

Yield prediction model of rice in Bulsar district of Gujarat

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ABSTRACT

Efforts were made for utilization of ICT to develop suitable agrometeorological model for rice yield prediction in Bulsar district of Gujarat. Six weather variables viz. bright sunshine hours (X_1), rainfall (X_2), maximum temperature (X_3), minimum temperature (X_4), morning relative humidity (X_5) and afternoon relative humidity (X_6) were analyzed for the crop weather relationship to develop regression models. Five approaches were used for fitting of the models i.e. week wise, stage wise, period wise, week number as weight and correlation coefficient as weight.

The sowing of rice is mainly concentrated around the second week of June in Gujarat. Hence, the data pertaining to weather parameters for the period 23rd to 42nd meteorological standard weeks (MSW) were included in the present investigation. Four out of the five approaches, which were used for fitting the models, models fitted with stage wise, period wise, week number as weight and correlation coefficient as weight approaches could not be identified as acceptable models. Only one, 18 week model fitted with week wise approach which provided earlier rice yield prediction (2 weeks before harvest) and explained higher variation in rice yield (Adjusted $R^2 = 99.8\%$) is preferred.

Keywords: Rice productivity, agrometeorological model, stepwise regression, weather parameters

India ranked first in area and second in production of rice in the world. Among the major rice growing states in India, Gujarat ranked 15th in area (0.66 million hectare) as well as in production (1.73 million ton) and 11th in productivity (2.61 t ha⁻¹) (IRRI, 2007).

Advances in ICT have progressively reduced the costs of managing information, enabling individuals and organizations to undertake information-related tasks much more efficiently, and to introduce innovations in products, processes and organizational structures.

Agrometeorological models are defined as the product of two or more weather factors each representing functioning between yield and weather. These models do not require hypothesis of the plant and environment process. Thus the input requirement is less stringent but the output information is more dependent on the input data. Thus ICT based agrometeorological models are a practical tool for the analysis of crop response to weather and estimating the yield.

MATERIALS AND METHODS

The present study was undertaken with a view to utilise the ICT to develop appropriate yield prediction of rice for Bulsar district of Gujarat by using combined effects of different weather parameters viz. rainfall, bright sunshine hours, maximum and minimum temperature and morning and afternoon relative humidity on rice yield.

Considering the specific objectives of the study, rice yield data of Bulsar district for the years 1980 to 2005 were

extracted from District wise Area, Production & Yield of Important Food & Non-food Crops in Gujarat State, Directorate of Agriculture, Gujarat. The complete meteorological datas of Navsari station (Lat: 20.57° N, Long: 72.54°E, Height: 10 m AMSL), a representative centre of the district were collected from the data bank maintained by the Department of Agricultural Meteorology, Anand Agricultural University, Anand for the corresponding period.

Weekly averaged data of weather variables viz., (1) bright sunshine hours [X_1] (2) maximum temperature [X_3] (3) minimum temperature [X_4] (4) morning relative humidity [X_5] (5) afternoon relative humidity [X_6] and (6) weekly total rainfall [X_2] were collected for the period of the growing season of rice in Bulsar district for the years under consideration. The sowing of rice is mainly concentrated around the second week of June in Gujarat (Anon, 2004). Hence, the data pertaining to weather parameters for the period 23rd to 42nd meteorological standard weeks (MSW) were included in the present investigation.

For selecting the best regression equation among number of independent variables, the stepwise regression procedure was adopted (Draper and Smith, 1966). Statistical Package for the Social Sciences (SPSS) computer software was used for the analysis of the data with probability level of 0.05 to enter and 0.1 to remove the variables. The sets of multiple linear regression models were obtained using data upto year 2005 for each model. A regression model was fitted considering the entered variables obtained from individual stepwise regression analysis to predict rice yield for the

subsequent years.

The following approaches were tried to find out the suitable interval which can satisfactorily forecast the rice yield in a given year.

- 1 Weekwise approach using original weather variables
- 2 Crop stagewise approach using original weather variables
- 3 Periodwise approach using original weather variables
- 4 Week number as weight using generated weather variables
- 5 Correlation coefficient as weight using generated weather variables.

These approaches are adoption of the models developed by Aggrawal *et al.*, (1986) and are mostly used by various workers in India. Patel (2005) used these models for preharvest forecasting of rice yield based on weather parameters in Kheda district of Gujarat.

Weekwise approach

In this approach, weekly averaged data of different weather variables were considered in original form from 23rd to 42nd meteorological standard weeks. With a view to have forecasts before actual harvest, different models based on 12, 14, 16, 18 and 20 weeks crop duration were fitted.

The mathematical expression of this model was,

$$Y = A_0 + \sum_{i=1}^p a_{ij} X_{ij}$$

where,

Y = Average rice yield of the district (kg ha⁻¹)

A₀ = Constant

X_{ij} = Observed value of ith weather variable in jth week, i=1, 2,...p=6 and j=1, 2,... w= 12,14,16, 18 and 20

a_{ij} = partial regression coefficients associated with each X_{ij}

Crop stagewise approach

The 18 weeks of crop period were divided into 5 important crop stages and average value for the respective stages were considered to fit the model.

Five models were fitted considering the data upto 1st, 2nd, 3rd, 4th, and 5th crop stages i.e. seedling(S), active tillering (A), vegetative lag (V), flowering (F) and grain development (G) stages, respectively.

The mathematical model for this approach was

$$Y = A_0 + \sum_{i=1}^p a_{ij} X_{ij}$$

where,

Y = Average rice yield of the district (kg/ha)

A₀ = Constant

X_{ij} = Observed value of ith weather variable in jth crop stage i=1, 2,...p=6 and j=1,2...s=1, 2, 3, 4 & 5

a_{ij} = partial regression coefficients associated with each X_{ij}

Periodwise approach

In this approach, monthly averaged data of different weather variables were considered in original form from 6th to 10th meteorological standard periods. With a view to have forecasts before actual harvest, different models based on 1, 2, 3, 4 and 5 periods crop period were fitted.

The mathematical expression of this model was,

$$Y = A_0 + \sum_{j=1}^m \sum_{i=1}^p a_{ij} X_{ij}$$

where,

Y = Average rice yield of the district (kg/ha)

A₀ = Constant

X_{ij} = Observed value of ith weather variable in jth period, i=1,2,...p=6 and j=1,2,... m= 1, 2, 3, 4 and 5

a_{ij} = partial regression coefficients associated with each X_{ij}

Generated weather variables were also tried to explain the relationship in a better way as it gives appropriate weightage to different periods. These models were successfully used for forecasting yield of various crops at district and zone level (Agrawal *et al.*, 2001).

Week number as a weight

Here in this approach new variables (Z_{ij}) and (Q_{ij}) were generated from original weekly averaged weather variable data as per the formula given below

$$Z_{ij} = \frac{\sum_{w=1}^n w^j X_{iw}}{\sum_{w=1}^n w^j} \quad \text{and} \quad Q_{ij} = \frac{\sum_{w=1}^n w^j X_{iw} \cdot X_{iw}}{\sum_{w=1}^n w^j}$$

Z_{ij} and Q_{iij} are generated first and second order variables defined as,

where,

- n = number of weeks up to the time of forecast
- w = week identification ($w=1, 2, \dots, n=12, 14, 16, 18$ and 20)
- X_{iw} = value of the i^{th} weather variable in the w^{th} week ($i=1, 2, \dots, 6$ and $j=0, 1, 2$)

The weighted averages of weekly weather variables and their interactions using powers (0, 1 and 2) of week number as a weight were used.

Sixty three explanatory generated variables along with time trend variable were subjected to stepwise regression analysis for developing forecasting model.

The mathematical expression of the fitted model was

$$Y = A_0 + \sum_{i=1}^p Z_{ij} + \sum_{i \neq i'=1}^p Q_{iij}$$

where,

- Y = Average rice yield of district kg ha^{-1}
- A_0 = Constant
- p = No. of weather variables ($p=1,2,\dots,6$)

a_{ij} and b_{iij} are partial regression coefficients associated with each Z_{ij} and Q_{iij} , respectively ($i=1,2,\dots,p$ and $j=0,1,2$)

Using these variables, forecasting models were developed for 12, 14, 16, 18 and 20 weeks crop periods to explore the possibility of early forecast before harvest.

Correlation coefficients as a weight

The correlation coefficients between rice yield and different weather variables were worked out weekwise and they were used as weight and new variables Z'_{ij} and Q'_{iij} (taking interaction of variables) were generated using following formula

$$Z'_{ij} = \frac{\sum_{w=1}^n r_{iw}^j \cdot X_{iw}}{\sum_{w=1}^n r_{iw}^j} \text{ and } Q'_{iij} = \frac{\sum_{w=1}^n r_{i'iw}^j \cdot X_{iw} \cdot X_{iw}}{\sum_{w=1}^n r_{i'iw}^j}$$

Z'_{ij} and Q'_{iij} are generated first and second order variables defined as,

where,

- n = number of weeks up to the time of forecast
- w = week identification ($w=1,2,\dots, n=12, 14, 16, 18$ and 20)
- X_{iw} = value of the i^{th} weather variable in the w^{th} week ($i=1, 2, \dots, p$ and $j=0,1,2$)
- r_{iw} = correlation coefficient of yield with the i^{th} weather variable in the w^{th} week
- $r_{i'iw}$ = correlation coefficient of yield with the product of the i^{th} and i'^{th} weather variable in the w^{th} week.

In order to explore the possibility of early forecasts before 8, 6, 4 and 2 weeks of harvest of rice crop, four models were fitted using generated weather variables for the period of 12, 14, 16, 18 and 20 weeks crop periods.

Sixty three explanatory variables comprising of 18 first order generated variables (Z'_{ij}), 45 second order generated variables (Q'_{iij}) were subjected to stepwise regression analysis using following model.

$$Y = A_0 + \sum_{i=1}^p Z'_{ij} + \sum_{i \neq i'=1}^p Q'_{iij}$$

where,

- Y = Average rice yield of the district kg ha^{-1}
- A_0 = Constant
- a_{ij} and b_{iij} are partial regression coefficients associated with each Z'_{ij} and Q'_{iij} respectively. ($i=1,2,\dots,p$ and $j=0,1,2$)
- p = No. of weather variables ($p=1,2,\dots,6$)

Selection of the model

The model was selected as the suitable preharvest forecast model based on these two criteria viz. (i) earliness in forecast before harvest of rice crop and (ii) higher coefficient of determination (adjusted R^2). The nomenclature used for different adjusted R^2 (%) values is presented in Table 1.

RESULTS AND DISCUSSION

Weekwise approach

In this approach, original weekwise weather variables

Table 1: Nomenclature used for adjusted R² (%) values for selection of models

Adjusted R ² (%)	Nomenclature
> 90	Very high
75 – 90	High
50 – 75	Moderate
50 – 30	Low
< 30	Very low

were utilized for fitting the regression equations. The fitted equations, their coefficients of multiple determinations for five different models corresponding to 12, 14, 16, 18 and 20 weeks crop periods are presented in Table 2.

Results of 12 week crop period revealed that the weekly weather variables viz., X₁₀₆, X₁₁₀, X₁₁₁, X₂₀₂, X₅₀₉ and X₅₁₁ entered in the model. These variables explained about 99.4% variation in rice yield. The results indicated that the partial regression coefficients for bright sunshine hours of 28th week (X₁₀₆) and 33rd week (X₁₁₁) and morning relative humidity of 31st week (X₅₀₉) and 33rd week (X₅₁₁) were positive and significant whereas the partial regression coefficients for bright sunshine hours of 32nd week (X₁₁₀) and rainfall of 24th week (X₂₀₂) were negative and significant.

Only 49.1% variation in yield of the rice crop was explained by weekly weather variables X₁₀₁, X₁₀₆, X₂₁₁ and X₆₀₅ in 12 week crop period. Results indicated that the partial regression coefficients for bright sunshine hours of 23rd week (X₁₀₁) and rainfall of 33rd week (X₂₁₁) were positive and significant, whereas partial regression coefficients for bright sunshine hours of 28th week (X₁₀₆) and afternoon relative humidity of 27th week (X₆₀₅) were negative and significant.

The variables entered in 14 and 16 weeks crop period were the same. The set of explanatory variables entered in the equations consisted of weekly weather variables viz., X₁₀₆, X₁₀₇, X₁₁₄, X₂₀₇, X₂₁₁ and X₆₁₄. These variables explained 78.1% variation in yield of the rice crop. The partial regression coefficients for bright sunshine hours of 29th week (X₁₀₇) and rainfall of 29th week (X₂₀₇) and 33rd week (X₂₁₁) were positive and significant, whereas partial regression coefficients for bright sunshine hours of 28th week (X₁₀₆) and 36th week (X₁₁₄) and afternoon relative humidity of 36th week (X₆₁₄) were found negative and significant.

The results relating to 18 week crop period revealed that the set of explanatory variables entered in the equation were weekly weather variables viz., X₁₀₃, X₁₀₆, X₁₀₇, X₁₀₉, X₁₁₁, X₁₁₄, X₂₀₃, X₂₀₇, X₂₁₁, X₂₁₂, X₂₁₆, X₃₀₅, X₃₀₈, X₃₁₃, X₄₀₅, X₄₁₃, X₅₁₇ and X₆₁₄. About 99.8% variation in rice yield was explained by

these variables. Results indicated that the partial regression coefficients for bright sunshine hours of 29th week (X₁₀₇) and 33rd week (X₁₁₁), rainfall of 29th week (X₂₀₇), 33rd week (X₂₁₁) and 38th week (X₂₁₆), maximum temperature of 30th week (X₃₀₈), minimum temperature of 27th week (X₄₀₅) and morning relative humidity of 39th week (X₅₁₇) were found positive and significant, whereas partial regression coefficients for bright sunshine hours of 25th week (X₁₀₃), 28th week (X₁₀₆), 31st week (X₁₀₉) and 36th week (X₁₁₄), rainfall of 25th week (X₂₀₃) and 34th week (X₂₁₂), maximum temperature of 27th week (X₃₀₅) and 35th week (X₃₁₃), minimum temperature of 35th week (X₄₁₃) and afternoon relative humidity of 36th week (X₆₁₄) were found negative and significant.

The set of weekly weather variables found to enter in the equation relating to 20 week crop period were X₁₀₆, X₁₀₉, X₁₁₇, X₂₁₁, X₂₁₉, X₃₁₄, X₃₁₈, X₃₂₀, X₆₁₇ and X₆₁₈ and explained about 96.0% variation in yield of the rice crop. Positive and significant partial regression coefficients were observed bright sunshine hours of 31st week (X₁₀₉), rainfall of 33rd week (X₂₁₁) and 41st week (X₂₁₉), maximum temperature of 36th week (X₃₁₄) and 40th week (X₃₁₈), whereas for bright sunshine hours of 28th week (X₁₀₆) and 39th week (X₁₁₇), maximum temperature of 42nd week (X₃₂₀) and afternoon relative humidity of 39th week (X₆₁₇) and 40th week (X₆₁₈) negative and significant partial regression coefficients were observed.

The fitted equations under this approach revealed that R² was low (49.1%) in 12 week model. While for 14 and 16 weeks crop period model it was high (78.1%). It was very high in 18 week (99.8%) and 20 week (96.0%) models. Thus, 18 week model could be considered as a yield prediction model based on very high R² value and earliness of forecasting under this approach.

Crop stagewise approach

Original crop stagewise weather variables were utilized in this approach for fitting the regression equations to get an idea about the influence of weather variables prevailed during different crop stages on rice yield. The fitted equations and their coefficients of multiple determinations for five different models corresponding to 1, 2, 3, 4 and 5 stages are presented in Table 3.

The results of presented in Table 3 indicated that none of the weather variables could enter in 1, 2, 3 and 4 stage models. Only one weather variable entered as explanatory variable in the equation related to 5 stage crop period viz., X₁₅ which explained 15.4% variation in yield of rice. The partial regression coefficient for bright sunshine hours during grain development (G) stage (X₁₅) was found negative and significant.

Table 2: Partial regression coefficients of rice yield on different original weather variables

Variables in the equation	Weeks				
	12	14	16	18	20
Constant A ₀	3926.284**	5128.229**	5128.229**	5788.423**	6276.784**
X ₁₀₁	70.082*	-	-	-	-
X ₆₀₅	-22.368**	-	-	-	-
X ₁₀₆	-202.831**	-135.696**	-135.696**	-86.852**	-70.601**
X ₂₁₁	1.657**	2.344**	2.344**	3.730**	2.428**
X ₁₀₇	-	69.929**	69.929**	106.213**	-
X ₂₀₇	-	1.794**	1.794**	2.468**	-
X ₁₁₄	-	-154.646**	-154.646**	-106.465**	-
X ₆₁₄	-	-32.018**	-32.018**	-41.871**	-
X ₁₀₃	-	-	-	-23.633**	-
X ₂₀₃	-	-	-	-0.152**	-
X ₃₀₅	-	-	-	-69.951**	-
X ₄₀₅	-	-	-	59.487**	-
X ₃₀₈	-	-	-	103.573**	-
X ₁₀₉	-	-	-	-33.494**	22.381**
X ₁₁₁	-	-	-	25.878**	-
X ₂₁₂	-	-	-	-0.844**	-
X ₃₁₃	-	-	-	-170.012**	-
X ₄₁₃	-	-	-	-70.315**	-
X ₂₁₆	-	-	-	0.604**	-
X ₅₁₇	-	-	-	41.795**	-
X ₃₁₄	-	-	-	-	93.612**
X ₁₁₇	-	-	-	-	-139.812**
X ₆₁₇	-	-	-	-	-24.502**
X ₃₁₈	-	-	-	-	12.450**
X ₆₁₈	-	-	-	-	-16.249**
X ₂₁₉	-	-	-	-	1.369*
X ₃₂₀	-	-	-	-	-115.819**
Adjusted R ² (%)	49.1	78.1	78.1	99.8	96.0

*, ** Significant at 5% and 1% level of significance, respectively

Very low R² (15.4%) was observed in case of 5 stage model. Thus no model could be considered as a yield prediction model under this approach.

Periodwise approach

Meteorological standard periodwise original weather variables were used in this approach and five models related to 1, 2, 3, 4 and 5 periods were fitted. The fitted equations and their coefficients of multiple determinations for five different models corresponding to 1, 2, 3, 4 and 5 periods are presented in Table 4.

All the weather variables were removed in 1, 2 and 3 period crop models. Results of 4 and 5 crop periods were same and only one weather variable viz., X₁₄ entered and explained 21.3% variation in yield of rice. Negative and significant partial regression coefficient was observed for bright sunshine hours during fourth (September) period (X₁₄).

Among the equations fitted under this approach R² was very low (21.3%) for 4 and 5 period models. Thus, none model could be considered as a yield prediction model under this approach.

Table 3: Partial regression coefficients of rice yield on different original weather variables

Variables in the equation	Stages				
	1	2	3	4	5
Constant A_0	-	-	-	-	2736.439**
X_{15}	-	-	-	-	-110.949*
Adjusted R^2 (%)	-	-	-	-	15.4

*, ** Significant at 5% and 1% level of significance, respectively

Table 4: Partial regression coefficients of rice yield on different original weather variables

Variables in the equation	Periods				
	1	2	3	4	5
Constant A_0	-	-	-	2720.000**	2720.000**
X_{14}	-	-	-	-124.595*	-124.595*
Adjusted R^2 (%)	-	-	-	21.3	21.3

*, ** Significant at 5% and 1% level of significance, respectively

Week number as a weight

In this approach, generated weather variables (week number as weight) were used. The fitted equations and their coefficients of multiple determination of five different models corresponding to 12, 14, 16, 18 and 20 weeks crop periods for different districts are presented in Table 5.

Results of 12 weeks model indicated that only one variable viz., Z_{62} (quadratic weight of week number to afternoon relative humidity) entered in the equation and influenced the yield of rice positively and significantly. This variable explained about 15.3% variation in the yield of the rice crop.

All the 63 generated variables were removed in 14 weeks model. Only one variable viz., Z_{62} (quadratic weight of week number to afternoon relative humidity) entered in the equation related to 16 weeks crop period. About 21.5% variation in the yield of the rice crop was explained by this variable. The rice yield was positively and significantly influenced by first order generated variable Z_{62} (quadratic weight of week number to afternoon relative humidity).

Same variable viz., Z_{62} entered in 18 weeks model and explained about 28.1% variation in rice yield. First order generated variable Z_{62} (quadratic weight of week number to afternoon relative humidity) positively and significantly influenced rice yield.

The explanatory variable observed to enter in the equation of 20 weeks crop model was Z_{61} . This variable

explained 24.1% variation in the yield of the rice crop. The result indicated that the first order generated variable Z_{61} (linear weight of week number to afternoon relative humidity) influenced the yield of rice positively and significantly.

In general R^2 was very low (<30%) in all the equations fitted under this approach. Thus, none of the model could be considered as a yield prediction model under this approach.

Correlation coefficient as a weight

In this approach, 63 generated weather variables (correlation coefficient as weight) were utilized. The fitted equations and coefficients of multiple determination of five different models corresponding to 12, 14, 16, 18 and 20 weeks crop periods are presented in Table 6.

The results presented in Table 6 indicated that only one generated variable Q'_{361} entered in the equation. This variable explained about 32.5% variation in yield of rice. The rice crop yield was positively and significantly influenced by the variable Q'_{361} (linear weight of correlation coefficient to cross product of maximum temperature and afternoon relative humidity).

Only one first order generated weather variable viz., Z'_{11} entered the equation of 14 weeks model and explained about 38.6% variation in the yield of the rice crop. The first order generated variable Z'_{11} (linear weight of correlation coefficient to bright sunshine hours) negatively and significantly influenced the yield of rice.

The variables observed to enter in the equation related to 16 weeks model were Z'_{11} and Z'_{21} and explained about 46.5% variation in the yield of the rice crop. The first order generated variable Z'_{21} (linear weight of correlation coefficient to rainfall) influenced the yield of rice positively and significantly whereas, linear weight of correlation coefficient to bright sunshine hours (Z'_{11}) negatively and significantly influenced the yield of rice.

The variables entered in the equation related to 18 weeks model consisted of weather variables Z'_{21} and Z'_{31} . These variables explained about 50.0% variation in rice yield. The influence of first order generated variable Z'_{21} (linear weight of correlation coefficient to rainfall) on rice yield was positive and significant whereas, the influence of first order generated variable Z'_{31} (linear weight of correlation coefficient to maximum temperature) was found negative and significant.

The generated weather variables Z'_{11} , Z'_{21} , Z'_{31} , Q'_{141} and Q'_{341} entered in the equation related to 20 weeks model and explained about 71.4% variation in the yield of rice.

Table 5: Partial regression coefficients of rice yield on different generated weather variables

Variables in the equation	Weeks				
	12	14	16	18	20
Constant A_0	-573.912	-	-680.967	-509.158	-543.602
Z_{62}	0.06928*	-	0.03117*	0.02137**	-
Z_{61}	-	-	-	-	0.215**
Adjusted R^2 (%)	15.3	-	21.5	28.1	24.1

*, ** Significant at 5% and 1% level of significance, respectively

Table 6: Partial regression coefficients of rice yield on different generated weather variables

Variables in the equation	Weeks				
	12	14	16	18	20
Constant A_0	571.024	2554.280**	2329.940**	2930.010**	2181.959**
Q'_{361}	0.516**	-	-	-	-
Z'_{11}	-	-129.784**	-99.384*	-	-132.250**
Z'_{21}	-	-	1.357*	2.609**	1.304*
Z'_{31}	-	-	-	-40.008*	-32.686
Q'_{141}	-	-	-	-	1.644*
Q'_{341}	-	-	-	-	1.353**
Adjusted R^2 (%)	32.5	38.6	46.5	50.0	71.4

*, ** Significant at 5% and 1% level of significance, respectively

Positive and significant influence was observed for the weather variables viz., Z'_{21} (linear weight of correlation coefficient to rainfall), Q'_{141} (linear weight of correlation coefficients to products of bright sunshine hours and maximum temperature) and Q'_{341} (linear weight of correlation coefficients to cross products of maximum and minimum temperature) whereas, negative and significant influence of weather variables viz., Z'_{11} (linear weight of correlation coefficient to bright sunshine hours) and Z'_{31} (linear weight of correlation coefficient to maximum temperature) was observed on the yield of rice.

The observed R^2 was low (32.5%) in 12 weeks, (38.6%) in 14 weeks and (46.5%) in 16 weeks model whereas it was moderate (50.0%) in 18 weeks and (71.4%) in 20 weeks period crop model. Thus, no model could be considered as a yield prediction model under this approach.

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