

# **Pre Harvest Forecasting of Kharif Rice Yield Using Weather Parameters for Strategic Decision Making in Agriculture**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author YAG act as Principal Investigator (PI) of the current study project and author VST act as Co-PI designed the study, performed the statistical analysis, wrote the first draft of the manuscript. Authors RRP and VTS managed the daily weather data to weekly weather data analyses of the study. All authors read and approved the final manuscript.*

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## **ABSTRACT**

In the recent year, pre harvest crop yield forecasting has been a topic of interest for producers, policy makers, government and agricultural related organizations. Pre harvest crop forecasting is important for national food security. Construction of appropriate yield forecast promotes the output of scenario analyses of crop production at a farm level, which enables suitable tactical and strategic decision making by the farmer. Indeed, considerable benefits apply when seasonal forecasting of crop performance is applied across the whole value chain in crop production. Timely and accurate yield forecast is essential for crop production, marketing, storage and transportation decisions as well as for managing the risk associated with these activities. In present manuscript efforts were made for development of pre harvest forecast models by using different statistical

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approaches viz. multiple linear regression (MLR), discriminant function analysis and ordinal logistic regression. The study utilized the crop yield data and corresponding weekly weather data of last 30 years (1985-2014). The model development was carried out at 35th and 36th SMW (Standard Meteorological Week) for getting forecast well in advance of actual harvesting of the field crop. The study revealed that method of discriminant function analysis gave best pre harvest forecast as compare to remaining developed models. It was observed high value of Adj. R<sup>2</sup>= 0.94, low value of RMSE= 164.24 and MAPE= 5.30. The model can be used in different crop for reliable and dependable forecast and these forecasts have significant value in agricultural planning and policy making.

**Keywords:** Pre harvest forecast; rice crop yield; weather indices; MLR; discriminant function and ordinal logistic.

## 1. INTRODUCTION

Indian rural economy mainly depends on agriculture and provides food and livelihood activities to much of the Indian population. Rice is a staple food for more than half of world's population. India is an important rice growing countries in the world which has the largest area (44.8 million hectares) followed by China and Bangladesh. In respect of production, India ranks second with 154.6 million tonnes of paddy (103.6 million tonnes, milled basis) next to China (206.4 million tonnes of paddy, 144.4million tones on milled basis), [1]. In the Gujarat state, rice is grown on an average about 6.50 to 7.25 lakh hectares of land comprising nearly 55 to 60 per cent of upland (drilled) rice. Timely and reliable forecasting provides vital and appropriate input, foresight and informed planning. Forecasts are used by the government & industry to protect life and property. The weather and climatic information plays a major role before and during the cropping season and if provided in advance it can be helpful in stirring the farmer to form and use their own resources in order to gather the benefits. The advance knowledge of weather parameters in a particular region is advantageous in effective planning.

The several studies have been conducted for suitable pre harvest forecasting of crop yield. The Fisher [2] and Hendricks and Scholl [3] developed models which required small number of parameters to be estimated while taking care of distribution pattern of weather over the crop season. Agrawal et al. [4] modified this model by expressing effects of changes in weather parameters on yield in the particular week as second degree polynomial in respective correlation coefficients between yield and weather parameters. This model was further

modified [4,5,6] by explaining the effects of changes in weather parameters on yield in particular week using correlation as weight using linear function. Patel et al. [7], Chauhan et al. [8], Garde et al. [9], Mahdi et al. [10], Singh et al. [11], Pandey et al. [12], Yadav et al. [13] and Banakara et al. [14] studied the relationship of weather parameters and rice crop yield in different regions. Varmola et al. [15], Agrawal et al. [16], Sisodia et al. [17], Garde et al. [18] and Diwan et al. [19], developed forecast models for Wheat crop in different regions of India. Similarly, for pigeon pea Kumar et al. [20] and Sarika et al. [21], for Sugarcane Priya and Suresh [22] and for Ground nut Dhekale et al. [23] developed pre harvest crop yield models.

In the current situation of India faces increasing population and industrial development which are adversely distressing the crop yield in India. Keeping in mind early crop yield forecast will help farmer to formulate the cropping pattern, agricultural practices which will results in to the increase yield of the farmers. Therefore main objective of the present study was to develop different approaches for forecasting the rice yield before harvesting with help of weather parameters.

## 2. MATERIALS AND METHODS

The present study was carried out in the Navsari, district of South Gujarat. Considering the specific objectives of the study, *Kharif* rice yield data were collected from the Directorate of Economics and Statistics, Government of Gujarat, Gandhinagar, Gujarat from year 1985 to 2014. The study utilized weekly weather data which were collected from the Department of Agrometeorology, Navsari Agricultural University, Navsari. Different weather parameters were taken under consideration viz. Maximum

temperature ( $X_1$ ), Minimum temperature ( $X_2$ ), Morning relative humidity ( $X_3$ ), Evening relative humidity ( $X_4$ ), and Total rainfall ( $X_5$ ) to study the effect on *Kharif* rice yield. The weekly weather data related to *Kharif* crop season starting from a first fortnight before sowing to last of reproductive stage were utilized for the development of statistical models. Accordingly for the each year, to get forecast in advance (35<sup>th</sup> and 36<sup>th</sup> SMW), the weather data for *Kharif* rice crop, from last week of May (22<sup>nd</sup> standard meteorological week, SMW) to first week of September (36<sup>th</sup> standard meteorological week, SMW) were utilized for development statistical models. The first 27 years data from 1985 to 2011 have been utilized for model fitting and remaining three years (2012 to 2014) were utilized for the validation of the models.

### 2.1 Development of Weather Indices Using Correlation Coefficient as Weight

The model is developed by using weather indices as predictors. The two types of weather indices were constructed viz. (i) un-weighted indices and (ii) weighted indices, where weigh being correlation coefficient between yearly crop yields and weather parameters with respective weeks. The forms of weather indices were given as below

$$Z_{i,j} = \sum_{w=1}^m \sum_{j=0}^1 r_{iw}^j X_{iw}$$

Where,

$Z_{ij}$  is the developed weather indices of  $j^{th}$  weight for  $i^{th}$  weather variable

$r_{iw}$  is correlation coefficient of de-trended Y with  $w^{th}$  week of  $i^{th}$  weather variable in  $w^{th}$  week

$m$  is week number up to forecast the yield

$i = 1, 2, \dots, p$

$j = 0, 1$  (un weighted = 0, weighted = 1)

$w = 1, 2, \dots, m$

$p$ 's are the number of parameters included in the model

### 2.2 Ordinal Logistic Regression

In this approach the crop years have been divided into three groups namely adverse (0), normal (1) and congenial (2) on the basis of crop yield adjusted for year effect. Crop years were grouped into three, where residuals (after fitting linear regression between yield and year) have

been arranged into ascending order and divided into three equal groups namely adverse (0), normal (1) and congenial (2). Using weather indices in these three groups, probabilities were obtained by ordinal logistic regression. These probabilities along with year as regressors were used for development of forecast model. The models were developed using stepwise regression procedure.

At week 35<sup>th</sup> and 36<sup>th</sup> SMW, the weather indices corresponding to the pre-defined groups have been used to compute probabilities by stepwise logistic regression.

#### 2.2.1 Ordinal logistic regression modelling with three groups

When dependent variable has an ordinal nature i.e. taking three values as zero, one, and two then the ordered multiple response models assume the relationship:

$$\begin{aligned} \text{logit}[P(Y \leq j - 1|x)] \\ = a_j + \beta_1 x_1 + \beta_2 x_2 + \dots \\ + \beta_p x_p, \quad j = 1, 2 \end{aligned}$$

The ordinal logistic regression model is given as:

$$P_0 = \frac{\exp(a_1 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p)}{1 + (a_1 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p)}$$

$$P_0 + P_1 = \frac{\exp(a_2 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p)}{1 + (a_2 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p)}$$

$$\text{and } P_0 + P_1 + P_2 = 1$$

Where,  $P_0$  is probability of  $Y = 0$ ,  $P_1$  is probability of  $Y = 1$  and  $P_2$  is probability of  $Y = 2$ ,  $a_j$ 's are the intercepts and  $\beta_j$  are the regression coefficients.

Yield forecast models were fitted using stepwise regression at 35<sup>th</sup> and 36<sup>th</sup> SMW taking probabilities  $P_1$  and  $P_2$  at week of forecast along with year as regressors. The fitted model is given below

$$\text{Model 1} \quad Y = A_0 + b_1 P_1 + b_2 P_2 + b_3 T + e$$

Where,

$P_1$  and  $P_2$  are the probabilities of  $Y=1$  and  $Y=2$

' $A_0$ ' is intercept of the model

$b$ 's are the regression coefficients

$T$  is year

$e$  is error term normally distributed with mean zero and constant variance

### 2.3 Discriminant Function Analysis

Similarly the crop years have been divided into three groups namely adverse (0), normal (1) and congenial (2) on the basis of crop yield adjusted for year effect. The corresponding weekly weather data were used to development discriminant scores. The procedure was started using weather data of 22<sup>nd</sup> SMW, the discriminant scores have been computed using five weather parameters. At the next week (23<sup>rd</sup> SMW), five weather parameters along with the scores computed at the initial week (22<sup>nd</sup> SMW) have been used as discriminator variables. Based on these variables the discriminant analysis has been done and two new discriminant score have been obtained. The same calculations have been repeated at third week (24<sup>th</sup> SMW). This procedure continued up to 35<sup>th</sup> and 36<sup>th</sup> SMW and final two discriminant score have been obtained.

The regression model has been fitted by these two scores obtained at the 35<sup>th</sup> and 36<sup>th</sup> SMW, along with trend variable as the predictors and crop yield as the dependent variable.

$$\text{Model 2 } Y = A_0 + b_1 ds_1 + b_2 ds_2 + b_3 T + e$$

Where,  
 'A<sub>0</sub>' is intercept of the model  
 b<sub>i</sub>'s are the regression coefficients (i = 1, 2, 3)  
 ds<sub>1</sub> and ds<sub>2</sub> are two discriminant scores  
 T is the trend variable (year)  
 e is error term normally distributed with mean zero and constant variance

Further discriminant scores were developed by using weighted weather indices. Two discriminant score have been obtained from these indices. For quantitative forecast, regression models were fitted by taking the discriminant scores and trend variable as the regressors and crop yield as the regress and [16]. The form of the developed model is as follows:

$$\text{Model 3 } Y = A_0 + b_1 ds_1 + b_2 ds_2 + b_3 T + e$$

Notation same as discussed in the model 2

### 2.4 Multiple Linear Regression (MLR) Technique

The forecast models were obtained by applying the Multiple Linear Regression Techniques (MLR) by taking predictors as appropriate

weighed and un-weighted weather indices. Stepwise regression analysis was used for selecting significant variables. The form of regression model is as follows:

Model 4

$$Y = A_0 + \sum_{i=1}^p \sum_{j=0}^1 a_{i,j} Z_{i,j} + \sum_{i \neq j=0}^p \sum_{i=1}^1 a_{i,i',j} Z_{i,i',j} + cT + e$$

Where,  
 Z<sub>i,j</sub> and Z<sub>i,i',j</sub> are the weather indices, i, i' = 1, 2, ...p  
 P is Number of weather variables under study  
 Y is District total crop yield (q/ha)  
 T is the trend variable (year)  
 'A<sub>0</sub>' is intercept of the model  
 a<sub>ij</sub>, a<sub>i*i*'j</sub>, c are the regression coefficient  
 e is error term normally distributed with mean zero and constant variance

In another approach, Multiple Linear Regression Techniques (MLR) was fitted to see effect of un-weighted indices by taking predictors as un-weighted indices. The form of regression model is given below:

$$\text{Model 5 } Y = A_0 + \sum_{i=1}^p a_i Z_i + cT + e$$

Where,  
 P is Number of weather variables under study  
 Y is District total crop yield (q/ha)  
 T is the trend variable (year)  
 'A<sub>0</sub>' is intercept of the model  
 e is error term normally distributed with mean zero and constant variance

### 2.5 Comparison and Validation of Models

The comparisons and validation of models were done using following approaches

#### 2.5.1 Forecast error (FE) %

WhenThe validation of the model using observed yield (O<sub>i</sub>) and forecasted yield (E<sub>i</sub>) was computed using below formula,

$$\text{Forecast Error (FE)\%} = \left[ \frac{O_i - E_i}{O_i} \right] \times 100$$

#### 2.5.2 Coefficient of multiple determination (adjusted R<sup>2</sup>)

The best fitted model among developed models were decided based on highest value of Adjusted (Adj.) R<sup>2</sup>

$$\text{Adj. } R^2 = 1 - \frac{SS_{\text{res}}/(n-p)}{SS_t/(n-1)}$$

Where,

$SS_{\text{res}}/(n-p)$  is the residual mean square  
 $SS_t/(n-1)$  is the total mean sum of square.

### 2.5.3 Root Mean Squared Error (RMSE)

The cross validation of the model were done using RMSE, for the year 2012 to 2014 using observed yield ( $O_i$ ) and forecasted yield ( $E_i$ ) and was computed using below formula,

$$RMSE = \left[ \frac{1}{n} \sum_{i=1}^n (O_i - E_i)^2 \right]^{\frac{1}{2}}$$

## 3. RESULTS AND DISCUSSION

The data analysis was carried out by using 30 years of the data from the year 1985 to 2014. The trend of the *Kharif* rice yield is presented in Fig. 1. It was showed increasing trend since 1985.

The model development was carried out for 35<sup>th</sup> SMW and 36<sup>th</sup> SMW by using all five models as

discussed in above section. The best fit models were selected based on highest value of Adjusted  $R^2$ . From the Table 1 to Table 5, it was observed that value of Adj.  $R^2$  varies from 0.74 per cent to 0.94 per cent. The Model 2 at the 36<sup>th</sup> SMW showed highest Adj.  $R^2$  while Model 5 at 36<sup>th</sup> SMW lowers Adj.  $R^2$ . Further validation of best fit models was done by using three years of data from the year 2012 to 2014. The comparisons of the different developed models were carried out with Forecast error (FE %), Root Mean Square Error (RMSE), Mean Absolute Per cent Error (MAPE).

The Comparison of different forecast models at 35<sup>th</sup> SMW were done and presented in Table 6. It revealed that Model 2, of discriminant function analysis found highest Adj.  $R^2$  values (0.93) as compared to remaining four models. Also the Model 2, based on original weekly weather variables showed minimum value of RMSE (164.24) and MAPE (5.30) followed by Model 4 with RMSE (165.13) and MAPE (5.35). Therefore based on Adj.  $R^2$ , significantly low FE %, RMSE and MAPE, the study revealed that Model 2 found good for forecast of rice yield at 35<sup>th</sup> SMW using method of discriminant function analysis. The graphical representation of the observed yield and forecast yield at 35<sup>th</sup> SMW is shown in Fig. 2.

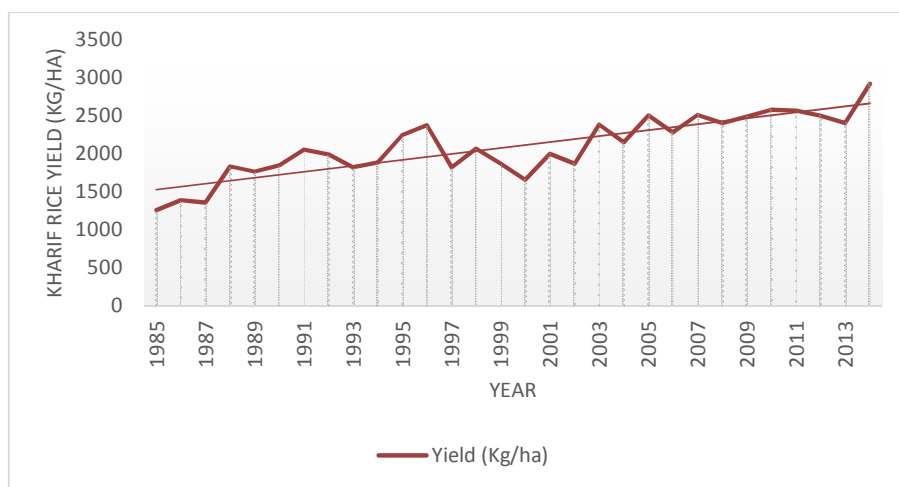


Fig. 1. Rice yield distribution over the year 1985-2014

Table 1. Ordinal logistic forecast Model 1 equations

Model 1	Forecast model equation	Adj. $R^2$
35	$Y = -79056.324 + 40.581T - 331.180P_1$	0.78
36	$Y = -77489.631 + 39798T - 316.238P_1$	0.76

**Table 2. Discriminant Function forecast Model 2 equations**

Model 2	Forecast model equation	Adj. R <sup>2</sup>
35	$Y = -72280.171 + 37.195T - 42.237ds_1 - 17.417ds_1$	0.93
36	$Y = -71971.326 + 37.040T - 39.726ds_1 - 21.530ds_1$	0.94

**Table 3. Discriminant Function forecast Model 3 equations**

Model 3	Forecast model equation	Adj. R <sup>2</sup>
35	$Y = -73307.590 + 37.709T + 95.962ds_1$	0.89
36	$Y = -74648.275 + 38.380T + 95.769ds_1$	0.89

**Table 4. MLR forecast Model 4 equations**

Model 4	Forecast model equation	Adj. R <sup>2</sup>
35	$Y = 2394.744 + 41.381T + 0.775Z_{3,1} + 20.982Z_{2,1}$	0.86
36	$Y = 2401.860 + 40.786T + 0.695Z_{3,1} + 19.070Z_{2,1}$	0.85

**Table 5. MLR forecast Model 5 equations**

Model 5	Forecast model equation	Adj. R <sup>2</sup>
35	$Y = -90319.902 + 47.734T - 8.354Z_2$	0.75
36	$Y = -90063.202 + 47.532T - 7.442Z_2$	0.74

**Table 6. Comparison of different forecast models at 35<sup>th</sup> SMW**

Model	Year	Observed yield	Forecast yield	FE %	RMSE	MAPE	Adj. R <sup>2</sup>
Model 1	2012	2499	2608	-4.37	233.93	8.45	0.78
	2013	2405	2693	-11.98			
	2014	2920	2657	9.02			
Model 2	2012	2499	2556	-2.26	164.24	5.30	0.93
	2013	2405	2526	-5.04			
	2014	2920	2669	8.60			
Model 3	2012	2499	2547	-1.93	267.01	7.25	0.89
	2013	2405	2514	-4.52			
	2014	2920	2473	15.31			
Model 4	2012	2499	2521	-0.87	165.13	5.35	0.86
	2013	2405	2651	-10.23			
	2014	2920	2776	4.93			
Model 5	2012	2499	2633	-5.38	255.25	9.10	0.75
	2013	2405	2789	-15.95			
	2014	2920	2746	5.96			

The Comparison of different forecast models at 36<sup>th</sup> SMW were done and presented in Table 7. It revealed that Model 2, based on discriminant function analysis found highest Adj. R<sup>2</sup> values (0.94) as compared to remaining four models. The model 2, based on original weekly weather

variables showed minimum value of MAPE (5.31) followed by model 4 with MAPE (5.35). In addition, Model 2 showed significantly low FE % as compared to Model 4. Therefore based on Adj. R<sup>2</sup>, significantly low FE % and MAPE, the study revealed that Model 2 found good

for forecast of rice yield at 36<sup>th</sup> SMW using method of discriminant function analysis. The graphical representation of the observed yield and forecast yield at 36<sup>th</sup> SMW is shown in Fig. 3.

The discriminant function analysis was utilized to develop pre-harvest forecasting models by Agarwal et al. [16]; Sisodia et al. [17]; Garde et al. [18] and Goyal [24] and the method of logistic

regression was utilised by Kumari et al. [13] and Verma et al. [25]. These models were observed superior results as compared with traditional models. In the present study similar finding were observed and revealed that method of discriminant function analysis gave best pre harvest forecast as compare to remaining developed models. It was observed high value of Adj. R<sup>2</sup>= 0.94, low value of RMSE= 164.24 and MAPE= 5.30.

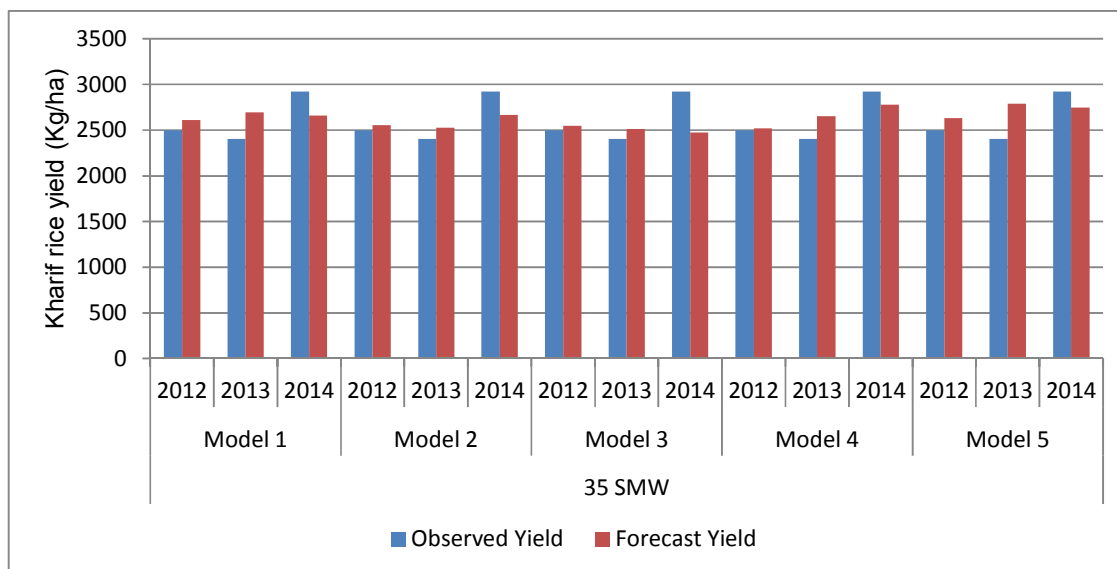
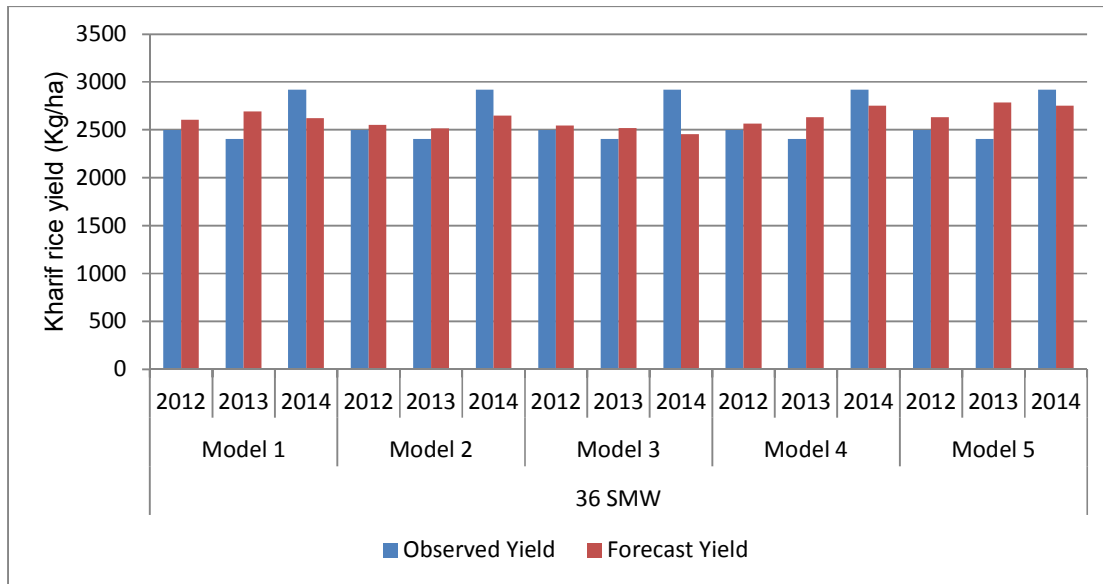


Fig. 2. Comparison of observed yield and forecast yield at 35<sup>th</sup> SMW

Table 7. Comparison of different forecast models at 36<sup>th</sup> SMW

Model	Year	Observed yield	Forecast yield	FE %	RMSE	MAPE	Adj. R <sup>2</sup>
Model 1	2012	2499	2606	-4.29	246.36	8.80	0.76
	2013	2405	2693	-11.96			
	2014	2920	2624	10.15			
Model 2	2012	2499	2551	-2.07	171.82	5.31	0.94
	2013	2405	2514	-4.54			
	2014	2920	2648	9.32			
Model 3	2012	2499	2545	-1.84	277.87	7.51	0.89
	2013	2405	2520	-4.77			
	2014	2920	2455	15.93			
Model 4	2012	2499	2564	-2.58	167.77	5.94	0.85
	2013	2405	2633	-9.49			
	2014	2920	2752	5.76			
Model 5	2012	2499	2635	-5.44	253.93	9.09	0.74
	2013	2405	2784	-15.76			
	2014	2920	2752	5.76			



**Fig. 3. Comparison of observed yield and forecast yield at 36<sup>th</sup> SMW**

#### 4. CONCLUSION

Agriculture represents a core part of the economy and provides food and livelihood activities to much of the Indian population. The main factor affecting crop yields are agricultural inputs and weather parameters. Use of these factors forms one class of pre harvest model of forecasting rice crop yield. The study revealed that forecasting with ordinal logistic regression, discriminant function analysis and MLR techniques were play significant role in crop yield forecasting. The technique of discriminant function is found useful in classifying the crop year in to congenial, normal and adverse year with respect to crop yield. In the present study Model 2 found best model among the remaining model for pre harvest forecasting rice yield in the 35<sup>th</sup> or 36<sup>th</sup> SMW. The discriminant function analysis technique was adopted for development of Model 2 which utilised original weekly weather variables. This methodology can be applicable in many crops viz. wheat, pulses, oil seeds, sugarcane etc. to develop forecasting models and these forecasts have significant value in agricultural planning and policymaking.

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#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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