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Forecasting of wheat yields on the basis of weather variables

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ABSTRACT

The data from 1970 to 1999 of Mehsana district of Gujarat state, were used for fitting a pre harvest forecast model for wheat yield based on weather parameters using stepwise regression technique. Models based on original weather variables with week wise and crop stage wise approach and the generated variables taking week number and correlation coefficient as weight, were tried. Among the different approaches, the model based on generated weather variables (correlation coefficient as weight) was identified on the basis of R^2 values (0.943) and the simulated forecast errors(<6%) which can predict the wheat yield at the end of 12^{th} week after sowing.

Key words : Generated variables, technological trend, stepwise regression

Weather is a major factor affecting crop production in India. Early forecast of crop yield may help the planners in deciding the polices. Therefore, an attempt has been made to quantify the effect of weather parameters and technological advancement on wheat crop for Mehsana district of Gujarat State. The district falls under North Gujarat Agro climatic Zone and has the highest area of about 69,000 ha (Anon.,1975) under wheat crop.

MATERIALS AND METHODS

Wheat crop is grown during November to March in *rabi* season. Time series data on weather parameters (X_1 = maximum temperature (°C), X_2 = minimum temperature (°C), X_3 = morning relative humidity (%) X_4 = evening relative humidity (%), X_5 = wind speed (kmh^{-1}) and X_6 = bright sunshine hours) from 1970-71 to 1998-99 were collected from the observatory situated at Main Wheat Research Station, Vijapur in Mehsana district. Wheat productivity data of Mehsana district for the same periods were collected from the published reports of the Directorate of Agriculture, Gujarat State, Ahmedabad (Anon. 1970-71 to 1998-99). Following four different approaches (models) were studied.

Model- I (standard week wise approach)

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=1}^{w} a_{ij} \cdot X_{ij}\, cR + dT \quad ..... (i)$$

Model –II (crop stage wise approach)

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=1}^{5} a_{ij} \cdot X_{ij}\, cR + dT \quad ..... (ii)$$

where, i = 1, 2.......p (X_i weather variables), j= 1,2, ...w or s (w-weeks after sowing(1-18) and s-stage of crop(1-6)), Y = productivity (kg ha^{-1}), X_{ij} are the values of ith weather variables in jth standard week(w) or crop stage(s) i.e. std. week 46 to 48 sowing to crown root initiation stage(s_1), std. week 49 to 51 crown root initiation to initiation of tillering stage(s_2), std. week 52 to 2 tillering to jointing stage(s_3), std. week 3 to 5 jointing to flowering stage(s_4), std. week 6 to 8 flowering to milking stage(s_5) and std. week 9 to 11 milking to soft dough stage(s_6)). R = rainfall (mm), T = time trend, a_{ij}, b_{ij}, c and d are regression coefficients.

Model- III (by taking week number as weight

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} \cdot Z_{ij} +$$

$$\sum_{i=1}^{p} \sum_{j=0}^{2} b_{ii'j} \cdot Q_{ii'j} + cR + dt \text{ ....(iii)}$$

$$\text{where } Z_{ij} = \left(\sum_{w=1}^{n} w^j \cdot X_{iw} \right) / \sum_{w=1}^{n} w^j \text{ and}$$

$$Q_{ii'j} = \left(\sum_{w=1}^{n} w^j \cdot X_{iw} \cdot X_{i'w} \right) / \sum_{w=1}^{n} w^j$$

Model- IV (by taking correlation coefficients as weight)

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} \cdot Z_{ij} +$$

$$\sum_{i=1}^{p} \sum_{j=0}^{2} b_{ii'j} Q_{ii'j} + cR + dT \text{ .... (iv)}$$

$$\text{Where } Z_{ij} = \left(\sum_{w=1}^{n} r^j_{iw} \cdot X_{iw} \right) / \sum_{w=1}^{n} r^j_{iw} \text{ and}$$

$$Q_{ii'j} = \left(\sum_{w=1}^{n} r^j_{ii'w} \cdot X_{iw} \cdot X_{i'w} \right) / \sum_{w=1}^{n} r^j_{ii'w}$$

Zij and $Q_{ii'j}$ are the generated first and second order variables, $r_{ii'w}$ = correlation coefficient between i and i' weather variable for wth week and r_{iw} = correlation coefficient between wheat yield and ith weather variable

Using these approaches the forecast models were fitted based on step wise regression technique (Draper and Smith, 1966) and simulated forecast errors were worked out for the subsequent years which were not included in fitting the model.

RESULTS AND DISCUSSION

Week wise approach (Model I)

District average wheat yield was regressed on weekly weather data along with time trend and rainfall.The results indicated that time trend (T) and wind speed($X_{5'09}$) in 9th week after sowing (Table 1) have significant influence on wheat yield in all four periods (12, 14,16 and 18 weeks after sowing). As the period was extended from 12 to 16 weeks, the wind speed of 13th week($X_{5'13}$), maximum temperature of 16th week($X_{1'16}$), morning relative humidity for 15th and 16th weeks ($X_{3'15}$ and $X_{3'16}$) and sunshine hours of 17th week($X_{6'17}$) entered in the step wise regression model and their regression coefficient were significant. The coefficient of determination (R^2) was comparatively

Table 1: Variables selected, coefficient of determination and range of forecast errors in week wise approach (*Model I*)

Variables selected		R^2 and simulated forecast errors (%)				
		70-71 to 91-92	70-71 to 92-93	70-71 to 93-94	70-71 to 94-95	70-71 to 95-96
(I) 12 weeks model T, $X_{5'09}$	R^2 Range of Errors	0.826 3.45 - 12.41	0.800 1.22 – 10.19	0.782 0.77 – 7.01	0.805 0.29 – 8.28	0.796 0.99 – 6.94
(II) 14 weeks model T, $X_{5'09}$ and $X_{5'13}$	R^2 Range of Errors	0.870 0.38 – 4.93	0.870 0.42 – 7.41	0.870 0.34 – 7.18	0.890 0.38 – 7.22	0.882 0.07 – 2.54
(III) 16 weeks model T, $X_{1'16}$ $X_{3'15}$ and $X_{3'16}$ 6, $X_{5'09}$ and $X_{5'13}$	R^2 Range of Errors	0.930 0.27- 1.36	0.931 0.33 - 1.67	0.931 0.67 – 1.79	0.941 0.75 – 1.37	0.942 0.90 – 1.81
(IV) 18 weeks model T, $X_{1'16}$ $X_{3'13}$ and $X_{3'}$ $_{16'}$ $X_{5'09}$ and $X_{5'13}$ $X_{6'17}$	R^2 Range of Errors	0.969 0.43 – 3.36	0.969 0.65 – 3.24	0.969 0.77 - 3.58	0.974 0.65 3.36	0.974 1.07 3.13

low for 12 week period model, and showed increasing trend as the periods beyond 12 weeks after sowing were added in the models. The simulated forecast errors were higher in 12 week model and consistently lower in 16 week model in all sets and hence, the model of 16[th] week was selected as a pre-harvest forecast model.

$$Y = 1579.72 + 30.01\,T + 16.26\,X_{1,16} - 7.45\,X_{3,15} + 4.60\,X_{3,16} + 176.65\,X_{5,09} - 131.41\,X_{5,13}\ (R^2{=}0.942) \quad \text{............ (1)}$$

All the regression coefficients except for max. temperature were significant or highly significant. The model accounted for about 94.2 per cent of total variation in wheat yield. The simulated forecast errors were in the range of 0.9 to 1.81 per cent for the years 1996-97 to 1998-99. Thus, the model is found to be reliable for forecasting the wheat yield at the end of 16[th] week after sowing.

Crop stage wise approach (Model II)

In crop stage wise approach two sub models were fitted based on original data of weather variables. The first model

Table 2: Variables selected, coefficient of determination and range of forecast errors in stage wise approach (Model II)

Variables selected		R^2 and simulated forecast errors (%)				
		70-71 to 91-92	70-71 to 92-93	70-71 to 93-94	70-71 to 94-95	70-71 to 95-96
(I) 4 stage model T, (X_{23}, X_{24}, &X_{53})	R^2	0.707	0.692	0.681	0.677	0.694
	Range of Errors	0.37 - 11.26	1.38 - 13.51	2.09 - 14.98	0.59 - 9.84	0.78 - 9.16
(II) 6 stage model T,(X_{53}, X_{56}& X_{63})	R^2	0.692	0.676	0.659	0.681	0.663
	Range of Errors	7.09 - 18.57	2.69 - 13.44	2.06 - 11.02	0.49 - 12.42	2.76 - 7.43

consisted of first four stages (from germination (s_1) to flowering stage(s_4) i.e. 46 std. week to 5th std. week) and the second having six stages (sowing (s_1)to dough stage(s_6) i.e. 46 std. week to 12th std. week.

The results indicated that time trend minimum temperature of jointing stage(s_3) and flowering stage (s_4) and wind speed in jointing stage were found to have significant influence on wheat yield in model based on first four stages. In the model based on first six crop stages, time trend, wind speed of third and sixth stages and sunshine hours of third stage were found to have significant influence on wheat yield. However, the R^2 values for both the models in different sets were low (<71%) and the simulated forecast errors were higher (up to 18.57%) than the week wise approach. Therefore, these models were not considered suitable as the pre-harvest forecast models.

Generated weather variables - Week number as weight (Model III)

The forecast models based on generated weather variables (Model III) by taking week number as weight were fitted to the data (Sowing to 12 th week period i.e. 46 std. week to 5th std. week) and it was found that only the time trend variable was selected in the model and the R^2 value of different sets were about 46 to 54 percent (Table 3). The simulated forecast errors were also high as compared to the model of same period in week wise approach with original weather variables (Table 1). Thus, generated weather variables approach taking week number as weight was not tried for the other periods.

Generated weather variables - Correlation coefficient as weight (Model IV)

The original weekly weather variables were given weight by taking correlation

Table 3: Variables selected, coefficient of determination (R^2) and range of forecast errors in generated weather variable approach.

Variables selected	R² and simulated forecast errors (%)					
		70-71 to 91-92	70-71 to 92-93	70-71 to 93-94	70-71 to 94-95	70-71 to 95-96
Week number as weight (Model III)						
(i) 12 weeks model						
T	R^2	0.578	0.511	0.459	0.517	0.504
	Range of Errors	5.81 - 19.43	7.70 - 17.17	6.37 - 11.35	8.29 - 13.57	6.78 - 11.84
Corr. Coeff. as weight (Model IV)						
(i) 12 weeks model						
T, Q'_{141}, Q'_{151}, Q'_{241}	R^2	0.941	0.942	0.939	0.942	0.943
	Range of Errors	0.49 - 5.17	0.84 - 5.58	0.15 - 6.01	0.68 - 5.20	1.60 - 5.34
(ii) 14 weeks model						
T, Z_{51}, Q'_{241}, Q'_{451}, Q'452	R^2	0.928	0.928	0.928	0.936	0.936
	Range of Errors	0.51 - 4.73	1.52 - 4.60	1.92 - 4.28	0.41 - 3.02	0.15 - 3.81
(iii) 16 weeks model						
T, Q'_{151}, Q'_{241}, Q'_{142}	R^2	0.947	0.947	0.946	0.952	0.952
	Range of Errors	0.19 - 3.00	0.44 - 3.12	0.15 - 3.26	0.22 - 2.05	0.41 - 1.28
(iv) 18 weeks model						
T, Z_{51}, Q'_{241}, Q'_{142}	R^2	0.910	0.911	0.911	0.922	0.922
	Range of Errors	0.21 - 3.90	0.12 - 3.71	0.63 - 3.71	0.22 - 2.13	0.49 - 2.11

coefficients between weather variables and wheat yield and the models (Model IV) were fitted for 12, 14, 16 and 18 weeks periods. The results indicated that models of all weeks in all sets accounted more than 91 per cent of variation in wheat yield and the simulated forecast errors were below 6 per cent in all the sets (Table 3). However, looking to the R^2 values and earliness of forecast, 12 weeks model based on 1970-71 to 1995-96 data was selected which is as under

$$Y = 1989.92 + 28.14T - 0.53\,Q'_{141} + 0.97\,Q'_{151} + 1.48\,Q'_{241} \quad (R^2=0.943) \qquad \text{.............(2)}$$

The model included time trend which had highly significant positive regression coefficient indicating increasing trend of technology over years, cross product (i,i') of maximum temperature and after noon relative humidity (Q'_{141}) showed negative significant influence on wheat yield, cross product of maximum temperature and wind speed (Q'_{151}), cross product of minimum temperature and after noon relative humidity (Q'_{241}) both these have positive and significant influence on wheat yield. All these cross products were given linear weight (j=1) by correlation coefficients ($r^j_{i,i'w}$). The proposed model accounted for about 94.3% variation in wheat yield. The simulated forecast errors were below 6 % in all the years. Pandey and Singh (1993) for U.P., Raja (1978) for some districts of Gujarat state, Chaurasia and Minakshi (1997) and Appa Rao (1983) have reported forecasting models for predicting wheat yield based on climatic variables. The present findings are on similar line.

Thus, both the proposed forecast models (1 and 2), can be used as a pre harvest forecast model. However, model (2) can be prefered to that of model (1) as it forecasts 5-6 weeks before the harvest of the wheat crop in the district.

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