International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452
Maths 2023; SP-8(3): 23-29

https://www.mathsjournal.com
Received: 21-04-2023
Accepted: 22-05-2023

Chetna
Ph.D Scholar, Department of Mathematics & Statistics, CCSHAU, Hisar, Haryana, India

Monika Devi
Assistant Scientist, Department of Statistics, Department of Agricultural Economics, CCSHAU, Hisar, Haryana, India

Aditi
Research Scholar, Department of Mathematics and Statistics, CCS HAU, Hisar, Haryana, India

Ajay Sharma
Ph.D Scholar, Department of Mathematics & Statistics, CCSHAU, Hisar, Haryana, India

Corresponding Author:
Aditi
Research Scholar, Department of Mathematics and Statistics, CCS HAU, Hisar, Haryana, India

A study on impact of climate change on rice yield

Chetna, Monika Devi, Aditi and Ajay Sharma

Abstract
Climate change may have an impact on food availability, accessibility, and quality. For instance, agricultural output may be impacted by decreased projected temperature rises altered precipitation patterns, altered extreme weather occurrences and decreased water availability. Different statistical models have been developed as a result to examine how climate change may affect rice yield at various phases of the crop as well as it has been attempted to forecast its output for Karnal District. Time series data on rice yield for the past 35 years crop and weather variables have been used in the Karnal area of Haryana from 1985-1986 through 2019-20. The relationship between rice crop and various models has been investigated. You can boost your yield by creating fresh weather indices from weekly data. The model takes the weather variable into account. It was discovered that the best models (models I, II, and VII, VIII) for assessing the impact of specific weather variables were linear functions across weeks adjusted crop yield for trend effect and weekly data and weather variables as the independent variables. A forecast model was also built and the findings showed that forecasting at the 15th week of the crop period or one and a half months before harvest, was reliable.

Keywords: Weather indices, crop production, statistical model, and pre-harvest forecast

1. Introduction
There is a significant impact of climate fluctuation and change on agricultural production. Indian agriculture, in particular, is extremely subject to changes in climate conditions. The south-west monsoon's performance, as well as ideal weather conditions, is critical to Indian agriculture's prosperity. Farmers and policymakers alike are concerned about unusual weather patterns. The burning of fossil fuels by automobiles, coal by power plants, industrial sector emissions of greenhouse gases, large-scale deforestation, and other factors have contributed to an increase in the earth's surface temperature and a shift in rainfall patterns in recent years. Climate change has resulted in a loss of moisture, an increase in the frequency of cyclones, thunderstorms, and floods, as well as a rise in sea level, which might inundate many coastal cities and towns. Even a little increase in the earth's surface temperature might cause a significant decline in the country's agricultural productivity, compromising the quality of rice (particularly basmati rice), fruits, vegetables, and medicinal plant products that are highly valued for export. Various studies have been conducted Agrawal *et al*. (1980, 1983 and 1986) [2, 3, 6], Jain *et al*. (1980) [5], Yadav *et al*. (2014) [14], and Sisodia *et al*. (2014) [14] have all studied in this approach to find out how crop yield and weather variables are related. Agnolucci & De (2020) [1], Shammi & Meng (2021) [13], Cao *et al*. (2022) [4], and Pham *et al*. (2022) [11] have also studied the impact of climate change on crop yield using various statistical approaches. As a result, in this research, an attempt is made to investigate the individual effects of weather conditions on rice yield and their forecast for the Karnal district (Haryana).

2. Material and Methodology
The research was carried out in the Karnal area in North-Central Haryana, India, which is located between the latitudes of 26°47' and 82°12'. It is located in Haryana's North-Central Plain Zone (EPZ). Rice can be successfully grown in humid to subhumid climates with subtropical and temperate climates and soils with good water holding ability. In soils with a pH range of 5.5 to 6.5, rice thrives best.

Clay, silt clay, and silt clay loam are three of the greatest soil types for growing rice. Medium to medium-heavy texture deep alluvial soils are readily cultivable. Rice crops require between 1400 and 1800 millimetres of water. Rice farming is a natural choice for the area due to the ideal temperature, soil, and abundance of irrigation facilities. Rice is often grown during the Kharif season, when the atmosphere is more conducive to rice agriculture in terms of water availability. The study looked at weekly weather information on maximum and minimum temperatures as well as morning relative humidity relative humidity in the evening, rainfall, and sun-shine(hours) from 1985-86 to 2019-20. The Department of Agro Meteorology, Chaudhary Charan Singh Haryana Agriculture University of Hisar, Haryana, provided this meteorological data. The Statistical Abstract of Haryana provided time series data on rice yield for the Karnal district (Haryana) for the years 1985-86 to 2019-20.

2.1 Crop Season

Rice is commonly grown in Karnal District in the third week of June, when the average daily temperature is around 41°C. Rice is sown at a lower temperature, which causes in poor germination, limited tillering, and early flowering, exposing the floral components to heat damage. All of these variables lower agricultural yields. Vegetative, reproductive, and ripening stages are the three stages of crop growth. The early growth stage encompasses the time from sowing to emergence, as well as the crop's vegetative stage, which lasts for eight weeks from June 18 (25^{th} SMW) to August 12(32^{th} SMW). The reproductive and ripening stages of the crop are included in the maturity phase, which lasts 9 weeks from August 13 (33^{rd} SMW) until October (41^{st}SMW). As a result, this study included data from 17 weeks (25^{th}SMW to 41^{st}SMW) for each weather variable under consideration.

2.2 Statistical Analysis

The impact of weather conditions on yield was examined using weekly meteorological data from June 1 (about a fortnight before sowing) to harvest, while forecast models were developed using data from the half crop season. Data from a fortnight before to sowing were included because it is thought that this time period affects crop establishment.

2.2.1 Statistical Models Studied:

The statistical models have been developed by expressing effect of change in meteorological variables on yield in w th week as a linear function of respective correlation coefficient between yield and weekly weather data (Agrawal *et al*., 1986) [3]. In all, we have considered eight models.

Model I: The first model due to Agrawal *et al.* (1986) [3]

$$Y = a + b_0\sum_{w=1}^{n} X_w + b_1\sum_{w=1}^{n} r_{xy(w)} X_w + b_2\sum_{w=1}^{n} r^2_{xy(w)} X_w + cT + \varepsilon$$

$= a + b_0Z_0+b_1Z_1+b_2Z_2+cT+e$

a, bj(j=0, 1, 2), and C are model parameters. N is the number of weeks before harvest. W is the week identification. Y is rice yield (kg/ha). The yield has a correlation coefficient of rxy with the weather variable being studied in the current week of X_w, and vice versa (w). It is anticipated that the error terms will follow a normal distribution with a mean of zero and a constant variance σ^2 where T refers for the trend variable (Time index) and ε stands for the error terms.

Model II: The model changes to the following when the phrase b_2Z_2 is dropped:

$$Y = a + b_0Z_0 + b_1Z_1 + cT + e$$

Model III & IV: The only difference between these models and models I and II is that $r_{xy(w)}$ is calculated using yield adjusted for trend impact.

Model V: The following model is produced by inserting quadratic terms of meteorological parameters and correlation coefficients into model I:

$$Y = a + b_0\sum_{w=1}^{n} X_w + b_1\sum_{w=1}^{n} r_{xy(w)} X_w + b_2\sum_{w=1}^{n} r^2_{xy(w)} X_w + b_{00}\sum_{w=1}^{n} X_w^2 + b_{11}\sum_{w=1}^{n} r_{x^2y(w)} X_w^2 + b_{22}\sum_{w=1}^{n} r^2_{x^2y(w)} X_w^2 + cT + \varepsilon$$

$$= a + b_0Z_0 + b_1Z_1 + b_2Z_2 + b_{00}Z_{00} + b_{11}Z_{11} + b_{22}Z_{22} + cT + \varepsilon$$

Model VI: The quadratic terms b_2Z_2 and $b_{22}Z_{22}$ are eliminated from model V to achieve this, leaving the following model:

$$Y = a + b_0Z_0 + b_1Z_1 + b_{00}Z_{00} + b_{11}Z_{11} + cT + e$$

Model VII & VIII: Models V and VI are identical with the exception that adjusted yield for trend influence is used to determine correlation coefficients.

Data on relative humidity have been converted to arc-sine root proportions, as they were previously expressed in percentages. To choose significant generated weather indices, stepwise regression was employed (independent variables in the models). By differentiating the models with respect to X_w, the impacts on yield per unit change in weather variables in wt^h week have been estimated.

Forecast model and time of forecast

The subsequent model including single and various combinations of weather variables to exhibits their interaction effects on crop yield was fitted using partial crop season data.

$$Y = a + \sum_{i=1}^{p}\sum_{j=0}^{1} b_{ij} Z_{ij} + \sum_{i\neq i'=1}^{p}\sum_{j=0}^{1} b_{ii'j} Z_{ii',j} + cT + e$$

Where

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

Y stands for yield, p for number of meteorological variables employed, and m for number of weeks taken into account when creating the model. yield and the ith weather variable (Xi)/the sum of the two weather variables (and) in the week are correlated. The symbol T stands for the temporal trend variable. The variables in the model are a, bij, bii',j, and c. The error terms e are presumptively distributed normally, with a mean of zero and variance. To fit the model, various values of m (m=12, 13,..., 15) were employed. As production was to be predicted well in advance of harvest, the data collected after the 15^{th}weeks were not used. The coefficient of determination is calculated using the following formula (R^2).

Accuracy Measures of developed model

Several accuracy parameters, including as R2 (Coefficient of Determination), Percent Deviation, Percent Standard Error (CV), and Root Mean Square Error (RMSE) were employed to verify the suitability of the developed model.

3. Results and Discussion

To determine the ideal correlation between crop output and various meteorological variables, we looked at eight different models. A overview of the fitted models is shown in Table 1 along with their coefficient of determination (R2) values. Table 1 demonstrates that I models that used yield-adjusted correlations outperformed models that used simple correlations, and (ii) including quadratic terms of weather variables and the second power of the correlation coefficient did not generally improve the model. However, after fitting them with data using step-wise regression analysis, the models I, II, VII, and VIII came out to be identical. To investigate the influence of meteorological variables on rice yield, we adopted model VII.

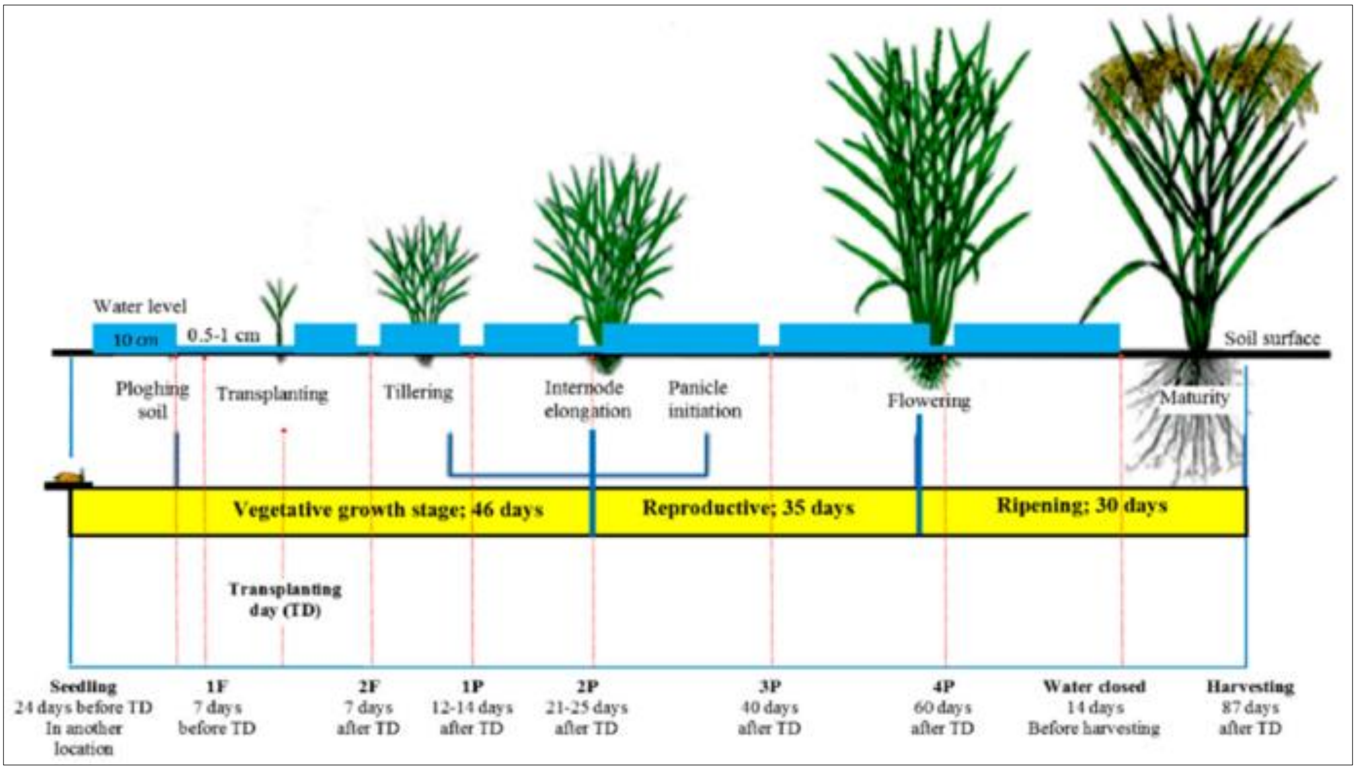


Fig 1: Stages of rice crop growth

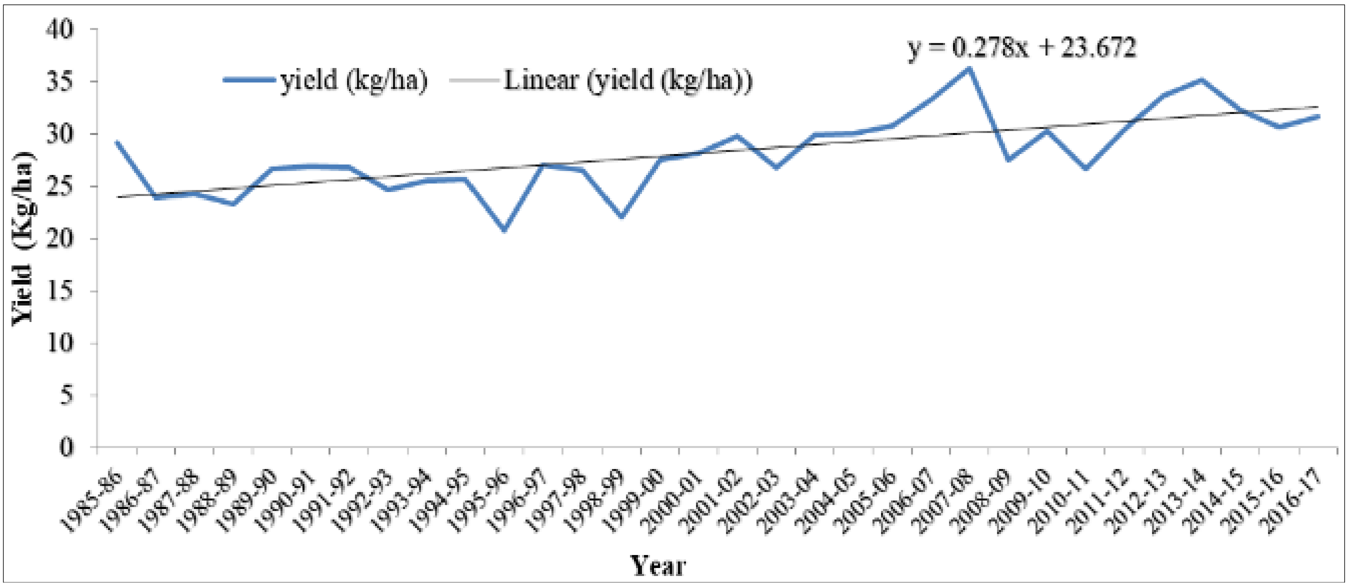


Fig 2: Annual Rice yield (Kg /ha) of Karnal district

3.1 Effect of climatic variables on Rice yield

The effects of a one-unit increase in meteorological variables on average yield at various crop growth stages have been explored in this section. Table 2 lists the effects. Reversing the vertical scale results in the impact of one unit decreasing below the average.

3.1.1 Effect of Maximum Temperature

The Multiple Regression equation for Maximum Temperature (Model-I) is shown below.

$$Y = -38.8951 + 0.095Z_0 + 1.393Z_1 + 0.900T$$

(R^2=0.73)

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = 0.095 + 1.393 r_{xy(w)}$$

During the initial growth and vegetative growth stages of the crop a 1 °C increase over the average weekly maximum temperature had a positive effect on rice yield (Table 2). During the reproductive stage an increase in maximum temperature has had the opposite effect on rice yield. Increases in maximum temperature were found to be advantageous in general during the ripening and maturity stages.

3.1.2 Effect of Minimum Temperature

The following is the Multiple Regression equation (Model-I) for Minimum Temperature is given below:

$$Y = -23.552 + 1.144 Z_1 + 0.881 T \quad (R^2=0.65)$$

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = 1.144 r_{xy(w)}$$

Table 2 shows that a temperature increase of 1 °C above the average has a negative effect during the vegetative growth stage. However, the effect was helpful throughout the reproductive stage. During the ripening and maturity stages of the crop, the effects have been determined to be unfavorable in general.

3.1.3 Effect of Relative Humidity at Morning

The following is the Multiple Regression equation (Model-V) for Relative Humidity at morning is given below:

$$Y = 86.354 - 0.886 Z_{11} + 0.943 T \quad (R^2=0.74)$$

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = 0.886 \times 2 X_w r_{x^2 y(w)}$$

With the exception of the last stage of crop growth, a rise of one percent over the normal weekly humidity has had a generally positive effect on rice output. *i.e.*, ripening and maturity period. Hence, rise in humidity during last four - five weeks before the harvest could be detrimental to the rice yield.

3.1.4 Effect of Relative Humidity at Evening

The following is the Multiple Regression equation (Model-V) for Relative Humidity at evening is given below:

$$Y = -46.177 + 0.001 Z_{11} + 1.068 T \quad (R^2=0.74)$$

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = 0.001 \times 2 X_w r_{x^2 y(w)}$$

With the exception of the harvesting stage, the effects were generally negative on rice yields throughout the crop growth period. As a result, a slight increase in humidity in the evening during the harvesting stage may be helpful to rice yield. However, the 20th week has no impact.

3.1.5 Effect of Rainfall

The following is the Multiple Regression equation (Model-1) for Rainfall is given below:

$$Y = 6.993 - 0.002 Z_1 + 0.752 T \quad (R^2=0.76)$$

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = -0.002 \times 2 X_w r_{x^2 y(w)}$$

In general, a one-mm increase in rainfall over the normal weekly rainfall has had favorable effect up to the vegetative growth stage. However, the effects were negative during the reproductive, ripening, and maturity stages of crop development. It is also common knowledge that increased rainfall during the ripening and harvesting stages reduces rice production.

3.1.6 Effect of Sunshine Hours

The following is the Multiple Regression equation (Model-V) for Sunshine Hours is given below:

$Y=7.090-0.002Z_1-0.003Z_{00}+0.750T$ ($R^2=0.73$)

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = -0.002 r_{xy(w)} - 0.003 \times 2 X_w$$

Increases in sunshine hours of one unit over the normal weekly sunshine hours have been found to be helpful in general during the crop's sowing and vegetative growth stages (Table 2). On the other hand due to an increase in the number of sunshine hours a detrimental effect has been observed during the reproductive, ripening and maturity stages of the crop. However, Table 2 shows that a one-hour increase in sun shine hours over the weekly sunlight hours during the eighth week of the crop resulted in a 1.3 percent increase in rice output.

Table 1: The Coefficient of determination (R^2) for various Models

Weather variables	Model							
	I	II	III	IV	V	VI	VII	VIII
Max Temperature	0.73	0.73	0.65	0.65	0.72	0.72	0.66	0.66
Min Temperature	0.65	0.65	0.61	0.61	0.64	0.64	0.62	0.62
RH at morning	0.64	0.64	0.60	0.60	0.74	0.74	0.73	0.73
RH at evening	0.67	0.67	0.63	0.63	0.77	0.77	0.76	0.76
Rainfall	0.76	0.76	0.65	0.65	0.75	0.75	0.74	0.74
Sunshine hours	0.69	0.69	0.66	0.66	0.73	0.73	0.72	0.72

Table 2: Percent change in yield with per unit increase in weather variable over its average value

Growth Phases	Week No	SMW	Weather Variables					
			Max. Temp	Min. Temp.	RH at Morning	RH at Evening	Rainfall	Sunshine Hours
Preparation	1	22	0.021	-0.073	0.234	-0.000	2.900	0.094
	2	23	0.011	0.220	0.350	-0.000	-0.000	0.167
	3	24	0.121	-0.061	0.163	-5.900	8.180	0.159
Sowing	4	25	0.224	-0.054	0.119	3.040	0.000	0.028
Vegetative Growth Stage	5	26	0.168	0.233	0.047	-1.250	0.000	0.070
	6	27	0.015	0.087	0.156	-8.500	9.600	0.162
	7	28	0.067	0.238	0.078	-4.800	0.000	0.045
	8	29	0.072	-0.032	0.198	-3.500	0.000	1.345
	9	30	0.008	-0.123	0.203	-0.000	0.000	0.111
	10	31	0.014	0.169	0.206	6.920	0.000	0.055
	11	32	0.011	-0.086	0.261	-6.100	0.000	0.188
Reproductive Stage	12	33	0.109	0.280	0.123	-6.110	0.000	0.034
	13	34	0.181	0.062	0.165	-0.000	6.320	-0.062
	14	35	0.499	0.261	0.405	-0.000	-0.000	-0.005
	15	36	0.085	0.049	0.307	-7.400	-1.100	-0.034
	16	37	0.187	0.194	-0.361	-7.260	-0.000	0.001
Ripening Stage	17	38	0.083	-0.139	-0.356	1.440	-0.000	-0.078
	18	39	0.032	0.042	-0.416	6.300	-9.700	-0.020
	19	40	0.123	-0.022	-0.560	8.240	-6.800	-0.059
	20	41	0.110	-0.130	-0.504	0.000	-0.000	-0.033

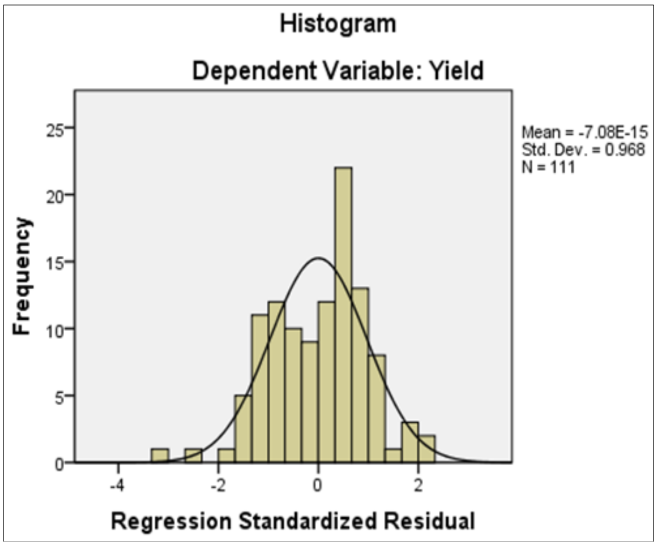
Table 3: Models fitted for Kurukshetra district at m= 12, 13, 14,15 and 16

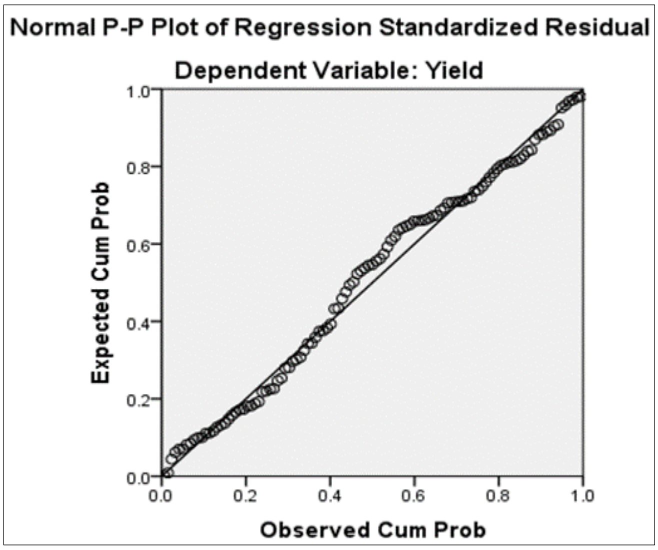
m	MODEL	R^2	Adj.R^2
12	$Y = 14.220 - 1.085Z_{40} - 0.048Z_{451} + 0.023Z_{241} + 0.811T$ (7.784) (0.407) (0.018) (0.004) (0.145)	81.0	79.6
13	$Y = 14.420 - 1.082Z_{40} - 0.041Z_{451} + 0.020Z_{241} + 0.815T$ (7.782) (0.403) (0.016) (0.006) (0.148)	82.1	78.0
14	$Y = 14.420 - 1.080Z_{40} - 0.041Z_{451} + 0.020Z_{241} + 0.815T$ (7.783) (0.402) (0.012) (0.008) (0.147)	83.9	79.7
15	$Y = 13.420 - 1.088Z_{40} - 0.045Z_{451} + 0.019Z_{241} + 0.810T$ (7.780) (0.406) (0.013) (0.001) (0.141)	84.0	79.8
16	$Y = 14.423 - 1.080Z_{40} - 0.042Z_{451} + 0.021Z_{241} + 0.810T$ (7.779) (0.402) (0.012) (0.004) (0.144)	79.9	78.2

It is the best time to predict wheat output in the Karnal district according to a perusal of Table 3 in 15th week ((second week of September)) as the value of R^2 does not significantly increase when data from later periods are included. Finally, the model generated for m=15 is

$$Y = 13.420 - 1.088Z_{40} - 0.045Z_{451} + 0.019Z_{241} + 0.810T$$

(R^2=0.84)





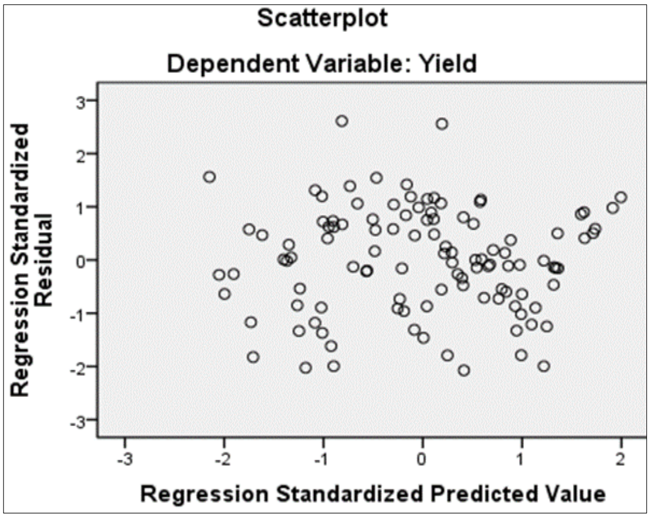


Fig 3: Regression diagnostics of the selected zonal model

Table 3: Forecast yields along with accuracy measures. The above model makes it clear that the significant explanatory variables are the weighted weather indices interactions of rainfall and sunshine hour as well as unweighted weather indices of rainfall and weighted weather indices interactions of minimum temperature and rainfall including time trend variable (T). The yield predictions for the year 2017-18, 2018-19 and 2019-20 have been calculated using the forecast model that has been fitted as mentioned above and are shown in table 3. The analysis of table 4results shows that the forecast yield and the observed yield were quite closely matched. The forecast percent deviation ranged 1.70 to 5.66.The forecast percent standard error ranged from 3.76 to 4.12. Therefore, it can be inferred that the aforementioned model can accurately predict wheat yield one and a half month before the harvest.

Table 4: Comparison between observed and forecast yield along with statistical measures at m=20 for Karnal district of Haryana

Year	Actual Yield (q/ha)	Forecast Yield (q/ha)	Percent Deviation	PSE (CV)	RMSE
2017-18	37.97	36.06	5.03	3.76	1.68
2018-19	33.50	32.93	1.70	4.12	
2019-20	37.60	35.47	5.66	3.82	

4. Conclusion

In terms of the effect of individual weather variables on rice yield, it can be stated that an increase in the magnitude of most weather variables per unit has had a negative effect on yield throughout the crop season, with the exception of particular stages during crop growth. The production of rice increased by one degree Celsius above the average weekly maximum temperature during the early growth and vegetative growth stages of the crop. During the reproductive stage of the crop, each unit rise in minimum temperature has had a favourable effect. With the exception of the last stage, ripening and harvesting, a rise of one percent over the average weekly humidity has had a generally favourable effect on rice output throughout the crop growth period. In general, a one-mm increase in rainfall over the normal weekly rainfall has had a favourable effect up to the vegetative growth stage. During the sowing and vegetative growth stages of the crop, In general, it has been shown that an increase of one unit above the average weekly sunshine hours is beneficial. It may also be determined that a reliable pre-harvest forecast for rice can be produced 1.5 months before to harvest utilizing the suggested forecast model with a fair percent standard error of around 4.12%

5. References

1. Agnolucci P, De Lipsis V. Long-run trend in agricultural yield and climatic factors in Europe. Climatic Change. 2020;159(3):385-405.
2. Agrawal Ranjana, Jain RC, Jha MP. Joint effects of weather variables on rice yields. Mausam. 1983;34(2):177-181.
3. Agrawal Ranjana, Jain RC, Jha MP. Models for studying rice crop weather relationship. Mausam. 1986;37(1):67-70.
4. Cao J, Wang H, Li J, Tian Q, Niyogi D. Improving the Forecasting of Winter Wheat Yields in Northern China with Machine Learning–Dynamical Hybrid Subseasonal-to-Seasonal Ensemble Prediction. Remote Sensing. 2022;14(7):170-177.
5. Jain RC, Agrawal Ranjana, Jha MP. Effect of climatic variables on rice yield and its forecast. Mausam. 1980;31(4):591-596.
6. Mall RK, Singh R, Gupta A, Srinivasan G, Rathore LS. Impact of climate change on Indian agriculture: A Review. Climatic Change. 2006;78:445-478.
7. Mingione F. Forecasting with principal component analysis: an application to financial stability indices for Jamaica. Journal of Jamaica. 2011;3:1-27.
8. Muema FM, Home PG, Raude JM. Application of benchmarking and principal component analysis in measuring performance of public irrigation schemes in Kenya. Agriculture. 2018;8(10):162.
9. Niedbała G. Application of multiple linear regression for multi-criteria yield prediction of winter wheat. Journal of Research and Applications in Agricultural Engineering. 2018;63(4):253.
10. Pal Y, Sharma HC, Kumar A. Prediction of sugarcane yield in weather variable parameters. India Sugar. 1996;46(7):513-517.
11. Pham HT, Awange J, Kuhn M, Nguyen BV, Bui LK. Enhancing Crop Yield Prediction Utilizing Machine Learning on Satellite-Based Vegetation Health Indices. Sensors. 2022;22(3):719.
12. Rathore LS, Singh KK, Saseendran SA. Modelling the impact of climate change on rice production in India. Mausam. 2001;52(1):263-274.

13. Shammi SA, Meng Q. Modeling the Impact of Climate Changes on Crop Yield: Irrigated vs. Non-Irrigated Zones in Mississippi. Remote Sensing. 2021;13(12):22-49.
14. Sisodia BVS, Yadav RR, Kumar S, Sharma MK. Forecasting of pre-harvest crop using discriminant function analysis of meteorological parameter. Journal of Agrometeorology. 2014;16(1):121-125.
15. Singh VP, Khedikar S, Verma IJ. Improved yield estimation technique for rice and wheat in Uttar Pradesh, Madhya Pradesh and Maharashtra States in India. Mausam. 2019;70(3):541-550.