

## WEATHER-BASED RICE CROP YIELD FORECASTING USING DIFFERENT REGRESSION TECHNIQUES & NEURAL NETWORK APPROACH FOR PRAYAGRAJ REGION

### ABSTRACT

Rice crop yield data and weather data for the past twenty-nine years (1991-2019) were collected for Prayagraj District of Uttar Pradesh from DACNET & College of Forestry, SHUATS Prayagraj respectively. Analysis was carried out by fixing 26 years of dataset for calibration (90%) and the remaining dataset for validation (10%). In this study, 75.9 % of data were used for training the ANN model and the remaining 24.1% of data were used for testing and Validation (100%) for model efficiency. Stepwise linear regression technique and neural network used for predicting the yield of rice crop. Performance analysis is done with the least Normalized Root Mean Squared Error (nRMSE) values for the study. Regression-based model outperforms the ANN model as the performance of nRMSE is best suited. The present study concluded that the performance of Bright Sunshine Hour with respect to nRMSE and coefficient of determination is recorded at 0.00025 and 0.94 respectively.

**Keywords:** Regression, yield, model, parameter, artificial neural networks, coefficient of determination

### Introduction

UNDER PEER REVIEW

Agriculture has always been one of the vital occupations that serve mankind, both in terms of livelihood and employment. Due to the substantial increase in the population, the nutritional status of the poor is growing bad, which must be improved. The major effect of population increase has been prominently shown on the environment, the damage of which is increasing rapidly, which ultimately hinders agricultural production. Predicting the yield of the crop is a vital agricultural problem. Every single farmer constantly tries to estimate how much yield can be expected from their fields. In the past, the prediction of yield was calculated by analyzing the farmer's previous results on a particular crop. Crop yield is primarily dependent on weather conditions, pests, and the planning of harvest operation. Accurate information about the history of crop yield is a vital criterion for making decisions related to agricultural risk management. The proposed method uses Regression and Neural Network techniques to predict the yield of rice. Predicting crop yield is crucial to addressing emerging challenges in food security, particularly in an era of global climate change. Accurate yield predictions not only help farmers make informed economic and management decisions but also support famine prevention efforts.

Several yield prediction models have been developed using number of weather variables and crop data to establish regression and artificial neural network models. These have been widely used to evaluate the association between weather parameters and crop yield of different regions (Banakara, *et al.*, 2018; Latwal, *et al.*, 2017; Diwanet *al.*, 2018 and Kumar *et al.*, 2014). Bankaraet *al.*,2018) compared the technique of Multiple Linear Regression (MLR). (Diwanet *al.*, 2018) also developed crop yield forecast model by employing stepwise linear regression technique and found that temperature (maximum & minimum) and relative humidity were significant predictors in crop yield forecast. Similar studies were conducted by (Kalubarme and Ahuja, 1996; Chauhanet *al.*, 2009) to develop agrometeorological data based rice yield prediction model for Karnal, central Punjab and Bulsar district of Gujarat respectively.(Ghosh *et al.*, 2014) also developed rice forecast model for various district of West Bengal.

In this research paper, regression models and ANN technique are used for predicting the yield of rice crop depending on weather and crop parameters are proposed. The best yield prediction technique has been developed based on the nRMSE.

### **Study area**

The study was conducted for Prayagraj district of Uttar Pradesh. Prayagraj is situated in Southern Eastern part of the state of Uttar Pradesh. It lies between the parallels of 24° 47' north latitude and 81° 19' east longitudes. Prayagraj is bounded on the eastern side by district Sant Ravi Das Nagar (Varanasi).

## **MATERIALS AND METHODS**

Yearly Production (Kg) and area (ha) under Rice crop in Prayagraj District for the period 1991 – 2019 were collected from the (Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare). Weekly and Monthly data of maximum & minimum Temperature (°C), Relative Humidity (%), and Rainfall (mm) number of rainy days for the period 1991 – 2019 were collected from the agro meteorological observatory located in Sam Higginbottom University of Agriculture, Technology and Sciences, Department of Agrometeorology,

College of Forestry, Prayagraj. In the present study rice yield forecasting was done using **artificial neural network & multi linear** regression technique. SPSS software was used for the statistical analysis and to develop a multiple regression model for rice.

*Development of Statistical Regression Model Using Weekly Weather Parameter*

Overall analysis was carried out by fixing 26 years of dataset for calibration (90%) and remaining dataset for the validation (10%). In this method the rice yield prediction model was developed using weekly weather parameter of crop growing season .i.e. SMW 22<sup>nd</sup> to 37<sup>th</sup>. In this study weekly weather parameters are considered as independent variables and rice yield was considered as **dependent variable** in SPSS. The stepwise regression technique in SPSS was used to develop the multivariate statistical models.

*Development of Statistical Regression Model using Weighted and Un-weighted Parameter*

Here, the rice crop yield data set consists of a total 29 years. Out of which 26 year records are considered as training & testing. Weighted and un-weighted parameter is considered as independent variable and rice yield was considered as dependent variable in SPSS. The stepwise regression technique in SPSS was used to develop the multivariate statistical models.

Simple and weighted weather indices are developed for Prayagraj District. Summation of individual weather **variable or interaction** of two weather variable at a time were used for generating simple weather indices, sum product of individual weather variable or interaction of weather variables and its **correlation with adjusted crop yield** were resulted with weighted weather indices. Computation of simple and weighted weather indices were based on following formula.

**Table1. Simple and weighted weather indices:**

**Simple weather indices**

$$Z_{ij} = \sum_{w=1}^m X_{iw}$$

$$Z_{ij} = \sum_{w=1}^m X_{iw}$$

$$Z_{ii'j} = \sum_{w=1}^m X_{iw} X_{i'w}$$

**Weighted weather indices**

$$Z_{ij} = \sum_{w=1}^m r^j_{iw} X_{iw}$$

$$Z_{ii'j} = \sum_{w=1}^m r^j_{ii'w} X_{iw} X_{i'w}$$

Where,

$X_{iw}/X_{i'w}$  = value of  $i^{th}/i'^{th}$  weather variable under study in weather week,

$r^j_{iw}/r^j_{ii'w}$  = correlation coefficient of yield with  $i^{th}$  weather variable or product of  $i^{th}/i'^{th}$  weather variable in the week.

<i>Weather Parameter</i>	<i>Simple weather indices</i>					<i>Weighted Weather indices</i>				
	<i>Tmax</i>	<i>Tmin</i>	<i>R/F</i>	<i>RH(I)</i>	<i>RH(II)</i>	<i>Tmax</i>	<i>Tmin</i>	<i>R/F</i>	<i>RH(I)</i>	<i>RH(II)</i>
<i>Tmax</i>	<i>Z10</i>					<i>Z11</i>				

<i>Tmin</i>	Z120	Z20		Z121	Z21					
<i>R/F</i>	Z130	Z230	Z30	Z131	Z231	Z31				
<i>RH (I)</i>	Z140	Z240	Z340	Z40	Z141	Z241	Z341	Z41		
<i>RH (II)</i>	Z150	Z250	Z350	Z450	Z50	Z151	Z251	Z351	Z451	Z51

**Table 2: Simple and weighted weather indices used for developing model:**

Now, Simple and weighted weather indices used for developing model are given in Table 4.

### *Development of Statistical Regression Model Using Bright Sunshine Hour with Weighted & Un-weighted Parameter*

In this study, rice yield prediction model was developed using Bright Sunshine Hour of crop growing season .i.e. SMW 22<sup>nd</sup> to 37<sup>th</sup> with weighted & un-weighted parameter. These parameters are considered as independent variable and rice yield was considered as dependent variable in SPSS. The stepwise regression method used in SPSS for statistical modeling.

### *Development of Statistical Regression Model Using Actual Evapotranspiration with Weighted & Un-weighted Parameter*

In this technique the regression equation for rice yield model was developed using Actual Evapotranspiration and weighted and un-weighted parameters were considered of SMW 22<sup>nd</sup> to 37<sup>th</sup> week. A multivariate model was then formed for the rice yield prediction using statistical regression technique in SPSS.

### *Rice yield forecasting using machine learning approach (ANN)*

Multilayer perceptron (MLP) technique is one of the popular neural network types. This network interpreted as a form input-output model, with weights and threshold (biases) as free parameters of the model. The number of hidden layers and the number of neurons in each hidden layer are often varied to optimize the performance of the final model (Tufail et al., 2008). The number of nodes in each layer is evaluated by trial and error. The MLP is trained with a training set of input and known output data. MLP transforms  $m$  inputs to  $n$  outputs through some nonlinear functions. With activation of the units in the output layer, the output of the MLP network will be determined as follows:

$$X_o = f(\sum X_h w_{ho} + b_j)$$

where,  $f$  is the activation function,  $X_h$  is the activation of hidden layer node;  $w_{ho}$  is the interconnection between hidden and output layers nodes and the  $b_j$  is the bias. Back propagation proposed by (Rumelhart et al., 1986) is the most popular algorithm for training of the MLP network (Wasserman, 1989; Fausett, 1994; Haykin, 1994).

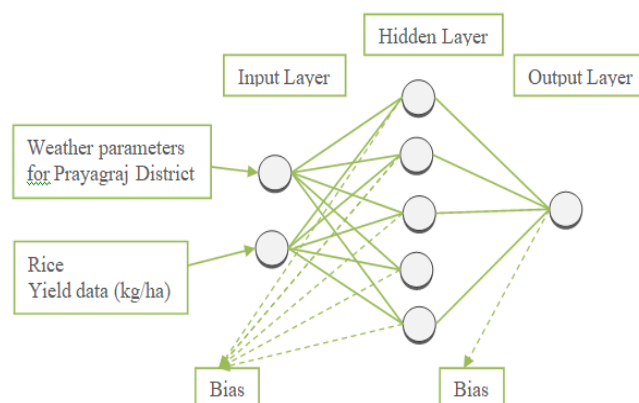


Fig.1. Different layers and different network structural representation of the ANN used in the study.

### Training ANN model

In this study, 76 % data were used for training ANN model and remaining 24% data were used for testing and for validation (100%) of data is been used. In this (Table 3), the ANN model with transfer functions of Hyperbolic Tangent gives the best results in training and testing stages (i.e., the least RMSE and nRMSE values).

Table 3: The Network Information

<b>Input Layer</b>	Number of Units <sup>a</sup>	30
	Rescaling Method for Covariates	Standardized
<b>Hidden Layer(s)</b>	Number of Hidden Layer	1
	Number of Units in Hidden Layer 1 <sup>a</sup>	5
	Activation Function	Hyperbolic Tangent
<b>Output Layer</b>	Dependent Variables	Yield
	Number of Units	1
	Rescaling Method for Scale Dependents	Standardized
	Activation Function	Identity
	Error Function	Sum of Squares

a. Excluding the bias unit

### Model Performance

For testing the performance of developed statistical forecasting models,  $R^2$ , Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (nRMSE) were calculated using the following formula:

$$R^2 = \left( \frac{\frac{1}{n} \sum_{i=1}^n (M_i - \bar{M}) (O_i - \bar{O})}{\sigma_M \sigma_O} \right)^2$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (O_i - M_i)^2}$$

$$nRMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (O_i - M_i)^2} \times \frac{100}{\bar{O}}$$

Where,

RMSE is Root Mean Square Error, nRMSE is Normalized Root Mean Square Error,  $P_i$  is the predicted value,  $O_i$  is the observed value,  $n$  is the number of observations and  $M$  is the mean of observed value.

Model performs excellent having nRMSE value > 10%, good having nRMSE value between 10-20%, fair having nRMSE value between 20-30%.

## RESULTS

### *Rice yield prediction using statistical modeling based on different weather parameters.*

In this method the rice yield prediction model was developed using various weather parameter of crop growing season .i.e. SMW 22<sup>nd</sup> to 37<sup>th</sup>. In this study various weather parameters are considered as independent variables and rice yield was considered as dependent variable in SPSS. The stepwise regression technique in SPSS was used to develop the multivariate statistical models are as follows:

#### *Development of Statistical Regression Model Using Weekly Weather Parameter*

In this only one model was developed, Model 1 has taken time as an independent factor to estimate the rice yield for Prayagraj region having R<sup>2</sup> value of about 0.55 which has explained the 55% variation on yield. Thus Model 1 was used to obtain forecast yield of rice for Prayagraj & can be observed from (Table 4). It may be observed for 2018 and 2019 model had underestimated the yield of rice crop (Table 5) where for the year 2017 Model has predicted the rice yield nearby actual yield, so it may be inferred that Model has performed well for 2017. It can be observed from the results of the (Table 5) that the percent deviation ranges from 7.05 to 15.99 is also indicating that the model is best fitted.

The above result can be justified by the research on yield forecasting of Rice and Wheat for Central Uttar Pradesh using Statistical Model by Khan *et al.*, 2020 in which twenty three years (1992-2015) weather data of rainfall (mm), Maximum and Minimum temperature (°C), maximum and minimum relative humidity (%) and yield data of rice and wheat crop for 12 districts were used for yield prediction using statistical method under FASAL Project, Department of Agronomy, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur Uttar Pradesh. The regression equation was generated for statistical method using SPSS package. The models were validated using 2 year (2016 and 2017) data. The result indicated that model explained 45 to 73 percent variation in rice crop yield and 49 to 74 percent variation in wheat crop in different districts.

*Table 4. Rice yield forecast equation using stepwise regression method based on different parameters.*

Parameter	Model	Yield forecast equation	R <sup>2</sup>	Std. Error
Bright Sunshine Hour	1	Y=3050.840+1.680(Z251)	0.406	260.872
	2	Y=2952.795+2.193(Z251)+51.442(TIME)	0.651	212.258
	3	Y=5520.653+2.084(Z251)+90.284(TIME)+2.942(Z131)	0.866	140.41
	4	Y=4218.547+2.711(Z251)+49.740(TIME)+3.797(Z131)+0.079(Z250)	0.946	96.51
Actual Evapotranspiration	1	Y= 1510.268+43.649*(TIME)	0.673	263.577
	2	Y=1944.048+51.035*(TIME)+1.40*(Z251)	0.782	219.598
	3	Y=3446.649+60.969*(TIME)+1.327*(Z251)+1.811*(Z131)	0.844	189.546
	4	Y=2260.633+55.417*(TIME)+1.796*(Z251)+1.783*(Z131)+0.043*(Z250)	0.875	173.237
Weighted and Unweighted	1	Y= 1588.077+35.641*(TIME)	0.556	248.822
	2	Y=2049.774+43.823(TIME)+1.499(Z241)	0.756	188.501

Weekly Weather	1	Y= 1588.077+35.641*(Time)	0.556	248.82
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### *Development of Statistical Regression Model using Weighted and Un-weighted Parameter*

In this case only two models had been developed. Model 1 has taken time as an independent factor to estimate the rice yield for Prayagraj region having R<sup>2</sup> value of about 0.55 and Model 2 has taken time and Z241 as the independent variable which has explained the 75% variation by them. Thus Model 2 was used to obtain forecasted yield of rice for Prayagraj (Table 4). It was observed for 2018 and 2019 model had underestimated the yield of rice crop (Table 5) where for the year 2017 Model has predicted the rice yield nearby actual yield, so it may be inferred that Model has performed well for 2017.

As a justification of work, a study is conducted by Kakati *et al.*, 2022, yield forecasting models which are based on simple weather variables and composite weather variables (weighted and un-weighted) for period of 1992-2018, various multiple linear regression equation is obtained for the forecasting of yield of rapeseed and mustard.

### *Development of Statistical Regression Model Using Bright Sunshine Hour with Weighted & Un-weighted Parameter*

Total four multivariate statistical models for rice yield had been developed using stepwise regression technique in SPSS. The best model from the total four models was used to obtain forecasted yield of rice for Prayagraj. In this case model four has taken Z251, Z131, Z250 and time as an independent factor to estimate the rice yield for Prayagraj region having R<sup>2</sup> value of about (0.94) It may be observed from the (Table 4) that model number four has been the best model with 94% variability explained by the parameters used in equation. It was observed that for the year 2019 (Table 5), Model 4 has overestimated the rice yield whereas for year 2017 it has underestimated the yield of rice crop. For the 2018 Model 4 has predicted the rice yield nearby actual yield, so it may be inferred that Model has performed well for 2018.

A same sort of research is conducted by Rajave *et al.*, 2018, the models are developed to forecast district level yield of rice in Chhattisgarh in mid-season, multi variate models has been developed based on BSS for period of 2014 and 2015. Forecast yield obtained is validated with actual yield of corresponding year to find the accuracy of developed model.

Methods		2017		2018		2019	
		Predicted Yield	Error %	Predicted Yield	Error %	Predicted Yield	Error %
Bright Sunshine Hour	Model 1	2315	15.6	2113	13.75	2438	13.74
	Model 2	2608.60	4.93	2397.43	23.15	2873.21	7.939
	Model 3	2521.54	8.10	2951.41	5.403	3307.75	-5.98
	Model 4	2396.01	12.6	3050.16	2.238	3347.20	-7.24
Actual Evapotranspiration	Model 1	2823.79	-2.9	2872.44	7.934	2921.08	6.405
	Model 2	2708.40	1.29	2591.85	16.92	2913.67	6.642
	Model 3	2560.40	6.69	2825.12	9.451	3058.41	2.005
	Model 4	2605.20	5.05	2894.44	7.229	3159.65	-1.23
Weighted and Unweighted	Model 1	2550.38	7.05	2586.02	17.11	2621.66	15.99
	Model 2	2576.01	6.12	2440.40	21.78	2774.16	11.11

Weekly Weather	Model 1	2550.40	7.05	2586.04	17.11	2621.68	15.99
Artificial Neural Network	Model 1	2533.87	7.65	2861.5	8.285	2954.19	5.344

Table5. Validation of Rice yield forecast models & error analysis.

### *Development of Statistical Regression Model Using Actual Evapotranspiration with Weighted & Un-weighted Parameter*

In this study the four yield prediction model has been developed for rice crop. Model 4 has shown the  $R^2$  value (0.87) with the variable i.e. minimum temperature & maximum relative humidity, maximum temperature & minimum temperature, minimum temperature & maximum relative humidity & time. Four models are used to obtain forecasted yield of rice for Prayagraj. It may be observed from the (Table 4) that model number four has been the most suitable model with 87% variability. It was observed that for the year 2019, Model 4 has overestimated the rice yield whereas for year 2017 it has underestimated the yield of rice crop. For the 2018 Model 4 has predicted the rice yield nearby actual yield, so it may be inferred that Model has performed well for 2018, it can be observed from (Table 5). This model was used to obtain forecast yield of rice for Prayagraj.

Based on the results conducted by Patil and Puttanna, 2009, a model has been generated to predict yield of finger millet with time for Bangalore area. A multi linear statistical equation has been developed based on GDD, actual Evapotranspiration and BSS for period of 1988-2005. This same model was used to forecast the yield of finger millet for Kharif 2005.

### *Rice yield forecasting using machine learning approach (ANN)*

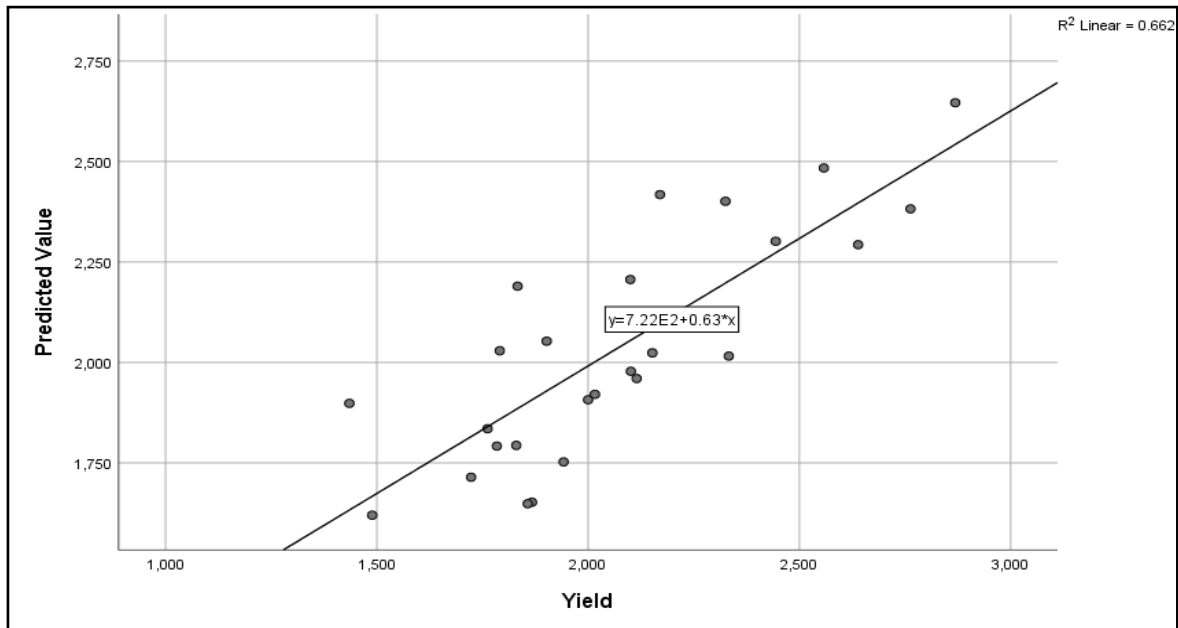
The model summary deals with Training and Testing within the sum of square error of 3.462 & 1.641 respectively has been mentioned in Table no 6. It may be observed from the Fig.2 that the coefficient of determination was 0.66 between the yield predicted by the ANN and observed yield. Rice yield model developed using ANN approach has explained 66% variability in rice due to weather parameters. It was observed that for the year 2019, model has underestimated the rice yield whereas for year 2017 has predicted the rice yield nearby actual yield, so it may be inferred that the ANN model developed by using MLP has performed well for year 2017.

The percent deviation for testing period was observed to vary from range 5.34 to 8.28 % (Table no.5), which had come under the accepted range of PD. It implies that model has perfectly predicted the yield of rice crop with maximum deviation of about 8%.

Table 6. Model summary of neural network model for training and testing for single network

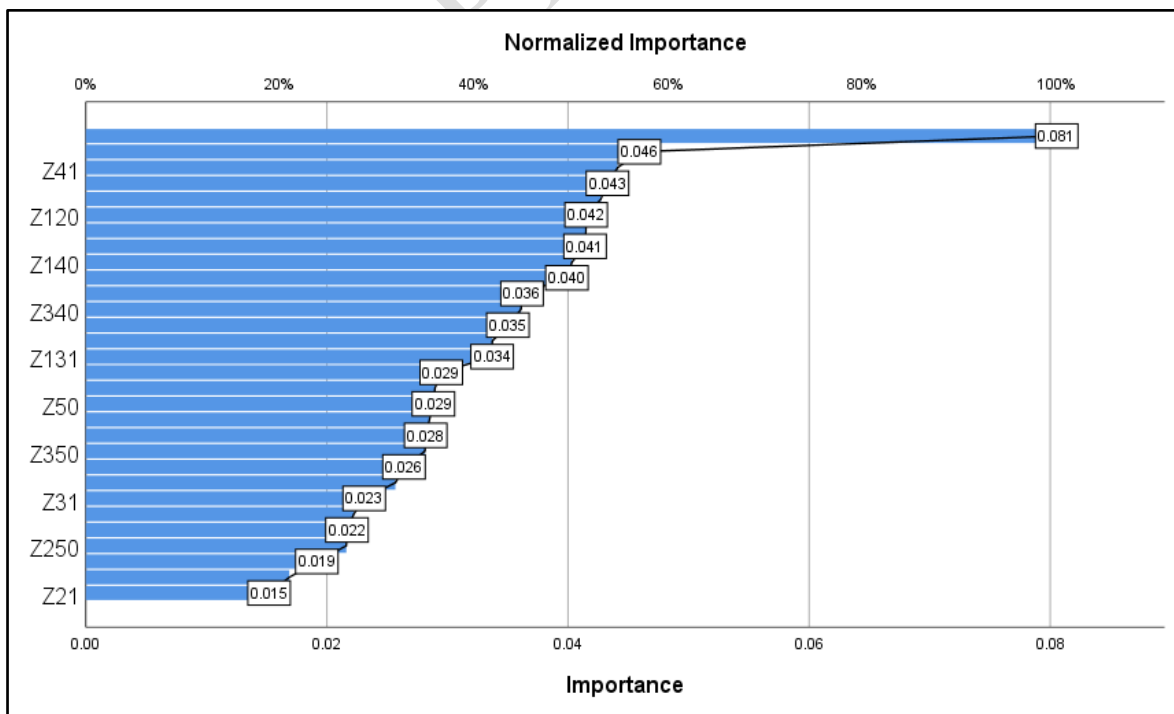
Training	Sum of Squares Error	3.462
	Relative Error	0.346
	Stopping Rule Used	1 consecutive step with no decrease in error
	Training Time	0:00:00.02
Testing	Sum of Square Error	1.641

	Relative Error	1.279
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**Fig.2. Comparison between actual and predicted yield**

A study is conducted by **Emamgholizadeh *et al.*, 2015** on ‘Seed yield prediction of sesame using artificial neural network’. In this study, two methods namely artificial neural network (ANN) and multiple regression model (MLR) were employed to estimate the seed yield of sesame (SYS) from readily measurable plant characters. The ANN and MLR were tested using field data. Results showed that the ANN predicts accurately with a root-mean-square-error (RMSE) of 0.339 t/ha and a determination of coefficient ( $R^2$ ) of 0.901.



**Fig.3. Relative contribution of predictors (weighted and un-weighted weather variables)**

Fig.3. presents the relative contribution of predictors (weighted and un-weighted weather variables) to the prediction of rice yield, obtained by ANN. The vertical axis represents top ten input variables (weighted and un-weighted weather variables) plotting the highest contributing variable (largest sum of square derivative SSD value) at the top and other variables below in their decreasing order of contribution to prediction of a given variable. The scale of the horizontal axis varies with the different mean importance. The variable having the highest SSD value (i.e, the highest contribution) is assigned a value of 100%. Other variables are assigned this value (in %) based on their SSD values in comparison to the SSD value of the highest contributing variable.

The predictors have significant contributions for the yield prediction of rice (Fig. 3). Results indicate that predictor, followed by the morning relative humidity (Z41) is the most important determinants of yield prediction.

### Performance analysis of fitted models for different methods

The accuracy of the predicted model has been presented with the help of RMSE and nRMSE. Among the regression models developed using stepwise regression technique, the best models are taken to compare it with the ANN model.

It may be observed from the (Table 7) that the model developed with regression technique having BSS and AET as additional input with the weighted and un-weighted weather parameters has shown best results with least nRMSE, followed by ANN network approach, weighted & un-weighted model and lastly by model developed by weekly weather parameters. If we go through by RMSE, then the model developed using AET has shown best result among all.

Table 7. Inter comparative study of Regression and ANN based fitted best models with accuracy measure of RMSE & nRMSE

Weekly Weather		Bright Sunshine		Weighted and Un-weighted		Actual Evapo-transpiration		Artificial Neural Network	
RMSE	nRMSE	RMSE	nRMSE	RMSE	nRMSE	RMSE	nRMSE	RMSE	nRMSE
0.436	0.0061	0.242	0.00025	0.451	0.00135	0.154	0.00027	0.215	0.00051

### Conclusion

The effort demonstrated that regression techniques can be utilized for yield prediction for the area with satisfactory results. In order to predict the yield, Regression model and ANN is utilized as a prediction tool as yield should be dependent variable and weather parameters should be independent variable. Every model is run a few times to deal with conceivable estimations of normalized root mean square and  $R^2$  statistics values. By utilizing the best method for the investigation, the forecast of generation of rice crop is done for chosen years. The outcomes demonstrate that the proposed regression model is a suitable method for foreseeing yield production. The results of different models are compared based upon the normalized root mean square,  $R^2$  statistics and percentage prediction error. The model which gives the lower Normalized root mean square, percentage prediction error and Higher  $R^2$  statistics values is considered to be the best model for crop yield prediction.

From the recent study, development of yield prediction model of rice crop using various statistical methods and machine learning approach shows the best performing method. It may be observed that the best fitted model based on performance analysis, the Model-4 of Bright Sunshine Hour with weighted and un-weighted weather parameter had the least nRMSE value of 0.00025 and higher variability of 94% among all other models.

As Bright Sunshine Hour based model had least nRMSE value from all the models selected from different technique used in the study, Thus Bright Sunshine Hour with weighted and un-weighted weather parameter is considered as the most accurate and reliable weather variable for the prediction of rice crop yield.

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Due to the substantial increase in the population, the nutritional status of the poor is growing bad, which must be improved.

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