THE JOURNAL OF AGRICULTURE
OF THE UNIVERSITY OF PUERTO RICO

Issued quarterly by the Agricultural Experiment Station of the University of Puerto Rico, for the publication of articles by members of its personnel, or others, dealing with any of the more technical aspects of scientific agriculture in Puerto Rico or the Caribbean Area.

Vol. XXXVIII October 1954 No. 4

The Effect of Weather and Climate on the Sucrose Content of Sugarcane

M. A. Lugo-López and B. G. Capó[1]

INTRODUCTION

The importance of harvesting a sugarcane crop with a high sucrose content can hardly be overemphasized. High-sucrose canes mean more sugar per acre without increased cane tonnage which involves high labor costs in harvesting and processing. In a previous paper (17)[2] the possibility of increasing sucrose yields through the use of superior varieties was discussed. Data on the influence of fertilizers in this respect have also been presented (20). This paper reports data pointing to the significant influences of weather and climate on the sucrose content of sugarcane at harvesttime.

ANNUAL VARIATIONS IN SUCROSE CONTENT OF SUGARCANE

The effect of weather on the sucrose content of sugarcane may be evaluated, in part, by observing the variations in sucrose yields in any sugar-producing country from year to year. The same variety of cane grown with strictly the same agronomic practices will vary in sucrose content from one year to another, even when grown on the same soil.

These variations are largely the results of variations in weather. In 1931, Das (18), in Hawaii, wrote: "In spite of our best efforts the sucrose content of our cane varies from year to year due more to weather conditions than to any other single factor". Table 1 gives historical production data for sugarcane in Puerto Rico for the past 32 years. There have been large fluctuations in sucrose yields (available 96° sugar-percent-cane) from year to year. Extremely low values of 10.53, 10.70, 10.75, and 10.85 percent occurred in the early twenties and again in 1952. Canes of very high sucrose

[1] Associate Soil Scientist, and Associate Director for Research, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. Thanks are due to Mr. I. Bangdiwala and Dr. G. Samuels for their cooperation in planning and conducting the study. Appreciation is also expressed to Dr. J. A. Bonnet who provided the necessary data from his long-time experiments at Río Piedras and Guánica.

[2] Numbers in parentheses refer to Literature Cited, p. 168–9.

TABLE 1.—*Historical production record of sugarcane in Puerto Rico for the period 1920-52*[1]

Crop year	Cane ground	96° sugar produced	Area in cane	Cane yield per acre	Sugar yield per acre	Sucrose yield
	Tons	*Tons*	*Acres*	*Tons*	*Tons*	*Percent-cane*
1920	4,512,000	485,000	240,000	18.8	2.02	10.75
1921	4,468,000	491,000	241,000	18.5	2.04	10.99
1922	3,651,000	406,000	244,000	15.0	1.66	11.12
1923	3,370,000	379,000	240,000	14.1	1.58	11.24
1924	4,253,000	448,000	237,000	18.0	1.89	10.53
1925	6,173,000	661,000	240,000	25.7	2.75	10.70
1926	5,436,000	606,000	243,000	22.4	2.49	11.15
1927	5,665,000	630,000	236,000	24.0	2.67	11.12
1928	6,405,000	752,000	238,000	26.9	3.16	11.73
1929	5,244,000	587,000	251,000	20.9	2.34	11.18
1930	7,199,000	872,000	254,000	28.3	3.43	12.12
1931	7,037,000	788,000	279,000	25.2	2.82	11.19
1932	8,418,000	992,000	294,000	28.6	3.37	11.79
1933	7,165,000	834,000	300,000	23.9	2.78	11.64
1934	9,076,000	1,114,000	300,000	30.2	3.71	12.27
1935	6,391,000	781,000	299,000	21.3	2.61	12.21
1936	7,592,000	926,000	300,000	25.3	3.09	12.19
1937	8,144,000	996,000	301,000	27.1	3.31	12.23
1938	8,800,000	1,077,000	301,000	29.3	3.58	12.24
1939	6,875,000	852,000	314,000	21.9	2.71	12.39
1940	8,795,000	1,019,000	303,000	29.0	3.36	11.58
1941	7,745,000	932,000	337,000	23.0	2.76	12.03
1942	10,010,000	1,148,000	338,000	29.6	3.40	11.46
1943	8,678,000	1,039,000	319,000	27.2	3.26	11.97
1944	5,602,000	724,000	313,000	17.9	2.31	12.91
1945	7,998,000	964,000	336,000	23.8	2.87	12.05
1946	7,539,000	909,000	352,000	21.4	2.58	12.06
1947	9,286,000	1,088,000	365,000	25.5	2.98	11.72
1948	9,541,000	1,108,000	369,000	25.8	3.00	11.62
1949	10,998,000	1,277,000	376,000	29.2	3.40	11.62
1950	10,614,000	1,286,000	382,000	27.8	3.37	12.12
1951	10,501,394	1,227,623	396,000	26.5	3.10	11.69
1952						10.85

[1] Information obtained from reports of the Association of Sugar Producers of Puerto Rico.

values such as 12.91 percent in 1944, and containing more than 12 percent were harvested in 1930, 1934, 1935, 1936, 1937, 1938, 1939, 1941, 1945, 1946, and 1950, as can be seen from table 1. The sucrose yields fell in between 11 and 12 percent for the rest of the period. From 1929 to 1930 there was an increase of 0.94 in sucrose-percent-cane, but an equivalent drop occurred during the following milling season. A similar increase occurred from 1943 to 1944. In 1950, the mean yield of sucrose-percent-cane was 12.12, but it

TABLE 2.—*Seasonal variation in mean sucrose-percent-cane for 4 varieties of sugarcane grown at Isabela Substation*[1]

Variety	Mean yield in sucrose-percent-cane for				Mean of the 4 crops
	Plant cane 1946–48	First ratoon 1948–49	Second ratoon 1949–50	Third ratoon 1950–51	
M. 28	13.63	11.68	12.87	12.02	12.55
P. O. J. 2878	13.01	10.67	11.81	10.52	11.50
P. R. 902	13.74	11.46	12.50	11.94	12.41
P. R. 905	13.78	11.55	12.27	12.18	12.45
Mean of all varieties	13.54	11.34	12.36	11.67	12.23
Least significant difference needed between varieties of same crop at:					
5-percent level	0.35	0.47	0.52	0.41	0.28
1-percent level	.48	.65	.71	.57	.36
Least significant difference needed between crops at:					
5-percent level	.44				
1-percent level	.66				

[1] Calculated from data presented in: Response of four sugarcane varieties to fertilizers during the Isabela Cycle, 1946–51, Pablo Landrau, Jr., and George Samuels, *J. Agr. Univ. P. R.* **38** (2) 83 1954.

dropped during the next 2 years to 10.85 in 1952, a loss of 1.27 sucrose-percent-cane.

In Table 2 an example is given of variations in the sucrose content of sugarcane from different harvests during a variety trial. In any one crop year, varieties P.R. 902, M. 28, and P.R. 905 (with exception of the second ratoon) outyielded P.O.J. 2878 in sucrose. However, these varieties displayed significant variations in sucrose content from one crop year to another. Table 2 shows that the 1946–48 crop had the highest sucrose content, whereas the 1948–49 and 1950–51 crops were lowest. The mean sucrose yield ran from a high of 13.54 for the 1946–48 crop season to a low of 11.34 for the 1948–49 season, a difference of 2.20 percent. This seasonal difference was much higher than any difference encountered between varieties.

SUCROSE CONTENT OF SUGARCANE

WHEN GROWN IN DIFFERENT CLIMATIC BELTS

Table 3 gives data on sucrose yields during the period 1947–52 for the various sugarcane-producing districts of Puerto Rico.[3] There is a variation

[3] The geographical distribution adopted by the Association of Sugar Producers of Puerto Rico was used. Hence, north includes the general area where the Río Llano,

TABLE 3.—*Mean sucrose yields (percent-cane) of sugarcane grown in 5 geographical districts of Puerto Rico during the period 1947-52*

Crop year	North	South	East	West	Interior	Mean
1947	11.42	12.09	11.27	11.91	11.76	11.69
1948	11.22	11.98	11.31	11.98	11.82	11.66
1949	11.35	12.18	10.96	11.71	11.55	11.55
1950	11.49	13.02	11.47	12.53	11.66	12.03
1951	11.43	12.06	11.03	12.18	11.47	11.63
1952	10.44	11.52	10.35	11.30	10.48	10.81
Mean	11.23	12.14	11.06	11.94	11.46	11.56

in sucrose due to year influences which can be attributed to variations in the weather. The highest production of sucrose was obtained in 1950 and the lowest in 1952.

Table 3 further shows that there are distinct differences in the sucrose concentrations of the cane obtained from the various geographical districts. Figure 1 shows these variations more clearly. Irrespective of yearly influences, the highest sucrose-yielding canes were harvested at the southern irrigated plantations where rainfall is very low the year around, but especially from December to May. Furthermore, the field-irrigation schedules usually provide for the "drying out" of the canes for some 45 to 60 days prior to harvest. At that time growth decreases and the ripening processes of the green-leaf millable cane are promoted.

The western region invariably produces canes higher in sucrose than the interior, northern, and eastern regions. In western Puerto Rico there is generally a marked dry season during the months corresponding to the sugarcane-harvesting season. In the other three geographical areas rainfall decreases during the harvesting season, but occasional rains of variable intensity are likely to occur which presumably hinder the ripening process and promote new vegetative growth. This type of weather is not uncommon at Río Piedras, Cayey, San Lorenzo, Humacao, Naguabo, and other areas in the northern, eastern, and interior districts.

Los Caños, Cambalache, Plazuela, Monserrate, San Vicente, Constancia-Toa, Juanita, Victoria, and Canóvanas sugar mills are located; while in the south the general area around the following mills is included: Guánica, San Francisco, Rufina, Mercedita, Constancia, Cortada, Aguirre, Machete, Lafayette, and Guamaní. East includes the area of the Fajardo, Pasto Viejo, El Ejemplo, and Roig sugar mills; west, that of the Coloso, Rochelaise, Eureka, and Igualdad; and interior refers to the area near the Plata, Soller, Santa Juana, Juncos, and Cayey mills. Any further mention in this article of the various climatic, geographic, or sugarcane-producing districts refers to the areas above described.

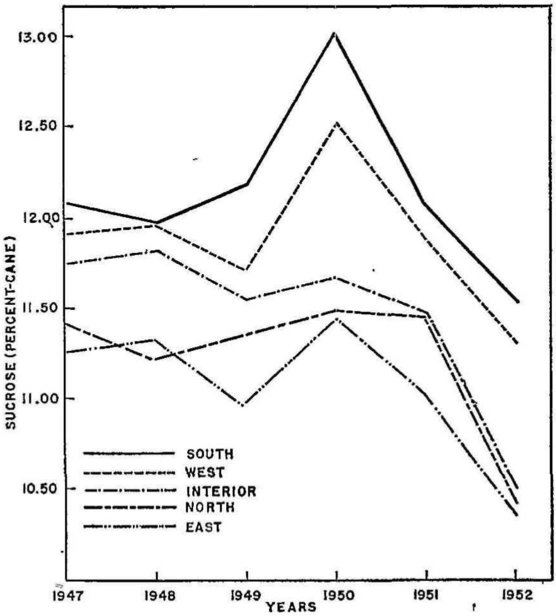

FIG. 1.—Sucrose yields of sugarcane in Puerto Rico for the 6-year period 1947-52, by geographic regions.

In the interior district, in spite of the relatively heavy rainfall occurring throughout the year, canes with richer juices are harvested than in the North and East. The interior is characterized by relatively low temperatures, especially during the nights which are conducive to decreased respiratory activity, and consequently to increased storage of sucrose.

AS RELATED TO RAINFALL

A plentiful supply of water is normally required for adequate plant growth as well as for the formation and translocation of sucrose. It has long been recognized that although total rainfall is of importance, its seasonal distribution must be considered also. As far back as 1898, Stubbs (22), working in Louisiana, recognized the detrimental effects of heavy rains during the ripening months: "Eighteen hundred and ninety-eight was notorious for excessively green cane. The rainfall, while not up to the normal for the year, was excessive during the fall months and carried the cane into the grinding season gorged with moisture and exceedingly immature."

Quintus (19) from Java reported:

> Sugarcane requires a fairly accentuated alternation of monsoons. It is necessary that a period of plentiful rain be succeeded by some months of dry weather, as other-

wise the cane is unable to attain full maturity, so that a large crop of cane is indeed gathered, but the percentage of sugar is so low that the profit is inconsiderable. Likewise, the time when the dry period commences is of importance; if it arrives too late, the cane does not ripen completely; and this is also the case if the dry weather sets in too early; when the cane, moreover, dies prematurely.

The researches of Jorgensen (14), Geerligs (12), Das (8, 9), Beauchamp (1), McDonald (18), Tengwall and Van der Zyl (23), Van Deventer (25), and Thiem (24), working under various conditions, all indicated that high sucrose yields are associated with abundant rainfall during the growing period and dry weather for a few months prior to harvesting. Prolonged droughts may be harmful also. The unfavorable effects of prolonged droughts are best summarized by Geerligs (12): "Cane having had an abnormal growth owing to drought often ripens very rapidly; the ripening process proves to be very short, the cane soon becomes over ripe and loses in sugar content."

Figure 2 shows the fluctuations in sucrose content of the cane harvested in Puerto Rico for the past 32 years and the total rainfall for the corresponding crop years. Since no direct rainfall measurements were available it was assumed for plotting the data that the crop year extended from April of a given year to March of the following year. This, of course, introduces

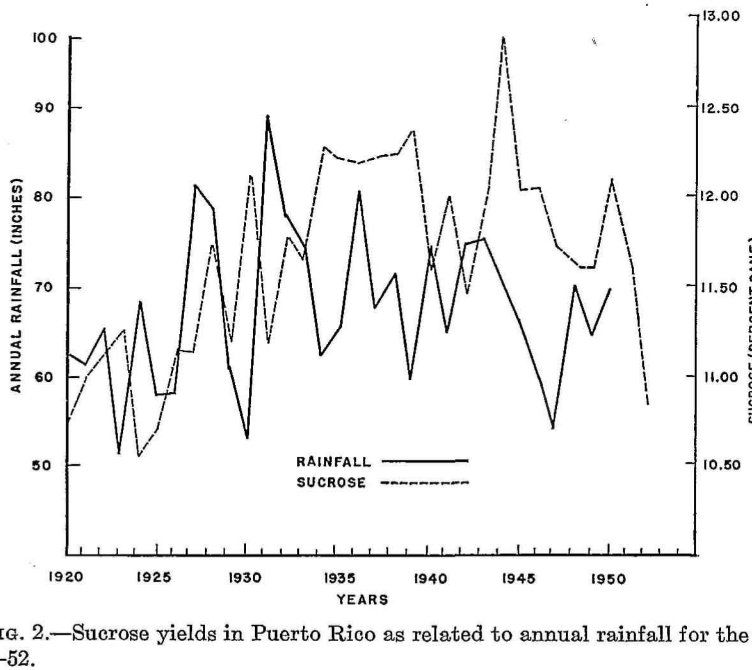

FIG. 2.—Sucrose yields in Puerto Rico as related to annual rainfall for the period 1920–52.

obvious errors since the cane was harvested anywhere from January to May or June; and March may not be necessarily typical of the whole season throughout the 32-year period.

In spite of obvious limitations the data indicate that variations in sucrose are generally in inverse relationship with variations in rainfall for the crop year. Thus, high sucrose yields were generally obtained in years when rainfall was least, while low-sucrose canes were usually harvested in years of high rainfall. The high peak in sucrose observed in 1944 cannot be explained wholly on a basis of decreased rainfall. In the previous year the import of fertilizers sharply decreased because of the war emergency. Cane and sugar yields decreased accordingly (table 1), but the sucrose concentration of the juices increased. The lack of sufficient nitrogen for that crop year may have resulted in reduced tonnage due to the production of canes of less succulence, but with more concentrated juices.

FUNCTIONAL RELATIONSHIPS AT VARIOUS PERIODS PRIOR TO HARVEST

The literature already cited indicates that excessive rainfall during the harvesting period is deterimental to the quality of cane juices. A study was conducted to determine the critical period at which rainfall would have maximum effect on the concentration of the juices.

Data covering a 10-year period (1939–49) were gathered from various specific commercial fields on several sugarcane estates in east-central Puerto Rico, a humid section. A large number of cases was studied to determine the correlation between sucrose content and rainfall at various periods prior to harvesting. Table 4 shows significant regression coefficients found in 20 fields at the various estates. It is evident from table 4 that sucrose contents are lowered in a considerable number of cases by increases in rainfall in the months approaching harvesttime. The last 3 months seem to be more decisive.

There is a distinct possibility that some other factor may to some extent mask the effect of rainfall on sucrose yields. Soil conditions may be of importance. At Colonia Esperanza satisfactory correlation was observed in four out of five fields studied. The predominant soils there belong to the Las Piedras and Juncos series, both well-drained soils of medium productivity derived from granitic and tuffaceous materials. Significant regressions were obtained at Santa Teresa in fields of alluvial soils, such as those of the Irurena and Josefa series where adequate drainage has been provided by open ditches, but none was observed in soils like those of the Reparada and Palmas Altas series which have high water tables. A significant regression was obtained at Río Grande between sucrose content and total rainfall 3 months prior to harvest only in a field of Juncos silt loam, but none in fields of Mabí clay. Similar results were obtained elsewhere.

TABLE 4.—*Regression coefficients between sucrose content (percent-cane) and total rainfall during 5 periods prior to harvesting on various estates in Puerto Rico*[1]

Estate	Field No.	Soil type	Variety	Number of years	Regression coefficient between sucrose and rainfall—				
					1 month before harvesting	2 months before harvesting	3 months before harvesting	4 months before harvesting	5 months before harvesting
Factoría	59	Múcara silty clay loam	P.O.J. 2878	6			−0.171**		
Esperanza	78	Las Piedras silty clay loam	do.	9					−0.149*
Do.	82	do.	do.	7		−0.155**		−0.179*	− .151*
Do.	17	do.	do.	10		− .396**			
Do.	21	Juncos silt loam	do.	10	−0.270*				
Preston	47	do.	do.	7				− .244*	
Mandry	78	Aguadilla loamy sand	do.	11	− .579*	− .422*			
Eugui	36	Cayaguá silt loam	P.R. 803	5	− .068*	− .043*			
Do.	9	do.	do.	7					− .063*
Río Grande	17	Juncos silt loam	B.H. 10/12	7			− .207*		
Buena Vista	71	do.	do.	6				− .190*	
Santa Teresa	2	Irurena clay	do.	10	− .290*	− .282**	− .186**	− .149*	
Do.	11	Irurena loam	do.	10	− .304*	− .247**	− .172**		
Do.	15	Josefa clay loam	do.	10	− .418*	− .245*	− .227*		
Miraflores	240	Toa loam	do.	7		− .331*		− .109*	
Do.	241	do.	do.	8			− .177*		
Santa Rosa	216	Coloso clay	do.	5			− .140*		
Do.	223	do.	do.	5			− .138*		
Doctores	2	Juncos silt loam	do.	5		− .555*			
Do.	10	Toa loam	do.	4		− .454*	− .327*		

[1] * = Significant value of the coefficient of regression; ** = highly significant value of the coefficient of regression.

TABLE 5.—*Relationship between the sucrose yield (percent-cane) of sugarcane and rainfall at various periods prior to harvest in selected areas of Puerto Rico*

Area	Cases (number)	Functional relationship[1]	Coefficient of determination	Correlation coefficient	F value[2]
Guánica	64	$Y = 12.76 - 0.2380\ X_1$	0.09	−0.31	6.74*
	64	$Y = 13.12 - .2028\ X_2$	.29	− .53	25.44**
	64	$Y = 13.41 - .1474\ X_3$	.50	− .70	62.36**
	64	$Y = 13.57 - .1080\ X_4$	.42	− .65	45.68**
	64	$Y = 13.64 - .0830\ X_5$	.23	− .48	19.07**
	64	$Y = 13.42 - .0556\ X_6$	.08	− .27	5.11*
Aguirre	122	$Y = 12.89 - .1662\ X_1$	.11	− .33	15.22**
	122	$Y = 13.30 - .1627\ X_2$	.28	− .53	47.96**
	122	$Y = 13.27 - .0933\ X_3$	.20	− .44	30.27**
	122	$Y = 13.65 - .0971\ X_4$	.28	− .53	48.01**
	122	$Y = 13.41 - .0575\ X_5$	.12	− .34	16.50**
	122	$Y = 13.70 - .0584\ X_6$	.15	− .39	18.54**
Boca Chica	57	$Y = 12.46 - .6042\ X_1$	.54	− .73	65.81**
	57	$Y = 12.55 - .3198\ X_2$	.35	− .58	29.30**
	57	$Y = 13.09 - .2642\ X_3$	.62	− .78	85.45**
	57	$Y = 13.22 - .1797\ X_4$	.65	− .80	103.87**
	57	$Y = 13.40 - .1404\ X_5$	.53	− .73	63.07**
	57	$Y = 13.58 - .1171\ X_6$	.35	− .59	30.01**
Mercedita	76	$Y = 11.79 - .0098\ X_1$	.001	− .03	.08**
	76	$Y = 12.07 - .0616\ X_2$	.10	− .32	8.70**
	76	$Y = 12.33 - .0720\ X_3$	.23	− .47	21.98**
	76	$Y = 11.93 - .0144\ X_4$	.01	− .14	.89**
	76	$Y = 12.71 - .0623\ X_5$	.23	− .47	21.80**
	76	$Y = 12.57 - .0418\ X_6$	.09	− .33	7.42**
Machete	145	$Y = 12.57 - .0225\ X_1$	.002	− .06	.42**
	145	$Y = 12.83 - .0760\ X_2$	.07	− .26	10.99**
	145	$Y = 13.36 - .1202\ X_3$	.28	− .53	56.52**
	145	$Y = 13.85 - .1253\ X_4$	.42	− .64	102.06**
	145	$Y = 14.16 - .1102\ X_5$	.37	− .61	84.76**
	145	$Y = 14.26 - .0903\ X_6$	.24	− .49	45.63**

[1] Y = Sucrose percentage to be estimated; X_1, X_2, X_3, X_4, X_5, and X_6 = rainfall during 1, 2, 3, 4, 5, and 6 months immediately prior to harvest, respectively.

[2] * = Regression is significant; ** = regression is highly significant.

Additional and more precise data were processed from five broad areas in the semiarid South where irrigation is indispensable if a crop of sugarcane is to be raised successfully. Information was obtained on sucrose yields for each month of the harvesting season and accurate rainfall records for each month of the crop year were gathered covering the period 1929–43. Table 5 shows the functional relationships worked out and gives coefficients of determination and correlation. Almost invariably a relatively large percentage of the variation in the sucrose content of the cane at harvesttime can be explained on basis of the total rainfall during 1 to 4 months immediately preceding harvest. The regression coefficients are all negative, indicative of decreases of sucrose with increases in rainfall in this critical period.

Estimates of the sucrose content of cane can be made by using a linear regression as a first approximation by means of the equation:

$Y = (\bar{Y} - b\bar{X}) + bX$, where

Y = sucrose percentage to be estimated

$\bar{Y}$ = mean sucrose content of cane for the period to the data of which the equation applies

b = regression coefficient

X = rainfall at a given period prior to harvest, and

$\bar{X}$ = mean rainfall for same period as X

Table 5 shows that 50 and 42 percent of the variability in sucrose yield at Guánica could be explained by taking as a basis the rainfall 3 and 4 months prior to harvest, respectively. Over 20 percent of the variation in sucrose yield at Aguirre could be explained on a basis of total rainfall either 2, 3, or 4 months before harvest. In the lands of the old Boca Chica mill near Ponce, more than half of the variability in sucrose yield could be explained on a basis of the rainfall 1 month before harvest. The rainfall 3 or 4 months prior to harvest could account for over 60 percent of the variability in sucrose yield.

Table 6 shows a comparison of measured sucrose yields at Boca Chica for a given time and estimated yields on basis of the rainfall 4 months prior to harvest. The deviations of the estimated from the observed values are rather small.

AS RELATED TO TEMPERATURE

The influence of temperature on the sucrose content of cane was recognized at an early date by Browne and Blouin (5) in Louisiana. The sucrose yields of the Louisiana 1903 and 1904 crops were strikingly different and the authors could attribute this only to the extreme differences in temperature between the two years. Deer (11) reported:

> In those places that have an uniformly high temperature and no cool season, an impure cane of low sugar content and high in reducing sugars is almost invariably harvested. In such a case there is an opportunity for continuous vegetative growth and the crop as it reaches the mill will consist of canes full of vegetative vigor.

Ishida and Sawasaki (13), in Formosa, found that a rise of 1°C, above normal during the ripening season decreased the sucrose content of cane by nearly 0.5 percent, while an equivalent fall in temperature induced increases in sucrose. Koenig (15, 16), in Mauritius, Van Deventer (25), in Java, and

TABLE 6.—*Comparison of actual sucrose yields at Boca Chica, P. R., and values calculated on a basis of total rainfall 4 months prior to harvest*

Date	Rainfall 4 months prior to harvest	Measured sucrose values	Calculated sucrose values[1]	Deviation
	Inches	*Percent-cane*	*Percent-cane*	
Jan. 1936	12.67	11.02	10.95	−0.07
Apr. 1936	1.36	13.09	12.98	− .11
June 1936	6.90	11.82	11.98	.16
Feb. 1937	11.86	11.45	11.09	− .36
Apr. 1937	5.57	12.63	12.22	− .41
Apr. 1937	5.57	12.78	12.22	− .56
May 1939	6.69	12.42	12.02	− .40
Jan. 1938	14.24	10.31	10.66	.35
Jan. 1938	14.24	10.48	10.66	.18
Feb. 1938	9.75	11.44	11.47	.03
Feb. 1938	9.75	11.20	11.47	.27
Mar. 1938	6.86	12.27	11.99	− .28
Mar. 1938	6.86	12.04	11.99	− .05
Apr. 1938	.92	13.29	13.06	− .23
May 1938	1.02	12.71	13.04	.33
Dec. 1939	20.38	9.37	9.56	.19
Jan. 1940	16.59	9.87	10.24	.37
Feb. 1940	14.19	10.66	10.67	.01
Mar. 1940	10.54	11.46	11.33	− .13
Mar. 1940	10.54	11.51	11.33	− .18
Apr. 1940	6.97	12.02	11.97	− .05
May 1940	7.58	12.20	11.86	− .34
Jan. 1941	21.10	9.53	9.43	− .10
Feb. 1941	15.97	10.69	10.35	− .34
Mar. 1941	6.82	11.61	12.00	.39
Mar. 1942	6.59	12.10	12.04	− .06
Apr. 1942	5.17	11.90	12.30	.40

[1] Calculated from the equation: $Y = 13.22 - 0.1797\ X_4$, where Y is the estimated sucrose percentage and X_4 is the total rainfall 4 months immediately prior to harvest.

McDonald (18), in Louisiana, all agreed that low night temperatures, especially in the months just previous to harvesting, improved the sucrose yields of cane.

Das (10) in his studies of the relation of weather to juice quality, in Hawaii, showed that the range of temperatures significantly affected the juice quality. A high temperature range, such as occurs when the days are bright and clear while the nights are cool, can be conducive to higher sucrose accumulation. Low ranges such as are usual when days are cloudy, exert an opposite effect.

The physiological processes involved in the ripening of cane are not yet clearly understood. However, Das' (8) explanation of the effects of day and

TABLE 7.—*Annual fluctuations in temperature (°F.) in 5 broad sugarcane-producing districts of Puerto Rico*[1]

Crop year	North	South	East	West	Interior	Mean
			Mean temperature			
1946	77.2	79.9	76.8	76.8	73.1	76.76
1947	77.8	80.6	78.0	77.7	74.8	77.78
1948	77.8	80.8	78.4	77.6	74.3	77.78
1949	77.1	79.2	77.1	76.6	73.8	76.76
1950	76.6	78.8	77.2	76.6	72.7	76.38
1951	77.3	79.8	77.5	77.4	75.2	77.44
1952	76.6	79.3	78.4	77.9	—	78.05
Mean	77.20	79.77	77.63	77.23	73.98	77.2
			Maximum temperature			
1946	89.9	92.7	87.8	91.1	86.6	89.62
1947	90.0	92.4	88.8	91.6	88.2	90.20
1948	90.2	92.9	88.9	90.7	88.6	90.26
1949	89.4	91.9	87.3	89.9	80.3	87.76
1950	88.1	92.0	86.9	89.6	86.3	88.58
1951	89.2	92.2	87.8	89.4	87.0	89.12
Mean	89.47	92.35	87.92	90.38	86.17	89.3
			Minimum temperature			
1946	65.8	66.4	64.9	62.2	61.4	64.14
1947	66.6	67.9	66.0	63.3	61.1	64.98
1948	66.0	67.5	66.5	64.2	59.6	64.76
1949	65.0	66.2	66.0	63.3	58.6	63.82
1950	64.4	65.4	65.6	63.0	58.2	63.32
1951	64.8	64.4	64.9	63.1	58.7	63.18
Mean	65.43	66.30	65.65	63.18	59.60	64.0

[1] The basic information for individual stations obtained from reports of the U. S. Weather Bureau was regrouped and averages were calculated for the sugarcane producing districts.

night temperatures seems logical:

Temperature during the daytime controls the processes of assimilation, translocation, and respiration of the plant. During the nighttime, the process of assimilation by which the leaf elaborates carbohydrates stops, but the other two processes still go on. The process of respiration causes a loss of material elaborated during the daytime; for some of the material is broken down to supply the energy for the chemi-

TABLE 8.—*Mean monthly variations in temperature (°F.) in 5 broad sugarcane-producing districts of Puerto Rico*[1]

Regions	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Mean temperature						
North	73.9	73.4	74.3	75.9	78.0	79.6	79.6	80.2	79.9	79.4	77.6	75.3
South	77.1	76.9	77.3	79.0	79.9	81.6	82.0	82.5	82.4	81.4	80.3	78.4
East	73.9	73.8	75.1	76.1	79.2	80.4	80.4	80.6	79.6	79.4	77.5	75.2
West	73.8	73.8	74.8	76.4	78.3	79.4	79.6	79.6	79.5	78.9	77.6	75.0
Interior	70.7	70.7	72.1	73.6	75.5	76.9	76.1	77.5	77.2	76.4	73.5	72.7
Mean	73.88	73.72	74.72	76.20	78.18	79.58	79.54	80.08	79.72	79.10	77.30	75.32
						Maximum temperature						
North	84.7	85.6	88.0	90.4	91.6	91.4	90.2	91.4	92.1	91.8	89.2	87.0
South	89.7	89.7	90.6	90.9	92.3	93.2	94.5	95.2	94.1	94.2	93.0	91.9
East	84.2	84.5	86.2	86.9	89.2	88.7	89.3	90.7	90.6	90.5	87.8	85.6
West	86.6	87.7	88.3	90.5	91.7	92.1	92.3	92.2	91.8	92.0	91.1	88.1
Interior	84.4	84.3	86.3	86.5	87.5	88.6	88.5	89.9	90.1	89.4	88.7	86.1
Mean	85.92	86.36	87.88	89.04	90.46	90.80	90.96	91.88	91.74	91.58	89.96	87.74
						Minimum temperature						
North	61.9	60.8	62.2	63.1	66.8	67.4	68.6	69.3	68.3	68.0	65.9	63.0
South	62.6	61.2	63.0	65.3	67.7	69.6	70.0	69.6	69.2	68.4	67.1	63.9
East	61.8	60.2	59.9	63.7	67.8	69.6	70.0	69.8	68.6	68.6	66.0	62.4
West	59.9	58.9	58.9	61.0	64.2	65.7	66.1	66.1	66.7	65.9	64.1	61.2
Interior	55.9	58.4	55.9	57.7	60.8	61.9	61.0	62.4	62.4	62.3	67.3	58.8
Mean	60.42	59.90	59.98	62.16	65.46	66.84	67.14	67.44	67.04	66.64	66.08	61.86

[1] The basic information for individual stations obtained from reports of the U. S. Weather Bureau was regrouped and averages were calculated for the sugarcane producing districts.

cal reactions in the plant. Within certain limits, the higher the temperature, the greater the respiratory activity of the plant. Now, if we consider the total matter stored in the plant to be the difference between total matter assimilated and total matter lost by respiration then, we can see that relatively-high night temperatures will produce a greater loss of elaborated material and thus prevent the accumulation of a large amount of sucrose in the plant.

One of the striking features of the climate of Puerto Rico is the relatively uniform high temperatures that predominate throughout the year. On the coast, variations are at a minimum; in the interior they are a little more pronounced. Table 7 shows the mean and the range of temperature for five broad geographical regions during the period 1946–52. Table 8 gives monthly fluctuations in temperature for the same regions. The following tabulation facilitates comparison of the yield data shown in table 3 and the temperature data in tables 7 and 8:

Region	*Mean sucrose yields, percent-cane*	*Mean differences between highest and lowest temperatures, °F*
South	12.14	26
West	11.94	27
Interior	11.46	27
North	11.23	24
East	11.06	22

In general, where the range in temperatures is wider, as in the south, the west, and the interior, and where the differences between maximum and minimum temperatures are from 26° to 28°F., sucrose yields are higher than in the north and east where the differences are only from 22° to 24°F.

In all probability in Puerto Rico, as in other areas where the temperature does not vary widely from year to year, the sucrose content of the cane is not so much influenced by the temperature as it is by rainfall. Statistical studies under way have shown some degree of correlation between the sucrose content of the cane at harvesttime and mean temperature throughout the growing and harvesting seasons in the west and interior districts of Puerto Rico. A summarized analysis of the significant data is given in table 9.

The regression coefficients are all negative, indicating that sucrose yields are depressed as the temperature rises. Although the regression was highly significant in the cases presented, there was no significance whatsoever in the majority of them. The temperature data used were not obtained by direct measurements in the months corresponding to the harvesting and grow-

TABLE 9.—*Summarized analysis of the significant data obtained in the west and the interior on the relationship between temperature and the sucrose content of sugarcane*[1]

Item	West			Interior	
Months before harvest the temperature of which was correlated with sucrose yields	5	6	12	1	4
Regression coefficient	−.45	−.94	−.74	−.13	−.28
Coefficient of determination	.89	.73	.77	.70	.87
Correlation coefficient	.94	.85	.88	.83	.93
F value	32.24**	18.38**	13.65**	2.86*	26.86*

[1] ** = Regression is highly significant; * = regression is significant.

TABLE 10.—*Relationships between sucrose yields, sunlight, and night temperatures in 5 broad sugarcane-producing districts of Puerto Rico*

Region	Mean sucrose yields 1947–52	Sunlight		Mean night temperatures
		Total	Mean per day	
	Percent-cane	*Day-degrees*	*Day-degrees*	*°F*
South	12.14	8,158	2.352	66.3
West	11.94	7,439	20.38	63.2
Interior	11.46	5,902	16.17	59.6
North	11.23	7,106	19.47	65.4
East	11.06	6,541	17.92	65.6

ing season, but by assuming that all the cane was harvested in April. This method, used also for rainfall, obviously introduced serious errors.

AS RELATED TO SUNLIGHT

Studies in Hawaii (7) indicated a close relationship between juice purities and the total number of clear days for the period 1902–16. Borden (2) compared the effect of full and decreased sunlight upon sucrose yields. Decreased sunlight was obtained by lining the tops and sides of glass-roofed sheds with burlap. Plants of variety 31-1389 were grown under identical conditions for 5 months when the treatment differentials were imposed. They were subsequently harvested at 12 months of age. Plants enjoying full sunlight yielded stalks containing 13.55 percent of sucrose and juices with 88.7-percent purity, while those grown under decreased sunlight produced only 9.27 percent of sucrose and juices of 80.2-percent purity. The differences were highly significant.

No direct solar-radiation measurements are yet available in Puerto Rico. Some have been taken at a north coast station and at a southern station. However, an indirect measurement may be useful. "Total day-degrees" has been correlated with sugar yields (2). This can be defined as degrees above 70°F. for a given period. If for a given day the maximum temperature is 85°F., the crop that day enjoys 15° in excess of 70°F. These measurements may be misleading on cloudy days when a very short period of sunshine may raise the temperature considerably.

As shown in table 10 both "total day-degrees" and sucrose yields increased or decreased together for the combined period 1947–52, except in the interior of the Island, where the night temperatures which drop below 60°F. seem to be dominant.

AS RELATED TO OTHER CLIMATIC FACTORS

In India, Somers-Taylor (21), correlated the sucrose content of sugarcane with the relative humidity of the atmosphere in the months prior to

TABLE 11.—*Mean monthly evaporation and wind velocity at 2 stations in Puerto Rico, as related to sucrose yielded by sugarcane, 1946–52*[1]

Station	Sucrose yields	Weather factor	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Percent-cane													
North (San Juan)	11.23	Evaporation (inches)	6.93	6.67	8.16	7.87	8.01	7.72	8.43	8.00	6.81	6.02	5.22	5.88
		Wind (mi./mo.)	5,675	4,553	6,302	4,900	3,827	4,644	4,043	4,139	3,191	2,713	4,414	5,165
West (Mayagüez)	11.94	Evaporation (inches)	3.45	3.86	5.30	4.98	4.52	4.21	4.14	4.28	4.12	3.98	3.68	3.17
		Wind (mi./mo.)	396	465	3,312	2,749	408	314	195	—	519	424	—	385

[1] The basic information on evaporation and wind velocity was obtained for individual years from the U. S. Weather Bureau and subsequently summarized for this report.

harvest. From his work it is evident that early ripening is induced by low humidities, while relatively high humidities tend to delay ripening.

The effect of length of day is involved with that of temperature and sunlight. The longer the days the more rapid the growth of the cane. Short days during harvesttime favor higher sucrose accumulations in the green-leaf section of the cane because of the favorable effects of lower night temperatures, which retard the process of respiration and thus favor the accumulation of sucrose in the plant cells.

Very little attention has been given to the effect, if any, of evaporation, wind, or any other climatic influences on the final sucrose concentration of cane at harvest. Verret and McLennon (26) measured the effect of wind currents on cane growth and observed a decrease in the total green matter produced by cane plants subjected to strong currents. However, this test, lasted only 56 days. A shredding of the cane tops of two varieties at three periods of growth was used to simulate the effect heavy winds might cause under field conditions (4). Variety 31-1389 was not affected, but in D. 1135 there was a pronounced effect on the purity and sucrose content of the juices when the shredded leaves were those attached to the twenty-third and the thirtieth nodes. This late shredding affected both the part of the stalk to which the shredded leaves were attached and the section immediately below. Earlier shreddings did not affect the sucrose yield of the canes.

Table 11 gives data on evaporation and wind velocity for two stations in Puerto Rico: San Juan in the north and Mayagüez in the west, for a limited number of years. Losses of water by evaporation are almost twice as much in the north as in the west. Winds blow with more intensity in the north, too. The strongest winds blow in San Juan from December to April, covering most of the sugarcane-harvesting season. In Mayagüez, winds are strongest during March and April. Sucrose yields over a period of years have been higher in the west than in the north.

INTEGRATED INFLUENCE OF WEATHER AND CLIMATE ON SUCROSE CONTENT OF SUGARCANE

Although attempts have been made to evaluate separately the probable influence on the sucrose content of cane of each climatic component, it must be realized that it is the integral effect, rather than the effect of each component separately, which really counts.

The results obtained from the experiments of Clements (6), in Hawaii, exemplify best the integral effect of climate upon the physiological processes active in sucrose formation and accumulation. Towards the middle of 1930, sugarcane variety 31-1389 was planted in large concrete pots filled with clayey soils taken from fields at Kailua and Waipio. Some replications were grown at Kailua and others at Waipio. At the former location days are

TABLE 12.—*Analysis of variance of the aggregate of the combined sucrose yields of several sugarcane crops harvested under 2 different climatic conditions*[1]

Source	Degrees of freedom	Sum of squares	Variance	F value
Total	47	22.55		
Climate	1	13.70	13.70	72.11**
Completely randomized error	46	8.85	.19	

[1] ** = Highly significant.

generally cooler and a fairly heavy rainfall is characteristic. At the latter days are bright and warm, but rainfall is scant. The Kailua crop received 154 inches of rain while the Waipio crop was irrigated with about 100 inches for the 22-month cycle. Despite similarity in fertilization and moisture conditions the Kailua crop was smaller in tonnage than that of Waipio, but the quality of the juices at Waipio were considerably better.

The classical work of Borden (3) with three varieties of cane, each grown on two different soil types under identical cultural conditions and all replicated under two distinctly different climatic conditions, emphasized the dominant effect of climate.

Data provided by Bonnet and coworkers[4] from their fertilizer experiments point to the influence of climate upon sucrose yields. Eleven crops of cane were grown at two locations: Río Piedras in the north and Guánica in the south. The former is characterized by a humid climate and sugarcane can generally be grown without supplemental irrigation, while at the latter the climate is semiarid and irrigation is necessary to grow a crop of cane successfully. Despite the similarities in fertilization the Guánica crops all contained more sucrose than the Río Piedras crops.

Table 12 summarizes the analysis of variance of the aggregate of all the combined crops from each location. The differences between locations are highly significant. The mean sucrose yields of all the combined Guánica crops was 12.96 percent-cane, while that of the Río Piedras crops was only 11.52, a difference of 1.44. A critical examination of the data from each individual crop reveals that the sucrose yields were invariably higher at Guánica than at Río Piedras. In spite of the recognized soil differences these large and consistent yield differences must be attributable to climate. The measured differences in sucrose content agree with data previously presented in figure 1.

SUMMARY

In the endeavor to ascertain the influence of some specific weather and climatic factors on the sucrose content of sugarcane at harvesttime in Puerto

[4] Bonnet, J. A., et al, Unpublished data.

Rico, data on past crops of such commercial varieties as, P.R. 902, M. 28, P.R. 905, P.O.J. 2878, and others, were re-examined and re-evaluated.

There were significant variations in the sucrose content of the same varieties when grown in the same regions in different crop years. These variations were related to weather conditions. Canes harvested at southern irrigated plantations with low rainfall consistently yielded more sucrose than those grown elsewhere, while those grown in the west were higher in sucrose than those grown in the interior, north, or east. In the former region field-irrigation schedules provide for a drying out of the cane from 45 to 60 days before harvest, while the cane was normally harvested during the drier season of the year in the other regions mentioned.

Generally speaking, high sucrose yields were also obtained in years of low rainfall, and vice versa. Sucrose yields were usually lowered if rainfall increased during the 3 or 4 months just prior to harvest. These effects were modified by soil conditions to some extent.

Sucrose yields were also generally higher in the south, west, and interior of the Island, where the temperature range varied from 26° to 28°F. between maximum and minimum, then in the north and east where such differences were in the neighborhood of 22° to 24°F. However, the influence of temperature was less than that of rainfall. Cool nights undeniably favored increased sucrose yields.

There was a direct relation between sunlight (as measured by "total day-degrees") and sucrose yields for the period 1947–52. Both factors increased or decreased together, except in the interior regions of the Island, where the night temperature which dropped below 60°F. seemed to be dominant.

The sucrose content of the cane could be correlated with atmospheric relative humidity, early ripening accompanying low humidity. Wind and evaporation also affected cane-sucrose yields, these being lower where the winds were strongest and the evaporation was presumably most rapid.

The integrated effect of these climatic and meteorological components is, however, the thing of primary importance. In spite of recognized soil differences, differences in yields of cane and sucrose are greatly affected by climate. The integrated effects of various climatic factors upon yields of sugarcane and of sucrose therein are presented in one table included in this report.

RESUMEN

En un esfuerzo por investigar el efecto específico que pudiera tener algún factor climático sobre el contenido de sacarosa en la caña de azúcar, al tiempo de cosecharse, se examinó y evaluó la información referente a algunas variedades comerciales de Puerto Rico, tales como las P. R. 902, M. 28, P. R. 905, P. O. J. 2878 y otras.

Se registran en este trabajo las variaciones significativas en el contenido de sacarosa de una variedad que se ha venido cosechando en la misma región en años distintos. Estas variaciones estuvieron relacionadas con las condiciones del tiempo. Las cañas producidas en los plantíos bajo riego de la zona sur, donde la lluvia es muy escasa, produjeron siempre jugos de mayor contenido de sacarosa que las de todas las otras zonas, mientras que las cañas del oeste resultaron con mayor contenido de sacarosa que las producidas en las zonas del interior, norte y este. Es práctica rutinaria en la zona sur suspender los regadíos 45 ó 60 días antes de la cosecha. En las otras zonas donde no se riega la caña, se cosecha durante la época más seca del año.

En términos generales, se obtuvieron cañas con jugos más ricos en sacarosa durante los años en que la lluvia fué baja y vice versa. Generalmente los rendimientos de sacarosa fueron más bajos cuando la lluvia aumentó durante los 3 ó 4 meses anteriores a la cosecha. Dentro de ciertos límites estos efectos del clima se modifican de acuerdo con los del suelo.

Los rendimientos de sacarosa fueron generalmente mejores también en las zonas del sur, oeste e interior de la isla, donde las diferencias promedios entre las temperaturas máximas y mínimas fluctuaron entre 26° y 28°F., comparados con las zonas del norte y este, donde estas diferencias fluctuaron entre 22° y 24°F.. La influencia de la temperatura fué menor que la de la lluvia, sin embargo, no hay duda de que las noches frescas favorecen un aumento en los rendimientos de sacarosa.

Se encontró una relación directa entre la cantidad de luz solar, (medida en días-grados totales) y los rendimientos de sacarosa durante el período 1947–52. Ambos factores aumentaron o disminuyeron conjuntamente, excepto en el interior donde la temperatura durante la noche bajó hasta 60°F., lo cual parece ejercer una influencia dominante.

Los rendimientos de sacarosa de la caña se pueden relacionar con la humedad relativa de la atmósfera. Generalmente, una madurez temprana va asociada a una humedad relativa baja.

El viento y la evaporación también afectan los rendimientos de sacarosa, los cuales son más bajos cuando los vientos son más fuertes y la evaporación es más rápida.

El efecto integral de todos los componentes climáticos es de una importancia primordial. A pesar de las diferencias en los suelos, las variaciones en rendimientos de la caña y su sacarosa son grandemente afectados por el clima. Se presenta en forma tabular, la información que señala la importancia del efecto integral del clima sobre los rendimientos de sacarosa.

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