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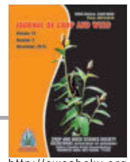

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A study on impact of climate change on wheat production in Kurukshetra district of Haryana and development of forecast models

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ABSTRACT

The present paper attempts to study the effect of wheat production in the Kurukshetra area of Haryana, India, as affected by changes in meteorological conditions.The study examined 35 years of time series data on wheat yield as well as weekly data on five weather variables for the crop season from 1985-86 to 2019-20. Using weather indices and time trend as regressor variables and wheat yield as regress and the effect of various factors was investigated using step-wise regression analysis. It has been found that weighted weather indices of each weather variable including time trend have exhibited significant effect on the wheat yield. It has also been found that rise in all five weather variables except relative humidity has been detrimental to wheat yield during harvesting phase of the crop.The overall results indicate the fact that changes in climatic variables show detrimental as well as beneficial role depending upon the phases of crop production in getting out its final output.

Keywords : Climate change, regression model, weather indices, weather variables.

Climate change and fluctuation have a huge impact on agricultural production. Indian agriculture, in particular, is extremely subjected 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. Changes in climate factors have resulted in a loss of moisture, an increase in the frequency of cyclones, thunderstorms and floods, as well as a rise in sea level. It is possible that several coastal cities and towns may be destroyed. In terms of food grain production, even a small increase in the earth's surface temperature could result in a significant drop in the country's wheat production, as well as a significant reduction in the quality of rice (especially basmati rice), fruits, vegetables, and medicinal plant products that are highly valued for export. Various research workers (Ranjana *et al*., 1983 & 86; Jain *et al*., 1980; *Kaul and Ram* 2008; Rathore *et al*., 2001; Saseendran *et al*., 1999; Mall *et al*., 2006) have worked in the direction to workout relationship between crop yield and weather variables.Various research workers (Monika *et al*., 2022 and Chetna *et al.,* 2022) have worked in the direction of modelling and forecasting wheat production in Punjab states of india using hierarchical times series models and development of zonal wheat yield forecast models through Principal Component Analysis. The current work attempts to investigate the impact of changes in meteorological variables on wheat yield by creating appropriate statistical models.

MATERIALS AND METHODS

Area and crop covered

The study was conducted in the Kurukshetra area of eastern Haryana, India, between the latitudes of 29° 522 and 30° 122 and the longitudes of 76° 262 and 77° 042 in the northeastern part of the state. It lies in the eastern plain zone of Haryana. On the surface, the soils are loamy sand to sandy loam and in the subsurface, sandy loam to clay loam, however they are easily ploughable. Wheat farming is a natural choice for the area due to the ideal climate, soil and lack of irrigation facilities. Wheat crops are often cultivated during the *rabi* season, when the weather is more conducive to their growth.

Data description

Yield data

Time series data on yield for wheat crop of Kurukshetra district of Haryana for35 years (1985-86 to 2019-20) have been collected from the Statistical Abstract of Haryana.

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Weather data

The Department of Agro Meteorology, Chaudhary Charan Singh Haryana Agriculture University of Hisar, Haryana, provided weekly weather data on weather variables in the Kurukshetra district of Haryana during the different growth phases of wheat crop from 1985-86 to 2019-20. The data was collected for the first 27 weeks of crop cultivation, from the 41^{st} to 52^{nd} standard meteorological week (SMW) of one year and the 1^{st} to 15^{th} SMW of the following year. The study included data from five weather variables: Minimum Temperature, Maximum Temperature, Relative Humidity, Rainfall and Sun-shine (hr).

Crop season

Wheat is usually planted in October and harvested in April. The stages of crop development are covered in detail here.

Preparation and sowing phase

This phase covers 3 weeks from about October 8 (41^{th} SMW) to about October 28(43^{th} SMW). This phase of the crop is important because in this phase the land is prepared for the sowing. If the weather condition is adverse during this phase the sowing of the crop is generally delayed.

Vegetative phase

The vegetative phase covers 10 weeks from about October 29 (44^{th} SMW) to about Dec. 31(52^{nd} SMW).Vegetative phase include germination, crown root initation stage, tillering, jointing. Germination generally takes about 5-7 days depending upon temperature.The crown-root initiation(CRI) occurs in the dwarf wheat at about 20-25 days after sowing(DAS).The crown roots comprise several nodes. Tiller production in wheat often starts at 15 DAS with a new tiller added every 4-5 days until 45 DAS. Jointing is the peak plant growth stage starting from 45-60 DAS.The upper and intermediate nodes expand during this period.The internodes become progressively, nodes expand during this period.The internodes become progressively longer from the base to the top.The uppermost internodes is the longest.

Flowering, milking and dough stage

This phase covers 10 weeks from about Jan. 1 (1^{st} SMW) to about March 11(10^{th} SMW). This stage is also known as physiological maturity.

Ripening and harvesting phase

This phase covers 5 weeks from about March 12 (11^{th} SMW) to about April 15(15^{th} SMW).

Individual effect of weather variables

Two new variables from each weather variable were developed in order to analyse the effect of each weather variable following the procedure developed by Ranjana *et al*.(1986). Let X_{iw} be the value of the i^{th} weather variable X_i at w^{th} weeks (w = 1, 2,…..n). In this study n was 27. Let r_{iw} be the simple correlation coefficient between weather variable X_i at w^{th} week and adjusted crop yield (Y) for trend effect over a period of K years. The generated variables are then given by

$$Z_{ij} = \sum_{w=1}^{n} r_{iw}^{j} X_{iw} \Big/ \sum_{w=1}^{n} r_{iw}^{j} \ ; j = 0, 1 \quad \text{......................} (1)$$

For j = 0,
We have unweighted generated variable

$$Z_{i0} = \sum_{w=1}^{n} X_{iw} \Big/ n \quad \text{..} (2)$$

and for j = 1, we get weighted generated variables

$$Z_{i1} = \sum_{w=1}^{n} r_{iw} X_{iw} \Big/ \sum_{w=1}^{n} r_{iw} \quad \text{..} (3)$$

The new variables Z_{i0} and Z_{i1} were generated for each weather variable i(i=1, 2….p). The following model was then fitted to study the effect of individual weather variable on crop yield

$$Y = a_0 + a_1 Z_{i0} + a_2 Z_{i1} + c\mathrm{T} + e \ i=1,2,....p \quad \text{..........} (4)$$

where, Y is the actual crop yield; T is variable expressing time effect, a_0, a_1, a_2 and c are parameters of the model to be evaluated for the effect of variables and ε is error term supposed to follow normal distribution with mean zero and variance σ^2. The above model is fitted using step wise regression method for each weather variable.

The effects were obtained by differentiating the fitted model (4) with respect to X_{iw} variable X as follows :

$$\frac{\partial Y}{\partial X_{iw}} = a_1 / n + a_2 r_{iw} \Big/ \sum_{w=1}^{n} r_{iw} \quad \text{.................................} (5)$$

Let Y_0 be the yield of the crop estimated from fitted model (4) by replacing X_{iw} by $\bar{X}_{iw}$ where is the average of (i^{th} weather variable) at w^{th} week over k years. is then given by

$$Y_0 = \hat{a}_0 + \hat{a}_1 \sum_{w=1}^{n} \bar{X}_{iw} \Big/ n + \hat{a}_2 \sum_{w=1}^{n} r_{iw} \bar{X}_{iw} \Big/ \sum_{w=1}^{n} r_{1w};$$

ignoring trend effect

where $\hat{a}_i$ (i = 0, 1, 2) are estimated value of a_i

RESULTS AND DISCUSSION

New weather variables have been created (unweighted and weighted means of weekly weather data). Stepwise regression analysis was used to investigate the impact of individual meteorological variables on agricultural productivity. At various weeks of crop growth, fitted models were used to determine the effects of one unit rise above average in climatic variables. Reversing the vertical scale resulted in the impact of one unit decreasing below the average. Table1 and 2 summarises these consequences, the results are presented and discussed in the following section.

Effect of maximum temperature

The Multiple Regression equation (Model-I) for Maximum temperature is given below.

$$Y = -30.933 + 0.954Z_0 + 4.414Z_1 + 0.986T \quad (R^2=0.72^{**})$$

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = -0.954 + 4.414 r_{xy(w)}$$

The effect of 1^0C above the average during preparation, sowing and Crown root initation stage has been demonstrated to be positive. The effect of 1^0C above the average during germination, jointing stage, flowering and milking stage has been demonstrated to be negative. However, the impacts varied between the tillering and dough stages. During the ripening and harvesting stages, the impacts have been found to be favorable. The 7^{th}, 8^{th}, 20^{th}, 21^{st}, 24^{th}, 25^{th} and 26^{th} weeks all showed significant benefits.

Effect of minimum temperature

The Multiple Regression equation (Model-VII) for Minimum temperature is given below

$$Y = 32.143 - 2.148Z_0 + 0.362Z_{00} - +0.060Z_{11} + 0.768T \quad (R^2=0.75^{**})$$

The results were derived from

$$\frac{\partial X}{\partial X_{xy(w)}} = -2.148 + 0.362 \times 2X_w + 0.060 \times 2X_w r_{x^2 y(w)}$$

From Table 2 during the preparation, seeding, germination, tilling stage, jointing stage, flowering and milking stages, it was discovered that a 1^0C increase above the average had a beneficial effect. During the Crown root initation stage, however, the benefits were inconsistent. During the dough stage, the impacts have been found to be favourable. The 20^{th} week revealed considerable positive benefits. The effect of 10 degrees Celsius over the average during the ripening and harvesting stages has been shown to be negative.

Effect of relative humidity

The Multiple Regression equation (Model-V) for Relative Humidity is given below.

$$Y = -61.905 - 0.198Z_0 + 8.174Z_1 + 0.001Z_{00} + 0.903T \quad (R^2=0.71^{**})$$

The effects were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = 0.198 + 0.001 \times 2X_w + 8.174 \times 2X_w r_{x^2 y(w)}$$

With the exception of the harvesting stage, the effects were generally positive to wheat yields throughout the crop growing period. However, the seventh week had no effect.

Effect of rainfall

The Multiple Regression equation (Model-III) for Rainfall is given below.

$$Y = -7.006 - 0.202Z_0 + 0.040Z_{11} + 1.194T \quad (R^2=0.71^{**})$$

The results were derived from

$$\frac{\partial Y}{\partial X_{xy(w)}} = 0.202 + 0.040 \times 2X_w r_{x^2 y(w)}$$

In general, a one-mm increase in rainfall over the normal weekly rainfall had a negative effect on the germination, dough, ripening and harvesting stage. However, during preparation, sowing, crown root initation stages, tillering, jointing, flowering and milking stage the effects were changeable. During the milking process, the effects have been found to be useful. In the 19^{th} week, the results were noticeable.

Effect of sunshine hours

The Multiple Regression equation (Model-III) for Sunshine Hours is given below.

$$Y = -16.883 - 7.153Z_0 + 7.833Z_1 + 1.321T \quad (R^2=0.71^{**})$$

The effects were obtained from

$$\frac{\partial Y}{\partial X_{xy(w)}} = -7.153 + 7.833 r_{xy(w)}$$

Increases in sunshine hours of one unit over the normal weekly sunshine hours have been observed to have a negative impact on crop yield throughout the wheat production cycle, except for the milking, dough and ripening stages. As a result, an increase in sunlight hours from milking through harvesting phases may be favorable to wheat productivity. The effects were most noticeable between the 19^{th} and 27^{th} weeks. However, the fourth week had no effect.

It is the best time to predict wheat output in the Kurukshetra district according to a perusal of Table 3 in 20^{th} week (3^{rd} week of February) as the value of R^2 did not significantly increase when data from later periods were included. Finally, the model generated for m=20 is

$$Y = 14.420 - 1.080Z_{40} - 0.041Z_{451} + 0.020Z_{241} + 0.815T$$

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

Table 1: Coefficient of determination (R^2) for Kurukshetra district under several models

Weather variables	Model							
	I	II	III	IV	V	VI	VII	VIII
Maximum Temperature	0.72	0.72	0.71	0.71	0.72	0.72	0.72	0.72
Minimum Temperature	0.70	0.70	0.71	0.71	0.71	0.71	0.75	0.75
Relative humidity	0.68	0.68	0.69	0.69	0.71	0.71	0.70	0.70
Rainfall	0.71	0.71	0.75	0.75	0.71	0.71	0.70	0.70
Sunshine hours	0.69	0.69	0.70	0.70	0.68	0.68	0.69	0.69

Table 2: Per cent change in yield per unit increase in weather variable over its average value

Growth phase	Week no.	SMW	Weather variable				
			Max. temp	Min. temp	Relative humidity	Rainfall	Sunshine hours
Preparation and Sowing	1	41	0.483	0.003	6.814	0.001	-61.35
	2	42	1.745	0.008	3.889	-0.000	-4.294
	3	43	0.776	0.017	4.001	0.004	-4.685
Germination	4	44	-0.452	0.009	4.421	-0.002	0.000
Crown root initation stage	5	45	0.169	0.008	1.605	0.001	-4.813
	6	46	0.036	-0.010	0.402	-0.001	-4.144
	7	47	1.610	-0.000	0.000	-0.004	-4.281
Tillering stage	8	48	1.311	0.003	0.825	-0.000	-3.299
	9	49	0.318	0.002	1.144	-0.003	-3.777
	10	50	-1.088	0.008	2.980	0.003	-3.451
Jointing stage	11	51	-0.114	0.014	2.506	-0.012	-2.674
	12	52	-0.156	0.031	2.751	-0.010	-2.850
	13	1	-1.253	0.009	3.758	0.006	-3.806
Floweing stage	14	2	-1.010	0.024	1.972	-0.003	-2.800
	15	3	-0.369	0.006	2.700	-0.000	-4.098
	16	4	-1.509	0.009	3.268	0.010	-3.679
Milking stage	17	5	-0.747	0.008	3.780	-0.005	3.543
	18	6	-1.657	0.019	3.536	0.001	2.610
	19	7	-0.762	0.022	4.038	1.840	2.424
Dough stage	20	8	1.356	3.100	4.403	-0.011	1.748
	21	9	1.589	0.002	4.137	-0.001	1.839
	22	10	-0.299	-0.012	2.257	-0.004	3.253
Ripening stage	23	11	0.533	-0.031	2.180	-0.002	1.950
	24	12	1.452	-0.006	1.993	-0.009	2.744
	25	13	1.308	-0.003	4.503	-0.004	2.184
Harvesting stage	26	14	1.138	-0.012	-3.210	0.004	1.937
	27	15	0.732	-0.010	-3.114	-0.002	2.666

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 4. The results of Table 4 show that the forecast yield and the observed yield were quite closely matched. The forecast per cent deviation ranged from 1.32 to 8.93.The forecast per cent standard error ranged from 3.47 to 3.75. Therefore, it can be inferred that the aforementioned model can accurately predict wheat yield one and a half month before the harvest.

CONCLUSION

The weighted weekly means of all five climatic parameters, including temporal trend, had a substantial impact on wheat production (T). The impact of a 1°C increase in maximum temperature has been found to be positive in general during the crop's preparation, sowing,

Table 3: Models fitted for Kurukshetra district at m=18, 19, 20, 21 and 22

m	MODEL	R^2	Adj.R^2
18	$Y = 14.220 - 1.085Z_{40} - 0.048Z_{451} + 0.023Z_{241} + 0.811T$		
	(7.784) (0.407) (0.018) (0.004) (0.145)	81.0	79.6
19	$Y = 14.420 - 1.082Z_{40} - 0.041Z_{451} + 0.020Z_{241} + 0.815T$		
	(7.782) (0.403) (0.016) (0.006) (0.148)	82.1	81.0
20	$Y = 14.420 - 1.080Z_{40} - 0.041Z_{451} + 0.020Z_{241} + 0.815T$		
	(7.783) (0.402) (0.012) (0.008) (0.147)	83.9	79.7
21	$Y = 13.420 - 1.088Z_{40} - 0.045Z_{451} + 0.019Z_{241} + 0.810T$		
	(7.780) (0.406) (0.013) (0.001) (0.141)	79.9	78.2
22	$Y = 14.423 - 1.080Z_{40} - 0.042Z_{451} + 0.021Z_{241} + 0.810T$		
	(7.779) (0.402) (0.012) (0.004) (0.144)	79.7	78.1

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

Year	Observed yield(q ha^{-1})	Forecast yield(q ha^{-1})	Per cent deviation	PSE	RMSE
2017-18	48.20	47.56	1.32	3.75	2.68
2018-19	49.51	51.37	3.76	3.47	
2019-20	47.12	51.32	8.93	3.48	

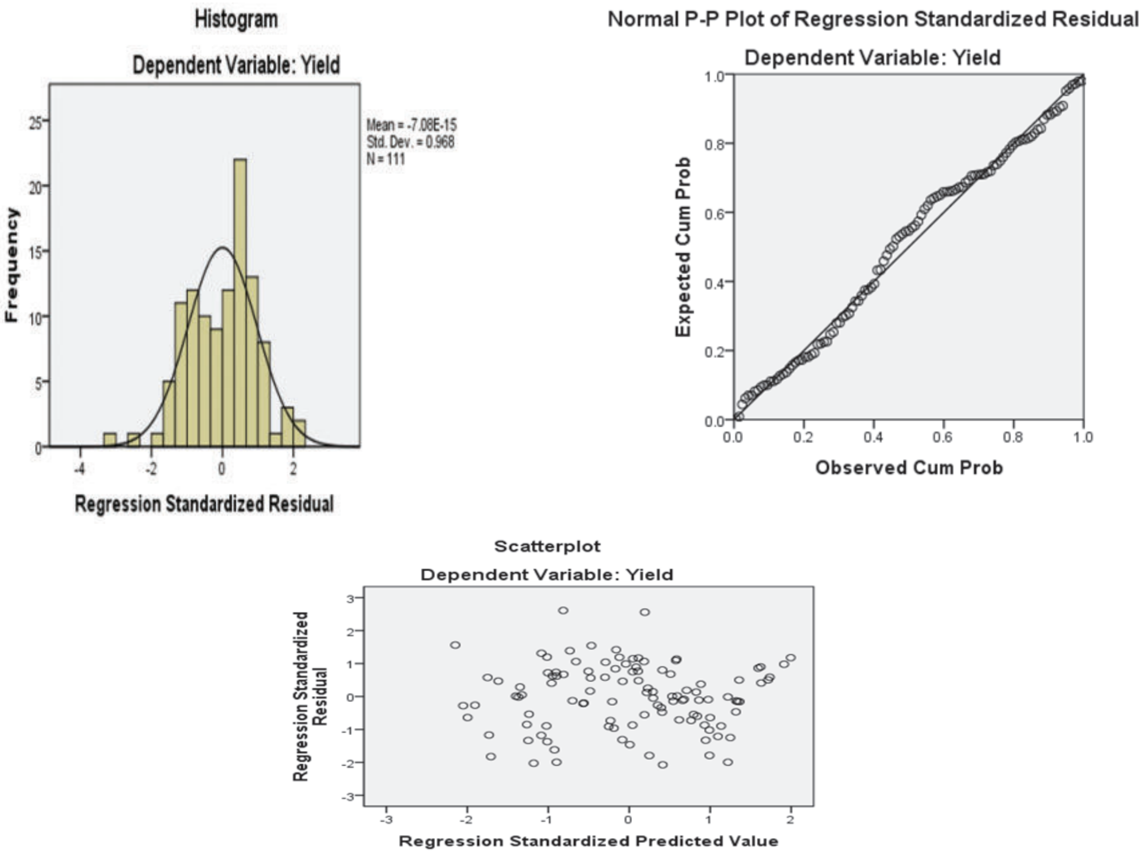

Fig. 3.1: Regression diagnostics of the selected zonal model

germination, tillering stage, jointing stage, flowering and milking stages. In general, a 1°C increase in minimum temperature has been proven to be unfavourable during the ripening and harvesting stages of the crop. Increased humidity at the maximum crown root initiation to flowering stage may benefit wheat yields, but it may have the opposite effect during the last weeks, i.e. harvesting stage. It's worth noting that a one-hour increase in sunshine hours during the crop's harvesting phase increased wheat output by 3.2 percent. Except during harvesting, rainfall plays a critical impact in all phases of crop production. However, the overall data show that increases in all five meteorological variables, save relative humidity, are deleterious to wheat yield during the harvesting period of the crop. It also shows that, depending on the stages of crop production and the final output, changes in climatic variables can have both negative and positive effects.

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