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CONSERVATION AND CONSUMPTIVE USE OF WATER WITH SUGAR CANE UNDER IRRIGATION IN THE SOUTH COASTAL AREA OF PUERTO RICO*

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INTRODUCTION

Water is a fundamental requirement for the maintenance of plant life. It is used in varying amounts under different conditions, from less than 10 inches annually by some of the desert plants to several hundred inches by some plants living in water or on marshy lands. The use of water by common commercial crops lies well within these extremes, yet there is variability in use with different crops, and with the different climatic conditions under which they are grown. In any agricultural area the amount of water required by a given crop is extremely important. If the farmer depends entirely upon rainfall to provide the necessary water, his crops must be restricted to those having a water requirement not greater than the amount of precipitation available during the growing season. If irrigation water is to be used, the available supply and the water requirements of the crop must be compatible. Thus, accurate knowledge about the water requirements of various crops become a vital, immediate problem in any area where water supplies are limited.

Water is costly in the irrigated areas of Puerto Rico. The east-west range of mountains limits precipitation and water supplies on the south side of the Island, so that irrigation is necessary. The surplus waters of the north flowing streams are sometimes collected, and conveyed by tunnels to the south side of the ridges for irrigation on the south coastal plain. Costs for developments of this kind tend to be high. The estimate is $225.00 per acre foot of storage capacity, for storage and collecting works in connection with the Southwestern Puerto Rico project now under construction (6).

Sugar cane is by far the major crop in Puerto Rico and it is grown on approximately 95 per cent of the irrigated land of the Island. There is a total of about 125,000 acres under irrigation. At best, the available water supply is limited and costly. And there is very little definite information about the amount of water needed by cane or about how to use the water most efficiently. For these reasons the present studies were started.* The broad objectives have been to determine: (1) the amount of water necessary to grow sugar cane; (2) the moisture conditions most favorable for

by Soil Conservation Service Research, the Bureau of Plant Industry, Soils and Agricultural Engineering; and the Office of Experiment Stations.

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* The cooperation of the Agricultural Experiment Station of the University of Puerto Rico has introduced the best possible local background of technical knowledge and technical thinking into the work; and Luce and Co. has provided much of the essential practical knowledge of needs and procedures as well as financial support for labor, equipment, and supervision. Without this cooperation the work and the accomplishments now being reported would have been impossible of achievement.

cane growth; (3) the possible usefulness of tensiometers or resistance blocks as practical guides to water application in field production; (4) the methods of water distribution in irrigation which supply the needed water most efficiently; and (5) to relate the practical objectives to soil, climate, water, and plant growth characteristics in such a way that the fundamental principles and interrelationships will be clearly understood

The first step in achieving these objectives was the determination of the efficiency of the prevailing methods of irrigation application so that accurate evaluations could be made of the available water held in or used from the root zone of the soil profile. In calculating the efficiencies it was demonstrated that the accuracy of such measurements can be considerably increased through the addition of a correction factor for water use during the period between the soil moisture samplings before and after irrigation. Efficiency values in this bulletin all include the correction factor. Details of this work have been reported elsewhere (8, 9).

Concurrently with and following the determinations of irrigation application efficiencies, a major part of our effort was directed toward measurements of evapotranspiration, or "consumptive use". This term has been widely used as defined by Blaney, et al (3), as "The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow or intercepted precipitation on the area in any specified time". Investigations of consumptive use have been conducted for various crops at different locations in Western United States by Blaney, Criddle and their associates (1, 2, 3, 4, 7). Often the studies of unit consumptive use have been conducted as part of a valley- or region-wide study of water requirements. In these studies of consumptive use, data for individual crops have proved to be necessary. No previous, detailed work of this nature is known to have been conducted with sugar cane.

The studies included in this report were concentrated in two parallel phases, each intended to supplement the other. These two phases are (1) field studies, and (2) tank studies.

FIELD STUDIES

Eight fields were chosen from Luce and Company lands in the area bounded by Juana Diaz on the west and Aguirre on the east. Detailed records of water applied, both irrigation and rainfall, and soil moisture conditions were made throughout a complete crop growing season. The plan here was to determine actual seasonal water use by the cane growing in the field, through accurate determination of moisture accumulations in the soil root zone resulting from each application of water. This was done by taking numerous soil samples before and after each irrigation, from the

TABLE 1

Details of Water Application Efficiency Computations

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Test Numbers	Stage of Crop Growth†	P_w‡ Before Irrigation (Per Cent)	P_w‡ After Irrigation (Per Cent)	P_w‡ Difference (Per Cent)	Measured Difference in Soil Moisture (Inches)	Time Lapse in Period A (Days)	Time Lapse in Period B (Days)	Approximate Consumptive Use by Crop in Period A (Inches)	Approximate Consumptive Use by Crop in Period B (Inches)	Net Water Accounted for in Root Zone (Inches)	Total Volume of Irrigation—Water Applied (Acre Inches)	Irrigation Water Applied per Acre (Acre Inches)	Rainfall in Periods A & B (Inches)	Total Water Applied per Acre (Inches)	Water Application Efficiency (Per Cent)
FIELD A—Bernard—Average Apparent Specific Gravity 1.29—Number of Sampling Locations 10—Acres 9.08															
1	I	24.5	25.2	0.7	0.33	1½	1½	0.15	0.21	0.69	21.8	2.40	—	2.40	29
2	I	23.8	24.7	0.9	0.42	1½	1½	0.15	0.21	0.78	22.8	2.51	—	2.51	31
3	I	24.5	25.9	1.4	0.65	1½	1½	0.15	0.21	1.01	22.8	2.51	—	2.51	40
4	II	25.4	26.3	0.9	0.42	1½	1½	0.21	0.30	0.93	15.8	1.74	1.0	2.74	34
5	II	22.2	27.2	5.0	2.32	3	2	0.42	0.40	3.14	38.2	4.20	—	4.20	75
6	II	24.1	26.9	2.8	1.30	1½	1½	0.21	0.30	1.81	16.9	*4.20	1.15	5.35	34
7	II	25.0	25.4	0.4	0.19	3	2	0.42	0.40	1.01	41.6	4.57	—	4.57	22
8	II	25.0	27.7	2.7	1.25	2	1	0.28	0.20	1.73	29.9	3.29	0.49	3.78	46
9	II	23.0	27.7	4.7	2.18	4	3	0.56	0.60	3.34	56.2	6.18	0.41	6.59	51
10	II	23.6	27.9	4.3	2.00	2	5	0.28	1.00	3.28	60.0	6.69	0.15	6.84	48
11	II	22.8	26.9	3.7	1.72	1	4	0.14	0.80	2.66	40.5	4.46	0.36	4.82	55
12	II	23.8	26.9	3.1	1.44	2	5	0.28	1.00	2.72	29.5	3.25	2.05	5.30	51
13	II	25.3	27.8	2.5	1.16	1	3	0.14	0.60	1.90	33.8	3.71	0.0	3.71	51
14	II	23.1	26.4	3.3	1.53	1½	2½	0.21	0.50	2.24	40.5	4.46	0.0	4.46	50
15	II	24.1	26.5	2.4	1.11	3	4	0.42	0.80	2.33	40.5	4.46	0.0	4.46	52
FIELD B—Carmen—Average Apparent Specific Gravity 1.47—Number of Sampling Holes 10—Acres 10.68															
16	I	23.1	24.5	1.4	0.74	1	2	0.10	0.28	1.12	30.6	2.87	0.03	2.90	39
17	I	23.0	25.0	2.0	1.06	2	2	0.20	0.28	1.54	30.0	2.81	—	2.81	55
18	I	23.8	24.6	0.8	0.42	1½	1½	0.15	0.21	0.78	48.1	4.51	0.17	4.68	16
19	II	20.8	24.4	3.6	1.91	3½	1½	0.49	0.30	2.70	55.0	5.17	0.10	5.27	51
20	II	23.9	24.7	0.8	0.42	1	2	0.14	0.40	0.96	110.0	10.34	—	10.34	9
21	II	19.9	22.8	2.9	1.54	3	2	0.42	0.40	2.36	111.0	10.40	—	10.40	22
22	II	18.3	23.4	5.1	2.70	2	4	0.28	0.80	3.78	52.0	4.86	—	4.86	78
23	II	21.4	23.6	2.2	1.16	2	4	0.28	0.80	2.24	52.0	4.86	0.24	5.10	44
24	II	21.6	23.0	1.4	0.74	2	4	0.28	0.80	1.82	72.0	6.74	0.0	6.74	27
25	II	21.6	25.6	4.0	2.12	3½	2½	0.49	0.50	3.11	72.0	6.74	0.67	7.41	47
26	II	20.9	23.0	2.1	1.11	4½	2½	0.63	0.50	2.24	72.0	6.74	0.0	6.74	33
27	II	21.1	24.4	3.3	1.74	2	4	0.28	0.80	2.82	84.0	7.86	0.0	7.86	36
FIELD C—Juana Diaz—Average Apparent Specific Gravity 1.32—Number of Sampling Holes 12—Acres 17.12															
28	I	23.8	24.3	0.5	0.24	2	2	0.20	0.28	0.72	56.4	3.29	—	3.29	22
29	II	24.9	26.5	1.6	0.76	1½	1½	0.21	0.30	1.27	54.7	3.19	0.05	3.24	39
30	II	23.2	25.3	2.1	1.00	2½	2	0.35	0.40	1.75	59.2	3.45	—	3.45	51
31	II	22.2	27.8	5.6	2.66	2	2	0.28	0.40	3.34	83.6	4.88	0.12	5.00	67
32	II	25.4	26.1	0.7	0.33	2	2	0.28	0.40	1.01	103.6	6.04	—	6.04	17
33	II	28.0	28.4	0.4	0.19	5	5	0.70	1.00	1.39	91.4	5.33	0.46	5.79	33
34	II	26.5	29.0	2.5	1.19	2	2	0.28	0.40	1.87	80.0	4.67	0.10	4.77	39
35	II	26.5	29.9	3.4	1.61	2	3	0.28	0.60	2.59	95.3	5.56	—	5.56	47
36	II	26.9	27.8	0.9	0.43	1½	4½	0.21	0.90	1.54	116.4	6.79	0.35	7.14	22
37	II	22.2	29.3	7.1	3.37	3	3	0.42	0.60	4.39	95.0	5.54	0.25	5.79	76
38	II	26.9	28.8	1.9	0.90	1½	2½	0.21	0.50	1.61	84.8	4.89	0.0	4.89	33
39	II	26.8	26.6	−0.2	−0.09	4	5—	0.56	1.00	1.47	81.6	4.77	0.0	4.77	31
40	II	28.3	29.8	1.5	0.71	2½	2½	0.35	0.50	1.56	86.4	5.04	0.0	5.04	31

* Only 4 acres irrigated.

† Growth state "I" was during the first 2 months of growth; "II" was from the 3rd to the 10th month.

‡ P_w is the soil moisture content expressed as percentage on a weight basis.

TABLE 1—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Test Numbers	Stage of Crop Growth†	P_w‡ Before Irrigation (Per Cent)	P_w‡ After Irrigation (Per Cent)	P_w‡ Difference (Per Cent)	Measured Difference in Soil Moisture (Inches)	Time Lapse in Period A (Days)	Time Lapse in Period B (Days)	Approximate Consumptive Use by Crop in Period A (Inches)	Approximate Consumptive Use by Crop in Period B (Inches)	Net Water Accounted for in Root Zone (Inches)	Total Volume of Irrigation—Water Applied (Acre Inches)	Irrigation Water Applied per Acre (Acre Inches)	Rainfall in Periods A & B (Inches)	Total Water Applied per Acre (Inches)	Water Application Efficiency (Per Cent)
FIELD D—Destino 55—Average Apparent Specific Gravity 1.34—Number of Sampling Holes 10—Acres 9.09															
41	I	24.9	25.9	1.0	0.48	2½	1½	0.25	0.21	0.94	48.1	5.30	0.50	5.80	16
42	I	25.1	25.8	0.7	0.34	1½	1½	0.15	0.21	0.70	46.5	5.12	—	5.12	14
43	I	24.5	26.1	1.6	0.77	1	1	0.10	0.14	1.01	51.0	5.62	—	5.62	18
44	II	25.6	26.1	0.5	0.24	3	1	0.42	0.20	0.86	44.8	4.93	0.80	5.73	15
45	II	25.4	26.8	1.4	0.68	3	4	0.42	0.80	1.90	78.0	8.58	0.25	8.83	22
46	II	25.4	27.1	1.7	0.82	3	4	0.42	0.80	2.04	104.0	11.44	—	11.44	18
47	II	23.4	26.7	3.3	1.59	2	2	0.28	0.40	2.27	120.0	13.20	—	13.20	17
48	II	22.5	26.0	3.5	1.69	3	3	0.42	0.60	2.71	128.2	14.12	0.65	14.77	18
49	II	24.7	24.9	0.2	0.10	2	3	0.28	0.60	0.98	90.0	9.90	0.55	10.45	9
50	II	24.0	25.0	1.0	0.48	2	3	0.28	0.60	1.36	82.0	9.04	—	9.04	15
51	II	22.0	23.9	1.9	0.92	1½	3½	0.21	0.70	1.83	80.0	8.80	—	8.80	21
52	II	22.7	27.3	4.6	2.21	1	2	0.14	0.40	2.75	90.0	9.90	0.55	10.45	26
53	II	24.0	25.8	1.8	0.87	1½	4½	0.21	0.90	1.98	75.0	8.25	0	8.25	24
54	II	23.1	27.6	4.5	2.17	1½	3½	0.21	0.70	3.08	121.5	13.37	0	13.37	23
FIELD E—Destino 14-15—Average Apparent Specific Gravity 1.31—Number of Sampling Holes 10—Acres 10.40															
55	I	23.2	24.0	0.8	0.38	2	2	0.20	0.28	0.86	17.0	1.63	—	1.63	53
56	I	22.4	25.5	3.1	1.46	1	1	0.10	0.14	1.70	24.0	2.31	0.14	2.44	70
57	II	22.6	23.5	0.9	0.42	2	2	0.28	0.40	1.10	24.0	2.31	—	2.31	48
58	*II*	*23.2*	*25.5*	*2.3*	*1.08*	*4*	*1*	*0.56*	*0.20*	1.84	*48.0*	4.62	0.37	4.99	37
59	II	22.9	25.1	2.2	1.04	1½	1½	0.21	0.30	1.55	28.5	2.74	0.17	2.91	53
60	II	22.1	26.7	4.6	2.16	2	4	0.28	0.80	3.24	60.0	5.77	0.98	6.75	48
61	II	24.2	25.1	0.9	0.42	4½	1½	0.63	0.20	1.35	55.0	5.29	0.57	5.86	23
62	II	22.3	25.4	3.1	1.46	1½	2½	0.21	0.50	2.17	45.0	4.33	—	4.33	50
63	II	22.9	25.7	2.8	1.32	2	4	0.28	0.80	2.40	48.0	4.62	0.22	4.84	50
64	II	21.4	25.7	4.3	2.03	1½	4½	0.21	0.90	3.14	68.5	6.59	0	6.59	48
65	II	20.4	25.6	5.2	2.46	2½	5½	0.35	1.10	3.91	66.0	6.36	1.95	8.31	47
66	II	22.5	25.1	2.6	1.23	1½	1½	0.21	0.30	1.74	72.0	6.94	0	6.94	25
67	II	19.5	25.3	5.8	2.73	2	5	0.28	1.00	4.01	81.0	7.80	0.21	8.01	50
FIELD F—Paso Seco 55—Average Apparent Specific Gravity 1.42—Number of Sampling Locations 12—Acres 12.55															
68	I	19.8	22.2	2.4	1.23	1½	2½	0.15	0.35	1.73	22.0	1.75	—	1.75	99
69	I	19.8	21.6	1.8	0.92	1	1	0.10	0.14	1.16	24.5	1.96	—	1.96	59
70	II	19.8	24.2	4.4	2.25	1½	1½	0.21	0.30	2.76	37.2	2.96	0.30	3.26	85
71	II	19.4	23.9	4.5	2.30	1	1	0.14	0.20	2.64	38.5	3.06	—	3.06	86
72	II	20.2	22.5	2.3	1.18	1½	1½	0.21	0.30	1.69	42.0	3.36	—	3.36	50
73	II	22.5	23.0	0.5	0.26	1	4	0.14	0.80	1.20	24.0	1.91	1.90	3.81	32
74	II	20.8	24.7	3.9	1.99	1½	1½	0.21	0.30	2.50	60.0	4.88	0.60	5.48	46
75	II	20.2	23.3	3.1	1.58	2	4	0.28	0.80	2.66	48.0	3.83	—	3.83	70
76	II	22.1	24.0	1.9	0.97	2	3	0.28	0.60	1.85	48.0	3.83	0.30	4.13	45
77	II	21.0	23.8	2.8	1.43	1½	2½	0.21	0.50	2.13	55.0	4.38	0.35	4.73	45
78	II	18.9	24.2	5.3	2.71	2½	3½	0.35	0.70	3.76	63.0	5.01	—	5.01	75
79	II	19.3	23.5	4.2	2.15	1½	2½	0.21	0.50	2.86	62.5	4.98	—	4.98	57
80	II	17.9	23.4	5.5	2.81	1½	2½	0.21	0.50	3.52	60.0	4.78	0	4.78	74
81	II	20.1	24.6	4.5	4.30	4	3	0.56	0.60	3.46	63.0	5.01	0.55	5.56	62
82	II	20.0	21.3	1.3	0.66	1½	½	0.21	0.10	0.97	60.0	4.78	0.30	5.08	19
83	*II*	*21.5*	*24.9*	*3.4*	*1.74*	*1½*	*1½*	*0.21*	*0.30*	2.25	*56.0*	4.46	*0*	4.46	*50*
84	II	23.5	25.2	1.7	0.87	3	1	0.42	0.20	1.49	50.0	4.00	0	4.00	37
85	II	21.6	23.5	1.9	0.97	1	2	0.14	0.40	1.51	50.0	4.00	0.0	0.0	38
86	II	21.5	24.7	3.2	1.64	2	1	0.28	0.20	2.12	50.0	4.00	0.0	0.0	53

TABLE 1—*Concluded*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Test Numbers	Stage of Crop Growth†	P_w‡ Before Irrigation (Per Cent)	P_w‡ After Irrigation (Per Cent)	P_w‡ Difference (Per Cent)	Measured Difference in Soil Moisture (Inches)	Time Lapse in Period A (Days)	Time Lapse in Period B (Days)	Approximate Consumptive Use by Crop in Period A (inches)	Approximate Consumptive Use by Crop in Period B (Inches)	Net Water Accounted for in Root Zone (Inches)	Total Volume of Irrigation—Water Applied (Acre Inches)	Irrigation Water Applied per Acre (Acre Inches)	Rainfall in Periods A & B (Inches)	Total Water Applied per Acre (Inches)	Water Application Efficiency (Per Cent)
			(Riser #26) FIELD G—(Overhead 26)—Average Apparent Specific Gravity 1.38—Number of Sampling Holes 9—Acres 2.5												
87	I	18.0	19.1	1.1	0.36	½	⅓	0.05	0.07	0.48	1.97	0.79	—	0.79	61
88	I	21.4	21.9	0.5	0.17	0	1	—	0.14	0.31	2.00	0.80	—	0.80	39
89	I	23.2	25.8	2.6	0.86	0	1	—	0.14	1.00	2.47	0.99	—	0.99	101
90	I	23.4	25.4	2.0	0.66	0	1	—	0.14	0.80	2.25	0.90	0.38	1.28	62
91	II	22.4	28.4	6.0	1.98	0	2	—	0.40	2.38	2.70	1.08	1.58	2.66	90
92	II	23.4	25.7	2.3	0.76	0	1	—	0.20	0.96	2.60	1.04	—	1.04	92
93	II	23.6	24.4	0.8	0.26	1	1	0.14	0.20	0.60	2.60	1.04	—	1.04	58
94	II	24.0	24.6	0.6	0.20	0	1	—	0.20	0.40	2.25	0.90	—	0.90	44
95	II	23.9	26.0	2.1	0.69	0	2	—	0.40	1.09	2.60	1.04	—	1.04	105
96	II	24.2	25.2	1.0	0.33	0	2	—	0.40	0.73	2.65	1.06	—	1.06	69
97	II	24.2	25.6	1.4	0.46	3	2	0.42	0.40	1.28	2.25	0.90	0.20	1.10	116
98	II	23.6	24.4	0.8	0.26	0	3	—	0.60	0.86	2.25	0.90	—	0.90	96
99	II	24.8	25.3	0.5	0.17	0	2	—	0.40	0.57	2.50	§1.00	—	1.00	57
100	II	25.2	26.6	1.4	0.23	½	1½	0.07	0.30	0.60	2.4	0.95	0.15	1.10	54
101	II	22.0	25.1	3.1	0.51	½	3½	0.07	0.70	1.28	2.4	0.95	0.20	1.15	112
102	II	25.1	27.5	2.4	0.40	1	1	0.14	0.20	0.74	2.5	1.00	0	1.00	74
103	II	25.1	27.6	2.5	0.83	½	½	0.07	0.10	1.00	2.5	0.95	0	0.95	105
104	II	24.2	26.1	1.9	0.63	½	½	0.07	0.10	0.80	2.4	0.95	0	0.95	85
105	II	24.5				1½					2.5	1.00			
			FIELD H—Overhead 31—Average Apparent Specific Gravity—1.38—Number of Sampling Holes 9—Acres 2.50												
106	I	17.7	18.0	0.3	0.10	1	½	0.10	0.07	0.27	1.80	0.72	—	0.72	37
107	I	21.2	22.0	0.8	0.26	0	1	—	0.14	0.40	2.05	0.82	—	0.82	49
108	I	21.6	24.4	2.8	0.93	0	1	—	0.14	1.07	2.47	0.99	—	0.99	108
109	I	20.6	24.0	3.4	1.13	½	½	0.05	0.07	1.25	2.25	0.90	0.38	1.28	98
110	II	24.7	25.6	0.9	0.30	½	1½	0.07	0.30	0.67	2.60	1.04	1.58	2.62	26
111	II	22.6	23.0	0.4	0.13	2	2	0.28	0.40	0.81	2.47	0.99	0.32	1.31	62
112	II	21.2	22.4	1.2	0.40	½	½	0.07	0.10	0.57	2.47	0.99	—	0.99	58
113	II	20.2	22.2	2.0	0.66	1	1	0.14	0.20	1.00	2.47	0.99	—	0.99	100
114	II	19.2	19.8	0.6	0.20	½	½	0.07	0.10	0.37	1.10	0.44	—	0.44	84
115	II	20.6	21.4	0.8	0.26	0	1	—	0.20	0.46	2.25	0.90	—	0.90	51
116	II	21.2	21.3	0.1	0.03	0	2	—	0.40	0.43	2.60	1.04	—	1.04	41
117	II	20.2	21.0	0.8	0.26	0	2	—	0.40	0.86	2.60	1.04	—	1.04	83
118	II	21.2	21.3	0.1	0.03	3	2	0.42	0.40	0.85	2.25	0.90	—	0.90	95
119	II	20.2	21.4	1.2	0.40	1	1	0.14	0.20	0.74	2.37	0.95	0.29	1.24	60
120	II	21.2	23.0	1.8	0.60	0	2	—	0.40	1.00	2.50	1.00	—	1.00	100
121	II	20.6	23.9	3.3	0.54	0	2	—	0.40	0.94	2.50	1.00	0.23	1.23	76
122	II	23.0	23.2	0.2	0.03	½	1½	0.07	0.30	0.40	2.4	0.95	0.15	1.10	36
123	II	18.9	23.0	4.1	0.68	½	3½	0.07	0.70	1.45	2.3	0.90	0.20	1.15	126
124	II	23.0	24.9	1.9	0.31	1	1	0.14	0.20	0.65	2.5	1.0	0	1.0	65
125	II	22.7	25.0	2.3	0.76	½	½	0.07	0.10	0.93	2.3	0.93	0	0.93	100
126	II	22.8	23.3	0.5	0.16	½	½	0.07	0.10	0.33	2.3	0.93	0	0.93	36
127	II	21.8	24.5	2.7	0.90	½	½	0.07	0.10	1.07	2.5	0.98	0	0.98	112
128	II	20.7	22.7	2.0	0.66	½	½	0.07	0.10	0.83	2.4	0.95	0	0.95	88

§ Only 1 acre irrigated.

first, second, and third foot of soil with a 1″, open side sampling tube. The net effect of the irrigation on the soil moisture was thus determined. The samples were taken within a radius of 10 to 15 feet of carefully selected locations in each field. There were from 8 to 14 of these selected locations marked with stakes in each field and, in order to avoid extreme moisture conditions, the samples were all taken about half way between the furrow bottoms and the ridge tops. Moisture was determined on each sample individually. The repetition of measurements under similar conditions provides a good indication of the accuracy of single efficiency determinations. Whenever an efficiency varies more than about 10% from the average for the field there is usually a rather obvious reason to explain it. Large variations in the volume of the water application is the most common cause. Very small applications are usually quite efficient; very large applications are usually wasteful.

In soil profile sampling in pits we have estimated that 75% to 80% of the cane roots of variety BH-10-12 occur in the surface 12 inches. Studies by other investigators (12) have shown that more than 90% of the roots of sugar cane are located in the upper three feet of soil. For the purpose of this study the effective root zone is considered to be the top 36 inches. Although in the early stages of growth the root zone will actually be less than this, still if no roots are present in the lower layers of this upper three feet of soil, then any water stored there at a tension higher than field capacity will remain until needed by the crop as growth develops.

The sets of field soil samples taken periodically throughout the season provide basic data for determining rates of consumptive use of water at different stages of crop growth by computing the soil moisture depletions in the intervals between irrigations (Table 2). The consumptive use rates over short periods serve as a check against the seasonal use figure for the fields.

In studying the soils of the various fields, the Utah-Kelley (12) mechanical soil sampler cooperatively developed by the Utah Scientific Research Foundation and reported by Kelley, et al (12), proved to be very valuable. Undisturbed soil cores were taken from each of the fields studied. These were carefully examined and described. Then undisturbed sections were encased in used quart oil cans for percolation, pore space and other measurements in the laboratory (19), thus providing for accurate soil profile characterization.

Soil Properties of the Experimental Fields

From the standpoint of major profile properties which may influence soil use or productivity, the soils involved in this study are described and compared in Table 3. This type of soil characterization has been explained in more detail elsewhere (18). The general, comparative rating offered by

TABLE 2

Consumptive Use of Water by Sugar Cane Over Short Period

1	2	3	4	5	6	7	8	9	10	11
Field	Inclusive Dates	Use Interval (Days)	Average Soil Moisture: Beginning of Period (Per Cent)	Average Soil Moisture: End of Period (Per Cent)	Difference (Per Cent)	Aver ge Apparent Specific Gravity	Net Soil Moisture Depletion (Inches)	Rainfall in Period (Inches)	Total Consumptive Use (Inches)	Average Consumptive Use Per Day (Inches)
				Up to 2 Months After Planting						
A	5/2–5/28	21	25.2	23.8	1.4	1.29	0.65	1.65	2.30	0.11
B	4/22–4/30	8	24.5	23.0	1.5	1.47	0.79	0.65	1.44	0.18
B	5/4–5/18	14	25.0	22.7	2.3	1.47	1.22	1.32	2.54	0.18
B	5/18–5/25	7	22.7	23.8	1.1	1.47	0.58	0.45	1.03	0.15
B	5/28–6/6	9	24.6	23.8	0.8	1.47	0.42	0.0	0.42	0.05
D	5/7–5/16	9	25.9	25.1	0.8	1.34	0.39	1.30	1.69	0.19
D	5/19–5/30	11	25.8	24.5	1.3	1.34	0.63	0.0	0.63	0.06
D	6/1–6/6	5	26.1	25.6	0.5	1.34	0.24	0.55	0.79	0.16
E	4/13–4/23	10	24.6	23.2	1.4	1.31	0.66	0.0	0.66	0.07
E	4/27–5/16	19	24.0	22.4	1.6	1.31	0.75	1.23	1.98	0.10
E	5/18–5/27	9	25.5	22.6	2.9	1.31	1.37	0.0	1.37	0.15
F	4/14–4/25	11	21.6	20.2	1.4	1.42	0.71	0.0	0.71	0.06
F	4/28–5/5	7	23.4	21.9	1.5	1.42	0.77	0.25	1.02	0.15
F	5/23–6/1	9	22.2	19.8	2.4	1.42	1.22	0.0	1.22	0.14
								Average	0.12	
				2 to 3 Months After Planting						
B	6/24–7/1	7	24.6	21.8	2.8	1.47	1.48	0.10	1.58	0.22
C	5/5–5/23	18	26.5	23.2	3.3	1.32	1.57	1.38	2.95	0.16
D	6/23–7/2	9	25.5	25.4	0.1	1.34	0.05	0.40	0.45	0.05
E	5/31–6/13	13	23.5	23.2	0.3	1.31	0.14	0.75	0.89	0.07
F	6/3–6/13	10	21.6	19.8	1.8	1.42	0.92	0.80	1.72	0.17
F	6/25–7/5	10	23.1	19.4	3.7	1.42	1.89	0.40	2.29	0.23
								Average	0.15	
				3 to 4 Months After Planting						
A	7/7–7/18	11	27.2	24.1	3.1	1.29	1.44	0.40	1.84	0.17
B	7/15–7/22	7	21.8	23.4	−1.6	1.47	−0.85	1.0	0.15	0.21
B	7/22–7/27	5	23.4	23.9	−0.5	1.47	−0.26	0.75	0.49	0.10
C	5/28–6/20	23	25.3	23.0	2.3	1.32	1.09	1.48	2.57	0.11
C	6/20–6/27	7	23.0	25.5	−2.5	1.32	−1.19	1.83	0.64	0.09
D	7/9–7/19	10	26.8	23.6	3.2	1.34	1.54	0.0	1.54	0.15
E	6/30–7/11	11	23.4	22.9	0.5	1.31	0.24	0.61	0.85	0.08
F	7/7–7/15	8	23.9	20.2	3.7	1.42	1.89	0.25	2.14	0.27
									Average	0.15
				4 to 5 Months After Planting						
A	7/21–8/16	26	26.9	25.2	1.7	1.29	0.80	4.46	5.26	0.20
A	8/26–9/1	6	27.5	26.7	0.8	1.29	0.37	0.0	0.37	0.06
A	9/1–9/14	13	26.7	25.0	1.7	1.29	0.80	2.0	2.80	0.22
B	7/30–8/17	19	24.7	19.9	4.6	1.47	2.42	0.85	3.27	0.17
B	8/27–9/8	12	24.4	24.5	−0.1	1.47	−0.05	2.10	2.05	0.17
C	6/27–7/5	8	25.5	22.2	3.3	1.32	1.57	0.40	1.97	0.25
									Average	0.18

TABLE 2—*Continued*

1	2	3	4	5	6	7	8	9	10	11
Field	Inclusive Dates	Use Interval (Days)	Average Soil Moisture Beginning of Period (Per Cent)	Average Soil Moisture End of Period (Per Cent)	Difference (Per Cent)	Average Apparent Specific Gravity	Net Soil Moisture Depletion (Inches)	Rainfall in Period (Inches)	Total Consumptive Use (Inches)	Average Consumptive Use Per Day (Inches)
				5 to 6 Months After Planting						
A	9/28–10/4	6	28.7	26.9	1.8	1.29	0.84	0.57	1.41	0.23
C	8/12–8/31	19	26.1	26.4	−0.3	1.32	0.90	2.40	3.30	0.17
D	9/7–9/15	8	24.4	23.4	1.0	1.34	0.48	0.60	1.08	0.13
D	9/29–10/4	5	26.5	24.9	1.6	1.34	0.77	0.30	1.07	0.21
E	9/7–9/13	6	24.4	22.7	1.7	1.31	0.80	0.00	0.80	0.13
E	9/13–9/16	3	22.7	22.2	0.5	1.31	0.24	0.33	0.67	0.22
F	9/6–9/12	6	23.0	20.8	2.2	1.42	1.12	0.0	1.12	0.19
F	9/29–10/4	5	24.0	22.2	1.8	1.42	0.92	0.30	1.22	0.24
									Average	0.19
				6 to 7 Months After Planting						
B	10/1–10/24	23	24.1	20.9	3.2	1.47	1.69	1.82	3.51	0.15
F	10/26–11/2	7	23.3	22.1	1.2	1.42	0.61	0.65	1.25	0.18
									Average	0.16
				7 to 8 Months After Planting						
A	11/1–11/10	9	28.7	25.0	3.7	1.29	1.72	1.05	2.77	0.31
A	11/15–12/1	16	27.7	23.0	4.7	1.29	2.18	0.48	2.66	0.17
B	10/24–11/29	36	20.9	18.3	2.6	1.47	1.38	5.54	6.92	0.19
C	9/26–10/3	7	29.2	28.5	0.7	1.32	0.33	0.47	0.80	0.11
D	11/1–11/10	9	26.0	24.7	1.3	1.34	0.63	0.30	0.93	0.10
D	11/15–11/28	13	24.9	24.0	0.9	1.34	0.43	0.35	0.78	0.06
E	11/1–11/10	9	26.7	24.2	2.5	1.31	1.18	0.44	1.62	0.18
E	11/16–11/28	12	25.1	22.3	2.8	1.31	1.32	0.49	1.81	0.15
F	11/7–11/17	10	24.0	21.0	3.0	1.42	1.53	0.55	2.08	0.21
F	11/21–12/3	12	23.8	18.9	4.9	1.42	2.50	0.0	2.50	0.21
									Average	0.17
				8 to 9 Months After Planting						
A	12/9–12/21	12	27.7	25.1	2.6	1.29	1.21	0.48	1.69	0.14
A	12/21–12/27	6	25.1	23.6	1.5	1.29	0.70	0.25	0.95	0.16
B	12/5–12/14	9	23.4	21.4	2.0	1.47	1.06	0.10	1.16	0.13
B	12/20–1/4	15	23.6	21.3	2.3	1.47	1.22	0.45	1.67	0.11
C	11/1–11/17	16	28.4	26.5	1.9	1.32	0.90	1.03	1.93	0.12
D	12/3–12/19	16	25.0	22.0	3.0	1.34	1.44	0.0	1.44	0.09
E	12/2–12/14	12	25.4	22.9	2.5	1.31	1.18	0.29	1.47	0.12
F	12/9–12/19	10	24.2	19.3	4.9	1.42	2.50	0.0	2.50	0.25
									Average	0.13

TABLE 2—*Continued*

1	2	3	4	5	6	7	8	9	10	11
			Average Soil Moisture							
Field	Inclusive Dates	Use Interval (Days)	Beginning of Period (Per Cent)	End of Period Per Cent)	Difference (Per Cent)	Average Apparent Specific Gravity	Net Soil Moisture Depletion (Inches)	Rainfall in Period (Inches)	Total Consumptive Use (Inches)	Average Consumptive Use per Day (Inches)
				9 to 10 Months After Planting						
A	1/3–1/18/50	15	27.0	22.8	4.2	1.29	1.94	0.0	1.94	0.13
A	1/23–2/1/50	9	26.9	23.8	3.1	1.29	1.43	1.03	2.46	0.27
B	1/17–1/30/50	13	23.0	16.8	6.2	1.47	3.29	0.45	3.74	0.29
C	11/21–12/1/50	10	29.0	26.5	2.5	1.32	1.19	0.25	1.44	0.14
C	12/10–12/28/49	18	29.9	26.9	3.0	1.32	1.42	1.24	2.66	0.15
D	1/24–2/14/50	21	27.3	24.0	3.3	1.34	1.59	1.50	3.09	0.15
E	12/20–1/11/50	22	25.7	21.4	4.3	1.31	2.03	0.58	2.61	0.12
F	12/23–1/10/50	18	23.5	17.9	5.6	1.42	2.86	0.0	2.86	0.16
								Average	0.18	
				10 to 11 Months After Planting						
A	2/8–2/16/50	8	26.9	25.3	1.6	1.29	0.54	0.0	0.54	0.07
A	2/20–3/2/50	10	27.8	23.1	4.7	1.29	1.58	0.0	1.58	0.16
B	2/21–3/7/50	14	25.6	20.9	4.7	1.47	2.48	0.67	3.15	0.22
C	1/3–1/21/50	18	27.8	22.2	5.6	1.32	2.66	0.10	2.76	0.15
D	2/20–3/9/50	17	25.8	23.1	2.7	1.34	1.30	0.00	1.30	0.08
E	1/17–2/2/50	16	25.7	20.4	5.3	1.31	2.50	0.52	3.02	0.19
F	2/2–2/14/50	12	21.3	21.5	−0.2	1.42	−0.10	1.20	1.10	0.09
F	2/17–2/24/50	7	24.9	23.5	1.4	1.42	0.72	0.0	0.72	0.10
								Average	0.13	
				11 to 12 Months After Planting						
B	3/14–3/29/50	15	23.0	21.1	1.9	1.47	1.00	0.0	1.00	0.07
C	1/27–2/13/50	17	29.3	26.9	2.4	1.32	1.14	0.95	2.09	0.13
D	3/14–4/2/50	19	27.6	21.4	6.2	1.34	2.99	0.0	2.99	0.16
E	2/24–3/3/50	11	25.1	22.8	2.3	1.31	1.09	0.0	1.09	0.10
F	2/28–3/10/50	11	25.2	20.8	4.4	1.42	2.25	0.0	2.25	0.20
F	3/24–3/30/50	6	23.5	21.5	2.0	1.42	1.02	0.0	1.02	0.17
								Average	0.14	
				12 to 13 Months After Planting						
C	2/17–2/28/50	11	28.8	26.8	2.0	1.32	0.95	0.19	1.14	0.10
E	3/27–4/10/50	14	25.3	22.4	2.9	1.31	1.37	0.15	1.52	0.11
								Average	0.11	

Table 3, should provide enough information for a better understanding of this paper as a whole. The soils represented tend to be similar, but have some distinct differences. The ratings are based on profile sampling with the Utah-Kelley soil sampling machine, laboratory study of samples, field observations, and both field and plot results in the records of Luce and Company. From one to four cores were taken with the machine in each field at locations selected as typical of the field. The selection of locations and study of the soils was based not only on outward appearances but on

TABLE 3

Characteristics of the soil profiles of the several experimental fields and of the soil in the consumptive use tanks in terms of major properties which directly influence soil use or productivity

Field Name	Profile depth (Effective)	Workability	Erodibility	Water intake capacity	Water transmission in profile	Permanent available water holding capacity	Tightness available water is held	Aeration capacity	Acid Int. pH	Sol. Salts	Gen. Fertility	Available nitrogen
Bernard	3 (Sand)	5	7	5	5	2–3	3	3	5	5	3	2
Carmen	5	7	6	4	2	3–4	4	3	5	5	5	3
J.D. 56	3 (Gravel)	6	6	5	6	2	3	5	5	5	5	3
Dest. 14 & 15	5	6	7	5	3	2–3	3	4	5	5	5	3
Dest. 55	5	5	7	5	5	2–3	3	5	5	5	3	3
Paso Seco	4 (Gravel)	5	7	5	6	2	3	5	5	5	4	2
Overhead 26 & 31	3 (Gravel)	5	6	5	6	2	3	5	5	5	4	2
Tanks	4 (Gravel)	6	7	4	5	2	3	5	5	5	4–5	3

Numbers have the following meanings:

Ideal		
5		Excellent
4 . 6		Very good
3 7		Good
2 8		Fair
1 9		Poor
0 10		Very poor
too little or too loose	too much or too heavy	

knowledge and experience of technical men representing Luce and Company, who are thoroughly familiar with the soil and their past performances.

Supplementing Table 3, the pF curves in Figures 1 to 5 show detailed soil water and pore space relationships. These curves actually may be considered as more precise expression of properties involving water. The water-holding capacity between pF 2.7 and 4.2 is not generally as high as for some clay soils. This fact, plus limitations by sand and gravel layers, is the basis for rating the soils low (2 to 4) in permanent available water-holding capacity. More water is held loosely and can therefore be lost by drainage than in an ideal soil.

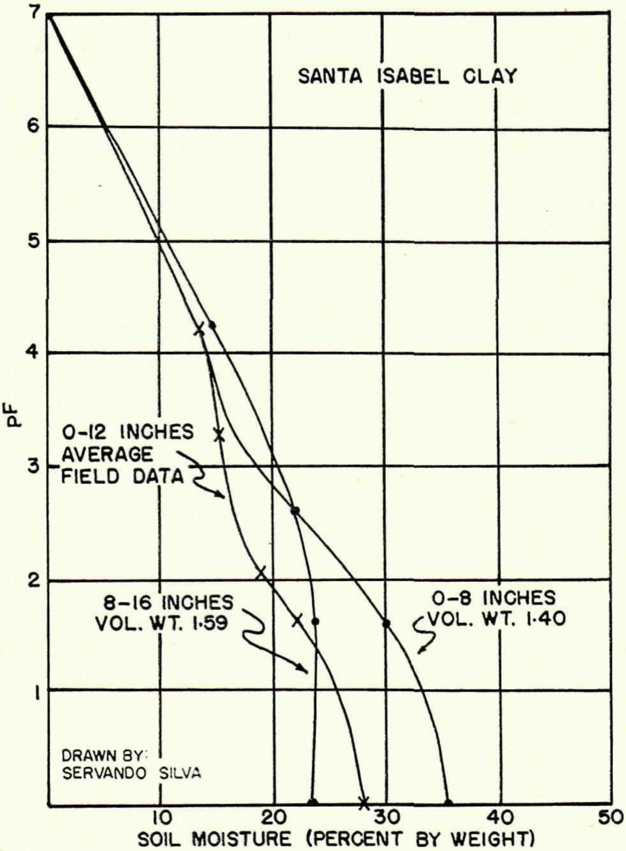

FIG. 1. Moisture tension curves for the soil used in consumptive use tanks at Aguirre, Puerto Rico.

Lowest permeability was found in Carmen (Table 3): Subsoil percolation rates in three cores averaged less than 0.05 inches per hour at unit hydraulic head in the tightest layer, which was in the second foot of the profile. This checks with field observations that water moves very slowly in this soil after it becomes wet.

The excellent ratings for acidity and soluble salts are based on pH and conductivity measurements. Fertility ratings are based on limited chemical

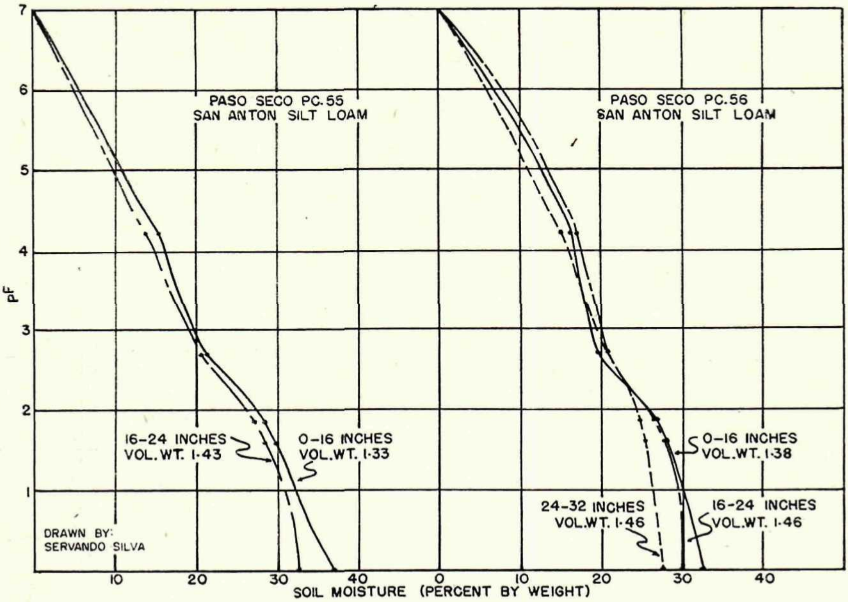

FIG. 2. Soil Moisture Tension Curves.

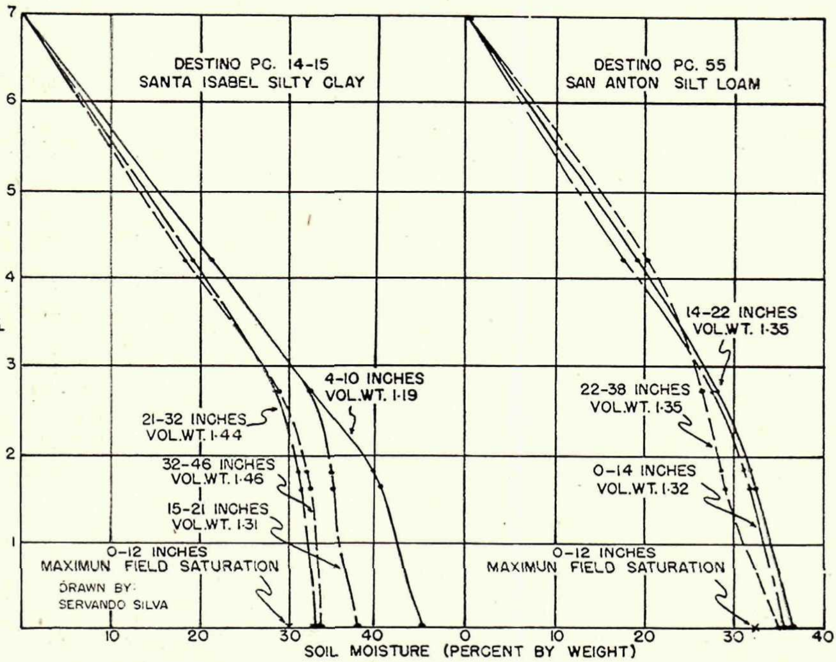

FIG. 3. Soil Moisture Tension Curves.

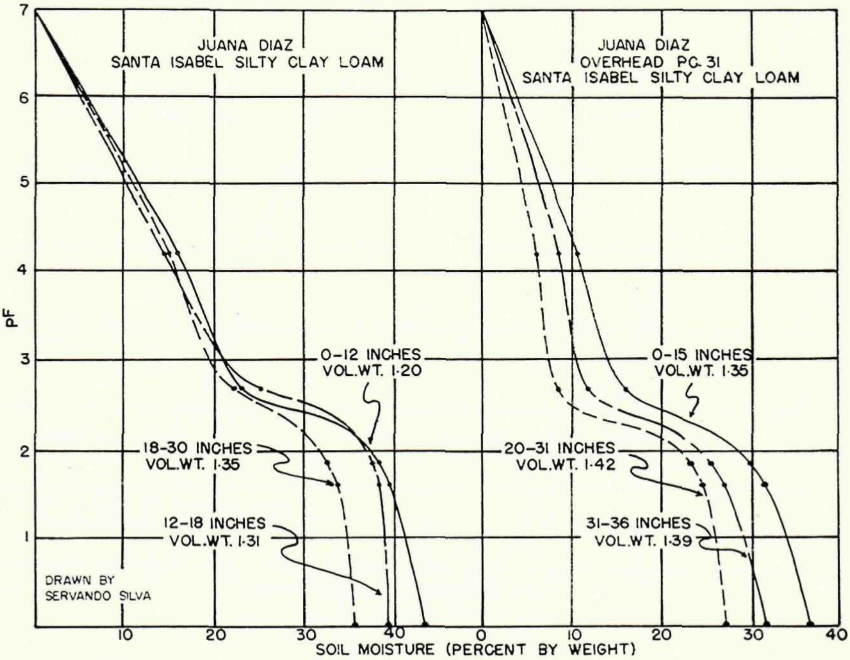

FIG. 4. Soil Moisture Tension Curves.

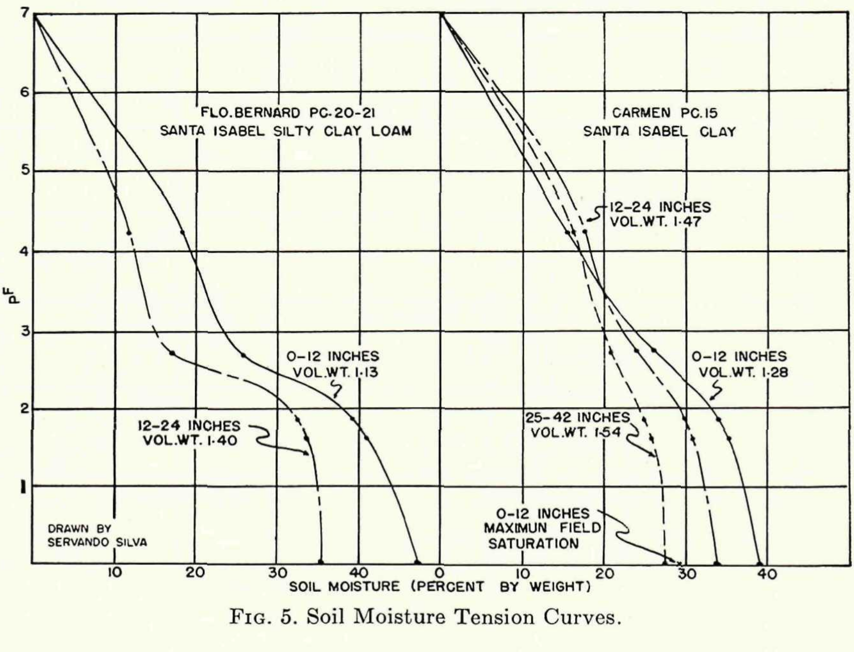

FIG. 5. Soil Moisture Tension Curves.

data, on considerable general information of the Agricultural Experiment Station, and small plot and field scale results of Luce and Company.

Surface soil structural units are not highly water stable so the soils are considered rather erodible, but this is not serious because of favorable slopes. The clay is flocculated and forms small structural units which provide good workability and generally excellent water intake. Subsoil sand and gravel layers may let water move away too rapidly in the several cases where subsoil transmission rates are shown as too high. Most of the true sand or gravel layers carry water at more than 50 inches per hour at unit hydraulic head.

More irrigation water is normally lost by subsoil seepage in the soils where gravel layers are within 3 feet of the surface. Least seepage probably occurs in Carmen, where the subsoil is considered to be too tight for handling heavy rainfall or high water applications.

Water Application Efficiency of Irrigation in Fields

All water applied to each of 8 fields, whether as irrigation or rainfall, was measured and recorded. In order to compute the actual water used, however, it is necessary to determine what is known as the water application efficiency.

Water application efficiency is defined as "the ratio of the amount of water stored or accounted for in the root zone to the amount of water delivered to the farm, usually expressed as a percent." Computations of water application efficiency were made for most of the irrigations on the experimental fields.

The method used in determining water application efficiency is basically the same as that used by Israelsen, et al, in Utah as reported in 1944 (10) except that a correction factor is introduced to account for the consumptive use by the crop in the interval between the dates of sampling for "before irrigation" and "after irrigation" soil moisture. In explaining this procedure, the following symbols will be used:

A —Area of field, acres.

A_s —Average apparent specific gravity of soil in root zone.

D —Depth of root zone, inches.

d_a —Depth of water applied, inches.

d_r —Equivalent depth of water accounted for in the crop root zone resulting from the water applied, inches.

E_a —Water application efficiency, percent.

P_{w1}—Moisture in root zone before irrigations, per cent on a weight basis.

P_{w2}—Moisture in root zone after irrigation, per cent on a weight basis.

Q —Discharge of irrigation stream, cubic feet per second.

r —Rainfall between samples P_{w1} and P_{w2}, inches.

t —Time required to irrigate field, hours.

u_a —Consumptive use in Period A (the interval between the time P_{w1} sample is taken and the time irrigation water is applied), inches.

u_b —Consumptive use in Period B (the interval between the beginning of irrigation and the time P_{w2} samples is taken), inches.

As used in this report, water application efficiency is computed by the basic equation:

$$E_a = \frac{d_r}{d_a} \times 100 \qquad \text{(Eq. 1)}$$

But, as used herein,

$$d_r = \frac{(P_{w2} - P_{w1})\ A_s D}{100} + u_a + u_b \qquad \text{(Eq. 2)}$$

And

$$d_a = \frac{Qt}{A} + r \qquad \text{(Eq. 3)}$$

And therefore

$$E_a = \left(\frac{\dfrac{(P_{w2} - P_{w1}) A_s D}{100} + u_a + u_b}{\dfrac{Qt}{A} + r} \right) 100 \qquad \text{(Eq. 4)}$$

The determination of consumptive use correction factor involved in accurately determining efficiency of application has been explained in detail by Fuhriman (8, 9) and will not be carried further here.

Details of determinations of efficiency for most of the irrigations on each of the fields studied have been shown in Table 1.

Some explanation of the data in each of the columns of the table will assist the reader in a careful study of the results tabulated:

Column 1—Test number: Arbitrarily assigned for ease of future reference.

Column 2—Stage of crop growth: Stage I refers to crop less than 2 months after planting; Stage II, more than 2 months.

Column 3—P_w before irrigation (per cent): The percentage moisture in the soil a short time (see column 7) before irrigation, expressed as percent on a weight basis.

Column 4—P_w after irrigation (percent): The percentage moisture in the soil a short time (see column 8) after irrigation, expressed as a percent on weight basis.

Column 5—P_w Difference (percent): Column 3 entry subtracted from entry of column 4.

Column 6—Measured difference in soil moisture (inches): Column 5 entry converted to inches depth of water in the root zone; computed by multiplying entry in column 5 by $36A_s \div 100$ (36 is depth of root zone in inches).

Column 7—Time lapse in period A (days). This represents the average time interval from the time P_{w1} sample is taken to the time irrigation begins.

Column 8—Time lapse in period B (days). This represents the average time interval from the time of irrigation to the time P_{w2} sample is taken.

Column 9—Approximate consumptive use by crop in period A (inches): This is the product of the consumptive use correction factor for "before irrigation" use, and the number of days shown in the column 7. This is the u_a of equation 4.

Column 10—Approximate consumptive use by crop in period B (inches): This is the product of the consumptive use correction factor for "after irrigation" use, and the number of days shown in column 8. This is the u_b of equation 4.

Column 11—Net water accounted for in root zone: The sum of entries in columns 6, 9, and 10. This is the numerator of equation 4.

Column 12—Total volume of irrigation water applied (acre-inches). The product of the size of irrigation stream in c.f.s. and the number of hours used for a given irrigation.

Column 13—Irrigation water applied per acre (acre-inches): Computed by dividing acres irrigated into the entry in column 12.

Column 14—Rainfall in periods A and B (inches): This represents the rainfall, measured near the field, which occurred between the time of taking the P_{w1} and P_{w2} samples.

Column 15—Total water applied per acre (inches): The sum of entries in columns 13 and 14. This is the denominator of equation 4.

Column 16—Water application efficiency (percent): Computed by dividing entry of column 11 by column 15 entry, and multiplying by 100.

It will be noted that in most tests the efficiencies were low when amounts of water applied were high, or when the soil was already wet. These facts were utilized in estimating efficiencies in the few instances when data were not collected for measuring the efficiency.

Evaluation of Effective Rainfall in Fields

Not all of the recorded rainfall is stored in the soil for use by the crop. One can observe in any heavy rainstorm the surface runoff which occurs after the rain has filled the surface soil to capacity or the rainfall intensity

TABLE 4a

Total Water Applications—Bernard

(Planted April 4-5—BH 10-12—Area 9.08 acres)

Date	Application	Total (Acre-Inches)	Depth Applied (Inches)	Water Appl. Eff. (Per Cent)	Amount Retained
4/5-4/7/49	1st Irr.	38.25	4.21		None
4/16-4/17/49	2nd Irr.	20.25	2.23	50*	1.2
4/30-5/1/49	3rd Irr.	21.75	2.39	29	0.7
	(Apr. 5-30—No rain)				0.0
5/22-5/25/49	4th Irr.	22:75	2.50	31	0.8
6/2-6/3/49	5th Irr.	22.75	2.50	40	1.0
6/8/49	6th Irr.	15.75	1.73	34	0.6
	(May—Rain)		1.65	—	1.6
	(June—Rain)		4.43	—	3.0
7/5-7/6/49	7th Irr.	38.25	4.21	75	3.1
7/19/49	8th Irr. (Irr. 4.00 only)	16.87 (4.22" over 4.0 acres)	1.83	34	0.6
	(July—Rain)		3.30	—	2.9
8/22-8/23/49	9th Irr.	42.75	4.70	50*	2.4
	(Aug.—Rain)		6.89	—	2.9
9/16-9/18/49	10th Irr.	41.64	4.58	22	1.0
	(Sept.—Rain)		9.15	—	4.0
10/27-10/29/49	11th Irr.	49.50	5.45	40*	2.2
	(Oct.—Rain)		4.41	—	2.3
11/12-11/13/49	12th Irr.	29.92	3.29	46	1.5
	(Nov.—Rain)		1.22	—	1.2
12/3-12/6/49	13th Irr.	56.25	6.19	51	3.1
12/27-12/29/49	14th Irr.	60.75	6.69	48	3.2
	(Dec.—Rain)		1.30	—	1.3
1/19/50	15th Irr.	40.50	4.46	55	2.4
	(Jan.—Rain)		1.54	—	1.5
2/2-2/3/50	16th Irr.	29.50	3.25	51	1.7
2/16-2/17/50	17th Irr.	33.75	3.71	51	1.9
	(Feb.—Rain)		2.05	—	2.0
3/3-3/4/50	18th Irr.	40.50	4.46	50	2.2
3/18-3/20/50	19th Irr.	40.50	4.46	50*	2.3
3/21-4/1/50	20th Irr.	40.50	4.46	52	2.3
	(Mar.—Rain)		0.80		0.8
4/25/50	21th Irr.		4.46	50*	2.3
	(Apr.—Rain)		1.44	—	1.4
Soil moisture deficit at harvest					3.8
Total use for season (406 days)					65.2
Use per day = 0.16 inch					

* Estimated.

is at a faster rate than the surface soil can absorb. With small rains there is no runoff, all of the water being absorbed by the soil. Since no absolute "Efficiency" determinations were made for rainfall applications it was

TABLE 4b

Total Water Applications—Carmen

(Planted April 5-10-49—BH 10-12—Area 10.68 acres)

Date	Application	Total (Acre-Inches)	Depth Applied (Inches)	Water Appl. Eff. (Percent)	Amount Retained
4/6–4/12/49	1st Irr.	82.8	7.75		None
4/18–4/21/49	2nd Irr.	30.6	2.86	39	1.2
	(April—Rain)		0.71		0.7
5/2–5/3/49	3rd Irr.	30.0	2.80	55	1.5
5/26–5/28/49	4th Irr.	48.1	4.51	16	0.7
	(May—Rain)		1.94		1.9
	(June—Rain)		5.80		3.8
7/9–7/10/49	5th Irr.	55.0	5.15	51	2.7
7/27–7/30/49	6th Irr.	110.0	10.29	9	0.9
	(July—Rain)		1.95		1.9
8/18–8/22/49	7th Irr.	111.0	10.39	22	2.3
	(Aug.—Rain)		6.35		3.0
	(Sept.—Rain)		7.14		4.0*
	(Oct.—Rain)		3.64		3.6
	(Nov.—Rain)		1.57		1.5
12/1–12/2/49	8th Irr.	52.0	4.86	78	3.8
12/15–12/17/49	9th Irr.	69.0	6.46	44	2.8
	(Dec.—Rain)		0.79		0.8
1/12–1/14/50	10th Irr.	72.0	6.74	27	1.8
	(Jan.—Rain)		0.58		0.6
2/17–2/20/50	11th Irr.	72.0	6.74	47	3.2
	(Feb.—Rain)		1.60		1.6
3/10–3/13/50	12th Irr.	72.0	6.74	33	2.2
3/30–4/1/50	13th Irr.	84.0	7.86	36	2.8
	(Mar.—Rain) *None*				—
4/21-4/23/50	14th Irr.		6.74	40*	2.6
	(April—Rain)		0.30		0.3
5/15–5/16/50	15th Irr.		8.18	35*	2.9
	(May—Rain)		0.15		0.1
Soil moisture deficit at harvest (June 7)					5.1
Total use for season (423 days) = 0.14 inch/day average					60.4

* Estimated.

necessary to estimate the effective amount. Observations have shown that, generally, if a rainfall of less than one inch (in one day) occurs in the south coastal plain area, there is no runoff. Moisture data confirm that the soil usually has that much capacity. By checking through the daily rainfall records and the most recent soil moisture contents, and assuming that for

TABLE 4c

Total Water Applications—Juana Diaz #56

(Planted February 14-23-49—P.O.J. 2878—Area 17.12 acres)

Date	Application	Total (Acre-Inches)	Depth Applied (Inches)	Water Appl. Eff. (Percent)	Amount Retained
2/15-2/23/49	1st Irr.	58.10	3.39		
	(Rain—Feb. 23-28)		0.16		0.2
3/24-3/28/49	2nd Irr.	63.0	3.67	50*	1.4
	(Rain—March)		1.93		1.9
4/12-4/14/49	3rd Irr.	56.4	3.29	22	0.8
	(Rain—April)		0.20		0.2
5/3-5/5/49	4th Irr.	54.7	3.19	39	1.2
5/25-5/27/49	5th Irr.	59.2	3.45	51	1.8
	(Rain—May)		1.43		1.4
	(Rain—June)		3.31		2.3
7/7-7/9/49	6th Irr.	83.6	4.88	67	3.3
	(Rain—July)		5.52		3.4
8/9-8/11/49	7th Irr.	103.6	6.05	17	1.0
	(Rain—Aug.)		2.78		2.2
	(Rain—Sept.)		10.90		4.9
10/24-10/29/49	8th Irr.	91.4	5.34	33	1.8
	(Rain—Oct.)		4.57		2.0
11/18-11/19/49	9th Irr.	80.0	4.67	39	1.8
	(Rain—Nov.)		0.87		0.9
12/5-12/9/49	10th Irr.	95.3	5.56	47	2.6
12/29-12/30/49	11th Irr.	116.4	6.79	22	1.5
	(Rain—Dec.)		1.74		1.7
1/23-1/25/50	12th Irr.	95.0	5.54	76	4.2
	(Rain—Jan.)		0.65		0.6
2/14-2/15/50	13th Irr.	84.8	4.89	33	1.6
	(Rain—Feb.)		0.94		0.9
3/1-3/6/50	14th Irr.	81.6	4.77	31	1.5
3/18-3/21/50	15th Irr.	86.4	5.04	31	1.6
	(Rain—Mar.—None)				
	(Rain—April)		2.62		2.3
Soil moisture depletion over season (harvest May 1, 1950)					2.6
Total use for season (441 days) = 0.12 inches/day average					53.6

* Estimated.

any daily rainfall in excess of one inch a high percentage was lost by surface runoff or by subsoil seepage unless the soil was very dry, the "effective"

TABLE 4d

Total Water Applications—Destino #55

(Planted April 4-6-49—BH 10-12—Area 9.09 acres)

Date	Application	Total (Acre-Inches)	Depth Applied (Inches)	Water Appl. Eff. (Percent)	Amount Retained
4/6-4/10/49	1st Irr.	75.5	8.30		
4/19-4/20/49	2nd Irr. (Apr.—no rain)	38.5	4.23	30*	1.3
5/5-5/6/49	3rd Irr.	48.1	5.29	16	1.0
5/17-5/18/49	4th Irr.	46.5	5.11	14	0.7
5/31-6/1/49	5th Irr.	51.0	5.54	18	1.0
	(Rain—May)		1.55		1.6
6/9/49	6th Irr.	44.7	4.92	15	0.7
	(Rain—June)		4.05		3.4
7/4-7/6/49	7th Irr.	78.0	8.58	22	1.9
	(Rain—July)		4.85		3.3
8/1-8/3/49	8th Irr.	104.0	11.44	18	2.1
	(Rain—Aug.)		8.10		4.3
9/16-9/19/49	9th Irr.	120.0	13.20	17	2.2
	(Rain—Sept.)		10.55		4.3
10/27-10/29/49	10th Irr.	128.2	14.10	18	2.5
	(Rain—Oct.)		4.80		2.8
11/10-11/11/49	11th Irr.	90.0	9.90	9	0.9
11/29-11/30/49	12th Irr.	82.0	9.02	15	1.4
	(Rain—Nov.)		1.20		1.2
12/20-12/21/49	13th Irr. (Dec.—No rain)	80.0	8.80	21	1.8
1/21-1/23/50	14th Irr.	90.0	9.90	26	2.6
	(Rain—Jan.)		0.85		0.8
2/15-2/16/50	15th Irr.	75.0	8.25	24	2.0
	(Rain—Feb.)		1.20		1.2
3/10-3/11/50	16th Irr.	121.50	13.37	23	3.1
	(Rain—Mar.) (None)				—
4/4-4/5/50	17th Irr.		13.3	20	2.7
4/21-4/22/50	18th Irr.		8.0	25	2.0
	(Rain—April)		1.2		1.2
5/12-5/13/50	19th Irr.		9.1	25	2.3
	(Rain—May)		1.9		1.9
Soil moisture depletion over season (harvest June 2)					2.7
Total use for season (423 days) = 0.14 inches/day average					60.9

* Estimated.

rainfall over any period can be closely estimated. This is the procedure which was used to evaluate effective rainfall. The maximum possible error is, of course, relatively small over the entire season.

TABLE 4e

Total Water Applications—Destino 14–15

(Planted March 24–26, 1949—P.O.J. 2878—Area 10.40 acres)

Date	Application	Total (Acre-Inches)	Depth Applied (Inches)	Water Appl. Eff. (Percent)	Amount Retained
3/26–3/27/49	1st Irr.	28.0	2.70		
4/11–4/12/49	2nd Irr.	17.6	1.69	50*	0.8
4/25/49	3rd Irr.	17.0	1.64	53	0.9
	(Rain—April)		0		0
5/17/49	4th Irr.	24.0	2.31	70	1.6
5/29/49	5th Irr.	24.0	2.31	48	1.1
	(Rain—May)		1.32		1.3
6/17/49	6th Irr.	48.0	4.62	37	1.7
6/28–6/29/49	7th Irr.	38.0	3.66	50*	1.8
	(Rain—June)		3.95		3.0
7/12–7/13/49	8th Irr.	28.5	2.74	53	1.4
7/28–7/29/49	9th Irr.	35.5	3.42	50*	1.7
	(Rain—July)		4.51		3.7
	(Rain—Aug.)		7.83		4.2
9/20–9/21-49	10th Irr.	48.9	4.71	50*	2.4
	(Rain—Sept.)		10.13		4.1
10/27–10/29/49	11th Irr.	60.0	5.78	48	2.8
	(Rain—Oct.)		3.73		2.4
11/14–11/15/49	12th Irr.	55.0	5.29	23	1.2
11/29–11/30/49	13th Irr.	45.0	4.33	50	2.2
	(Rain—Nov.)		1.06		1.1
12/15–12/16/49	14th Irr.	48.0	4.62	50	2.3
	(Rain—Dec.)		1.01		1.0
1/12–1/13/50	15th Irr.	68.5	6.59	48	3.1
	(Rain—Jan.)		0.86		0.9
2/4–2/5/50	16th Irr.	66.0	6.36	47	3.0
2/22–2/23/50	17th Irr.	72.0	6.94	25	1.7
	(Rain—Feb.)		1.95		1.9
3/21–3/23/50	18th Irr.	81.0	7.80	50	3.9
	(Rain—Mar.)		0.29		0.3
4/13–4/14/50	19th Irr.		6.07	50*	3.0
	(Rain—Apr.)		0.89		0.9
Soil moisture depletion over season (harvest 6–2–50)					2.4
Total use for season (434 days) = 0.15 inches/day average					63.8

* Estimated.

Consumptive Use in Fields

Tables 4a to 4h, inclusive, show the details of water applied and used in each of the fields. The usable water listed in column 6 of these tables was computed from the water application efficiency in the case of irrigation

TABLE 4f

Total Water Applications—Paso Seco

(Planted March 31-April 5, 1949—BH 10-12—Area 12.55 acres)

Date	Application	Total (Acre-Inches)	Depth Applied (Inches)	Water Appl. Eff. (Percent)	Amount Retained
4/2-4/5/49	1st Irr.	26.0	2.07		
4/13/49	2nd Irr.	25.6	2.04	80*	1.7
4/26/49	3rd Irr.	19.2	1.53	80*	1.2
	(April—No rain)				
5/6/49	4th Irr.	16.0	1.27	80*	1.0
5/20-5/21/49	5th Irr.	22.0	1.75	99	1.7
	(May—Rain)		1.55		1.5
6/2/49	6th Irr.	24.5	1.95	59	1.1
6/14-6/15/49	7th Irr.	37.2	2.97	85	2.5
6/21/49	8th Irr.	24.5	1.95	80*	1.6
	(June—Rain)		4.05		3.4
7/6-7/7/49	9th Irr.	38.5	3.07	86	2.6
7/15-7/16/49	10th Irr.	42.0	3.35	50	1.7
	(July—Rain)		4.85		3.6
	(Aug.—Rain)		8.10		4.6
9/2/49	11th Irr.	24.0	1.91	32	0.6
9/13-9/14/49	12th Irr.	60.0	4.89	46	2.2
	(Sept.—Rain)		10.55		4.0
10/5-10/6/49	13th Irr.	63.7	5.07	60*	3.0
10/21-10/22/49	14th Irr.	48.0	3.82	70	3.7
	(Oct.—Rain)		4.80		3.1
11/3-11/4/49	15th Irr.	48.0	3.82	45	1.7
11/18-11/19/49	16th Irr.	55.0	4.38	45	3.0
	(Nov.—Rain)		1.20		1.2
12/5-12/6/49	17th Irr.	63.0	5.01	75	3.8
12/20-12/21/49	18th Irr.	62.5	4.98	57	2.8
	(Dec.—No Rain)				
1/11-1/12/50	19th Irr.	60.0	4.78	74	3.5
1/21-1/23/50	20th Irr.	63.0	5.01	62	3.1
1/28-2/1/50	21st Irr.	60.0	4.78	19	0.9
	(Jan.—Rain)		0.85		0.8
2/15-2/16/50	22nd Irr.	56.0	4.46	50	2.2
2/27/50	23rd Irr.	50.0	4.00	37	1.5
	(Feb.—Rain)		1.20		1.2
3/13/50	24th Irr.	50.0	4.00	50*	2.0
3/22/50	25th Irr.	50.0	4.00	38	1.5
	(Mar.—Rain—*None*)				0
4/1/50	26th Irr.	50.0	4.00	53	2.1
4/13/50	27th Irr.		4.00	40*	1.6
4/21/50	28th Irr.		4.00	30*	1.2
	(Apr.—Rain)		1.20		1.2
Soil moisture depletion over season (harvest 5/9/50).....................					4.1
Total for season (404 days)... = 0.20 inch/day average					82.2

* Estimated.

TABLE 4g

Overhead Riser 26—Water Applied

(Planted May 9, 1949—P.O.J. 2878—Area 2.50 acres)

Date	Depth Applied (Inches)	Date	Depth Applied (Inches)	
5/10/49		1/31/50	0.93	
5/12/49	0.42	2/9/50	0.95	
5/17/49	0.80	2/15/50	0.93	
5/24/49	0.90	2/22/50	0.95	
5/27/49	0.90	2/24/50	0.98	
5/30/49	0.80	3/1/50	0.93	
6/2/49	1.00	3/7/50	0.95	
7/1/49	0.90	3/9/50	1.00	
7/5/49	1.02	3/15/50	0.98	
7/12/49	1.02	3/21/50	1.00	
7/18/49	1.08	3/29/50	1.00	
8/4/49	1.02	April (None)		
8/10/49	1.05	May	0.95	
8/19/49	1.05	June	0	
9/16/49	0.30			
9/20/49	1.10	Total	38.17	
10/20/49	0.90			
10/26/49	1.02		*Rainfall*	
11/2/49	1.05			
11/8/49	1.06			*Est. Use*
11/19/49	0.90	May 9–30	1.05	1.0
11/25/49	0.90	June	3.15	2.2
11/30/49	0.98	July	3.55	3.0
12/6/49	1.00	August	3.14	2.7
12/8/49	0.50	September	9.39	5.0
12/20/49	0.95	October	3.65	2.6
12/28/49	0.95	November	1.05	1.0
1/11/50	1.00	December	1.92	1.9
1/19/50	0.95	January	0.50	0.5
1/25/50	1.00	February	0.97	2.0
		March		0
		April	2.90	2.9
		May	2.10	2.1
		June	2.80	2.8
				28.7

Since average efficiency is 77%

Total water used (irrigation) = .77 × 38.07 = 29.3

Rain used 28.7

58.1

Plus depletion at end 1.4

Total 59.5

Average: 59.5 = 0.15 inch/day

40.6

TABLE 4h

Overhead Riser 31—Water Applied

(Planted May 9, 1949—P.O.J. 2878—Area 2.5 acres)

Date	Depth Applied (Inches)	Date	Depth Applied (Inches)	
5/9/49		1/25/50	0.99	
5/10/49		1/31/50	0.90	
5/12/49	0.40	2/9/50	0.93	
5/17/49	0.80	2/15/50	0.90	
5/23/49	0.82	2/22/50	0.93	
5/27/49	0.90	2/24/50	0.95	
5/30/49	0.79	3/1/50	0.93	
6/2/49	1.00	3/7/50	0.93	
7/1/49	0.90	3/9/50	0.93	
7/6/49	1.00	3/16/50	0.95	
7/12/49	1.00	3/21/50	0.98	
7/18/49	1.05	3/28/50	0.95	
8/4/49	1.00	May	0.93	
8/10/49	1.00			
8/19/49	1.00	Total	38.13	
9/16/49	1.08			
9/20/49	1.10			
10/20/49	0.90		*Rainfall*	
10/26/49	1.00			
11/2/49	1.05			*Est. Use*
11/8/49	1.05	May 9–30	1.05	1.0
11/19/49	0.90	June	3.15	2.2
11/25/49	0.90	July	3.55	3.0
11/30/49	0.95	August	3.14	2.7
12/6/49	0.99	September	9.39	5.0
12/7/49	0.50	October	3.65	2.6
12/20/49	0.95	November	1.05	1.0
12/28/49	0.95	December	1.92	1.9
1/11/50	1.00	January	0.50	0.5
1/19/50	0.90	February	0.97	1.0
		March	0.00	0.0
		April	2.90	2.9
		May	2.10	2.1
		June	2.80	2.8
				28.7

Ave. efficiency—72%; water used = 38.13 × .72 = 27.5
Plus rain 28.7
Plus depl. over season 2.6

58.8

Use per day = $\frac{58.8}{40.6}$ = 0.15

water, and the rainfall evaluation described above in the case of monthly rainfall. Due to the large number of applications of water to Fields G and H, computation of usable water for each application was not made, but the average water application efficiency as determined above was used to compute the irrigation water used over the season. Effective rainfall was evaluated as before.

Fertilizer Practices in Fields

In fields, the standard treatments with fertilizer were as follows:

10–6–8 fertilizer at time of planting—400 pounds per acre.

Ammonium sulphate, 6 weeks after planting—600 pounds per acre.

TABLE 5

Summary of Sugar Cane Yields and Consumptive Use of Water in Fields at Aguirre

Field Name	Total Water Applied	Soil Moisture Deficit at Harvest	Total Consumptive Use	Length of Season	Yield		Water Use Per Day	Water Use Per Ton Green Cane	Water Use per Ton Sugar	Water use per day	
					Green Cane	Sugar				Per Ton Green Cane	Per Ton Sugar
	Inches	*Inches*	*Inches*	*Days*	*Tons per Acre*		*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Bernard	61.4	3.8	65.2	406	33.3	5.1	0.16	1.95	12.8	0.0048	0.032
Carmen	55.3	5.1	60.4	423	47.3	6.3	0.14	1.28	9.6	0.0030	0.023
Juana Diaz	51.0	2.6	53.6	441	39.8	5.1	0.12	1.35	10.5	0.0031	0.024
Destino 14–15	61.4	2.4	63.8	434	50.5	7.3	0.15	1.27	8.7	0.0029	0.020
Destino 55	58.2	2.7	60.9	423	48.9	6.4	0.14	1.25	9.5	0.0029	0.023
Paso Seco	78.1	4.1	82.2	404	38.7	4.8	0.20	2.10	17.1	0.0053	0.042
Overhead 26	58.1	1.4	59.5	406	46.8	5.4	0.15	1.27	11.0	0.0031	0.027
Overhead 31	56.4	2.6	58.8	406	46.8	5.4	0.15	1.26	10.9	0.0031	0.027

This treatment amounts to about 160 pounds per acre of nitrogen, the nutrient which experiments have shown to be the main nutrient limitation.

The field fertilization appears to assure a reasonably high nutrient supply for the crop in the soils represented, which are relatively fertile (See Table 3).

Cane Yields in Fields

Table 5 summarizes cane yields along with water use information on the several fields. Six of the eight fields checked rather closely in average water use per day as well as in use per ton of cane or per ton of sugar. It is interesting that the 2 fields which gave the lowest efficiency of water use also gave the lowest yields. This may indicate that too much water was applied and was actually harmful to growth; or it might indicate that the more vigorous crops were actually more efficient in water use. At least, a poor crop appears to be wasteful of water.

TANK STUDIES

Sugar cane in this study was grown in twelve double-walled lysimeter tanks similar to those used by Blaney, et al (3, 4) in Western United States investigations The tanks were constructed of 18 gauge sheet metal. The inner tank was 3 feet in diameter and 4 feet deep with a removable bottom and drainage holes in sides and bottom to allow free passage of water into the outer tank. The outer tank was water-tight, 3 inches larger diameter and 3 inches deeper than the inner one. Thus free drainage was provided, yet all of the drainage water was collected and measured.

The tanks were filled with undisturbed field soil, all from the same area, by setting the inner tank, with bottom removed, over the desired soil area and excavating a trench around the tank. By excavating close to the tank, its own weight tended to move the tank downward encircling the soil column. Extra weights were used as required. When the soil was completely enclosed by the tank the bottom was jacked into place under the tank and bolted there. The tank with soil column enclosed was then lifted by a large crane into a truck and hauled to the area where the outer tanks had already been buried flush with the ground surface. The inner tank with soil was then suspended in the outer one leaving a space between the sides and bottoms of the two tanks. Cane variety BH-10-12 was planted in the tanks as in the fields with care to obtain a dense uniform stand. The initial stand was more than double that of the fields. This permitted self pruning to operate and to establish the maximum stand which the conditions would support.

Cane was also planted in the area surrounding the tanks to give uniform boundary conditions to the cane growing in the tanks.

Soil moisture levels in the tanks were controlled by mercury tensiometers and nylon resistance blocks within the following ranges:

Treatment A—(3 tanks) Tanks irrigated to field capacity when dried out to a moisture tension of one third atmosphere at 6 to 8 inches depth.

Treatment B—(3 tanks) Tanks irrigated to field capacity when dried out to a soil moisture tension of about two atmospheres at 6 to 8 inches depth.

Treatment C—(3 tanks) Tanks irrigated to field capacity when dried out to a soil moisture tension of about 6 atmospheres at 6 to 8 inches depth.

Treatment D—(3 tanks) Tanks irrigated to field capacity when dried out to a soil moisture tension of about 12 atmospheres tension.

The differential moisture treatments and accurate measurements of water applications were delayed until the cane had been growing for almost two months. This enabled the cane to attain rather uniform growth in the early stages.

Daily readings of the tensiometers and moisture blocks were made each morning. Amounts of water added or drained were recorded daily. In order to evaluate climatic effects, a complete weather station, including standard evaporation pan, anemometer, hygrothermograph, standard and automatic rain gage and maximum-minimum thermometers, was established at the tank station. Observations were made daily at the weather station.

TABLE 6

Some Chemical Data for the Santa Isabel Clay Soil Used in Consumptive Use Tanks at Aguirre

PART I

Original Data on Profile Samples Taken in the Field at the Location Where Tanks were Filled

Depth Inches	pH		Total N		Organic Matter		C-N Ratio		Total Bases* me/100 gms	
	South End	North End	South	North	South	North	South	North	South	North
			%	%	%	%				
0–12	7.9	7.7	0.13	0.14	2.3	2.5	10	10	43	43
12–18	7.7	7.7	0.06	0.06	0.8	0.9			53	44
18–40	7.7	7.6	0.04	0.03	0.5	0.3			45	36
40–48	7.9	7.5	0.02	0.03	0.3	traces			45	34

PART II†

Tests of Surface Soil in Three Consumptive Use Tanks in Cane

(Sampled in Summer of 1949 before Second Application of Fertilizer)

Tank	pH	Exch. Cap. me/100 gms	Organic matter	Ca	K	Mg	P	Total N
			%	*ppm*	*ppm*	*ppm*	*ppm*	%
9	7.2	31	3.0	4860	145	535	90	0.12
3	6.8	26	2.3	4570	160	500	46	0.11
2	7.0	20	2.1	3980	170	410	70	0.12
Approx. Av.........	7.0	26	2.5	4500	160	475	70	0.12

* By the modified Kappen and equilibrium method.

† Data supplied by the Soils Department of the Insular Agricultural Experiment Station.

Soil in the Consumptive-use Tanks

The soil used for filling the tanks was described and sampled in the field in the pits formed by removing the tanks. It conforms well with the description of Santa Isabel clay by Roberts (15). The surface soil contained a small amount of sand not always seen in this soil type. The gravel layer started at a depth varying from about 15 to about 30 inches, representing the main difference among individual tanks, but no relation was found between cane growth and this difference in depth to gravel. Free lime was found at from 26 to 48 inches in the profile. Figure 1 shows average pF curves for surface and for subsoil (excluding subsoil gravel). Table 6 shows some chemical data for the surface foot (plow layer). The pF curves indicate low permanent available water-holding capacity in the pF range from

TABLE 7

The salt status of consumptive use tanks at the end of the first year's growth of cane

Moisture treatment	Tank	Irrigation water added	Total salts in water added*	A Total salts added to soil	B Salts found in soil	Difference A–B
	No.	*Inches*	*Tons per acre*	*ppm for soil*	*ppm in soil*	*ppm in soil*
A	1	103.5	7.1	605	265	+340
	5	66.3	4.5	383	330	+ 53
	9	66.7	4.5	383	320	+ 63
B	3	46.8	3.2	272	275	− 3
	6	32.2	2.2	187	330	−143
	10	66.7	4.5	383	365	+ 18
C	2	19.8	1.4	119	290	−171
	8	29.3	2.0	170	210	− 40
	11					
	11	40.5	2.8	238	280	− 52
D	4	19.5	1.3	110	135	− 25
	7	24.3	1.7	145	180	− 35
	12	23.0	1.6	136	220	− 84

* Assuming that average salt content of water was 600 ppm, as determined on two sampling dates.

2.7 to 4.2. Soil from tank 10 gave higher soil moisture contents at particular tension values at each moisture sampling than did other tanks. This may explain why tank 10 gave such excellent cane compared to the other two tanks with the same moisture tension control. There was apparently no period when the cane in this tank failed to get water fast enough, although the cane in the two replicate tanks suffered and some of it died.

Fertilization of Tanks

In order to eliminate nutrient limitations insofar as possible, a double rate of fertilizer was applied to the tanks. Both the normal mixed fertilizer and the ammonium sulphate treatments were repeated after about 4

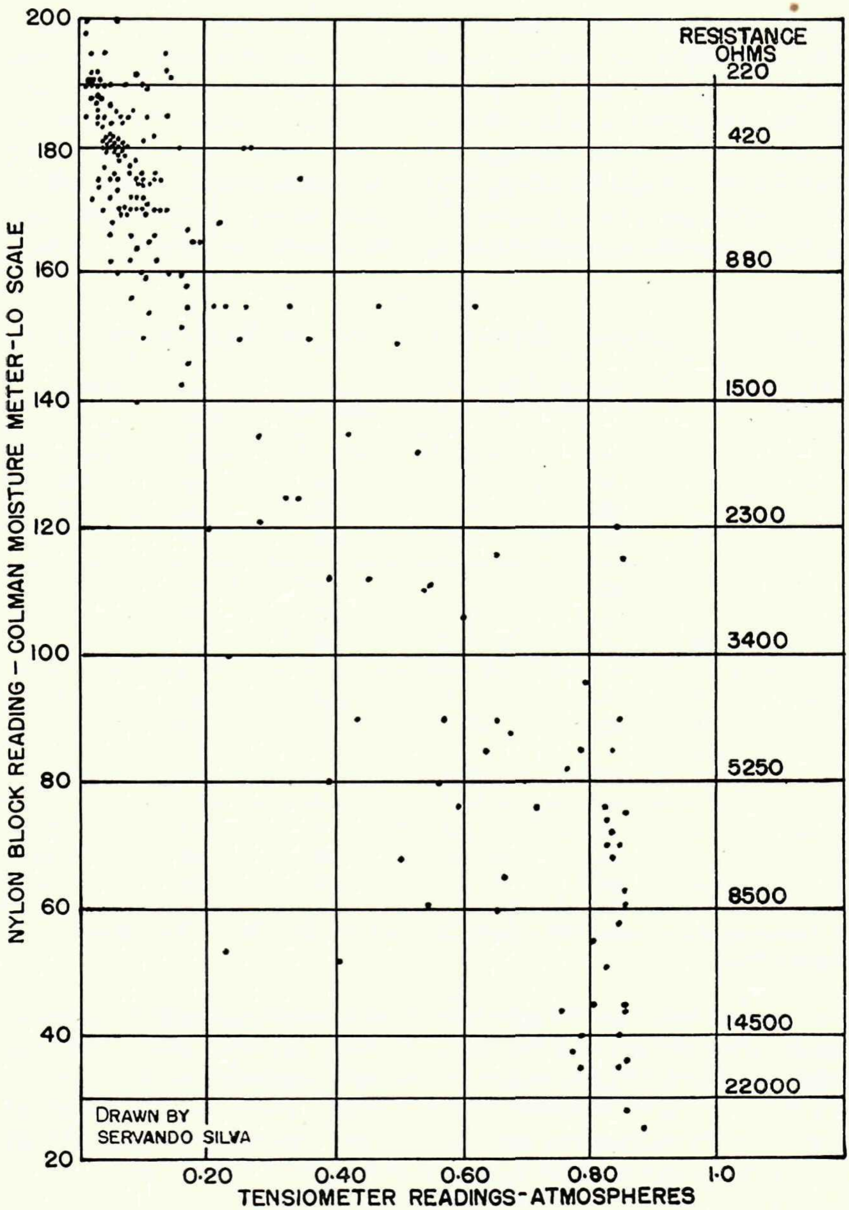

FIG. 6. Relation between tensiometer and nylon block readings in consumptive use tanks growing cane at Aguirre, during the early part of the experiment, August 1949.

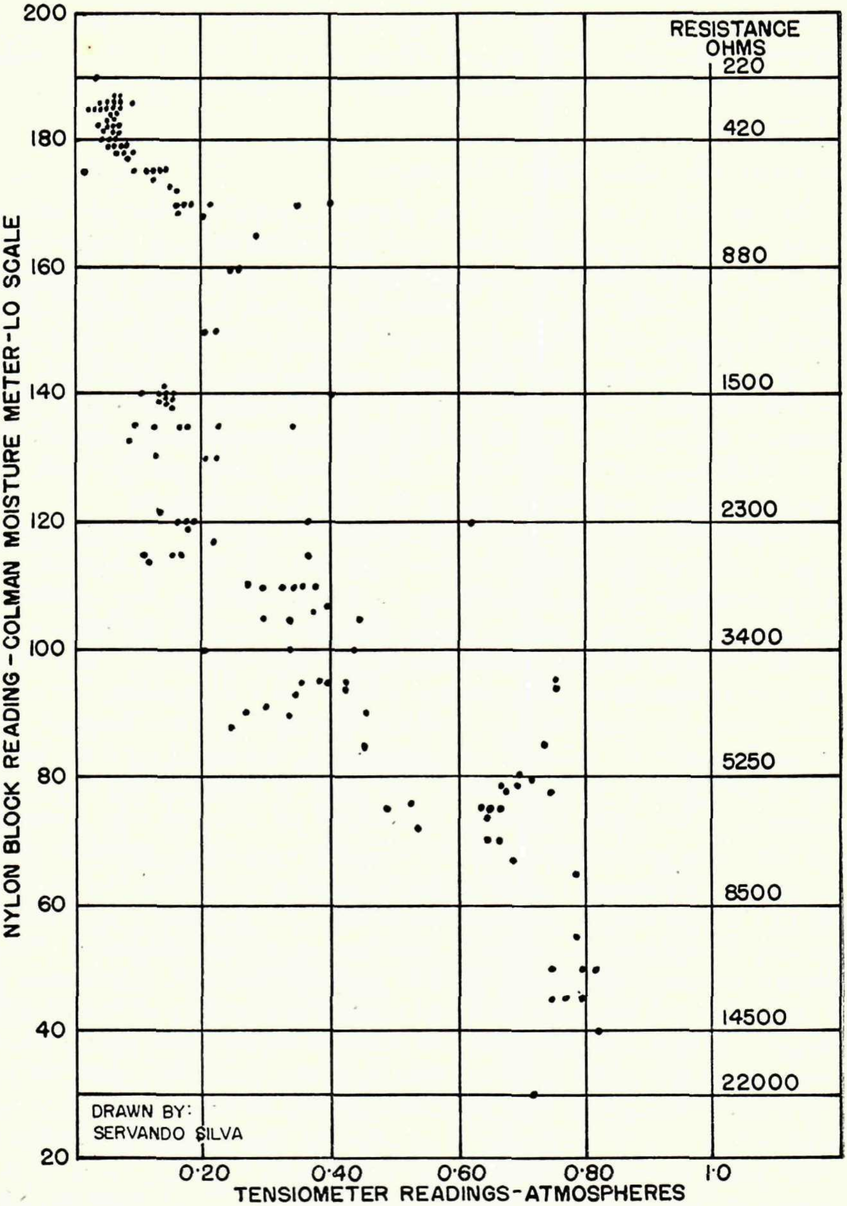

FIG. 7. Relation between tensiometer and nylon block readings in consumptive use tanks growing cane at Aguirre, during the last part of the experiment, April 15 to May 18, 1950, after salts had been somewhat increased by a season of irrigation without leaching. (Compare with Figure 6.)

months of cane growth. Thus, the tanks received nitrogen at the rate of 320 pounds per acre, and P_2O_5 and K_2O at 48 and 64 pounds, respectively. Some chemically available nutrients and other soil features are shown in Tables 3 and 6.

Tensiometer-Resistance Block Calibrations

One valuable result obtained from the tank studies was the relationship found to exist between readings on tensiometers and Bouyoucos type nylon resistance blocks buried at the same depth. A Colman type electrical soil moisture meter was used for the resistance readings. Figures 6 and 7 show this relationship and indicate that within the salt limits represented (Table 7), the nylon blocks can be used with reasonable accuracy to follow soil moisture tension changes over the entire soil moisture range from 0 to 15 atmospheres. Resistance blocks used in the past (primarily gypsum blocks) have been mainly limited to use in the tension range greater than one atmosphere, lacking in sensitivity in the high moisture range.

It should be noted that the blocks were not calibrated in the laboratory against soil moisture. Experience has indicated that the readings may be changed considerably by handling or squeezing, but that once a block is installed in the soil the readings are rather consistent with the corresponding soil moisture tension. Block failures are fairly common. Our practice has been to remove and discard any blocks which start giving erratic or unreasonable readings. Since repeated sampling of soil from the tanks for soil moisture would have had a serious effect on the relatively small quantity of soil present, little attempt was made to calibrate the blocks or tensiometers by direct sampling. Laboratory pF analyses were made on soil cores obtained at the site where the tanks were filled, and these data, together with a few sets of soil moisture samples taken from the tanks at the end of the season, provided information for calibration with actual amount of moisture present for a given tension or block resistance. These average data were used to draw the field pF curve of figure 1. It is interesting to note that the laboratory pF curve and field data are at considerable variance. In fact, it appears that the moisture control limits set for irrigation, which were based upon the laboratory curve, actually were not too well-chosen because the field data showed that normal filling of the soil pores resulted in very little water available in the range of soil moisture above one atmosphere of tension (See pF curve, Figure 1). It is in this range that three of the moisture control treatment limits were set. This may account for the damage suffered in most of the tanks—even possibly in the "B" treatment. Any slight soil difference or error in block readings could have actually allowed the soil moisture tension to approach the wilting point a short time after the actual 2-atmosphere tension was reached. Another interesting fact noted with the tension readings was that, in most cases, the soil moisture was largely depleted from the upper soil before any considerable draft on the lower layers was evident. The water use with depth is roughly proportional to the relative quantities of roots, approximately 75% to 80% of which are in the surface 12 inches.

Consumptive Use in Tanks

Table 8 gives a breakdown of use by months for each of the tanks. There is appreciable error in the determination of the monthly figures,

TABLE 8

Monthly consumptive use of water in inches by sugar cane in tanks at Aguirre, Puerto Rico

1949–1950 Month	Treatment A				Treatment B				Treatment C				Treatment D			
	1	5	9	Ave. "A"	3	6	10	Ave. "B"	2	8	11	Ave. "C"	4	7	12	Ave. "D"
Apr. 13–May 31*	16.10	16.10	16.10		15.50	15.50	15.50		13.40	13.40	13.40		13.20	13.20	13.20	
June	7.49	9.34	11.25	9.36	11.50	12.90	11.76	11.78	9.03	10.75	10.75	9.32	7.90	9.34	8.32	8.52
July	13.13	10.89	10.05	11.02	8.55	7.43	7.54	7.84	7.31	8.95	6.72	7.66	8.25	7.71	8.93	8.30
August	14.71	12.38	11.92	12.39	11.00	9.69	10.02	10.27	7.31	10.97	10.22	9.50	9.39	8.81	10.25	9.48
September	12.62	10.10	10.08	10.58	9.48	9.75	10.34	9.52	7.57	6.98	8.21	7.59	6.54	7.81	8.26	7.54
October	11.56	9.87	7.02	9.48	6.79	8.42	6.75	7.32	6.33	6.70	7.23	6.75	4.46	8.12	5.31	5.96
November	14.83	13.79	12.17	13.60	11.65	8.94	11.26	10.62	3.93	4.01	8.26	5.40	5.36	4.76	5.44	5.19
December	19.90	10.87	9.65	13.47	6.55	6.86	10.72	8.04	3.52	4.70	7.55	6.26	4.13	2.87	3.15	3.38
January	16.40	7.64	7.37	10.47	6.00	4.77	9.11	6.63	3.61	2.30	7.15	4.35	2.67	3.40	3.95	3.34
February	9.76	4.87	6.61	7.08	3.10	2.00	7.66	4.25	2.84	1.96	2.80	2.53	1.90	3.48	1.57	2.32
March	10.75	6.08	8.63	8.06	2.54	2.23	9.60	4.79	1.41	2.69	4.62	2.91	1.89	1.63	1.30	1.61
April 1–4	3.22	1.41	2.81	2.48	1.06	0.75	3.44	1.75	0.54	1.40	0.61	0.85	0.84	0.13	0.34	0.44
Total	150.47	113.34	113.66		93.78	89.24	113.70		66.80	76.30	87.52		66.53	71.26	70.02	
Av. per day	0.41	0.31	0.31		0.26	0.24	0.31		0.18	0.21	0.24		0.18	0.20	0.19	

* Approximation for the first 48 days.

since the holdover at the end of each month had to be calculated from block and tensiometer readings as related to moisture capacity. However, it is important to realize that this error is not reflected in a like cumulative error in the total amount of water used over several months or for the season: seasonal totals and consistent trends are quite accurate.

Figure 8 indicates that total yield and total water use seem to be related so long as the cane received enough water to keep it alive. Also, it is evident that yield per inch of water use was higher for moist or dry treatments than for the wet, so long as the soil moisture stayed above the point at which canes are damaged and start to die. In both the moist and the dry treatments the canes were damaged in 2 tanks at some time during the season and the crop did not recover. However, in the one healthy, undamaged tank in each of these treatments the yield was high and more

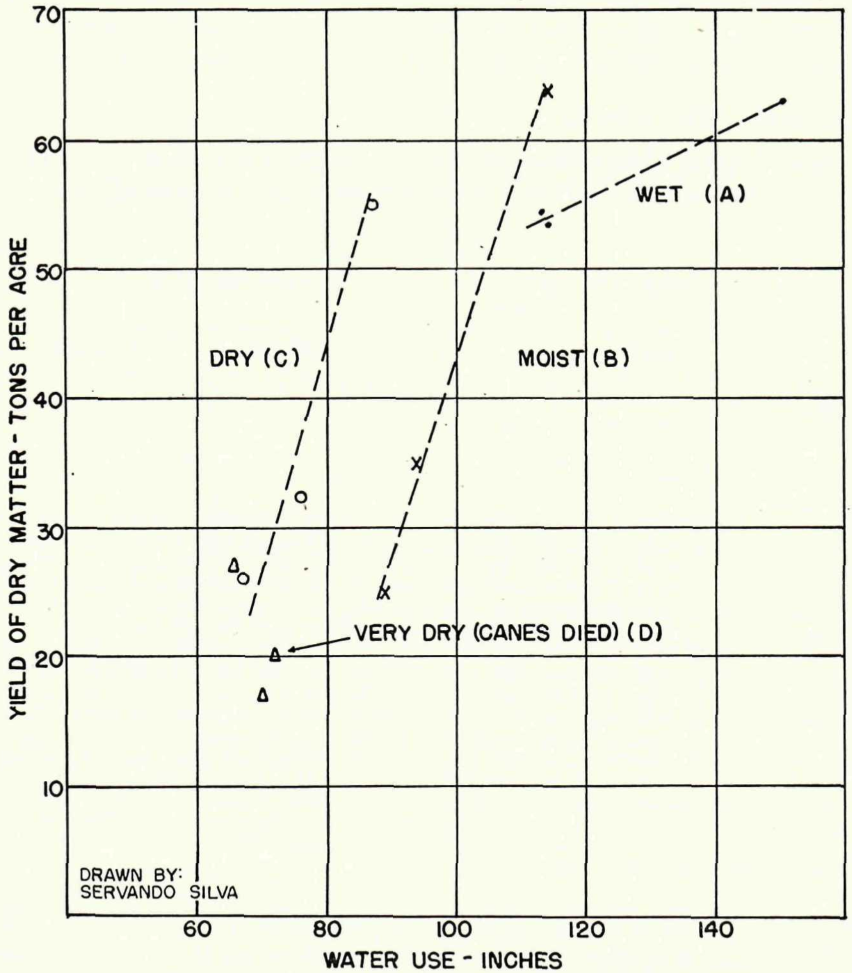

FIG. 8. The relation between water use by cane and total yield of dry matter in consumptive use tanks under four different soil moisture treatments, showing that total water use and total yield are closely related except in the very dry treatment, where practically all canes died after about 6 months. All tanks were heavily treated with mixed fertilizer including N at 320 lbs. per acre. Total dry matter yields (including leaves) are about two thirds of the yield weight of green cane.

efficient than in the wet tanks. There is no proof of any benefit from wetness (low soil moisture tensions) except to supply water at a fast enough rate to avoid damage to plant protoplasm.

Evaporation from Fallow Soil

After the cane in the tanks was harvested, the soil was kept bare to provide information about evaporation losses. The most accurate values are obtained by considering two individual tanks where the soil moisture guide readings were most consistent, and three tanks where free water levels were maintained continuously.

Evaporation calculations for these tanks during May, June, and July, follow:

Tank No. 1: $9.6''$ (Rainfall)—$1.0''$ (Fill)* $= \dfrac{8.6''}{90 \text{ days}} = 0.094''$ per day

Tank No. 10: $9.6''$—$2.6''$ (Fill)* $= \dfrac{7.0''}{90 \text{ days}} = 0.078''$ per day

Ave. of 3† tanks: water level maintained continuously at 30″ below the surface. $9.6'' - 1.0''$ (Fill)* $= \dfrac{8.6''}{90 \text{ days}} = 0.094''$ per day

The soil moisture content of tanks number 1 and 10 was continuously high, and was seldom below essential field capacity at 6 inches below the surface. For soil at or near field capacity, therefore, the average daily evaporation for May, June and July was from 0.078″ to 0.094″ per day. Open pan evaporation for the same period was about 0.26″ per day.

For the period from May 27 to July 31, in tanks with free water at 30″, the loss by evaporation was slightly more than rainfall, which was 0.064″ per day. Soil moisture tension remained below 1 atmosphere at the 6″ depth at all times.

For moderately dry soil the evaporation per day is certainly no more than 0.05″ per day if exposed, and much less if shaded. Evaporation is insignificant with shade by good plant cover.

In tanks D the April water use was about 0.03″ per day with all canes dead and for Treatment C—0.05″ per day with most canes dead. The soil averaged well below field capacity in these cases.

From these results it appears that 0.1 inch per day is about the highest evaporation loss which need be expected from bare soil over any considerable period of time. This much loss will occur only when the surface soil moisture is maintained continuously near the maximum field holding capacity. At average, normal field ranges of soil moisture, evaporation from bare soil would be close to 0.06 inches per day, and in the lower range of available water the losses would be 0.03 inches per day or less. Any shade by a crop would greatly reduce these values, in approximate propor-

* "Fill" in soil pores represents water held at end of period in excess of that held at the beginning, based on tensiometer and block readings.

† Tanks number 4, 7, and 12. Water was added to the outer tanks as required to maintain the water level at essentially 30 inches from the ground surface.

tion to the percentage of the ground covered with shade. Under more or less complete shade the losses of water by evaporation would clearly be insignificant. In considering total evapotranspiration losses with sugar cane, it appears that transpiration of a crop with at least several months of growth will be about three times the normal evaporation from bare moist soil. During the first two or three months of sugar cane growth,

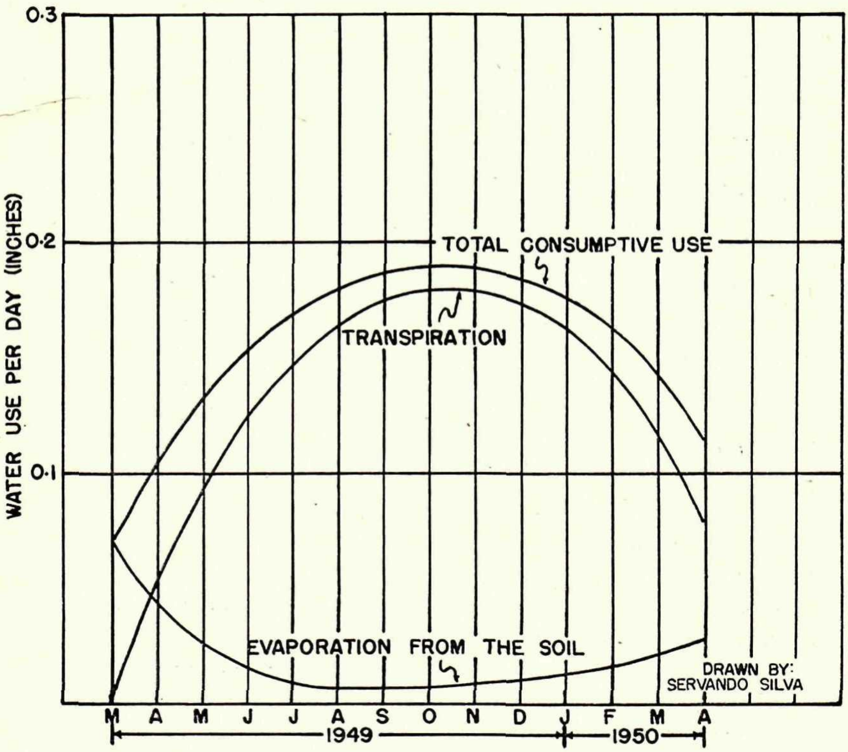

FIG. 9. Approximate, general representation of the apparent relations between evaporation, cane transpiration, and total consumptive use of water during a year of growth of cane planted in March.

evaporation may amount to as much as one-half of the total consumptive use of water. As shade by the crop increases, evaporation decreases, but the decreased evaporation is not enough to balance the increased transpiration by the cane. Thus the total consumptive use increases and reaches a maximum during the period when all of the soil is shaded and evaporation is insignificant. The decreased evapotranspiration toward the end of the season is primarily a matter of ripening of the cane. Some soil probably becomes exposed to sunlight, enough to give perhaps a few hundredths of an inch of evaporation per day, but this is not enough to prevent the marked downward trend with maturity of the crop. Excess irrigation near the end of the season may contribute to the significance of evaporation losses during this period. Figure 9 shows the apparent normal seasonal trends in evaporation, transpiration and total consumptive use.

TABLE 9

Summary of consumptive use of water and sugar cane yields in tanks at Aguirre, Puerto Rico

Tank	Total consumptive use	Length of season	Use per day	Yields		Use per ton		Use per day per ton	
				Green cane	Sugar	Green cane	Sugar	Green cane	Sugar
	Inches	*Days*	*Inches*	*Tons per acre*		*Inches*	*Inches*	*Inches*	*Inches*
Treatment A									
1	150.5	365	0.41	109	17.4	1.38	8.6	0.0038	0.024
5	113.3	365	.31	92	14.9	1.23	7.6	.0034	.021
9	113.7	365	.31	79	12.7	1.44	9.0	.0039	.024
Av. A	126.0	365	.35	93	15.0	1.35	8.4	.0037	.023
Treatment B									
3	93.8	365	.26	54*	4.6	1.73	20.4	.0048	.056
6†	89.2	365	.24	39*	3.4	2.29	26.2	.0062	.071
10	113.7	365	.31	106	17.1	1.07	6.7	.0029	.018
Av. B	99.0	365	.27	62	8.4	1.60	11.8	.0044	.032
Treatment C									
2	66.8	365	.18	40*	4.6	1.67	14.5	.0045	.039
8	76.3	365	.21	49*	5.6	1.56	13.6	.0043	.038
1	87.5	365	.24	56	10.2	1.56	8.6	.0043	.023
Av. C	77.0	365	.21	50	6.8	1.56	11.3	.0042	.031
Treatment D									
4	66.5	365	.18	42*	4.0	1.58	16.6	.0043	.045
7	71.3	365	.20	31*	3.4	2.30	21.0	.0065	.059
12	70.0	365	.19	27*	2.5	2.60	28.0	.0070	.076
Av. D	69.0	365	.19	33	3.3	2.10	20.9	.0059	.059

* Calculated from the total dry weight, assuming that green cane was 65% of total dry matter, because a part or all of the canes were dead at harvest in these tanks.

† Severe early damage by stalk borers in this tank.

FIELD AND TANK GROWTH AND YIELDS IN RELATION TO WATER USE

Tables 5 and 9 summarize yields as well as water use. Figure 10 shows some general relations between tank yields and moisture treatments which may help to explain what actually took place. Both green cane and sugar yields increased with increasing wetness. In the case of green cane, the average increase is from 0 to 93 tons per acre. With sugar, although all canes finally died in the D treatment, there was considerable yield from dry stalks of very low quality. Also with total dry weight the yield increased with wetness, but to a much less degree than with sugar or green cane. This, of course, is consistent with the fact that considerable dry matter grew before the plants were actually killed by an extreme lack of water

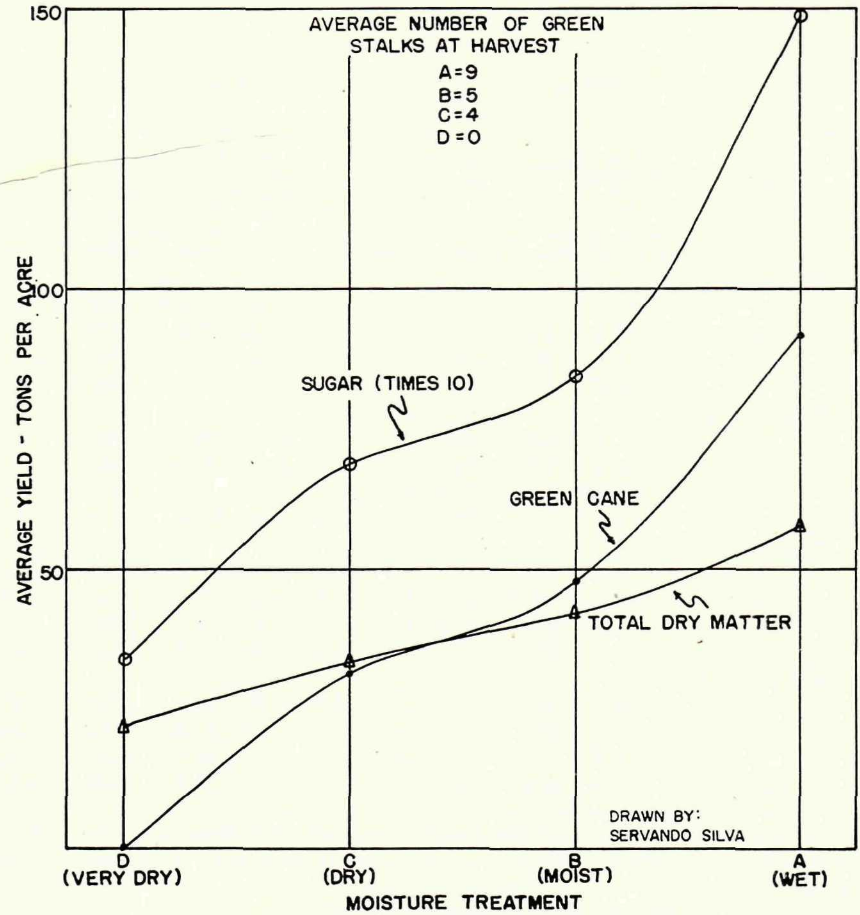

FIG. 10. Yields of green cane, sugar, and total dry matter shown in relation to 4 moisture treatments in consumptive use tanks at Aguirre, Puerto Rico.

which occurred in the fall and winter months. In fact, there was no noticeable difference in growth among the moisture treatments until that time.

In connection with this figure it should be remembered that the decreased yields associated with dryness seem to be directly related to the dying of canes during critical periods when the rate of delivery of water was too slow to keep the plant protoplasm alive. Dry soil inflicted its greatest damage on the crop by actually killing canes. Available water below one foot, where roots are sparse, did not prevent severe crop damage. There is no evidence in the data that increasing dryness (i.e. increased soil moisture tension) had any marked detrimental effects except where canes were actually killed. This is confirmed by the close relation between yield and number of live canes at harvest time, which are 9, 5, 4, and 0 respectively for the A, B, C, and D treatments. The detailed relation involving in-

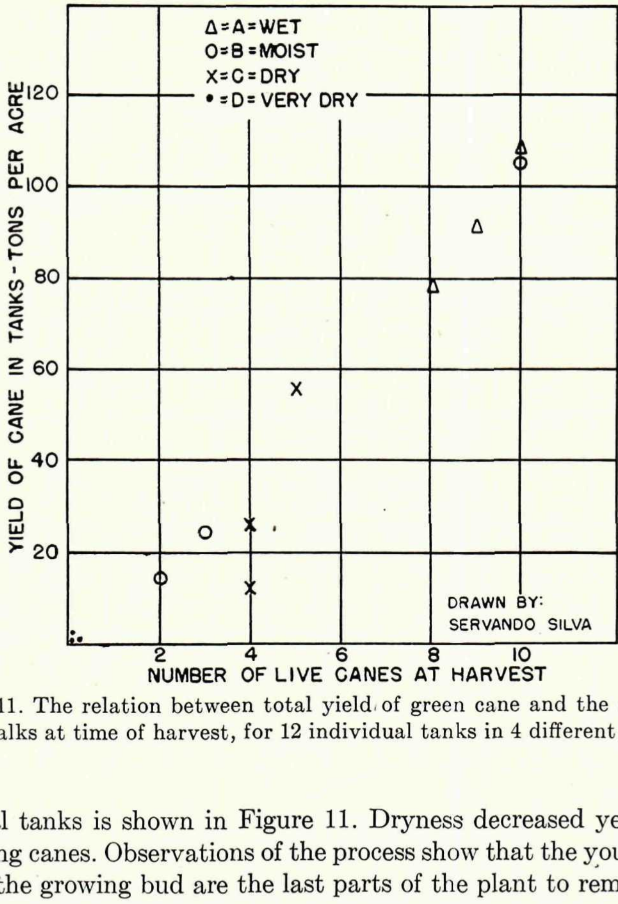

FIG. 11. The relation between total yield of green cane and the number of live, green stalks at time of harvest, for 12 individual tanks in 4 different moisture treatments.

dividual tanks is shown in Figure 11. Dryness decreased yeilds primarily by killing canes. Observations of the process show that the young leaves and finally the growing bud are the last parts of the plant to remain green and alive.

Evapotranspiration losses from the tanks and from fields (Figure 12) show that there is a definite consistent seasonal variation as well as differences caused by moisture treatment. In all cases, water use declined toward the end of the season. And since open pan evaporation generally increased from December to May (Figure 13), while water use declined, it is evident

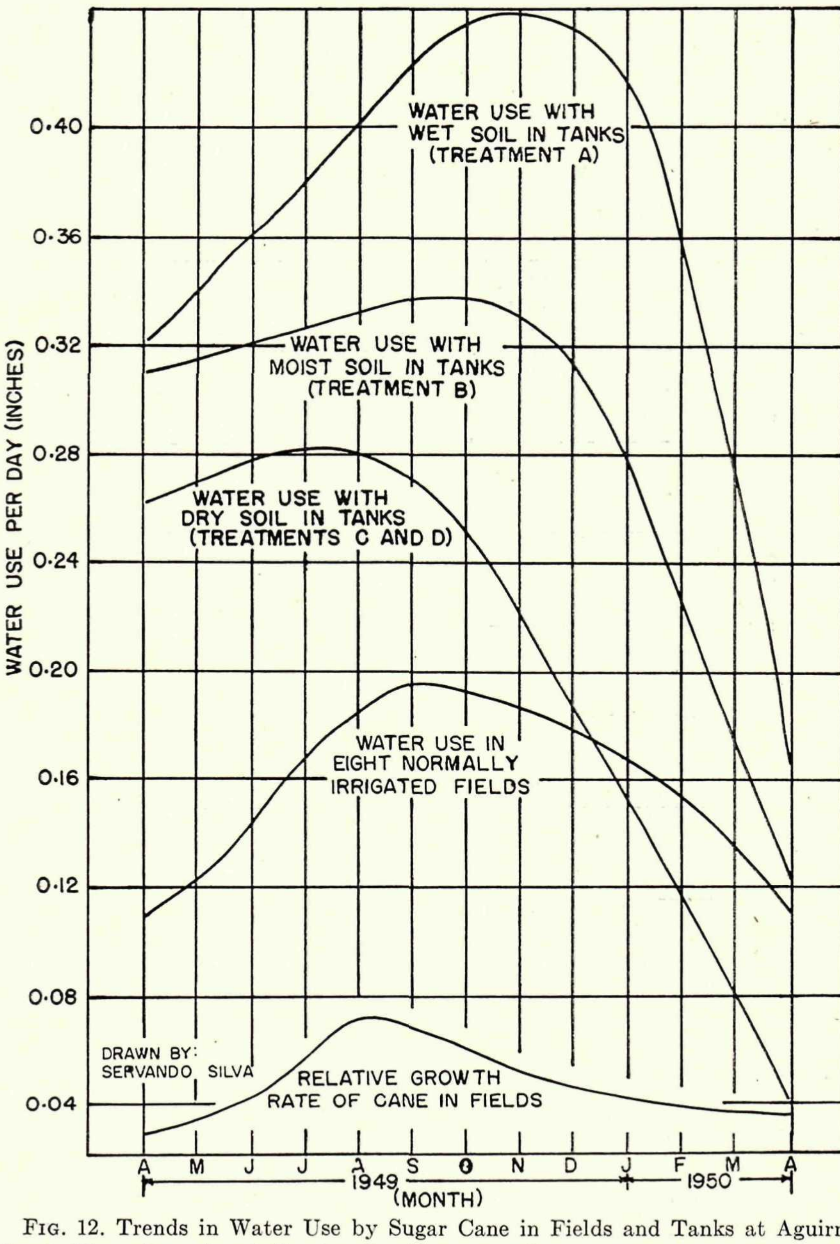

FIG. 12. Trends in Water Use by Sugar Cane in Fields and Tanks at Aguirre, Puerto Rico, shown in relation to rate of cane growth.

that maturing of the crop with drying and loss of leaves is the major factor involved in the lower water use.

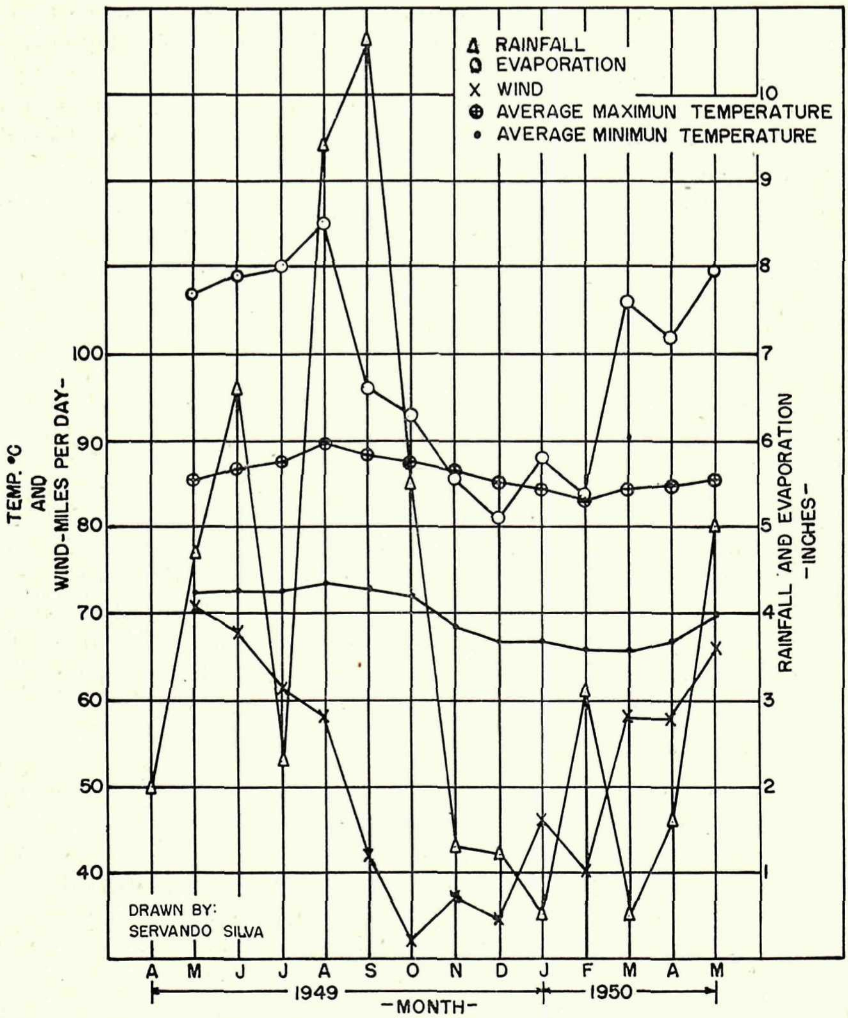

FIG. 13. Summary of certain weather influences at Aguirre, during the 1949–1950 cane season.

Early in the season the use also tended to be lower. In spring planted fields the average use was 0.12 inch per day for the first few months, increasing to about 0.19 inch in the early fall at the period of peak growth. Since temperature and evaporation also increased from April to September, a part of the increased water use is caused by the climatic factor. But consumptive use coefficients as calculated by Blaney and Criddle (2), would be 0.86 for the September rate compared to 0.57 for that of the preceding April. These values approximate the relative evapotranspiration referred to a uniform climatic base and show that there is a real difference associated with the stage of the crop.

The high initial use in all tanks compared to fields is probably related to the dense stand in the tanks, which was at least double a normal field stand. As time went on, this stand, in terms of live canes, was maintained only in the wet treatment. Final yields of live green cane are in approximate proportion to water use at the end of the season, as follows:

Tanks	Water Use in March & April	Final Yield of Green Cane Tons per Acre	Average No. of Live Canes Per Tank Area
	Inches		
A	13.9	93	9
B	8.5	49	5
C	4.5	32	4
D	2.5	0	0
Field	7.6	45	Approx. 4 or 5

This comparison suggests that high yields in the field, approaching that of the wet tanks, might require dense stands. Without adequate water and fertility (especially N) a denser field stand would probably die back to about that of the average of the B and C treatments, but a denser field stand might be feasible at high moisture and nitrogen levels, unless some other factor, such as light, controls the upper limit of stand density.

The Ripening Period

The seasonal trends (Figure 12) seem to explain the question of whether the withholding of water late in the season is necessary or desirable in order to ripen a cane crop. With variety BH-10-12, at least, the answer seems to be that the practice is right but the reason for doing it has not been clear. Since the crop uses less water toward the end of the season, it is a wasteful practice to keep adding water on the same schedule as during the peak of growth. In fact, much of what is added merely leaches away through the soil, sometimes taking needed nutrients with it. But there is no evidence that this water prevents the crop from maturing. For in our wet tanks, irrigation was continued all the way to the end of the season. The cane matured, gave a very high yield, and the sugar analyses were very good (Ave. = 16.1%). When soil moisture is used as the basis for irrigating, considerable water and labor can be saved by withholding late irrigations, because a set schedule will merely keep the soil wetter than it was earlier in the season, and will keep it wetter than is necessary or desirable. Moreover, the increased wetness will tend to increase evaporation from the soil, which helps to obscure the fact that the crop, itself, is using much less water.

With the dry treatments in tanks the picture was similar except that use dropped off much quicker. The quick drop was apparently caused more by the actual death of a part or all of the canes because of lack of water rather than by a mere stunting of growth.

Consumptive use coefficients calculated by the Blaney & Criddle method (2), are about 0.54 for the ripening period of field cane compared to 0.86 for the fall season of peak water use.

EVAPOTRANSPIRATION POTENTIAL

Whatever water use information is to be transferred from one location to another it is necessary to know what influence to expect from the weather. It is accepted that evaporation from a free water surface is one of the best indices of the power of the weather to remove water from plants by transpiration or from soil or other surfaces by evaporation. In a recent general review, Musgrave (14) has indicated that crop plants commonly use approximately 0.6 as much water as that which evaporates from an open pan*. But since evaporation measurements are not always available, it is important to be able to estimate evaporation or evapotranspiration potentials from other weather data. It is reasonably clear, as indicated by Musgrave, that solar energy, humidity, and air movement are major factors to consider. Actually, solar energy might be accepted as the primary factor, according to Penman (15), Russal (17), and others (14), but vapor pressure gradient modifies the effect of solar energy in most cases. Humidity and air movement are apparently the factors, other than solar energy itself, which control the vapor pressure gradient.

In considering present data from Aguirre, as well as U. S. Weather Bureau records for San Juan and Mayagüez, it seems clear that normal wind variations must be included in any formula used to estimate evaporation or the evapotranspiration potential of the weather. As a first approximation it appears that a factor, $(1 + \frac{W}{200})$, expresses the wind influence reasonably well, in a formula such as the following:

$$E = k\,T\,S\,(1 + 200)$$

Where T = Average temperature in °F.
S = Hours of sunshine per month
W = Wind, in miles per day
E = Evaporation, in inches per month
k = A constant, which may vary with the relative humidity of the air.

* Standard open pans as used by the U. S. Weather Bureau.

If wind velocity and temperature are known for any subhumid location in Puerto Rico, it would be reasonable to predict approximate rates of evaporation or of consumptive use of water by sugar cane relative to the measured rates found at Aguirre. For example, if an area has temperatures and sunlight essentially the same, but wind movement of 100 miles per day instead of approximately 50, as at Aguirre, the relative evapotranspiration potential would be predicted as follows:

$$\left(1 + \frac{100}{200}\right) \text{ divided by } \left(1 + \frac{50}{200}\right)$$

or

$$\frac{1.50}{1.25} = 1.2.$$

That is, the area with 100 miles of wind would be expected to lose about 1.2 times as much water by evaporation or transpiration as the area with 50 miles of wind per day. This would represent an important difference in some cases, whereas in other cases it would be overshadowed by crop or other variables. Accurate evaluations of local wind effects might require considerable detail of measurement, including attention to types of turbulence as well as total air movement.

Seasonal temperature differences may be great enough to cause 10% more evapotranspiration in summer than in winter. Variations of temperature with location in the irrigated area are generally smaller than the extreme seasonal range. During any time period, wind and sunshine are evidently the main weather factors which combine their influence with crop characteristics and soil moisture to largely determine evapotranspiration losses at different locations.

GENERAL CONCLUSIONS

1. Prevailing methods of irrigation in Puerto Rico can be reasonably efficient in the use of water (about 50% retained) if the systems are carefully laid out and if the irrigators are well trained and conscientious. With the standard, short-run, big-furrow, McLane methods the greatest losses are caused by applying too much water in one irrigation and by applying water at times when the soil has very little available storage capacity. At its best, the short furrow (McLane) method has a high labor requirement and is therefore rather expensive.

Properly designed sprinkler irrigation has shown a consistently high efficiency of about 75%.

Major changes in irrigation methods, other than by sprinkling, would require alteration of field lay-outs, land preparation, cultural operations, and labor practices. Further study is needed to determine whether some such alterations might be feasible, and compatible with high cane yields. There are too many interdependent factors to permit much change in irrigation methods without upsetting other features of the system of cane culture as a whole.

Details of irrigation methods (9) and of their efficiency (8) have already been reported elsewhere.

2. Regardless of the irrigation methods used, the periods of greatest opportunity for saving water with sugar cane are the first few and the last few months of the crop season. The greatest danger of damage to the crop because of lack of water normally comes during the season of peak growth which also corresponds with the highest average temperatures. Consumptive use of water at this time averages about 0.18 inch per day compared to 0.10 or 0.12 during the first and the last part of the season.

3. Soil moisture guides appear to offer the most promising present basis for determining when to irrigate. By depending upon soil moisture rather than upon arbitrary schedules or field men's judgment it appears to be possible to increase cane yields, save water, and save labor, all at the same time. These indications are being given extensive field scale tests by Luce and Co. at Aguirre. Both mercury type tensiometers (constructed by the BPISAE shop at Beltsville) and Boyoucos type nylon resistance blocks* are giving satisfactory results. The blocks are preferred because of simplicity of operations. Normal salt variations in soil have not affected block readings. Inherent block errors and block failures have been satisfactorily overcome by using 4 or more replicates at carefully selected stations representing a unit irrigation area. Any blocks which deviate seriously from the average are removed and replaced.

The resistance or tension readings which serve as the basis for irrigation have been established by our tank and field studies and by laboratory soil moisture tension curves. For soil like the Santa Isabel clay in the area from Juana Diaz to Aguirre it is not safe to let the soil moisture tension in the main root zone of cane go much beyond one atmosphere. With any Puerto Rican soil a safe tension for irrigation should probably correspond with a point which is at least 5% above the wilting point on a laboratory pF (moisture retention) curve.

4. Present field results indicate that high sugar cane yields per acre probably mean less water use per unit of crop produced. This is the basis for a field scale experiment by Luce and Co. comparing two, block-controlled soil moisture levels, each with two levels of fertilization.

* These blocks are sold by the Wood and Metal Products Co., Bloomfield Hills, Michigan. The "Colman" meter being used with the blocks is sold by the Berkeley Scientific Company, Richmond, California.

5. Under Puerto Rican conditions, crop characteristics and soil moisture levels probably overshadow the influence of variations in the weather factor on evapotranspiration much more often than under climates of the temperate zone where the weather factor is highly variable. In any detailed considerations of climatic influences, the weather records from Aguirre, San Juan, and Mayagüez, indicate that differences in wind movement should be given major consideration along with hours of sunshine and seasonal temperatures.

BIBLIOGRAPHY

(1) Beckett, S. H., Harry F. Blaney, and Colin A. Taylor. Irrigation water requirement studies of citrus and avocado trees in San Diego County, California, 1926 and 1927. Calif. Agr. Exp. Sta. Bul. 489. 1930.

(2) Blaney, Harry F., and W. D. Criddle. A method of estimating water requirements in irrigated areas from climatological data. (Provisional) U. S. D. A. Soil Conservation Service mimeographed report. 1947.

(3) Blaney, Harry F., and W. D. Criddle. Consumptive use of water in the irrigated areas of the upper Colorado River basin. (Provisional) U. S. D. A. Soil Conservation Service mimeographed report. 1949.

(4) Blaney, Harry F., Paul A. Ewing, Karl V. Morin, and W. D. Criddle. Consumptive water use and requirements. Report of the participating agencies, Pecos River Joint Investigation. National Resources Planning Board. 1942.

(5) Blaney, Harry F., and Karl V. Morin. Evaporation and consumptive use of water formulas. Trans. Am. Geophys. Union, part **1:** 76–83. 1942.

(6) Bonnet, J. A., and P. Tirado-Sulsona. Soil Study in Lajas Valley. P. R. Agric. Exper. Station Bulletin. 1950.

(7) Criddle, W. D. Estimate of water requirements of crops in irrigated areas of Idaho. U. S. D. A. Soil Conservation Service mimeographed report. 1947.

(8) Fuhriman, D. K. Greater accuracy in water application efficiency determinations through a consumptive use correction factor. A Graduate Thesis. Utah State Agricultural College, Logan, Utah. 1950.

(9) Fuhriman, D. K. Greater accuracy in measuring water application efficiency in irrigation. Agricultural Engineering. In press.

(10) Fuhriman, D. K., and R. M. Smith. Irrigation practices in Puerto Rico. Agric. Engineering. **32:** 46–50. 1951.

(11) Israelsen, O. W., W. D. Criddle, D. K. Fuhriman, and V. E. Hansen. Water application efficiencies in irrigation. Utah Agr. Expt. Sta. Bul. 311. 1944.

(12) Kelley, O. J., J. A. Hardman, and D. S. Jennings. A soil-sampling machine for obtaining to four-inch diameter cores or undisturbed soil to a depth of six feet. Soil Science Society Amer. Proc. **12:** 85–87. 1947.

(13) Lee, H. A. The distribution of roots of young D1135 plant cane in the soil. Hawaiian Planters' Record **30:** 267–270. 1926.

(14) Musgrave, G. W. Estimating Evapotranspiration. Mimeograph. Soil Conservation Service. 1950.

(15) Penman, H. L. The dependence of transpiration on weather and soil conditions. Jour. of Soi. Sci. **I:** 74–89.

(16) Roberts, R. C. Soil Survey of Puerto Rico. U. S. D. A. coop. with Univ. of Puerto Rico Agric. Expt. Sta. 1942.

(17) Russell, E. W. Water utilization by crops and the ability of soils to supply water to them. World Crops. March 1950. Pgs. 114–118.

(18) Smith, R. M., and George Samuels. A system of soil profile characterization. Jour. of Soil and Water Conservation. **5:** 158–164, 198. 1950.

(19) Smith, R. M., D. K. Fuhriman, and Servando Silva. Simple procedures for studying soil cores collected with the Kelley (Utah) Sampling machine. Research Report No. 181, Bur. of Plant Ind. Soils and Agr. Eng., U. S. D. A., March 1, 1950. (Mimeographed).