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**“Quel devenir pour l’agriculture caribéenne ?
Qualité, économie, progrès social, environnement”**

**“What is the future of Agriculture in the Caribbean ?
Quality, Economy, Social Progress, Environment”**

**“¿ Cuál es el futuro de la Agricultura en el Caribe ?
Cualidad, Economía, Progreso Social, Medio ambiente”**



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A SIMPLE PROCEDURE FOR ESTIMATING EVAPOTRANSPIRATION IN TROPICAL ISLAND ENVIRONMENTS

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RESUME

L'Organisation des Nations Unies pour l'Alimentation et l'Agriculture (OAA) a recommandé la méthode de "Penman-Monteith" comme unique méthode pour estimer les références d'évapotranspiration à travers le monde. Cependant, l'inconvénient de la méthode, est son besoin d'information relativement élevé. La vitesse du vent, l'humidité (ou la température au point de rosée) et la radiation ont tendance à être le moins disponible des paramètres requis; par conséquent, l'OAA a présenté un protocole d'estimation pour ces paramètres. Le but de cette étude était d'évaluer un protocole d'estimation des données climatiques qui doivent être utilisées dans la méthode de "Penman-Monteith" pour l'estimation quotidienne des références d'évapotranspiration à long terme et de vérifier l'exactitude du protocole à quatre emplacements à l'intérieur de Puerto Rico. La comparaison des références d'évapotranspiration déterminées par l'utilisation des données climatiques estimées et mesurées est d'opinion satisfaisante. Les méthodes présentées dans cette communication sont potentiellement de grande valeur pour le calcul de la moyenne journalière des références d'évapotranspiration à long terme à n'importe quel endroit à l'intérieur de Porto Rico. Un exemple est fourni afin d'illustrer l'utilisation du protocole d'estimation pour les paramètres climatiques. Cette étude présente une comparaison des références d'évaporation calculées par la méthode "Penman-Monteith" avec des précédentes estimations faites par l'utilisation de la méthode de "Hargreave-Samani", pour 34 emplacements à Puerto Rico. De plus, l'estimation du pic d'évapotranspiration à partir du "guide d'irrigation SCS" pour la zone caribéenne, les méthodes de SCS de "Blaney-Criddle" et de "Penman-Monteith" ont été comparées pour six cultures de légumes à trois emplacements à Porto Rico. Les résultats dénotent que des systèmes d'irrigation peuvent avoir été mal conçus en terme de débit à Porto Rico.

ABSTRACT

This paper describes a simple method for estimating long-term average monthly climate data for tropical island environments. These data (i.e., minimum and maximum air temperature, dew point temperature, wind speed, and solar radiation) are needed as input to the Penman-Monteith method for calculating reference evapotranspiration. The climate data can be estimated from just two site parameters (latitude and elevation) and specification of a climate division (or zone). In this study, the climate data estimation procedure was applied to Puerto Rico. Comparison of reference evapotranspiration determined by using the proposed method and measured climate data from four locations in Puerto Rico showed good agreement. This method may serve as a means for estimating reference evapotranspiration in other Caribbean Islands.

INTRODUCTION

The ability to estimate consumptive water use by crops is essential for good water and fertility management. Water consumptive use or evapotranspiration (ET) is affected by air temperature, solar radiation, wind speed, humidity, and crop characteristics. ET can be estimated from the relation $ET = K_c ET_0$, where K_c is a crop coefficient and ET_0 is the reference evapotranspiration. The Penman-Monteith method has been recommended as the best method for estimating ET_0 by the United Nations Food and Agriculture Organization (FAO) (Allen *et al.*, 1998). A disadvantage of the Penman-Monteith method, however, is its relatively high data requirement; data that are often not available for a site. Traditionally, practitioners have used simpler ET estimation formulas requiring less input. The FAO, however, discourages this approach; rather, they recommend the use of the Penman-Monteith method based on estimated climate data (Allen *et al.*, 1998).

This paper describes a simple procedure for estimating climate data suitable for use with the Penman-Monteith method. Although developed for use in Puerto Rico, the method may be generally applicable to tropical island environments. Many of the islands of the West Indies archipelago share similar characteristics with respect to climate. This is due in part to the influence of the trade winds and the islands' mountainous topography (Kent, 2002). Generally, for these islands, rainfall is greatest in the northeast and interior mountain areas. Due to orthographic effects, the leeward side may be quite dry and even semi-arid, as in the case of southwest Puerto Rico. The rainy season tends to be from June to November and the dry season from December to May. For a given location, air temperature variations throughout the year are small; however, air temperatures are highly correlated with elevation. An exception to this occurs within interior mountain valleys where warm air can become trapped. In some cases average temperatures within interior mountain valleys may be higher than coastal areas at lower elevations.

PROPOSED CLIMATE ESTIMATION PROCEDURES FOR PUERTO RICO

Estimation procedures are presented below for long-term average daily climate parameters on a monthly basis for Puerto Rico. Climate data include: minimum air temperature (T_{min}), maximum air temperature (T_{max}), dew point temperature (T_{dew}), solar radiation (R_s) and wind speed (U). A more detailed description of the method background can be found in Harmsen *et al.* (2002).

Minimum and Maximum Air Temperature: Goyal *et al.* (1988) developed regression equations for minimum and maximum long-term average daily air temperatures for Puerto Rico based on surface elevation. Table 1 lists the regression coefficients for the daily average minimum and maximum air temperatures in Puerto Rico by month. The regression equations have the following general form:

$$T = A - (B \cdot 10^{-5}) \cdot Z \quad (1)$$

where T is temperature ($^{\circ}\text{C}$), A and B are regression coefficients and Z is elevation (m) above mean sea level.

Table 1. Relationships among temperatures (T) and elevations (Z) for Puerto Rico (Goyal *et al.*, 1988)¹

Month	Mean Daily Maximum Temperatures, °C			Mean Daily Minimum Temperatures, °C		
	A	B	r ²	A	B	r ²
Jan.	29.24	770	0.73	18.58	544	0.44
Feb.	29.37	752	0.72	18.37	558	0.46
Mar.	30.08	711	0.71	18.71	590	0.48
Apr.	30.59	687	0.71	19.9	686	0.63
May	31.16	707	0.76	21.23	608	0.63
Jun.	31.76	686	0.73	21.92	577	0.59
Jul.	32.07	717	0.64	22.14	591	0.58
Aug.	32.12	682	0.75	22.21	585	0.58
Sep.	32.12	696	0.79	21.95	586	0.62
Oct.	31.84	705	0.79	21.48	553	0.59
Nov.	30.89	706	0.75	20.68	562	0.55
Dec.	29.83	744	0.73	19.52	547	0.47

¹ $T = A - (B \cdot 10^{-5}) Z$, where T = temperature, °C; Z = elevation above mean sea level, m; and A and B are regression coefficients and r² is the coefficient of determination.

Dew Point Temperature: The FAO (Allen *et al.*, 1998) has reported that T_{dew} can be estimated on the basis of the daily minimum air temperature. A correction factor based on local conditions should be added to the minimum temperature as follows:

$$T_{\text{dew}} = T_{\text{min}} + K_{\text{corr}} \quad (2)$$

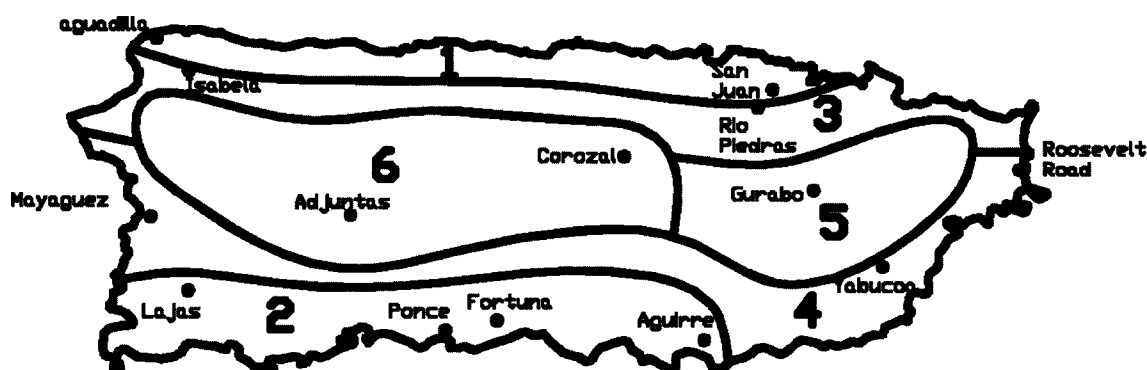
where K_{corr} is a temperature correction factor in degrees °C, listed in Table 2. Correction factors (K_{corr}) were calibrated for three of the six Climate Divisions of Puerto Rico as defined by the U.S. National Oceanic and Atmospheric Administration (NOAA), and are presented in Table 2. Figure 1 shows the Climate Divisions for Puerto Rico. A climate division is defined as region possessing similar climatic characteristics. Long-term average T_{dew} data were not available for Climate Divisions 3, 5 and 6, therefore, these Divisions were assigned a value of 0 °C similar to that of Division 4 (humid conditions).

Table 2. Temperature correction Factor K_{corr} used in Equation 2 for Climate Divisions¹ within Puerto Rico

Climate Division ¹	1	2	3,4,5,6
K _{corr} (°C)	1.0 if T _{dew} is estimated using estimated T _{min} data -1.5 if T _{dew} is estimated using measured T _{min} data	-2.9	0

¹ See Figure 1 for Climate Divisions

Figure 1. Climate Divisions of Puerto Rico: 1, North Coastal; 2, South Coastal; 3, Northern Slopes; 4, Southern Slopes; 5, Eastern Interior; and 6, Western Interior.



Wind Speed: The Penman-Monteith method is based on a wind speed measured 2 m above the ground and is referred to as U_2 . Wind speeds that are collected at heights other than 2 m above the ground were adjusted to the U_2 value using an exponential relationship. Table 3 presents U_2 values for Puerto Rico. These wind speeds were estimated by averaging station data within the Climate Divisions established by the NOAA.

Solar Radiation: The FAO recommends that solar radiation be estimated by using the following equation for islands:

$$R_s = (0.7 R_a - b) \quad (3)$$

where R_s is solar radiation, b is an empirical constant, equal to 4 mega-joules per meter squared per day ($\text{MJ m}^{-2} \text{day}^{-1}$) and R_a is the incoming extraterrestrial radiation. Table 4 lists values of R_a by month and for latitudes applicable to Puerto Rico. Values of R_a for other latitudes are given by Allen et al. (1998). Equation 3 is limited to elevations of less than 100 m above sea level. Therefore, for higher elevations, in the interior areas of Puerto Rico, where the ocean does not moderate air temperatures as much as along the low altitude coastal areas, the Hargreaves radiation formula should be used:

$$R_s = k_{Rs} (T_{\max} - T_{\min})^{1/2} R_a \quad (4)$$

where k_{Rs} is an adjustment factor equal to 0.19.

Table 3. Average Daily Wind Speeds (U_2) by Month and Climate Division¹ within Puerto Rico.

Climate Division ¹	Average Daily Wind Speeds at 2 m Above the Ground (m/s) ²											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	2.7	2.8	3.0	2.9	2.6	2.6	2.9	2.7	2.1	1.9	2.2	2.6
2	1.8	2.0	2.2	2.1	2.2	2.4	2.4	2.1	1.7	1.5	1.4	1.5
3	2.2	2.4	2.6	2.4	2.2	2.4	2.7	2.5	2.0	1.8	2.0	2.3
4	1.8	2.0	2.1	2.1	2.0	2.0	2.0	1.8	1.6	1.6	1.6	1.6
5	1.1	1.3	1.4	1.5	1.6	1.7	1.6	1.3	1.1	0.9	0.9	0.9
6	1.3	1.5	1.5	1.5	1.6	1.8	1.8	1.5	1.2	1.1	1.0	1.0

¹ See Figure 1 for Climate Divisions

² Averages are based on San Juan and Aguadilla for Div. 1; Ponce, Aguirre, Fortuna and Lajas, for Div. 2; Isabela and Río Piedras for Div. 3; Mayagüez, Roosevelt Rd. and Yabucoa for Div. 4; Gurabo for Div. 5; and Corozal and Adjuntas for Div. 6. Measured wind speeds were adjusted to the wind speed 2 m above the ground (U_2) using the following equation: $U_2 = (4.87U_z)/[\ln(67.8z-5.42)]$, where U_z in m/sec is the wind speed at height z in meters above the ground.

Method Verification

Harmesen *et al.* (2002) compared reference evapotranspiration (ET_o) based on estimated and measured climate data at four locations in Puerto Rico (Figure 2). Estimates of reference evapotranspiration based on estimated climate data (ET_{oe}) were in reasonably good agreement with estimates based on measured climate data (ET_{om}). A linear regression analysis of the data shown in Figure 2 resulted in a coefficient of determination (r^2) equal to 0.93. Harmesen *et al.* (2002) provide a discussion on the limitations associated with applying the methodology in Puerto Rico.

Example Application

Using the climate estimation procedures developed for Puerto Rico, reference evapotranspiration was estimated for the following conditions: location: Dos Bocas, Arecibo County, PR; elevation: 60 m; latitude: 18°20' (18.33 decimal degrees). Table 5 gives the estimated climate data and long-term average daily reference evapotranspiration for January through December. Minimum and maximum air temperatures were calculated with data from Table 1. Dos Bocas is in Climate Division 6; therefore, as per Table 2, dew point temperatures were equal to the minimum air temperatures (i.e., $K_{corr} = 0$ °C). Wind speeds were obtained from Table 3 for Climate Division 6. Values of R_a were obtained from Table 4 and have been included in Table 5.

Table 4. Extraterrestrial radiation by month and latitude within Puerto Rico

Month	Extraterrestrial Radiation, R_a (MJ/m ² -day) ¹						
	Latitude (decimal degrees N)						
	17.90	18.00	18.10	18.20	18.30	18.40	18.50
Jan	27.90	27.85	27.80	27.74	27.69	27.64	27.58
Feb	31.36	31.32	31.27	31.23	31.19	31.14	31.10
Mar	35.33	35.30	35.28	35.25	35.23	35.20	35.18
Apr	38.03	38.02	38.02	38.02	38.01	38.01	38.01
May	39.02	39.03	39.04	39.06	39.07	39.09	39.10
Jun	39.07	39.09	39.12	39.14	39.16	39.19	39.21
Jul	38.91	38.93	38.95	38.97	38.99	39.01	39.03
Aug	38.30	38.31	38.31	38.32	38.32	38.33	38.33
Sep	36.38	36.36	36.35	36.33	36.32	36.31	36.29
Oct	32.91	32.88	32.84	32.81	32.77	32.74	32.70
Nov	29.10	29.05	29.01	28.96	28.91	28.86	28.81
Dec	26.89	26.84	26.78	26.73	26.67	26.61	26.56

¹ mega-joules per square meter per day.

Figure 2. Comparison of reference evapotranspiration (ET_o) calculated with measured data (subscript m) and estimated data for all climate parameters (subscript e) (Harmsen et al. 2002).

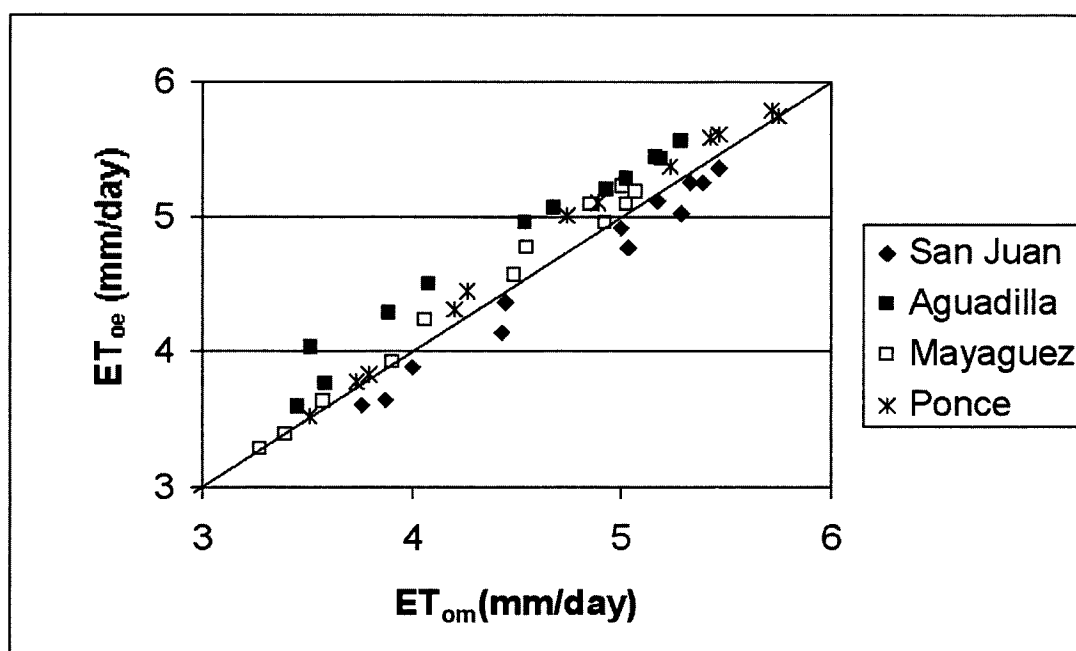


Table 5. Estimated Climate Data and Reference Evapotranspiration for Dos Bocas, PR.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
T_{\max} °C	28.8	28.9	29.7	30.2	30.7	31.3	31.6	31.7	31.7	31.4	30.5	29.4
T_{\min} °C	18.3	18.0	18.4	19.5	20.9	21.6	21.8	21.9	21.6	21.1	20.3	19.2
T_{dew} °C	18.3	18.0	18.4	19.5	20.9	21.6	21.8	21.9	21.6	21.1	20.3	19.2
U_2 m/s	1.3	1.5	1.5	1.5	1.6	1.8	1.8	1.5	1.2	1.5	1.0	1.0
R_a , MJ m ⁻² day ⁻¹	27.7	31.2	35.2	38.0	39.1	39.2	39.0	38.3	36.3	32.8	28.9	26.7
R_s , MJ m ⁻² day ⁻¹	15.4	17.8	20.7	22.6	23.4	23.4	23.3	22.8	21.4	18.9	16.2	14.7
ET_o , mm/day	3.2	3.7	4.3	4.7	4.9	5.1	5.1	4.9	4.6	4.1	3.3	2.9

Definitions: maximum daily air temperature (T_{\max}), minimum daily air temperature (T_{\min}), dew point temperature (T_{dew}), wind speed, measured at 2 meters above the ground (U_2), extraterrestrial radiation (R_a) solar radiation (R_s) and long-term daily average reference evapotranspiration (ET_o).

Considerations for Applying this Methodology to Other Caribbean Islands

For the new island locations, climate divisions should be established. The following divisions may be applicable as in the case of Puerto Rico: north coastal, south coastal, northern slopes, southern slopes, eastern interior, and western interior. It is desirable to have long-term measured data (minimum and maximum air temperature, dew point temperature, wind speed, and solar radiation) for each of the island's climate divisions. "Long-term" as used in this paper is greater than approximately fifteen years in duration. If complete data sets are not available for all climate zones, certain estimates or assumptions may need to be made; as for example the K_{corr} values, which were assumed to be zero for Climate Divisions 3, 5 and 6 for Puerto Rico.

The values of A and B used in equation 1 were based on temperature-elevation data from approximately eighty locations in Puerto Rico. Most islands will not have this quantity of historical data. Note that the parameter A is the average monthly temperature at an elevation of zero or sea level. Therefore, it is recommended that any long-term temperature data obtained at sea level be averaged and used for the parameter A. The parameter B represents the slope of the temperature-elevation curve. If average temperature data is available from higher elevations within the island, the slopes can be adjusted from the equation $B = (T_z - A_0) / (10^{-5} \cdot Z)$, where T_z is the average temperature at elevation Z, and A_0 is the value of the average temperature at sea level.

The correction factor K_{corr} can be calculated from the difference between the monthly average dew point temperature and minimum air temperature within each climate division. As an approximation, following the Puerto Rico K_{corr} distribution, a value of 1 can be used for the island's northern coast, zero between the northern and southern coast, and -3 in dry areas considered to be more or less semi-arid (often the southwestern coast).

Long-term monthly average wind speed is perhaps the most problematic parameter because it cannot be estimated without historical data. In Puerto Rico, wind speeds from highest to lowest fell into the following order by climate division: north coastal; northern slopes; south coastal; southern slopes; western interior and eastern interior. Perhaps this ordering may exist in other Caribbean Islands.

Solar radiation can be calculated using equations 3 and 4. Values of extraterrestrial radiation (R_a) for the island's latitude range can be obtained from Allen *et al.* (1998).

The methods described in this paper, although approximate, do allow incorporation of the important parameters known to influence the process of evapotranspiration. Ultimately the quality of the ET_0 estimate will depend on the quality and quantity of available long-term measured climate data.

CONCLUSION

This paper describes a simple method for estimating climate data to be used as input to the Penman-Monteith reference evapotranspiration calculation method. Puerto Rico was used as a case study for the method development. Comparison of reference evapotranspiration based on estimated and measured data showed reasonably good agreement. An example was given to illustrate the use of the proposed climate parameter estimation procedure for Dos Bocas, PR. Because of similar climatic conditions, the procedure applied in Puerto Rico, may be generally applicable in other tropical island environments.

REFERENCES

- Allen, R. G., L. S. Pereira, Dirk Raes and M. Smith, 1998. Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome.
- Clarke, D., 1998. CropWat for Windows: User Guide. Version 4.2.0013.
- Capiel, M. and R. J. Calvesbert, 1976. On the climate of Puerto Rico and its agricultural water balance. J. of Agric. Univ. P.R. 60(2):139-153.
- Goyal, M. R., E. A. Gonzalez and C. Chao de Baez, 1988. Temperature versus elevation relationships for Puerto Rico, J. of Agric. Univ. P.R. 72(3):440-467.
- Harmsen, E. W., M. R. Goyal and S. Torres-Justiniano, 2002. Estimating Evapotranspiration in Puerto Rico. UPR Journal of Agriculture. Vol. 86 No. 1 & 2. (in press).
- Kent, R. B. 2002. West Indies. Microsoft® Encarta® Online Encyclopedia 2002.