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Research Article

Crop Weather Relationship and Cane Yield Prediction of Sugarcane in Bihar

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ABSTRACT

Cane yield of sugarcane varies from year to year depending on prevailing weather conditions during the growing season. Forecasting of sugarcane yields would therefore help in evaluating its demand and supply for the sugar industry. The present study involves average sugarcane productivity of Samastipur district of north Bihar and daily weather data (for the period of 1968-2010) to predict the cane yields. Seasonal average rainfall was 1214 mm, while the average maximum, minimum and mean temperatures were 31.7, 19.2 and 25.4°C, respectively. Both minimum and mean temperatures had positive impacts on cane yields at all stages, especially at tillering and active growth stages of the crop. Weather and time (year) accounted for 72% variation in cane yields. The regression model was tested with independent datasets for the period 2006-2010, where deviation of predicted yields from actual yields varied from -15.9 to 1.4%.

Key words: Rainfall, Temperature, Yield, Sugarcane

Introduction

Sugarcane is an important cash crop providing raw materials to the sugar industry. The yield forecasting is useful for determining policies related to procurement, demand of raw material for sugar industry, marketing, and import-export of sugar. Owing to late harvest of *kharif* rice crop and high antecedent soil moisture content, farmers in Bihar find it difficult to plant sugarcane during October-November months. It is planted in February under irrigated condition and grown as spring-planted crop. As a result, the crop is subjected to variability in rainfall, temperatures and solar radiation during its growth, which affect the sugar recovery and cane yield. In north-east Andhra Pradesh, Kumar (1984) reported that maximum and minimum temperatures and relative humidity had significant influence on cane yield. Weather parameters like temperature, relative humidity, sunshine hours, and rainfall at different phases of growth showed significant correlations with cane yield of sugarcane in districts of Uttar Pradesh (Samui *et al*., 2003). While reviewing the crop-weather relationships in sugarcane crop in various sugarcane growing countries, Biswas (1988) concluded that the optimum temperature for germination of cane could be 20-32 °C. Similarly, number of factors were identified which influenced sugarcane yield in Louisiana (Greenland, 2005) and Okhlahama (Lee *et al.,* 2013). However, similar study has not been reported for sugarcane growing regions in Bihar. Moreover, the cane yield forecasting models are also not available. In this study, the impact of

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rainfall, maximum and minimum temperatures and solar radiation during various phenophases on the cane yield was analyzed. A simple regression model was further developed for yield forecasting of sugarcane in Samastipur district of north Bihar.

Materials and Methods

The study was conducted at Rajendra Agricultural University, Pusa, Bihar. Average cane yields of sugarcane of Samastipur district of north Bihar for the period 1968-2010 was recorded from Sugarcane Research Institute, Pusa, Bihar. Daily weather data on rainfall, sunshine hours, maximum, minimum and mean temperatures for the same periods were collected from the Agrometeorology Division, Rajendra Agricultural University, Pusa (25.8 ^{0} N latitude, 86.7 ^{0} E longitude; 52 m above mean sea level), Samastipur. Following the method described by Doorenbos and Pruitt (1977), data on bright sunshine hours (recorded by Campbell Stokes sunshine recorder) were converted into solar radiation by considering values of *a* and *b* as 0.31 and 0.46, respectively. Since a meager area is under cultivation of autumn-planted crop, the average yields used in the present study represent mostly the spring-planted crop in Samastipur district. The growing season of spring-planted sugarcane has been divided into four phases: germination and establishment stage (GS1; 7-14 Standard Meteorological Weeks, SMW), tillering stage (GS2; 15-24 SMW), grand growth stage (GS3; 25-42 SMW), and ripening and maturity stage (GS4; 43 to 52 SMW).

Daily data on maximum, minimum and mean temperatures were averaged and daily rainfall and solar radiation were summed up over different growth phases and seasons. Mean, standard deviation (SD±) and coefficient of variation (CV) of total rainfall during GS1, GS2, GS3 and GS4, and the entire growing season (seasonal) were determined. Simple correlation coefficient (Gomez and Gomez, 1984) values between cane yield and weather parameters were computed, and the best-fit regression equations between cane yield and weather parameters at different phases of growth have been developed. Multiple linear regressions through stepwise regression method (Draper and Smith, 1966) were performed to develop regression for predicting cane yield of sugarcane. Accumulated rainfall and solar radiation, and average temperatures during different phases of growth and year have been used as independent variables, while cane yield for the period (1968-2005) have been used as dependent variable. As suggested by Huda *et al*. (1976), Chowdhury and Sarwade (1985) and Krishna Priya and Suresh (2009-10), the year has been used as one of the independent variables to analyze the trend of yields due to adoption of improved varieties and package of practices in crop production. The general form of model (Gomez and Gomez, 1984) is given by

$$Y=a+b_1x_1+b_2x_2+b_3x_3+b_4x_4+b_5x_5+T$$

where *Y* is average cane yield in t ha^{-1}, x_1 and x_2 are accumulated rainfall (mm) and radiation (MJ m^{-2}), respectively; x_3, x_4 and x_5 are average maximum, minimum and mean temperatures (°C), respectively; *T* is year number; *a* is the intercept and *b* is the regression coefficient.

The prediction model was validated with an independent data of 5 years (2006-2010).

Results and Discussion

Variation in agroclimatic environment

Total rainfall varied from 15.8 mm during GS1 to 1026.5 mm during GS3 stage (Table 1). The CV was highest (124.4%) in GS4 stage, and the lowest (36.7%) was in GS3 stage, indicating highly variable rainfall during GS4 stage. Although seasonal rainfall variability was less (CV 32.4%), variability of rain over the growing phases adversely affected the crop by inducing water stress as argued by Virmani (1975).

Total solar radiation varied from 119.1 (GSI) to 125.1 MJ m^{-2} (GS4) and was equally variable (CV 5.3-5.4%) at different growth phases as well as for the entire season (Table 1). The variability was substantially smaller than the rainfall. Maximum temperature ranged from 27.5 (GS4) to 36.1 (GS2) ^{0}C. The variability was 4.1, 3.8, 2.4 and 1.7% in GS1, GS2, GS4 and GS3 stages,

Table 1. Mean, standard deviation and coefficient of variation (%) of weather parameters during different growth phase of sugarcane

Statistical parameters	Growth phase				
	GS1	GS2	GS3	GS4	Seasonal
			Rainfall (mm)		
Mean	15.8	156.0	1026.5	16.1	1214.4
SD	18.42	85.68	377.23	20.08	393.64
CV	116.8	54.9	36.7	124.4	32.4
			Solar radiation (MJ m^{-2})		
Mean	119.1	121.8	123.7	125.1	125.7
SD	6.31	6.50	6.52	6.71	6.69
CV	5.3	5.3	5.3	5.4	5.3
			Maximum temperature (°C)		
Mean	30.4	36.1	32.8	27.5	31.7
SD	1.24	1.36	0.55	0.65	0.57
CV	4.1	3.8	1.7	2.4	1.8
			Minimum temperature (°C)		
Mean	14.4	23.4	25.3	13.5	19.2
SD	1.30	1.38	1.53	1.57	1.18
CV	9.0	5.9	6.0	11.7	6.2
			Mean temperature (°C)		
Mean	22.4	29.8	29.0	20.5	25.4
SD	0.89	1.06	0.81	0.78	0.61
CV	4.0	3.6	2.8	3.8	2.4

respectively. The lowest variability during GS3 stage could be attributed to comparatively stable day temperature due to monsoonal climate prevailing at this stage. Minimum temperature varied from 13.5^0 C during GS4 to 25.3 ^{0}C during GS3 stage, while the highest (11.7 %) and the lowest (5.9 %) CV values were recorded during GS4 and GS2 stages, respectively. Mean temperature ranged between 20.5 (GS4) and 29.8 ^{0}C (GS2) with CV values varying from 2.8 at GS3 stage to 4.0% at GS1 stage. The seasonal mean temperature was of 25.4°C with CV of 2.4%.

The germination and establishment phase had average total rainfall of 16 mm, and average maximum, minimum and mean temperatures of 30.4, 14.4 and 22.4°C, respectively. Optimum temperature for germination was reported as 20-32 ^{o}C (Subba Rao and Prasad, 1960). During tillering, the crop received an average rainfall of 156 mm, while maximum, minimum and mean temperatures were recorded as 36.1, 23.4 and 29.8 ^{o}C. At grand growth stage, the average rainfall was 1027 mm, maximum and minimum temperatures were 32.8 and 25.3 °C. At ripening and maturity phase, the average rainfall, and maximum and minimum temperatures were 16 mm, 27.5 and 13.5 °C, respectively.

Crop-weather relationships

Except at GS4, rainfall during all growth phases showed negative correlation with cane yield (Table 2). Solar radiation demonstrated significant negative correlations with cane yields. Greenland (2005) observed that high water table and higher soil water availability and precipitation, which are inversely related to radiation and temperature, demonstrated negative correlations with cane yields. Maximum temperature during GS1 and GS4 stages was negatively correlated with cane yields, while the same during GS2 and GS3 registered positive correlation. High day-temperature during GS1 and GS4 phases adversely affected the yield. Since the crop is irrigated, rainfall and higher maximum temperature during GS1 could have impeded the germination, and therefore led to low cane yields. While higher maximum temperature is detrimental to germination, higher minimum temperature might cause favourable thermal environment. Samui *et al.* (2003) also observed that maximum temperature had negative correlation with germination. Higher day-temperature coupled with higher rainfall during GS2 and monsoon rainfall during GS3 enhanced tillering and dry matter production, respectively. Greenland (2005) reported that higher than average maximum temperature along with optimum available soil moisture were beneficial for sugarcane yields. At tillering stage, higher day- and night-temperatures helped in improving the cane yields. An early growth is favoured by 21-38 °C temperature (Lenka, 1998) and at grand growth stage, temperatures demonstrated positive correlation with yield. Stalk length and girth growth are highly influenced by maximum and minimum temperatures, the optimum range could be 21-38^{o}C (Lenka, 1998). With increase in temperatures, yield of cane increased and the

Table 2. Correlation coefficients between weather parameters and cane yield (t ha^{-1})

Phases of growth	Weather parameters				
	Rainfall	Solar radiation	Max temperature	Min temperature	Mean temperature
GSI	-0.06	-0.50	-0.12	0.60	0.36
GS2	-0.16	-0.47	0.25	0.67	0.60
GS3	-0.13	-0.40	0.06	0.51	0.50
GS4	0.02	-0.37	-0.22	0.52	0.43
Seasonal	-0.16	-0.37	0.04	0.70	0.69

Significance of $r \geq 0.41$ at 1 % level; Significance of $r \geq 0.32$ at 5% level

Table 3. Relationship between cane yield (t ha^{-1}) and weather parameters during different phases of growth

Phases of growth	Weather parameters	Equations	R^2
GS1	Minimum temperature	$Y= 43.32\ln(x) - 75.53$	0.362
GS2		$Y = 0.465x^2 - 18.12x + 207.9$	0.501
GS3		$Y= 0.708x^2 - 31.36x + 378.1$	0.441
GS4		$Y = 19.14e^{0.053x}$	0.275
GS1	Mean temperature	$Y = -1.233x^2 + 58.15x - 642.7$	0.149
GS2		$Y = 0.180x^2 - 7.053x + 89.96$	0.359
GS3		$Y = 2.358x^2 - 129.3x + 1805$	0.411
GS4		$Y = -0.522x^2 + 24.99x - 252.1$	0.193
GS1	Solar radiation	$Y= -0.025x^2 + 5.662x - 266.0$	0.322
GS2		$Y = -0.029x^2 + 6.775x - 341.4$	0.330
GS3		$Y= -0.037x^2 + 8.683x - 465.1$	0.346
GS4		$Y = -0.037x^2 + 8.970x - 488.6$	0.342

optimum maximum and minimum temperatures were recorded as 32 and 28°C, respectively (Samui *et al.*, 2003). At ripening and maturity stage, lower maximum temperature and higher minimum temperature were found to augment yield.

Minimum and mean temperatures at all growth stages exhibited significant positive correlations with cane yields. Mean temperature range of 21 to 38 °C is conducive for better growth of sugarcane (Lenka, 1998). We found mean temperatures during germination & establishment, tillering, grand growth, and ripening & maturity stage as 22.4, 29.8, 29.0 and 20.5 °C, respectively (Table 1), which were within the optimum range of 21 to 38 °C, as reported earlier. So, it is apparent that higher minimum and mean temperatures during growing season of sugarcane is associated with higher cane yields in north Bihar.

Relationships between cane yield and weather parameters

Minimum temperatures at all phases of growth showed increasing trends with coefficient of determination (R^2) varying from 0.28 in GS4 to 0.50 in GS2 (Table 3). Mean temperatures at all phases of growth also demonstrated increasing trends, with R^2 varying from 0.15 in GS1 to 0.41 in GS3. Minimum temperature during GS1 stage showed logarithmic relationship with cane yield, polynomial relationship during tillering and grand growth stages and exponential relationship during maturity stage of the crop. Mean temperature and solar radiation exhibited polynomial relationships at all phases of growth. Samui *et al.* (2003) observed that maximum and minimum temperatures showed linear relationship with cane yield. They further observed that when maximum temperature during germination and tillering phases, and minimum temperature during

Table 4 Multiple regression equation for forecasting cane yield (t ha^{-1}) of sugarcane (data base=38 years)

Equation	R^2
$y=-254.902+0.144x_1-1.107x_2+1.489x_3+1.475x_4+0.126x_5+1.260x_6-0.641x_7$	0.72**

x_1=Seasonal minimum temperature; x_2=Radiation during GS1; x_3=Radiation during GS3; x_4=Minimum temperature during GS2; x_5=Time variable; x_6=Seasonal mean temperature; x_7=Radiation during GS2.

** Significant at 1 % level.

germination, tillering and early growth phases increased, cane yields of sugarcane increased.

Multiple regression equation for yield prediction

Multiple linear regression, involving minimum temperature during GS2 and entire growth phase (seasonal), radiation during GS1, GS2 and GS3, seasonal mean temperature and time variable (year) during 1968 to 2005 as independent variables and average cane yield of sugarcane as dependent variable during corresponding periods has been developed to predict the cane yield (Table 4). The coefficient of determination (R^2) of the model is 0.72 which is significant at 1% level. Thus, the model can account for 72 % of the total variation in actual yield of sugarcane. With the help of the regression equation, predicted yields during 1968 to 2010 were determined, which had a good fit with the actual yields (R^2 = 0.84 at 1% level of significance; Fig. 1).

By using multiple regression equation (Table 4), cane yields between 2006 and 2010 were simulated (predicted yields) and compared with actual yields for corresponding periods (Table 5; Fig. 1). It was observed that deviation of predicted yields from the actual varied from -15.9 % in 2007 to 1.4 % in 2009.

Table 5. Comparison between observed and predicted yields (t ha^{-1}) of sugarcane during 2006 to 2010

Year	Observed yield	Predicted yield	Deviation %
2006	46.00	44.38	3.52
2007	35.80	41.50	-15.92
2008	44.30	46.74	-5.50
2009	43.40	42.81	1.36
2010	51.40	43.99	14.41

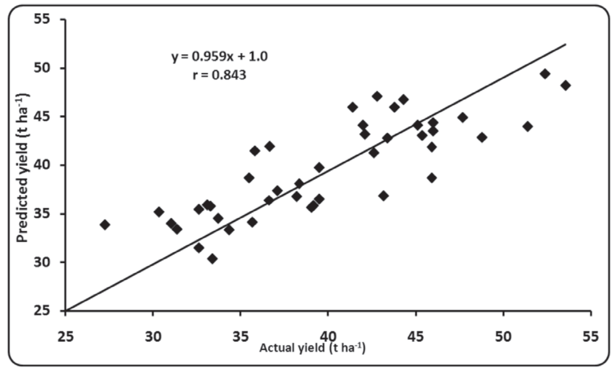

Fig. 1. Comparison of actual and predicted cane yields (t ha^{-1}) of sugarcane

Conclusions

The regression model developed in the study could be useful in predicting the cane yield of sugarcane in north Bihar. While the higher maximum temperature reduced the rate of germination, higher minimum temperature may actually induce it. Higher minimum and mean temperatures are beneficial for cane yields. The model could further be refined by using relative humidity, saturation deficit and evaporation, stored soil moisture status of soil and index of moisture adequacy.

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