Chapter 9
Print ISBN: 978-93-5547-674-6, eBook ISBN: 978-93-5547-753-8

Recent Advances in Agricultural Commodity Forecast Techniques in the Purview of Climate Change

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DOI: 10.9734/bpi/cagees/v6/3331C

ABSTRACT

In most of the developing and third world countries and India being no exception to it agriculture truly serves as the spine of the nation's economy with a major percentage of the population directly involved in farming for livelihood. Climate plays one of the most significant role in almost every aspect of crop production starting from crop growth, crop development to eventually the yield of the crop. Climate also influences outbreak of crop pests and diseases and the water uptake of the crops. Possible changes in weather parameters like precipitation, temperature and CO_2 concentration are anticipated to have a crucial impact on the crop growth process. Prediction of crop yield changes in the purview of changing climatic conditions can prove beneficial to the farmers in terms of devising a synchronized crop production activity as per changes in the climatic conditions. Thereby, bringing out suitable policy changes benefitting the farming community as well as the nation as a whole. In this book chapter an overview of all the statistical models and methodologies has been outlined that helps to forecast agricultural commodities under changing climatic conditions. The recent developments in the same field has also been enlisted.

Keywords: Climate change; weather parameters; food security; agricultural commodity forecast; statistical models; recent developments.

1. INTRODUCTION

Climate has a very significant role in agricultural production. It predominantly influences growth and development of the crop and eventually crop yield. Climate also significantly influences the outbreak of disease and pest; it affects the requirement of water by the crop. Climate is one of the crucial factors that determine the fertilizer requirement because soil nutrient mobilization is influenced by climate. Any fluctuation or aberration in the weather parameter may bring about a physical harm to the crops and lead to erosion of soil. Weather also

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determines the quality of the produce of the crop from farm to storage and also its transportation to the market. In case of non-congenial weather during transport of crop produce its quality may be hampered, similarly bad weather during storage may worsen the vigour of seed and its viability. Thus, every aspect of agriculture is sensitive to weather regimes. While considering on a climatological basis, weather variables show spatial and temporal variation. Short period weather data and inter yearly weather fluctuations are considered in case of cropping purposes. At any given time, the magnitude of departure of an extreme value from the measure of its central tendency is a measure of the variability present in the parameter. The degree of variability present in the weather parameter is more in case the time unit is short. For different range of weather factors the magnitude of variation is different. Temporally as well as spatially rainfall is the most volatile of all-weather variables. Prognosticating crop production is a challenging task for every nation while looking towards food security goal.

India being an agrarian country, farming provides key livelihood to majority of the population of the nation. Development of agriculture of the country is of prime importance as it has a direct and an indirect association to a large percentage of farmers, private companies and the government sector. A profitable agriculture is one which fetches remunerative prices owing to better yield. Hence apriori crop yield prediction is advantageous for proper planning of farm activities as well as to make strategic marketing. It is very important to the public and private sectors in framing various policies with respect to domestic food supply, international food trade, export, imports. So, this sets a strong need for reliable and efficient forecasting methodologies for various aspects relating to agriculture and more importantly the crop yield.

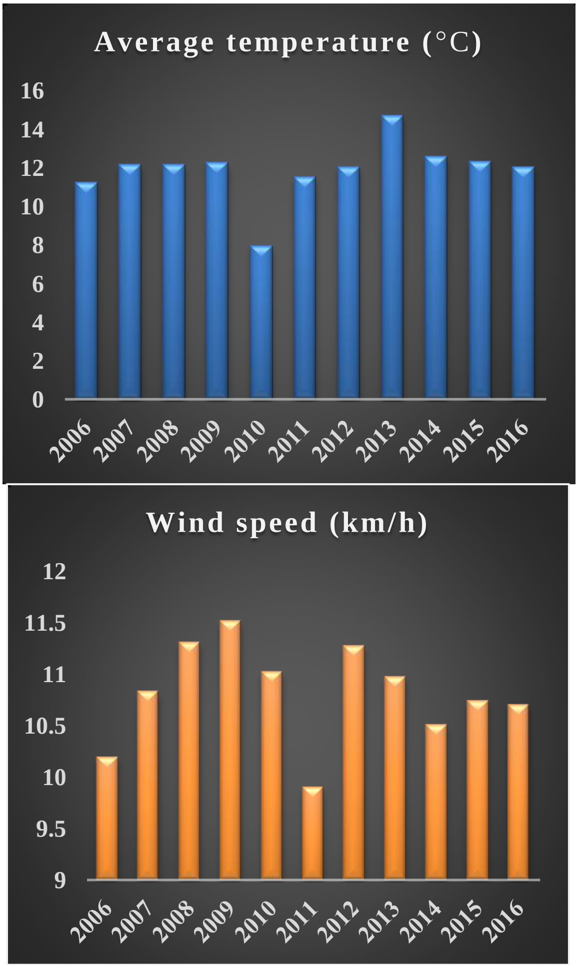
1.1 Impact of Climate Change

Agriculture production is directly dependent on changes in climate and weather. Possible changes in weather factors, like precipitation, temperature and CO_2 concentration are expected to have a significant impact on crop growth. There is a possibility that global agricultural production be increased due to the doubling fertilization effect of CO_2. India is also expected to begin to experience more seasonal variations in temperature with the winters becoming warmer than summers. There has been a history of 23 scale droughts starting from 1891 to 2009 in India and the frequency of droughts is increasing since then.

Variation in weather parameters over last ten years has been presented in Fig 1. Climate change is posing a great threat to agriculture and food security. The most critical agricultural input is water, as of 55% of the total cultivated areas do in India are rainfed. Eventually in rainfed agriculture pattern, intensity and distribution of rainfall becomes most significant factor influencing the crop production to a greater extent. In developing countries like India, one of the additional burden is climate change since ecological and socioeconomic systems are already burdened from population hike, industrialization and economic development. Globally also, this is a potentially identified issue to ensure global food security.

1.2 Global Food Security

It has been studied that all the 4 dimensions *viz.* food security: food availability, food utilization, food accessibility and food systems stability are influenced by changes in climate. Climate change will bring about an impact on human health, livelihood, food production and marketing, as well as it will also have an effect of the change in purchasing power and market flows. It will have short-term impacts occurring because of more frequent and intense extreme weather events, whereas the long-term effects will be caused due to changes in temperatures and unpredictable patterns of precipitation. Various potential climate changes due to global warming are portrayed in Fig. 2 which has direct or indirect influence to agriculture and food security.



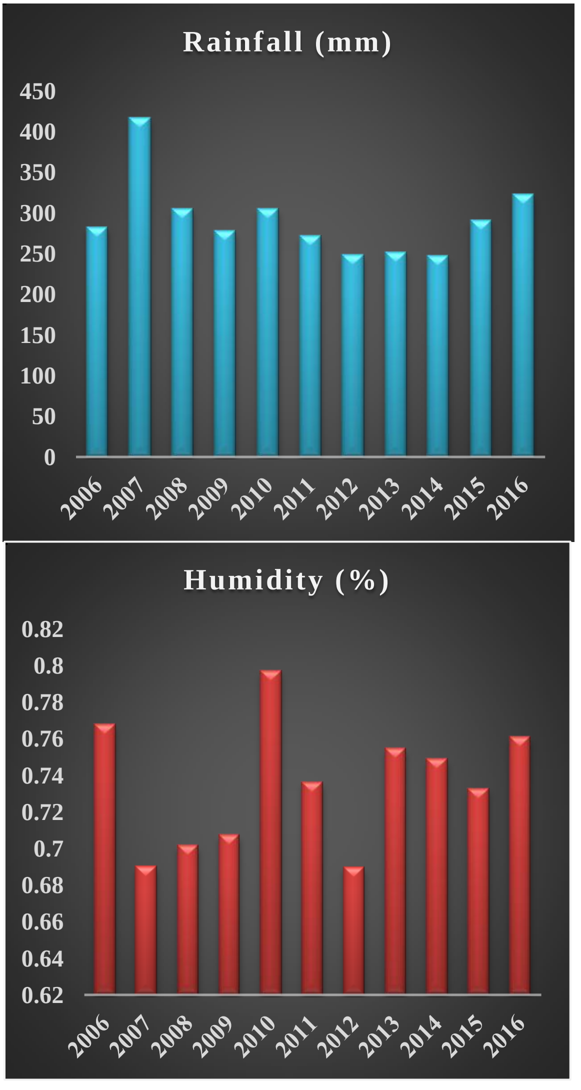


Fig. 1. Variation in Weather Parameters over last 10 years
(Source: IMD, worldweatheronline.com)

In May 2007, at the 33rd Session of the Committee on World Food Security, FAO (Food and Agricultural Organization) issued a statement to reaffirm its vision of a food-secure world:

"FAO's vision of a world without hunger is one in which most people are able, by themselves, to obtain the food they need for an active and healthy life, and where *social safety nets ensure that those who lack resources still get enough to eat." (FAO, 2007)*

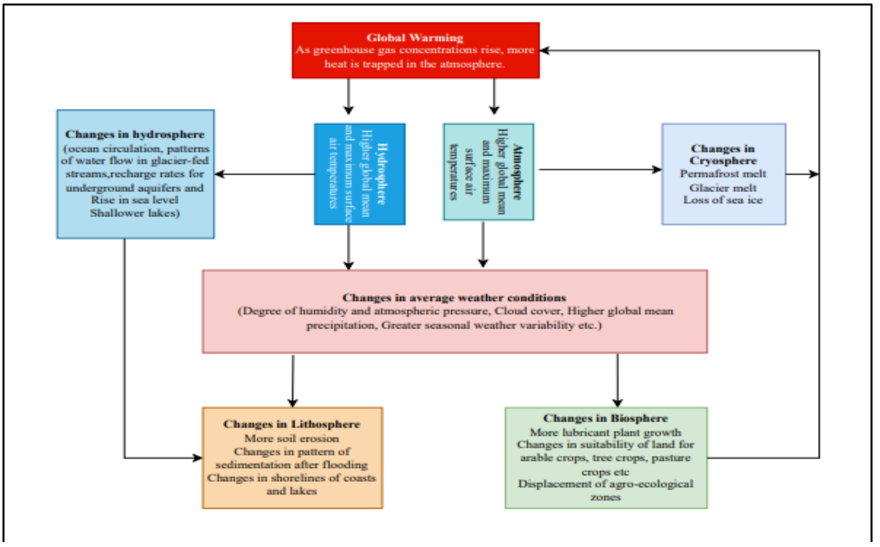


Fig. 2. Global warming and changes in the climatic condition

Climate change and food security combined together results in multiple interrelated risks and uncertainties for both ecology and societies. Agriculture has a bi-fold advantage in terms of food security, firstly, it leads to food production that the food people eat; and the most important being it is a primary source of livelihood for 36% of the cumulative global workforce. As per International Labour Organization, 2007.

"*In the heavily populated countries of Asia and the Pacific, this share ranges from 40 to 50%, and in sub-Saharan Africa, two-thirds of the working population still make their living from agriculture."*

Hence, in the underdeveloped and developing countries of Africa and Asia with a marginal economy if adverse climate change affects agricultural production it will have a catastrophic effect on the livelihood of a significant fraction of the rural poor making them more vulnerable to food insecurity.

2. KNOWLEDGE ON EXISTING DATA FRAMEWORK: PRESENT NATIONAL SCENARIO OF PRODUCTION

Agriculture is the backbone of India's economy. India is the world's largest producer of milk, pulses and jute, and second largest producer of rice, wheat, sugarcane, groundnut, vegetables, fruit and cotton (FAO, 2018). India also significantly contributes to production of spices, fish, poultry, livestock and plantation crops. The main source of livelihood in India is based on agriculture and its allied sectors. About 70% of its rural households still dependent primarily on agriculture for their livelihood with 82% of farmers being small and marginal (Census, 2011). According to Agricultural Statistics at a glance total food grain production was 297.5 million tonnes (MT). India is the largest producer (25% of global production), consumer (27% of world consumption) and importer (14%) of pulses in the world. India's annual milk production was 198.41 MT (2019-20), making India the largest producer of milk, incomplete jute and pulses [1]. The country contributes a significant role in the world fruit (10.9%) and vegetable (8.6%) production. Although there has been substantial growth in production over the years, there is also a substantial variability about the trend. The time series data regarding Indian crop production 1960-2020 are represented in Fig. 3 with respect to harvested area and yield (FAO, 2020). Variability in weather and climate is regarded as the primary cause of year-to-year fluctuations in yields. For example, the crop production for the year 2017-18 has been lower due to the uncertainty of southwest monsoon. The monsoon rainfall was below normal that severely affected the overall crop production in 2017-18. The state wise distribution of area and production of total food grain, pulses and oilseeds has been presented in Fig. 4. Rajasthan, Uttar Pradesh and Madhya Pradesh share maximum area while Uttar Pradesh, Punjab and Rajasthan share maximum production in total food grain. In case of Pulses Rajasthan, Madhya Pradesh and Maharashtra contributed maximum area and production [1].

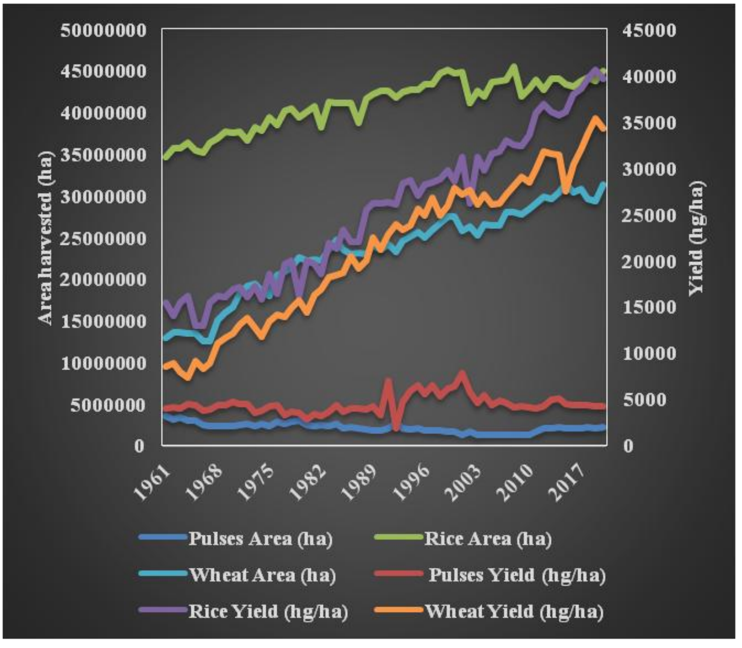


Fig. 3. Crop Production scenario in India from 1960 to 2020

3. STATISTICAL TECHNIQUES IN AGRICULTURAL COMMODITY PRODUCTION FORECAST

3.1 Empirical Statistical Models

Agricultural production and price forecasting is valuable for farmers, governments and agricultural based industries. As food production have special place in nation's security, governments have become both chief suppliers and users of agricultural forecasts. To implement policies forecasts are required, which in turn provide technical and market support for agriculture sector.

Various references on the influence of weather variables on crop yield and thereby forecasting of commodity production are available in literature. Fisher [2] described the effect of weather on the wheat yield by taking into consideration weekly rainfall; for prediction of yield. In recent time, remote sensing based method [3] is continually attaining popularity, satellite data provide considerable benefit to estimating yield and production of agriculture all around the cropping season because of their temporal coverage, spectral and spatial resolutions, availability in well time to users and economical. However, they are having shortcomings too i.e. may not be appropriate and cost effective in developing countries, also in small farm sizes stratified agricultural systems. Further, mathematical models based on plant characters for yield forecasting e.g., assessing the leaf color to examine plants health can be used for some cases where regular system of observing plant physiological characters exist. However, it is to be noted that in contrast to mathematical models, statistical models are frequently in use for forecasting purposes. Statistical models are also adaptable in incorporating various categories of existing information and making such models more representative of the underlying process [4]. In the linear framework, regression models one of the most frequently used models which offers flexibility of incorporating related auxiliary information playing a major role in explaining the variability of the response variable. Therefore, for accuracy of these types of models, a fair amount of covariates having significant correlation is crucial, but involving a number of covariates becomes limited.

The crop yield is mostly influenced by weather variability and technological change. It can be seen that increase in yield with time can be due to technological factors and weather is also a factor that have a volatile effect on yield, therefore, along with year, other parameters of time can be taken into consideration while studying the overall effect of weather and technology on yield of crop. For between/within year prediction of crop yield, time series forecasting models based on historic data can be suitable alternative. When previous year data is used as auxiliary variable, they may take care of cumulative effect of weather, existing technology factors, and all other related covariates [5].

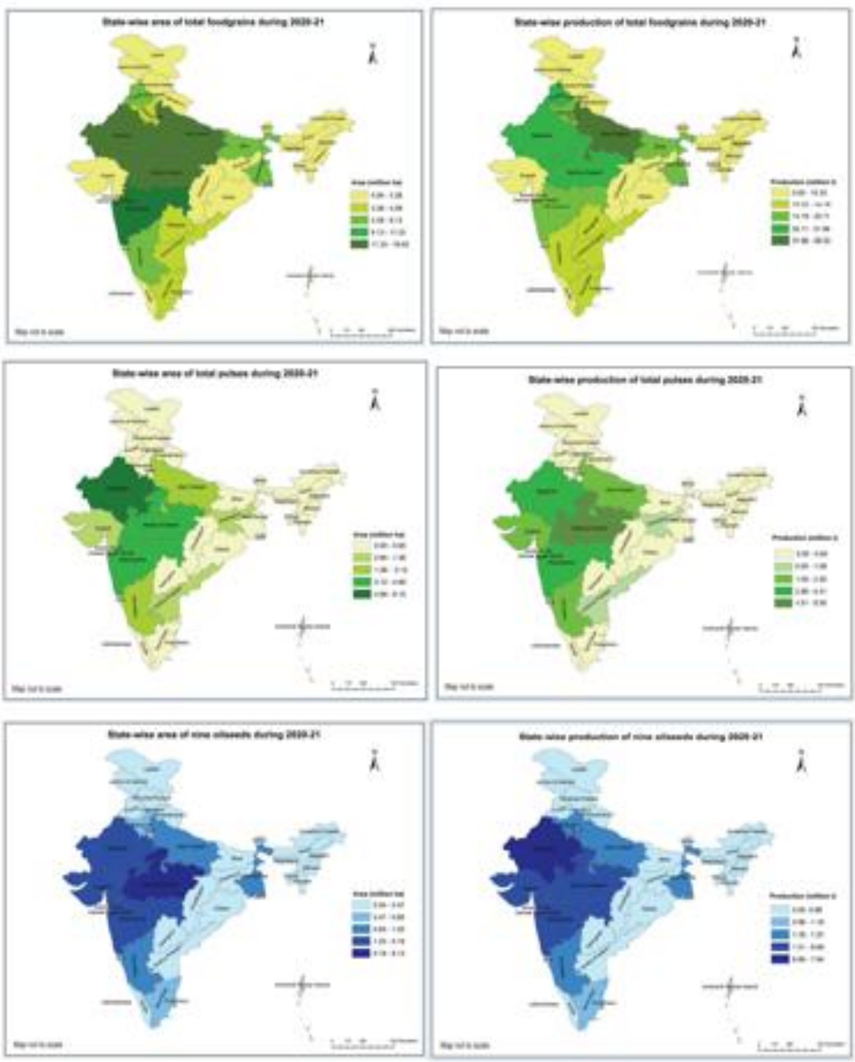


Fig. 4. State wise area and production status of total food grains, pulses and oilseed (ARDB, 2022)

3.2 Yield Forecasting by Linear Regression and Time series Models

Linear regression establishes linear relationship between response variable and predictor(s). Suppose, y be the response variable and $X_1,\ldots,X_m$ be m independent variables. Then, linear regression equation can be expressed mathematically as,

$$y = \beta_0 + \beta_1 X_1 + ... + \beta_m X_m + \varepsilon$$

where, β_i's (i = 1, … , m) are unknown parameters and ε is error term which is assumed to be identically and independently distributed with mean zero and constant variance. Sample data can be used to estimate theses unknown model parameters in the regression equation. Regression equation having one auxiliary is known as simple regression model and that having more than one auxiliary is known as multiple regression equation. Time series mainly deals with observations that are collected over time. The character that distinguishes this series from another is that observations in future depend on the past observations in a stochastic way, which is useful for predicting the future. With the help of time series, it is possible to find models that reflect the underlying dynamics and therefore can be considered for further forecasting the series trend. The pioneer models for that are used frequently to model linear dynamics structure is Autoregressive moving average (ARMA). Other time series models that are often used in yield forecasting are simple exponential smoothing, double exponential smoothing, damped-trend linear exponential smoothing, ARIMA and ARIMAX,

3.3 Recent Developments

Since last decades, various machine learning techniques has drawn a great deal of attention in the forecasting of crop production in agriculture. Techniques such as prediction, classification, regression and clustering are utilized to model and forecast crop yield. Machine learning (ML) techniques like Artificial neural network (ANN), Support vector machines (SVM), Decision trees (DT), Naïve Bayes (NB) are some of the popular methods/algorithms used for prediction purposes. ANN has been proved to be much promising for forecasting temporal yield series. Non-parametric, data-driven and self-adaptive nature of ANN has made it more easily approachable method as opposed to other model based nonlinear alternatives. Studies have been undertaken on agricultural price system forecasting also using ANN models. O'Neal et al. [6] explored ANN model to predict maize yield at three scales using local crop-stage weather data and yield data from 1901 to 1996. As per the study of Kaul et al. [7], ANN gives better results than traditional statistical methods while predicting soybean yield. Jeong [8] used Random Forests (RF) technique to predict crop yield responses to climate and biophysical variables at global and regional scales and found RF highly capable of predicting crop yields. Iizumi et al (2018) has used a multi-model ensemble method for global crop yield forecasting. Kumar et al [9] developed SVM based classification models for the rice yield prediction in India. Experiments have been conducted involving one-against-one multi classification method, k-fold cross validation and polynomial kernel function. Palanivel and Surianarayanan [10] performed an investigation on how various machine learning algorithms are useful in prediction of crop yield. Choudhury et al. [11] reported ensemble ANN model had better forecasting ability than ARIMA model. Lischeid et al. [12] suggested machine learning models are one of the powerful tool for crop yield modelling. Besides, the application of machine learning approaches, remote sensing and geographical information systems (GIS) emerges as alternative approach for crop yield modelling. Wall et al. [13] recommended the early explanatory power of normalized difference vegetation index (NDVI) in crop yield modelling. In literature, it has been found that the multifactorial and complex pattern of crop growth violates certain assumptions of a particular model. As a results, a single modeling may not able to model crop yield completes. It motivates the researchers toward the application of ensemble approach i.e. the combination of two approach. The different types of combination/ensemble approach available like decomposition based ML model (EMD-ANN), feature selection based ML model (PCA-ANN), GIS based ML model etc. Das et al. [14] applied decomposition based support vector regression model for forecasting agricultural price. Teresa et al. (2018) applied Artificial intelligence and Satellite imagery for agricultural crop yield prediction. Janifer et al. [15] developed spatiotemporal hybrid random forest model for tea yield prediction using satellite-derived variables. They showed the hybrid model improved tea yield forecasting over other standalone machine learning approaches with the least relative error value. Shetty et al [16] checked performance analysis on machine learning algorithms with deep learning model for crop yield prediction. Gong et al. [17] tried to apply deep learning techniques like temporal convolutional network (TCN) and recurrent neural network (RNN) for prediction of greenhouse crop yield.

4. CONCLUSION

It is concluded that an overview of all the statistical models and methodologies has been outlined in this study which helps to forecast agricultural commodities under changing climatic conditions. The recent developments in the same field have also been enlisted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Agriculture Research Data Book. ICAR-IASRI, New Delhi, India; 2022.
2. Fisher RA. The influence of rainfall on the yield of wheat at Rothamsted. Philosophical Transactions of the Royal Society of London. Series B, Containing Paper of a Biological Character. 1925;213:89-142.
3. Prasada AK, Chai L, Singha RP, Kafatos M. Crop Yield Estimation Model for Iowa Using Remote Sensing and Surface Parameters. Int J Appl Earth Obs Geoinf. 2006;8:26-33.
4. Sellam V, Poovammal E. Prediction of Crop Yield using Regression Analysis. Indian J Sci Technol. 2016;9(38):1-5.
5. Dharmaraja S, Jain V, Anjoy P, Chandra H. Empirical Analysis for Crop Yield Forecasting in India. Agric Res. 2020;9(1):132-138.

6. O'Neal MR, Engel BA, Ess DR, Frankenberger JR. Neural network prediction of maize yield using alternative data coding algorithms. Biosys Eng. 2002;83(1):31-46.
7. Kaul M, Hill RL, Walthall C. Artificial neural network for corn and soybean prediction, Agricultural System. 2005;85:1-18.
8. Jeong JH, Resop JP, Mueller ND, Fleisher DH, Yun K, Butler EE, Kim SH. Random forests for global and regional crop yield predictions. PLoS One. 2016;11(6):e0156571.
9. Kumar S, Kumar V, Sharma RK. Rice Yield Forecasting Using Support Vector Machine. Int J Rec Tech and Eng. 2019;8(4).
10. Palanivel K, Surianarayanan C. An approach for prediction of crop yield using machine learning and big data techniques. Int J Comp Eng & Tech. 2019;10(3):110-118.
11. Choudhury K, Jha GK, Das P, Chaturvedi KK. Forecasting Potato Price using Ensemble Artificial Neural Networks. Indian Journal of Extension Education. 2019;55(1):71-77.
12. Lischeid G, Webber H, Sommer M, Nendel C, Ewert F. Machine learning in crop yield modelling: A powerful tool, but no surrogate for science, Agricultural and Forest Meteorology. 2022;312.
Available:https://doi.org/10.1016/j.agrformet.2021.108698
13. Wall L, Denis L, Pierre- Majorique L. The early explanatory power of NDVI in crop yield modelling. International Journal of Remote Sensing. 2008; 29(8):2211-2225.
14. Das P, Jha GK, Lama A, Parsad R, Mishra D. Empirical mode decomposition based support vector regression for agricultural price forecasting. Indian Journal of Extension Education. 2020;56(2):7-12.
15. Janifer JJS, Ahmed AAM, Bose A, Raj N, Sharma E, Soar J, Chowdhury, MWI. Spatiotemporal hybrid random forest model for tea yield prediction using satellite-derived variables. Remote Sensing. 2022;14(3):805.
Available:https://doi.org/10.3390/rs14030805
16. Shetty SA, Padmashree T, Sagar BM, Cauvery NK. Performance analysis on machine learning algorithms with deep learning model for crop yield prediction. In Data Intelligence and Cognitive Informatics. 2021;739-750.
Springer, Singapore.
17. Gong L, Yu M, Jiang S, Cutsuridis V, Pearson S. Deep learning based prediction on greenhouse crop yield combined TCN and RNN. Sensors. 2021;21(13):4537.

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