

A Statistical Investigation on Different Modeling Techniques For Crop Yield Influenced By Weather Parameters in Northern Hills of Chhattisgarh

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Abstract: A statistical analysis was carried out for the period of 1974-2011 to access the better relationship between weather parameters productivity of crops like rice, maize and groundnut in Northern Hills of Chhattisgarh. The statistical tools namely different nonlinear models were used for statistical analysis. The different models were used to predict productivity of crops with the help of individual weather parameter. Models were selected on the basis of significance of the variable and R^2 , which explains the variation in dependent and independent variables. Nonlinear models were used for predicting yield using each weather parameter, among that power, compound, cubic, s- curve, logarithmic and quadratic models were found significant. For each crop, different model were significant but mainly quadratic and cubic model were best because of higher R^2 , a indicator of good relationship between dependent and independent variables.

Keywords: Rice, Maize, Groundnut, Weather parameters, Regression coefficients, Simple linear regression, Coefficient of determination, nonlinear models.

1.INTRODUCTION:

The geography of Chhattisgarh is easy to ascertain; it is located in the central India and is spread across 135,194 sq km, making it the tenth largest state of the India. The climate of Chhattisgarh is governed by a monsoon and the distinct seasons are summer (March to May), winter (November to February), and the intervening rainy months of the southwest monsoon (June to September). The summer is hot, dry, with high wind velocity and high temperatures typically reaching at least 85 °F (about 30 °C) in all parts of the state; in some areas temperatures regularly rise above 100 °F (upper 30 °C). Winters are usually pleasant and dry, with high temperatures in the upper 70s °F (mid-20s C). In December and January, there is considerable rainfall in the northern hills of the state, although the state as a whole receives most of its precipitation during June to September. Annual rainfall usually ranges from 1,200 to 1,500 mm. Out of total geographical area (1925025 ha) of Surguja division (Northern hills of Chhattisgarh), the total cropped area is 1136013 ha. The average annual rain fall is around 1392.5 mm, and the major crops growing are Rice, Maize, Groundnut, Sugarcane etc.

A statistical model is an equation or set of equations which represents the relationships among variables. Modeling may lead to less ad hoc experimentation, as models sometimes make it easier to design experiments to answer particular questions, or to discriminate between alternative mechanisms. Modeling provides powerful tools for investigating the dependence and nature of relationships among the variables of interest. The relationship among variables must be determined for the purpose of predicting the values of one or more variables on the basis of observation on other variables. Model building or regression techniques are currently applied in many fields *i.e.*, Agriculture, Biometrics, Economics, Education, Meteorology, Industry, Sociology, Anthropology, Archeology etc. In meteorological studies the weather parameters are highly erratic and in such cases meaningful interpretations can be drawn only by using proper statistical models. Agarwal *et al.* (1986) reported that above average maximum daily temperature had beneficial effects during ripening stage detrimental effects during reproductive stage of rice crop, while in the initial growth Active and lag vegetative phase effects were fluctuating the effect of increasing in Minimum temperature was beneficial during initial lag vegetative and reproductive Stages detrimental during ripening stage and fluctuating during active vegetative Stage, above average relative humidity and rain fall has beneficial effects throughout the growth and detrimental effects during ripening phase of the crop in general. Kulkarni and Pandith (1987), studied that the contest of estimating crop yield- weather relations. It is necessary to account for the influence of improved technology on crop yields. In their study, the appropriateness of accepting a continuous time trend in the crop yields in contrast to introducing a discreet time effect has been examined using sorghum yields and monthly weather records for Parbhani district of Maharashtra. Kandiannan *et al.* (2002) have used Crop-weather models to predict rice yield in India. However, despite a significant influence of solar radiation on rice yield, none of these models have used solar radiation as one of the predictors. In this paper, an attempt was made to predict the first season (June-September) rice yield at Coimbatore, Tamil Nadu, India, by including solar radiation as one of the predictors Anup Prasad *et al.*

(2005) developed various indices using remote sensing data such as normalized difference vegetation index (NDVI), vegetation condition index (VCI) and temperature condition index (TCI) for mapping and monitoring of drought and assessment of vegetation health and productivity. NDVI, soil moisture, surface temperature and rainfall are valuable sources of information for the estimation and prediction of crop conditions. In the present paper, we have considered NDVI, soil moisture, surface temperature and rainfall data of Iowa state, US, for 19 years for crop yield assessment and prediction using piecewise linear regression method with breakpoint. Sarma *et al.* (2007) studied the importance of agro climatic models for excepted quantum of the rice production in Andra Pradesh by considering rain fall in relation to crop yield. The suggested statistical agrometeorological model imbibed the five (5) variables that have significant impact on yield. From the above facts it is evident that there is a considerable scope to undertake a statistical study of impact of weather parameters on crop yield. Therefore, the present statistical study was designed to develop crop yield prediction models using weather parameter.

2. MATERIALS AND METHODS:

The statistical data of three major crops (1974 to 2011) used during study was taken from various issues of "Agricultural Statistics" published by Directorate of Agriculture and Commissioner of land records and settlement, Madhya Pradesh. and Chhattisgarh, respectively. Secondary data on the weather parameters viz., rainfall, maximum temperature and minimum temperature of said period were collected from District Statistical Office (DSO) & meteorological websites like IMD and Main Research Station (MRS) Ambikapur (Surguja).

Simple linear regression analysis

The crop yields were predicted using different weather parameters. Taking crop yield as dependent variable and other variables i.e., weather parameter as independent variable linear regression analysis was carried out.

$$Y = \alpha + \beta x + \varepsilon$$

Where,

α is the intercept

β is the slope of regression line

ε is the random error, independently and normally distributed with mean 0 and standard Deviation σ_ε^2 Here the task was to find out the estimates of α ($\alpha = a$) and β ($\beta = b$). They were calculated as

$$\beta_0 = \bar{y} - \beta_1 \bar{x}$$

Significance of the coefficient

The significance of the regression coefficient was tested using F statistic. Here the null hypotheses was set as,

$$H_0: \beta = 0 \quad \text{v/s}$$

$$H_1: \beta \neq 0$$

To test this F – test was used.

$$F = \frac{\text{Regression } \sum \text{ of squares } / (n - 2)}{(\text{Error } \sum \text{ of squares }) / (n - k)}$$

Where,

$$\text{Regression sum of squares} = \sum (X_i - \bar{X}_i)^2 \\ ((b_1 \sum (X_i - \bar{X}_i)(Y_i - \bar{Y}_i)))$$

$$\text{Error sum of squares} = \sum y^2 - \text{regression sum of squares}$$

This calculated F value was compared with table F for 1 and (n-2) degrees of freedom.

Test for significance of regression coefficients

The standard error for regression coefficient β_1 is

$$SE \text{ of } (\beta_1) = \frac{S}{\sqrt{\sum (x_i - \bar{x})^2}}$$

Where $s^2 = \frac{\sum (y_i - \bar{y})^2 - \beta_1 \sum (x_i - \bar{x})^2}{n - 2}$ is unbiased

estimate of σ^2 .

The statistic 't' for testing the null hypothesis $H_0: \beta_1$ is zero or that there is no straight line sloping relationship

between the variables used & is given by $t = \frac{\beta_1}{SE \text{ of } (\beta_1)}$

Coefficient of determination (R^2)

Coefficient of determination Measures the "Proportion of total variation about the mean \bar{y} explained by the regression. It is expressed as a percentage by multiplying with 100. In fact, R is the correlation between y and \bar{y} and is usually called multiple correlation coefficient. It is expressed as

$$R^2 = \frac{(\hat{y}_i - \bar{y})^2}{(y_i - \bar{y})^2}$$

R^2 measures the contribution of the linear function of independent variables to the variation in dependent variable. Based on the R^2 , model of best fit to the data was selected.

Nonlinear models

The simplest way of representing any relation is by fitting a linear equation using the variables under study. But, in all the cases it may not follow. In the present study, taking crop yield as dependent variable and weather parameter as independent variables, non linear models were tried to fit to the data (Gomez and Gomez 1958).

Logarithmic model

$$Y = b_0 + b_1 \ln(t) \text{ is the linear form of the model.}$$

Y and t are yield and weather parameters respectively.

b_0 and b_1 are constants to be estimated and ln is Natural Log.

Quadratic model

The form of the equation is,

$$Y = b_0 + b_1 t + b_2 t^2$$

Where,

Y and t are yield and weather parameters respectively.

b_0 and b_1 are constants to be estimated.

Cubic model

Here the equation is,

$$Y = b_0 + b_1 t + b_2 t^2 + b_3 t^3$$

where,

Y and t's are crop yield and weather parameters respectively. b₀ and b_i's are constants to be

Estimated

Compound model

Compound model has the form,

$$Y = b_0 b_1^t$$

On transformation

$\ln(Y) = \ln(b_0) + t \ln(b_1)$. is obtained which is of the linear form where, Y and t's are yield and weather parameters respectively.

b₀ and b₁ s are constants to be estimated and ln is Natural Log.

Growth model

Growth model has the form,

$$Y = e^{(b_0 + (b_1 * t))}$$

or

$$\ln(Y) = b_0 + (b_1 * t)$$

which is a linear form of the model.

In this study Y and it's are crop yield and weather parameters respectively.

b₀ and b₁ are constants to be estimated ln is Natural Log and "e" is the exponential function.

S-curve

S-curve has a form

$$Y = e^{(b_0 + (b_1 / t))}$$

or

$$\ln(Y) = b_0 + (b_1 / t)$$

which is a linear form of the model.

In this study Y and it's are crop yield and weather parameters respectively.

b₀ and b₁ are constants to be estimated

ln is Natural Log and "e" is the exponential function.

3. RESULT AND DISCUSSION:

The secondary information collected from various sources were analyzed using various statistical tools.

Optimum Temperature and Water requirement of study Crops.

Optimum temperature and water requirement of paddy, groundnut and maize are 30-32 °C & 900-2500 mm, 20-25 °C & 750-850 mm and 30-35 °C & 800-900 mm, respectively.

Prediction models

In agriculture, statistical models play a major role in prediction of weather, crop yield, insect pest instance etc. An effort were made to build the prediction models for the crop yield level with the help of the weather parameters by using different statistical models and on the basis of significance, best model was selected. If more than one models were significant, then best model was selected on the basis and R² values.

Prediction models for rice

Different models used to predict rice yield level with the help of different weather parameter is presented in Table 1. For predicting yield level with the help of temperature maximum, quadratic, cubic models were found to be significant. Among these models, cubic model proved to be the best with highest R² (0.07) followed by quadratic (R² =0.05), Logarithmic (R² = 0.01).

In case of minimum temperature, cubic models were found to be significant and it was proved best with highest R² (0.13). In case of rainfall, quadratic models were found to be significant and it was proved best with highest R² (0.04).

Prediction models for maize

Different models used to predict maize yield level with the help of different weather parameter is presented in Table 2. For predicting yield level with the help of maximum temperature, quadratic, cubic and linear models were found to be significant. Among these models, quadratic and cubic models proved to be the best with highest R² (0.08) followed by linear (R² =0.05). In case of minimum temperature none of the models was significant hence none of the models have been selected. For predicting yield level with the help of rainfall, all the models were found to be significant. Among these models, cubic model proved to be the best with highest R² (0.14) followed by quadratic, compound and growth models (R = 0.09).

Prediction models for Groundnut

Different models used to predict groundnut yield level with the help of different weather parameter is presented in Table 3. For predicting yield level with the help of maximum temperature, linear, logarithmic, quadratic & cubic models were found to be significant. Among these models, quadratic and cubic models proved to be the best with highest R² (0.07) followed by linear and logarithmic (R² =0.02). For minimum temperature, all the models were found to be significant. Among these models, cubic model proved to be the best with highest R² (0.16). In case of rainfall, quadratic and cubic models were found to be significant and it was proved best with highest R² (0.06),

Table I: Model for rice in Surguja division

model	temperature maximum				temperature minimum				rainfall			
	coefficient		R ²		coefficient		R ²		coefficient		R ²	
Linear			-106.3	0.011			-166.5	0.05*			0.001	0.00004
Logarithmic			-7676	0.01			-7082	0.05*			-126	0

quadratic		-22058	355.8	0.05*		-7178	192.5	0.09*		-1.8	0.0006	0.04*
Cubic	1568506	-51198	556.9	0.07*	262538	-14688	273.3	0.13*	-5.54	0.0003	-6	0.04
Compound			0.274	0.007			0.859	0.09*			4.95	0.0002
S-curve			52.99	0.007			46.58	0.09*			110.89	0.01
Growth model			-0.053	0.007			-0.13	0.09*			-0.00001	0

*Significant at five percent level,

Table II: Model for maize in Surguja division

model	temperature maximum				temperature minimum				rainfall			
	coefficient			R ²	coefficient			R ²	coefficient			R ²
Linear			76.82	0.05*			4.41	0.00003			-0.245	0.032*
Logarithmic			5263	0.004			184.13	0.00003			-637	0.021*
quadratic		-33403	542.7	0.08*		-260.6	7.28	0.00008		2.24	-0.0008	0.09*
cubic	376474	-12742	143	0.08*	287170	-15850	291.2	0.004	-9.5	0.007	-0.00001	0.14*
Compound			-1.45	0.01			1.92	0.002			3.88	0.09*
S-curve			-32.04	0.009			4.03	0.002			178.57	0.05*
Growth model			0.035	0.01			-0.012	0.002			-0.00013	0.09*

*Significant at five percent level,

Table III: Model for groundnut in Surguja division

model	temperature maximum				temperature minimum				rainfall			
	coefficient			R ²	coefficient			R ²	coefficient			R ²
linear			74.6	0.02*			-102	0.07*			-0.49	0.005
Logarithmic			5217	0.02*			-4331	0.07*			-226	0.01
quadratic		-14011	228	0.07*		-2636	69.6	0.09*		-1.2	0.0004	0.06*
cubic	-25188	590.6	3.9	0.07*	170545	-9485	175.5	0.16*	-1.18	0.0004	0.000003	0.06*
Compound			-1.52	0.01			1.3	0.07*			-4.3	0.0002
S-curve			-28.03	0.01			17.9	0.07*			50.17	0.006
Growth model			0.03	0.01			-0.05	0.07*			0.00005	0.0002

*Significant at five percent level,

4. CONCLUSIONS

Weather parameters play an important and unique role in the growth and development of crops and affect the crops differently during different stages of development. There is a need to educate the farmers to consider weather parameters during cropping period and selection of crops in order to mitigate food scarcity. Comprehensive research

studies that focus on weather parameters and the crops yield. The results obtained from statistical evaluation of yield, rainfall and other weather parameters as well as impact studies would help in learning and drawing policy guidelines for the future planning.

The models are built in order to predict yield with the help of individual weather parameter. Best models were selected based on the significance of the variable and R²,

which explains the variation in dependent variable due to independent variables. Different non linear models were used for predicting yield using each weather parameter, among those generally compound, cubic, logarithmic and quadratic models were found significant and quadratic, cubic models are the best because they have found to be highest R^2 which indicate the good relationship between whether parameter and crop yield.

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