

An Intelligent Decision Framework For Soil Evaluation And Crop Selection Using Artificial Intelligence

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Abstract: Soil assessment and crop selection is a field that is growing quickly and helps farmers figure out which crops will grow best on their property and in their environment. Machine learning is very important for automating pest identification and crop suggestions, which helps farmers get the most out of their crops. Seven different machine learning models are used to show how to analyse soil, choose crops, and predict yields. This article provides a summary of machine learning methods for classifying soil, keeping an eye on its health, and figuring out which crops are best for it, with an emphasis on how they are used in precision farming. So, a system that uses machine learning to look at agricultural data and predict which crops would grow best in various kinds of soil might be very helpful for farmers and the general public. This would eventually improve productivity and sustainability.

Keywords: Soil Analysis, Crop Recommendation, Artificial Intelligence, Crop Selection, Sustainability, Crop Yield Prediction.

1. Introduction

Agriculture faces increasing challenges due to climate change, the world population is expanding, and the soil is becoming worse [1]. Even while traditional agricultural techniques work, they don't always take into consideration how different the soil and other environmental conditions might be. Precision agriculture, [2] which uses cutting-edge technology like machine learning, may help by

giving farmers personalized information that helps them improve their agricultural methods [3]. The health of farmers is very important for the economic development of any country [4]. For this to happen, modern technology must be used along with resources in a smart way. Machine Learning for crop prediction involves a variety of different methodologies [5] or algorithms. These algorithms can indicate how much of a crop will grow. Some areas are already using machine learning to make forecasts about agricultural output more accurate [6]. Machine learning has come a long way, but it still doesn't perform well for apps that use a lot of data [7]. How well the model fits the data and how good the data is determining how accurate it is. The input elements in the data that was collected also play a role. The main reason more people are using precision farming is because it gives them more crops. Farmers may keep a watch on their fields with astonishing accuracy and speed by employing technologies like GPS, sensors, and drones [8], as well as information analytics [9]. By keeping an eye on things all the time, farmers can quickly detect and remedy issues like illnesses, pest infestations, and nutritional deficits. This lowers the amount of money lost in manufacturing [10]. From choosing plants and planting them to setting up irrigation and harvest periods, it's possible to make better decisions at every stage of the farming cycle. This results in increased yields and superior food quality [11]. For precision farming to work, farmers need to be able to accurately predict how much their crops will produce and manage their resources well. However, elements

like soil quality, temperature, and humidity may make these responsibilities tougher. Conventional forecasting methods often ignore how these aspects are related to each other in a complicated way, which leads to bad recommendations for managing farms. This research addresses the issue by using IoT-based data collection and machine learning techniques to enhance the precision of agricultural output forecasts [12]. Crop suggestion systems are very important for helping farming respond to changes in the weather. Models that use machine learning to propose crops might make farming more productive and sustainable. These systems look at a lot of different facts, such as the weather, soil composition, and market movements, to provide you information. Machine learning algorithms may use this information to predict which crops will do best in a certain area. This research looks at how machine learning can be used to evaluate soil and choose crops, focusing on how it can make contemporary farming more efficient and sustainable [13]. ML models suggest the optimum crops for certain soil conditions by considering things like pH balance, nutrient availability, and moisture content, as well as environmental parameters like temperature, precipitation, [14] and historical crop yields.

2. Background

Soil analysis and crop recommendations are important parts of precision agriculture, where data-driven decisions may help crops grow better and last longer. In the last several years, machine learning has changed and become an important tool for automating and improving the steps involved in soil analysis and crop suggestion [15]. A substantial amount of research has concentrated on the integration of critical soil properties, such as chemical balance, nutrient density, and water retention, evaluated alongside agricultural performance data to enhance crop selection for specific land types. Different AI-driven models, such as hierarchical tree structures, ensemble-based predictors, hyperplane [16] classifiers, and multi-layered neural networks, have been used to look at the complicated relationships between soil properties and crop yield.

The ensemble model, which utilized data from 2016 to 2018, had a root mean square error (RMSE) of 9% for corn yields and 8% for soybean yields. Bi et al. [17] used Genetic Algorithms (GA), Neural Networks (NN), and GA-enhanced Deep Learning

(DL) for crop prediction, achieving a reduction in RMSE of around 10%. Shahhosseini et al. [18] developed a hybrid model for forecasting maize production that combines crop modeling and machine learning techniques, resulting in a reduction in RMSE by 7 to 20%. Woittiez et al. [19] explored production gaps in oil palm cultivation, emphasizing the need of understanding contributing factors to improve crop management strategies and refine yield forecasts. The findings from this research elucidate the many machine learning algorithms used to predict agricultural productivity. This will support ongoing research that seeks to improve the precision of predictions via the use of ensemble learning techniques. Oikonomidis et al. [20] proposed a deep learning model to assess the effectiveness of machine learning algorithms based on certain criteria. Their research focused on the XGBoost algorithm and several hybrid models that included a CNN with other techniques, including DNN, RNN, and LSTM. They used these models using [21] a publicly available soybean dataset of 25,345 samples and 395 characteristics related to meteorological and edaphic conditions. Their findings suggest that forthcoming advancements may amalgamate XGBoost with deep learning methodologies, such as LSTMs or RNNs, particularly for tasks necessitating sequential data, like forecasting agricultural output. The [22] proved how effectively random forest models function by swiftly and correctly analyzing huge datasets of agricultural output. This is particularly crucial for projecting how much food will be grown, which requires a lot of data [23]. Random forests are an example of a data mining technique that can identify hidden patterns and trends in huge datasets [24]. Data mining uncovers insights that empower organizations to make informed decisions about impending agricultural trends and conditions [25]. Hasan et al. (2023) introduced the K-nearest Neighbour Random Forest Ridge Regression (KRR) model in this work. The idea is to make accurate guesses on how much food will be produced, focusing on major crops like rice, wheat, and potatoes. This model has done better than traditional machine learning approaches. It also lets you utilize a recommender system to assist you find out which crops are optimal for improved planning and production in agriculture [26]. Boppudi (2024) introduces the Deep Ensemble Classifier Integrated Bird Swarm Butterfly Optimization Algorithm (DEC-IBSBOA) model for predicting agricultural production. This model uses the IBS-BOA approach for advanced data pre-processing, feature extraction,

and finding the best features. The DEC-IBSBOA model is quite accurate, with a low MAE of around 1.0, which is better than any other method [27].

Other research projects have employed Time Series Forecasting methods, including ARIMA models, to find seasonal and temporal patterns in yield data [28]. These models use historical patterns and how they change over time to estimate what future yields will be. But these models have certain problems. For one, they rely on stable assumptions, and for another, they don't consider many factors at the same time [29]. However, the effectiveness of these models may fluctuate considerably across various crops and situations [30]. Research using UAV-based multispectral data and several machine learning algorithms for yield prediction indicates that Random Forest is the optimal model for forecasting maize yields, while Gaussian Process regression [31] is the superior model for predicting wheat and soybean yields. Support Vector Machines (SVM) have shown exceptional effectiveness in predicting broad bean yields, whereas Convolutional Neural Networks (CNN) have displayed amazing accuracy in forecasting rice yields. These discrepancies suggest that broader framework techniques might be used to address yield prediction challenges across various crops and environmental conditions. Ensemble learning (EL) [35] enhances prediction accuracy by amalgamating many foundational models using techniques like as bagging, boosting, and stacking to use their respective strengths. In several situations [36], these techniques have consistently surpassed individual models for generalization performance.

But there are a number of intricate reasons why it's impossible to anticipate agricultural output. The quality of the soil, pests, genotypes [37], the weather, the time of year, and other factors all have an effect on crop yields. Second, the methods and steps used to anticipate yield change with time and are not always linear [38]. In agricultural systems, a large portion often eludes depiction using basic stepwise calculations, particularly in scenarios where datasets are complex, incomplete, or unclear. Some of the most frequent methods that computers produce predictions include via decision trees, linear regression, and ensemble learning. Linear regression is a simple and popular machine learning method that uses a linear model to predict the relationship between crop yield and other factors that affect it. Deep learning has been widely used in agriculture

[43] due to its efficacy in managing spatiotemporal data dependencies and extracting pertinent features without requiring human feature engineering [44]. Deep learning use multi-layer neural networks to extract abstract features from large datasets. These datasets might be supervised, partially supervised, or not organized at all. This strategy focuses on figuring out how functional characteristics and interaction components are related, which is important for making accurate forecasts about crop yields [45].

3. Data Description

The proportion of crops that each soil feature contributes is variable, which shows which crops are best for certain soil types. The data from each sample is put into a table, which makes it easy to compare soil conditions [46]. The line graph lets you see how that parameter changes from sample to sample. By looking at each rainfall bar and the pH and yield figures that go with it, stakeholders may figure out which circumstances are best for growing crops. the K/N ratio as well as the total nitrogen (N) and potassium (K) levels for six different crops. Giving useful [47] information for managing fertilizers and precision farming.

Table 1. Variable relationship mapping

Crop	Potassium(k) (mg/kg)	Nitrogen (N) (mg/kg)	K/N ratio	Yield (tons/ha)
Rice	37	52	0.8	4.8
Wheat	40	47	0.88	3.9
Maize	38	57	0.68	5.3
Cotton	42	62	0.69	1.0
Soybean	41	49	0.87	3.8

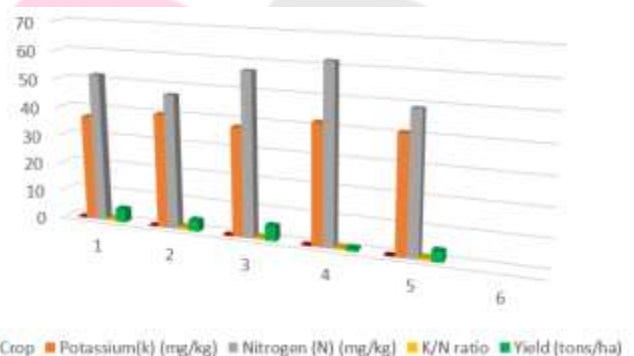


Figure 1. Variable relationship mapping

3.1 Kaggle Datasets

Farming is a very important part of the world economy. The ever-increasing number of people on Earth means that we need to know a lot about global agricultural production in [48] order to deal with

food security problems and lessen the consequences of climate change. It is very important for farmers to be able to predict how much their crops will grow. The main things that affect [49] agricultural production are the weather (like rain and temperature), the use of pesticides, and the availability of accurate historical crop yield data [50]. This data is very important for making smart decisions about managing agricultural risks and making predictions about the future, as shown in figure 2.

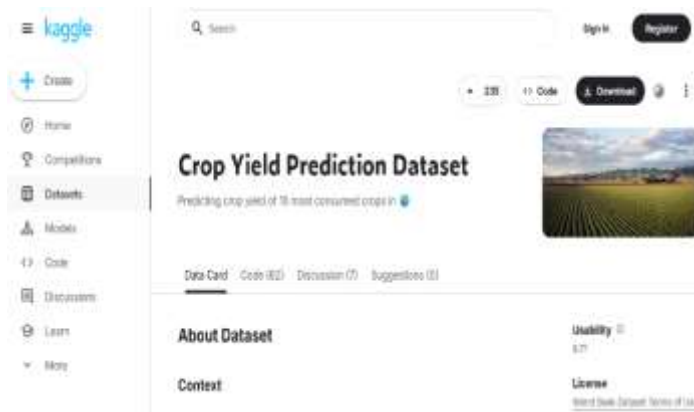


Figure 2. Kaggle Datasets for Crop Yield Prediction

4. The Suggested Model

In modern farming, getting the most out of crops is a complicated process that requires a deep understanding of soil quality, environmental conditions, and the needs of different plants. People used to choose which crops to grow based on their own experience, trial and error, or fundamental information that had been handed down through the years. In Figure 3, ML approaches make it easier to look at large datasets from many different sources. This makes it possible to make more accurate predictions about which crops [51] would grow best in certain types of soil and weather. This strategy not only aims to increase the number of crops that can be harvested, but it also [52] promotes environmentally responsible agricultural practices and the best use of resources.

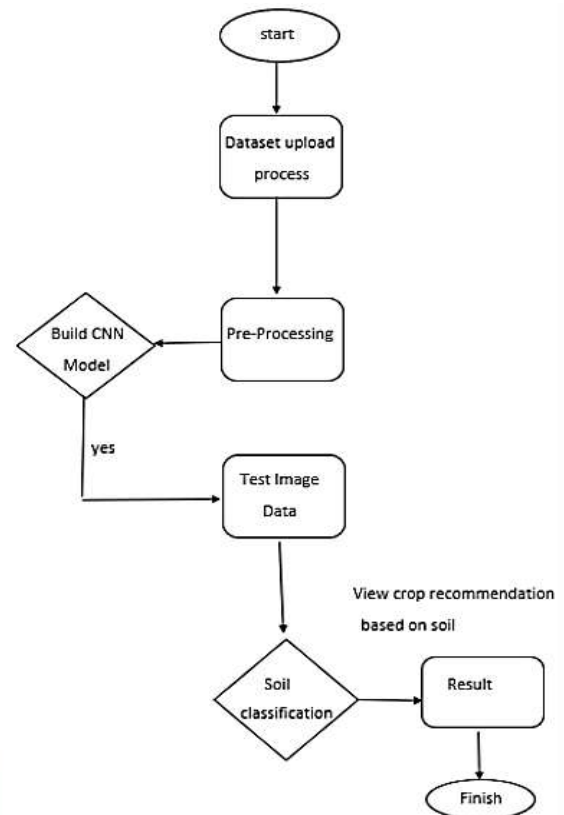


Figure 3. The Soil Evaluation and Crop Selection Methodology

Data from many sources is the most important part of any computer-based learning in agriculture. Soil composition data is the most important dataset needed. Moisture content measures how much water is in the soil. This is important for planning irrigation and figuring out which crops do well in varied moisture levels [53]. Important nutrients for plant development include nitrogen, phosphorus, potassium, calcium, and magnesium. The decomposing plant and animal matter gives the soil important nutrients and makes it stronger.

Along with soil data, you also need to [54] think about environmental parameters like temperature, rainfall, humidity, and changes in the seasons. These things affect how well crops grow, how often they are to become sick, and how much water they need [55]. To develop a good model for crop suggestion, you need historical crop yield data, information about agricultural techniques in the area, and information about the area's geography.

After acquiring raw data, it is important to take the time to prepare it so that it can be evaluated properly. Raw data might include mistakes, missing numbers, or discrepancies. Data points are generally on different scales, which may make it hard for computational learning models to find patterns. By normalizing data within a consistent range, you make

sure that no one characteristic takes over the [56] learning process. Using the Random Forest method, which is great at working with complicated datasets, to tell various types of soil apart. The algorithm learned from 500 soil samples that had already been given certain traits [57]. The result was that soil samples were put into groups like loamy, sandy, and clay-based soil. This helped figure out which crops would grow best in each group. Using a K-Nearest Neighbors framework to suggest crops depending on the kind of land and [58] the weather. The program learned from historical harvest performance records and current soil characteristics to predict which crop would do best in each part of the farm. We are used cross-validation to test the algorithms, [59] using precision indicators like Mean Squared Deviation (MSD) for continuous predictions like yield estimate and classification accuracy for figuring out what kind of soil is there [60]. A confusion matrix was used to assess the accuracy of the soil classification system.

5. Performance Evaluation

We used multiple efficiency metrics, such as accuracy rate, recall rate, and F1-score, to compare different computational learning methods for land appraisal and crop selection. Among the methods tested, Random Forest had the greatest success rate of 93.6%, making it the best at predicting the best crops based on soil parameters. The Support Vector Machine (SVM) model had an accuracy of 90.9%. The K-Nearest Neighbours (KNN) and Decision Tree models had slightly lower accuracy because they were more sensitive to noisy input. Logistic Regression didn't do as well as the others, which shows that it can't handle complicated soils and crop datasets very well [61]. When assessing land, important factors to consider are the acidity level, phosphate content, soil nitrogen, K nutrient level, and carbon content. The results showed that the best pH levels for most crops were between 5.5 and 7.5. Higher nitrogen levels were also helpful. Content (more than 200 mg/kg) had a good effect on crop output [62]. Potassium levels were also shown to be very important for determining how fertile the soil is and how productive farming is overall. Statistical analysis confirmed these findings, demonstrating a robust link between soil comparison and crop adaptability. The crop recommendation [63] system was tested in a variety of soil types, and it was able to properly advise the best crops for each kind of soil. For instance, rice grew best on soils with a lot of nitrogen, between 150 and 250 mg/kg, whereas

wheat grew best in soils that were fairly fertile. Balanced levels of nitrogen and potassium in the soil worked well for crops like maize and soybeans. Cotton, on the other hand, needed soil that was a little bit alkaline. Cross-validation of the model's predictions showed that it was 88% to 94% accurate overall, which further proved that it was reliable. Figure 4 and table 2 shows a chart that compares the performance of Logistic Regression, Decision Tree, KNN, SVM, and Random Forest [64] using four assessment metrics: accuracy (%), precision, recall, and F1-score. The y-axis shows the metrics being tested, while the x-axis goes from 0 to 100 [65]. We can easily observe that random forest has the best accuracy since each color-coded bar shows a distinct model. SVM is next, and Logistic Regression is last.

Table 2: Machine Learning Based Performance Metrics Comparison of Crop Yield Prediction Models

Model	Performance Summary for 80% - 20%			
	Precision	Accuracy	F1-Score	Recall
Decision Tree	85.8%	0.84%	0.85%	0.85%
SVM	90.9%	0.89%	0.90%	0.90%
Random Forest	93.6%	0.92%	0.93%	0.93%
Logistic Regression	81.3%	0.80%	0.81%	0.81%
KNN	87.4%	0.86%	0.87%	0.87%

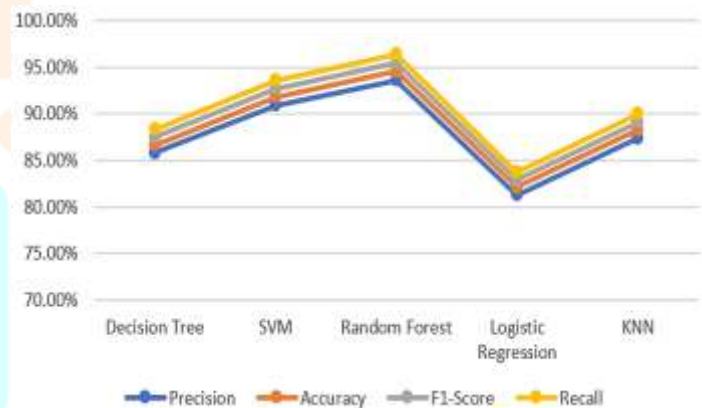


Figure 4. The Various Crop Yield Prediction Machine Learning Models

6. Conclusion

In the last several years, agricultural scientists have been very interested in figuring out how much food crops will produce. It is very crucial for the economy of any country to flourish. So, it's extremely essential for the government to make good economic judgments and for farmers to make excellent decisions so they can properly and rapidly predict crop yields. The soil moisture meter worked 99% of

the time and was more reliable than tensiometers, a few commercial moisture meters, and the conventional oven method. This proves that it is correct and useful for farming with a lot of detail. In general, the research shows that computational learning approaches work well in smart farming, giving farmers the capacity to make data-driven decisions about how to manage their crops. The findings indicate that the amalgamation of soil analysis and machine learning may markedly improve agricultural output, resource efficiency, and sustainability. It offers farmers accurate, up-to-the-minute information on the state of the soil, which helps them make better decisions about how to care for their crops and utilize their resources.

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