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SV Gholap
M.Sc. (Agri) Student, Department of Agricultural Meteorology, VNMKV, Parbhani, Maharashtra, India

BV Asewar
Head, Department of Agronomy, VNMKV, Parbhani, Maharashtra, India

AS Kale
M.Sc. (Agri) Student, Department of Agricultural Meteorology, VNMKV, Parbhani, Maharashtra, India

Corresponding Author:
AS Kale
M.Sc. (Agri) Student, Department of Agricultural Meteorology, VNMKV, Parbhani, Maharashtra, India

Development of regression model to predict BT cotton (*Gossypium* spp.) yield using meteorological variables for Parbhani and Nanded locations

SV Gholap, BV Asewar and AS Kale

Abstract
The urgent need of crop modeling under changing climatic conditions and increasing abiotic as well as biotic new stress an study entitled as "Development of regression model to predict Bt cotton (*Gossypium* spp.) yield using meteorological variables for Parbhani and Nanded locations" has been conducted at Department of Agricultural Meteorology, Vasantarao Naik Marathwada Krishi Vidyapeeth, Parbhani during 2019-20 to analyze the stepwise regression techniques for meteorological variables with the yield and to develop the regression model to predict the yield with meteorological variable. Weekly weather data (24th MW to 02nd MW) of 11 weather variables over a span of 15 years period (2002-03 to 2016-17) along with *kharif*, season Bt cotton production data for Parbhani and Nanded locations. All the information for significance of stepwise regression and multiple regression model was presented. Statistical analysis carried out by using Microsoft office and SPSS22 copyright Inc., USA Based Application guide.
For development of regression model initially correlation was worked out between yield and weather parameters based on 15 years data, a positive and significant relationship between rainy days (0.544*) and Bt cotton yield, while negative and significant relationship between bright sunshine hour (-0.548*) and Bt cotton yield was found, while relationship of wind speed (-0.717**) was negative and highly significant with Bt cotton yield. At Nanded, rainy days (0.616*) and Bt cotton yield had a favorable and significant association. Also, there was a negative and significant association between minimum temperature (-0.586*) and Bt cotton yield. Stepwise regression models were derived which revealed that for 15 years data both developed models are good fit. The R^2 value is high, residual error and error percent are low revealed the best fit model to predict Bt cotton yield. As a result, model number 3 (R^2=0.864) revealed the best fit model to predict Bt cotton yield, if we have a 15-year average data set for Parbhani. Maximum temperature, evening relative humidity and wind speed was found significant impact on Bt cotton yield at Parbhani. For Nanded, models 2(R^2=0.604) and 3(R^2=0.762) are suitable for predicting Bt cotton yield. Rainfall, rainy days and minimum temperature was found significant impact on Bt cotton yield at Nanded. Multiple regression models were also best fit to predict Bt cotton yield of 15 years data at Parbhani (R^2= 0.961) and Nanded (R^2= 0.819).

Keywords: Regression model, Meteorological variables, correlation, Bt cotton

Introduction
Cotton (*Gossypium* spp.) is popularly known as 'White Gold'. It is one of the most important commercial crops. Cotton belongs to the family *Malvaceae*. It is found in tropical and subtropical climates all over the world. It is grown in eighty countries around the world, with the top ten producers accounting for approximately 85% of global production: the United States, Australia, China, India, Brazil, Pakistan, Turkey, Mexico, Egypt, and Sudan. In India, all four cultivated species namely, *Gossypium hirsutum*, *Gossypium barbadense*, *Gossypium arboreum and Gossypium harbacium* are grown, all of which play a significant role in the Indian people economic and social status. Cotton is the king of natural fibres and it is cultivated in nearly every country on the planet.
Cotton fibre's hydrophilic quality makes it a valuable raw resource for the textile industry. Cotton has a significant impact on global economic, political and social issues. Cotton seed cake is a one of the by-products of cotton that is used as a livestock feed and fertilizer. It is a great organic source of nitrogen (N), phosphorus (P_2O_5), potassium (K_2O) and other essential plant nutrients.
Cotton produces 10% of the world's edible oil. The study presented here is to see how different climatic variables affect the crop during crop growing season. Correlation study for a week period gives a preliminary idea about the effect of any particular weather variable on the

yield during that week. The problem of predicting crop yield has occupied the attention of agronomist, Soil scientist, plant physiologist as well as Meteorologist for many years. The methods of predicting yield ranges from statistical approach7 to crop simulation models 1, 6. The former depends heavily on empirical correlation between yield and climatic variables.

Materials and Methods
Location of study area
Geographically Parbhani is situated at latitude, longitude and altitude of 19.27' N, 76.78' E and 347 m altitude and Nanded is situated at latitude, longitude and altitude of 19.15' N, 77.30' E and 362 m altitude respectively.

Collection of data
The present investigation consisted methodology of the collection of historiological weather and crop yield data of Parbhani and Nanded location. The weather data for 15 years collected from the Agromet observatory V.N.M.K.V. Parbhani and Agromet Observatory, Cotton Research Station, Nanded and the yield data of Bt cotton were collected from internet website (*www.mahaagri.gov.in*). The yield data of Bt cotton crop for 15 years (2002-03 to 2016-17) for Parbhani, Nanded location have been procured from the published booklets and official website *www.mahaagri.gov.in* Govt. of Maharashtra. Daily values of the metrological elements i.e., rainfall, maximum and minimum temperatures, maximum and minimum relative humidity, no. of rainy days, sunshine duration and evaporation were collected from the Agromet observatory and the other values are derived from these values. Parbhani and Nanded are located in Marathwada region of Maharashtra and come under hot moist semi-arid ESR with shallow and medium loamy clayey black soil, Cotton is sown in 24^{th} meteorological week, and total duration of crop varies from 180-220 days (Crop weather calendar of Cotton, Parbhani).

Correlation
Correlation is a measure of intensity of degree of linear relationship between two variables for 'n' pair of observations. In present statistical analysis correlation is computed by using MS-EXCEL Program Operating system windows 10.The significance of the correlation coefficient ® is tested by using 't' statistics and is given by,

$$t = \frac{r\sqrt{(n-2)}}{\sqrt{1-(r^2)}}$$

Where, R is the correlation coefficient.

Test statistics value is compared with critical value at (n-1) degrees of freedom at (0.01) and (0.05) level of significance.

Regression
Regression is the average relationship between dependent and independent variables.
The general form of regression model is,

$$Y = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \epsilon$$

Where, Y= Estimated yield (Kg/ha), α= Regression constant, β= Regression coefficients for meteorological predictor variables, X1= 1^{st} meteorological predictor variable 1= 1, 2, 3, ….,n

Results and Discussion
The correlation studies were carried out to determine the impact of several meteorological conditions that prevailed during the crop growth period on synthesis of Bt cotton yield. The following table shows the correlation coefficient between weather conditions and Bt cotton yield at Parbhani.

Table 1: Correlation coefficient of weather parameters with Bt cotton yield for 15 years data at Parbhani.

Weather Parameter	Correlation coefficient
RF (mm)	0.438
RD	0.544^{*}
Tmax (^{0}C)	-0.470
Tmin (^{0}C)	-0.101
Avg. temp(^{0}C)	-0.316
RH-I (%)	0.126
RH-II (%)	0.159
Avg. RH (%)	0.153
Epan (mm/day)	-0.394
BSS (hr/day)	-0.548^{*}
WS (km/hr)	-0.717^{**}

However, the results on rainy days showed positive significant correlation with Bt cotton yield. It means that the rainfall distribution was affecting on yield throughout the growing period of Bt cotton and at boll bursting and harvesting. Wind speed can also stress the cotton plant enough to reduce yield although, some wind may beneficial in very hot humid conditions. Wind modifies the temperature and humidity gradients around the Bt cotton plant which in turn changes the evaporative demand. Same results were found by Waghmare and Madhosingh (2017) [12].
The results of analysis showed that, the bright sunshine hours were negative and significant influence on the Bt cotton during crop growing period. Same results were also reported by Dendage *et al.*, (2018) [4]

Table 2: Correlation coefficient of weather parameters with Bt. cotton yield for 15 years data of Nanded.

Weather Parameter	Correlation coefficient
RF (mm)	0.277
RD	0.616^{*}
Tmax (^{0}C)	0.245
Tmin (^{0}C)	-0.586^{*}
Avg. temp(^{0}C)	-0.381
RH-I (%)	0.149
RH-II (%)	-0.317
Avg. RH (%)	-0.101

It was clear from the Table (3.2) that, rainy days (0.616*) and Bt cotton yield had a favorable and significant association. Also, there was a negative and significant association between minimum temperature (-0.586*) and Bt cotton yield. Rainfall, maximum temperature, average temperature, morning relative humidity, evening relative humidity, and average relative humidity all had no effect on Bt cotton yield. Waghmare and Madho Singh (2017) [12] reported that, rainy days showed positive significant correlation with Bt cotton yield. It means that the distribution of rainfall was affecting on yield throughout the crop growing period of Bt cotton at boll bursting and harvesting.

Table 3: Stepwise regression equations for Parbhani using 15 years data (2002-03 to 2016-17).

Model No.	Regression equation	R^2	Adj. R	SE
1	$Y=18703.574 - 3278.206 (X_{11})$	0.514	0.477	1327.10
2	$Y=41121.816 - 280.448 (X_7) - 5146.752 (X_{11})$	0.712	0.664	1064.56
3	$Y=135548.771 - 2681.209 (X_3) - 602.632 (X_7) - 3863.872 (X_{11})$	0.864	0.826	764.45

Where, (X_3)= Tmax, (X_7)= RH-II, (X_{11})= W.S

The equation derived from above table showed that, the weather parameter wind speed is the most important factor impacting Bt cotton production, followed by evening relative humidity and maximum temperature. The Wind speed alone accounts for 51 percent of overall variability in Bt cotton yield, and when paired with evening relative humidity, it accounts for 71 percent. The influence of meteorological variables such as maximum temperature, evening relative humidity and wind speed on Bt cotton yield is roughly 86 percent variation. Similar results were in close conformity with the results reported by Gill and Bhatt (2015) [6, 7].

Table 4: Stepwise regression equations at Nanded using 15 years data (2002-03 to 2016-17).

Model No.	Regression equation	R^2	Adj. R	SE
1	$Y= (-2389.503) + 124.254 (X_2)$	0.379	0.331	1369.58
2	$Y= 4616.896 + 105.042(X_2) - 389.916 (X_4)$	0.604	0.538	1138.76
3	$Y= 5040.293 - 3.501 (X_1) + 193.478 (X_2) - 471.296 (X_4)$	0.762	0.697	921.16

The equation created on the basis of Table (3.4) demonstrates that, the weather parameter rainy days is considered as the most important weather parameter impacting the Bt cotton yield followed by minimum temperature and rainfall. Rainy days account for 37.9% of total variability in Bt cotton production, and when paired with minimum temperature, they account for around 60.4 percent. Weather variables such as rainfall, rainy days and minimum temperature account for 76.2 percent of the variation in Bt cotton yield. Similar results were in close conformity with the results reported by Gill and Bhatt (2015) [6, 7].

Multiple regression analysis at Parbhani (15 years data)

Multiple regression analysis was carried out for determining the contribution of independent variables i.e., weather parameters with Bt cotton yield. The average weather data of 15 year pooled over to develop multiple regression equation and these equations were derived to predict the yield of Bt cotton.

$R^2 = 0.961$ Adj. R = 0.863

The resultant multiple regression equation was derived and expressed as,

$$Y= 78684.180 + 1.727 (X_1) + 10.601 (X_2) + 8854.454 (X_3) + 10338.222 (X_4) - 19918.111(X_5) - 113.307 (X_6) - 428.946 (X_7) - 234.998 (X_9) + 903.392 (X_{10}) - 5259.765 (X_{11}).$$

Table 5: Multiple regression model based on Bt cotton yield and weather parameters of Parbhani.

Variables	Regression Coefficients (B)	Standard Error (SE)	T value
Constant (B_0)	Constant (B_0)	Constant (B_0)	Constant (B_0)
X_1 (RF)	X_1 (RF)	X_1 (RF)	X_1 (RF)
X_2 (RD)	X_2 (RD)	X_2 (RD)	X_2 (RD)
X_3 (T_{max})	X_3 (T_{max})	X_3 (T_{max})	X_3 (T_{max})
X_4 (T_{min})	X_4 (T_{min})	X_4 (T_{min})	X_4 (T_{min})
X_5 (Avg.T)	X_5 (Avg.T)	X_5 (Avg.T)	X_5 (Avg.T)
X_6 (RH-I)	X_6 (RH-I)	X_6 (RH-I)	X_6 (RH-I)
X_7 (RH-II)	X_7 (RH-II)	X_7 (RH-II)	X_7 (RH-II)
X_9 (Epan)	X_9 (Epan)	X_9 (Epan)	X_9 (Epan)
X_{10} (BSS)	X_{10} (BSS)	X_{10} (BSS)	X_{10} (BSS)
X_{11} (WS)	X_{11} (WS)	X_{11} (WS)	X_{11} (WS)

Above table (3.5) shows that, the independent variables coefficient of determination (R^2) was 0.961, implying that, weather factors explain for 96.10 percent of overall variation in Bt cotton production with 1 to 10 percent deviations. The average temperature, evening relative humidity, and wind speed were all found to have negative and significant relationships with Bt cotton yield while, the temperature had a positive and minimum significant relationship with Bt cotton yield. Similar results were also found by Kalubarme and Saroha (2016).

Table 6: Multiple regression model based on Bt cotton yield and weather parameters of Nanded.

Variables	Regression Coefficients (B)	Standard Error (SE)	T value
Constant (B_0)	-7357.614	32744.420	-0.225
X_1 (RF)	-3.598	2.068	-1.740*
X_2 (RD)	204.307	69.949	2.921**
X_3 (T_{max})	-17.697	2575.635	-0.007
X_4 (T_{min})	-605.225	2378.765	-0.254
X_5 (Avg.T)	353.879	4704.722	0.075
X_6 (RH-I)	-109.435	462.541	-0.237
X_7 (RH-II)	-109.019	138.761	-0.786
X_8 (Avg. RH)	338.164	498.909	0.678

The resultant multiple regression equation was derived and expressed as,

$Y= (-7357.614) - 3.598 (X_1) + 204.307 (X_2) - 17.697 (X_3) - 605.225 (X_4) + 353.879 (X_5) - 109.435 (X_6) -109.019 (X_7) + 338.164 (X_8)$.
$R^2= 0.819$
Adj.R= 0.570

Table (3.6) shows that, the independent variables coefficient of determination (R^2) was 0.819, indicating that weather variables accounted for 81.90 percent of overall variation in Bt cotton yield with 1 to 20 percent deviations. It was also observed that amongst weather parameters rainy day was positive and highly significant with Bt cotton yield and rainfall was negative and significant relationship with Bt cotton yield. Similar results were in close conformity with the results reported by Rankja (2009) [11].

Table 7: Validation of Predicted and Observed Bt cotton yield at Parbhani (Multiple regression model).

Validation Year	Predicted yield ('00'bales)	Observed yield ('00'bales)	R^2	Residual error	Error %
2017-18	3315.50	3676.0	0.961	360.49	9.80
2018-19	3187.97	3273.47		85.49	2.61

The percentage difference between the predicted and observed yield data was done for the developed model for Bt cotton to see the performance of the model. Table (4.14) demonstrated that, the R^2 value is high, residual error and error percent are low at Parbhani. It was observed that, the developed model has overestimated the yield in 2017-18 and 2018-19 by 9.80% and 2.61% respectively. As results, multiple regression models are best fit to predict Bt cotton yield of 15 years data at Parbhani.

Table 8: Validation of Predicted and Observed Bt cotton yield at Nanded (Multiple regression model).

Validation Year	Predicted Yield ('00'bales)	Observed Yield ('00'bales)	R^2	Residual error	Error %
2017-18	3214.6	3117	0.819	-97.59	-3.13
2018-19	3451.56	3648.57		197.00	5.39

Table (3.8) demonstrated that, the R^2 value is high, residual error and error percent are low at Nanded. It was observed that, the developed model has overestimated the yield in 2018-19 by 5.39%, while in 2017-18 the developed model has underestimated the yield by 3.13%. As results, multiple regression models are best fit to predict Bt cotton yield of 15 years data at Nanded.

Conclusions

On the basis of experimental findings, it could be concluded that at Parbhani, a positive and significant relationship between rainy days (0.544*) and Bt cotton yield. And bright sunshine hour (-0.548*) was found negative and significant relationship and wind speed (-0.717**) negative and highly significant relationship with Bt cotton yield. At Nanded, showed the results that the rainy days (0.616*) and Bt cotton yield had a favorable and significant association.

There was a negative and significant association between minimum temperature (-0.586*) and Bt cotton yield. While developing the stepwise regression model for Parbhani and Nanded, the different weather parameters impact on Bt cotton yield. Amongst this developed equation (stepwise regression models) for Parbhani and Nanded model no. 3 and model number 2 and 3 found good fit model to predict the Bt cotton yield respectively.

Both developed multiple regression models for Parbhani and Nanded was found good to predict the yield. In-situ observations are necessary to get better results for yield prediction. Validation of the regression model is must for practical utilization to predict the yield of Bt cotton for more accuracy.

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