Soil Fertility and Crop Recommendation using Machine Learning and Deep Learning Techniques: A Review

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Abstract

Agriculture plays an important role in the economic growth of the nation. The agriculture sector has benefited by the rapid advancement in the area of Artificial Intelligence and Big Data. Machine Learning is the core subarea of Artificial Intelligence which provides the ability of self-learning without explicit programming.The application of Machine Learning techniques in the various fields had increased rapidly. Various Machine Learning algorithms have been applied for research in the areas of Agriculture. This study aims to provide a comprehensive review of different Machine Learning and Deep Learning techniques used in prediction of Soil Fertility and Crop Recommendation. The soil fertility rate is predicted by using soil micronutrients and macronutrients. We found that there is increasing usage of Machine Learning and Deep Learning Techniques in the area of Soil Science. Ensemble methods usually perform much better than the simpler approaches.

Keywords: *SVM, Random Forest, LSTM, K-NN, K-Means, ELM*

1. Introduction

Agriculture is the biggest sector of the Indian economy. It is the major provider of employment and source of revenue in India. The soil is entirely responsible for the sustainability of life on the earth. Soil is a critical part of successful agriculture and it is the source of nutrients that is used to grow crops. The productive capacity of soil is dependent on soil fertility. Soil fertility is an ability of soil to supply essential plants nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth.(Jayalakshmi & Devi, 2019) The physical, chemical and biological properties of the soil are useful to evaluate its fertility, to design a cultivation plan and to predict the crop productivity.(Sirsat et al., 2017)

Prediction of soil properties is the first and the most crucial step which influences the selection of crops. The soil properties are directly related to the geographic and climatic conditions of the land in use and hence is an important factor to take into consideration.(Sharma et al., 2021) A scientific analysis of soil micronutrients, soil macronutrients and pH is important for determining the soil fertility. Machine Learning algorithms are mainly used to solve such a diverse set of problems. Deep Learning is the subarea of Machine Learning which is trained by using a large dataset and uses Deep Neural Network to make intelligent decisions.

This review article will provide an insight into the research community about the importance of Machine Learning and Deep Learning Techniques for the Soil Fertility and Crop Recommendation. This paper is organized in three sections. The first section consists of different ML Techniques used for Soil fertility prediction, the second section consists of different ML Techniques used in Crop Recommendation depending on soil nutrients and the last section consists of the Conclusion part.

2. Related Work

2.1 Soil Fertility Prediction

(Trontelj & Chambers, 2021) used several ML Techniques like Random Forest, Decision Tree, Naïve Bayes, Support Vector Machine, Least-Square Support Vector Machine, Artificial Neural Network and Principal Component Analysis to predict soil nutrients. The results showed that multi-component analysis was more accurate than single-component soil prediction. Further, it also stated that the overall prediction accuracy was improved by Principal Component Analysis (PCA).

The soil fertility was predicted by the Artificial Neural Network (ANN) with two activation functions, relu and tanh. The five soil nutrient parameters such as Organic Carbon, Phosphorus, Potassium, Magnesium and Boron were used as input for the model. The relu activation function had performed well on four classified soil nutrient parameters out of five classified soil nutrient parameters.(J. Pant et al., 2021)

The 12 Soil Quality indicators, namely- pH, EC, OC, N, P, K, Fe, Cu, Mn, Zn, B and S are integrated into Soil Quality Indices (SQIs). Simple additive (SQISA), PCA based (SQI_{PCA}) and Correlation (SQIr) based weighted index methods were used for the SQI estimation. Random Forest (RF) method was employed to calculate the predicted soil quality indices (PSOIs). Results showed that SQIr and PSQIr proved more consistent in the correlation with crop yield. An optimal performance of RF for SQI prediction and PSQIr is found to be the most competent tool to predict the soil quality at un-sampled locations.(Paul et al., 2020)

Ca, Mg, pH water, OM, available P, total Nitrogen and CEC are the principal indicators derived from ANOVA and PCA analyses were used to control soil quality. Among seven principal indicators, four indicators namely- Ca, pH, OM and P were identified as important for assessing soil fertility status. Four soil fertility classes were identified based on physicochemical soil properties, fertility parameters and Soil Quality Index (SQI) namely very good fertility soils, good fertility soils, fairly good fertile soils and poorly fertile soils.(Nguemezi et al., 2020)

K-means clustering algorithm was used to analyze soil fertility clusters using various soil attributes like CY (Clay Content of Soil), SN (Quantity of Sand), SL (Salinity of the soil), PH, CaCl2, OC, N, Ca, P, Mg, K, Na and EC. Elbow method, Average Silhouette and Gap Statistic Methods were used to obtain the number of clusters. Four clusters were identified with cluster 1 having the highest fertility, followed by 2 and the fertility decreases with increasing number of clusters.(Hassan Hayatu et al., 2020)

A generalized Pedotransfer function derived with Machine Learning methods like GLMM (Generalized Linear Mixed Model Effect) and Residual Maximum Likelihood (REML) were used to predict Soil Electrical Conductivity (EC) and Soil Organic Carbon (OC). The prediction accuracy of both the algorithms recorded similarly. Victorian Soil Information System (VSIS) was the database used for the same.(Benke et al., 2020)

The soil quality classification and soil fertility were predicted by several Machine learning algorithms such as Support Vector Machine, Logistic Regression, Linear Discriminant Analysis (LDA) and K-NN using soil physical and chemical properties and macronutrients. Unsupervised K-Means clustering algorithm was used for labeling the data set. It was found that, SVM performed well with accuracy 96.62%.(H. Pant et al., 2020)

The Soil Fertility was predicted by using pXRF (Portable X-ray fluorescence) data with Machine Learning algorithms, namely, stepwise Generalized Linear Model (GLM) and Random Forest (RF). It had been reported that RF resulted in more accurate predictions of soil fertility predictions than GLM. (Benedet et al., 2021)

The spatial variation of Soil Organic Carbon (SOC) concentration was predicted by ensemble model consisted of six machine learning algorithms, namely, Partial least squares regression (PLSR), Generalized linear model (GLM), Recursive partitioning and regression trees (rpart), Support vector machines (SVM), Random Forest (RF) and k-nearest neighbors (KNN). It was found that , GLM, SVM and RF for the first depth (0-10 cm) and PLSR, GLM, SVM, and RF for the second depth (10-20 cm) were the most accurate machine learning algorithms in ensemble modelling.(Tajik et al., 2020)

In (Muneshwara et al., 2020), the analysis of agriculture fit soil and best suitable crop according the level of soil fertility was predicted by using SVM, k-NN, RF and Ensemble Technique using pH value, Electrical Conductivity, Moisture content, Temperature and (N)Nitrogen, (P)Phosphorous, (K) Potassium levels as Input Parameters. The recommendation for the most suitable crop was also provided.

Various soil properties were predicted by using vis-NIR spectroscopy. Calibration models including conventional models such as PLSR, SVMR, ANN were compared against proposed models such as RNN, CNN, CCNVR. The result showed that CCNVR achieved the best model performance with the lowest RMSE value (6.40, 0.45, 3.30, and 0.35 for OC, N, CEC, and pH, respectively) and the highest $R2$ (0.73, 0.70, 0.73, and 0.86 for OC, N, CEC, and pH, respectively). It was also found that, proposed CCNVR model has better resistance towards noise compared to other calibration models.(Yang et al., 2020)

To classify area wise soil fertility indices and pH levels based on the village level soil fertility Information, classification technique known as Extreme Learning Machine (ELM) with different activation functions like gaussian radial basis, sine-squared, hyperbolic tangent, triangular basis, and hard limit were used. It was found that the ELM with gaussian radial basis activation function achieved the best performance for soil nutrient fertility index classification. The ELM with hyperbolic tangent function achieved a good result for pH classification. (Suchithra & Pai, 2020)

Soil Fertility was predicted by examining macro and micro soil properties using Simple Linear Regression, Multi Variate Regression. Random Forest Classifier, Support Vector Machine and Gaussian NB were used for Crop Recommendation. Random Forest Classifier with accuracy score 72.74% had been proven better.(Keerthan Kumar et al., 2019)

(J. Pant et al., 2019) used Rough Set Theory to classify soil data based on fertility level class using feature selection method.

To analyze the soil data and to identify attributes to predict fertility, different Machine Learning algorithms like J48, Naïve Bayes and REPTree were used. It was found that J48 proved better.(Jayalakshmi & Devi, 2019)

A wide collection of regression methods had been used to generate pedotransfer functions that automatically predict the village-wise soil fertility indices for several relevant soil nutrients including organic carbon (OC), phosphorus pentoxide ($P2O5$), iron (Fe), manganese (Mn), and zinc (Zn). The best results were achieved by the extremely randomized regression trees (extraTrees).(Sirsat et al., 2018b)

Soil N-P-K prediction was performed by a prediction method namely, Adaboost.RT. The results showed that it is better than the traditional method.(Priya & Ramesh, 2018)

Boosted Regression Tree and Random Forest techniques were used to determine the most reliable and accurate model to predict SOC stocks. The results showed that Random Forest with Genetic Algorithm proven better than BRT.(Wang et al., 2018)

With the aim to analyze and classify different types of soil, several ML techniques like Decision Tree (C5.0), Random Forest (RF). Support Vector Machines (SVM) and eXtreme Gradient Boosting (XGBOOST) were used. XGBOOST outperformed the other algorithms.(Nagpal, 2018)

In this study (Ogunleye et al., 2018), Fuzzy Logic was used as an expert system to determine soil fertility and to predict the amount of fertilizers (NPK) needed to restore its fertility. The Fuzzy Inference System outperformed with 99.1% of accuracy.

The soil properties were predicted by using Machine Learning techniques such as Support Vector Regression (SVR), Ensembled Regression (ER) And Neural Network (NN). The results showed that Ensembled Regression (ER) outperformed as compared to SVM and NN.(Singhatiya & Ghosh, 2018)

(Sirsat et al., 2017) used a collection composed by 20 classifiers from families of Bagging, Boosting, Decision Trees, Nearest Neighbors, Neural Networks, Random Forests (RF), Rule Based and Support Vector Machines (SVM) to classify several nutrient levels and village- wise soil fertility indices. The class labels were quantified values (low, medium and high) of their numeric values. It also classified the soil type and pH, and the recommended crop for the next cycle as well as recommendation of fertilizers. The results showed that RF achieves the best performance followed by Adaboost, SVM and Gaussian Extreme learning machine.

A hybrid algorithm, an Advance Ant colony organization (ACO) in combination with an Adaptive Network-based fuzzy system (ANFIS) was used to predict CEC. The performance of the algorithm was done with the Multiple Linear Regression (MLR) model. ANFIS resulted in higher model efficiency.(Shekofteh et al., 2017)

(Ghosh & Koley, 2014) used Back Propagation Neural Network (BPN) to perform analysis of main soil properties such as organic matter, essential plant nutrients, micronutrient that affects the growth of crops and find out the suitable relationship percentage among those properties. Results showed that Artificial Neural Network with a certain number of neurons in hidden layers had performed better in predicting soil properties than multivariate regression.

Table 1 Comparison of different ML Algorithms for prediction of Soil Fertility.

Methods used for comparison	Best Method	Reference
Random Forest, Decision Tree, Naïve Bayes, Support Vector Machine, Least-Square Support Vector Machine and Artificial Neural Network, Principal Component Analysis.	Principal Component Analysis	(Trontelj & Chambers, 2021)
Artificial Neural Network (ANN) with two activation functions relu and tanh	relu activation function	(J. Pant et al., 2021)
Support Vector Machine, Logistic Regression, Linear Discriminant Analysis, K-NN	Support Vector Machine	(H. Pant et al., 2020)
PLSR, SVMR, ANN, RNN, CNN, CCNVR	CCNVR	(Yang et al., 2020)
Extreme Learning Machine (ELM) with activation functions like gaussian radial basis, sine-squared, hyperbolic tangent, triangular basis, and hard limit.	Gaussian radial basis activation function achieved best performance for soil nutrient fertility index classification. Hyperbolic tangent activation function achieved a good result for pH classification.	(Suchithra & Pai, 2020)
Simple Linear Regression, Multi Variate Regression, Random Forest Classifier, Support Vector Machine and Gaussian NB	Random Forest Classifier	(Keerthan Kumar et al., 2019)
J48, Naïve Bayes, REPTree	J48	(Jayalakshmi & Devi, 2019)
Regression techniques belongs to families of Neural Network, Deep Learning, Support vector regression, Random Forests, Bagging and Boosting, Lasso and Ridge Regression, Bayesian Models.	extraTrees Regressor	(Sirsat et al., 2018a)
Boosted Regression Tree, Random Forest	Random Forest	(Wang et al., 2018)
Decision Tree (C5.0), Random Forest (RF), Support Vector Machines (SVM) and eXtreme Gradient Boosting (XGBOOST)	XGBOOST	(Nagpal, 2018)
Classifiers from families of Bagging, Boosting, Decision Trees, Nearest Neighbors, Neural Networks, Random Forests (RF), Rule Based and Support Vector Machines (SVM).	Random Forest	(Sirsat et al., 2017)

2.2 Crop Recommendation

The right crop was predicted by using several soil fertility properties with the help of several Machine Learning Techniques such as Deep Neural Network, K-nearest neighbor (KNN), Decision Tree classifier, Support Vector

Machine (SVM), Gaussian NB and Linear discriminant analysis (LDA). The Deep Neural Network outperformed with 87% of accuracy. (N. & Choudhary, 2022)

(Nithya & Kalpana, 2022) used Modified Multi-Layer Perceptron Neural Network (MMLPNN) with back propagation model to improve the prediction accuracy of suitable crops suggestion model based on soil fertility and also the ranking of crops. The results were compared with Artificial Neural Network (ANN) and Recurrent Neural Network (RNN). Multiple datasets like crop, weather and other soil parameters were integrated into a single one. The Modified Multi-Layer Perceptron Neural Network (MMLPNN) outperformed with 99% accuracy.

(Kalimuthu et al., 2020) used Naïve Bayes Gaussian classifier with boosting algorithm to predict affordable crop for the given input. The results showed that Naïve Bayes Gaussian classifier with boosting algorithm given 97% accuracy.

With the aim to predict suitable major crops of the season, Deep Convolutional Regression Network (DCRN) along with Decision Tree (DT) and Self-Organizing Map (SOM) were used. Deep Convolutional Regression Network (DCRN) outperformed other methods such as Decision Tree (DT) and Self-Organizing Map (SOM) with 97% of accuracy.(Talasila et al., 2020)

In (Nigam et al., 2021), the yield of the crop was predicted on the basis of temperature, rainfall, season and area. It was found that Random Forest Regressor gives the highest yield prediction accuracy. Simple RNN performs better for Rainfall Prediction. LSTM outperformed for Temperature Prediction.

A two-tiered machine learning approach was used to identify nutrient deficiency in paddy crop images. The procedures were focused only on leaves. The proposed system outperformed the conventional approaches.(Shidnal et al., 2019)

An integrated model using ELM was used to predict the concluding growth amount of sugarcane. Prediction results were evaluated and further compared with Artificial Neural Network (ANN) and genetic programming models. Accuracy of the ELM model was promising.(Taherei Ghazvinei et al., 2018)

In this study (Kouadio et al., 2018), 18 different ELM-based models with single and multiple combinations of the predictor variable were compared with Multiple Linear Regression (MLR) and Random Forest (RF) by using soil micronutrients and macronutrients for the Robusta Coffee Crop yield. ELM model performed better than RF and MLR model.

The soil classification and crop yield suggestion were performed by several ML algorithms such as Weighted K-NN, Gaussian kernel based SVM and Bagged Tree. The results indicates that Bagged tree and K-NN showed good accuracy but among all the classifiers, SVM had given the highest accuracy in soil classification.(Rahman et al., 2019)

(Afrin et al., 2018) used Data Mining approach to analyze and predict soil properties, climatic factors and crop production. Techniques such as K-means, PAM, CLARA, DBSCAN were used for clustering and Regression Techniques such as Simple Linear Regression, Multiple Linear Regression, Stepwise Linear Regression and Generalized Linear Model were used to predict crop yield. PAM gave better results as compared to other Data mining techniques and Generalized Linear Model performed well as compared to other Regression techniques.

(Balakrishnan & Muthukumarasamy, 2016) used Ensemble Machine Learning model for the prediction of crops such as AdaSVM and AdaNaive along with SVM and Naïve Bayes. The results showed that the proposed methods were performed better.

Random Forest, Naïve Bayes, Linear SVM with Majority voting technique were used to design a recommendation system for accurate crop selection based on the various soil, rainfall and surface temperature parameters. It also used to improve crop productivity by providing predictions of high accuracy and efficiency through the ensembling technique. It is also used to reduce the wrong choice on a crop by application of principles of precision agriculture. The result showed 99.91% accuracy with ensembling method.(Kulkarni et al., 2018)

Table 2 Comparison of different ML Algorithms for Crop Recommendation.

Methods used for comparison	Best Method	Reference
Deep Neural Network, K-nearest neighbor (KNN), Decision Tree classifier, Support Vector Machine (SVM), Gaussian NB, Linear discriminant analysis (LDA)	Deep Neural Network	(N. & Choudhary, 2022)
Modified Multi-Layer Perceptron Neural Network (MMLPNN) with back propagation model, Artificial Neural Network (ANN), Recurrent Neural Network (RNN)	Modified Multi-Layer Perceptron Neural Network (MMLPNN)	(Nithya & Kalpana, 2022)
Deep Convolutional Regression Network (DCRN), Decision Tree (DT) and Self-Organizing Map (SOM)	Deep Convolutional Regression Network (DCRN)	(Talasila et al., 2020)
Random Forest Classifier, Artificial Neuron Network, K-Nearest Neighbours Classifier, XGBoost Classifier, Stochastic Gradient Descent Classifier, Random Forest Regressor, K-Nearest Neighbour Regressor, Simple RNN, LSTM	Random Forest Regressor gives highest yield accuracy. Simple RNN performs better for Rainfall Prediction LSTM is good for Temperature Prediction	(Nigam et al., 2021)
ELM, ANN and GP	ELM	(Taherei Ghazvinei et al., 2018)
ELM, MLR, RF	ELM	(Kouadio et al., 2018)
Weighted K-NN, Gaussian kernel based SVM, Bagged Tree	Gaussian kernel based SVM	(Rahman et al., 2019)
K-means, PAM, CLARA, DBSCAN, Regression Techniques such as Simple Linear Regression, Multiple Linear Regression, Stepwise Linear Regression and Generalized Linear Model.	PAM, Generalized Linear Model	(Afrin et al., 2018)
Support Vector Machine (SVM), Naïve Bayes, AdaSVM and AdaNaive	AdaSVM , AdaNaive	(Balakrishnan & Muthukumarasamy, 2016)

3. Conclusion

Artificial Intelligence continuously helps humans to solve diverse problems in various aspects of life. Machine Learning models provide an ideal way to analyze large data sets and help in introspecting the relations between various factors and their influence on each other. Hence it can be used for forecasting and predictions based on conditions. In this paper, authors had reviewed the literature based on Soil fertility prediction and Crop recommendation. The study discussed the objective of the research, different set of parameters, ML or DL algorithm used in this context and the appropriate algorithm or the techniques outperformed. Deep Neural Network, Extreme Learning Machine (ELM) are outperformed in the context of fertility prediction and also in suitability of the crop. Ensemble methods may perform better than simpler approaches.

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