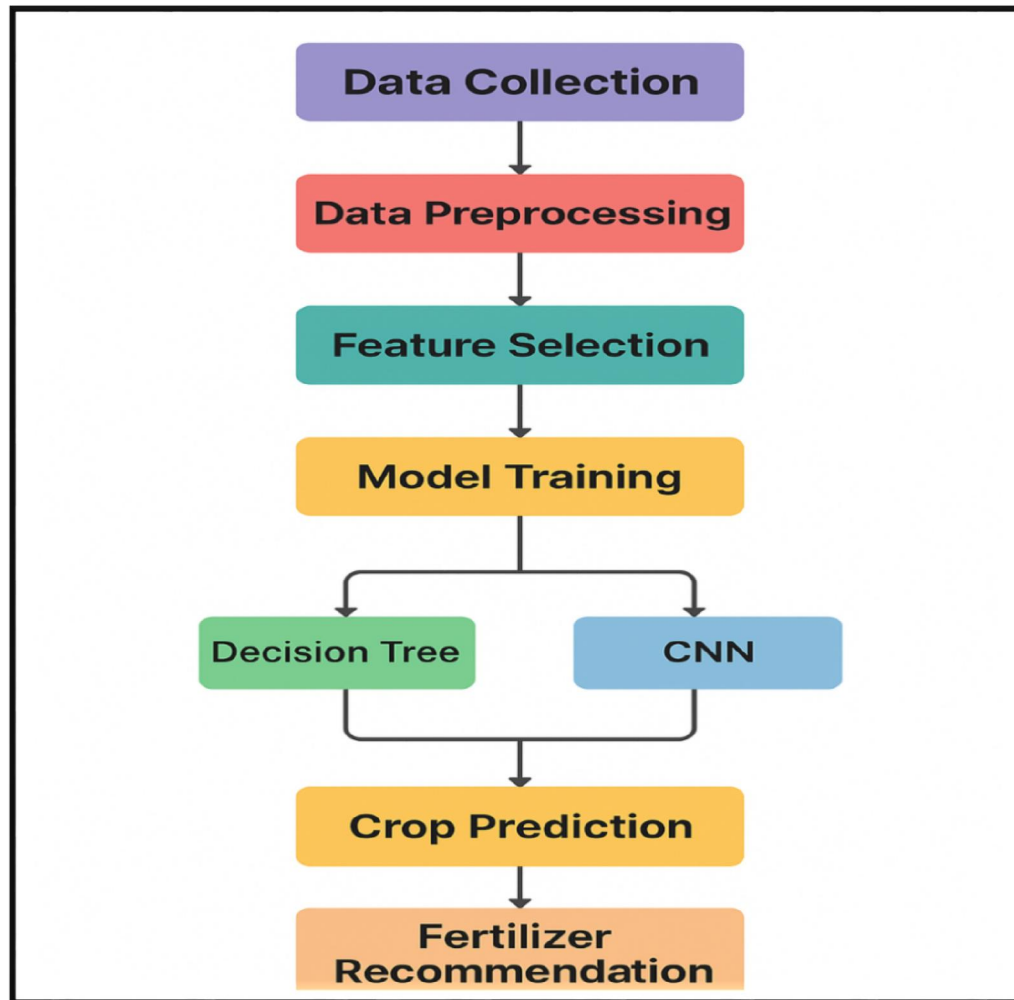


Fig 1: Crop and Fertilizer Prediction by using Machine Learning

Data Collection:

This is the basis of the system.

A variety of sources, including meteorological database, government agricultural records, and Internet of Things sensors, are used to collect data. The following parameters are gathered: temperature, humidity, rainfall, soil pH, moisture, and soil nutrients (potassium, phosphorus, and nitrogen). The dependability of ensuing prediction models is guaranteed by high-quality, real-time data.

Data preprocessing:

Unreliable units, missing values, and noise are common in collected data.

Preprocessing includes normalizing feature values, filling in missing data (by mean or interpolation), and cleaning the dataset by eliminating duplicates.

For machine learning algorithms, this stage also entails transforming categorical data (such as crop name or soil type) in to numerical form, making sure that all inputs are consistent and machine-readable.

Feature Selection:

Not every feature that has been gathered is equally significant.

The most important factors influencing crop yield and fertilizer requirements are determined in this step.

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Methods like Principal Component Analysis (PCA), correlation analysis, and Random Forest-style feature significance models are employed. This improves model accuracy and lowers computing costs.

Model Training

The processed dataset is used to train machine learning algorithms.

Models such as CNNs, Random Forests, and Decision Trees discover patterns that link soil and environmental factors to crop compatibility and fertilizer effectiveness.

To assess model correctness, the dataset is separated into training and testing sets.

Crop Prediction:

Following training, the system makes predictions about the best crop based on soil and environmental factors. For particular land conditions, it maximizes yield potential. It maximizes the potential yield for particular land types.

Fertilizer Recommendation:

In order to achieve effective and sustainable agriculture, the system ultimately recommends the best kind and amount of fertilizer for the anticipated crop, taking into account the nutrient levels of the soil and crop growth needs.

IV. CONCLUSION

Through data-driven decision-making, the use of machine learning (ML) in agriculture has become a viable strategy to maximize fertilizer use and increase crop output. Several machine learning models, datasets, and methods for crop and fertilizer prediction have been examined in this paper. It is clear from the literature that algorithms like Random Forests, Decision Trees, Support Vector Machines, and Neural Networks have demonstrated a great deal of promise in determining which crops are appropriate for a given soil and climate, as well as in suggesting the best kind and amount of fertilizer.

By accurately representing complex and nonlinear interactions between crop, soil, and environmental factors, these models perform better than conventional techniques.

Nevertheless, the review also identifies some shortcomings that require attention. Agricultural datasets are frequently small or region-specific, and their quality, quantity, and diversity have a significant impact on how well ML-based models perform. Key issues still include things like the requirement for cross-regional generalization, lack of standards, and model interpretability. Furthermore, the majority of current models prioritize yield maximization at the expense of sufficient consideration of environmental sustainability and long-term soil health.

In order to deliver real-time and location-specific predictions, future research should concentrate on creating explainable and hybrid machine learning frameworks that combine data from satellite photography, IoT devices, and GIS systems. To develop open, standardized datasets and implement farmer-friendly decision-support tools, cooperation between data scientists, agronomists, and legislators will be essential. Machine learning can be crucial to attaining sustainable agricultural development, guaranteeing food security, and encouraging environmental conservation by utilizing the power of artificial intelligence and precision agriculture.

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