Pre-Harvest Forecasting Model of Mustard Cropyield Basis on Weather Parameters in Gandhinagar District of Gujarat

C. M. Chaudhari[1], M. B. Thaker[2], N. V. Patel[3]

[1]Research Scholar, Pacific University Udaipur, Rajasthan, India

[2] M. G. Science Institute, Ahmedabad,Gujarat, India

[3]Research Scholar, Pacific University Udaipur, Rajasthan, India

Abstract: ***The crop productiondirectly or indirectly depends on Weather parameters. Therefore, Weather is an important factor for agriculture practice. Present investigation was done to examine three types of model using meteorological weather variables and mustard crop yield (Productivity)inGandhinagar district of Gujarat state in India. Data were used for mustard crop during the time period 1980-81 to 2014-15. The step wise regression analysis was employed for mustard crop to determine a set of explanatory variable,which satisfied the equation and explain maximum variation in yield. Average mustard yield was considering as dependent variable and weather variables like Maximum and Minimum Temperature in degree Celsius, Relative Humidity in morning and evening in percentage, Sun-Shine hours per day and Annual Rainfall in mm as independent variables. Finally, the model which has provided the earliest forecast with high coefficient of determination, t value and minimum percentage deviation from the observed mustard average yields of Gandhinagar district was consider as suitable pre harvest forecast model.***

Keywords: Weather variables, Mathematical approach

1. Introduction

Mustard (*Brassica*) seed is the third most important oil seed crop in India after soybean. It is also known as Rai, Mohari, Tikkiya, Serson in different regions of India. It accounts for nearly 20-22% of the total oil seed produced in the country. Mustard seed is a rabi season crop sown during October - November and harvest during March - April (APEDA 2015)

Canada is largest producer and India is the fourth producer of pure mustard seeds in the world. In India, mustard seed is mainly grown in North-West parts of India. Rajasthan (45%), Uttarpradesh (15%), Madhya Pradesh (11%) and Gujarat (5.6%) are the major mustard seed producing states in the country. The largest mustard seed producing state is Rajasthan in India. Mustard production is highly influenced by the vagaries of monsoon and other weather parameters. Therefore, the production is highly fluctuating from year to year. (Sahu Nov 09, 2015) .

Gujarat is the fifth largest mustard producing state in India andBanaskantha is the highest mustard seed producing District in Gujarat with a share of nearly 55% to the state's total production, followed by Patan (15%) and Mehsana (15%). Gandhinagar is one of mustard producing district. Hence, an attempt has been made to find the pre-harvest yield forecasting of mustard on the basis of weather parameters.

Reliable pre-harvest forecasts of crop production help as a basis of decision making policy for the government, agro-based industries, trades and agriculturalists. Government demands a reliable and valid pre-harvest forecast of production of crops for their policy decision in regard to procurement, distribution, buffer stocking, import-export, price fixation and marketing of agricultural commodities. The agro based industries and traders need them for proper planning of their operations, while agriculturalists use them as a basis for deciding the cultivation of a crop and its acreage during the subsequent season. Hence, the yield data obtained by reliable forecasts techniques will be very much useful for the country like India whose economy is mainly based on agriculture.

An attempt, therefore, is made here to estimate the mustard crop yield on the basis of weather parameters and examining them for developing forecasting model.

2. Literature Review

The investigations already done on Pre-harvest forecasting crop yield basis on weather parameters sited as follows.

(Fisher 1924)was the first who assumed that in wheat crop, the effects of change on weather variables in successive weeks would not be an erratic change but an orderly one that follows some mathematical law**.** He further assumed that these effects are composed of the terms of a polynomial function of time**.**

(Das, J.C.and Ramachandran,G. 1971)developed a forecasting model for bajra yield for Ahmedabad district of Gujarat state. They found that it could be possible to give final estimate of yield of bajra by third week of October.

(Agarwal, Rajana.; Jain R.C.and jha M.P. and Singh D 1980) developed a suitable statistical methodology for forecasting the yield of rice(*Oryza sativa* L.) in Raipur district using the yield data of 25 years and weekly weather variables, viz. maximum temperature, relative humidity, total rainfall and number of rainy days. Two models were found suitable. In the first, weighted averages of weekly

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weather variables and their interactions using power of week numbers as weight were used. The respective correlation coefficients with yield in place of week number were taken in the second model. The step-wise regression technique was followed for obtaining the forecast equations. The 11th week after sowing was found suitable for forecasting the yield of rice.

(Jha, M.P.,Jain, R.C. and Singh,D. 1981)developed a forecasting model for obtaining pre-harvest estimates of sugarcane yield by taking explanatory variables as the observations on biometrical characters. They identified that the number of canes and their height were two most important characters related to sugarcane yield. By using these explanatory variables in a linear multiple regression model, it was possible to forecast the crop yield about 2 to 3 months before harvest.

(Rai, T and Chandrahas 1999)observed that temperature (maximum and minimum) and sunshine hours were effective at the growing phase whereas sunshine hours found ineffective during early growth phase. All the variables under study at active vegetative phase explained about 87% of the total variation in rice yield.

(Rajeshkumar.,Gupta, B.R.D., Athiyaman, B.Singh, K.K.Shukla, R.K. 1999)used a step-wise regression technique to determine the effect of different climatic variables on the yield of pigeon pea. Five crop stages (sowing to germination, germination to branching, branching to flowering, flowering to seed formation and seed formation to maturity) were identified. The variables were correlated with yield on a weekly basis for an overlapping period of 17 weeks. Eight of the 17 variables were retained in the prediction equation. The yield variation in pigeon pea affected by climatic variables was 94% (significant at 0.1% level). The predicted yields for 1991 (1244 kg/ha), 1992 (1608 kg/ha) and 1993 (1190 kg/ha) were compared to actual yields (1189, 1665 and 1117 kg/ha, respectively). The study indicated that the prediction equation developed was capable of estimating yield before maturity.

(Malik, R.K.and Gupta, B.R.D. 2000)described an empirical statistical yield weather model for wheat in the Varanasi district of Uttar Pradesh. The weather parameters from the year 1970-71 to 1998-99 in Varanasi were selected for the regression equations. Yield was significantly related to rainfall, temperature, sunshine and rainy days from 51 to 2, 4 to 6, 49 to 2, and 51 to 3 weeks, respectively. Predicted yield using 4, 6 and 10 parameter models were within +15, +15 and +10% of actual district yield.

(Pandey, K.K.; Rai V. N.; Sisodia B. v. s. and Singh S.K. 2015)dealt with the effect of weather variables on rice crop in Eastern Uttar Pradesh. They determined the individual and joint effect of weather variables on rice yield in Faizabad. On basis of R^2 they found that individually sun shine (hr) is more important with 67.57 followed by wind velocity and rainfall with 48.63 and 46.74 respectively. The joint effect of weather variables is also playing an important role. According to R^2 more important combination is rainfall and wind velocity with 82.5% followed by rainfall and sun shine hour and wind velocity and sun shine hr 63% and 53.85% respectively.

3. Study Area

Gandhinagar District is located at North Latitude 23.56 to 23.01 and 73.33 to 72.33 East Longitude in Western India and north-central in Gujarat. Gandhinagar district occupies an area of approximately 649 square kilometres. This District has mostly black, sandy and clayey soil. Due to availability of different kinds of soil, a variety of seasonal crops are practiced by farmers. The highest temperature recorded is 45 °C and minimum temperature is 7.5 ^{0}C during the year. The annual rainfall is around 667mm but infrequent heavy torrential rains cause local rivers to flood and it is not uncommon fordroughts to occur when the monsoon does not extend as far west as usual. (Indianetzone 2013)

4. Research Methodology

Data on average yield (productivity) of mustard crop of Gandhinagar district from 1980-81 to 2014-15 were collected from District-wise Area, Production and Yield of Important Food & Non-food Crops in Gujarat State of respective years published by Directorate of Agriculture, Gandhinagar and Gujarat state. (Anonymous 1980-2015)

$$Z'_{ij} = \frac{\sum_{w=1}^{n} r_{iw}^{j} . X_{iw}}{\sum_{w=1}^{n} r_{iw}^{j}} \quad and \quad Q'_{ii'j} = \frac{\sum_{w=1}^{n} r_{ii'w}^{j} . X_{iw} . X_{i'w}}{\sum_{w=1}^{n} r_{ii'w}^{j}}$$

The weekly Average data of weather parameters viz.(1)Maximum temperature (^{0}C) (2)Minimum temperature (^{0}C) (3) Morning relative humidity (%) (4)Evening relative humidity (%) (5)Bright sunshine hours/day (6) Annual Rainfall (mm) of the respective years of Gandhinagar district from years 1980-81 to 2014-15 was collected from the Meteorological Centre, Ahmedabad.

There are broadly three approaches for forecasting the crop yield (Singh D.,Jha M.P., Krishna K.S,.Iyer V.N.and Ranjana Agrawal 1977). They are,(i)Based on eye observations of the growing crop, (ii) Based on weather and other input parameters and (iii) Based on biometrical characters observed during the crop growth.These approaches are complementary to each other and may be combined. The most frequently used approach is based on crop weather relationship studies in which, the periodical data of crop yields and weather variables are used. The forecast based on such relationship is objective in nature and do not require survey.

For this study the effect of important weather variables on yield of mustard crop, following weather variables with time trend were considered.

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Variables	Description
Y	Average mustard yield of Gandhinagar district in kg/ha
T	Time trend, year number included to correct upward or downward trend in yield
X_1	Maximum temperature (^{0}C)
X_2	Minimum temperature (^{0}C)
X_3	Morning relative humidity (%)
X_4	Evening relative humidity (%)
X_5	Bright sunshine hours/day
R	Annual Rainfall (mm)

For selecting the best regression equation among a number of independent variables, the step-wise regression procedure was adopted (Draper N.R. and Smith H. 1966). SPSS software was used for thedata analysis. Three sets of multiple linear regression equations were obtained separately for model-I(30 years), model-II (31 years) and model-III (32 years) and mustard yield for the subsequent years were predicted. Following model (Agarwal, Rajana.; Jain R.C.and jha M.P. and Singh D 1980)has been studied.

Generated weather variables using correlation coefficient as weight:

The correlation coefficients between mustard yield and different weather variables are worked out week-wise and they will be used as weight and new variables Z'_{ij} and $Q'_{ii'j}$(taking interaction of variables) were generated (Agarwal, Rajana.; Jain R.C.and jha M.P. and Singh D 1980)using following formula

Here, Z'_{ij} and $Q'_{ii'j}$ are generated first and second order variables defined as under,

n = number of weeks up to the time of forecast

w = week identification (w=1,2,…, n=11, 12, 13 and 14)

X_{iw}= value of the i^{th}weather variable in the w^{th}week ($i \neq i'$ = 1,2,… ,p and j=0,1,2)

r_{iw}= correlation coefficient of yield with the i^{th}weather variable in the w^{th} week

$r_{ii'w}$= correlation coefficient of yield with the product of the i^{th} and i'^{th} weather variable in the w^{th} week.

The details of first order (Z'_{ij}) and second order ($Q'_{ii'j}$) generated variables obtained from this way and included in analysis are given in below Table.

First order generated variables (Z'_{ij})

Z'_{ij}	Z'_{1j}	Z'_{2j}	Z'_{3j}	Z'_{4j}	Z'_{5j}
Z'_{i0}	Z'_{10}	Z'_{20}	Z'_{30}	Z'_{40}	Z'_{50}
Z'_{i1}	Z'_{11}	Z'_{21}	Z'_{31}	Z'_{41}	Z'_{51}
Z'_{i2}	Z'_{12}	Z'_{22}	Z'_{32}	Z'_{42}	Z'_{52}

Second order generated variables ($Q'_{ii'j}$)

$Q'_{ii'j}$	$Q'_{ii'0}$	$Q'_{ii'1}$	$Q'_{ii'2}$
Q'_{12j}	Q'_{120}	Q'_{121}	Q'_{122}
Q'_{13j}	Q'_{130}	Q'_{131}	Q'_{132}
Q'_{14j}	Q'_{140}	Q'_{141}	Q'_{142}
Q'_{15j}	Q'_{150}	Q'_{151}	Q'_{152}
Q'_{23j}	Q'_{230}	Q'_{231}	Q'_{232}
Q'_{24j}	Q'_{240}	Q'_{241}	Q'_{242}
Q'_{25j}	Q'_{250}	Q'_{251}	Q'_{252}
Q'_{34j}	Q'_{340}	Q'_{341}	Q'_{342}
Q'_{35j}	Q'_{350}	Q'_{351}	Q'_{352}
Q'_{45j}	Q'_{450}	Q'_{451}	Q'_{452}

In order to explore the possibility of early forecasts before 6, 5, 4and 3 weeks of harvest of mustard crop, three models would be fitted using generated weather variables for the period of 11, 12, 13and 14 weeks crop periods.

Forty-Five explanatory variables comprising of 15 first order generated variables (Z'_{ij}), 30 second order generated variables ($Q'_{ii'j}$) along with time trend variable (T) and annual total rainfall would be subjected to step-wise regression analysis using following model.

The mathematical expression for this model is,

$$Y = A_0 + \sum_{i=1}^{p}\sum_{j=0}^{2} a_{ij} Z'_{ij} + \sum_{i \neq i'=1}^{p}\sum_{j=0}^{2} b_{ii'j} Q'_{ii'j} + cT + dR$$

Where,

Y = Average mustard yield of Gandhinagar district (kg/ha)

A_0 = Constant

a_{ij}, $b_{ii'j}$, c and d are partial regression coefficients associated with each Z'_{ij}, $Q'_{ii'j}$, time trend and annual total rainfall respectively.

($i \neq i'$ = 1,2,…,p and j = 0,1,2)

T =Year number included to correct for the long term upward or downward trend in mustard yield

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

The significance of the coefficient of determination (R^2) will be tested by applying 'F' test for all the approaches (Rangaswamy 2002).

Simulated forecast

Using these fitted prediction equations, simulated forecasts are to be obtained for the subsequent years which are not included in the model. The percentage deviations of forecasted yields and reported yields are to be worked out to assess the suitability of these models as pre-harvest forecast models. Finally, the model which provides the early forecast before harvest of mustard crop, accounted higher variation in mustard yield with least deviation from the observed yield of the Gandhinagar district, would be considered to be the best pre-harvest forecast model.

The information on different sets, number of years, and their period included in the prediction model and corresponding simulated forecast periods are given in below Table.

Set	Years included in		The period of simulated	
No.	No. of	From ….	From	No. of
1	30	1980-81 to	2010-11to	5
2	31	1980-81 to	2011-12to	4
3	32	1980-81 to	2012-13 to	3

5. Results and Discussion

In this study, generated weather variables (correlation coefficient as weight) were utilized. The partial regression coefficients, coefficients of multiple determination and the t values of five different models corresponding to 11, 12, 13 and 14 weeks crop periods are presented in Tables A.1, B.1, C.1 and D.1 The corresponding simulated forecasts for the subsequent years (which were not included for fitting the equations) and their percentage deviations from actual district average yield are presented in Tables A.2,B.2, C.2 and D.2 respectively.

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The variables entered in the equations for 11 weeks crop period (Table A.1) were time trend (T), first order generated variable Z'_{12} and second order generated variables Q'_{152},Q'_{230} and Q'_{151}. The variations explained by these explanatory variables were 73.30 %, 81.20 % and 81.40 % in model-I, model-II and model-III respectively. The yield of Mustard crop was highly and significantly influenced by Q'_{152}(Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours) in model-I, Q'_{230} (zero weight of correlation coefficients to cross products of minimum temperature and morning relative humidity)and Q'_{151}(Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours) in model-II and Q'_{152}(Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours) and Q'_{230} (zero weight of correlation coefficients to cross products of minimum temperature and morning relative humidity) in model-III. The simulated forecasts for these models (Table A.2) showed -27.7 % to 16.88 % deviation from the actual mustard yield.

In case of 12 weeks crop period (Table B.1), the variables entered in the equation were time trend (T) and second order generated variables Q'_{151}, Q'_{232},Q'_{152}, Q'_{121} and Q'_{240}. The variations explained by these explanatory variables were 77.60 %, 75.30 % and 70.60 % in model-I, model-II and model-III respectively. The results revealed second order generated variables by Q'_{152}(Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours) in model-I and model-II and Q'_{151}(Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours) in model-III were significantly influenced the yield of Mustard crop. The simulated forecasts for these models (Table B.2) showed -27.40 % to 25.11 % deviation from the observed yield.

The regression equation related to 13 weeks model (Table C.1) revealed that the variables entered in fitted equations were time trend (T), second order generated variables Q'_{152}, Q'_{231},Q'_{151}, $Q'_{121,}$ and Q'_{240} and annual rainfall (R) and they explained 76.50 %, 75.30 % and 70.10 % variation in model-I, model-II and model-III respectively. The results revealed that second order generated variables by Q'_{151}(Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours) in model-I and model-II and Q'_{152}(Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours) in model-III were significantly influenced the yield of Mustard crop. The simulated forecasts for these models (Table C.2) showed -23.20 % to 25.28 % deviation from the actual yield.

In the fitted model of 14 weeks crop periods (Table D.1), the explanatory variables entered in the equations were second order generated variables Q'_{152},Q'_{140}, Q'_{151} and Q'_{240} and Total annual rainfall (R). The results revealed second order generated variables by Q'_{152}(Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours) in model-I and model-III and Q'_{151}(Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours) in model-II were significantly influenced the yield of mustard crop. The variations explained by these variables were 79.50 %, 77.20 % and 76.90 % by model-I, model-II and model-III respectively. The simulated forecasts for these models (Table D.2) showed -23.10 % to 23.66 % deviation from the actual yield.(* denoted Significant at 5 % level of significance and ** denoted Significant at 1 % level of significance.in below tables)

Table A.1: Partial regression coefficients of mustard yield on time trend, annual rainfall and different generated weather variables using correlation coefficients asweight approach(11 weeks)

Variables in the equations	Years		
	1980-81 to 2009-10 (Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
Constant	4221.62**(11.25)	6298.71**(6.63)	6177.12**(6.64)
Q'_{152} (Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours)	-7.77**(-8.38)	-	-6.38**(-7.01)
Q'_{230} (zero weight of correlation coefficients to cross products of minimum temperature and morning relative humidity)	-0.76*(-3.31)	-0.87**(-4.04)	-0.84**(-4.00)
T (Time Trend)	-	11.18*(3.53)	11.67*(3.78)
Z'_{12} (Quadratic weight of correlation coefficients to maximum temperature)	-	-81.17(-2.89)	-77.92(-2.83)
Q'_{151}(Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours)	-	-6.35**(-6.92)	-
R^2 (%)	73.3%	81.2%	81.4%

Figures in parenthesis indicate t value.

Table A. 2: Simulated forecasts based on the fitted equations (11 weeks)

Year	Observed Yield (Kg/ha)	Simulated forecasts (kg/ha)		
		1980-81 to 2010-11 (Model-II)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
2010-11	1632	1247.17(-23.6)		
2011-12	1523	1334.24(-12.4)	1408.56(-7.51)	
2012-13	1523	1298.24(-14.8)	1473.91(-3.22)	1485.41(-2.47)
2013-14	1723	1245.35(-27.7)	1424.57(-17.3)	1439.29(-16.5)
2014-15	1398	1491.64(6.70)	1616.85(15.65)	1633.98(16.88)

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Figures in parenthesis are per cent deviations from observed yield.

Table B.1: Partial regression coefficients of mustard yield on time trend, annual rainfall and different generated weather variables using correlation coefficients as weight approach (12 weeks).

Variables in the equations	Years		
	1980-81 to 2009-10 (Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
(Constant)	3791.35** (9.69)	3528.18**(10.04)	3331.75**(9.36)
Q'_{151} (Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours)	-	-	-7.50**(-6.14)
Q'_{232} (Quadratic weight of correlation coefficient to cross products of minimum temperature and morning relative humidity)	0.09*(2.33)	-	0.09*(2.14)
Q'_{152} (Linear weight of correlation coefficients to cross products of maximum temperature and minimum temperature)	-7.69**(-6.79)	-6.14**(-4.84)	-
Q'_{121} (Linear weight of correlation coefficients to cross products of maximum temperature and minimum temperature)	-	-1.27*(-2.63)	-
T (Time Trend)	-	8.02*(2.36)	-
Q'_{240} (zero weight of correlation coefficients to cross products of minimum temperature and evening relative humidity)	-0.70(-2.83)	-	-
R^2 (%)	77.6%	75.3%	70.6%

Figures in parenthesis indicate t value.

Table B.2: Simulated forecasts based on the fitted equations (12 weeks)

Year	Observed Yield (kg/ha)	Simulated forecasts (kg/ha)		
		1980-81 to 2009-10 (Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2010-12 (Model-III)
2010-11	1632	1184.3(-27.4)		
2011-12	1523	1386.87(-8.94)	1428.24(-6.22)	
2012-13	1523	1328.41(-12.8)	1492.51(-2.00)	1347.02(-11.6)
2013-14	1723	1322.5(-23.2)	1517.77(-11.9)	1420.66(-17.5)
2014-15	1398	1630.82(16.65)	1679.42(20.13)	1749.05(25.11)

Figures in parenthesis are per cent deviations from observed yield.

Table C.1: Partial regression coefficients of mustard yield on time trend, annual rainfall and different generated weather variables using correlation coefficients as weight approach (13 weeks)

Variables in the equations	Years		
	1980-81 to 2009-10 (Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
Constant	3972.04**(10.52)	3546.17**(9.90)	3462.66**(9.80)
Q'_{152} (Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours)	-	-	-7.57**(-5.77)
Q'_{231} (Linear weight of correlation coefficients to cross products of minimum temperature and morning relative humidity)	-	-	-0.06*(-2.09)
Q'_{151} (Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours)	-8.38**(-7.64)	-6.25**(-4.74)	-
Q'_{121} (Linear weight of correlation coefficients to cross products of maximum temperature and minimum temperature)	-	-1.22*(-2.72)	-
T (Time Trend)	-	7.86*(2.30)	-
Q'_{240} (zero weight of correlation coefficients to cross products of minimum temperature and evening relative humidity)	-0.86*(-3.29)	-	-
R (Annual total rainfall)	0.20*(2.09)	-	-
R^2 (%)	76.5%	75.3%	70.1%

Figures in parenthesis indicate t value.

Table C.2: Simulated forecasts based on the fitted equations (13 weeks)

Year	Observed Yield (kg/ha)	Simulated forecasts (kg/ha)		
		1980-81 to 2009-10 (Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
2010-11	1632	1252.68(-23.2)		
2011-12	1523	1342.44(-11.9)	1407.86(-7.56)	
2012-13	1523	1335.4(-12.3)	1483.76(-2.58)	1387.08(-8.92)
2013-14	1723	1354.35(-21.4)	1507.73(-12.5)	1425.65(-17.3)
2014-15	1398	1574.63(12.63)	1681.22(20.26)	1751.38(25.28)

Figures in parenthesis are per cent deviations from observed yield.

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Table D.1: Partial regression coefficients of mustard yield on time trend, annual rainfall and different generated weather variables using correlation coefficients as weight approach (14weeks)

Variables in the equations	Years		
	1980-81 to 2009-10(Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
Constant	4194.74**(11.39)	4271.73**(10.33)	4308.68**(10.41)
Q'_{152} (Quadratic weight of correlation coefficient to cross products of maximum temperature and bright sunshine hours)	-9.32**(-8.44)	-	-9.53**((-8.11)
Q'_{140} (zero weight of correlation coefficients to cross products of maximum temperature and evening relative humidity)	-	-0.47*(-2.67)	-0.47*(-2.65)
R (Annual total rainfall)	0.19*(2.17)	0.22*(2.27)	0.22*(2.24)
Q'_{151} (Linear weight of correlation coefficients to cross products of maximum temperature and bright sunshine hours)	-	-9.41**(-8.00)	-
Q'_{240} (zero weight of correlation coefficients to cross products of minimum temperature and evening relative humidity)	-0.85*(-3.37)	-	-
R^2 (%)	79.5%	77.2%	76.9%

Figures in parenthesis indicate t value.

Table D.2: Simulated forecasts based on the fitted equations (14 weeks)

Year	Observed Yield (kg/ha)	Simulated forecasts (kg/ha)		
		1980-81 to 2009-10 (Model-I)	1980-81 to 2010-11 (Model-II)	1980-81 to 2011-12 (Model-III)
2010-11	1632	1254.47(-23.1)		
2011-12	1523	1332.54(-12.5)	1356.96(-10.9)	
2012-13	1523	1349.74(-11.4)	1341.62(-11.9)	1349.1(-11.4)
2013-14	1723	1395.4(-19.0)	1420.15(-17.6)	1427.73(-17.1)
2014-15	1398	1663.39(18.98)	1715.61(22.72)	1728.8(23.66)

(Figures in parenthesis are percentage deviations from observed yield.)

6. Concluding Remarks

It could be observed from the above results that variation explained (i.e R^2) by fitted models ranged from 70.10% to 81.40% for all the three models. It could be seen that the deviations between observed yield and forecasted yield in percentage (Table A.2 to Table C.2) were ranged from -27.7% to 25.28%. Among the equations fitted under this approach, in models of 11 weeks crop period of 32 years (Model-III) R^2 was 81.40% which was found suitable for early forecast model under this approach.

Therefore, at least 6 weeks before actual harvest of the crop, reliable pre-harvest forecasting of mustard yield in Gandhinagar district can be made using original weather variables, week wise (11 weeks) approach by the following model:

$Y= 6177.12^{**} + 11.67^{*}\ T -6.38^{**}\ Q'_{152} - 0.84^{**}\ Q'_{230}-77.92\ Z'_{12}$

($R^2 = 81.40\%$).

The above equation can be made useful for the prediction purpose.

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