Intelligent Farming based on Uncertainty Expert System with Butterfly Optimization Algorithm for Crop Recommendation

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Abstract

Meeting the current population's food demands has become challenging, given the rising population, frequent climate fluctuations, and limited resources. Smart farming, also known as precision agriculture, has emerged as an advanced approach to tackle modern challenges in crop production. At the heart of this cutting-edge technology is machine learning, serving as the driving force behind its implementation. Though, there are many algorithms are available in crop prediction process, the problem of predicting vague information is still a challenging issue. Unfortunately, existing algorithms mostly avoids the complicated instances in crop recommendation dataset by not handling them effectively, due to imbalance class distribution. Hence in this research work to conduct an intelligent farming, two different uncertain theories are adopted to handle the issue of vagueness in appropriate recommendation of crop by considering soil fertility and climatic condition. The proposed is developed based on uncertainty expert system with both neutrosophicalparaconsistent inference model. The neutrosophic inference model is integrated with the paraconsistent logic to overcome the problem of uncertainty in prediction of appropriate crop by representing the factors in terms of certainty degree and contradiction degree. The rule generated by paraconsistent model is validated to improve the accuracy of crop prediction by fusing the knowledge of butterfly optimization algorithm. The nectar searching behavior of the butterflies are used for searching potential rules as a validation process. With the pruned rules generated by uncertainty expert model, the suitable crop is predicted more accurately compared to the other existing prediction models.

Keywords: Smart Farming, Crop Recommendation, Uncertainty Expert System, Paraconsistent Logic, Neutrosophic Logic, Butterfly Optimization Algorithm.

1 Introduction

Approximately two-thirds of the workforce on the continent is engaged in the agricultural sector, exerting a substantial influence on the economies of Asian nations (Wolfert, S., 2017). The data suggest that among the challenges in precision agriculture, predicting crop production stands out as one of the most formidable. Given the evolving environmental conditions, the future of agriculture may face considerable challenges, particularly because of global warming and climate variability (Bronson, K., 2019). Nowadays, digital agriculture is referred to as Agtech and precision farming. It represents a novel

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scientific field leveraging data-intensive methods to enhance agricultural productivity while concurrently minimizing its environmental footprint (Banavlikar, T., 2018). The field of agriculture information technology has undergone recent advancements, and it becomes an interesting and important research topic for crop production prediction. A significant issue that has not yet been resolved with the data at hand is the yield forecast problem (Motwani, A., 2022). The more advantageous options for precise agriculture are deploying data mining techniques (Venugopal, A., 2021). In order to forecast agricultural production for the following year, various data mining approaches are employed and assessed.

Big Data and machine learning are becoming increasingly common in many environmental fields, including weather forecasting and management, disaster preparedness, energy and smart water management systems, remote sensing are the contribution of advancements in high-resolution remote sensing techniques accompanied by communication technologies and social media (Pudumalar, S., 2017).

Though, many existing machine learning, deep learning and mining algorithms are developed for crop yield prediction, the problem of uncertainty handling is still in existence. Hence in this paper, the problem due to vague and inconsistent data of agriculture dataset for crop recommendation based on the soil fertility, climatic condition and nutrient availability are handled by developing an intelligent uncertainty expert system with behavioral algorithm. The detailed explanation is discussed in the following subsections.

2 Related Work

Gaadiet al (2016) developed a prediction model by applying normalized difference and soil adjusted vegetation index for potato tuber crop production. In this work satellite images of potato during its growing stage and performs zone wise classification.

Kalimuthu et al (2020) designed machine learning algorithm for crop prediction by collecting data of seeds. The android application is developed to collect the information of climatic and soil condition to predict the growth rate of crops. Naïve Bayes classifier is used to detect the type of crops to be suggested.

Rao et al (2022) performs detailed comparative analysis of three different classification models namely Decision Tree, K-Nearest Neighbor and Random Forest Classifier for crop prediction. Each algorithm is evaluated using Gini and entropy method. Random Forest achieves better result in crop prediction.

Madhuri et al (2022) devised a novel recommendation model to predict the suitable crop and required fertilizers to assist the farmers in harvesting. This work integrated k-means clustering and random forest algorithm. The fertilizes and crop suitability is predicted based on the ontology-based recommendation model.

Chougule et al (2019) designed voting-based recommendation model which uses characteristic and types of soil and crop yield as parameters. To perform precise agriculture, different ensemble algorithms are used. The ground truth parameters of statistics are used to analyse the suitable crop for harvesting.

Dasari et al (2019) conducted a detailed survey of machine learning algorithms usage in agriculture. Both classification and clustering algorithms-based crop prediction works are reviewed in this work. The necessity of datamining in the field of agriculture is also discussed.

Suraparaju et al (2011) presented pattern matching algorithm for effective crop prediction which utilizes historical data. They used Xarray functions datasets to retrieve the crop based on season and region. This system assists the farmers to choose appropriate crop for production.

Anjana et al (2021) designed a naturel language processing method known as chatbot for helping farmers to desirable farming. To detect appropriate crops, in this work geographical characteristics, conditions of soil and climate is considered. The audio-based input queries related to agriculture context is used in this work and the appropriate suggestion is forwarded to the concern person to assist them in crop production.

Sawant et al (2019) developed a recommendation model to tackle the issues in agriculture related requirements such as water, soil, fertilizer and crop prediction. The data mining algorithms are used for analysing the fluctuation climatic condition, soil fertility and rotation and water requirement.

Vijayakumar et al (2020) developed a RESENT based convolutional neural network for predict mellowness in dragon fruit. The images of the dragon fruit are used for analysing mellowness at its various stages. The VGG16/19 model is used for training and testing the dragon fruit image dataset. The deep learning model works better and produce more accuracy compared to other conventional classification models.

3 Problem Statement

With assistance of prediction model smart agriculture farming method has become an important research work (Angin, P., 2020). There are many existing research works are available related to the agriculture crop prediction, still the knowledge about the pattern of climatic parameters and soil fertility parameters are not well-defined in decision making about type of crop production which consequences to uncertainty. Hence, in this research work an innovative uncertainty expert system is developed by adapting the uncertainty theories neutron-paraconsistent logic. The certainty and contradictory degrees play a major role in generation of classification rules which suggest the type of crop that can be recommended for the particular land and climatic condition. The rules generated by uncertainty rule generation is validated by adopting the butterfly optimization algorithm. The detailed description about the proposed algorithm which involves in crop recommendation is discussed in the following sections.

Methodology: Uncertainty Expert System with Butterfly Optimization for Crop Recommendation

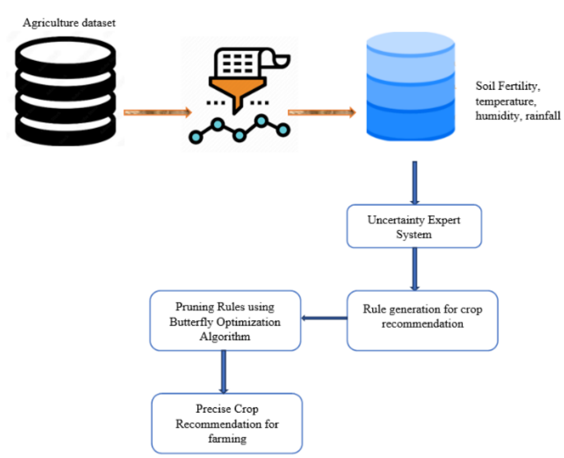


Figure 1: Overall Workflow of Intelligent Uncertainty Expert System with Butterfly Optimization for Crop Recommendation

This proposed work focuses on developing intelligent uncertainty expert system with butterfly optimization algorithm for crop recommendation based on the soil fertility and weather condition as depicted in figure 1. The dataset used in this work is collected from Kaggle repository (crop-recommendation-dataset) total number of instances in the dataset are 2200 with 7 attributes and a class variable. The data is preprocessed to maintain all the attributes values to be in same range. The preprocessed dataset is fed as input to the Uncertain Expert System (UES), the inference model of UES involves in analysing the pattern of input data and the rules are generated based on the values. The rules generated by UES is in the format of If…Then else and its consequence outputs the type of crop that is suitable for cultivation. The rules generated by the UES is validated by adopting the behavioral based artificial intelligence known as Butterfly Optimization Algorithm (BOA). The food source searching behavior of butterflies is used in BOA by computing the influence of each rule in improving the accurate rate of predicting suitable crop. The experimental section discussed in detail about the performance of the proposed UES-BOA model in predicting crop suggestion compared to the existing algorithms.

Dataset Description and Preprocessing

The crop recommendation dataset used in this work is collected from Kaggle Repository which augments fertilizer data, rainfall and climate data of India. The dataset comprised of 2200 instances with 7 attributes. The attributes are nitrogen ratio, potassium ratio and phosphorus ratio in content of soil, temperature, relative humidity, ph value of the soil and rainfall. Along with these attributes one dependent variable named as label is presented. The data normalization is done to convert attributes with different range of values to uniform by applying min-max normalization.

$$\mathrm{Inst_i}(\mathrm{att}_j) = \frac{\mathrm{att}_j - \min\,(\mathrm{att}_{k=1\ldots n})}{\max\,(\mathrm{att}_{k=1\ldots n}) - min\,(\mathrm{att}_{k=1\ldots n})}$$

Uncertainty Theory using Paraconsistent Logic

The premise of non-contradiction is suppressed by the paraconsistent logic (Decker, H., 2005) (de Carvalho, A., 2021), which also permits the theoretical processing of contradictory signals. It is created using proportionate formulas, also referred to as annotations; aech element is symbolized by a value attributed to a corresponding attribute in the proportional formula. This representation captures each input to different extents, particularly the Favorable degree of Evidence (γ') and Unfavorable degree of Evidence (τ'). In the presented approach, the degree of certainty (DCR) and the Degree of contradiction (DCT) are derived through Neutrosophication, and their values are confined within the range of +1 and -1.

The classifier creates a substantial set of rules when building the neutrosophic expert system, and it becomes laborious to execute all of those rules in their entirety without providing sufficient support for them. The introduction of a degree of confidence and the paraconsistent analysis are likely methods used in the field of artificial intelligence to manage the confirmation of truth or falsehood components in the presence of uncertainty.

Most of an obvious logic's characteristics are appropriate for ambiguous knowledge. Since the assumptions are measured to create the study, the arguments are well-balanced to argue that the features establish only a small number of indicators. The ensuing cases illustrate the crucial importance of paraconsistent logic.

Uncertainty Expert System for Predicting Precise Crop Farming

In this proposed work the uncertainty expert system is designed using Neutrosophic (Basha, S.H., 2019) inference system and paraconsistent logic. The neutrosophic model comprises a Neutrosophication Interface, which takes the crisp input of the crop recommendation dataset and assigns the relevant membership grades of truth, indeterminacy, and falsity. The neutrosophic Inference Engine then maps the input to the output variable, and the Deneutrosophication Interface transforms the neutrosophic value into a crisp value, as illustrated in Figure 2.

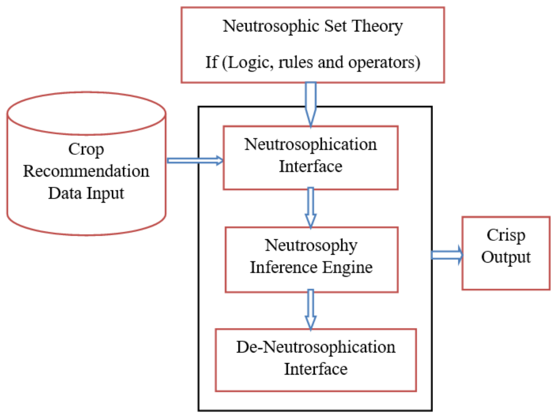


Figure 2: Functionality of Neutrosophic Rule Generation

Neutrosophic Rule Generation

In neutrosophic logic each instance is represented in terms of membership based on its truth factor (TR), false factor (FL) and indeterministic (IND) condition. Fuzzy trapezoidal is used to extract the membership values of TR, FL and IND. Each instance of the crop dataset has recommendations for 22 possible class labels with various crop kinds. Each instance of the dataset is characterized by n + 1 attributes. The initial n attributes represent the first n properties, while describe an instance's characteristics, while the final feature specifies the class to which the instance belongs. Three rules make up the normal, abnormal, and indeterminacy classes in the neutrosophic classifier.

In this work single valued neutrosophic values are used and it is denoted as

$$I_{NU} = \{r_1, r_2, r_3, s_1, s_2, s_3, t_1, t_2, t_3\}$$

The value of TR, FN, IND are not dependent. The formula for truthiness, falsity and indeterminacy are listed as follows:

$$TR_{I_{NU}}(x) = \begin{cases} \frac{x-r}{r_2-r_1}; & r_1 \leq x < r_2 \\ 1 \ ; & x = r_2 \\ \frac{r_3-x}{p_3-p_2}; & r_3 < x \leq r_2 \\ 0 \ ; & otherwise \end{cases}$$

$$IND_{I_{NU}}(x) = \begin{cases} \frac{s_2-x}{s_2-s_1}; & s_1 \leq x < s_2 \\ 0 \ ; & x = s_2 \\ \frac{x-s_2}{s_3-s_2}; & s_2 < x \leq s_3 \\ 1 \ ; & otherwise \end{cases}$$

$$FL_{I_{NU}}(x) = \begin{cases} \frac{t_2 - x}{t_2 - t_1}; & t_1 \le x < t_2 \\ 0 \ ; & x = t_2 \\ \frac{x - t_2}{t_3 - t_2}; & t_2 < x \le t_3 \\ 1 \ ; & otherwise \end{cases}$$

where, $0 \le TR_{I_{NU}}(x) + IND_{I_{NU}}(x) + FL_{I_{NU}}(x) \le 3$, $x \in I_{NU}$

The Neutrosophic representation of two instances is formulated as

$$(I_{NU})_{\mu, \upsilon, \lambda} = [TR_{NU1}(\mu), TR_{NU2}(\mu); IND_{NU1}(\upsilon), IND_{NU2}(\upsilon); FL_{NU1}(\lambda), FL_{NU2}(\lambda)]$$

were,

$$TR_{NU1}(\mu) = r_1 + \mu (r_2 - r_1)$$
$$TR_{NU2}(\mu) = r_3 - \mu (r_3 - r_2)$$
$$IND_{NU1}(\upsilon) = s_2 - \upsilon (s_2 - s_1)$$
$$IND_{NU2}(\upsilon) = s_2 + \upsilon (s_3 - s_2)$$
$$FL_{NU1}(\lambda) = t_2 - \lambda (t_2 - t_1)$$
$$FL_{NU2}(\lambda) = t_2 + \lambda (t_3 - t_2)$$

where, $0 < \mu \le 1$, $0 < \upsilon \le 1$, $0 < \lambda \le 1$ and $0 < \mu + \upsilon + \lambda \le 3$

The rules generated by neutrosophic model is used in classification process, consider that, I = $\{i_{1,}i_{2,}i_3,\ldots i_n\}$ were i_i refers to the i^{th} instance and n denotes number of instances in the dataset. Each instance has one class label signified as CL = $\{cl_{1,}c;_{2,}i_3,\ldots NCL\}$ where NCL is the number of classes in the dataset. Initially, the dataset is divided into training and testing data. The training and testing data are used for generating the neutrosophic rules.

The format of neutrosophic rules is as shown:

Rul_1: IF logical $expression_1$ THEN instance is $class_1$

. . .

Rul_n: IF logical $expression_m$ THEN instance is $class_k$

The monitored parameters are used to construct the condition section, and the categorization attribute is used to define the conclusion part. The testing rules are compared with the training rules by finding the difference among the testing rule and all training rules by applying euclidean distance. The training rule with minimum difference is allotted to the testing rule.

Few Examples of Neutrosophic Rules are:

$Rule_N$:

If t1 is low and t2 is medium and t3 is medium and t4 is low and t5 is low and t6 is low and t7 is medium then suitable for cropi [0.4]

$Rule_A$:

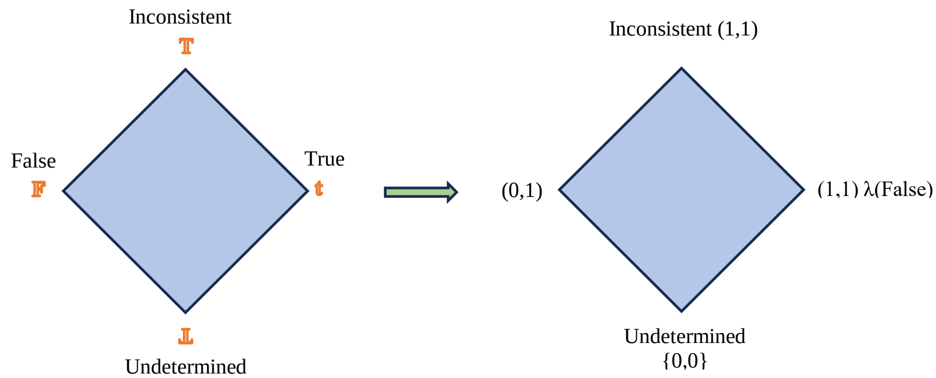
If t1 is high and t2 is low and t3 is medium and t4 is medium and t5 is high and t6 is medium and t7 is high then suitable for cropi [0.6]

$Rule_I$:

If t1 is medium and t2 is medium and t3 is medium and t4 is low and t5 is high and t6 is medium and t7 is medium then indeterministic [0.3]

where t1, t2,…t7 are attributes of the dataset used for crop prediction.

Paraconsistent analysis is used to examine whether the derived rules fall under certainty or contradictory. Contradictory laws address the issue of uncertainty, and situations that fit this description are viewed as atypical circumstances when attempting to forecast any kind of crop that will be grown.



Logical Representation of Paraconsistent Logic

Lattice with Annotation

Where μ and λ refers to favorable and unfavorable degree of evidence respectively. The degree of contradiction is greatly handled by using paraconsistent logic in crop recommendation system. The representation of paraconsistent logic is defined as shown in the below equation

$$PCL\ (X, Y) = \{\mu - \lambda, \mu + \lambda + 1\}$$

The neutrosophic inference system generates a lot of rules, but their accuracy as a source of rules for categorization is not guaranteed. As a result, this work searches for the best rules that are more involved in the classification process and contribute to a higher accuracy rate using knowledge of the Butterfly Optimization method. Finally, it generates rules that have been trimmed in a way that will result in fewer near misses and a higher accuracy of crop prediction.

4 Butterfly Optimization Algorithm (BOA)

To enhance and boost the performance of the uncertainty expert rule generation model, the perception of metaheuristic model of Butterfly Optimization Algorithm (BOA) is utilized (Arora, S., 2019) (Assiri, A.S., 2021). The rules generated by UCES model is pruned by inheriting the knowledge of BOA. Each rule is validated by determining the fitness value of them using food source searching method of butterflies.

BOA is constructed based on the foraging food behavior of the butterfly's metaheuristic sensing nature. Smell, taste, hear, touch and sight are the main factors involved in detection of food sources. The sensing behavior of butterflies is instrumental in laying eggs in a suitable location to protect them from predators. Smell, in particular, plays a crucial role as a sensory mechanism, enabling butterflies to identify nectar (food) even from a considerable distance. The sense receptors are distributed across various body parts such as palps, antennae, legs, etc., with nerve cells serving as chemoreceptors in butterflies.

This sophisticated sensory system allows butterflies to have a precise sense of the position of fragrance sources, enabling them to discern variations between different scents and their intensities. In the context of the Butterfly Optimization Algorithm (BOA), this sensory mechanism functions as a search agent, producing fragrance with a suitable intensity linked to its fitness. The physical intensity of the stimulus is utilized to formulate fragrance, a concept defined as...

$$Fr = cI^a$$

Where 'Fr' refers to the fragrance perceived by jth butterfly, 'c' is the sensor modality, 'SI' refers to the stimulus intensity, 'xp' refers to the power exponent.

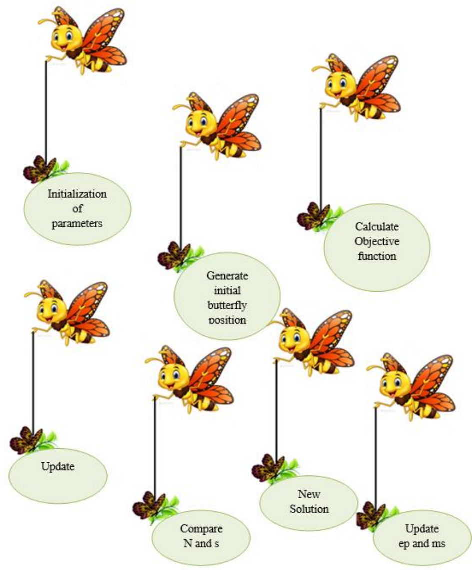


Figure 3: Process of BOA

Butterfly Optimization Algorithm for **Rule Selection**

Set $b(\boldsymbol{Z}), \boldsymbol{Z} = (\boldsymbol{z_1}, \boldsymbol{z_2}, \dots, \boldsymbol{z_m}), \boldsymbol{m} = \boldsymbol{no}$.of magnitudes
Createsmain population of H Butterflies $\boldsymbol{z_i} = (\boldsymbol{i} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{H})$
Stimulus Intensity $\boldsymbol{SI_i}$at$\boldsymbol{Z_i}$ is computed by$\boldsymbol{b}(\boldsymbol{z_i})$
Define modality sensor *ss*, exponent power x*p*and probability switch p*s*
while end condition is not met
{
for each *bof*in population
Calculate scent for *bof*using equation 8
Discovery the best *bof*
for each *bof*in population
{
createarandomRfrom [0,1]
if R<*ps***then**
Allocation in the route of best butterfly/solution
else
Allocationrandomly
end if
}
Modify *xp*value
}
Output: Optimized rule selection

The generated rules of uncertainty expert model are validated by applying behavioural algorithm known as butterfly optimization. Based on the food searching behaviour of butterflies, the flower with highest nectar is assigned with best fittest value. Likewise, in this proposed work the resultant rules are validated based on its accurate classification rate by applying fitness value evaluation. The rules with highest fitness value are considered to be more relevant in the task of predicting appropriate crop recommendation. Thus, it reduces the false detection rate by eliminating irrelevant and redundant of uncertainty expert system

5 Experimental Results

In this section the performance of the newly devised uncertainty expert system infused with butterfly optimization algorithm for forecasting the suitable crop farming based on the condition of soil fertility and climatic condition. The proposed UCES-BOA is simulated using python software and the dataset is collected from the Kaggle repository. The evaluation metrics used in this research work are accuracy, sensitivity and specificity. The existing models used for comparison are ANN, MLP and SVM.

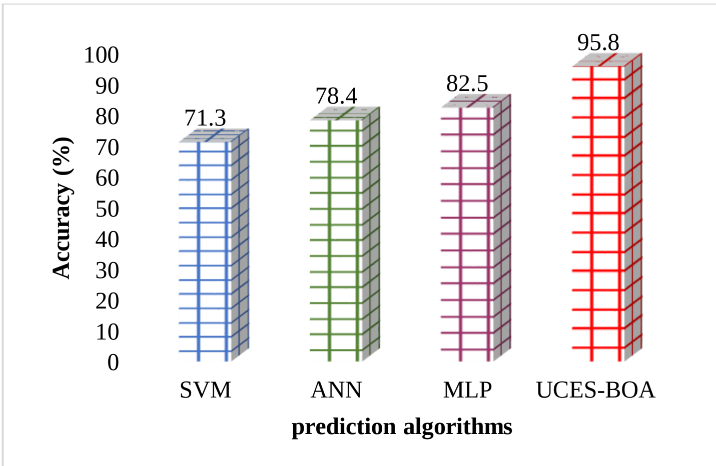


Figure 4: Comparison based on Accuracy

Figure illustrates the performance analysis of four different classification models involved in recommendation of suitable crop cultivation based on the different factors related to agriculture. The result explores that the proposed UCES-BOA produced highest rate of accuracy 95.8% compared to other three existing models. The presence of uncertainty in predicting the suitable crops is challenging task for traditional classification models due to imbalance class distribution among training and testing sets. But, UCES-BOA with the knowledge of uncertainty theory and optimization by butterfly food searching behavior it produced highest accuracy rate in prediction of suitable crops.

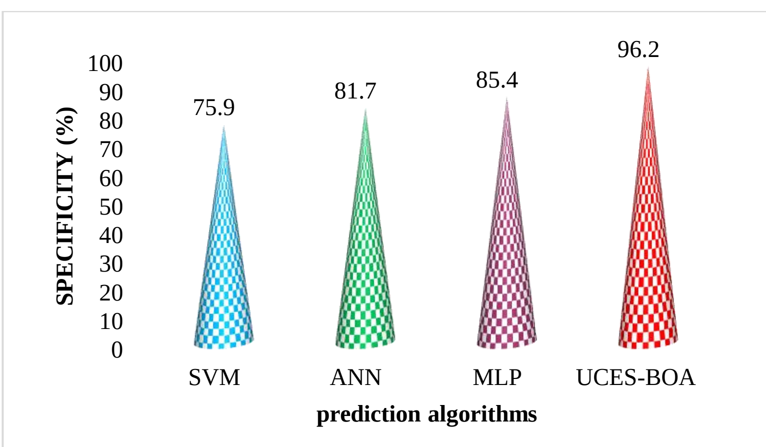


Figure 5: Comparison based on Sensitivity

The results shown in figure 4 explores the efficiency of UCES-BOA based on sensitivity rate for prediction of suitable crops based on the soil fertility and climatic conditions to improve smart farming. The uncertainty based expert system defines the instances in terms of grade of belongingness and non-belongingness to handle the vagueness in determining the appropriate crop farming. The rules generated by the UCES is validated by deploying butterfly optimization algorithm to improve the accuracy rate in recommending suitable crop production. The irrelevant and redundant rules are eliminated based on the fitness value evaluated by butterfly food searching behavior. The other existing models suffers from overfitting problem and produced least sensitive rate in predicting suitable crop production.

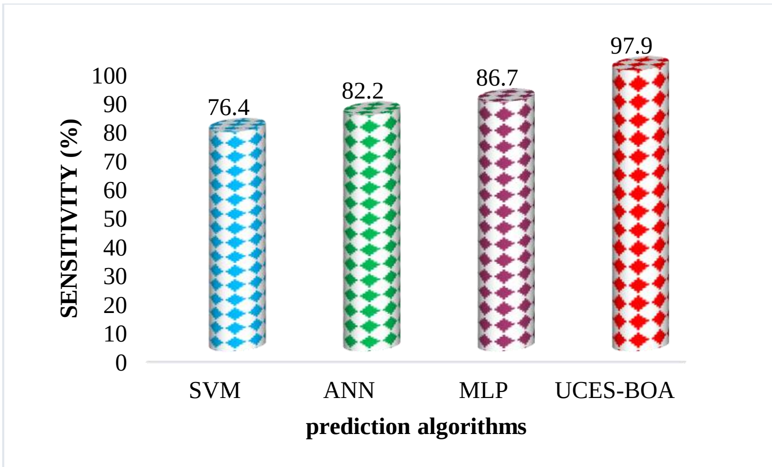


Figure 6: Comparison based on Specificity

The specificity rate of four different classification models in prediction of crop cultivation recommendation is displayed in figure 5. The SVM, MLP and ANN has the ability to work with small size datasets and balanced distribution of testing and training sets. But in real time datasets, it is not feasible and thus they produced less specificity values compared to the proposed UCES-BOA in crop recommendation system. The reason is uncertainty expert system infers the knowledge of each pattern of instance in depth and it gains the knowledge of butterfly searching behavior to involve only the most relevant rules which produced optimized classification result. Thus, the proposed UCES-BOA achieves highest rate of specificity in prediction of suitable crop recommendation to accomplish smart farming.

6 Conclusion

In this paper the problem of uncertainty in prediction of accurate crop production based on weather condition and soil fertility is handled by devising an optimized uncertainty expert system. The uncertainty in analysing the suitable crop for the specific soil and weather condition is handled in this proposed work by representing each instance in terms of degree of uncertainty. The rules generated by uncertainty expert model is validated and controlled by adopting butterfly optimization algorithm. The nature of butterflies in searching of nectar is used for searching irrelevant and redundant rules. The food source with highest nectar has been considered best fittest source in nature, the same is applied in artificial butterfly rule searching process to determine best rules generated by UCES for predicting crop production. The simulation results proved that performance of UCES-BOA produced better accuracy rate in suggestion of more appropriate crop suitable for farming.

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