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Linear regression model development for wheat yield using weather variables at different phenological stages

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Abstract
This study examines the effect of climatic factor e.g. Maximum Temperature, Minimum Temperature and sunshine variation on the yield of different stages of wheat in during Rabi season 2015-16 at research and instructional farm of IGKV Raipur (CG) India. The correlations of average wheat yield for 14 crop seasons (2001-02 to 2015-16) have been studies for kanchan variety. In multiple linear regression maximum temperature have significantly to has been found influenced the grain yield of Kanchan variety of wheat during all stages except the Maximum temperature at maturity. The maximum temperature of Kanchan variety (based on probability values associated with t statistics) during 50% flowering stage and it was followed by milk stage. The highest positive significant effect of rainfall was observed during 50% flowering. Rainfall at crucial phases of CRI, tillering, emergence, 50% flowering, milking and dough stages is helping to meet the crop water requirement which includes maintaining soil moisture status and evapotranspiration losses.

Keywords: wheat yield, weather variables, linear regression, phenological stage

Introduction
Wheat (*Triticum aestivum* L) is the most widely cultivated food grain crop of the world. It is grown not only in temperate zones but also in tropical and subtropical zones. In India, wheat is the second important staple food crop, rice being the first (Agrawal and Sinha, 1993) [1]. It has wide adaptability and can tolerate severe cold also. The best quality wheat is produced with cool and moist weather during the vegetative phase followed by dry warm weather during reproductive phase (Draganka *et al*, 2004) [4]. It is a long day plant. Temperature ranging between 20o to 25oC is ideal for seed sowing and germination. Whereas the optimum temperature for vegetative growth ranges from 16o to 22oC. During the grain development wheat requires a mean maximum temperature of about 25oC for at least 4-5 weeks. Wheat is grown well in those areas where annual rainfall ranges between 1200 mm to 1600 mm. Winter wheat generally completes its life-cycle most rapidly when grown in low temperatures during the early stages of growth but high temperature is required during the later stages of growth (Bobade 2010) [2].

Material and Methods
In statistical modeling, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or „predictors‟).

More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed. Less commonly, the focus is on a quantile, or other location parameter of the conditional distribution of the dependent variable given the independent variables. In all cases, the estimation target is a function of the independent variables called the regression function. In regression analysis, it is also of interest to characterize the variation of the dependent variable around the regression function which can be described by a probability distribution. Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning.

Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships.
We used regression models are given below: -

1. **Linear Regression** estimates the coefficients of the linear equation, involving one or more independent variables, which best predict the value of the dependent variable. The model‟s output is shown here in which the following abbreviations are used:

Tmax = Mean maximum temperature
Tmin = Mean minimum temperature
Rain = Rainfall in millimetres
SSH = Total sunshine hours
The value for R_2 (correlation coefficient) shows how strong is the correlation held between a predictor or independent variable and the dependant variables. The sign of r indicates the slope of the regression line (David 2009) [3].

2. **Regression equation** After analysis a multiple linear equation has been determined, which may be a useful tool for yield prediction of wheat crop in the region.

Regression equation for Predicted yield

Y = a + (b1) (x1) + (b2) (x2) + (b3) (x3) + (b4) (x4).

Where-
Y = Predicted yield
A = Intercept
b1, **b2, b3, b4 =** Regression coefficient
x1, x2, x3, x4 = Dependent variables

Formula of Error %

Error % = Actual yield – Predicted yield/Actual yield*100

Result and Discussion
Multiple linear regression models were used to estimate the effects of different weather variables on wheat yield. A relationship occurs when the magnitude of the effect of one independent variable on a dependent variable varies as a function of a second independent variable. The relationship between minimum temperature, maximum temperature, relative humidity (morning), and relative humidity (evening), evaporation on the wheat yield were included in the model. Table -1 shows the regression coefficients associated with each variable to indicate the change in yield corresponding to unit change in the respective weather variable.
Linear regression models have been developed for wheat yield using maximum temperature, minimum temperature, rainfall and sunshine at different phenological stages of Kanchan variety. Regression equation - Y = 2906.88 + (6.84) (z121) + (- 160.77) (z21).
To the most weather parameters-sensitive phenological stage influencing yield of wheat, linear regression modal between the yield of kanchan variety over three dates of sowing and 14 year of experimentation and phenological stage-wise average of maximum temperature, minimum temperature, rainfall and sunshine were fitted (Kumar 2015) [6]. Linear regression models of yield with weather parameters (maximum temperature, minimum temperature, rainfall, sunshine, separately) during all the seven phonological stage showed that maximum temperature during all stages significantly ($P<0.05$ and <0.01) and adversely influenced the grain yield of kanchan variety of wheat (except the Max-T at maturity of kanchan). The negative significance of the adverse effect of maximum temperature on yield of wheat Kanchan variety (based on probability values associated with t statistics) was highest during 50% flowering stage and it was followed by milk stage. Kumar *et al* (2015) [6]. It means the same value of maximum temperature on higher side at 50% flowering stage will adversely affect the grain yield as compared to the same maximum temperature value prevailing at milking stage. One interesting observation from the present study was that the maximum temperature has positive effect on the yield of Kanchan variety in the initial stage of crop growth (CRI, Tillering stage). It means that the Kanchan variety is responding well to the higher value of maximum temperature which is finally contributing for grain yield.
However it has been clear from the statistics that rainfall influenced the grain yield both positively and negatively. The highest significant effect of rainfall was observed during 50% flowering. Rainfall at crucial phases of CR, tillering, emergence, 50% floweing, milking and dough stages is helping to meet the crop water requirement which includes maintaining soil moisture status and evapotranspiration losses. At some stages like tillering and dough stages, the relationship with rainfall for Kanchan variety is found to be non-significant. The possible explanation for this is that the experiment is taken under assured irrigation and response with rainfall might have become apparent only depending on soil moisture status. Therefore, because of crop sensitivity to the maximum temperature and rainfall in Kanchan cultivar, 50% flowering and milking stage were identified as the critical stage for abiotic stresses. In addition to it 50% flowering stage rainfall was identified as critical parameter. The yield and all weather parameters conditions, pooled over cultivars, also showed 50% flowering to be the most sensitive phonological stage for both maximum temperature and rainfall with absolute t-values -4.54 ($P< 0.05$) and 2.51 ($P< 0.05$), respectively, closely followed by milking stage in maximum temperature.

Table 1: Linear regression models for wheat yield using maximum temperature, minimum temperature, rainfall and sunshine at different phenological stages of kanchan variety.

Weather Parameter	Statistics	CRI	Tiller	EMR	50% Flower	Milk	Dough	Maturity
Max-T	Intercept	252.1	1951.3	5000.2	8290.5	6624.7	4371.3	3280.6
	Linear	98.4	37.8	-68.9	-172.7	-113	-40.8	-7.82
	t- value	1.3	1.05	-1.22	-4.54	-2.96	-1.24	-2.31
	Pr > | t |	<0.05	<0.01	<0.05	<0.05	<0.05	<0.05	NS
	Adj. R^2	0.013	0.02	0.09	0.27	0.13	0.11	-0.19
	Pr > F	<0.05	<0.01	<0.05	<0.05	<0.05	<0.05	NS
Min-T	Intercept	2692.2	3851.3	3174.9	3612.39	3956.7	4554.5	3698.3
	Linear	25.6	-70.7	-13	-41.91	-59.5	-89.4	-36.96

	t- value	0.5	-1.08	-0.24	-0.91	-1.17	-1.88	-0.83
	Pr > | t |	NS	<0.01	NS	NS	<0.05	<0.05	NS
	Adj. R^2	-0.014	0.003	-0.018	-0.003	0.007	0.047	-0.006
	Pr > F	NS	<0.01	NS	NS	<0.05	<0.05	NS
RF	Intercept	2938.6	2991.5	3059.6	2920.1	2929.4	2973.4	3051.28
	Linear	9.28	2.33	-4.11	12.7	19.7	6.85	-12.38
	t- value	1.38	0.27	-1.12	2.51	1.6	0.84	-1.03
	Pr > | t |	<0.05	NS	<0.05	<0.05	<0.05	NS	<0.01
	Adj. R^2	0.017	-0.018	0.005	0.093	0.029	-0.005	0.001
	Pr > F	<0.05	NS	<0.05	<0.05	<0.05	NS	<0.01
SS	Intercept	2045	2865.1	3474.3	3709.15	3481.44	1808.59	2013.16
	Linear	130.98	18.92	-62.84	-87.37	-57.44	148.71	121.61
	t- value	1.31	0.25	-0.81	-1.12	-1.004	1.806	1.35
	Pr > | t |	<0.05	NS	NS	<0.05	<0.01	<0.05	<0.05
	Adj. R^2	0.014	-0.018	0.007	0.005	0	0.042	0.016
	Pr > F	<0.05	NS	NS	<0.05	<0.01	<0.05	<0.05

In minimum temperature was no significant effect on CRI stage, EMR, 50% flowering and maturity stages but other stages like tillering, milk and dough stages are significant for crop cultivar Kanchan stages no effectiveness on crop growth stage during crop cultivar. In kind of weather parameter on sunshine no impact on crop growth stages, sunshine are on significant at tillering and EMR stage and significant during CRI, flowering, milk, dough and maturity stages respectively. It has been found that higher sunshine values at CRI, dough and physiological maturity stages (based on probability values associated with t statistics) will contribute for higher grain yield production while more values of sunshine during 50% flowering and milking stage can adversely affect normal functioning and lead to physiological stress thereby adversely affect the grain yield. Overall it can be said that because of response of Kanchan variety to all the meteorological parameters, milking stage in wheat is found to be the most crucial stage. The influence of meteorological parameters will finally contribute to the grain yield. In this stage, maximum temperature, minimum temperature and sunshine are found to be negatively correlated while the rainfall has been found to be positively affecting the grain yield. Here, it is to mention here that meteorological factors are not affecting the metabolic activities and physiological mechanisms in their individual capacity but these are affecting the plant growth and development and final output in conjunction with one another (Kumar 2001) [7].

Conclusion

Conclusion between weather variables and wheat yield, four parameters are analyzed with wheat yield in Raipur condition maximum temperature and rainfall is identified as significant weather variables, the effect on wheat yield.

Overall it can be said that because of response of Kanchan variety to all the meteorological parameters, milking stage in wheat is found to be the most crucial stage. The influence of meteorological parameters will finally contribute to the grain yield. In this stage, maximum temperature, minimum temperature and sunshine are found to be negatively correlated while the rainfall has been found to be positively affecting the grain yield.

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