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Pre-harvest forecasting of rice (*Oryza sativa* L.) yield based on weather variables and technological trend

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ABSTRACT

To develop the pre harvest forecasting model of rice yield using weather variables and technological advances, 33 years yield data of Kheda district, Gujarat from 1967-68 to 2001-02 were collected. The weekly averages of weather variables viz., bright sunshine hours (BSS), rainfall (RF), maximum (MaxT) and minimum temperature (MinT) and morning relative humidity (MRH) from 23rd to 42nd standard meteorological weeks (MSW) of the respective years, were considered in the study.

The week-wise, crop stage-wise and generated weather variables (weighted) criteria were used. Time trend was also included as independent variable in all the criteria. To provide pre-harvest forecasts different week-intervals were considered. Step wise regression technique was employed for all forecasting models. Among these the models, the model based on week-wise criteria using original weather variables of 16 weeks provided a reliable pre-harvest forecasting of rice in Kheda district. The forecasting can be done four weeks before expected harvest (i.e. 3rd week of September/ at the end of 38 th MSW). The average absolute mean forecast errors of the selected model for the subsequent three years were found to be 10.97 percent. The pre-harvest proposed forecast model accounted 75.4% variation in rice yield.

Key words : Rice yield, forecasting, weighted weather variables, technology trend.

Pre-harvest yield forecasts are of considerable importance in taking policy decisions relating to the food procurement, distribution, price and import and export policies and for exercising several administrative measures for storage and marketing of agricultural commodities.

Weather is a major factor affecting crop production in advanced agricultural systems. There are many weather variables like temperature, relative humidity, wind speed, rainfall and sunshine hours that constitute the major meteorological influence contributing to the growth and development of the crop directly or indirectly.

Rice a staple food of masses, ranked first in area and second in production in the world (Anon., 2000a). Among the major rice growing states, Gujarat ranked 15th in area (0.58 million hectare) as well as in production (0.47 million ton) (Anon., 2000b). Kheda district being the major rice growing district of middle Gujarat it was selected for the present study.

MATERIALS AND METHODS

In present study average rice yield data for Kheda district for the years 1967 to 2001 were collected (Anon 2000c). Anand (22°35'N, 72°55'E; 45.1 m AMSL) was considered as the representative area of Kheda district. The data for meteorological variables *viz.*, bright sunshine hours (BSS), weekly total rainfall (RF), maximum temperature (MaxT), minimum temperature (MinT) and morning relative humidity (MRH) were collected from the Department of Agricultural Meteorology, Anand Agricultural University, Anand.

i) Original weather variables criteria

The effect of weather variables on the crop was studied by week wise and crop stage wise criteria. In week wise criteria the data of 23 to 40 meteorological standard weeks (MSW) were used. In crop stage wise criteria, averages for weather variables were worked out for different stages (Reddy & Reddi (1995). i.e. S_1- seedling stage(23-26 MSW), S_2 - active tillering stage(27-29 MSW), S3 - vegetative lag stage(30-33 MSW), S4 - flowering (34-37 MSW) and S_5 - grain development stage (38-40 MSW).

The step wise regression technique (Draper and Smith, 1966) was followed with probability of 0.1 and 0.2 to enter and to remove the variables, respectively in the model. The SPSS software was used for the analysis of data. The fitted model was as under :

$$Y = A0 + aT + \sum_{i=1}^{p} \sum_{j=1}^{w/s} b_{ij} X_{ij} \quad j=1$$

Where,

Y = Average rice yield of the district (kg ha^{-1})

A_0 = Constant

X_{ij} = Observed value of i^{th} weather variable in j^{th} week,

i = 1, 2,....p = 5 and

j = 01,02,... w = 12,14,16 and 18 weeks in week wise criteria and

j = 1, 2,...... s = 5 stages in stage wise criteria

T = Year number included to correct the long term trend in rice yield

a and b_{ij} are partial regression coefficients associated with time trend and each X_{ij} variables, respectively.

ii) Weighted weather variables criteria

In this criteria new variables (Z_{ij}) and ($Q_{ii'j}$) were generated from original weekly averaged weather variable data as per the formula given below (Agarwal *et al.*,1980).

$$Z_{ij} = \sum_{w=1}^{n} w^j . X_{iw} \Big/ \sum_{w=1}^{n} w^j \quad \text{and}$$

$$Q_{ii'j} = \sum_{w=1}^{n} w^j . X_{iw} . X_{i'w} \Big/ \sum_{w=1}^{n} w^j$$

where,

n = number of weeks up to the time of forecast (n= 12, 14, 16 and 18)

w^j = w is week identification (w=1 for MSW 39,and 2= MSW 40,… and j=0,1,2)

X_{iw} = value of the i^{th} weather variable in the w^{th} week

$X_{iw}.X_{i'w}$ = Interaction between X_i and $X_{i'}$ weather variable (i‘“i’ = 1,2… 5 and j=0,1,2)

The following model was fitted:

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{i \neq i'}^{p} \sum_{j=0}^{2} b_{ii'j} Q_{ii'j} + cT$$

Where,

Y = Average rice yield of district (kg ha^{-1})

A_0 = regression constant

T = Year number included to correct the long term trend in rice yield

p = No. of weather variables (p=1,2,...5)

a_{ij}, $b_{ii'j}$ and c are partial regression coefficients associated with each Z_{ij}, $Q_{ii'j}$, and time trend respectively (i,i’ = 1,2….p and j=0,1,2)

RESULTS AND DISCUSSION

(a) Week wise criteria

The meteorological standard week wise weather variables values were used as set of independent variables with time trend to predict the rice yield. The results are given in Table 1.

The results indicated that the set of explanatory variables explained about 67 to 89 % of total variation in rice yield in all the three models. The partial regression coefficients in 12 and 14 weeks period (model 1) for time trend (T) and rainfall of 34th MSW (RF 34) were positive and significant while effect of minimum temperature of 28th MSW (MinT 28) was negative and significant. In fitted model for 16 weeks crop period (model 2), the results indicated that the partial regression coefficients for time trend (T) and morning relative humidity of 32nd MSW (RHM 32) were positive and significant, whereas partial regression coefficients for bright sunshine hours of 27th MSW (BSS 27) was observed negative and significant. In fitted model for 18 weeks crop period (model 3), the partial regression coefficients for time trend (T), bright sunshine hours of 30th MSW (BSS 30), minimum temperature of 39th week (MinT 39) and morning relative humidity of 32nd MSW (RHM 32) were positive and significant, whereas for bright sunshine hours of 31st MSW (BSS 31), rainfall of 40th MSW (RF 40) and minimum temperature of 28th MSW (MinT 28) were significant and negative. The value of R^2 was improved by about 8 and 22 per cent in

Table 1 : Fitted regression model for rice yield on trend and different weather variables in week-wise criteria

Model No. 1 with weather variables upto 12 & 14 weeks		**Model No. 2 with weather variables upto 16 weeks**		**Model No. 3 with weather variables upto 18 weeks**	
Constant	3501.99 (1702.96)	Constant	546.13 (2006.48)	Constant	1539.65 (1582.31)
Trend	18.45** (5.77)	Trend	22.49** (5.23)	Trend	21.99** (4.00)
RF 34	1.24* (0.57)	BSS 31	-35.64 (24.31)	BSS 30	69.45** (20.74)
RF 31	1.76 (0.90)	MinT 28	-85.10 (48.17)	BSS 31	-69.46** (21.68)
MinT 34	135.78 (88.26)	RHM 38	10.53 (10.55)	RF 40	-10.21** (2.82)
MinT 28	-250.33** (60.26)	RHM 32	24.19* (10.14)	MinT 28	-90.56* (35.90)
RHM 25	7.20 (5.88)	BSS 27	-44.33* (19.36)	MinT 36	-110.87 (59.26)
				MinT 39	66.95* (28.11)
				RHM 37	12.69 (7.76)
				RHM 32	22.20* (9.50)
				BSS 27	-25.78 (14.42)
S. E.	244.70		211.4		151.11
R^2 (%)	67.10		75.40		89.70

*, ** Significant at 5 % and 1 % level of significance
Figures in parentheses indicates standard error

models 1 & 2 as compared to model 1.

(b) Crop stage-wise criteria

Crop stage-wise average of original weather variables were calculated for different stages as mentioned earlier and the models up to 3rd , 4th and 5th crop stages were fitted. The results are given in Table 2.

The results related to 3rd and 4th crop stages (model 4) were the same and accounted about 70 per cent variation in rice yield. The results revealed that the partial regression coefficients for time trend (T) and morning relative humidity of vegetative lag stage (MRH S_3) were found positive and significant while for minimum temperature in active tillering stage (MinT S_2) was found negative and significant. The results related to 5th crop stages (model 5) indicated that the set of explanatory variables explained 75.50 per cent variation in yield of the rice crop. The partial

Table 2: Partial regression coefficients of rice yield on trend and different original weather variables in crop stage-wise approach

Model No. 4 with weather variables upto 3rd & 4th stage		**Model No. 5 with weather variables upto 5th stage**	
Constant	-3086.73 (3634.53)	Constant	1741.97 (2055.61)
Trend	15.64* (5.60)	Trend	19.58** (5.19)
MRH S_3	60.05** (16.05)	MRH S_3	38.14** (9.73)
MinT S_2	-281.21** (69.15)	MinT S_2	-211.35** (53.55)
MinT S_3	243.34 (128.04)	RF S_4	1.28 (1.11)
		MinT S_5	106.68* (42.37)
		MaxT S_1	-32.26 (32.84)
S.E.	224.74		211.21
R^2 (%)	69.70		75.50

regression coefficients were positive and significant for time trend (T), morning relative humidity for vegetation lag stage (MRH S_3) and minimum temperature for grain development stage (MinT S_5) whereas, negative and significant for minimum temperature of active tillering stage (MinT S_2).

c) Weighted weather variables criteria

In this criteria weighted weather variables i.e.$Z_{i,j}$ and $Q_{i,i'j}$ of different weeks were calculated. These weighted variables with time trend were considered as a set of independent variables and stepwise regression technique was employed. The results are given in Table 3.

The results of 12 weeks model (model 6) indicated that out of 46 weighted explanatory variables, time trend (T), Q_{251}, Z_{41} and Q_{241} entered in the equations explained 57 per cent variation in the yield of the rice crop. Only time trend (T) and linear weight to week number to minimum temperature (Z_{41}) influenced the yield of rice significantly in positive direction. The model of 14 weeks crop periods, (model 7) consisted time trend (T), Q_{340}, Z_{52} and Q_{352} explained 58.40 per cent variation in the yield of rice crop. The result indicated that the second order weighted variables Q_{340} (zero weight to week number to cross product of maximum temperature and minimum temperature) and time trend (T)

Table 3 : Partial regression coefficients of rice yield on trend and different weighted weather variables in week number as weight in different weeks

Model No. 6 with weather variables upto 12 week		**Model No. 7 with weather variables upto 14 week**		**Model No. 8 with weather variables upto 16 week**		**Model No. 9 with weather variables upto 18 week**	
Constant	9219.42 (3070.60)	Constant	3716.64 (2577.18)	Constant	1792.73 (1551.62)	Constant	-560.37 (2263.29)
Trend	27.53** (6.30)	Trend	21.21** (7.20)	Trend	18.53* (7.07)	Trend	20.42** (6.74)
Q_{251}	-0.42 (0.29)	Q_{340}	-6.69* (2.61)	Q_{340}	-5.52** (1.29)	Z_{52}	44.89* (16.40)
Z_{41}	-335.71* (122.14)	Z_{52}	-19.03 (35.46)	Q_{352}	1.41* (5.54)	Q_{340}	-7.89* (3.20)
Q_{241}	1.76 (1.08)	Q_{352}	1.70 (1.19)			Q_{342}	5.48* (2.96)
S.E	266.90		263.28		252.11		254.73
R^2 (%)	57.00		58.40		60.30		61.10

Table 4 : Deviations of actual yield and predicted yield of rice by three selected models

Year	Actual yield (kg ha^{-1})	Predicted yield (kg ha^{-1}) with		
		Model 2	Model 3	Model 4
1998-99	1952	2036 (-4.3)	2174 (-11.4)	1835 (6.0)
1999-2000	2152	1908 (11.3)	1761 (18.2)	1815 (15.6)
2001-2002	1795	2105 (-17.3)	2028 (-13.0)	2188 (-21.9)
Absolute mean error (%)		11.5	14.2	14.2

Figure in parentheses indicates per cent deviations in prediction

significantly influenced the rice yield.

The regression equation obtained for 16 weeks model (model 8), indicated that explanatory variables entered in the equations were time trend (T), Q_{340} and Q_{352}. The variation explained by these variables was 60.3 per cent. Time trend (T), Q_{340} and Q_{352}(quadratic weight to week number to cross product of maximum temperature and morning relative humidity) significantly influenced the yield of rice. The regression equations related to 18 weeks model (model 9) consisted time trend (T),

Z_{52}, Q_{340} and Q_{342}. The variation explained by these variables together was 61.10 per cent. The results further indicated that all partial regression coefficients were significant.

The results indicated that method using weighted weather variables in week wise criteria no improvement in R^2 was noticed as compared to week wise criteria of original weather variables. Among the models based on original values of weather variables, the model for 16 weeks in week wise (model 2) and for crop stage S_5 model (model 5) accounted about 75 % variation while the model based on 18 weeks (model 3) accounted highest variation (R^2 = 89.7%). Using these three models the rice yield for three subsequent years were predicted and are given in Table 4.

The results indicated that the absolute mean forecast errors were least for model 2 week wise criteria based. For pre harvest forecasting the model should forecast satisfactory yield prior to harvest. Accordingly the model 3 and model 5 could not be selected on this ground. Thus the following model 2 which provided earlier forecast (4 weeks before harvest in 39[th] MSW) with least forecast errors was preferred as pre-harvest forecast model for rice yield of Kheda district of Gujarat state.

$$Y = 546.13 + 22.49^* T - 35.64\, BSSw_{31} - 85.10\, MinTw_{28} + 10.53\, RHMw_{38} + 24.19^*\, RHMw_{32} - 44.33^*\, BSSw_{27} \quad (R^2 = 75.4\ \%)$$

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