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Artificial Neural Networks for Rice Yield Prediction in U.S. Nagar District of Uttarakhand

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Abstract

Rice crop yield data and weather data were considered in this study, covering the past 20 years (2001-2020) in U.S. Nagar District, Uttarakhand. The data was sourced from DACNET and the Meteorological Observatory, Department of Agrometeorology, College of Agriculture, G.B. Pant University of Agriculture and Technology Pantnagar, Uttarakhand based on weather parameters during different growth stages of rice. Maximum temperature, Minimum temperature, Relative Humidity A.M, Relative Humidity P.M, Total rainfall, Sunshine hours, Wind velocity and Evapotranspiration were the weather parameters considered for the study. Soft computing technique namely Artificial Neural Network was employed in the study using R software. Out of the 20-year data, 16-year data were used for model calibration while remaining 4 years data were used for model validation. The different models developed using ANN are Artificial Neural Network model using weighted and unweighted weather indices based on weather parameters at different phenological stages (ANN- WI), Artificial Neural Network model based on weather parameters at different phenological stages (ANN-W) and Artificial Neural Network model based on deviations of observed averages of weather parameters from its optimum value during the different phenological stages of rice (ANN-D).Yield prediction models were compared based on statistical indices and error percentage (during validation). On the basis of maximum value of R^2 (0.974) and minimum value of RMSE (73.06), ANN-WI (ANN model developed by using weather indices as predictors) model could perform better than the other two models developed using ANN i.e. ANN-W and ANN-D.

Key words : *Prediction, yield, parameter, artificial neural networks, model.*

Introduction

The Indian economy is based primarily on agriculture, with paddy crops holding a dominant position. Technology advancements have made it possible to forecast and predict weather patterns, which has increased yield. In India rice is grown in 45.07 million ha, the production level is 122.27 million tones and the productivity is about 2713 kg/ha (1). It is grown under diverse soil and climatic conditions the productivity level of rice is low compared to the productivity levels of many countries in the world. Also about 90 % of the cultivated land belongs to Marginal, Small and a Medium farmer which is another constrain in increasing the productivity of rice in the country. There are improved technologies and various interventions which could be adapted to increase the productivity in the country. Cultivation of hybrid rice has potential to increase the productivity and needs to be promoted. Weather and climatic factors, such as rainfall, temperature, humidity, and sunshine hours, are few of the many factors affecting the crop production (2,3). Numerous investigations and analyses have been conducted employing statistical methods such as regression models, agro-meteorological models, and statistical models for crop production prediction. Artificial Neural Networks (ANN), a data mining technique, are now being used in the agricultural sector to improve policy makers and agricultural scientists decision-making for the purpose of offering farmers consulting service.

Materials and Methods

Study area and data collection : Yield Prediction models were developed based on the kharif rice yield data (kg/ha) and weather data of Udham Singh Nagar district of Uttarakhand state. This district is a part of the Kumaon Division and is located in the Terai area of Uttarakhand state. It is situated between 78° 45' E and 80° 08' E longitude and spans between 28° 53' N and 29° 23' N latitude.Time series data of rice yield (*Oryza sativa* L.) for U. S. Nagar districts of Uttarkhand for 20 years (2001 to 2020) has been obtained from the Dacnet website and the weather data were collected from the Meteorological Observatory, Department of Agrometeorology, College of Agriculture, G.B. Pant University of Agriculture and Technology Pantnagar, Uttarakhand, India.

Variables under study

Kharif rice yield (kg/ha)

Weather parameters

1. Maximum temperature (Tmax, ºc)

2. Minimum temperature (Tmin, ºc)

3. Humidity A.M. (Relative humidity at 7:00 hours, RH Ð %)

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4. Humidity P.M. (Relative humidity at 14 hours, RH ÐÐ %)

5. Total rainfall (mm)

6. Sunshine hours (SSH, hrs)

7. Wind velocity (km/hr)

8. Evapotranspiration(mm)

Table-1 : Phenological stages of rice crop and duration of each stage.

Stages	Duration of each stages
Seeding	First fortnight of May
Transplant	15-20 Days after Seeding
Tillering	35-40 * DAT
Stem Elongation	45-50 * DAT
Panicle Initiation	70-75 * DAT
Booting/ Heading	100-105 * DAT
Flowering	115-120 * DAT
Milking	120-125 * DAT
Dough	125-130 * DAT
Maturity	130-135 * DAT

*DAT (Days after transplant)

Calculation of weather indices

Calculation of weather parameters at different growth stages of rice : Average weather parameters at different phenological stages were calculated from daily weather data for a period of 20 years. Tmax(i), Tmin(i), RH I(i), RH II(i), Rain(i), SSH(i), Wind(i), and EVP(i) were calculated from the provided daily weather data. Representation of different weather parameters during various phenological stages of rice are presented in table-2.

Detrending of yield : The fluctuations in yield time series data over the years is influenced by technology differences, climatic variability etc., leading to nonlinear and non- stationary trend which have to be removed before computing the basic correlation function to improve the prediction performance of the model (4).

Simple linear regression model can be fitted against time using the method of least squares.

$$Y_t \quad {}_0 \quad {}_1 t$$

Y_t = crop yield at time

t = time t is the predictor

${}_0$ and ${}_1$ are the coefficients

The residuals (detrended yield) of this model were used for indices calculation.

Calculation of weather indices based on weather parameters at its phenological stages.

Unweighted weather indices :

$$Z_{ij} \quad {}^{n}_{p\ 1} X_{ip}, \; Z_{ii'j} \quad {}^{n}_{p\ 1} X_{ip} X_{i'p}$$

Weighted weather indices :

$$Z_{ij} \quad {}^{n}_{p\ 1} r^{j}_{ip} X_{ip}, \; Z_{ii'j} \quad {}^{n}_{p\ 1} r^{j}_{ii} X_{ip} X_{i'p}$$

n is the number of phenological stages under study.

$X_{ip}/X_{i'p}$ is the value of i^{th}/ i'^{th} weather variable

$r_{ip}/r_{ii'p}$ is the value of correlation coefficient of detrended yield with i^{th} weather variable/ product of i^{th} and i'^{th} weather variables during p^{th} phenological stage.

j=0 represents unweighted weather indices and j=1 represents weighted weather indices.

Calculation of deviations of observed averages from optimum value during different growth stages : Deviations of average weather parameters from optimum value were calculated and used as predictors for developing yield prediction models. Deviations of average maximum temperature and average minimum temperature from their optimum values during vegetative phase, reproductive phase, grain filling stage and maturity stage were calculated. Similarly, deviations of total rainfall, average sunshine hours and wind velocity from their optimum values during the growth period were calculated and used as predictors. Optimum values of weather parameters during important growth stages of rice (5) and the representation of deviations of weather parameters from optimum values during important growth stages of rice crop are presented in table-4.

Software used : R-Software and Microsoft Excel 2016 has been used for analysis and modeling. R is an open-source software and an effective platform for data analysis and management.

Soft computing technique : In the present study, we have used three layers namely input, hidden and output feed-forward artificial neural network (ANN). Each layer consists of neurons or nodes interconnected with each other. The number of nodes in input and output layer is fixed by the dataset used. The main problem in the implementation ANN is to find the optimum number of hidden neurons or nodes. We have selected the number of hidden nodes by 'train' function of the 'caret' package using the method 'nnet' with 10-fold cross-validation in R software (Kuhn 2008). In the present study, all 72 indices were used as inputs whereas yield was the response variable (Fig.-1).

Results and Discussion

Yield prediction models developed using Artificial Neural Network : Artificial Neural network models were developed using rice yield data (kg/ha) and weather data at different phenological stages of wheat for a period of 20 years. For training the model 16 years data, from 2001-02

Table-2 : Representation of different weather parameters during various phenological stages of rice.

Weather parameters at different phenological stages of rice	Representation of weather parameters at different phenological stages of rice
Maximum temperature during the ith phenological stage	Tmax (i)
Minimum temperature during the ith phenological stage	Tmin (i)
Relative Humidity A.M during the ith phenological stage	RH (i)
Relative Humidity P.M during the ith phenological stage	RH II (i)
Total rainfall during the ith phenological stage	Rain (i)
Sunshine hours during the ith phenological stage	SSH (i)
Wind velocity during the ith phenological stage	Wind (i)
Evapotranspiration during the ith phenological stage	EVP (i)

Table-3 : Formation of Unweighted/ Weighted weather indices.

Parameters	Tmax	Tmin	RH 1	RH 2	Rain	SSH	Wind	Evp
Tmax	Z_{1j}							
Tmin	Z_{12j}	Z_{2j}						
RH 1	Z_{13j}	Z_{23j}	Z_{3j}					
RH 2	Z_{14j}	Z_{24j}	Z_{34j}	Z_{4j}				
Rain	Z_{15j}	Z_{25j}	Z_{35j}	Z_{45j}	Z_{5j}			
SSH	Z_{16j}	Z_{26j}	Z_{36j}	Z_{46j}	Z_{56j}	Z_{6j}		
Wind	Z_{17j}	Z_{27j}	Z_{37j}	Z_{47j}	Z_{57j}	Z_{67j}	Z_{7j}	
Evp	Z_{18j}	Z_{28j}	Z_{38j}	Z_{48j}	Z_{58j}	Z_{68j}	Z_{78j}	Z_{8j}

j=0, 1 for unweighted and weighted indices respectively.

Table-4 : Representation of Deviations of weather parameters from their optimum values during different phenological stages.

Weather parameters during different growth stages	Optimum values of weather parameters during growth stages	Deviations of weather parameters from optimum during growth stages
Maximum temperature during vegetative phase (ºC)	28.50	ZD_1
Maximum temperature during reproductive phase (ºC)	21.25	ZD_2
Maximum temperature during grain filling phase (ºC)	19	ZD_3
Maximum temperature during maturity stage (ºC)	20	ZD_4
Minimum temperature during vegetative phase (ºC)	13.25	ZD_5
Minimum temperature during reproductive phase (ºC)	8	ZD_6
Minimum temperature during grain filling stage (ºC)	7.5	ZD_7
Minimum temperature during maturity stage (ºC)	6	ZD_8
Total rainfall during growth period (mm)	280	ZD_9
Sunshine hours during growth period (hrs)	8.5	ZD_{10}
Wind velocity during growth period (km/hr)	5	ZD_{11}

to 2016-2017 were used and for testing the model 4 years data, from 2017-18 to 2020-2021 were used. Training set establish the relationship between predictors and dependent variable. Testing data set determine the prediction accuracy of developed models. The different models developed using ANN are Artificial Neural Network model using weighted and unweighted weather indices based on weather parameters at different phenological stages (ANN- WI), Artificial Neural Network model based on weather parameters at different phenological stages (ANN-W) and Artificial Neural Network model based on deviations of observed averages of weather parameters from its optimum value during the different phenological stages of rice (ANN-D).

ANN-WI model was developed by taking weighted and unweighted weather indices (Z indices) as explanatory variables (Table-3) and kharif rice yield (kg/ha) as dependent variable.

ANN-W model was developed by using Weather parameters at different phonological stages of rice as predictors (Table-2) and kharif rice yield (kg/ha) as dependent variable.

ANN-D model was developed by using deviations of observed averages of weather parameters during different phenological stages from its optimum values as predictors (Table-4) and kharif rice yield (kg/ha) as dependent variable.

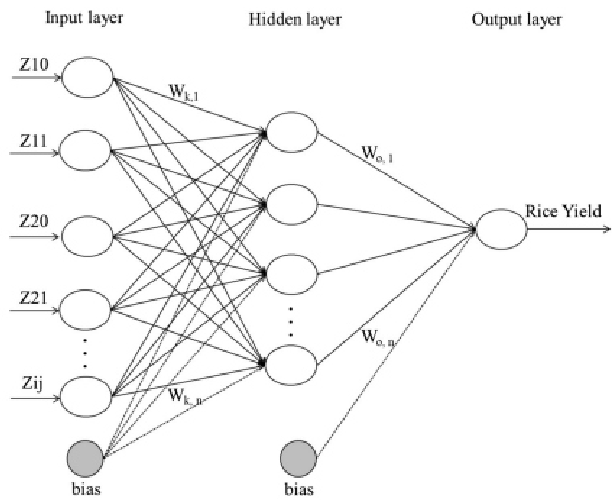

Fig.-1 : Schematical representation of the ANN used in the study. Zij indicates weather indices, Wk, n and Wo, n are hidden-input and output connection weights.

Table-5 : Yield Prediction Models developed using Artificial Neural Network.

Model	R^2cal	RMSE cal (Kg/ha)	nRMS Ecal (%)	MAE cal (Kg/ha)	R^2 val	RMSE val (Kg/ha)	nRMSE val (%)	MAEval (Kg/ha)
ANN-WI	0.983	61.93	0.054	53.28	0.974	73.06	0.201	31.176
ANN-W	0.981	71.71	0.021	21.96	0.842	126.3	0.334	79.67
ANN-D	0.973	80.11	0.05	48.21	0.813	189.17	0.356	125.41

Table-6 : Error analysis of models.

Year	Actual yield (kg/ha)	ANN-WI		ANN-W		ANN-D	
		Forecasted yield (kg/ha)	Error (%)	Forecasted yield (kg/ha)	Error (%)	Forecasted yield (kg/ha)	Error (%)
2017-18	3543.72	3555.41	-0.33	3484.35	1.68	3402.11	4.0
2018-19	3224.12	3198.92	0.78	3339.67	-3.58	3209.59	0.45
2019-20	3476.78	3502.37	-0.74	3478.92	-0.06	3400.23	2.20
2020-21	3727.61	3689.95	1.01	3854.22	-3.40	3525.04	5.43

Comparison of models developed using ANN : Statistical indices obtained for model ANN-WI, model ANN-W and model ANN-D is presented in table-5.

Table-5 reveals that the performance of model ANN-WI is found to be excellent and consistent during calibration and validation with lower RMSE (73.06) and high R^2 (0.974) (Table). On the other hand, model ANN-D performs poorly in comparison with other models. The model ANN-WI is the most appropriate one followed by the model ANN-W for the forecast of the rice yield during kharif season in U. S. Nagar district of uttarakhand.

Error analysis is carried out to evaluate the performance of the models during validation and is presented in Table 6 and a comparison of Actual rice yield with the Forecasted yield is also presented in Table-6.

Table-6 reveals that the error percentage of ANN-WI model varied from -0.74% to 1.01% during validation and it is the least range of error percentage recorded as compared to ANN-W and ANN-D models. Overall predictive performance of model ANN-WI found to be excellent.

Conclusions

Three different models were developed using ANN i.e. ANN model based on unweighted and weighted weather indices (ANN-WI), ANN model based on weather parameters at different phenological stages of rice (ANN-W) and ANN model based on deviations of observed averages from optimum value during important growth stages of rice (ANN-D). Yield prediction models were compared based on statistical indices and error percentage (during validation). On the basis of maximum value of R^2 (0.974) and minimum value of RMSE (73.06) ANN-WI (ANN model developed by using weather indices as predictors) model could perform better than the other two models developed using ANN i.e. ANN-W and ANN-D.

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