Original Research Article

Pre-harvest forecasting models for *kharif* rice yield in south Gujarat using statistical technique

ABSTRACT

The pre-harvest forecasting models were developed for *Kharif* rice yield forecasts for Navsari, Surat and Tapi districts respectively. The data of rice yield and the weather parameters from 1995 to 2017 was used for developing statistical models for three districts of south Gujarat. The weather indices like Z41, Z50, Z231, Z241, Z341, Z351 and Time were able to forecast the yield of rice for Navsari district. Similarly, Z41, Z51, Z131, Z141, Z231, Z241, Z351 and Time were found to be most efficient predictors for Surat district. Only two variables i.e., Z241 and Z251 were found to be able to forecast the rice yield in Tapi district. Models were validated with 3 years (2018, 2019 and 2020) data. Results indicated that models explained 53 to 93 percent variations for rice yield during F_1 stage, 54 to 92 percent variation for rice yield during F_2 stage and 52 to 93 percent variations during F_3 stage for rice yield in three districts. Hence these models can be used to some extent for forecast the yield in different districts of South Gujarat a few months before harvest.

Key words: rice, pre-harvest yield forecast, weather indices, south Gujarat

INTRODUCTION

Rice is the most important cereal food crop of India. It occupies about 23.3 % of gross cropped area of the country. It plays vital role in the national food grain supply. Rice contributes 43 % of total food grain production and 46 % of the total cereal production of the country. Rice is the staple food of more than half of the world's population. Among the rice growing countries, India has the largest area (44 million hectares) and it is the second largest producer (131 million tonnes) of rice next to China (197 million tonnes). To meet the food requirement of the growing population, the rice production has to be enhanced with good management practices with shrinking availability of land and water resources condition. 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 % of low land (transplanted) and 40 to 45 % of upland (drilled) rice (Anonymous, 2020). Pre harvest forecast may provide useful information to agriculturalists, administration offices and merchants. In the current study statistical crop modeling was engaged to provide forecast in advance harvesting for taking timely pronouncements. It helps in improve the efficiency of operations by planning. 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 crop weather relationship has been studied by Fisher (1924) and Hendricks and Scholl (1943) have done pioneering work at Indian Agricultural Statistic Research Institute, New Delhi. They 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.,* (1980) and Jain *et al.,* (1980) 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 (Agrawal *et al.,* 1986) by explaining the effects of changes in weather parameters on yield in particular week using linear function. The study proposed that modified model with incorporating technical and statistical indicators were effectively used for early pre-harvest forecasting of crop. Dhekale *et al.,* (2014) developed the pre-harvest forecast models using multiple linear regression (MLR) technique and found that the 18^{th} SMW forecast model accounts for 89 % of variation in yield with RMSE 107. Kumar *et al.,* (2016) studied crop yield forecasting of paddy and sugarcane through modified Hendrick and Scholl technique for south Gujarat using weather parameters. 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.

This paper reports the development of weather based statistical model for districts of South Gujarat i.e., Navsari, Surat and Tapi respectively. Therefore, main objective of the present study was to develop a simple approach for forecasting the rice yield before harvesting in South Gujarat region using weather indices generated using basic weather variables.

MATERIAL AND METHODS

The actual yield data of the *kharif* rice crops for the period of 23 years (1995-2017) were collected from Directorate of Agriculture, Government of Gujarat and the daily weather parameter such as maximum temperature ^{0}C (Tmin), minimum temperature ^{0}C (Tmin), morning relative humidity % (RH1), afternoon relative humidity % (RH2) and rainfall mm (Rain) from the agrometeorological surface observatories situated in respective districts (Navsari, Surat and Tapi) and the remaining 3 years from 2018 to 2020 were used for the validation of the models for each district. The daily weather data was used to compute the weekly averages from the transplanting to harvesting period of the *kharif* rice crop (23^{rd} to 42^{nd} Standard Meteorological Weeks (SMW)). Weekly weather data for growing season of rice crop i.e., 23^{rd} to 33^{rd} SMW for early-season (F_1) stage, 23^{rd} to 38^{th} SMW for mid-season (F_2) stage and 23^{rd} to 42^{nd} SMW for pre-harvest (F_3) stage were used for rice crop for different districts of south Gujarat.

Indian Agricultural Statistical Research Institute (IASRI), New Delhi suggested the methodology for crop yield forecasting models under major growing districts were developed using stepwise regression analysis. Weather variables are used as independent variables which are related to crop responses such as yield and to account for the technological changes some function of time is used as independent variables. IASRI modified the model of Hendricks and Scholl by expressing the effects of changes in weather variables on yield as function of respective correlation coefficients between yield and weather variables. This explains the relationship in a better way as it gives appropriate weightage to different periods. Under this assumption, the models were developed for studying the effects of weather variables on yield. These models are found to be better than the one suggested by Hendricks and Scholl. The forecast model finally recommended is as follows

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

Where,

$$Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw} \quad \text{and} \quad Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{ii'w}$$

A_0, α_{ij}, $\alpha_{ii'j}$ and c are constant

Z_{ij} is generated variable (individual)

$Z_{ii'j}$ is generated variable (interaction form)

X_{iw} is the value of i^{th} weather variable under study i w^{th} week

$X_{ii'w}$ is the value of i^{th} weather variable under study ii′ w^{th} week

r_{iw} is correlation coefficient of yield with i^{th} weather variable in w^{th} period

$r_{ii'w}$ is correlation coefficient (adjusted for trend effect) of yield with product of i^{th} and i'^{th} weather variables in w^{th} period

m is period of forecast

p is number of weather variables used

T is the time trend

e is random error distributed as N $(0,\sigma^2)$

For each weather variable, two weather indices were developed, one as simple accumulation of weather variable and the other one as weighted accumulation of weekly weather variable, weights being correlation coefficients of weather variable in respective weeks with yield (adjusted for trend effect, if present). Similarly, for interaction of weather variables, indices were generated using weekly products of weather variables taking two at a time (Table 1). Stepwise regression technique was used to select the important weather indices. These weighted coefficients were finally regressed with the district yield to find out the final model. The final models were selected on the basis of highest R^2 and the value of significance of F test.

Table 1: Weather indices used in models using composite weather variables

	Simple weather indices					Weighted weather indices				
	Tmax	Tmin	Rain	RH1	RH2	Tmax	Tmin	Rain	RH1	RH2
Tmax	Z10					Z11				
Tmin	Z120	Z20				Z121	Z21			
Rain	Z130	Z230	Z30			Z131	Z231	Z31		
RH1	Z140	Z240	Z340	Z40		Z141	Z241	Z341	Z41	
RH2	Z150	Z250	Z350	Z450	Z50	Z151	Z251	Z351	Z451	Z51

RESULTS AND DISCUSSION

Early - season (F_1) forecast of *kharif* rice

The crop yield forecasting models were developed during the year 2022 using the weather data from 23rd to 33rd SMW for Navsari, Surat and Tapi district by trial and error method for obtaining highest R^2 and significance of F test. Regression analysis was conducted to evaluate the cumulative effect of selective meteorological parameters on *kharif* rice yield. F_1 stage models for rice crop obtained R^2 is 0.93, 0.80 and 0.53 for the district Navsari, Surat and Tapi respectively. The best agrometeorological indices to incorporate in the agrometeorological yield model for rice was selected as Time trend, RH1 (Z41), Rain × RH2 (Z351), RH2 (Z50) and Tmin × RH1 (Z241) for Navsari district; Rain × RH2 (Z351), time trend, RH1 (Z41) and Tmax × Rain (Z131) for Surat district and Tmin × RH2 (Z251) for Tapi district. The results showed that the forecasted yields for early-season were 2751, 2054 and 2587 kg ha^{-1} of Navsari, Surat and Tapi district respectively for the year 2022 (Table 1).

Mid - season (F_2) forecast of *kharif* rice

Mid-season F_2 stage rice yield forecast model developed using weather data from 23rd to 38th SMW by trial and error method for obtaining highest R^2 and significance of F test. There was quite good relationship was found between actual yield and weather variables among the various districts as the coefficient of determination (R^2) ranged between 0.54 for Tapi to 0.92 for Navsari district (Table 1). Rice yield forecast model for F_2 stage relied on Time trend, Tmin × Rain (Z231) and RH1 (Z41) for Navsari district; Tmin × Rain (Z231), Time trend, RH1 (Z41) and Tmin × RH1 (Z241) for Surat district and Tmin × RH2 (Z251) for Tapi district. The results showed that the forecasted yields for mid - season were 2753, 2145 and 2653 kg ha^{-1} of Navsari, Surat and Tapi district respectively for the year 2022 (Table 1).

Pre-harvest (F_3) forecast of *kharif* rice

Pre-harvest F_3 stage forecasting models were developed using weather data from 23rd to 42nd SMW by trial and error method for obtaining highest R^2 and significance of F test. The results show that the model have higher coefficient of determination (R^2) value for the Navsari district (0.93), while Tapi district R^2 value is lower (0.52). The best pre-harvest model for rice was selected as Time trend, Rain × RH1 (Z341) and RH1 (Z41) for Navsari district; Rain × RH2 (Z351), Time trend, RH2 (Z51) and Tmax × RH1 (Z141) for Surat district and Tmin × RH1 (Z241) for Tapi district. The results showed that the forecasted yields for pre-harvest were 2620, 2507 and 2759 kg ha^{-1} of Navsari, Surat and Tapi district respectively for the year 2022 (Table 2).

Table 2: Yield forecast models of *kharif* rice for different districts of south Gujarat

District	Crop Stage	Regression equation	R^2	F	Forecasted yield for the year 2022
Navsari	**F_1**	Y = -1274.451 + 30.140*Time + 22.928*Z41 + 0.007*Z351 + -2.141*Z50 + 0.517*Z241	0.93	52.6	2751
	F_2	Y = -996.769 + 24.307*Time + 0.031*Z231 + 17.098*Z41	0.92	74.2	2753
	F_3	Y = -1084.433 + 26.424*Time + 0.008*Z341 + 14.118*Z41	0.93	84.5	2620

Surat	**F_1**	Y = 2360.940 + -0.044*Z351 + 26.034*Time + 27.814*Z41 + 0.160*Z131	0.80	18.7	2054
	F_2	Y = 1034.924 + 0.038*Z231 + 23.112*Time + 30.678*Z41 + -0.354*Z241	0.88	35.7	2145
	F_3	Y = 2910.594 + 0.007*Z351 + 19.323*Time + 7.792*Z51 + 0.322*Z141	0.87	30.7	2507
Tapi	**F_1**	Y = 4185.076 + 0.327*Z251	0.53	24.4	2587
	F_2	Y = 4257.407 + 0.230*Z251	0.54	24.9	2653
	F_3	Y = 4399.998 + 0.155*Z241	0.52	21.8	2759

Validation of the rice yield forecast model

The validation of model for the year 2018 to 2020 are shown in Table 3. Result revealed that yield forecast is better for Navsari and Surat district during F_1, F_2 and F_3 stages in all years except Tapi district. The forecasted rice yields for Navsari and Surat districts are within acceptable error limit (±10%) in three of the years of validation; however, Tapi district found higher error.

Table 3: Validation of model for forecast of *kharif* rice for different districts of south Gujarat

Year	F_1			F_2			F_3		
	O	F	Error (%)	O	F	Error (%)	O	F	Error (%)
				Navsari					
2018	2659	2330	-12.3	2659	2416	-9.1	2659	2519	-5.3
2019	2656	2407	-9.4	2656	2797	5.3	2656	2877	8.3
2020	2718	2729	0.4	2718	2605	-4.1	2718	2679	-1.4
				Surat					
2018	2448	2351	-3.9	2448	2352	-3.9	2448	2202	-10.1
2019	2360	2384	1.0	2360	2286	-3.1	2360	2237	-5.2
2020	2310	2299	-0.5	2310	2406	4.2	2310	2248	-2.7
				Tapi					
2018	3201	2690	-15.9	3201	2575	-19.5	3201	2642	-17.4
2019	2877	2640	-8.0	2877	2557	-11.0	2877	2593	-10.0
2020	3039	2524	-16.9	3039	2806	-7.6	3039	2618	-13.8

O = Observed yield (kg ha^{-1}), F = Forecasted yield (kg ha^{-1})

CONCLUSION

The yield forecasting models for *kharif* rice in three districts of South Gujarat i.e. Navsari, Surat and Tapi have been validated and developed using statistical methods. During the process of development of the models, simple and weighted weather indices are prepared for individual weather variables as well as for interaction of two at a time considering throughout the crop growing season. The performance of the model in predicting yields at different districts for various stages of rice is quite satisfactory. Using these models, early-season, mid-season and pre-harvest stage estimates rice yield can be computed successfully in advance with accuracy. This will help the Government authorities to plan the rice production more efficiently.

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