CONSUMPTIVE WATER USE ESTIMATES FOR PUMPKIN AND ONION AT TWO LOCATIONS IN PUERTO RICO[1]

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ABSTRACT: This study compares consumptive water use (CU) estimates for pumpkin and onion for the SCS Blaney-Criddle and Penman-Monteith methods, at two locations in Puerto Rico. Estimates of monthly CU have been made for numerous agricultural crops in Puerto Rico using the SCS Blaney-Criddle method, during the late 1970s and 1980s. Recently, the United Nation's Food and Agriculture Organization (FAO) has recommended the Penman-Monteith method as the single calculation method that should be used for estimating CU. In this study, large over and under estimates by the SCS Blaney-Criddle method, relative to the Penman-Monteith method, were observed. Results from this preliminary study provide sufficient evidence for recommending recalculation of CU using the FAO-recommended approach for all existing CU databases within Puerto Rico.
KEY TERMS: Consumptive Use; Evapotranspiration; Penman-Monteith; Blaney-Criddle, Pumpkin, Onion.

INTRODUCTION AND OBJECTIVES

Estimates of monthly consumptive use (CU) have been made for numerous agricultural crops in Puerto Rico. These data are essential for determining monthly irrigation volumes, sizing of pumps and water conveyance devices, and for determining irrigation system fixed and operating costs. The majority of published estimates of CU have been made using the Soil Conservation Service (SCS) Blaney-Criddle method. The Penman-Monteith methodology has proved to have global validity as a method for estimating CU, and has been recommended by the United Nation's Food and Agriculture Organization (FAO) as the single approach that should be used (Allen et al., 1998).

Goyal (1989a) used the SCS Blaney-Criddle method to estimate CU for fifteen vegetable crops at Fortuna and Isabela, PR. Estimates were also made for seven other crops by Goyal in other studies. In 1990 a committee of the United Nations Food and Agriculture Organization (FAO) recommended the Penman-Monteith method as the single approach to be used for calculating CU. This recommendation was based on comprehensive studies, which compared several CU calculation methods with weighing lysimeter data (Jensen et al., 1990 and Choisnel et al., 1992). These studies found the Penman-Monteith method to produce superior results, while the SCS Blaney-Criddle method significantly over and under estimated CU. For example, in the American Society of Civil Engineer's study (Jensen et al., 1990), the SCS Blaney-Criddle method was found to overestimate on average by 17% in the humid regions and underestimate on

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average by 16% in the arid regions. Unfortunately the Penman-Monteith method was not available during the 1970s and 80s, a period when CU estimates for numerous crops, using the SCS Blaney-Criddle method, were made in Puerto Rico and published.

The objectives of this study were: (1) To estimate using the Penman-Monteith method, the monthly long-term average consumptive water use (CU) for pumpkin and onion at Fortuna and Isabela, Puerto Rico; (2) To compare these results with estimates previously made using the USDA Soil Conservation Service (SCS) Blaney-Criddle method (SCS, 1970); and (3) to determine if recalculation of the additional crops considered by Goyal (1989a and other studies) should be reevaluated.

PREVIOUS WORK

The SCS Blaney-Criddle method has been used extensively in Puerto Rico, and the associated studies represent a significant percentage of the published literature on consumptive use by crops in Puerto Rico.

Monthly water consumption for fifteen different vegetable crops for Fortuna and Isabela locations in Puerto Rico were made by Goyal (1989a, Goyal and González, 1988a). The SCS Blaney-Criddle approach was used, which is based on monthly percentage of annual daylight, mean air temperature, a crop growth coefficient and a humid area factor for Puerto Rico. The purpose of this research was to estimate CU, net and gross irrigation requirements. The applicability of the data was further enhanced by the fact that each crop was evaluated for various lengths of growing season. As a part of this study, Onion and Pumpkin were evaluated for season lengths varying between 75 and 135 days, and 105 and 165 days, respectively. Furthermore, each growing season was evaluated for starting dates of the 1^{st} and 15^{th} of each month, for a total of 24 predictions for each season length.

The SCS Blaney-Criddle method has also been used for non-vegetable crops. Goyal (1989b) estimated monthly CU for papaya at seven Agricultural Experimental Stations located at Adjuntas, Corozal, Fortuna, Gurabo, Isabela, Lajas and Mayagüez. Average daily CU varied between 2.8 mm/day at Adjuntas and 3.7 mm/day at Fortuna. In widening the geographic extent of the survey the author increased the applicability of the data. However, in this report the author cautioned that the CU estimates have not been compared with experimental data, and that such experimental data are obtained with lysimeters studies and are not available for Puerto Rico.

Goyal and González-Fuentes (1989) used the SCS Blaney-Criddle method to estimated monthly CU for sugar cane at Fortuna, Gurabo, Isabela and Lajas locations in Puerto Rico. The monthly CU was minimum in April and maximum in August at all four sites. Average daily CU varied between 4.1 to 4.4 mm/day. These estimates compared reasonably well with the range for sugar cane determined by the Aguirre area, using a water balance method (Fuhriman and Smith, 1951).

Several other estimates were made using the SCS Blaney-Criddle method involving sorghum at two locations (Goyal and González, 1988b), Plantain at seven locations (Goyal and González, 1988c), and bell and Cubanelle peppers at two locations (Goyal and González, 1988d). In the Plantain study, CU data was estimated for the Gurabo Experiment Station, which can be compared with the results from a water balance study by Abruña et al. (1979). Abruña et al (1979) determined the maximum and minimum CU values to be 3.6 and 1.5 mm, respectively, for September and December. For these same months Goyal and

González (1988c) derived values of 5.1 and 3.82 mm, respectively. It should be noted that Goyal and González (1988c) based their calculations on mean monthly averages climate data, whereas non-average conditions may have been encountered by Abruña et al. (1979) during their study.

METHODS AND MATERIALS

The Penman-Monteith method was used to calculate the long-term monthly average CU for the conditions considered by Goyal (1989a) for Pumpkin and Onion at Fortuna and Isabela, PR; and for season durations of 105, 120, 150 and 165 days for pumpkin; and 75, 90 105, 120 and 135 days for onion.

The consumptive use (CU) or evapotranspiration (ET) was calculated from the following equation:

$$ET = K_c\, ET_o \qquad (1)$$

where K_c is the crop coefficient (dimensionless) and ET_o (mm/day) is the reference evapotranspiration. In this study, the approach used will be referred to as the Penman-Monteith method when K_c is determined by the FAO-recommended procedure and ET_o is calculated using the Penman-Monteith equation. The reference evapotranspiration (ET_o) is defined as the evapotranspiration from a hypothetical grass covering an extensive area, under well-watered, non-stressed conditions. Input to the Penman-Monteith equation includes: maximum and minimum air temperature, humidity, wind speed and radiation. Estimation of the long-term average monthly ET_o was performed using the computer program CROPWAT (Clarke 1998).

Long-term average monthly minimum and maximum air temperatures were obtained from published data for the two Experiment Stations (Goyal, 1988). Long-term average monthly wind speed data were obtained from daily average wind speed collected at the Experiment Stations and published in the National Oceanic and Atmospheric Administration (NOAA) Climatological Data Sheets. Long-term average monthly humidity and radiation were not available for the Experiment Stations; therefore these data were estimated by procedures recommended by the FAO (Allen et al., 1998). Humidity was calculated using the vapor pressure equation with the daily minimum temperature instead of the due point temperature, which only introduces a small error in the relative humidity estimate (Allen, et al., 1998). Radiation was estimated from the following equation recommended by the FAO for island locations:

$$R_s = (0.7R_a - b) \qquad (2)$$

where R_s is solar radiation (MJ $m^{-2}day^{-1}$), R_a is extraterrestrial radiation (MJ $m^{-2}day^{-1}$), and b is a constant equal to 4 MJ $m^{-2}day^{-1}$. The empirical constant (b) represents the fact that in island locations some clouds are usually present, and reduces the average solar radiation by 4 MJ $m^{-2}day^{-1}$ below the nearly clear sky envelope ($0.7R_a$) (Allen, et al., 1998). It should be noted that the FAO recommends using the Penman-Monteith method over all other methods even when local data is missing (e.g., humidity and radiation). Studies have shown that using estimation procedures for missing data with the Penman-Monteith equation will generally provide more accurate estimates of ET_o than will other available methods requiring less input data (Allen et al., 1998).

The effects of characteristics that distinguish the field crops from grass are integrated into the crop coefficient (K_c). Unfortunately it was not possible to use the crop growth coefficients used by Goyal (1989a) as this parameter is not equivalent to the crop coefficient used in equation 1 (Burman, et al., 1981). Consequently, it was necessary to develop crop coefficients independently using the FAO-recommended approach.

Determination of the K_c curves required the use of table values of crop coefficients for three crop stages: initial stage K_{cint}, mid stage K_{cmid} and end stage K_{cend}; crop stage durations (initial stage, development stage, mid-stage and end stage); and adjustments to K_{cint} for wetted area, and K_{cmid} and K_{cend} for wind speed, relative humidity and crop height. Table values of K_{cint}, K_{cmid} and K_{cend} for onion and pumpkin were obtained from Allen (et al., 1998). The crop stage durations were approximated by graphing the crop growth coefficients used by Goyal (1989a). The initial stage wetted area was assumed to be 40%, which is consistent with drip-irrigated conditions common in Puerto Rico.

RESULTS AND DISCUSSIONS

In this section, results of comparisons between the Penman-Monteith (PM) and the SCS Blaney-Criddle (SCS BC) methods are presented. Based on weighing lysimeter comparison studies reported by Jensen, et al. (1990), we will assume that the Penman-Monteith method is capable of producing results similar to a weighing lysimeter, and consequently will be considered the standard against which the SCS Blaney-Criddle method will be evaluated. Therefore, a statement such as “the SCS Blaney-Criddle method underestimated,” implies that the SCS Blaney-Criddle method produced a CU value, which was less than the Penman-Monteith method. Since the seasonal differences in CU are taken as SCS BC minus PM, a negative difference represents an underestimation by the SCS BC method, and a positive difference represents an overestimation by the SCS BC method.

In Figure 1, the differences (DELTA) in the seasonal CU, as calculated by the two methods, are plotted on the vertical axes versus time in months on the horizontal axes. Figure 1 shows:

- At Fortuna, during May through October, the SCS BC method overestimated seasonal CU for onion and pumpkin by around 80 to 90 mm (3.1 to 3.5 inches). This trend was reversed during the winter months, with a maximum underestimation of around 50 to 60 mm in December and January. If the grower used the SCS BC method data for estimating crop water requirement, he might apply an excess amount during the summer, which could result in leaching of agricultural chemicals and contamination of the groundwater.
- At Isabela, the SCS BC method tended to underestimate during most of the year for onions, with some months where some of the treatments (i.e., season durations) overestimated. Maximum underestimation by the SCS BC method was greater than 100 mm in January.

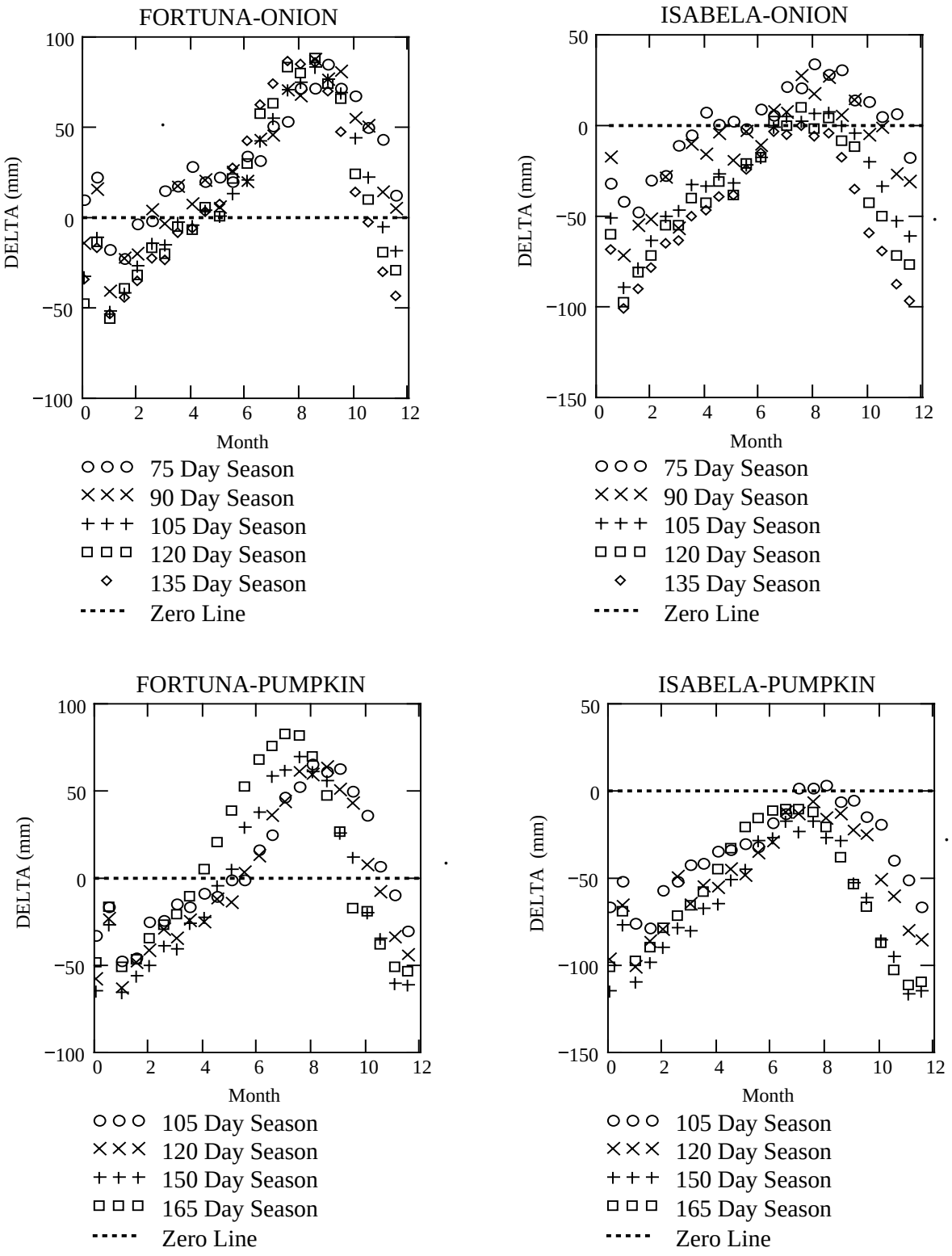

Figure 1. Differences (DELTA) in the seasonal consumptive use (CU) estimates between the SCS Blaney-Criddle (SCS BC) and Penman-Monteith (PM) methods. (DELTA = SCS Blaney-Criddle minus Penman-Monteith)

- At Isabela, the SCS BC method underestimated for virtually all months. Relatively good agreement was observed between the two methods during midsummer. The largest overestimations were greater than 110 mm in December and January.

Table 1 presents the results of a statistical analysis, in which paired T-tests were performed to determine if a significant difference existed (at the 99% confidence level) between the mean seasonal CU estimates for the two methods. The mean seasonal CU values are averages of all estimates for a crop at a location. For example, the seasonal water consumption for onion at Fortuna was determined for five different season lengths and twenty-four season starting dates. In this example, the sample size used in the paired T-test for comparing the SCS BC and PM methods was 24 x 5 = 120 pairs of data. In all cases but the pumpkin at Fortuna, there was a significant difference in the seasonal mean CU estimate at the 99% confidence level. There was no statistically significant difference between the mean seasonal CU for the two methods for pumpkin at Fortuna. This result does not mean that the two methods were in agreement (see Figure 1), but only that there mean seasonal CU was in agreement. Table 1 also shows the results of the paired T-test for all CU estimates combined individually for each method. On average the SCS BC method under estimated the seasonal mean CU relative to the PM method by 16.47 mm or 0.65 inches. As in the case of pumpkin at Fortuna, this result may be misleading, as a 16.47 mm deviation is not very serious. However, if you consider the results in Figure 1, there were periods during the year when severe over and under estimation by the SCS Blaney-Criddle method were observed.

Table 1. T-Test results showing significance differences between the mean seasonal consumptive use estimates for the SCS Blaney-Criddle and Penman-Monteith methods.

Crop	Location	Tvalue	Tcritical value	Seasonal Mean SCS Blaney-Criddle (mm)	Seasonal Mean Penman-Monteith (mm)	Mean Difference (mm)	Significant Difference @ the 1% Level
Onion	Fortuna	5.23	2.62	421.50	402.50	19.01	YES
Pumpkin	Fortuna	0.02	2.63	477.55	477.55	0.07	NO
Onion	Isabela	10.77	2.62	379.53	416.19	-36.67	YES
Pumpkin	Isabela	15.76	2.63	444.39	496.51	-52.12	YES
Onion and Pumpkin	Fortuna and Isabela	7.20	2.59	427.38	443.85	-16.47	YES

Figure 2 shows an example of the daily evapotranspiration for a 120-day onion crop started on February 1st. The peak ET was 5.86 mm/day and 4.53 mm/day for the Penman-Monteith and the SCS Blaney-Criddle methods, respectively. The peak ET is an important design parameter used to design irrigation systems. An underestimate in the peak ET can result in the design of an irrigation system that does not have sufficient capacity to meet the peak

water demand. In most cases the system can be run longer to provide the additional water needed. However, if the system is designed to run for a large number of hours per day (e.g. 20 hr/day) then it may not be possible to increase the application time.

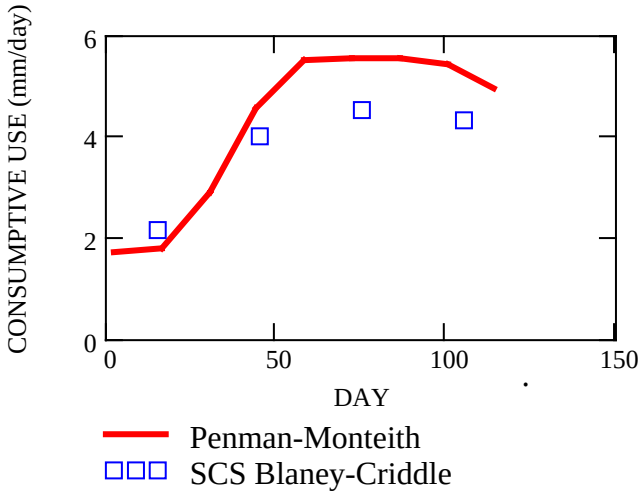

Figure 2. The daily consumptive use (CU) for onions at Fortuna, PR, for a 120-day season starting on February 1st.

CONCLUSIONS

From this study the following conclusions can be made:

1. Large potential differences can be expected between the SCS Blaney-Criddle and the Penman-Monteith methods, with underestimations some months and overestimation in other months.
2. For Fortuna, the SCS Blaney-Criddle method appears to overestimate seasonal CU (for both crops) during the summer months and underestimate during the winter months.
3. For Pumpkin at Isabela, the SCS Blaney-Criddle method may underestimate CU throughout most of the year. Onion at this location exhibited a similar trend but showed more overestimation of CU during the summer months.
4. The literature review indicates that monthly average CU estimates have been determined for twenty-two crops by means of the SCS Blaney-Criddle method. Considering the fairly extensive CU database developed for Puerto Rico, and the potential errors in the methods upon which they are based, a recalculation of these data is imperative using the FAO Penman-Monteith equation.

REFERENCES

Abruña, F. J. Vicente-Chandler, H. Irizarry and S. Silva. 1980. Evapotranspiration with Plantains and the Effect of Frequency of Irrigation on Yields. J. Agric. U.P.R. 64(2):204-10.

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.

Burman, R.D., P.R. Nixon, J. L. Wright, W. O. Pruitt, 1981. Water Requirements, Chapter 6 in Design and Operation of Farm Irrigation Systems. American Society of Agricultural Engineers, Edited by Marvin E. Jensen, St. Joseph, Michigan.

Choisnel, E., O. De Villele, and F. Lacroze, 1992. “Une approache uniformisée du calcul de l’ évapotranspiration potentielle pour l’ensemble des pays de la Communauté Européenne.” Com. Commun. Européennes, EUR 14223 FR, Luxembourg, 176 pp.

Clarke, D. 1998. CROPWAT for Windows: User Guide. Version 4.2.0013.

Fuhriman, D. K. and r. M. Smith, 1951. Conservation and consumptive use of water with Sugar Cane under irrigation in the south coastal area of Puerto Rico. J. of Agric. University of Puerto Rico, Vol. 35(1):1-45.

Goyal M. R., 1989a. Estimation of Monthly Water Consumption by Selected Vegetable Crops in the Semiarid and Humid Regions of Puerto Rico. AES Monograph 99-90, June, Agricultural Experiment Station, University of Puerto Rico Rio Piegras, PR.

Goyal M. R., 1989b. Research Note: Monthly consumptive use of papaya at seven regional sites in Puerto Rico. J. Agric. U.P.R. 73(2):00.

Goyal, M. R. and E. A. González, 1988a. Water Requirements for Vegetable Production in Puerto Rico. ASCE Symposium on Irrigation and Drainage, July.

Goyal M. R., and E. A. González (1988b). Requisitos de riego para sorgo en las costas Sur y Norte de Puerto Rico. J. Agric. University of Puerto Rico. 72(4)585-98.

Goyal, and E. A. González (1988c). Requisitos de riego para plátano en siete regions ecológicas de Puerto Rico. J. Agric. University of Puerto Rico. 72(4):599-608.

Goyal and González (1988d). Seasonal consumptive use of water by bell and Cuanelle peppers in semiarid and humid coastal sites in Puerto Rico. J. Agric. U.P.R., 72(4):609-14.

Goyal, M. R. and E. A. González-Fuentes, 1989. Estimating Water Consumptive Use by sugarcane at four regional sites in Puerto Rico. J. Agric. U.P.R. 73(1):00

Jensen, M. E., R. D. Burman, and R. G. Allen. 1990. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice No. 70. 332 pp.

SCS, 1970. Irrigation Water Requirements, Technical Release No. 21. USDA Soil Conservation Service, Engineering Division.