



Predicting optimal Fertilizers using Machine Learning and Deep Learning

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Abstract. The use of machine learning (ML) methods is the new wave of precision agriculture that will transform the traditional methods of farming by refining fertilizer recommendations, increasing crop yields, and reducing environmental impacts. This study provides a comparative analysis of the ML and deep learning algorithms to the problem of fertilizer recommendation with the use of the 10,098 samples that have certain attributes such as nitrogen, phosphorus, potassium, moisture, humidity, temperature, crop type, and soil type. The dataset was divided into training and testing subsets after a thorough preprocessing of data and analysis of the exploratory data. After that, various models, such as random forest, gradient boosting, SVM, logistic regression, k-nearest neighbors, and deep learning were trained and evaluated based on the Mean Average Precision at 3 (MAP3) metric. The results reveal that the random forest algorithm was better performing with a MAP3 score of 0.2805, which justifies its application in the management of site-specific nutrients in heterogeneous tabular data. The MAP3 index enables a consistent prioritization of fertilizer recommendations, hence helping farmers in making adaptive decision-making. This study highlights how ensemble machine learning methods can be used to achieve precision agriculture, and indeed indicates that more needs to be explored in the advanced deep learning architecture to come up with a cost effective and scalable solution.

Keywords: Precision agriculture, Machine learning, Fertilizer recommendation, Random forest, MAP3, Crop yield, Soil health, Nutrient management

1 Introduction

The increasing population of the world and the necessity to suppress the climatic changes imposes the radical change of the methods of farming. The traditional forms of agriculture normally depend on the homogenous application of inputs which can easily result into over use of synthetic fertilizers and other environmental degrade, which include the erosion of soil and the run off of nutrients [1]. Such inefficiencies are not only threatening the stability of the ecosystem, but a huge economic burden to the farmers who now face the uncertainty of the input prices and unreliable harvests [2].

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Along such challenges, awareness has risen on the need to have data-driven and sustainable solutions within the agricultural sector. One of such opportunities is the Precision Agriculture (PA), which takes advantage of the ability of the computational intelligence to apply resources into the management of site-specific zones. Agricultural data collection and the use of digital sensors combined with remote sensing and strong data collection instruments have revolutionized the methods of collecting, and using agriculture data. These technologies have opportunities to monitor the health of soils and crops in real time and thus, such a method of managing farms is more sensitive and dynamic [3].

Machine Learning(ML) is increasingly becoming the force behind this paradigm shift because it can be used to analyze complex and high-dimensional agricultural data to optimize

Resource utilization and enhance system resilience and sustainability[4]. ML models can solve the problem of variability in the fertility of soils and nutrient requirements of crops, which is essential to obtaining sustainable intensification of agriculture, by revealing complex trends in agronomic data. The eventual aim is to not only improve the production of crop, but also preserve the health of the soil and decrease the amount of inputs used in fertilizers, water and pesticides. The recent predictions indicate that 10-20 percent decrease in operational costs can be achieved through the implementation of data-driven resource planning resulting in the reduction of operational costs[5].

The ML algorithms avail substantial decision support instruments that transcend the conventional, generalized, rule-based fertilizer application suggestions. The fundamental activity is the identification of the best kind and quantity of the fertilizer, having multi-modal inputs that characterize the soil properties, environmental factors and requirements of the crop. Proper assessment of the nutritional status of the plants, especially the levels of essential macro-nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K) is a grounded principle since the dispensation of the nutrients causes un-optimal growth of the plants and reduced productivity. Site-specific, smart recommendations in this case are, therefore, a foundation towards sustainable and profitable agriculture[6,7].

2 Literature Review

Vhatkar et al.[8] introduce a machine learning solution that is expected to increase crop yield forecasting and soil health assessment to develop sustainable agriculture. Their output makes use of numerous ML algorithms to evaluate the complicated agricultural input and output products, and enhance the precision of the yield prediction and the nutrient condition of the soil. The article shows the positive effects of ML in maximizing fertilizer application and reducing its environmental effects, which is a viable framework of sustainable farming operations.

Ennaji et al.[9] review all machine learning methods used in managing nutrient in agriculture. The paper explains how ML models can be used to optimize the use of fertilizers using the soil nutrients information, plant growth, and environmental con-

siderations. It focuses on the fact that ML helps increase the efficiency of nutrient utilization and cost-effectiveness of inputs and minimizes the ecological footprint, and the existing gaps such as the necessity to include more detailed datasets and feature selection methods.

Waqas et al.[10] provide a general overview of the ways machine learning and deep learning are used in agriculture and include various examples of their application, including crop-based tracking, pest detection, and resource management. They assess the progress of the ML-enabled systems that are moving the precision agriculture and highlight how the ML can change the efficiency of agriculture and its sustainability. They also discuss problems that face these technologies like handling of huge heterogeneous data.

Musanase et al.[11] make a data-driven variable of crop and fertilizer recommendations based on machine learning algorithms. The nutrient is combined in their system. The proportions of the soils, the requirements of the crops, and the information about the environment to come up with specific fertilizer prescriptions to increase the productivity without excessive utilization of the fertilizers. This journal reveals the transformational potential of ML in agriculture with the presentation of practical, location-specific contributions, which represent the most effective use of resources.

Kalyani and Prakash [12] worry about the intelligent agriculture process which involves machine learning to define the fertility and dynamics of the soil. The authors use ML models that calculate the properties of soil and nutrient concentrations that enable the management of fertilizers to be done accurately. They have found that such application of ML can lead to the equilibrium of the level of soil nutrients, improved health of crops, and sustainable agriculture.

The proposal offered by Cheema and Pires [13] is an AIoT-based machine-learning-based soil nutrient analysis and recommendation system. To accomplish this, they integrate sensor data capture and smart ML algorithms to provide real-time and accurate fertilizer recommendations. The procedure is more efficient in managing the nutrient content and increasing the yield of a crop under the constant monitoring and decision making.

More and Ingle[14] propose a predictive analytics based real-time, spatially explicit fertilizer recommendation system. They operate by basing their technique on environmental and soil data to create maps of fertilizer applications that vary with the local variability of the fields, increasing the accuracy of managing nutrients. This model assists farmers with dynamic decision-making to enhance efficiency in inputs, as well as lowering environmental hazards.

Thorat and Jahirabadkar[15] analyze the latest techniques of deep learning in predicting fertilizers. They are concerned with methods like artificial neural networks and long short-term memory models, which demonstrate their success in forecasting the fertilizer requirements using big agricultural data. The article identifies issues with the completeness of the dataset and the significance of features that should be improved to enhance the work of a model.

Veeresh and Sindhu[16] introduce a numerical data-driven system of fertilizer recommendations that uses machine learning to maximize the use of the fertilizer by the farmers. Their system combines soil nutrient analysis, crop-specific requirements and

environmental information to provide personalized fertilizer recommendations. The strategy is to ensure the crop yields by maximizing and the fertilizer waste by minimizing to reduce the cost-effective and environmental friendly method of farming.

3 Methodology

Figure 1 shows the overall work flow of the paper which starts by taking a dataset then applying data preprocessing and exploratory data analysis(EDA) to find the data relevance and check whether data is consistent or not. After that dataset is split into training and testing dataset then machine learning and deep learning model are trained in training dataset and evaluated against the test data set using the mean average precision at 3 (MAP3) metric and at last results are compared to get the best model.

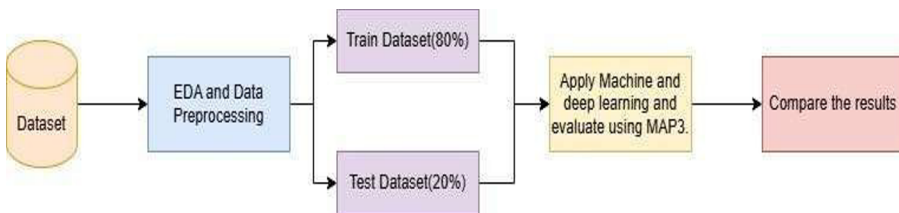


Fig-1 Work flow of the model

3.1 Dataset description

The dataset is taken from the kaggle named as predicting optimal fertilizers[17]. The dataset contains 10098 samples with 10 attributes that also include target attribute fertilizer name and other attributes can be categorised in two type of features first is numerical features that are Potassium, Phosphorous, Nitrogen, Moisture, Humidity, Temperature and second is categorical that are crop_Type and Soil_type. After applying statistical analysis there are no missing and duplicate values in the dataset. Also when checked with IQR test method no outlier is present.

3.2 EDA and data preprocessing on dataset

To analyze the dataset we have to preprocess the numerical and categorical dataset separately. Figure 2 shows the correlation heatmap of the numerical features that suggests that all correlation coefficient are near to 0 so there is no significant relationship among the numerical features. Any of the features does not show the multicollinearity and structure is consistent for all the datasets.

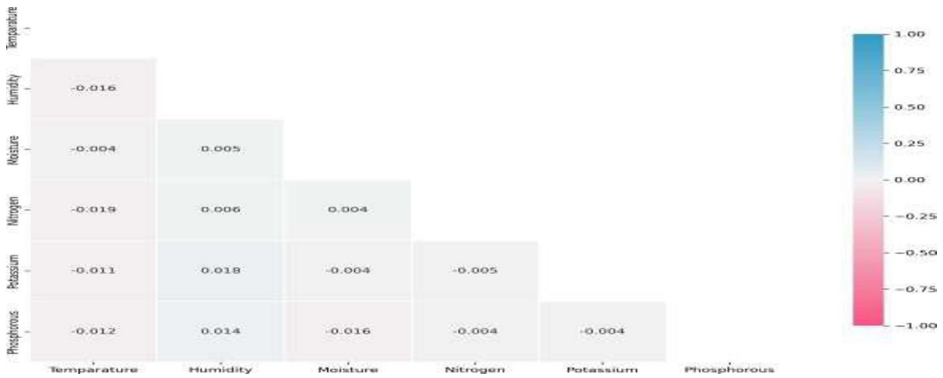


Fig-2 Correlation Heatmap of Numerical Features

Figure 3 shows the distribution of categorical features. There are two type of categorical features that are soil type and crop type. This dataset contains 5 types of soil sandy, clayey, loamy, black and red. The distribution of each type of soil is highly balanced and each type of soil represents nearly 19-21% of total data. Dataset includes 11 types of crops that are paddy, pulses, cotton, wheat, tobacco, millets, ground nuts, barley, maize, oil seeds and sugar cane. Distribution of each crop is uniform ranging from 8-11% for all given crops in which paddy and pulses appear most of the time and sugar cane appears lowest time.

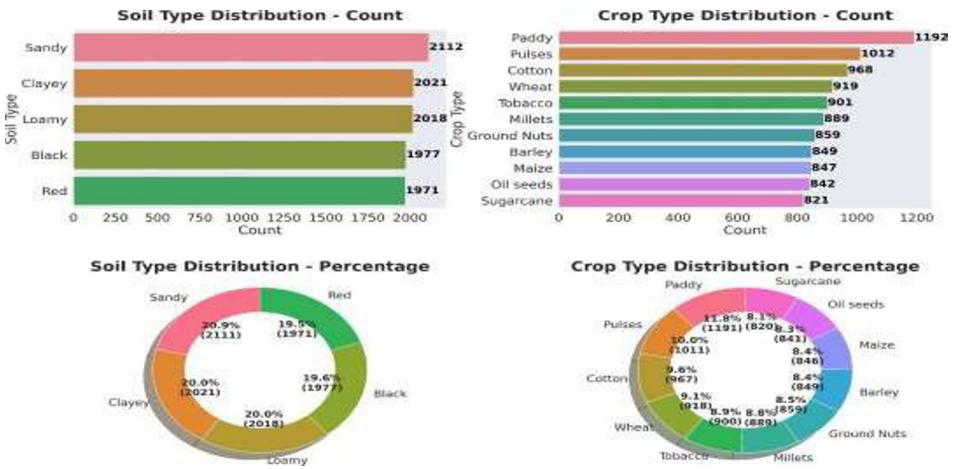


Fig-3 Categorical Feature Distribution

4 Result and Discussion

Performance of each model is calculated using the mean average precision at 3(MAP3) metric. This metric is used that correctly find the fertilizer type and rank each fertilizer type based on the predictions. MAP3 calculates how three predicted

fertilizer names match with the true fertilizer and the score of MAP3 is high if correct fertilizer appears in the prediction.

In this paper total 10098 data has been used and for the implementation purpose dataset is divide into 80% training data and 20% testing data against the 7 fertilizers name.

In this paper total 5 machine learning algorithms random forest, gradient boosting, SVM, logistic regression and k nearest neighbours and deep learning algorithm is implemented. Figure 4 shows the MAP3 values of various ML and DL models. 0.2805 result is achieved by the random forest algorithm.

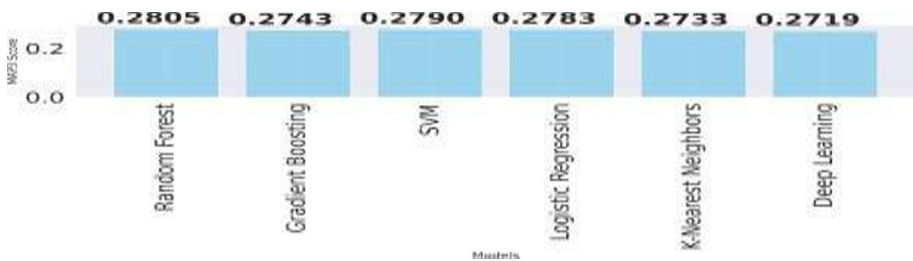


Fig-4 MAP3 values of different models

Figure 5 shows the detailed analysis of random forest model against the number of samples.



Fig.5- Category score of random forest.

5 Conclusion and future scope

After applying various machine learning and a deep learning algorithms for fertilizer recommendation the random forest algorithms outperform other by evaluated using the Mean Average Precision at K=3(MAP3) that gives the score of 0.2805. This outcome validates the use of the robust ensemble methods as the essential foundation for predictive modeling in precision agriculture, confirming their superior ability to handle heterogeneous tabular data. The MAP3 metric successfully reframes the problems a high-utility ranking task, providing the realistic measure of the system's

performance as the prescriptive tool. While the current score indicates the presence of the uncertainty but the ranking approach significantly aids farmers in their adaptive decision-making for site-specific nutrient management. For future advanced tabular deep learning architecture can be used that can be economic and cost sensitive.

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