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A Review of State-of-Art Machine Learning Algorithms Used in Agricultural Yield Prediction

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A B S T R A C T

Agriculture produces food, which is a basic need for mankind and also plays a vital role in global economy. Agriculture is regarded as the primary source of employment in the majority of the nations. A number of factors, including diminishing resources, dwindling acreage, increasing labour costs, input costs, weather volatility, and fluctuating market prices, have made agricultural employment increasingly risky. One emerging area of computer science that has great potential for use in the farming industry is Machine Learning. It can help modernize traditional farming methods in the most economical way possible. Machine learning can be used extensively over the entire planting, growing, and harvesting cycle to improve yield. The process begins with sowing a seed, continues with soil preparation, seed breeding, crop health monitoring, water feed measurement, and ends with robots employing computer vision techniques to pick up the harvest. In precision agriculture, machine learning models are developed for crop selection, yield prediction, soil classification, weather forecasting, irrigation system, fertilizer prescription, disease prediction, and figuring out the least support price. A detailed assessment of the most recent applications of machine learning in agricultural yield prediction is presented in this review paper.

Keywords: Agriculture, Smart Farming, Machine Learning, Precision Agriculture, Agricultural Research

1. Introduction

The core of the Indian economy is agriculture, which provides the majority of income for India's rural population. The need for food is increasing exponentially as the population of India and other nations rises. According to a meta-analysis of anticipated world population and food demand, between 2010 and 2050, food consumption is expected to increase by +0% to +20% and +35% to +56%, respectively [1]. A significant increase in agricultural production is necessary to keep up with the world's population expansion. Due to shifts in market demand and production losses, agricultural sector also faces numerous difficulties and uncertainties. Though the ability to predict disasters and changes in the climate has improved, more technological integration is still required in order to make well-informed decisions. Crops produced with traditional farming techniques won't be able to meet future demands. To boost productivity, the agricultural sector should undertake methodical reforms and integrate technology at every stage, from seed selection to supply and demand forecasting. Future food security can be ensured by integrating technology with agriculture and automating the process. Machine learning (ML) has the potential to help the agriculture industry overcome it`s problems [2]. In order to increase crop productivity, forecast plant disease, and meet consumer demand, research is being done to leverage machine learning and a data-centric strategy in agriculture [3].

2. What is Machine Learning?

A group of algorithms known as machine learning (ML) techniques work to identify patterns in data and link those patterns to specific groups of data samples [4]. The computational process of identifying the underlying models of system behavior is known as machine learning [5]. After datasets are processed, machine learning looks for causative variables. The last ten years have seen a huge revival in machine learning due to the vast amounts of data that are now available and the notable improvements in computing power [6].

3. Working of Machine Learning Algorithms

A machine learning algorithm's learning system is divided into three primary components by UCBerkeley [7].

A Decision Process: Predictions and classifications are typically made using machine learning algorithms. An estimate of a pattern in the data will be generated by the algorithm based on certain input data, which may or may not be labelled.

An Error Function: An error function is a tool used to assess a model's prediction.

An error function can assess the correctness of the model by comparing it to known cases.

Model Optimization: Weights are changed to lessen the difference between the model estimate and the known example if the model fits the training set's data points more closely. This process is known as model optimization. This iterative "evaluate and optimize" procedure will be repeated by the algorithm, which will update weights on its own until an accuracy level is reached.

4. Machine Learning in Agriculture

With its predictive and data-driven methodology, machine learning has the power to completely transform crop management [8]. This section discusses some of the main applications of machine learning in agriculture.

- **Crop Management**

Crop variety selection is one of the applications and methods of machine learning in agriculture [9]. For crops to become resistant to weather and disease, they need to have the correct gene sequence. Crop breeding can be made easier with the help of machine learning (ML) [10]. Algorithms just gather empirical data on the behavior of plants and utilize it to create a probabilistic model. We can increase the productivity and sustainability of farming activities by utilizing AI algorithms and methodologies [11].

- **Yield Prediction**

Forecasting yields is important for the economy, both locally and globally. Any farm needs to know when to harvest a crop and what crops to cultivate in order to meet market demands. Yield quantity can be affected by a wide range of elements, such as meteorological information, phenotypic data, and environmental conditions [12]. All the elements can be analyzed by modern ML models to improve yield prediction accuracy. Using data from previous years, machine learning is a popular method for yield prediction [13].

- **Disease Detection**

Loss of food as a result of crop infection from bacteria, fungi, and other viruses is a persistent problem that farmers have faced for many years. Accurately diagnosing this illness could stop this loss [14]. One of the biggest risks to agriculture that significantly reduces production quantity and quality is crop disease [15]. Agronomists used to manually survey fields, wasting time and making mistakes as they searched for symptoms of crop diseases like curled or withering leaves. Pesticides can only be applied to sick plants rather than the entire field thanks to machine learning (ML)-based image software analysis tools that evaluate the health of the soil and individual crops [16].

- **Weed Detection**

For any farmer, weeds are a known nemesis [17]. They spread fast, encroach on agricultural lands, spread a variety of plant diseases, and reduce productivity. Herbicides are the most used method of weed control [18]. Although this approach works well, farmers typically saturate entire fields with herbicides, which has a negative impact on the ecosystem. With the help of computer vision-powered systems, farmers may apply herbicides to specific portions of their fields instead of the entire one by identifying undesired plants [19]. This can significantly lessen herbicides' detrimental effects.

- **Price Forecasting**

Economists have been attempting to predict agricultural prices with statistical models for many years. But with the development of machine learning, there are now state-of-the-art techniques to anticipate crop prices with far greater accuracy [20]. These price predictions have the potential to be very useful tools for improving financial choices [21].

5. Review of Recent ML Algorithms Used in Yield Prediction

The articles for review were selected from IEEE Explore (https://ieeexplore.ieee.org/), which included all type of recent papers from 2023 to 2024. Top 10 papers were selected that were relevant to the key words ("Crop Yield Prediction using Machine Learning") given to search the article data base. Detailed review of the 10 papers with the key techniques and metrics is presented below.

Sharma et al., "Predicting Agriculture Yields Based on Machine Learning Using Regression and Deep Learning", used machine learning techniques, such as decision trees, random forests, and XGBoost regression, as well as deep learning techniques, such as convolutional neural networks and long-short term memory networks, to estimate agricultural productivity [22].

Comparisons were made between accuracy, standard deviation, losses, mean absolute error, root mean square error, and mean square error. The random forest and convolutional neural network outperformed other deep learning and machine learning techniques. The random forest's mean absolute error was 1.97, its root mean square error was 2.45, its standard deviation was 1.23, and its maximum accuracy was 98.96%. The evaluation of the convolutional neural network showed a minimum loss of 0.00060.

Singh Boori et al., “Wheat Yield Estimation and Predication Via Machine Learning”, in order to accurately estimate and predict wheat production at a resolution of 10 meters, used a large amount of heterogeneous data in machine learning viz - linear regression (LR), decision tree (DT), and random forest (RF) regression [23]. When the three regressions are compared, RF exhibited the highest accuracy with a R2 of 98 and an RMSE of 1.40 that likewise increases from the seedling to the harvest growth stage.

Ashfaq et al., “Accurate Wheat Yield Prediction Using Machine Learning and Climate-NDVI Data Fusion”, forecasted wheat yield in the Multan region of Pakistan's Punjab province by merging data from several sources [24]. By integrating publicly available data within the GEE (Google Earth Engine) platform, including climate, satellite, soil properties, and spatial information data, the findings were compared to the benchmark provided by Crop Report Services (CRS) Punjab. Three popular machine learning (ML) techniques—support vector machine (SVM), Random Forest (RF), and Least Absolute Shrinkage and Selection Operator (LASSO)—were used to develop alternative empirical models for yield prediction using data from 2017 to 2022, choosing the best attribute subset related to crop output. According to the findings, merging all datasets and applying three machine learning methods improved yield prediction performance (R2: 0.74-0.88). Benchmark models that use spatial information and other features increased prediction from 0.08 to 0.12. With a R2 of 0.88 and a Root Mean Square Error (RMSE) of 0.05 q/ha, random forest performed better than the competing models. The research found, random forest gave 97% and SVM gave 93% accuracy.

Lagrazon & Tan, did a comparative analysis by employing machine learning techniques, to identify which machine learning models, such as Support Vector Machine, Decision Tree, Gaussian Process Regression, Ensemble, and Neural Network—gave the most accurate for predicting agricultural yield [25]. The best crop yield prediction method was examined by testing and training the datasets. With an RMSE of 0.046579., it was discovered that the Gaussian Process Regression performed better than all other models when the hyperparameters of the various models were adjusted.

M. J. Hoque et al., “Incorporating Meteorological Data and Pesticide Information to Forecast Crop Yields Using Machine Learning”, has offered an agricultural production forecast method that makes use of machine learning algorithms, pesticide records, crop yield data, and meteorological data over a full year [26]. Gradient Boosting, K-Nearest Neighbors, and Multivariate Logistic Regression were the three machine learning models that were used after using exacting techniques to collect, clean, and improve the data. In order to optimize the model's performance by preventing overfitting, they used the GridSearchCV approach for hyper-parameter tweaking to determine the most appropriate hyper-parameter during K-Fold cross-validation. With an almost perfect coefficient of determination (R2) of 99.99%, the Gradient Boosting model performs remarkably well and shows great promise for accurate yield prediction.

Nurcahyo, et al., “Interpretable Machine Learning for Multi-Class Crop Yield Prediction”, used interpretability tools such as Shapley Additive explanations (SHAP) and explainable artificial intelligence (XAI) methodologies to enhance the interpretability of their prediction model [27]. According to their results, the XGBoost model performed the best, with an accuracy of 99.86%; SVM Poly Kernel came in second with 99.32%, and Random Forest came in third with 98.82%.

Three regression techniques—Random Forest, Xtreme Gradient Boosting (XGB) regression, and Least Absolute Shrinkage & Selection Operator (LASSO) regression—are used in the study's framework to estimate wheat grain yield. To determine the best method, several facets of the three models are examined, and the outcomes are contrasted. Data from three wheat experimental fields with three distinct sowing dates (SD1, SD2, and SD3) are collected using drone-based multispectral sensors, and the impact of the seeding strategy on crop yield is investigated. A variety of evaluation criteria are used to evaluate the prediction performance of the models at various phases of the crop's growth. With a mean absolute error (MAE) of 21.72 and a coefficient of determination (R2) of 0.93, the results indicate that LASSO performed at its best in April.

Shafi et al., “Tackling Food Insecurity Using Remote Sensing and Machine Learning-Based Crop Yield Prediction”, used regression techniques—Random Forest, Xtreme Gradient Boosting (XGB) regression, and Least Absolute Shrinkage & Selection Operator (LASSO) regression, to estimate wheat grain yield [28]. To determine the best method, several facets of the three models were examined, and the outcomes were contrasted. Data from three wheat experimental fields with three distinct sowing dates (SD1, SD2, and SD3) were collected using drone-based multispectral sensors, and the impact of the seeding strategy on crop yield was investigated. A variety of evaluation criteria were used to evaluate the prediction performance of the models at various phases of the crop's growth. With a mean absolute error (MAE) of 21.72 and a coefficient of determination (R2) of 0.93, the results indicated that LASSO performed at its best.

Rajendiran & Rethnaraj, “Lettuce Crop Yield Prediction Analysis using Random Forest Regression Machine Learning Model in Aeroponics System”, employed Random Forest (RF) regression model for yield prediction in aeroponics system for lettuce crop [29]. The aeroponic lettuce growing tower provided the data for this study. Investigating the random forest model's potential for accurate lettuce crop production prediction in an aeroponics system is the aim of this research project. When it comes to predicting the yield of lettuce crops, the RF model outperformed the other regression methods with an accuracy rate of 92%.

Nurcahyo, Soeparno, et al., “Rice Yield Prediction in Sumatra Indonesia Using Machine Learning and Climate Data”, studied machine learning (ML) regression-based approach to estimate rice yields across eight Sumatran provinces in Indonesia utilizing four combinations of climate and crop production data [30]. Six regression algorithms were used in predictive modelling. To enhance each model's performance, hyperparameter tuning techniques like Grid Search CV or Randomized Search CV were used. To assess unbiased models, k-fold splitting and cross-validation (CV) ere employed. With an R2-score of 88.48, XGBRegressor appeared to be the most successful model out of the six, followed by Support Vector Regressor (85.21) and Random Forest Regressor (86.39).

S. Kumar et al., “Improved Crop Yields and Resource Efficiency in IoT-based Agriculture with Machine Learning”, proposed an ensemble model for crop prediction based on IoT data acquired from IoT sensors using the PLX-DAQ tool [31]. The model used machine learning. Naive Bayes, Decision Tree, Random Forest Support Vector Machine, and K-Nearest Neighbour were machine learning models used. The results of the experiment showed that ensemble learning was the most accurate at predicting early crop yields, with a 97.45% accuracy rate.

6. Discussion and Conclusion

The summary of the results of the performance of various algorithms along with the best result from each paper reviewed is shown in Table 1.

Table 1. Summary of results of the papers reviewed

S.No	Title of the paper	Methods	Result of best performance	Authors
1.	“Predicting Agriculture Yields Based on Machine Learning Using Regression and Deep Learning”	Decision trees, Random forests, XGBoost regression and Deep learning techniques	Random Forest 98.96% accuracy	Sharma et al., 2023 [22]
2.	“Wheat Yield Estimation and Predication Via Machine Learning”	Linear regression (LR), Decision tree (DT), and Random Forest (RF) regression.	Random Forest – 98% accuracy	Singh Boori et al., 2023 [23]
3.	“Accurate Wheat Yield Prediction Using Machine Learning and Climate-NDVI Data Fusion”	Support vector machine (SVM), Random Forest (RF), and Least Absolute Shrinkage and Selection Operator (LASSO)	Random forest gave 97% accuracy	Ashfaq et al., 2024 [24]
4.	“A Comparative Analysis of the Machine Learning Model for Crop Yield Prediction in Quezon Province, Philippines”	Support Vector Machine, Decision Tree, Gaussian Process Regression, Ensemble, and Neural Network	Gaussian Process Regression performed well with RMSE of 0.046579	Lagrazon & Tan, 2023 [25]
5.	“Incorporating Meteorological Data and Pesticide Information to Forecast Crop Yields Using Machine Learning”	Gradient Boosting, K-Nearest Neighbors, and Multivariate Logistic Regression	Gradient Boosting with 99.99%, R2	Hoque et al., 2024 [26]
6.	“Interpretable Machine Learning for Multi-Class Crop Yield Prediction”	XGBoost, SVM Poly Kernel, Random Forest	XGBoost with 99.86 % accuracy	Nurcahyo, et al., 2023 [27]

7.	"Tackling Food Insecurity Using Remote Sensing and Machine Learning-Based Crop Yield Prediction"	Random Forest, Xtreme Gradient Boosting (XGB) regression, and Least Absolute Shrinkage & Selection Operator (LASSO) regression	LASSO gave better result with (R2) of 0.93	Shafi et al., 2023 [28]
8.	"Lettuce Crop Yield Prediction Analysis using Random Forest Regression Machine Learning Model in Aeroponics System"	Random Forest (RF) regression	Random Forest gave 92% accuracy	Rajendiran & Rethnaraj, 2023 [29]
9.	"Rice Yield Prediction in Sumatra Indonesia Using Machine Learning and Climate Data"	XGBRegressor, Support Vector Regressor and Random Forest Regressor	XGBRegressor 88.48 R2	Nurcahyo, Soeparno, et al., 2023 [30]
10.	"Improved Crop Yields and Resource Efficiency in IoT-based Agriculture with Machine Learning"	Naive Bayes, Decision Tree, Random Forest Support Vector Machine, and K-Nearest Neighbour	Ensemble learning gave 97.45 % of accuracy	S. Kumar et al., 2024 [31]

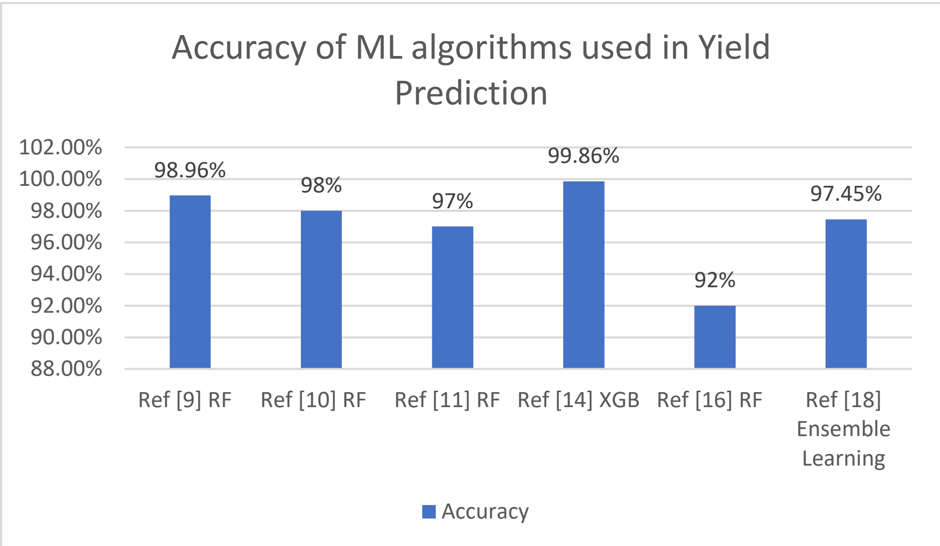

Fig 1. Accuracy of ML algorithms used in Yield Prediction (Source: Author)

A graph was plotted with the accuracies from the reviewed paper which is shown in Figure 1. From the graph we can deduce that Random Forest had outperformed other algorithms consistently in many research works. This is also corroborated by other works [32] [33] [34]. Highest accuracy was achieved by XGBoost (99.86%). This review paper reviewed state of art Machine Learning techniques used in crop yield prediction. It provides a compressive analysis of 10 research papers with various algorithms and their comparative performance. The review found that in crop yield prediction Random Forest algorithm had outperformed many other algorithms in terms of accuracy.

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