JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

IoT-Enabled Decision Support System for Crop Recommendation Using Machine Learning Algorithms

Farheen Siddiqui[1], Shilpi Shukla[2], Dr. Yusuf Perwej[3], Sweta Singh[4], Dr. Nikhat Akhtar[5]

[1] Assistant Professor, Department of Computer Science & Engineering, Shri Ramswaroop Memorial University, Deva Road, Lucknow
[2] Assistant Professor, Department of Computer Science & Information System, Shri Ramswaroop Memorial University, Deva Road, Lucknow
[3] Professor, Department of Computer Science & Engineering, Shri Ramswaroop Memorial University, Deva Road, Lucknow
[4] Assistant Professor, Department of Computer Science & Information System, Shri Ramswaroop Memorial University, Deva Road, Lucknow
[5] Professor, Department of Computer Science & Engineering, Goel Institute of Technology & Management, Lucknow

Abstract: Farmers need to get crop recommendations to boost their production and profits. But conventional approaches for recommending crops sometimes rely on heuristic principles or expert knowledge, which may not be precise or responsive to changing environmental and market circumstances. So, there has to be a data-driven method that can use the knowledge about soil, weather, and crops that is already accessible to provide farmers the best crop options. In this research, we provide a cohesive methodology that employs IoT data and machine learning models to improve precision agriculture. We gathered a large secondary dataset from an internet data source that included environmental factors including temperature, humidity, and soil nutrient levels from several sensors put up in agricultural areas. The data were cleaned up and utilized to develop algorithms that could estimate crop production and provide advice. Our assessment indicates that the Decision Tree, Light GBM, and Random Forest classifiers attained high accuracy rates of 98.2%, 98.3%, and 99.31%, respectively. The IoT data gathering made it possible to monitor things in real time and enter data accurately, which greatly improved the models' performance. The results of this study might help farmers, agronomists, and politicians make better decisions about how to use resources and increase agricultural output by using data-driven insights.

Keywords: Agriculture Data, Crop Recommendation, Machine Learning, Crop Selection, Pre-process, Crop Yield Prediction.

1. Introduction

As the world's population grows, so does the agricultural market. Because agricultural phenology changes every year and crops depend on the weather, soil, and climate, it is hard to control farming operations [1]. Most farmers don't earn the money they want because of these problems. Farmers need help right once with Eco viewpoints on crops. To help farmers make more money, an analysis is needed. Estimating yield is one of the hardest things about farming [2]. Every farmer wants to know more about crop productivity. It is very important to know a lot about the history of crop production while giving advice on farming [3]. In the past, crop production predictions were based on how well the farmer knew the crop. Also, there are a lot of agricultural data, and it takes a long time to look at it all by hand. Producers often used the previous year's crop yields to predict future production. Machine Learning for crop prediction uses a number of different methods [5] or algorithms, and these algorithms can tell how much of a crop will grow. Machine learning is now being used in certain fields to make agricultural production predictions more accurate [6]. Machine learning has made a lot of progress, but it still doesn't work well for data-driven applications [7]. The accuracy of the model depends on how well it represents the data and how good the information is, as well as the input factors in the data that was gathered. The rise in the use of precision farming is largely due to higher yield. Farmers can keep an eye on their fields with amazing precision and efficiency by using technology like GPS, sensors, and drones [8], as well as information analytics [9]. Farmers may promptly find and fix problems like bug infestations, diseases, and nutrient deficiencies by keeping an eye on things all the time. This cuts down on production losses [10]. Better decision-making is feasible at every step of the agricultural cycle, from picking plants and planting them to setting up irrigation and harvest times. This leads to higher yields and better-quality food [11]. Precision farming needs precise projections of how much crops will produce and good resource management, but these jobs are frequently made harder by things like soil quality, temperature, and humidity. Conventional forecasting techniques sometimes neglect the complex interrelations among these factors, resulting in suboptimal agricultural management advice. This work tackles this problem by using IoT-based data collecting with machine learning approaches to improve the accuracy of agricultural production estimates [12].

2. Background

Traditional farming practices sometimes aren't very accurate or efficient, which leads to wasted time and money. For example, using pesticides and fertilizers evenly throughout large fields might lead to too much or too little of these inputs being used, which would harm the environment and cost more money and provide inferior results [13]. Farmers have a hard time making decisions because they don't have easy access to up-to-date and accurate information on market demands, the weather, and the health of the soil [14]. Additionally, all of these problems are made worse by a lack of money and infrastructure, especially in rural areas, which makes it hard for farmers to use the best practices and the latest technologies [15]. Khaki et al. [16] employed deep learning (DL) techniques, including Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), Random Forest (RF), Deep Feedforward Neural Networks (DFNN), and the Least Absolute Shrinkage and Selection Operator (LASSO), to forecast corn and soybean yields in the Corn Belt of the United States. The ensemble model, which used data from 2016 to 2018, has 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, attaining a decrease in RMSE of around 10%. Shahhosseini et al. [18] introduced a hybrid model for predicting maize production that integrates crop modelling and machine learning approaches, achieving a decrease in RMSE by 7 to 20%. Woittiez et al. [19] examined output gaps in oil palm farming, highlighting the need of comprehending contributing aspects to enhance crop management tactics and refine yield projections.

The combined results of these studies help us understand the different machine learning techniques used to estimate agricultural output. This will help continuing research that aims to enhance the accuracy of predictions by applying ensemble learning methods. Oikonomidis et al. [20] suggested a deep learning model to evaluate the efficacy of machine learning algorithms using certain criteria. Their study concentrated on the XGBoost algorithm and other hybrid models that integrated a CNN with additional methodologies, such as DNN, RNN, and LSTM. They used these models using [21] a publicly accessible soybean dataset of 25,345 samples and 395 parameters pertaining to meteorological and edaphic factors. Their results indicate that future developments may integrate XGBoost with deep learning techniques, such as LSTMs or RNNs, especially for jobs requiring sequential data, such predicting agricultural production. The [22] showed how well random forest models work since they can quickly and accurately analyze enormous datasets of agricultural productivity. This is especially important for predicting agricultural output, which needs a lot of data [23]. Random forests are a good example of a data mining method that can find hidden patterns and trends [24] in massive datasets. Data mining reveals insights that enable businesses to make educated choices on forthcoming agricultural trends and circumstances [25]. In this study, Hasan et al. (2023) presented the K-nearest Neighbour Random Forest Ridge Regression (KRR) model. The goal is to provide accurate predictions about how much food will be grown, concentrating on important crops like rice, wheat, and potatoes. This model has outperformed conventional machine learning methods. It also makes it possible to use a recommender system that helps figure out which crops are best for better agricultural planning and production [26]. Boppudi (2024) presents the Deep Ensemble Classifier Integrated Bird Swarm Butterfly Optimization Algorithm (DEC-IBSBOA) model for forecasting agricultural output. The IBS-BOA method is used in this model for sophisticated data pre-processing, feature extraction, and optimum feature selection. The DEC-IBSBOA model is quite accurate, with a low MAE of around 1.0, which is better than any other techniques [27].

Additional research initiatives have used Time Series Forecasting methodologies, namely ARIMA models, to identify seasonal and temporal trends in yield data [28]. These models are designed to predict future yields by looking at past patterns and how they relate to one other throughout time. However, these models are limited by their dependence on stable assumptions and their failure to include several impacting elements concurrently [29]. Nonetheless, the efficacy of these models may vary significantly across different crops and contexts [30]. Studies that use UAV-based multispectral data and several machine learning algorithms to predict yields show that Random Forest is the best model for predicting maize yields and Gaussian Process regression [31] is the best model for predicting wheat and soybean yields. Support Vector Machines (SVM) have shown remarkable efficacy in forecasting broad bean yields, whereas Convolutional Neural Networks (CNN) have exhibited extraordinary precision in predicting rice yields. These differences show that more broad framework approaches might be used to solve yield prediction problems for a wide range of crops and environmental situations. Ensemble learning (EL) [35] improves prediction accuracy by combining many basic models using methods like bagging, boosting, and stacking to take advantage of their strengths. Across several applications [36], these methods have consistently outperformed individual models in terms of generalization performance.

But predicting agricultural yields is hard for a lot of complicated reasons. First of all, the quality of the soil, pests, genotypes [37], the weather, the time of year, and other things all affect crop yields. Second, the process and techniques of yield prediction are time-dependent and full of non-linearity [38]. In agricultural systems, a significant percentage often evades representation via fundamental stepwise computations, especially in contexts where datasets are intricate, partial, or ambiguous. Linear regression, decision trees, and ensemble learning are some of the most common ways that machines make predictions. Linear regression is a straightforward and widely used machine learning technique that predicts the correlation between crop output and other influencing variables by fitting a linear model. Deep learning has been a commonly used technique in agriculture [43] because it can successfully deal with the spatiotemporal dependencies of data and pull out relevant features without the need for human feature engineering [44]. Deep learning uses multi-layer neural networks to learn abstract characteristics from big datasets. These datasets may be supervised, semi-supervised, or unstructured. This method focuses on understanding the relationships between functional qualities and interaction elements, essential for precise crop output predictions [45].

3. Things influencing Crop Yield Prediction

Businesses such as food and agriculture rely heavily on accurate crop yield prediction models to keep up with raw material demands. Forecasting agricultural productivity is crucial, but studies examining advanced machine-learning algorithms [46] that may provide reliable forecasts are few. Proactively predicting agricultural production requires sophisticated models to account for a rising population and shifting consumer habits. Agriculturalists sometimes have difficulties in accurately and quickly forecasting crop yields because of the impact of several interconnected elements, including weather, soil, crop type, fertilizer use [47], and pesticide use. The key to solving this challenge is getting a grasp on the agricultural production cycle of crops. Unfortunately, perfect crop growth is now impeded by climatic instability. Machine learning models are able to provide timely and precise information because of the use of information technology, which is the foundation of other technologies such as data mining. Thanks to data mining and machine learning models, which are essential for forecasting crop yields, technological progress has greatly enhanced agriculture [48]. Accurate forecasts of agricultural production cannot be achieved using conventional methods. An important problem in agriculture is producing accurate predictions of crop yields, which affect decisions on a global, regional, and even per-crop basis. There are limits to the current methods' ability to achieve high accuracy when utilizing varied data sources and traditional machine learning models [49]. To improve yield estimates and guide agricultural management techniques, it is important to have a well-developed predictive framework that can incorporate many models. The goal of this research is to create an AI model that can reliably foretell crop yields. Several agricultural characteristics will be included in a complete dataset to achieve this. In order to measure crop yields, the suggested technique makes use of Kaggle datasets and open-source data.

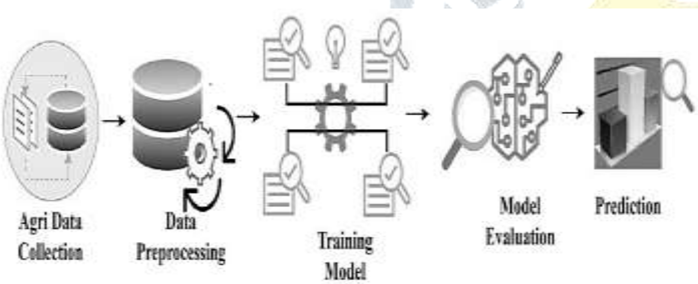

Figure 1. Factors responsible for Crop Yield Prediction

3.1 Kaggle Datasets

Farming is essential to the global economy. The persistent growth of the human population necessitates a comprehensive knowledge of global agricultural output to tackle food security issues and mitigate the effects of climate change. Predicting crop productivity is a vital agricultural issue. Agricultural production is chiefly influenced by meteorological conditions (such as precipitation and temperature), pesticide application, and the availability of precise historical crop yield data [50], which is crucial for informed decision-making in agricultural risk management and future forecasting, as depicted in figure 2.

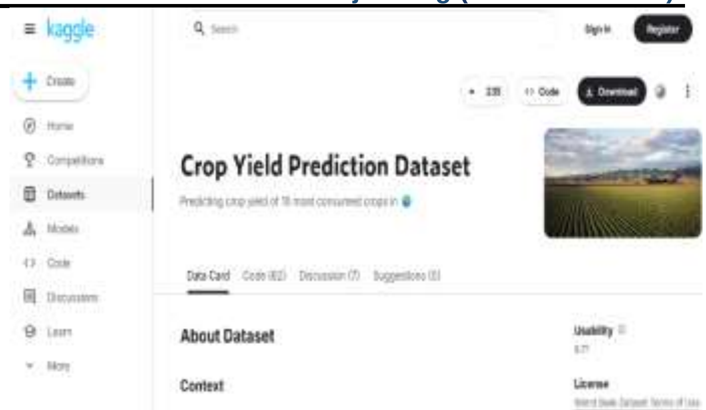

Figure 2. Kaggle Datasets for Crop Yield Prediction

4. The Suggested Model

The system design includes preprocessing and analyzing agricultural data to figure out what crops would grow best and how much they would generate. It uses machine learning methods including Light-GBM, Random Forest, decision tree classifier, and logistic regression to effectively sort crop labels [51]. It uses IoT and machine learning to provide production predictions and crop suggestions depending on the weather, with the goal of getting the most out of farming. Data preparation, exploratory data analysis, classification modeling, and output assessment [52] are all part of the process. Figure 3 shows the whole process. Figure 2 has two basic parts: hardware and software. The gear has a microprocessor and sensors that check the amounts of nutrients in the soil. The sensors send these data to the microcontroller, which then sends them to Firebase, which finally sends them to the Android app.

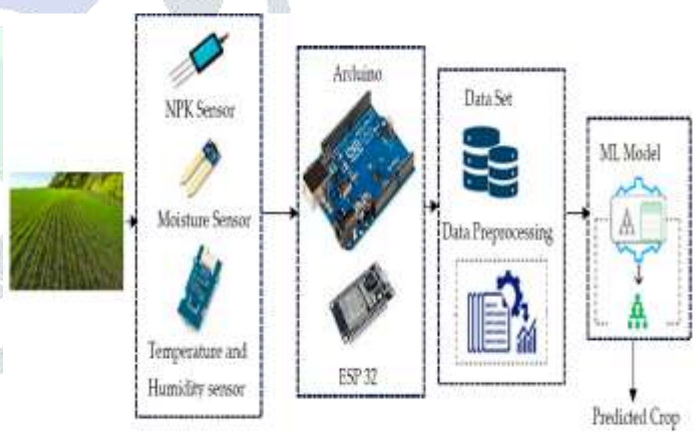

Figure 3. The IoT-Based Model for Crop Yield Prediction

The subsequent Kaggle dataset was taken from online storage sites. The dataset includes labels for [53] various types of crops as well as other information like temperature, moisture, p-H, NPK, and rainfall. The work builds machine learning models, mostly using Light GBM (Light Gradient Boosting Machine), to guess crop labels based on the attributes that were given after pre-processing and EDA. The models are quite accurate, which illustrates how valuable they are for things like suggesting crops and predicting yields. The study includes visuals including correlation matrices, bar charts, and scatter plots [54] to help further evaluate the Kaggle data and model performance. The paper introduces a comprehensive technique that utilizes IoT data and ML algorithms to efficiently suggest crops and predict agricultural output. The Modbus protocol, which is open-source and free to use, is used to talk to Arduino. Modbus TCP lets you send data across Ethernet TCP/IP networks and RS-485, RS-422, and RS-232 interfaces. To confirm the precision and dependability of the soil moisture meter [55] used in this work, it was compared with other recognized moisture measurement methods. Soil moisture meters are instruments that are put at different depths in the soil to check how wet it is [56]. These meters keep track of changes in the moisture content of the soil to see how much water is accessible to plants. We can learn more about how moisture is spread throughout the root zone by putting meters at various depths. This information is very important for making irrigation plans that work best and making sure that plants get the proper quantity of water to flourish.

5. Performance Evaluation

We ensured sure that our machine learning models would operate effectively in real-world farming situations by carefully checking how well they worked throughout testing and outcomes review. We split our dataset into training and testing sets using techniques like cross-validation. This made it possible to test the models in a reliable way. We used accuracy, precision, recall, and F1-scores to see how well the models could accurately identify and predict agricultural outcomes. We made sure that the models and evaluation methodologies we employ were ready to be used in real-life farming situations by making them better over and over again. For efficient crop management and production development, it is important to have accurate and reliable predictions. The assessment of several machine learning methods indicates promising results for yield prediction and crop recommendation [57]. The Light-GBM-Classifier, Decision-Tree-Classifier, and Random-Forest-Classifier are all able to choose the best crops with high accuracy scores over 98% and precision, recall, and F1-scores that stay around 99%. These models help with precision farming and getting the most out of resources by giving reliable advice on what crops to plant and how much output to anticipate. The Logistic-Regression model is a valuable tool for recommending crops and predicting yields when computational resources are limited. This is because it maintains a good level of precision, whereas the other measures above measure performance even when they are not as accurate. These findings show how machine learning can help farmers do their jobs better and produce food in a way that doesn't harm the environment.

Table 1: Machine Learning Based Performance Metrics Comparison of Crop Yield Prediction Models

Model	Performance Summary for 80% - 20%			
	Precision	Accuracy	F1-Score	Recall
Decision Tree	98.6%	98.2%	98.8%	97.8%
Light GBM	98.4%	98.3%	98.6%	98.76%
Random Forest	99%	99.31%	99%	99%
Logistic Regression	93.9%	93.75%	93.4%	94.85%

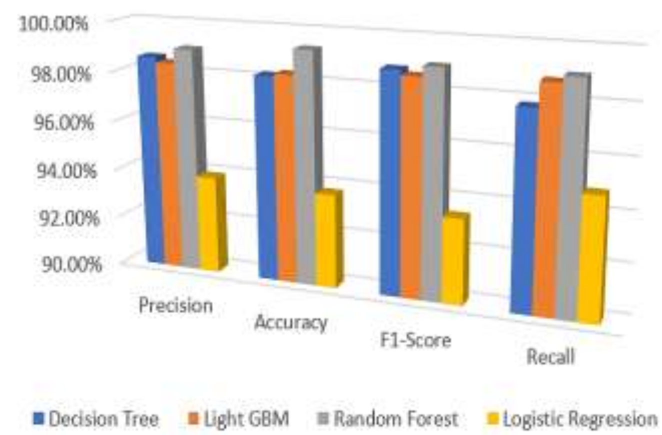

Figure 4. The Various Crop Yield Prediction Machine Learning Models

The findings from the IoT-based [58] soil monitoring system illustrate its considerable potential in advancing precision agricultural methodologies. The technology gives useful information that might help crops grow better and make better use of resources by letting you keep an eye on important soil factors all the time [59]. This sensitivity is essential for implementing informed modifications in agricultural practices to improve overall output [60]. It is also crucial to think about how the system may be used in various types of farms and how it can be changed to fit those needs. The model has performed well in the investigated settings [61], but it has to be tested in other places with different soil types and weather conditions [62]. To make sure that the system works well in a range of agricultural settings,

6. Conclusion

In the past few years, predicting crop yields has been a hot topic in agricultural science research. It is highly important for the economic growth of any nation. So, being able to accurately and quickly anticipate crop yields is very important for the government to make good economic policies and for farmers to make good decisions. The soil moisture meter worked 99% of the time and was dependable when compared to tensiometers, several commercial moisture meters, and the usual oven technique. This shows that it is accurate and good for precision agriculture. The Light-GBM-Classifier, Decision-Tree-Classifier, and Random-Forest-Classifier machine learning models had accuracy rates of about 98%. The Logistic Regression model, on the other hand, was a little less accurate but is still useful when there aren't many computing resources available. In conclusion, the IoT-based soil monitoring system is a big step forward for precision agriculture. It gives farmers real-time, precise information on soil conditions, which helps them make better choices about how to manage their crops and use their resources.

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