SUELO Y AGUA
SOIL AND WATER

ARTÍCULO ORIGINAL

Estimación de los coeficientes de cultivo de la papaya para mejorar la programación del riego en el sur de La Habana

Estimation of the papaya crop coefficients for improving irrigation water management in south of Havana

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RESUMEN. La papaya (*Carica papaya L.*) es una de las principales frutas regadas en Cuba y en las regiones tropicales y subtropicales. Para los intereses medioambientales y de programación de riego, es importante estimar la evapotranspiración del cultivo y los requisitos para la precisión de la programación del riego. El objetivo del presente estudio es determinar los coeficientes de cultivo (Kc) y la fracción de agotamiento sin estrés hídrico (p) de la papaya, variedad Maradol, cultivada en el sur de La Habana. Los experimentos tuvieron lugar durante el período de marzo – noviembre de 1997 en una área experimental dónde predominan los suelos ferralíticos rojos. El modelo de simulación ISAREG se aplicó a los datos observados. La calibración del modelo consistió en la búsqueda de los coeficientes de cultivo y la fracción de agotamiento minimizando las diferencias entre los valores de humedad del suelo observados y simulados. Se usaron varios indicadores estadísticos para evaluar la bondad de ajuste. Los resultados muestran un ajuste bueno entre las observaciones y predicciones del modelo, con el coeficiente de la regresión forzado al origen cerca de 1 (b = 1.01) y un R^2 alto = 0.86. La raíz del error medio cuadrático (RMSE) y el error medio absoluto (AAE) es pequeño, respectivamente RMSE = 6.5 mm y AAE = 4.9 mm. Después de la calibración, el modelo fue usado para evaluar la planificación de la irrigación actual; muestra de los resultados que se previeron las fechas de la irrigación relativa a los requerimientos y profundidades de la irrigación sea excesiva, así como un drenaje profundo. El modelo de ISAREG se usará para generar más allá y para evaluar horarios de la irrigación alternativos apuntados a la productividad de agua mejorada.

Palabras clave: balance de agua en el suelo, modelación.

ABSTRACT. The papaya (*Carica papaya* L.) is a main irrigated fruit crop in Cuba and in the tropical and subtropical regions. For environmental and irrigation management purposes, it is important to accurately estimate its crop evapotranspiration and irrigation requirements. The objective of the present study is to determine the crop coefficients (K_c) and the depletion fraction for no stress (*p*) of the papaya, variety Maradol, as cultivated in southern Havana. Experiments took place during the period March – November, 1997 in an experimental area where soils are compacted red iron soils. The ISAREG irrigation simulation model was applied to those observed data. The calibration of the model consisted in searching the crop coefficients and the depletion fraction for no stress that minimize the differences between observed and simulated available soil water. Several statistical indicators were used to assess the goodness of fit. Results show a good adjustment between observations and model predictions, with the regression coefficient forced to the origin close to 1 (*b* = 1,01) and a high R^2 = 0,86. The root mean square error (*RMSE*) and the average absolute error (*AAE*) are small, respectively *RMSE* = 6,5 mm and *AAE* = 4,9 mm. After calibration, the model was used to assess the current irrigation scheduling; results show that irrigation dates were anticipated relative to the required and irrigation depths were excessive, thus a large percolation occurred. The ISAREG model will be further used to generate and evaluate alternative irrigation schedules aimed at improved water productivity.

Keywords: soil water balance, modelling, irrigation management.

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INTRODUCTION

The papaya (*Carica papaya* L.) is one of the main fruit trees in the tropical and sub-tropical countries. This relates to the high nutritional value of the fruit, its excellent flavor, and utility for food industry (Alonso *et al.,* 2008). Environmental factors such as temperature (Campostrini and Glenn, 2007), wind speed, water stress (Marler and Clemente, 2006) and soils chemical and physical characteristics affect papaya productivity and physiology (Campostrini and Glenn, 2007).

Papaya irrigation management relates both with excess and deficit soil moisture. A water deficit restricts the plant growth and favors the production of male flowers (Terra de Almeida *et al.,* 2003; Niklas and Marler, 2007; dos Santos *et al.,* 2008), reducing the production of fruits (Aiyelaagbe *et al.,* 1986; Masri *et al.,* 1990; Kruger and Mostert, 1999). Studies have shown that the crop stages more sensitive to water stress are the mid vegetative stage, flowering and fruit enlargement (Aiyelaagbe *et al.,* 1986). Excess irrigation affects the absorption of nutrients, favours their lixiviation, decreases oxygen availability in the root zone, and increases plant propensity to diseases (Campostrini and Yamanishi, 2001; Campostrini and Glenn, 2007). Several studies indicate that papaya should be cropped in soils with good structure and internal drainage, thus avoiding waterlogging that may cause severe damages to the plant, even its death (dos Santos *et al.,* 2008). Hence, good irrigation management practices are needed when papaya has to attain high levels of production. However, there are few publications dealing with water requirements of papaya.

Papaya is a main crop fruit in Cuba, with approximately 5000 ha harvested (Alonso et al., 2008). The establishment of papaya in the South of Havana is being promoted because favorable climatic and soil conditions exist there. It is therefore important to develop appropriate irrigation schedules to improve papaya irrigation management and water productivity.

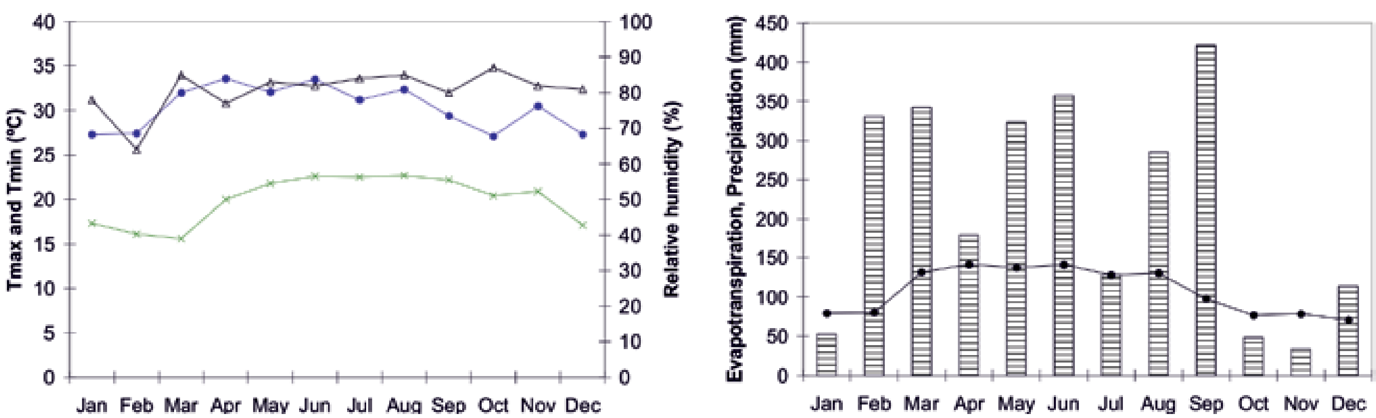
Mathematical models for simulating the soil water balance are useful tools for irrigation management (Pereira *et al*., 2003) but require proper calibration before being used for different crops and environments. This is the case of the ISAREG irrigation scheduling simulation model, which performs the soil water balance at field level and simulates alternative irrigation schedules (Teixeira and Pereira, 1992; Pereira *et al*., 2003) including assessing the impacts of those irrigation schedules on crop yields. This model has been used world-wide for a variety of crops and environments (e.g., Liu *et al*., 1998, 2006; Popova *et al*., 2006; Cholpankulov *et al*., 2008), including for Cuban conditions (Chaterlán et al., 2008, 2009).

The objective of this study is to determine the crop coefficients (K_c), and the depletion fraction for no stress (p) for papaya, which are not available in literature. Calibrating the model for its further use in irrigation management in Cuba is another objective of the study.

METHODS

Experimental site characterization

Field data were collected at the IIRD Experimental Station, located in the municipality of Alquizar; province of La Habana, Cuba (latitude 22º 46' N; Longitude 82º 37' W; altitude 6 m) during the period March to November of 1997. A climatic characterization of the experimental site for that year (1997) is presented in Figure 1. The reference evapotranspiration (ET_o) was computed using the FAO-PM method (Allen *et al.,* 1998). According to the methodology locally developed by Pacheco *et al*. (1995), 1997 is considered a wet year, with annual precipitation of 2 118 mm, ranging 34 to 421 mm month^{-1}. For this year, precipitation largely exceeded ET_o except for the dry season.



a) b)

FIGURE 1. Climatic data: a) maximum (—●—) and minimum (—✕—) temperature, and mean relative humidity (—△—), b) monthly precipitation (▤) and monthly reference evapotranspiration, ET_o (—●—).

Soils are red iron compacted soils, Rhodic Ferralsol according to the classification of FAO/UNESCO (Institute of soil, 1996a, b), also called clayey (Cid, 1995). Main characteristics of these soils are presented in Table 1. The total available soil water (*TAW*) averages 119 mm when the rooting depth is 0,70 m. Observations of soil water potential were performed with tensiometers at 0,20, 0,40 and 0,60 m with 3 measurements at each depth (Hernández *et al.,* 2003). Soil water content data were obtained through the Van Genuchten model (López, 1996).

Field experiments were carried out with the papaya tree (*Carica papaya* L.) variety Maradol, with a plant density of 1 851 plants ha^{-1}; Experiments were performed in the period 20 March to November 6, 1997. The dates for the papaya crop growth stages are given in Table 2.

Micro-irrigation was used. Irrigation uniformity tests were carried out (Pizarro, 1990); the uniformity coefficient was UC = 90% and the application efficiency was 85%. Table 3 shows the irrigation schedule used in the experiments; the total irrigation applied was 157 mm, with irrigation depths ranging 6,10 – 28,14 mm.

TABLE 1. Soil physical characteristics of the Alquizar experimental site, Havana

Soil layer (m)	Sand (%)	Silt (%)	Clay (%)	θ_{FC} ($m^3\ m^{-3}$)	θ_{WP} ($m^3\ m^{-3}$)
0,0-0,40	18,50	22,39	59,17	0,46	0,29
0,40-0,60	22,10	13,78	64,12	0,45	0,27
0,60-1,00	24,71	23,50	51,78	0,45	0,29

θ_{FC} and θ_{WP} represent the soil water content at field capacity and wilting point

TABLE 2. Papaya crop development stages, Alquizar, Havana (1997)

Crop Growth stages	Dates
Planting/Initiation	20 Mar
Start rapid growth	20 Apr
Start mid-season	23 Jul
Start senescence/maturity	16 Sep
End-season/harvesting	6 Nov

TABLE 3. Irrigation dates and depths (mm) relative to the testing trial

Date	Irrigation depth (mm)	Date	Irrigation depth (mm)
9 May	17,34	2 Jul	20,20
26 May	12,43	12 Jul	20,60
31 May	8,90	17 Jul	6,12
6 Jun	6,73	9 Aug	13,66
21 Jun	28,14	27 Aug	10,20
27 Jun	6,12	22 Oct	6,10

The ISAREG model

The ISAREG model (Pereira *et al.,* 2003) was selected to simulate and assess alternative irrigation schedules for papaya after proper calibration. Experimental data collected at the Irrigation Station of Alquízar were used to calibrate the model. The procedure applied is described in former applications to horticultural crops in the same location (Chaterlan *et al.,* 2008, 2009). The actual crop evapotranspiration (ET_a) is lower than ET_c when the soil water depletion exceeds the depletion fraction for no stress (p). ET_a is estimated through the soil water balance as a function of the available soil water in the root zone as described by Teixeira and Pereira (1992). Depletion is limited to the management allowed depletion (MAD). When water stress is not admitted, then $MAD \leq p$ is adopted; when deficit irrigation is applied then $MAD > p$.

The model computes the water balance for a multilayered soil and is able to consider the impacts of salinity (Pereira *et al.,* 2007) and to estimate the groundwater contribution (GC) through a parametric function (Liu *et al.,* 2006). The impact of the water stress on crop yields is evaluated with the Stewart model (Stewart *et al.,* 1977).

Goodness of ISAREG model simulations

In order to assess the goodness of model predictions, qualitative and statistical strategies were used. The qualitative strategy consisted of representing graphically comparisons between soil water content values observed in the field and those simulated by the model. This strategy provides a good perception of the trends and/or biases in modeling and when they occur. The second assessment strategy used linear regression forced through the origin between observed and predicted soil water content data. When the regression coefficient (b) is close to 1 then the covariance is close to the variance of the observed values which means that the predicted and observed values are statistically close; if the determination coefficient (R^2) is also close to 1,0, then most of the total variance of the observed values is explained by the model. Additionally, two indicators of residual estimation errors were used. The selected indicators are based upon former applications (Liu *et al.,* 1998; Cholpankulov *et al.,* 2008; *Chaterlan et al.,* 2009).

The indicators are defined bellow:

1) the Regression and determination coefficients relating observed and simulated data, b and R^2:

$$b = \frac{\sum_{i=1}^{n} O_i P_i}{\sum_{i=1}^{n} O_i^2} \qquad (1)$$

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} \left(O_i - \overline{O}\right)\left(Pi - \overline{P}\right)}{\left[\sum_{i=1}^{n} \left(O_i - \overline{O}\right)^2\right]^{0.5} \left[\sum_{i=1}^{n} \left(P_i - \overline{P}\right)^2\right]^{0.5}} \right\}^2 \quad (2)$$

2) the root mean square error, RMSE, which characterizes the variance of the estimation errors:

$$RMSE = \left[\frac{\sum_{i=1}^{n} \left(P_i - O_i\right)^2}{n} \right]^{0.5} \quad (3)$$

3) the average absolute error, *AAE*, which expresses the size of estimation errors in alternative to *RMSE* ,is

$$AAE = \frac{1}{n} \sum_{i=1}^{n} \left| O_i - P_i \right| \quad (4)$$

where O_i and P_i (i = 1, 2, …, n) are the pairs of observed and model predicted values of a given variable, and Ō and P are the respective mean values:

RESULTS AND DISCUSSION

The calibration procedure consisted on adjusting the crop parameters K_c and *p* considering the range of values they can assume, in order to minimize the difference between observed and simulated available soil water. The calibrated values are presented in Table 4. The results from comparing the simulated and the observed available soil water (mm) are presented in Figure 2. The soil water in excess is also represented in Figure 2 between field capacity (*FC*) and soil saturation (dashed line above *TAW*); it corresponds to drainable water due to rainfall or to excess irrigation. To note that 3 observations were performed after irrigation and precipitation occurred and therefore they lay above *FC*. Results show that the field observed values cover a large range of soil water content values and that the model simulates well.

TABLE 4. Calibrated crop coefficients (K_c) and depletion fractions for no stress (*p*), corresponding to crop growth stages (Table 2) for the calibration experiment (1997), Havana

	Crop growth stages			
	Initial	**Development**	**Mid season**	**End season**
Crop coefficients, K_c	0,90	0,90-1,10	1,10	0,90
Depletion fraction, *p*	0,40	0,40	0,40	0,40

The computed goodness of fitting indicators are as follows: *b* = 1,01, thus indicating that predicted values are close to the observed ones; R^2 = 0,86, hence expressing that most of the variance is explained by the model; and the estimation of errors *RMSE* = 6.5 mm and *AAE* = 4,9 mm, representing less than 5% of *TAW*, thus indicating that estimation errors are small and that there is a good agreement between simulated and observed available soil water. Summarizing, results indicate that the model performs well the simulation of the soil water balance of the micro-irrigated papaya.

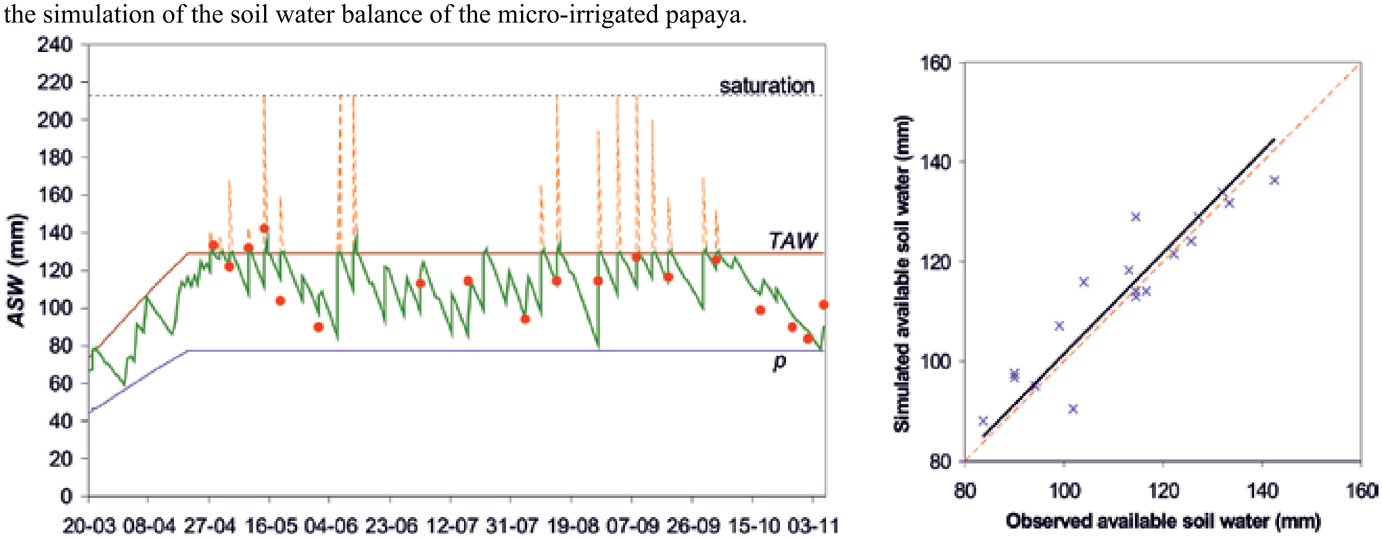


FIGURE 2. Comparison between observed and simulated available soil water content for papaya at the Irrigation Station of Alquízar, Cuba: on the left, the simulated curve of the available soil water (——) compared with observed values (●); on the right, the regression between observed and simulated available soil water values, 1997.

The irrigation schedule used in the calibration experiment was evaluated. Results (Table 5) show that deep percolation attained very high values (40% of the total used water, *i.e.,* the sum of irrigation and precipitation). Irrigation depths were high (up to 28 mm), also favoring deep percolation and poor use of precipitation. Thus, the current irrigation schedule is not appropriate to cope with water scarcity conditions. A more efficient use of the irrigation water is required. This implies that irrigation dates should be better adjusted and irrigation depths controlled to decrease deep percolation.

An improved irrigation schedule using *MAD = p* with a fixed irrigation depth of 8 mm was also simulated. Results are presented in Table 5 showing that a decrease in season irrigation may be adopted without promoting any stress but decreasing deep percolation.

TABLE 5. Summary of main outputs of the soil water balance of papaya using the current and improved schedules

Water balance components	Current	Improved
Season irrigation (mm)	157	96
ASW at planting (mm)	67	67
ASW at harvesting (mm)	91	93
Precipitation (mm)	1781	1781
Non-used precipitation (mm)	232	210
Percolation (mm)	801	481
ET_m (mm)	931	931
ET_a (mm)	931	931

CONCLUSIONS

- The ISAREG model was successfully calibrated using past observation data of micro-irrigated papaya, including the available soil water. Results show that the regression coefficient relating simulated and observed data was close to 1.0 and a high determination coefficient (0,86) was obtained. The estimation errors *RMSE, AAE* are small respectively 6,5 and 4,9 mm, representing less than 5% of soil *TAW*. Therefore, it can be concluded that the study produced good estimates of the crop coefficient and depletion fraction for no stress. Furthermore, the analysis of the current irrigation schedule showed high non-beneficial water use as deep percolation, and an inadequate use of the precipitation. Further developments may be attained when using the model to design improved irrigation strategies aiming higher water productivity and saving.

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