A review of the application of data mining techniques for decision making in agriculture

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***Abstract*—This paper provides a review of research on the application of data mining techniques for decision making in agriculture. The paper reports the application of a number of data mining techniques including artificial neural networks, bayesian networks and support vector machines. The review has outlined a number of promising techniques that have been used to understand the relationships of various climate and other factors on crop production. This review proposes that further investigations are needed to understand how these techniques can be used with complex agricultural datasets for crop yield prediction integrating seasonal and spatial factors by using GIS technologies.**

Keywords—agriculture; artificial neural network; association rule mining; Bayesian network; data mining; decision making; support vector machines

I. Introduction

Many computer science techniques such as data mining and machine learning are used to study the influence of various parameters and make predictions of the crop production [1,2,3,4,5,6,7]. Data mining is the process of identifying the hidden patterns from large and complex data [8,9,10,11]. It may provide crucial role in decision making for complex agricultural problems.

A comprehensive review of the application of various techniques such as artificial neural networks, bayesian network, support vector machines and association rule mining will be provided with examples to show how these have been applied to variety of agricultural data sets. The role that these techniques play in the development of decision support tools for agricultural crop production predictions, pest and disease management, will also be explored. This paper reviews the application of data mining techniques applied in the field of agriculture. Recommendations for future research directions for the application of these techniques for decision making in agricultural context will be provided.

II. Review of Literature

Knowledge discovery from databases and data analysis is an inter-disciplinary concept termed as data mining [12]. A multi-facet approach is used which can include statistical analysis, data visualization, neural networks, knowledge discovery, pattern recognition and data base management [13]. The widely used data mining techniques has been discussed in a review by [14].These techniques have also been applied in the agricultural domain.

For example, a *k*-nearest neighbor technique was applied by [15] to evaluate forest inventories and to estimate forest variables analyzing satellite imagery. The simulation of daily precipitations with other weather variables and forecast of pollution in the atmosphere was carried out using the k-means method [16,17]. Classification of soil in combination with GPS-based technologies and plants has also been performed using k-means approach [18, 20]. The apples were checked before sending to market by using different classification approaches. Further k-means approach is used by [21] to analyse color images of fruits as they run on conveyor belts.

In Targhadia, Gujarat, India the impact of rainfall on crop productivity was studied by [19]. This study considered the dataset of 39 years from 1958 to 1996. Correlation and regression techniques were applied to derive the relationship between rainfall and crop yield. Crop yield prediction model for major crops was developed using the results of this study. In Pakistan, a study was carried out on the excessive usage of pesticides affecting the crop yield. Using data mining techniques interesting patterns of farmer practices were revealed from these clusters along with pesticide usage dynamics [22]. Data mining techniques has also been applied for Western Australian soil data to achieve optimal results compared to the statistical methods [23]. This study showed that the data mining techniques has taken less time compared to the statistical methods and have produced accurate results.

A study by [24] identified Powdery Mildew disease in mango using various data mining techniques. A novel unsupervised algorithm, called CLimate and rEmote sensing Association patteRnsMiner, for mining association patterns on heterogeneous time series from climate and remote sensing data integrated in a remote sensing information system was developed to improve the monitoring of sugar cane fields [25]. Rules generated by this new algorithm showed the association patterns for different periods in each time series. This indicated a time delay between the occurrences of patterns in the series analyzed. This could corroborate the forecasts of specialists without need to analyze numerous data charts.

Using wireless sensor network a simulated experiment was conducted by [26] to interpret the crop-pest-weather relations on groundnut pest thrips. The data was transformed using data mining techniques into effective relations between the dynamic

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crop-weather-pest. Using regression models the obtained data was validated. A study by [27] uses data mining techniques on environmental and biotic input variables to predict annual yield of major crops. The study used the findings to make recommendations planting different crops in different districts in Bangladesh.

A number of recent studies have discussed the potential of applying data mining techniques in agriculture [28,29,30,31,32,33,34]. Good crop yield prediction results have been achieved by many researchers after applying data mining techniques under different climatic scenario [35,36,37,38,39, 40, 41].

A. Artificial Neural Network (ANN) in Agriculture

Human brain's biological neural processes form the basis for the ANN structure. A model can be developed using interrelationships of correlated variables. These symbolically represent the interconnected processing neurons or nodes of the human brain that are used. To establish model prediction, large number of input and output example are used to develop a formula to ascertain the relationship [42]. With little a priori knowledge of the functional relationship, nonlinear relationships, which are overlooked by other prediction methods, can be determined [43]. An ANN model requires a minimum of three layers: the input, hidden and output layers. The input and output layers contain nodes that correspond to input and output variables, respectively. Data move between layers across weighted connections.

ANN在农业中的应用

Agronomic-based models have been developed using artificial neural networks and have been discussed by various researchers. Agronomic ANN applications include crop development modeling [44], pesticide and nutrient loss assessments [45], soil water retention estimations [46], and disease prediction [47]. A study by [48] used ANNs to classify eggs as fertile or infertile. When predicting applied nitrogen leaking below the root zone of turf grass, it was reported that an ANN model performed better than a regression model [49]. Despite the fact that regression model expends more time to be developed, an ANN model can deliver more reliable and accurate crop yield forecasting compared to other methods such as regression models [50]. Aerial pictures have been used for crop yield prediction before harvesting [51]. These photos were able to provide spatial cloud free data of the yields spectral qualities. Another study by [52] used X-ray images of apples to monitor the presence of watercores. A neural network was trained for discriminating between good and bad apples.

For the prediction of rice yield based on weather data, back propagation network was used in a study by [53]. A study by [54] described the use of artificial neural networks to predict maize yield based on rainfall, soil and other parameters and obtained a testing error of 14.8%. Another study by [55] applied principal-component based neural network model and applied it to a water level prediction. A neural network to build a hybrid prediction model and performed a prediction experiment on the precipitation in the northern, central and southern regions of the Guangxi province has also been reported [56]. Data mining techniques were employed for the monitoring of the wine fermentation process. Taste sensors were used to obtain data from the fermentation process and classified using ANNs [57].

Work by [58] used a back propagation network to predict rice yield using climatic observation data and predicted with a maximum of 45-60kg/ha. A study by [59] used neural networks to predict rice yield based on soil parameters and achieved a testing error of 17.3%. Another study reported the use of ANN in the development of straightforward and precise estimation to predict rice yields [60]. Work by [61] developed a year round air temperature prediction models. These models predicted the horizons of 1 to 12 h using Ward-style ANNs. These models were found to be useful for general decision support by the farmers.

Another study by [62] examined the performance of ANN to predict crop yields in Nepal. The predicted outcome could be utilised for enhancing the paddy yield in Siraha district of Nepal and also in other regions where the topography and vegetation are similar to Siraha district.

Prediction of rice crop production in Phimai district, Thailand showed the effectiveness of a decision support system which used ANN [63]. The application of using ANN using feed forward back propagation for agricultural crop yield prediction is demonstrated by [64]. A study by [65] used ANN for rice crop yield prediction in Maharashtra state, India. This study concluded that ANN is a beneficial tool for crop prediction.

B. Bayesian Networks (BN) in Agriculture

The computer science technique of BN is considered to be ideal for situations enabling diagnostic reasoning on conditional dependencies to assess model structural and as well as parameter uncertainty [66]. BN is a method for representing beliefs and knowledge using probabilities, especially relevant for systems that are highly complex in their structure and functional interactions [67]. BN uses the probabilistic components of a framework, as opposed to deterministic comparisons to describe the connections among variables. [68].

Bayesian Networks are increasingly popular method for modeling uncertain and complex domains. Many studies have reported on the advantages and challenges using BN for complex problems such as environmental modeling [69]. The technique provides a graphical model that encodes probabilistic relationships among variables of interest [70]. This model has several advantages for data modeling when used in conjunction with statistical techniques.

A few studies have reported on the application of BN for the agricultural domain. For example, these BNs have been used for predicting yield response of winter wheat to fungicide programmes [71]. Other studies have reported its use for the estimation of genetic parameters of calving ease in first and second parties of Canadian Holsteins that has also been implemented using BN [72]. The development of a decision support system for growing malting barley without use of pesticides utilized a BN approach [73]. Applications have also been shown where BN has been developed for decisions associated with the selection of irrigation systems for irrigated dairy farms in Northern Victoria [74]. BN are also emerging as a valid approach for modeling and supporting decision making in other related fields such as water resource management [75]. Bayesian Belief Networks (BBN) have also been used to incorporate characteristics of land managers in the modeling process and to enhance the understanding of land-use change based on the limited and disparate sources of information [76].

Other research has described the use of BN classifiers for modeling of a weed infestation risk inference system that implements a collaborative inference scheme based on rules extracted in a corn crop [77]. Another study by [78] on the best pest control decision making program also based its approach on BN. The study describes the flowchart of a BN and the principles used to calculate the conditional probabilities required in it. It proves that BN is effective tool for crop disease. A study by [79] used BN to model the crop disease coffee rust cause's premature defoliation, weakening the plant and reducing subsequent yield. Improved prediction using BN proved to reduce the use of fungicides, producing healthier quality product and decreasing both economic costs and environmental impact [79].

Research by [80] reported key indicators of rice production and consumption, correlation between them and supply demand prediction. The findings of the study suggested that there were many techniques used for forecasting purpose but FIS and Bayesian technique outperform others. Other recent studies have highlighted the application of BN in an agricultural context [81,82,83,84,85,86,87,88].

C. *Support Vector Machines (SVM) in Agriculture*

SVMs are one of the newest supervised machine learning techniques. A number of studies have reported on the application of SVMs in an agricultural context. For example, [89] described the use of SVMs to classify crop and [90] highlighted its usefulness in classifying smell of milk. Another study by [91] used SVMs to classify pizza sauce spread, and [92] uses SVMs for detecting weed and nitrogen stress in corn.

A number of other studies have shown the variety of uses for SVMs in agriculture. One study reported on how SVM was applied for reduction of precipitation for climate change scenarios [93]. Data mining techniques were also applied to study sound recognition. Work by [94] demonstrated the use of SVMs to classify the sound of birds and other different sounds. SVM has also been applied for the estimation of crop biophysical parameters using aerial hyper spectral observations [95]. Another application reported for SVM was the modeling of urban land use conversion. This research derived the relationship between rural-urban land use change and various factors [96]. SVM was also applied to provide insights into crop response patterns related to climate conditions by providing the features contribution analysis for agricultural yield prediction [93,97] analysed different possible changes of the weather scenarios using SVMs. Other studies have described the use of discretization based SVM for classification of agricultural datasets [98]. Another study reported how SVM was used to forecast the demand and supply of pulpwood. It was used to minimize the generalization error bound to achieve generalized performance [99]. A study by [100] showed the prediction of rice crop yield for Maharashtra state, India using SVM. This study concluded that SVM could be used for crop prediction.

D. *Association Rule Mining in Agriculture*

The application of Association Rule Mining have been demonstrated for many cases in agriculture for elucidating hidden patterns and associates between different climate and crop production. For example, one study demonstrated this with remotely sensed and spatial data sets in the agricultural domain [101,102]. Another study by [103] aimed to develop an effective risk management system for tracing frequent occurrences of droughts and floods which both adversely affect the sustainability of Indian agriculture. A data mining algorithm was used to discover association rules between extreme rainfall events and climatic indices. Association rules were generated for the regions of India, which shows strong relationships between the climatic indices chosen, i.e., Darwin sea level pressure, North Atlantic Oscillation, Nino 3.4 and sea surface temperature values, and the extreme rainfall events.

An exhaustive survey on association rule mining in the field of agriculture conducted by [104] found that five major algorithms were most commonly used for the discovery of association rule mining. These included apriori, partition, pincer search, dynamic item set counting and FP-Tree growth algorithm. Another study by [105] also showed the application of association rule mining algorithm for control of agricultural pests. This study found that method significantly improved the quality and efficiency of the data analysis. In another study by [106] on organic cultivated land of the three different municipalities of Thassos, Greece analysed data with a classification algorithm OneR, a k-means clustering algorithm and Apriori association rule mining algorithm. The result of this investigation indicated that organic cultivation could improve the production of olives and olive oil. The climate differences among the three municipalities were also suggested to be a factor involved in production efficacy.

A recent study by [107] presented a theoretical survey on apriori, ID3 and C4.5 algorithms to be used for another agricultural dataset. Another study by [108] provided a comparative study of various association rule mining techniques, which included A Priori Algorithm, Partition Algorithm, Pincer Search Algorithm, Dynamic Item Set (DIC) Algorithm and FP-tree growth algorithm. When these were applied in agricultural domain the best results were generated by FP-Tree growth Algorithm.

Some other recent work has highlighted the use of association rules in agriculture for pattern mining [109,110]. Another study by [111] reported on the use of aprior with WEKA for frequent pattern mining. Other research by [112] conducted another investigation on the performance evaluation of association rule mining on partitioned data. This work found that confusion could exist between the performance of multidimensional database and its association with the rule mining.

Other examples on agricultural datasets include work by [113] that implemented association rule mining for different soil types in agriculture with the aim of establishing meaningful relationships using apriori algorithm. Similar findings in a study by [114] analysed the quality of association rules by computing an interestingness measures. This research concluded that statistical interestingness measures are really helpful for finding interesting rules among large association rules.

A recent study on wheat yield losses caused by stripe rust has also been undertaken by [115]. The work described the development of a computer intelligent system that uses improved apriori algorithm to extract spatial association rules from spatial databases, which helps in a decision support system for wheat crop yellow rust disease management.

III. CONCLUSION

In this paper a review of the application of data mining techniques like artificial neural network, bayesian networks and support vector machines in agricultural domain was discussed. Various studies have reported on the application of data mining techniques. The review has outlined a number of promising techniques that have been used to understand the relations of various climate and other factors on crop production. Further investigations are needed to understand how these techniques can be used with complex agricultural datasets and used for crop yield prediction with an integration of both seasonally and spatially using GIS technologies.

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