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Comprehensive Analysis of Artificial Intelligence based Crop Recommendation and Soil Analysis

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***Abstract*—In recent years, crop recommendation has become a significant research area that utilizes environmental characteristics of humidity, temperature, soil Potential of Hydrogen (pH) and rainfall to determine the appropriate crops for production. The prediction of crop yields is a difficult task that depends on weather, soil conditions, crop-specific variations, and environmental factors. The automated crop recommendation approach is essential in helping farmers make prior knowledgeable decisions regarding production and crop cultivation. In this survey, machine learning (ML) and deep learning (DL) algorithms are analyzed for soil analysis and crop recommendations. The performance of the existing methods is estimated based on various performance measures such as accuracy, recall, f1-score, precision, sensitivity, kappa, area under curve (AUC), (RMSE), mean absolute percentage error (MAPE), mean square error (MSE) and mean percentage error (MPE). This survey concludes that various soil analysis and crop recommendation approaches overcome drawbacks such as high time consumption and inaccurate crop outcomes.**

Keywords—Agriculture, Crop Recommendation, Deep Learning, Machine Learning, Soil Analysis

I. INTRODUCTION

The agricultural industry plays an important role in the economic development of the country due to the quality of soil required for the large-scale cultivation process. Smart devices such as planning tools, analysis machines and production control mechanisms are perfect for ensuring delicate organic soil, plant nutrition and water quality [1]. Agriculture is not only significant in importance from an economic point of view, but also is a key driver of food and raw materials supply for industries [2]. Many small-scale farmers are still unaware of soil health which is the most important factor for growing good crops and improving profitable yields [3]. Land is fundamental in farming as it supplies the most important parameters such as fertility of the soil, crop production estimate, available nutrients, recommended crops, and many other crucial factors. It is useful for all farmers to select suitable crops to grow on their land; also, the farmer should know which crop facilitates growth and avoid unexpected situations after sowing the seeds [4]. Plant growth is determined by important elements such as macronutrients, micronutrients, and minerals such as zinc, iron, manganese, and magnesium. Also, factors like pH value, water content, temperature, electrical conductivity, and organic carbon are important. Plant growth is affected by external factors, for instance, climatic conditions [5].

Agriculture is a leading part of urban life and is progressing at a rapid pace, but most of the losses in agriculture happen due to the selection of wrong crops in the available soil. Also, the integration of agricultural sensors, IoT, ML, and DL in smart and accurate agriculture is increasing significantly [6]. An artificial intelligence algorithm using soil parameters in data accurately estimates fertility rates, provides crop recommendations, and optimizes nutrition in a focused and economical way [7]. Thus, it helps the farmers to make wise decisions about soil management and crop selection, and the best results are recognized. Machine learning (ML) and deep learning (DL) algorithms are often used for prediction in recent times due to the various advantages and facilities they offer [8]. ML approach recommends the appropriate crops by using various mathematical or statistical methods, alongside directing farmers on the most appropriate crops to grow in a particular region to aid in maximizing the profits [9]. DL algorithms were referred to as machine learning algorithms that could predict the outcome for the values of preset parameters without requiring direct human involvement. This type of model must be trained with soil and with weather data first in order for it to make successful predictions about better crop yields [10].

This survey paper is discussed as follows: a literature survey on soil analysis and crop recommendation is given in Section 2. A taxonomy of soil analysis and crop recommendation is presented in Section 3. A comparative analysis of various approaches is discussed in Section 4, while Section 5 presents the problem statement and the conclusion of this paper is given in Section 6.

II. RELATED WORKS

The various existing techniques are analyzed for evaluation of the soil and recommendation of crops during selection. However, some existing approaches face issues in analyzing the soil and recommending the crops. In this section, the related works about soil analysis and recommendations for crops are described along with their benefits and limitations.

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Escorcia-Gutierrez et al. [11] developed the intelligent agricultural modeling of soil nutrients and pH classification using ensemble DL approaches. An intelligent technique with soil nutrients and classification of pH with weighted voting ensemble deep learning (ISNpHC-WVE) was accordingly designed. The ISNpHCWNE approach was designed to assess and analyze soil nutrients, alongside analyzing the pH levels. Moreover, DBN, BiLSTM, and GRU methods for 3 DL approaches were used for a predictive analysis. Furthermore, the WVE model approach was utilized; whereas, a WV was assigned to each DL model of ensemble layer dependent on achieved accuracy in each class. Yet, the developed approach was required to utilize the hybrid metaheuristic optimizers with feature selection procedure for precisely selecting the relevant features and enhancing the model's performance.

Vidhya et al. [12] presented the agricultural farm production approach for recommendations of smart crop yield using ML techniques. The k-nearest neighbor (KNN) technique was used to identify the best crops under various conditions for helping the farmers in the optimal cultivation. This analysis was integrated into an interactive web interface that enabled users to input average rainfall amounts and soil pH values using the KNN algorithm. By applying IoT devices and web application, the presented system benefited a large number of farmers and provided smart irrigation. However, this approach was required to enhance the crop recommendation as it considered the less climatic and soil parameters.

Kiruthika and Karthika [13] developed an IoT based professional crop recommendation system using a weight based long-term memory approach. This research developed a novel approach as Improved Distribution-based Chicken Swarm Optimization with Weight-based Long Short-Term Memory (IDCSO-WLSTM) for crop predictions. It was also utilized for enhancing the recommendation of crops with the aid of IoT approaches. Pre-processing and selection attributions were performed over IDCSO, while crop prediction was performed by WLSTM. Next, pre-processing methods were used in this approach to improve the quality of the input. As a result, the ITCSO-WLSTM method achieved higher crop prediction accuracy due to the careful selection of climatic parameters, but the developed approach was more time-consuming.

Sheeba et al. [14] presented the ML algorithm for soil analysis and classification of micronutrients in IoT-enabled automated farms. A fast learning classification technique was used in training the model using data to classify micronutrients in soil as per use of extreme learning method. The type of soil is determined based on the carried out analysis of nutrients and the conditions for planting are recommended for the regions considered. The use of this methodology was helpful in developing soil fertility maps, and to also assess fertility of other similar nutrients. However, due to the analysis, to diagnose the soil parameters in agroecological regions, the presented approach had to involve.

Hasan et al. [15] suggested the recommendation system based on ensemble ML for the effectual production of appropriate agriculture crop cultivation. First, the data was collected and prepared from the research organizations of Bangladesh and then the K-nearest Neighbor Random Forest Ridge Regression (KRR) model was built. Supporting this, KRR was developed after a study on five baseline traditional machine learning models that includes Support Vector Regression, Naïve Bayes, and Ridge Regression, and ensemble learning comprising of Random Forest and CatBoost. It also offered a DM test to prove that the current framework surpassed all the available ML approaches. However, some factors like variation of the soil properties, production cost and the market price were not taken into consideration hence collecting the data was a very tedious affair.

III. Taxonomy of Soil Analysis and Crop Recommendations

In this section, a taxonomy is performed for soil analysis and recommendation of crops by analyzing the ML and DL algorithms. Therefore, soil testing acts as an advisory tool for farmers to enable them to make proper decisions about fertilization, irrigation, and soil management, further helping to increase agricultural productivity, as well as reduce the input costs. Figure 1 illustrates the taxonomy diagram of soil analysis and recommendation of crops.

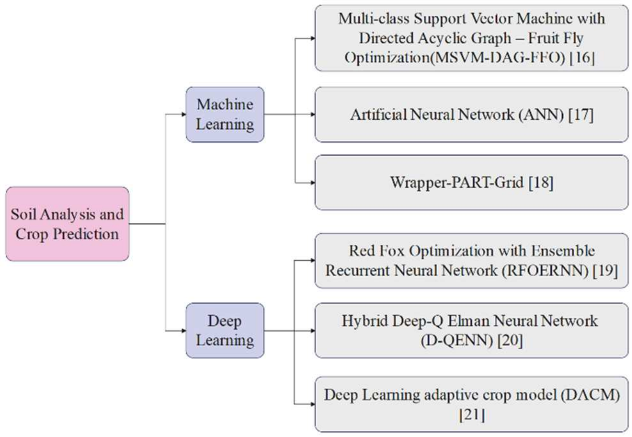

Fig. 1. Taxonomy Diagram of soil analysis and crop recommendation

A. *Machine Learning*

Various ML techniques are considered for soil analysis and crop recommendations, and their brief descriptions are presented in this section. The various ML techniques such as Multi-Class Support Vector Machine - Directed Acyclic Graph and Fruit Fly Optimization (MSVM-DAG-FFO), Artificial Neural Network (ANN), Wrapper-PART-Grid are discussed below.

1) Multi-Class Support Vector Machine - Directed Acyclic Graph and Fruit Fly Optimization: Senapathy et al. [16] developed the soil nutrient analysis and crop recommendation based on IoT (IoTSNA-CR) for precision agriculture. This approach was developed through hybrid algorithms as MSVM-DAG-FFO approach, the kernel function of MSVM model should be optimally selected by utilization of FFO technique. For the purpose of performing an overall benchmark experimental evaluation of IoTSNA-CR model, the benchmark dataset was employed. As a result of the developed methodology MSVM-DAG-FFO algorithm the farmers were enabled to use the presented preprocessed soil data and it was developed to access the cloud data to analyze that which crop is more suitable for cultivation.

2) Artificial Neural Network: Indiramma and Indiramma [17] presented an integrated crop recommendation system based on an artificial neural network (ANN) by utilizing the

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soil and climate parameters. Recommendations covering the soil characteristics, crop characteristics and climatic conditions mainly contain valuable information required for this analysis. This research mainly focused on maize, sugarcane, finger millet and rice for the analysis. This framework recommends crop selection based on the ease of cultivation, climatic suitability and genetic characteristics of the crop. This approach not only solves the problem of farmers deciding the most appropriate crop during the cropping season, but also helps them save and reduce the wastage of resources.

3) Wrapper-PART-Grid: Garg and Alam [18] suggested an efficient crop recommendation technique by utilizing ML approaches such as the Wrapper-PART-Grid technique. This research considers the utilization of an ML classification approach that employs soil nutrient data for recommending the appropriate effective crops. Wrapper-PART-Grid technique provides the best suitable crops by the integration of crop recommendation data. This hybrid approach integrates the grid-search technique (GS) for parameter tuning, the wrapper feature elimination technique, and the partial C4.5 trees (PART) classifier for crop suggestions. The suggested Wrapper-PART-Grid approach was aimed at aiding the farmers in becoming familiar with cultivating suitable crops. This approach not only tried to diminish the entire wastage, but also aimed to augment the crop yield along with enhancing the crop quality.

B. Deep Learning

The various DL techniques are analyzed in the analysis of soil and crop recommendation, also those brief explanations are defined in this section. The various DL techniques as red fox optimization with ensemble recurrent neural network (RFOERNN), Hybrid Deep-Q Elman Neural Network and Deep Learning Adaptive Crop Model are discussed below.

1) Red Fox Optimization with Ensemble Recurrent Neural Network: Gopi and Karthikeyan [19] introduced the red fox optimization with an ensemble recurrent neural network for crop recommendation and yield prediction model (RFOERNN-CRYP). RFOERNN-CRYP utilizes ensemble learning to integrate three various DL approaches namely, gated recurrent unit (GRU), long short-term memory (LSTM), and bidirectional LSTM (BiLSTM). It is utilized for accomplishing an enhanced performance of prediction in contrast with other approaches in terms of predictive accuracy. Furthermore, the RFO approach was effective for hyperparameter selection of these three DL models which enhances the overall performances. The analysis outcomes exhibit that the developed approach surpasses various recent techniques that regard the numerous measures. The developed RFOERNN-CRYP approach aids farmers in the decision-making procedure by utilizing various agriculture parameters.

2) Hybrid Deep-Q Elman Neural Network: Shingade and Mudhalwadkar [20] implemented the hybrid deep-Q Elman Neural Network (DQENN) based on the environmental variations. The Q-learning and Elman Neural Network (ENN) were integrated to aid the exact mapping of raw data to the prediction values. The integrated approach utilized the Q-learning and ENN that trained with input parameters selected by enhanced Archimedes optimization algorithm from the dataset. The model performances are assessed based on datasets that are constructed by utilizing the samples of data attained over the utilization of sensors in various regions of Maharashtra. The developed AI-integrated self-learning approach enhanced the prediction procedure by identifying suitable crops based on the input parameters.

3) Deep Learning Adaptive Crop Model: Zhu et al. [21] developed the DL crop model for adaptive yield evaluation in large regions. This research presented a novel DL adaptive crop model (DACM) which enabled high-precision yield evaluation through large regions. This approach was focused on adaptively learning the spatial heterogeneity of crop development by the extraction of the entire crop production data. An analysis of the focus values and estimation stability exhibited that the DACM effectively captured the spatial variability of crop growth, and used adaptive approaches to improve yield prediction accuracy. DACM balanced the stability and interpretability of performance and also provided the analysis for evaluating the crop yield across broad regions by dynamically learning spatial heterogeneity patterns of crop growth.

IV. Comparative Analysis

The soil analysis and crop recommendation are evaluated for the existing models to enhance the performance of the model. The comparative analysis is significant in the development and effective enhancement of the model's performance. The comparative analysis comprises the employed methodology, advantages, limitations, and performance measures. Table 1 displays the comparative analysis of the existing approaches.

TABLE I. COMPARATIVE ANALYSIS OF EXISTING APPROACHES

Author	Methodology Employed	Advantage	Limitation	Performance Measure
Senapaty et al. [16]	The soil nutrient analysis and crop recommendation based on IoT (IoTSNA-CR) for precision agriculture.	This approach helped farmers determine the right crops for harvesting, in accordance to the conditions of the local environment.	The extensive analysis of crop fields and real-time data acquisition were required from various geographical locations for accomplishing a precise crop recommendation under the government's control of the agriculture department.	Recall, Accuracy, F1, Precision
Madhuri and Indiramma [17]	An integrated system of crop recommendation based on ANN by utilizing soil along with climatic parameters.	A well-trained ANN is utilized for location-specific soil data along with historical weather data-based recommendations of the appropriate crops.	This approach was required to use various soil samples from numerous regions for generalizing the model. Because this approach cannot be generalized with various soil types, it was only tested with a single region in India.	Accuracy, MSE

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Garg and Alam [18]	The efficient crop recommendation approaches by utilizing ML algorithms	This approach considered various parameters and criteria to reduce impurity and also enhanced the accuracy of crop recommendations	This approach was required to apply the clustering technique in classifiers to enhance the precision and accuracy of crop classification.	Accuracy, Precision, Recall, F1-score, MAE, RMSE
Gopi and Karthikeyan [19]	Ensemble Recurrent Neural Network based on Red Fox Optimization for recommendation of crops and yield forecasting	The RFOERNN-CRYP approach aids farmers in decision-making procedure by utilizing various agricultural parameters.	This approach was required to be tested on real-time large-scale datasets for analyzing the performance so as to provide suitable crop recommendations.	Accuracy, Precision, Recall, Specificity, PR-Score, ROC-score, F1 and MCC
Shingade and Mudhalwadkar [20]	Environmental variations based hybrid deep-Q Elman neural network for predicting and recommending the crops.	The developed AI integrated self-learning approach enhanced the forecasting procedure by identifying relevant crops based on input parametric values.	This approach needs to consider a more reliable model for enhancing the performance as it considers lesser parameters for crop recommendation.	Precision, Recall, F1-score, Kappa, Accuracy, AUC
Zhu et al. [21]	The DL crop model for adaptive yield analysis in larger region	This approach enhances the yield assessment's accuracy in large regions with DACM by adaptively learning the crop growth's spatial heterogeneous patterns.	For regional divisions in large regions, this approach makes it difficult to obtain precise knowledge, while its segmentation disconnects intrinsic correlations among regions.	RMSE, R2, MAPE, MPE

V. Problem Statements

- The existing approach was required to enhance the data quality and accessibility for accurate crop recommendations in soil because of inadequate or noisy data that affected the suboptimal outcomes.
- Soil properties significantly varied even within small geographical areas and it was challenging to create a one-size-fits-all recommendation system due to this diversity.
- Due to high computational resources, small-scale farmers with limited resources adopted the recommendations of crops based on DL approaches.
- The existing approaches are required to expand the dataset to include a broader geographical area, which considers the diverse agricultural situations discovered in various regions for enhancing the system's robustness.

VI. Conclusion

There are many factors or parameters in soil, whereby suitable structures are required for optimal plant growth. The crop recommendation is a feasible research that utilizes environmental characteristics to determine the appropriate crops for production. The taxonomy of various methods is discussed for soil analysis and recommendation of crops. The performance metrics such as accuracy, AUC, recall, f1-score, RMSE, precision, sensitivity, MAPE, kappa, MSE, and MPE are analyzed in this taxonomy. Moreover, this paper discusses the advantages and drawbacks in a survey pattern, further aiding to create some improved methodologies by overcoming the drawbacks. This survey concludes that various soil analysis and crop recommendation approaches overcome deficiencies. There is an option to combine techniques to create an ensemble technique for improving the crop quality.

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