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EVALUATING WHEAT YIELD IN SOUTHWESTERN PUNJAB USING STATISTICAL MODELS

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Wheat (*Triticum aestivum* L.) is staple cereal crop. India ranks second in terms of area and production of wheat after rice. In Punjab, wheat is a major cereal crop, grown during *rabi* season. In 2016-17, the crop was grown in an area of 34.95 lakh hectares with production and productivity of 176.36 lakh tonnes and 50.46 quintals per hectare, respectively (Anonymous, 2018). Aggarwal (2008) studied the impact of rising temperature on the wheat crop and found that every 1˚C rise in temperature caused yield loss of 4-5 million tons in India even with adaptation strategies like carbon fertilization, changes in water availability through irrigation, etc. By 2080-2100, reduction of up to 40 per cent in the food grain production in India is an assumption under increasing temperature (Fischer *et al*., 2002, Parry *et al*., 2004 and IPCC, 2007). The wheat productivity will suffer a negative impact as per the predictions by the warming scenarios. IPCC (2014) has predicted an increase in global surface temperature in the range of 0.4-2.6˚C during 2046-2065 and 0.3-4.8˚C during 2081-2100 relative to 1986-2005.

Climate change has been realized everywhere all over the world in terms of increasing temperature and change in precipitation. The negative impact of change in temperatures and precipitations on Indian agriculture has been reported from the many recent studies (Neog *et al*., 2020). A huge variation in wheat productivity is also being observed due to the increased weather variability in recent years. Thus, wheat productivity in India has been impacted by climate change. Under the current climate change scenario, it is indispensable to maintain crop productivity at a higher level to meet the future food demand of the increasing population of India. As wheat is a long day thermo-sensitive plant, the rising temperature due to climate change affects the production of the crop in India. Both the beginning and end of wheat crop season are limited by the onset and end of favorable temperature regimes which ultimately affect the quality and yield of wheat (Reddy, 2006). Low temperature and dew formation during the early phase promote tillering, whereas, hot and humid condition encourages insects and diseases. On the other hand, wheat yield is reduced by 7.5 per cent for every 1.0˚C increase in temperature during the grain growth period of the crop (Gracila *et al.,* 2009). Efforts have been made to relate the weather viabilities with the yield of the crop by many workers.

In the present study, the data on the yearly production, area of cultivation, irrigation, and fertilizer under wheat yield crop in Bathinda (1981-2017) and Faridkot (2001-2017) were collected from the Statistical Abstract of Punjab. Long series of weekly data of different weather elements (maximum temperature, minimum temperature and rainfall) were collected from the two research stations of PAU, i.e. Regional Research Station, Bathinda, and Regional Research Station, Faridkot. The data covers the months during which the wheat crops completed their life cycle i.e. 43rd to 12th standard meteorological weeks.

The sensitive period window (43rd -12th SMW) for the crops is considered and a basic model (model 1) was developed using the weather parameters. G Stat was used for correlation studies and the development of multiple regression equations between yield and weather variables for the sensitive crop periods. The average reported crop yield was considered as dependent variable, while weather parameters were considered as independent variables. The correlation and regression techniques were used to correlate yield and meteorological parameters for statistical and phenological significance. For regression analysis, statistically and phenologically significant sensitive periods were selected in terms of standard meteorological weeks (SMWs).

The basic model was then modified (model 2) through the inclusion of an assumed composite index while other independent variables were kept constant. The advancement in the various agricultural technologies like the use of high yielding variety seeds, timely operations, better irrigation and drainage facilities, large scale use of fertilizers and pesticides, etc, have contributed to the yield of earlier years. Superimposition of the agricultural technology impact in the form of linear time scale dummy variable is done for improvement of the yield forecast accuracy.

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SPSS software was used as a model for wheat forecast analysis. Analysis of regression was done using SPSS (Statistical Product and Service Solutions) software (model 3). Computation of Pearson's correlations was done for weather parameters and their combination along with the observed yield of crops SPSS software was used to analyze the multiple regression between the dependent variable (yield) and independent variables (time, sum and sum products for different weather parameters) while regression formula was used for the formulation of the regression equations.

Regression equation for all the three models is given by:

$ye = a0 + \sum aixi + \sum ajxj$

Where,

ye = Estimated yield, kg/ha

a0 = Regression constant

ai = Regression coefficient for meteorological predictor variables

xi = ith meteorological predicator variable i=1, 2 , 3, 4 ,5. . .n

aj = Regression coefficient for technological trend variables j = 1, 2 , 3, 4 ,5. . .n

xj = jth technological trend variables

In the testing phase, model performance was evaluated with standard statistical indicators. According to Willmott (1982) the correlation coefficient and the coefficient of determination are of little practical value in evaluating the predictive capabilities of models because their magnitudes are not consistently related to the accuracy of the prediction. More appropriate criteria include mean bias error (MBE), root mean square error (RMSE), normalized root mean square error (RMSE) and mean absolute percentage error (MAPE). These measures are defined as follows:

$$MBE = \frac{1}{n}\left[\sum_{i=1}^{n}(\text{model} - \text{data})\right]$$

$$RMSE = \sqrt{\left(\sum_{i=1}^{n}(\text{model} - \text{data})2\right)/n}$$

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

$$MAPE = \frac{1}{n}\left[\sum_{i=0}^{n}\left(\left|\frac{\text{data} - \text{model}}{\text{data}}\right|\right)\right]100$$

Basic model (model 1)

The weather data (recorded during critical periods) correlated with grain yield was used for regression analysis. Two multiple linear regression models (model 1) were developed for determining the effect of climatic parameters on wheat yield. The regression equations developed for two districts are given below.

For Bathinda district

Y=9329.13-34.46*Tmax(48-50)-205.63*Tmax(2-3)-66.15*Tmax(6-7)+35.21*Tmin(48)+39.74*Tmin(4)+33.00*RF(2-4)+42.86*RF(10-11)

$R^2 = 0.47$

Most of the climatic parameters in sensitive window reflected negative regression coefficient except for maximum temperature during 48th-50th weeks and minimum temperature during 48th week. Maximum temperature was significant at 5 per cent probability level and dependent variable (wheat yield) showed 47 per cent variations as explained by variables in the functions (weather parameters) for the Bathinda region.

For Faridkot district:

Y=6390.3-10.44*Tmax(43-50)-13.86*Tmin(2-3)-92.04*Tmin(6-12)-40.91*RF(43)-2867*RF(45)-18.74*RF(6-8)

$R^2 = 0.87$

Most of the climatic parameters in sensitive window reflected positive regression coefficient for maximum temperature during 43rd – 50th week and negative for minimum temperature during 2nd – 3rd week and 6th – 12th week. The maximum temperature was significant at 5 per cent probability level. The dependent variable (wheat yield) showed 87 per cent variations as explained by variables in the functions (weather parameters) for the Faridkot region.

Modified model (model 2)

Regression equations derived using modified model for wheat yield analysis for Bathinda region is as follows:

Y=5016.37+12.46*Tmax(48-50)-177.94*Tmax(2-3)-1.49*Tmax(6-7)-11.01*Tmin(48)+11.73*Tmin(4)+21.85*RF(2-4)-57.57*RF(10-11)+10.62* Composite Index

$R^2 = 0.74$

Most of the climatic parameters in sensitive window reflected negative regression coefficient except for maximum temperature during 48th-50th weeks and minimum temperature during 48th week and composite index. Maximum temperature was significant at 5 per cent probability level. Variation in wheat yield for Bathinda region was 74 per cent explainable using weather variables and CI together.

Regression equation derived using modified model for wheat yield analysis for Faridkot region is as follows:

$$Y=5973.91-9.24*Tmax(43\text{-}50)-19.44*Tmin(2\text{-}3)-88.65*Tmin(6\text{-}12)-47.64*RF(43)-3027.7*RF(45)-20.46*RF(6\text{-}8)+3.36*\text{Composie Index}$$

$R^2 = 0.88$

Most of the climatic parameters in sensitive window reflected positive regression coefficient for maximum temperature during 43rd – 50th week and negative for minimum temperature during 2nd – 3rd week and 6th – 12th week. The maximum temperature was significant at 5 per cent probability level. Variation in wheat yield for Faridkot region was 88 per cent explainable using weather variables and Composite Index together.

Model 3

The impact of climatic parameters (maximum temperature, minimum temperature and rainfall) on wheat productivity was studied. The following regression equations were obtained for Bathinda district of Punjab:

$$Y=2890.92+69.60*Time+24.21*Z11+36.29*Z21+2.38*Z131$$

$R^2 = 0.96$

Where,

Z11 is the sum product of maximum temperature

Z21 is the sum product of minimum temperature

Z131 is sum product of maximum temperature and rainfall

The sum product is the relation between correlation values and sum of all Standard Meteorological weeks (43rd–12th week) pertaining sensitive window for the crop. The above equation clearly explained the relationship between time, maximum temperature and minimum temperature and its combination with rainfall which played an important role in determining the wheat yield for Bathinda region. The R^2 value indicated that the 96 per cent variation of wheat yield in Bathinda region was explained by the weather variables.

The following regression equation is obtained for analysis in Faridkot district of Punjab:

$$Y= 5887.03+33.57*Z21$$

$R^2=0.68$

Where,

Z21 is sum product of minimum temperature.

The above equation clearly explained the relationship between time and its combination with maximum temperature and minimum temperature which played an important role in determining the wheat yield at Faridkot region. The R^2 value indicated that the variation of wheat yield at Faridkot region was 68 per cent explainable by the weather variables.

Validations of the models

The forecasted yields of wheat grown at Bathinda and Faridkot were validated against the actual yield and the error percentages were estimated for three years (2017-2020) (Fig. 1). For Bathinda, in the model 3, the lowest (- 0.7 per cent) and the highest (-14.2 per cent) error percentage were recorded during 2017-18 and 2019-20, respectively. In the case of basic model (model 1), error percent ranged from -5.1 (2019-20) to -40.3 percent during the year 2017-18. When the modified model was used to forecast the crop yield, the lowest error percent of -23.2 was recorded during 2019-20, while the highest error percent of -24.7 was recorded during 2017-18. Among three models, the model 3(SPSS software) was the best fit with the R^2 value of 96 per cent.

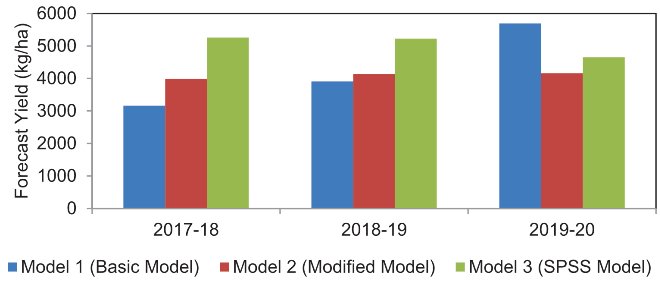

Fig. 1. Validation of statistical models in wheat at Bathinda (2017-2020)

For wheat grown in Faridkot district, the results depicted (Fig. 2) that the modified model (model 2) was the best fit with R^2 value of 88 per cent. The error per cent was calculated and found at par for all the three models. For both the models i.e. basic model (model 1) and modified model (model 2), the lowest error percentage (-5.7 per cent) during the year 2018-19 was recorded. While the highest (-7.7 per cent & -7.5 per cent) was found for model 1 & model 2, respectively during the year 2017-18. Error per cent recorded by using SPSS software was -6.2 per cent during the year 2017-18, which went up to -8.0 per cent during the year 2019-20.

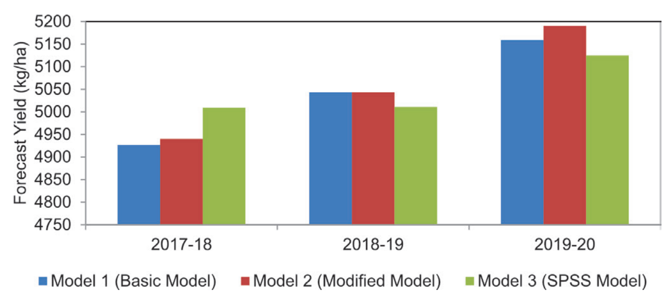

Fig. 2. Validation of statistical models in wheat at Faridkot (2017-2020)

Forecast of wheat yield can be made by using three models, *viz.,* basic model, modified model and SPSS software with the error per cent below 30 per cent in all these models. For wheat grown in Bathinda, SPSS

Table 1. Statistical parameters of wheat for south western districts of Punjab

District	Models	% deviation	NRMSE	RMSE	MBE	R^2	MAPE	SD (Actual)	SD (Observed)
Bathinda	Model 1	-34.0	28.36	1527.89	-1133	0.047	21.03	81.1	1301.6
	Model 2	-31.6	23.99	1292.17	-1292	0.74	23.98	81.1	92.0
	Model 3	-7.2	8.59	462.82	-343	0.96	6.37	81.1	342.3
Faridkot	Model 1	-7.5	7.00	379.43	-376	0.87	6.94	1.0	116.1
	Model 2	-7.1	6.71	363.53	-361	0.88	6.67	130.8	125.6
	Model 3	-7.3	6.91	374.52	-371	0.68	6.84	130.8	66.3

software was the best fit as R^2 value was 96 per cent, while for the wheat grown in Faridkot, the modified model (model 2) was the best fit (88 per cent).

Statistical analysis of different wheat cultivars from 2017-18 to 2019-2020

Statistical analysis of validation period (2017-18 to 2019-2020) of wheat was calculated and is presented as Table 1. The results were statistically analysed using per cent error, mean bias error (MBE), root mean square error (RMSE), normalized root mean square error (NRMSE), mean absolute percentage error (MAPE), standard deviation (SD) of actual yield and observed yield and R^2 (coefficient of determination) as given in Sandhu *et al*. (2018). The average per cent deviation ranged from -7.2 % (model 3) to -34.0 % (model 1) for Bathinda region. Whereas, it ranged between -7.1 (model 2) per cent to -7.5 per cent (model 1) for Faridkot region. This shows a very good agreement between the predicted and actual yield. The value of NRMSE ranged between 6.71 to 28.36 % and Jamieson *et al*. (1991) proposed that if the NRMSE is less than 10 per cent, the prediction is considered excellent. Based on this theory, model 3 was showing excellent result for both the stations. The MBE showed underestimation by ranging from -343 to -1292 kg ha^{-1} in wheat yield prediction.

Authors' contribution

Conceptualization of research work and designing of experiments (KKG); Execution of field/lab experiments and data collection (RK); Analysis of data and interpretation (RK, KB);Preparation of manuscript (RK, KKG)

LITERATURE CITED

Aggarwal P K 2008. Global climate change and Indian agriculture: Impact adaptation and mitigation. *J Agric Sci* **78**: 911-19.

Anonymous 2018. *Package and practices for kharif crops of Punjab.* Punjab Agricultural University, Ludhiana, India, pp. 41.

Fischer R A, Santiveri F and Videl I R 2002. Crop rotation tillage and crop residue management for wheat and maize in the sub-humid tropical highland: Wheat and legume performance. *Field Crops Res* **79:** 107-22.

Gill KK, Sandhu S S, Kaur P, Babuta R and Bhatt K 2015. Wheat yield prediction using weather based statistical model in central Punjab. *J Agri Phy* **15**(2): 157-62.

Gracial O M, Travasso M I, Rodriguez G R, Solman and Nunez M 2009. climate change and wheat production in Argentina. *Int J Global Warming* **1**: 214-26.

IPCC 2007.Summary for Policymakers. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 18 p.

IPCC 2014. *Climate change Impacts, adaptation and vulnerability*. Working group II contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change. Technical report. Cambridge University Press, Cambridge, UK/New York, USA.

Neog P**,** Sarma PK, Saikia D, Borah P, Hazarika GN, Sarma MK, Sarma D, Chary GR and Rao Ch S 2020. Management of seasonal drought in *Sali* rice under increasing rainfall variability in North Bank Plains zone in north eastern Himalayan region of India. *Climatic Change* **158**: 473–84.

Parry M L, Zweig R C, Lglesias A, Livermore M and Fischer G 2004. Effects of climate change on global food production under SRES emission and socio-economic scenarios. Glob Environ Change **14:** 53-67.

Sandhu S S, Prabhjyot-Kaur, Singh J, Nigam R and Gil, K K 2018. Evaluation of greencrop tracker for the estimation of leaf area index in wheat using digital photography. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*. https:/ /doi.org/10.1007/s40011-018-0974-0.

Reddy S R 2006. *Agronomy of field crops*. Kalyani Publishers. New Delhi, pp. 143-88.

Willmott C J 1982. Some comments on the evaluation of model performance. *Bull Am Meteorol Soc.* **63** (11): 1309–1313.