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Effects of Meteorological Variables on Sucrose Content of Sugarcane

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ABSTRACT

Meteorological variables like rainfall, maximum and minimum temperatures and bright sun shine were found to have a significant effect on the sucrose content of sugarcane. Changes in sucrose content occur if any meteorological variable deviates from its monthly average (total for rainfall) condition. For bright sunshine, change in sugar accumulation began from 3rd week of May and maximum (0.055) sucrose per cent was observed at the 3rd week of July. In case of minimum temperature, change in sucrose content started at the 3rd week of October. Maximum change (-0.031) occured at the beginning of December. It was linearly decreased by time (month) at the rate of 0.00834 and 0.0111 in case of rainfall and maximum temperature respectively. Change in sucrose content started at the beginning of September in case of rainfall and it started at the 3rd week of November in case of maximum temperature. But for any positive deviation, bright sunshine showed a positive change whereas the other variables showed negative change in sucrose in the stated period.

Key words : Meteorological variables, sugarcane, sugar, rainfall, temperature, sunshine.

INTRODUCTION

Meteorological variables like rainfall, maximum and minimum temperature, sunshine etc play an important role in sugarcane growth, sucrose formation and accumulation. These variables are not static. They vary frequently and affect sugarcane yield. Among the meteorological variables, rainfall, maximum and minimum temperatures and bright sunshine are four important variables responsible for sucrose formation and accumulation in sugarcane. Apart from meteorological variables, a few other variables like number of green leaves, their areas and angles to the sun and slanting of sugarcane plant to the ground may also be responsible for sucrose formation in sugarcane. Several workers studied crop-weather relationship for sugarcane in tropical part of India (Gangopadhyaya and Sarker, 1964; Subbaramayya and Rupakumar, 1980; Gupta and Singh, 1988). Their studies play no role in determining effects on sucrose content of sugarcane. Weather condition of Bangladesh is different from tropical part of India and not static. As such weather variables play different role in Bangladesh. It is emphasized that year to year differences in sugarcane yield and sucrose content are due to year to year differences in meteorological variables. Therefore, present investigation of sucrose content and meteorological variables relationship was undertaken in determining effects of meteorological variables on sucrose content of sugarcane.

MATERIALS AND METHODS

The study period 1972-95 was considered for rainfall, maximum and minimum temperatures while 1973-95 for bright sunshine, with some gaps owing to unavailability of data on sucrose content and meteorological variables. Statistical analysis was done during 1998-1999 cropping season. Data were collected from the following areas of Bangladesh :

Place of data collection		Sample size (No.)	
Meteorological	Sucrose content	Rainfall and temperature	Bright sunshine
1. Dhaka	Deshbandu Sugar Mills	21	16
2. Mymensingh	Kalia Chapra Sugar Mills	12	11
3. Faridpur	Faridpur Sugar Mills	16	08
4. Rajshahi	Rajshahi Sugar Mills	15	14
5. Bogra	Joypurhat Sugar Mills	19	17
6. Rangpur	Shyampur Sugar Mills	18	12
7. Dinajpur	Thakurgaon Sugar Mills	10	06
8. Jessore	Mobarakganj Sugar Mills	14	19
9. Ishurdi	North Bengal Sugar Mills	21	20

In each year, two time periods i.e. (a) crushing period (September to February) for rainfall and temperature and (b) sugar formation period (May to October) for bright sunshine were considered.

Probabilistic models that include terms involving X, X^2, X^3 (or higher order terms) or more than one independent variable are called multiple regression models. The gen eral and complete form of this model is,

$$y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots+\beta_gX_g+\beta_{g+1}X_{g+1}+\beta_{g+2}X_{g+2}+\ldots+\beta_kX_k+\varepsilon$$

Where, y is the response variable as a function of k independent information contributing variables $X_1, X_2, X_3,\ldots X_k$ measured without error. Actually $X_1, X_2, X_3,\ldots X_g \ldots X_k$ can be functions of variables as long as the functions do not contain unknown parameters. $\beta_0, \beta_1, \beta_2, \beta_3 \ldots \beta_g \ldots \beta_k$ are population parameters with unknown values and ε is a random error. Since $\beta_0, \beta_1, \beta_2, \beta_3 \ldots \beta_g \ldots \beta_k$ and $X_1, X_2, X_3,\ldots X_g \ldots X_k$ are non-random, the quantity $\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots+\beta_gX_g+\beta_{g+1}X_{g+1}+\beta_{g+2}X_{g+2}+\ldots+\beta_kX_k$ represents the deterministic portion of the model.

Therefore, y is composed of two components- one fixed and one random and thus y is also a random variable. The random error term ε is actually added to make the model probabilistic rather than deterministic. For any given set of values of $X_1, X_2, X_3,\ldots X_g \ldots X_k$, the random error ε has a normal probability distribution with mean equal to zero and constant variance σ^2 and the errors ε's are independent in terms of probability. The assumptions that have been described imply that the mean value E(y), for a given set of values of $X_1, X_2, X_3,\ldots X_g \ldots X_k$ is equal to $E(y)=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots+\beta_gX_g+\ldots+\beta_kX_k$ Models of this type are called linear statistical models because E(y) is linear function of the unknown parameters $\beta_0, \beta_1, \beta_2, \beta_3 \ldots \beta_g \ldots \beta_k$. The estimated model is,

$y=\hat{\beta}_0+\hat{\beta}_1X_1+\hat{\beta}_2X_2+\beta_3\hat{X}_3+\ldots+\beta_g\hat{X}_g+\ldots+\beta_k\hat{X}_k$. The head $\wedge$ changes the β's to their estimators.

Accordingly for statistical analysis, following Fisher's polynomial technique (Fisher 1924) as adapted by Hendricks and Scholl (1943) and its modified form by Pal and Saini (1998), Range (1968), Huda et al. (1975) and Pandey and Gupta (1989), a second degree multiple regression equation (complete model) was fitted to quantify the impact of individual meteorological variable on sucrose content of sugarcane.

$$y=\beta_0+\beta_1D_1+\beta_2D_2+\beta_3D_3+\beta_4D_4+\beta_5D_5+\beta_6D_6+\beta_7D_7+\beta_8D_8+\beta_9\sum_{i=1}^{n}t_i^0x_i+\beta_{10}\sum_{i=1}^{n}t_i^1x_i+\beta_{11}\sum_{i=1}^{n}t_i^2x_i+\beta_{12}T+\varepsilon$$

Where, y is the sucrose content (%) of sugarcane; xi is the monthly meteorological variable [total for rainfall (mm) and average for temperature (°C) and bright sunshine (hour)]; ti is the standard month number [beginning with 1 for September and ending with 6 for February in case of rainfall (mm), temperature (°C) and in case of bright sunshine (hour), beginning with 1 for May and ending with 6 for October] and it indicates the middle or centre of month in case of graph; Subscript i=1 to n and n is the total number of month (6); D's are dummy variables where,

$X_1=D_1=$ 1 if Dhaka; 0 if Others	$X_4=D_4=$ 1 if Rajshahi; 0 if Others	$X_7=D_7=$ 1 if Dinajpur; 0 if Others
$X_2=D_2=$ 1 if Mymensingh; 0 if Others	$X_5=D_5=$ 1 if Bogra; 0 if Others	$X_8=D_8=$ 1 if Jessore; 0 if Others
$X_3=D_3=$ 1 if Faridpur; 0 if Others	$X_6=D_6=$ 1 if Rangpur; 0 if Others	

$$X_9=\sum_{i=1}^{n}t_i^0x_i,\quad X_{10}=\sum_{i=1}^{n}t_i^1x_i,\quad X_{11}=\sum_{i=1}^{n}t_i^2x_i,\quad X_{12}=T \text{ and } k=12$$

When all eight D's at the same time were set zero, the regression equation for ishurdi would arise (McClave and Benson, 1985); T is the year number (beginning with 1 for 1972 and ending with 24 for 1995 in case of rainfall and temperature and in case of bright sunshine, beginning with 1 for 1973 and ending with 23 for 1995)

which was included to correct for long term upward or downward trend in sucrose content and b's are the regression constants. This model is essentially a combination of a 2nd-order model (quadratic) with three quantitative variables (xi , ti and T) and a model with a single qualitative variable at nine levels.

2nd-order model with three quantitative variables is $y=\beta_0+\beta_9\sum_{i=1}^{n}t_i^0x_i+\beta_{10}\sum_{i=1}^{n}t_i^1x_i+\beta_{11}\sum_{i=1}^{n}t_i^2x_i+\beta_{12}T$ and model with a single qualitative variable at nine levels is $y=\beta_0+\beta_1D_1+\beta_2D_2+\beta_3D_3+\beta_4D_4+$ $\beta_5D_5+\beta_6D_6+\beta_7D_7+\beta_8D_8$.

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Where, y is the sucrose content (%) of sugarcane; xi is the monthly meteorological variable [total for rainfall (mm) and average for temperature (°C) and bright sunshine (hour)]; ti is the standard month number [beginning with 1 for September and ending with 6 for February in case of rainfall (mm), temperature (°C) and in case of bright sunshine (hour), beginning with 1 for May and ending with 6 for October] and it indicates the middle or centre of month in case of graph; Subscript i=1 to n and n is the total number of month (6); D's are dummy variables where,

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$$X_9=\sum_{i=1}^{n}t_i^0x_i\ ,\quad X_{10}=\sum_{i=1}^{n}t_i^1x_i\ ,\quad X_{11}=\sum_{i=1}^{n}t_i^2x_i\ ,\quad X_{12}=T \text{ and } k=12$$

When all eight D's at the same time were set zero, the regression equation for ishurdi would arise (McClave and Benson, 1985); T is the year number (beginning with 1 for 1972 and ending with 24 for 1995 in case of rainfall and temperature and in case of bright sunshine, beginning with 1 for 1973 and ending with 23 for 1995)

which was included to correct for long term upward or downward trend in sucrose content and b's are the regression constants. This model is essentially a combination of a 2nd-order model (quadratic) with three quantitative variables (xi , ti and T) and a model with a single qualitative variable at nine levels.

2nd-order model with three quantitative variables is $y=\beta_0+\beta_9\sum_{i=1}^{n}t_i^0x_i+\beta_{10}\sum_{i=1}^{n}t_i^1x_i+\beta_{11}\sum_{i=1}^{n}t_i^2x_i+\beta_{12}T$ and model with a single qualitative variable at nine levels is $y=\beta_0+\beta_1D_1+\beta_2D_2+\beta_3D_3+\beta_4D_4+$

$\beta_5D_5+\beta_6D_6+\beta_7D_7+\beta_8D_8$.

Following the method of least squares, the estimated equation is

$$y=b_0+b_1D_1+b_2D_2+b_3D_3+b_4D_4+b_5D_5+b_6D_6+b_7D_7+b_8D_8.+b_9\sum_{i=1} t_i^0 x_i+b_{10}\sum_{i=1} t_i^1 x_i+b_{11}\sum_{i=1} t_i^2 x_i+b_{12}T$$

where b's are estimators of β's and summation (Σ) i=1 to n.

The change in y for a unit increase or decrease in xi , ti and T is identical (i.e. the slopes of the lines are equal) for all nine areas. Furthermore, the following three assumptions were considered in the method :

1. One milimeter of rainfall affects sucrose content (%) of sugarcane by the same percentage, but in opposite directions above or below its monthly total and it is followed by all other meteorological variables above or below their monthly average.
2. The total effect on sucrose content (%) is directly proportional to the number of unit of each meteorological variable above or below their monthly average (total in case of rainfall).
3. The effect on sucrose content (%) in each period "t"is independent of the effect in any other time period.

RESULTS AND DISCUSSION

Four equations solved by the method of least squares, their respective co-efficients, estimates of their respective co-efficients, co-efficients of determination (R^2) and multiple correlation co-efficients (R) are given in Table 1.

It was observed in all four regression equations (Table 1) that more than 72 % ($100R^2$) of the variability in sucrose percent was explained by the variables shown in the right hand side of the complete model. The value of R^2 was an indicator of how well the prediction equation fitted to the data. However, since the value of R^2 would increase as more and more variables were added to the model. It could be forced to take a value very close to 1 (one) even though the model contributed no information for the prediction of Y (sucrose %). Infact, R^2 would be equal to 1 (one) when the number of terms in the model would equal to the number of data points. Therefore, by the side of R^2, R (multiple correlation) was calculated for all the equations and tested.

All multiple correlation co-efficients (R) were found highly significant (Table 1). However, since these were from overall F-test, a significant multiple correlation co-efficient did not mean that all the regression co-efficients in the equations were significantly greater than zero.

It was observed that most of the variations in Y (sucrose %) were explained by a few terms in the complete model where most of the regression co-efficients in all four equations were significant and that explained variation was more than 71 % with highly significant multiple correlation co-efficient (R) (Table 2).

Table 1. Statement showing the estimates for the co-efficients b of independent terms in the stated complete form of regression model, co-efficient of determination (R^2) and multiple correlation co-efficient (R).

Estimators of regression parameters	Estimates for regression parameters of different weather variables			
	Equation 1 for rainfall	Equation 2 for maximum temp.	Equation 3 for minimum temp.	Equation 4 for bright sunshine
b_0	7.8295	7.3628	6.9298	7.3965
b_1	-2.2222	-2.2791	-2.3516	-2.3836
b_2	0.48044	0.36754	0.41256	0.29712
b_3	-0.27711	-0.28944	-0.29425	-0.254
b_4	0.17576	0.11652	0.16887	-0.06235
b_5	-0.12421	-0.169	-0.19651	-0.35541
b_6	0.09175	-0.02406	0.02298	-0.08848
b_7	0.00524	-0.06436	-0.10881	-0.21456
b_8	0.13455	0.11884	0.04569	-0.14601
b_9	0.01116	0.04669	0.10751	-0.07493
b_{10}	-0.0282	-0.0168	-0.07551	0.08014
b_{11}	0.0053	0.00082	0.01065	-0.01236
b_{12}	0.03236	0.02702	0.02553	0.02481
$100\hat{R}^2$	77.44 %	77.24 %	77.26 %	72.54 %
$\hat{R}$	0.880 **	0.87886 **	0.87898 **	0.85170 **

** indicates significant at 0.01 probability level.

Table 2. Statement showing the estimates for the co-efficients b of independent terms in the stated reduced form of regression model, co-efficient of determination (R^2) and multiple correlation co-efficient (R).

Estimators of regression parameters	Estimates for regression parameters of different weather variables			
	Equation 1 for rainfall	Equation 2 for maximum temp.	Equation 3 for minimum temp.	Equation 4 for bright sunshine
b_0	7.8513 **	7.4518 **	7.0776 **	7.428 **
b_1	-2.2136 **	-2.2307 **	-2.2829 **	-2.2391 **
b_2	0.46442 **	0.41742 **	0.47523 **	0.41639 **
b_9	-	0.03869 **	0.11394 **	-0.07824
b_{10}	-0.00834 **	-0.0111 **	-0.08098 **	0.08464 *
b_{11}	-	-	0.01133 **	-0.01345 *
b_{12}	0.03183 **	0.02474 **	0.02384 **	0.02364 **
$100\hat{R}^2$	75.38 %	75.79 %	75.66 %	71.35 %
$\hat{R}$	0.86822 **	0.87057 **	0.86983 **	0.84469 **

* indicates significant at 0.05 probability level.

** indicates significant at 0.01 probability level.

The area dummy variables had the following interpretations :

b_1= -2.2136 (in case of rainfall), -2.2307 (in case of maximum temp.), -2.2829 (in case of minimum temp.) and -2.2391 (in case of bright sunshine) indicated that *Deshbandu* sugar mills' recoverable sucrose were on the average 2.2136%, 2.2307%, 2.2829% and 2.2391 % significantly less than North Bengal sugar mills.

b_2=0.46442 (in case of rainfall), 0.41742 (in case of maximum temp.), 0.47523 (in casof minimum temp.) and 0.41639 (in case of bright sunshine) indicated that *Deshbandu* sugar mills' recoverable sucrose were on the average 0.46242%, 0.41742%, 0.47523% and 0.41639% significantly more than *North Bengal* sugar mills.

Moreover, the recoverable sucrose of all other stated sugar mills were the same as North Bengal sugar mills. Changes of sucrose in cane occur if any meteorological variable deviates from its monthly average (total for rainfall) condition. Change in rainfall from its monthly total changes sucrose content in cane but in opposite direction (methodical assumption discussed earlier) and it is followed by all other meteorological variables above or below their average and the change in sucrose% was found significant in each case. On the average point of all meteorological variables, the change in sucrose% by month was graphically shown for each meteorological variable (Figure 1).

The change in sucrose % was -0.00834 (available sugar lost) at the beginning of the month of September and that change was linearly increasing on month. In case of maximum temperature, one degree increase from its monthly average changed 0.028 (sugar formation) to the sucrose % in September. But that change was gradually reduced and at the end of November or at the beginning of December, an adverse effect (available sugar lost) of maximum temperature began. On the otherhand, that adverse effect on sucrose began in the middle of October having maximum (-0.031) at the beginning of December in case of minimum temperature.

Due to one unit rise of bright sunshine (hour), a positive change to the sucrose content (i.e. sucrose formation due to sunshine) began in the 4th week of May showing maximum (0.055) at the 3rd week of July (Figure 2). At the end of September, sunshine began to affect adversely. However, for any positive deviation, the bright sunshine showed a positive change, whereas the other variables showed negative change in sucrose in the stated period.

The equations solved in that investigation indicated that one unit decrease of "rainfall (mm) from its monthly total in the observation period", "maximum temperature (°C) from its monthly average from the beginning of December", "minimum temperature (°C) from its monthly average in the period from October to January" (Figure 3) and one unit increase of "bright sunshine (hour) above its monthly average in the period from June to September" have the beneficial effect to the sucrose content of sugarcane (Figure 4). From the solved equations, it was observed that the year effect was positive which indicating increasing of sucrose content in cane year after year. This might be due to continuous development of high sucrose containing sugarcane variety.

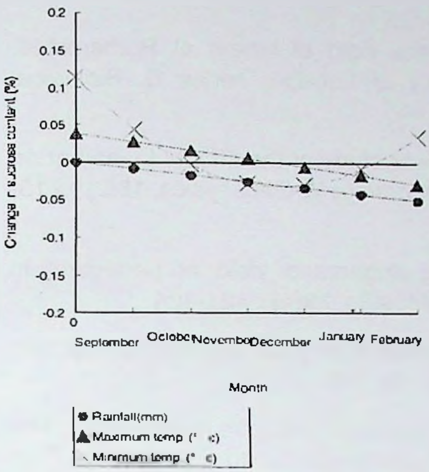


Figure 1. The graphs are showing the effect of time (month) on change in sucrose content (%) for a unit change in rainfall total and average temperatures.

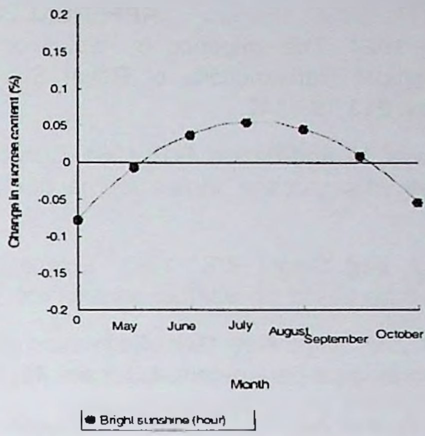
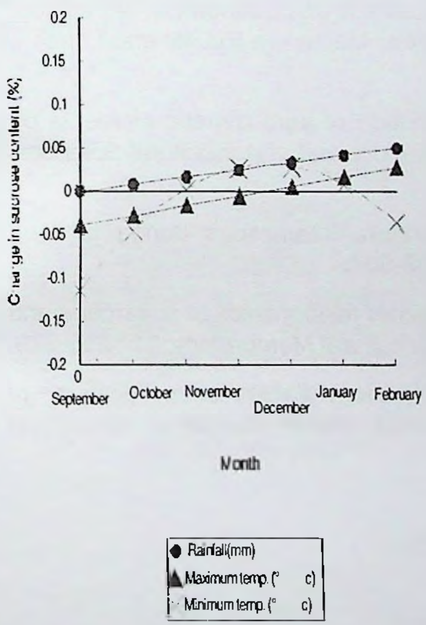


Figure 2. The graphs are showing the effect of time (month) on change in sucrose content (%) for a unit change in bright sunshine.



.Figure 3. The graphs are showing the effect of time (month) on change in sucrose content (%) for a unit change in rainfall total and average temperatures.

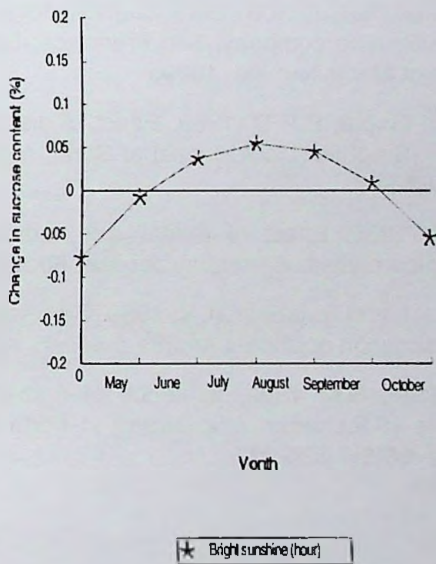


Figure 4. The graphs are showing the effect of time (month) on change in sucrose content (%) for a unit change in bright sunshine.

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