Original Research Article

Development of crop yield forecast model for *rabi* sugarcane in different districts of South Gujarat, India

ABSTRACT

The present study was under taken to investigate the feasibility of estimating productivity of rabi sugarcane crop based on weather variables using past weather and yield records of different districts of South Gujarat. In the modeling used, it was considered as an independent variable. The generated weather variables were developed using weighted accumulation of fortnightly data on weather variable, weights being the correlation coefficient of the weather variables, in respective fortnights with the dependent variable, i.e. the yield of sugarcane yield. Forecasting models were developed using from a time series of 26 years (1995 96 to 2020-21) of weather and yield data of sugarcane crop in four Navsari, Bharuch, Surat and Tapi districts and their performance have been validated against the observed yield during 2018-19, 2019-20 and 2020-21. Results indicated that coefficient of determination (R^2) values were 0.67 to 0.76 during mid-season (F_1) stage and 0.76 to 0.91 during pre-harvest (F_2) stage in four districts. Hence, these models can be used for forecasting sugarcane yield in preharvest stage which is very useful to government authorities to plan the sugarcane production more efficiently.

Key words: *Sugarcane, weather indices, pre-harvest yield forecast, South Gujarat*

INTRODUCTION

Sugarcane cultivation in the country extends from 7º to 32º N latitude covering both tropics and sub tropics. In India, sugarcane occupies about 4.60 million hectares area with a total production of 370.50 million tons at an average productivity 80.5 t ha^{-1} (Anon., 2021). India sugarcane belt containing, Uttar Pradesh, Maharashtra, Karnataka, Gujarat, Tamil Nadu, Bihar and Haryana contribute about 90 % of the total cane production and accounts for about 88 % of the total acreage under the crop area in the whole country. In India, sugar industry is the second largest agro-based industry, playing an important role. Sugar factories are considered as growth centers in rural areas. The low sugarcane yields in Indian states are due to extreme weather conditions, *viz.*, very high and very low temperatures, and prolonged dry spells in monsoon seasons. Long duration of flooding and lodging of sugarcane due to strong wind associated with cyclonic storms especially in the coastal districts causes reduction of yield year after year Srinivasarao *et al.,* (2013).

"Accurate early warning of crop failures can go a long way in mitigating the undesirable effects like price rise and agrarian distress through public policy. Since sugarcane productivity forecast could help in estimating the production and making decisions regarding export and import policies, distribution, price policies and for exercising measures for storage and marketing, an attempt has been made to develop suitable pre-harvest forecasting model for district of South Gujarat" [Suresh and Krishna, 2009].

Hendricks and Scholl (1943) have done pioneering work at Indian Agricultural Statistic Research Institute, New Delhi and developed composite models and combining biometrical character which required small number of parameters to be estimated while taking care of distribution pattern of weather over the crop season Mehta *et al.,* (2000). Kumar *et al.,* (2016) studied crop yield forecasting of sugarcane using statistical techniques for South Gujarat using weather parameters and developed crop yield forecast model, which help farmer to formulate the cropping pattern, agricultural practices. The present study was under taken to investigate the feasibility of estimating productivity of *rabi* sugarcane crop based on weather variables using past weather and yield records of different districts of South Gujarat.

MATERIAL AND METHODS

The actual yield data of the sugarcane crops for the period of 27 years (1995-96 to 2020-21) were collected from Directorate of Agriculture, Government of Gujarat and the daily weather parameter such as maximum temperature ^{0}C (Tmax), 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, Bharuch, Surat and Tapi) and the 3 years from 2018-19 to 2020-21 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 *rabi* sugarcane crop (6th to 42nd Standard Meteorological Weeks (SMW)) weekly weather data for growing season of sugarcane crop i.e., 6th to 27th SMW for mid-season (F_1) stage, 6th to 42nd SMW for pre-harvest (F_2) stage were used for sugarcane crop yield forecasting 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" [Yadav et al.2018; Kulkarni et al.2022]. These models are found to be better than the one suggested by Hendricks and Scholl at IASRI (Agrawal and Mehta, 2007). The forecast model finally recommended by the following Equation (1):

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

Where,

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

On what 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 iw^{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

mis 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 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

Mid - season (F_1) forecast of *rabi* sugarcane crop

The crop yield forecasting models were developed during the year 2022-23 using the weather data from 6th to 27th SMW for Navsari, Bharuch, 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 sugarcane yield. F_1 stage models for sugarcane crop obtained R^2 is 0.67, 0.73, 0.76 and 0.76 for the district Navsari, Bharuch, Surat and Tapi respectively. The best agrometeorological indices to incorporate in the agrometeorological yield model for sugarcane was selected as Tmax × RH1 (Z141) and Tmax (Z11) for Navsari district; Tmin × RH2 (Z251) and time trend for Bharuch district; RH1 xRH2 (Z451), Tmin x Rain (Z231) and Tmax x Tmin (Z121) for Surat district and Tmin x RH2 (Z250), Tmax x Rain (Z131) and Tmax (Z10) for Tapi district. The results showed that the forecasted yields for mid-season were 72857, 81993, 71508 and 70930 kg ha^{-1} of Navsari, Bharuch, Surat and Tapi district respectively for the year 2022-23 (Table 2).

Pre - harvest (F_2) forecast of *rabi* sugarcane crop

Pre - harvest(F_2) stage sugarcane yield forecast model developed using weather data from 6th to 42nd 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 districts as the coefficient of determination (R^2)

ranged between 0.91,0.84, 0.85 and 0.76 for Navsari, Bharuch, Surat and Tapi district respectively (Table 2). Sugarcane yield forecast model for F_2 stage relied on Tmax x RH1 (Z141), Tmax x RH1 (Z140) and RH2 (Z51) for Navsari district; Tmin x RH2 (Z251), Time trend and Tmax x Tmin (Z121) for Bharuch district; RH2 (Z51), Tmax (Z11) and Tmin x Rain (Z231) for Surat district and Tmin x RH2 (Z250), Tmax x Rain (Z131) and Tmax (Z10) for Tapi district. The results showed that the forecasted yields for pre- harvest were 75189, 76908, 74461 and 65660 kg ha^{-1} of Navsari, Bharuch, Surat and Tapi district respectively for the year 2022-23 (Table 2).

Table 2: Yield forecast models of *rabi* sugarcane for different districts of South Gujarat

District	Crop Stage	Regression equation	R^2	F	Forecasted yield for the year 2022-23
Navsari	F_1	Y = (-36327.710) + (4.623*Z141) + (769.726*Z11)	0.67	21.12	72857
	F_2	Y = 79207.350 + 13.708*Z141 + -2.502*Z140 + 441.019*Time + 175.234*Z51	0.91	43.31	75189
Bharuch	F_1	Y = 19771.963 + (19.434*Z251) + (348.452*Time)	0.73	27.67	81993
	F_2	Y = 41201.701 + 11.461*Z251 + 502.551*Time + 12.204*Z121	0.84	31.32	76908
Surat	F_1	Y = 84229.059 + (2.534*Z451) + (0.641*Z231) + (8.086*Z121)	0.76	20.67	71508
	F_2	Y = 118226.261 + 342.922*Z51 + 542.161*Z11 + 0.571*Z231	0.85	33.99	74461
Tapi	F_1	Y = 187227.537 + (-2.614*Z250) + (0.904*Z131) + (-85.259*Z10)	0.76	20.81	70930
	F_2	Y = 235215.246 + -2.080*Z250 + 1.022*Z131 + -167.417*Z10	0.76	18.41	65660

Validation of the *rabi* sugarcane yield forecast model

The validation of model for the year 2018-19 to 2020-21 are shown in Table 3. Result revealed that yield forecast is better for Navsari, Bharuch, Surat and Tapi district during F_1 and F_2 stages in all years. The forecasted sugarcane yields for Navsari Bharuch, Surat and Tapi districts are within acceptable error limit (± 17 %) in three of the years of validation. Similar type of results was found by Tripathi *et al.*, (2012).

Table 3: Validation of model for forecast of *rabi* sugarcane for different districts of South Gujarat

Year	F_1			F_2		
	O	F	Error (%)	O	F	Error (%)
			Navsari			
2018-19	63773	72760	14.1	63773	68222	7.0
2019-20	63773	72606	13.9	63773	64196	0.7
2020-21	63773	73631	15.5	63773	67937	6.5
			Bharuch			
2018-19	70000	75209	7.4	70000	76540	9.3
2019-20	70000	69102	-1.3	70000	69704	-0.4
2020-21	71000	68336	-3.8	71000	66192	-6.8
			Surat			
2018-19	75000	72224	-3.7	75000	73499	-2.0
2019-20	73500	69541	-5.4	73500	76614	4.2
2020-21	85000	71998	-15.3	85000	70936	-16.5
			Tapi			
2018-19	78000	71633	-8.2	78000	72642	-6.9
2019-20	76000	67733	-10.9	76000	71163	-6.4
2020-21	80000	72567	-9.3	80000	69839	-12.7

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

CONCLUSION

Using the forecast model, pre-harvest estimates of *rabi* sugarcane yield for South Gujarat districts could be computed successfully very much in advance before the actual harvest. The performance of the model in predicting yields at different districts for various stages of sugarcane is quite satisfactory. The forecasting models were able to explain the R^2 values were 0.67 to 0.91 during mid-season (F_1) stage to pre-harvest (F_2) stage in Navsari, Bharuch, Surat and Tapi district. Further Tmax, Tmin with combination of RH1, RH2 and rainfall have formed most important agrometeorological indices. This can be useful in forecasting of sugarcane yield in advance in South Gujarat.

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