Effect of Water Table Depth on the Yield of Seven Sugarcane Varieties in Puerto Rico[1]

Raúl Pérez Escolar and William F. Allison[2]

ABSTRACT

The effect of water table depth on yield of sugarcane varieties PR 980, PR 1028, PR 1059, PR 1141, PR 64-610, PR 61-632 and PR 64-2705 was studied in lysimeter tanks in the field. Using plastic drains at varying distances and depths, variety PR 980 was studied on a 5-ha farm. Results obtained show that varieties differ in their response to water table conditions. Varieties PR 980, PR 1059, PR 64-610, PR 61-632 and PR 64-2705 yielded significantly more cane and sugar when the water table was lowered. Varieties PR 1028 and PR 1141 did not show statistically significant differences among treatment differentials. Under actual field conditions, using perforated plastic drains, variety PR 980 yielded significantly more sugar than in undrained plots. The results obtained in the lysimeter tanks are in accord with those observed under commercial production.

INTRODUCTION

The main objective of drainage is to remove excess surface and groundwater as rapidly as is necessary to promote plant growth. An extensive root system provides the plant with a larger volume of soil for extraction of nutrients and water.

In Puerto Rico most of the sugarcane is grown in the humid coastal lowlands and river flood plains of eastern, western, and northern sections of the island. Drainage problems exist in a considerable portion of these lands due to occurrence of high water tables, inadequate drainage outlets, and occasional river overflows. Around 70,000 acres are reported to be affected by drainage problems. Sugarcane was formerly planted in these areas using the "grand-bank" system (4). In this system a ditch was dug on each side of every two, three or four rows. Deeper cross ditches were dug at intervals from about 20 to 40 ft. They emptied into larger drainage ditches. More recently, the need for mechanizing field operations and increased labor costs forced the grand-bank system to disappear and led to the adoption of a modified Louisiana planting system

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[2]Soil Scientist, Agricultural Experiment Station, College of Agricultural Sciences, and Associate Professor of Agricultural Engineering, Mayagüez Campus, University of Puerto Rico, Río Piedras, P.R.

(5). This system was successfully tried in Puerto Rico by Eastern Sugar Associates in 1936 (2). Yield increases of 20 tons/acre of cane were obtained over the local system in which cane was planted in the furrow. However, the new system did not alleviate poor subsurface drainage. The highest production of sugar from many of these areas has been obtained during periods of extended drought.

No formal experiments on the effect of water table depth on sugar yields had been conducted in Puerto Rico. In Taiwan, this effect was studied by Pao (3) in 1956. His experiment was carried out in cement pots using a sandy loam soil. The depths to the water table studied were 50, 100, and 150 cm. His findings can be summarized as follows: 1) the largest and thickest millable stalks were obtained in the 150-cm depth; the shortest and thinnest in the 50-cm depth; 2) the largest number of millable stalks was found in the 150 cm-depth; the smallest in the 50-cm depth; 3) the available sugar content in the cane of the 150-cm depth was significantly higher (14.83%) than in either that of the 100-cm depth (14.24%) or the 50-cm depth (14.25%); 4) the air-dry weight of roots obtained in the 150-cm depth was the highest; that of the 50-cm depth, the lowest.

MATERIALS AND METHODS

Drainage experiments were conducted in lysimeter tanks in the open under actual field conditions. The lysimeter tanks were made of drums 110 cm in diameter with a system of outlets such that six different water levels, 30, 45, 60, 75, 90 and 120 cm, could be kept constant. The treatments were replicated four times in a randomized block design. The tanks were supplied water by an adequate set of pipes. A Toa loam was used in this experiment in which sugarcane varieties PR 980, PR 1028, PR 1059 were studied throughout. A Coloso clay was used in a second set of tanks when the original ones had deteriorated. Sugarcane varieties PR 1141, PR 64-610, PR 6-632 and PR 64-2705 were successively planted in this second set of tanks. Both Toa and Coloso soils, with pH of 6.0, are very extensive members of the Mollisol and Entisol categories, respectively, of the humid sections of Puerto Rico. Single-eyed sugarcane cuttings were pregerminated, and the most uniform seeds were selected and planted when seedings were around 15 cm high. A month after transplanting all plants received an application of 14-4-10 fertilizer at the rate of 1700 kg/ha plus 112 kg/ha of Mg as $MgSO_4 \cdot 7H_2P$. When the cane was 4 months old, leaves 4, 5 and 6 were sampled and analyzed for N, P, K, Ca and Mg. If the amount of the nutrient elements analyzed was below the recommended level, the cane received an extra application of the element concerned following the recommendations of Capó et al. (1).

The field experiment was conducted on a 5-ha farm in which the predominant soil type was a Coloso silty clay loam. The soil profiles down to 3.6 m deep were examined at about 13 sites in the area. Permeability measurements were made in a stepwise manner in each soil profile studied. The values obtained varied from 0.73 to 22.5 cm/hr. Glover's equation, as modified by Van Schilfgaarde (6), was used to estimate the depth of the drains which could maintain 60-, 90-, and 120-cm water tables. The equation is as follows:

$$S = \left[\frac{9Ktd_e}{f[ln\,mo(2d_e + m) - ln\,m(2d_e + mo)]}\right]^{1/2}$$

where, S is the drain spacing; K is the permeability; r is the drainable porosity of soil (voids drained at 60-cm tension); d_e is the equivalent depth from the centerline or the drain to the impervious layer as adjusted by Van Schilfgaarde; m is the height of the water table above the center of the drain at midplane after time t; mo is the initial height of the water table m; and t is the time in days for water table to drop from mo to m. The drainage values were $f = 0.04$, $K = 0.5$ m/day and $d_e = 0.7$ to 1.7 m.

The field was leveled to a slope of 0.2%. A collector drain was dug along the farm's longest axis. It was 75 cm deep at the ends and 270 cm at the center where a pump was installed. The plastic drains, 10 cm in diameter, were located as follows: 1) every 12 m and 75 cm deep; 2) every 18 m and 120 cm deep; and 3) every 36 m and 150 cm deep. All discharged into the collector drain. In order to keep the desired water levels from affecting adjacent plots, surface ditches were made around a 6-m buffer zone. The water pumped from the collector drain circulated around these surface ditches. About 90 observation wells were installed in the whole field and weekly measurements of the water levels were made.

Sugarcane variety PR 980 was planted in such manner that the rows were parallel to the plastic drain lines. The cane was fertilized with 14-4-10 at the rate of 1700 kg/ha and harvested at the end of 18 months. No Mg was applied because of soil sufficiency.

RESULTS AND DISCUSSION

The results of the lysimeter tank experiments with respect to chemical composition of the leaves and sugar yields of the seven sugarcane varieties are presented in tables 1 and 2. Correlation coefficients between water table depth and leaf nutrient level, cane weight, sucrose percentage and sucrose weight are shown in table 3. The results of the field experiment in which plastic drains were used at different depths and distances are given in table 4. In variety PR 980, highly significant correlations ($r = 0.97$) were obtained between water table depth and percentage leaf K and Mg. All other nutrient elements, except P, tended to increase slightly with increase in depth of the water table. Table 3

TABLE 1.—*Chemical composition of cane leaves*

Water table depth	N	P	K	Ca	Mg
Cm	%	%	%	%	%
		PR 980			
30	1.07	0.14	0.89	0.30	0.07
45	1.07	.13	.92	.30	.07
60	1.01	.13	.98	.28	.08
75	1.07	.13	1.06	.28	.08
90	1.11	.15	1.09	.36	.09
120	1.20	.14	1.09	.36	.10
		PR 1028			
30	1.11	0.15	1.39	0.45	0.15
45	1.07	.15	1.25	.46	.16
60	1.20	.15	1.39	.51	.16
75	1.15	.14	1.33	.60	.21
90	1.40	.15	1.40	.64	.19
120	1.25	.15	1.23	.58	.16
		PR 1059			
30	0.98	0.16	1.08	0.47	0.09
45	1.03	.19	1.08	.48	.09
60	1.09	.17	1.10	.47	.09
75	1.14	.18	1.06	.50	.07
90	1.15	.19	1.05	.53	.11
120	1.23	.18	1.06	.54	.13
		PR 1141			
30	1.18	0.16	1.84	0.33	0.14
45	1.67	.16	1.87	.33	.16
60	1.39	.16	1.74	.35	.15
75	1.28	.16	1.95	.36	.15
90	1.76	.19	2.26	.32	.16
120	1.74	.16	2.12	.24	.15
		PR 64-610			
30	1.17	0.20	1.54	0.29	0.17
45	1.34	.18	1.50	.35	.19
60	1.32	.20	1.81	.29	.17
75	1.35	.22	1.89	.30	.17
90	1.45	.22	1.67	.31	.16
120	1.65	.19	2.19	.32	.19
		PR 61-632			
30	0.89	0.21	0.55	0.44	0.29
45	.97	.21	.41	.46	.29
60	1.21	.22	.59	.48	.23
75	1.55	.20	.67	.50	.36
90	1.34	.21	.44	.52	.36
120	1.56	.18	.69	.56	.31

TABLE 1.—*Continued*

Water table depth	N	P	K	Ca	Mg
Cm	%	%	%	%	%
		PR 64-2705			
30	0.81	0.11	0.35	0.42	0.35
45	.84	.10	.39	.40	.39
60	.90	.12	.32	.53	.25
75	1.12	.16	.44	.46	.37
90	1.22	.11	.54	.49	.37
120	1.31	.14	.51	.64	.29

shows that surgarcane weight was significantly correlated ($r = 0.88$) with water table depth. The effect was linear, and the equation $Y = 17.82 + 3.00X$ was developed to predict cane yield at particular water table depths. Sucrose percentage of the cane was rather high even in the high water table treatments. It was not altered by treatment differentials. Sugar yield was correlated ($r = 0.86$) with water table depth. Again, the effect was linear ($Y = 2.25 + 0.33X$).

Table 1 shows the effect of water table depth on leaf chemical composition of variety PR 1028. Only Ca content was correlated in a highly significant way ($r = 0.91$) with increasing water table depth. Table 3 shows no significant correlations between cane weight, sucrose percentage of cane, sugar weight and water table depth. This is in accord with the known behavior of this variety under commercial production conditions. Growers claim that PR 1028 can withstand high soil moisture conditions and still produce good yields. Drainage practices are, therefore, minimized.

Tables 1 and 2 show the leaf chemical composition and sugarcane yields of variety PR 1059. Highly significant correlations ($r = 0.98$ and 0.92) were measured between percent leaf N and Ca and water table depth. Significant correlations ($r = 0.87$ and $r = 0.89$) were measured between cane weight, sugar weight and water table depth, respectively. Equations $Y = 15.68 + 2.75X$ and $Y = 1.76 + 0.30X$ predict cane and sugar weights, respectively.

The statistical analysis of the data of tables 1 and 2 did not show significant influences on leaf chemical composition and sugarcane yields due to treatment differentials in variety PR 1141. It has been pointed out by agronomists and growers that this variety does rather well under high soil moisture conditions. Observation indicates that it is a relatively shallow rooted variety. Under the conditions of this experiment, roots were not able to penetrate beyond 75 cm. When hurricane Christina hit the Island in 1973 this variety suffered some lodging on account of uprooting.

TABLE 2.—*The effect of water table depth on sucrose percent and on cane yield*

Water table depth	Cane yield per lysimeter	Sucrose	Sugar yield per lysimeter
Cm	*Lb*	%	*Lb*
	PR 980		
30	20.65	12.46	2.57
45	23.65	12.73	3.01
60	24.90	11.66	2.92
75	22.25	12.39	2.76
90	26.45	11.79	3.12
120	31.02	12.16	3.78
	PR 1028		
30	25.80	11.38	2.93
45	28.30	12.27	3.47
60	26.53	12.07	3.19
75	28.30	11.83	3.36
90	27.63	11.62	3.21
120	28.75	11.56	3.34
	PR 1059		
30	18.50	11.46	2.11
45	17.53	11.36	2.00
60	24.07	10.89	2.63
75	22.10	10.74	2.38
90	24.20	11.52	2.76
120	26.07	11.03	2.93
	PR 1141		
30	28.00	12.46	3.49
45	31.90	11.97	3.82
60	28.80	13.93	3.81
75	34.05	12.86	4.38
90	33.30	13.31	4.10
120	33.35	12.17	4.06
	PR 64-610		
30	28.40	11.34	3.22
45	35.90	11.67	4.19
60	32.75	12.76	4.18
75	34.50	12.66	4.40
90	38.55	13.26	5.11
120	40.85	12.34	5.04
	PR 61-632		
30	14.00	14.45	2.02
45	13.81	15.35	2.12
60	16.80	13.35	2.24
75	18.91	11.37	2.15
90	18.81	14.19	2.67
120	22.37	14.35	3.21

TABLE 2.—*Continued*

Water table depth	Cane yield per lysimeter	Sucrose	Sugar yield per lysimeter
Cm	*Lb*	%	*Lb*
	PR 64-2705		
30	21.26	14.53	3.09
45	20.47	12.99	2.66
60	20.16	13.09	2.64
75	20.15	12.09	2.80
90	26.52	13.65	3.62
120	30.21	13.14	3.97

TABLE 3.—*Correlation coefficients between water table depth and leaf nutrients, cane weight and sugar weight of seven sugarcane varieties in Puerto Rico*

Variety	Water table depth vs:			
	Leaf nutrient	Cane weight	Percent sucrose	Sucrose weight
PR 980	K = 0.97** Mg = 0.97**	0.88*	N.S.	0.86*
PR 1028	Ca = 0.91**	N.S.	N.S.	N.S.
PR 1059	N = 0.98** Ca = 0.92**	0.87*	N.S.	0.89*
PR 1141	N.S.	N.S.	N.S.	N.S.
PR 64-610	N = 0.81** K = 0.76**	0.74**	0.77*	0.79**
PR 61-632	N = 0.86* Ca = 0.98**	0.97**	N.S.	0.93**
PR 64-2705	N = 0.96** K = 0.81*	0.92**	N.S.	N.S.

* Significant at .05 level.
** Significant at .01 level.

TABLE 4.—*Effect of the depth and spacing of plastic drains on cane yield and sucrose content of cane for variety PR 980*

Treatment	Cane yield	Sucrose	Sugar yield
	Tons/ha	%	*Tons/ha*
75 cm × 12 m	220.8	9.50	20.98
120 cm × 18 m	245.0	10.16	24.95*
150 cm × 36 m	233.3	10.65	24.95*
No drainage	158.3	8.80	13.93

* Significant at the .05 level.

Highly significant correlations ($r = 0.81$ and $r = 0.76$) for leaf N and K respectively, were obtained with increase in water table depth for PR 64-610. Water table depth had linear effects on both cane and sugar weight. The correlation coefficients, r, were 0.74 and 0.79, respectively. This variety is the only one in which sucrose percentage of cane was significantly affected by increasing water table depth. The correlation, r was 0.77 and the effect was quadratic. The equation $Y = 8.59 + 0.28X - 0.0044X^2$ was developed to predict sucrose percentage of cane as a function of water table depth. The shallower water table treatments, 30 and 45 cm, were harvested first for both PR 64-610 and PR 1141, since Brix values on top and bottom internodes indicated maturity had been reached. A week later the rest of the treatments were harvested. At this time it was assumed that the lower water table treatments had reached full maturity also. There is a possibility that higher sucrose contents could have been obtained if more time for ripening had been allowed the low water table treatments. This reasoning is supported by the results shown in table 5. Highly significant correlations were found between top and bottom Brix ratios (maturity index) and water table depth.

A significant correlation ($r = 0.86$) was found between water table depth and percent leaf N for PR 61-632. In the case of percent leaf Ca, a highly significant correlation ($r = 0.98$) was found. Water table depth had a linear effect on both cane and sugar weights. A correlation coefficient of 0.97 with $Y = 10.55 + 0.25X$ were the values obtained for the former and $r = 0.93$ with $Y = 1.49 + 0.033X$, for the latter.

PR 61-632 appears to be the lowest yielding variety tested so far. It is, however, a very sweet cane as shown by sucrose content values which

TABLE 5.—*The effect of water table depth on the maturity index of varieties PR 1141 and PR 64-610*

Water table depth	Maturity index	
	PR 1141[1]	PR 64-610[2]
cm		
30	94	81
45	84	79
60	83	68
75	73	76
90	42	61
120	41	53

[1] Water table depth vs maturity index, PR 1141, $r = 0.92^{**}$

[2] Water table depth vs maturity index, PR 64-610, $r = 0.91^{**}$

ranged from 11.37 to 15.35%. It is also one of the most erect canes available for use in this area, an important characteristic in mechanical harvesting.

The effect of water table depth on leaf chemical composition and sugarcane yields of variety PR 64-2705 are shown in tables 1 and 2. Correlation coefficients of 0.96 (highly significant) and 0.81 (significant) were measured between water table depth and percent leaf N and K, respectively. In spite of the fact that there was a highly significant correlation between water table depth and cane weight (r = 0.92) the relationship did not hold for sugar content or production. A maturity index was not followed this time in order to avoid using a sampler on the cane, which causes some deterioration. Tasseling, which occurred late in the deep water table treatments, was used as an approximate index.

Results of the field experiment are shown in table 4. The sensitivity of variety PR 980 to high water table conditions is clearly shown. Where no internal drainage was provided, the yields were significantly lower than where drains were located at 120- or 150-cm depth.

It is concluded that: 1) Sugarcane varieties PR 980, PR 1059, PR 64-610, PR 61-632 and PR 64-2705 yielded higher the deeper the water table. On the other hand, PR 1028 and PR 1141 were very tolerant of high water table conditions. 2) In general, N, K, Ca and Mg appeared to be absorbed in larger amounts as the water table was lowered. This is to be expected in view of the increasing soil volume that results from lowering the water table. 3) Lysimeter tank experiments provided practical indications of cane performance in the field. The findings obtained in them are in accord with experience under commercial conditions. 4) However, in the case of varieties resistant to high water tables, the soils may require subsurface drainage. Continued periods of rainfall generally cause a rise in the water table for extended periods (5 to 7 months) above the desired 60- to 90-cm well-drained zone and thus materially affect the growth of the resistant as well as susceptible varieties. Thus, the use of varieties whose yield is not affected as strongly as others does not do away with the need for subsurface drainage.

RESUMEN

En este trabajo se presentan los resultados de un estudio en el que se determinó el efecto de la profundidad del nivel freático en la producción de caña y azúcar de las variedades PR 980, PR 1028, PR 1059, PR 1141, PR 64-610, PR 61-632 y PR 64-2705 sembradas en tanques lisímetros a la intemperie. Mediante el uso de tubería plástica perforada instalada a distintas profundidades y distancias, se estudió en el campo el efecto de la profundidad del nivel freático en la producción de caña y azúcar de la variedad PR 980. Los resultados obtenidos demuestran que las variedades de caña difieren en su comportamiento con respecto a la profundidad del nivel freático. Las variedades PR 980, PR 1059, PR 64-610, PR 61-632 y PR 64-2705 produjeron significativamente más caña y azúcar según bajaba el nivel

freático. Las variaciones en profundidad del nivel freático no afectaron significativamente las producciones de las variedades PR 1028 y PR 1141. Bajo condiciones de campo, mediante el uso de tubería plástica perforada, la variedad PR 980 produjo significativamente más azúcar que en las parcelas testigos. En general, los elementos nutritivos N, K, Ca y Mg se absorbieron en mayores cantidades a medida que bajó el nivel freático. So puede decir que el uso de los tanques lisímetros para estos estudios es una buena indicación de lo que ocurre bajo condiciones de campo.

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