Potential evapotranspiration for the south coast of Puerto Rico with the Hargreaves-Samani technique[1]

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ABSTACT

The Hargreaves and Samani model was used to estimate monthly potential evapotranspiration (PET) for Central Aguirre, Fortuna and Lajas substations and Magueyes Island located on the south coast of Puerto Rico. The model uses maximum, minimum and average temperatures. Daily PET varies from 3.68 to 5.37 mm/day in the region with minimum in December and maximum in July. Annual PET was 1613.3 mm/year for Central Aguirre, 1653.5 for Fortuna, 1846.9 for Lajas, 1857.9 for Magueyes Island, with a regional average of 1704.6. These PET values can be used to estimate crop water requirements for vegetables and fruits, to plan irrigation and water management projects, and to schedule irrigation in the semiarid region of Puerto Rico.

INTRODUCTION

The main objective of irrigation is to provide plants with sufficient water to prevent stress that can reduce yield. The frequency of irrigation and quantity of water depends upon local climatic conditions, crop and stage of growth and soil-moisture-plant characteristics. The need for irrigation can be determined in several ways that do not require evapotranspiration (ET) rate. Crop indicators such as change of color or leaf angle, may be used. However, this information occurs too late to avoid reduction in crop yield or quality. Other methods of scheduling include determination of the plant water stress, soil moisture status or soil water potential. Methods of estimating crop water requirements using ET in combination with soil characteristics has the advantage of not only being useful in determining when to irrigate, but also enables us to know the quantity of water needed. ET estimates have not been used for Puerto Rico even though basic information on meteorological data is available. The water supply in Puerto Rico is dwindling because of luxury use of ground water. There is increasing demand for water for domestic, munici-

[1]Manuscript submitted to Editorial Board 23 January 1987.

This study was conducted under CBAG-23, "Irrigation Estimations in Puerto Rico." The author thanks George H. Hargreaves, Director, International Irrigation Center, Utah State University, Logan, for his valuable suggestions.

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pal and industrial uses and water quality is declining. Water is a limiting factor in Puerto Rico's goal for self-sufficiency in agriculture. Intelligent use of water will prevent the problem of sea water entering into aquifers. Introduction of new irrigation methods has encouraged marginal farmers to adopt these methods without taking into consideration economic benefits of conventional, overhead and drip irrigation systems. What is important is "net in the pocket" under limited available resources. Irrigation of crops in the tropics and on these soils requires appropriately tailored working principles for the effective use of all resources peculiar to the local conditions.

Hargreaves and Samani (3) indicated following relationships to calculate potential evapotranspiration (PET):

$$PET = 0.0023\ (R_A).\ (T^\circ C + 17.8).\ [(Tmax - Tmin)]^{0.5} \quad \ldots\ldots\ /1/$$

$$PET = 0.0135\ (R_S).\ (T^\circ C + 17.8) \quad \ldots\ldots\ /2/$$

where, PET and incident solar radiation (R_S) are in the same units of equivalent water evaporation (mm per unit of time), T is mean temperature in degrees centigrade, T max and T min are maximum and minimum temperatures in °C, and R_A is extraterrestrial radiation. R_A and R_S are related by the relationship: $R_S=0.075.(R_A)\ (S)^{0.5}$, where, S is a percent sunshine and is a ratio of actual daily bright sunshine hours to maximum daily bright sunshine hours.

Hargreaves and Samani (3, 4, 5) indicated that equation /1/ is superior to equation /2/. Doorenbos and Pruitt (2) have listed procedures to calculate PET with various models and have given climatic data for various latitudes in the northern and southern hemispheres.

The purpose of this study was to calculate monthly potential evapotranspiration (PET) for Central Aguirre, Fortuna and Lajas Substations, Magueyes Island in the semiarid south coast of Puerto Rico.

MATERIALS AND METHODS

Since complete meteorological data for the south coast of Puerto Rico is often unavailable or some data is missing, it was therefore decided to use the Hargreaves and Samani (3) model to calculate potential evapotranspiration (PET) for four locations (1, 7, 8, 9) in the semiarid zone of Puerto Rico with equation 1. Extraterrestrial solar radiation (R_A), incident net solar radiation (R_S), percent sunshine for 18° latitude were calculated with equations /1/ and /2/, and Samani and Pessarakli's (6) relationship given below:

$$R_A = 916.732\ (OM \times SIN(LAT) \times SIN(DEC) + COS(LAT) \times COS(DEC) \times SIN(OM))/ES \times 10/(596 - 0.55TC) \quad \ldots\ldots\ /3/$$

in which:

R_A = Extraterrestrial radiation in mm/day
TC = Average temperature in degree Celsius
LAT* = Latitude of the station in radians
(Latitude should be positive value for Northern Hemisphere and negative for the Southern Hemisphere)

$$DEC = -0.00117 - 0.40117 \times COS(\pi \times J/6) - 0.042185 \times SIN(\pi \times J/6) + 0.00163 \times COS(\pi \times J/3) + 0.00208 \times SIN(\pi \times J/3) \quad /4/$$

J = Number of the month, January = 1

$$ES = 1.00016 - 0.032126 \times COS(\pi \times J/6) - 0.003354 \times SIN(\pi \times J/6) \quad /5/$$

$$OM = \text{Arc. } COS(-TAN(LAT) \times TAN(DEC)) \quad /6/$$

$\pi = 3.14$

All data are tabulated in tables 1 and 2. Monthly PET was estimated with these data in combination with equations 1 and 2. PET estimates are shown in table 3.

RESULTS AND DISCUSSION

Table 2 indicates extraterrestrial solar radiation (R_A), incident net solar radiation (R_S), sunshine percentage (S) and calculated mean actual bright sunshine hours for 18° N latitude, respectively. Calculated monthly R_A values are higher than monthly R_A values listed by Doorenbos and Pruitt (2). The differences are due to local variations in maximum, minimum and average temperatures; Doorenbos and Pruitt took into consideration world averages for 18° N latitude. Monthly R_A was maximum for June-July and minimum for December. It varies from 11.3 to 16.4 mm/day during January through December. Calculated monthly R_S was maximum for August and minimum for December with Hargreaves and Samani (4) method. Monthly R_S varies from 6.69 to 10.03 mm/day during January through December. Monthly sunshine percentage (S) and actual bright sunshine daily hours were maximum during February and minimum during December. Monthly S varies from 61.1 to 74.5% during January through December. Actual bright sunshine daily hours vary from 6.9 to 8.6 hours during the year. Puerto Rico (1) lies between lat. 17° 55′-18° 32′ N and long. 65° 35′-67° 17′ W. Data indicated in table 2 for 18° N can be used to calculate PET for lat. 17° 55′-18° 32′ N with no significant differences in PET because of change in latitude. It can therefore be assumed that values in table 2, except R_s, are applicable for all of Puerto Rico.

Table 3 lists monthly PET (mm/day, mm/month) estimates for Central Aguirre, Fortuna and Lajas Substations and Magueyes Island on the south coast of Puerto Rico. Annual PET was 1613.3 mm/year for Central Aguirre, 1653.5 for Fortuna, 1846.9 for Lajas, 1857.9 for Magueyes Is-

TABLE 1.—*Mean temperature for the south coastal region of Puerto Rico*

	Mean temperature (T)°C										
	Lajas Substation (8)[1]			Fortuna Substation (9)[2]			Central Aguirre (7)[3]			South coastal (1)[4]	Magueyes Island (1)[5]
Month	Tmax	Tmin	Avg	Tmax	Tmin	Avg	Tmax	Tmin	Avg	Avg	Avg
JAN	29.9	16.1	23.0	29.1	18.9	24.0	29.9	20.0	25.0	24.0	23.6
FEB	30.2	15.9	23.0	30.1	19.1	24.6	29.8	19.9	24.9	24.2	23.8
MAR	30.8	15.8	23.3	30.4	19.4	24.9	30.2	20.5	25.4	24.5	24.8
APR	31.3	18.1	24.7	30.7	20.7	25.7	30.6	21.5	26.1	25.5	25.3
MAY	31.7	19.8	25.8	31.1	22.3	26.7	31.2	22.7	26.9	26.5	25.1
JUN	32.3	20.6	26.5	31.6	23.2	26.7	31.7	23.4	27.6	27.2	27.1
JUL	33.0	20.0	26.5	32.0	23.2	27.6	32.1	23.6	27.9	27.3	27.8
AUG	32.5	20.1	26.3	32.1	22.9	27.5	32.5	23.7	27.6	27.1	27.6
SEP	31.9	20.3	26.1	32.1	22.7	27.4	32.5	23.2	27.9	27.1	27.8
OCT	31.5	19.7	25.6	31.8	22.3	27.1	32.3	22.9	27.6	26.8	26.0
NOV	31.2	18.3	24.8	31.3	21.1	26.2	31.7	22.1	26.9	26.0	25.4
DEC	30.4	16.7	23.6	30.6	19.8	25.2	30.7	21.0	25.9	24.9	24.7
ANNUAL	31.4	18.4	24.9	31.1	21.3	26.2	31.3	22.1	26.7	25.9	25.7

[1] Numbers in parentheses refer to bibliographical reference. Weather station (1) No. 5097 lat. 18°3′ N long. 67°3′ W, elevation 27 m. Record 32 years.

[2] Weather station (1) No. 7292 lat. 18°1′ N long. 66°32′ W, elevation 21 m. Record 25 years.

[3] Weather station (1) No. 0152 lat. 17°58′ N long. 66°13′ W, elevation 7.5 m. Record 18 years.

[4] Average of Lajas, Fortuna, Aguirre data (1).

[5] Weather station (1) No. 5693, lat. 17°58′ N long. 67°3′ W, elevation 4.5 m. Record 28 years.

TABLE 2.—*Extraterrestrial radiation (R_A), incident solar radiation (R_s) and percent sunshine for Puerto Rico (18°* latitude)

Month	Radiation, mm/day			Sushine, %	Bright sunshine daily hours	
	Extraterrestrial, R_A		Incident, R_s[1]	$S = (R_s/0.075\ r_A)$	Mean maximum[2]	Actual[3]
January	11.68[4]	11.6[2]	6.97	63.3[5]	11.1	7.0
February	13.02	13.0	8.43	74.5	11.5	8.5
March	14.65	14.6	9.25	70.9	12.0	8.5
April	15.83	15.6	9.40	62.7	12.6	7.9
May	16.30	16.1	9.33	58.2	13.0	7.6
June	16.38	16.1	9.64	61.6	13.2	8.1
July	16.38	16.1	9.65	61.7	13.1	8.1
August	15.80	15.8	10.03	71.6	12.7	9.1
September	15.23	14.9	9.02	62.4	12.3	7.7
October	13.62	13.6	8.13	63.4	11.7	7.4
November	12.11	12.0	7.10	61.1	11.3	6.9
December	11.29	11.1	6.69	62.4	11.0	6.9

[1] Using $ET^o = (0.0135)(R_s)(T + 17.8)$ and data of Hargreaves and Samani (4) for Lajas.
[2] Doorenbos and Pruitt (2).
[3] Actual mean bright sunshine daily hours were calculated by means of the relationship mean maximum sunshine hours × (S/100).
[4] Using relationship given by Samani and Pessarakli (6) and for 18° latitude.
[5] Hargreaves and Samani (3).

land, and 1704.6 for the south coast (semiarid region) of Puerto Rico, respectively. PET based upon maximum and minimum temperatures is more accurate than PET based upon average temperatures (4, 5). PET values listed by Hargreaves and Samani (4) are those over predicted for Central Aguirre and under predicted for Lajas Substation.

During the year, daily PET values vary from 3.53 to 5.02 mm/day for Central Aguirre, 3.5 to 5.07 for Fortuna, 3.83 to 6.02 for Lajas, 3.84 to 6.15 for Magueyes Island, and 3.68 to 5.37 for the south coast of Puerto Rico. PET is minimum for December in all locations. Maximum PET is during July for all locations, except Magueyes Island.

Daily and monthly PET for the south coast can be used for other locations in this region to plan irrigation and water management projects and to schedule irrigation for vegetables and fruits.

Example: It is planned to transplant sweet peppers (var. Cubanelle) 1 December 1986 at Fortuna Substation and the last harvest is expected 31 March 1987. Average effective rainfall based upon a 25-year record is expected to be 97.3 mm during the crop season. Estimate crop irrigation requirements assuming 80% efficiency for drip irrigation system.

Potential evapotranspiration (PET) for December through March, table 3 = 490.0 mm

Seasonal crop coefficient (Doorenbos and Pruitt, 1977) = 0.80

TABLE 3.—*Reference crop evapotranspiration from temperature for south coastal region of Puerto Rico*

Month	Reference crop evapotranspiration (PET)											
	Central Aguirre		Fortuna Substation		Lajas Substation		South Coastal		Magueyes Island		Central Aguirre[1]	Lajas Substation[1]
	mm/day	mm/month	mm/day	mm/month	mm/day	mm/month	mm/day	mm/month	mm/day	mm/month	mm/month	mm/month
	PET = 0.0023 R_A (T°C + 17.8) (Tmax - Tmin)$^{0.5}$									PET = 0.0135 R_s (T°C + 17.8)		
Jan	3.62	112.2	3.59	111.3	4.07	126.2	3.76	116.5	3.89	120.6	124	119
Feb	4.02	112.6	4.21	117.9	4.62	129.4	4.28	119.9	4.73	132.4	135	130
Mar	4.53	140.4	4.77	147.9	5.36	166.2	4.89	151.5	5.32	154.9	163	158
Apr	4.82	144.6	5.01	150.3	5.62	168.6	5.15	154.5	5.47	164.1	167	163
May	4.89	151.6	4.95	153.5	5.64	174.8	5.16	160.0	5.40	167.4	175	171
June	4.93	147.9	4.94	148.2	5.71	171.3	5.19	155.8	5.84	175.2	174	171
Jul	5.02	155.6	5.07	157.2	6.02	186.6	5.37	166.5	5.94	184.1	185	181
Aug	4.61	142.9	4.99	154.7	5.64	174.8	5.08	157.5	6.15	190.7	190	184
Sep	4.88	146.4	4.85	145.5	5.24	157.2	4.99	149.7	5.55	166.5	166	160
Oct	4.36	136.2	4.34	134.5	4.67	144.8	4.46	138.2	4.81	149.1	155	149
Nov	3.86	114.6	3.91	117.3	4.26	127.8	4.01	120.3	4.14	124.2	129	123
Dec	3.53	109.4	3.67	113.8	3.83	118.7	3.68	114.0	3.84	119.0	122	117
Annual	4.42	1613.3	4.53	1653.5	5.06	1846.9	4.67	1704.6	5.09	1857.9	1884	1825

[1] Data of Hargreaves and Samani (4).

Pepper consumptive use, CU	=	490.9×0.80
	=	392.7 mm
Irrigation requirement, I	=	Cu − effective rainfall
	=	392.7 − 97.3
	=	285.4 mm
Drip irrigation requirement	=	I/efficiency
	=	285.4/0.80
	=	356.7 mm

Therefore, estimated drip irrigation requirement for 120-day pepper is 356.7 mm.

RESUMEN

Potencial de evapotranspiración para la costa sur de Puerto Rico usando la técnica de Hargreaves-Samani

El modelo de Hargreaves-Samani se usó para calcular el potencial de evapotranspiración (PET) mensual para la Central Aguirre, las subestaciones de Fortuna y Lajas y la isla de Magueyes, localizada en la costa sur de Puerto Rico. El modelo usa temperaturas máxima, mínima y media. El PET diario varía de 3.68 a 5.37 mm./día en la región, con PET mínimo en diciembre y máximo en julio. El PET anual fue 1613.3 mm./año en la Central Aguirre, 1653.5 para Fortuna, 1846.9 en Lajas y 1857.9 en la isla de Magueyes, con un promedio regional de 704.6. Se recomienda que estos valores de PET se usen para estimar los requisitos de agua para el cultivo de hortalizas o frutas, para planear proyectos de riego y uso del agua, y para planificar riegos en la región semiárida de Puerto Rico.

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