RIEGO Y DRENAJE

ARTÍCULO ORIGINAL

Estimation the water needs of some vegetables using the methodology of dual cultural coefficients

Estimación de necesidades hídricas de algunas hortalizas utilizando la metodología del coeficiente dual del cultivo

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ABSTRACT. In recent years there has been a notable increase in the activity of irrigation in agricultural areas for the cultivation of different vegetables so it is interesting the constant updating of knowledge and the technical and agronomic necessary for proper irrigation scheduling from the estimation of water requirements of these crops. For this we used the model SimDualKc which effected the calculation of crop evapotranspiration (ET_c) and irrigation scheduling based on the methodology of dual cultural coefficients ($K_c = K_{cb} + K_e$). We used field observations obtained in research conducted at the Experimental Station of Irrigation and Drainage, located in Alquízar, Cuba, developed between the period of the decades of the 80 and 90. The cultures used were garlic, onion, bell pepper and carrot. The calibration consisted of adjusting the parameters are not observed to be, taken from the set values (K_{cb}, *p, TEW, REW, TAW, RAW and* f_c) so as to minimize differences between observed and simulated soil moisture content. Was evaluated goodness of fit of the model's predictions, performing a series of statistical analysis used to verify that the coefficient of regression (*b*) is close to 1 in all cases, the R^2 varies between 0.80 and 0.97. It permitted to arrive at the conclusion that the model can be used to generate alternative irrigation schedules in these soil and climatic conditions.

Keywords: evaporation, transpiration, soil water balance, modeling, crop evapotranspiration.

RESUMEN. Resulta notable el aumento de la actividad de riego en las áreas agrícolas para el cultivo de hortalizas en los últimos años para lo que resulta necesaria la actualización constante del conocimiento y los requerimientos técnicos y agronómicos para una planificación adecuada a partir de la estimación de las necesidades hídricas de estos cultivos. Para esto usamos el modelo SimDualKc que efectúa el cálculo de la evapotranspiración del cultivo (ET_c) y la programación del riego basado en la metodología de los coeficientes culturales duales ($K_c = K_{cb} + K_e$). Fueron usadas observaciones de campo obtenidas en investigaciones realizadas en la Estación Experimental de Riego y Drenaje, localizada en Alquízar, Cuba, desarrolladas entre de las décadas de los 80 y 90. Los cultivos estudiados fueron ajo, cebolla, pimiento y zanahoria. La calibración consistió en ajustar los parámetros no observados, tomando los valores fijos (K_{cb}, *p, TEW, REW,* f_c) para minimizar las diferencias entre los valores observados y simulados del contenido de humedad de agua en el suelo. Se evaluó la bondad de ajuste de las predicciones del modelo, a partir de una serie de análisis estadístico que permitieron verificar que el coeficiente de regresión (*b*) está cerca de 1 en todos los casos, el R^2 varío entre 0.80 y 0.97. Se llegó a la conclusión que el modelo puede usarse para generar alternativas de programación del riego para estas condiciones edafoclimàticas.

Palabras clave: evaporación, transpiración, balance de suelo agua, modelación, evapotranspiración del cultivo.

INTRODUCTION

Sustainable use of resources that make up the agricultural production system is one of the means of support of environmental conservation. Among these, stands the water, finite and fundamental element for the development of agriculture. One of the main problems that it has been facing nowadays is the low implementation of advanced technologies for irrigation forecasts in real time so there are still using traditional methods by which water consumption is higher.

Most vegetables grow in the dry season and are sensitive to water deficit in the soil, thus requiring frequent irrigation and light to ensure soil moisture above 75% of the available taking into account those edaphoclimatic conditions in the period that rainfall is insufficient to satisfy the water demand. Irrigation management is performed according to crop water needs, so that will allow crops to reach their productive potential. For a rational forecast of water management is very important to know the crop evapotranspiration during the development phases since it is the most important element of the water balance. The study of this process and the determination of the coefficients dual cultural phases, are essential for designing and managing irrigation, allowing for increased productivity with the optimization of water resources (Allen *et al*., 1998, Jimenez *et al*., 2010).

In the literature concerning the management of irrigation of these vegetables (Kipkorir *et al*, 2002; Zamora *et al*, 2004[1]; Martin de Santa Olalla *et al*, 2004; Villalobos *et al*, 2004; Sezen *et al*, 2006; Siebert *et al*, 2007; Kumar et al., 2007; Bossie *et al*, 2009; López-Urrea *et al*., 2009; Jimenez *et al*, 2010; Chaterlán *et al*, 2011; Alam *et al*, 2010; Foday *et al*, 2012 and Nagaz Kamel *et al*, 2012) the vast majority related to the determination of the cultural coefficients means (K_c) in their work, which is insufficient for what has been discussed in relation to the using the methodology of dual cultural coefficients which highlights the results reported by Jimenez *et al*., 2010 for the cultivation of onion in Albacea, Spain.

The calculation of crop evapotranspiration (ET_c) using the methodology of cultural factors means (K_c) provides satisfactory results for calculations with different time slots, including the estimation of daily evapotranspiration for most applications (Pereira *et al*, 2007). However, for high frequency irrigation such as drip irrigation, and for crops with partial coverage of the soil as is the case for fruit and vegetables, as well as regions with frequent rainfall, the use of methodology of dual crop coefficients can produce more accurate estimates of evapotranspiration of the culture (Allen *et al*., 2005). In fact, dividing the coefficient cultural (K_c) in the components of soil evaporation (K_e) and the basal culture coefficient (K_{cb}) allows a better perception of the fractions of water from rainfall or irrigation, used by the crop and to evaluate the benefits of maintaining a dry soil fraction or the use of mulches to control soil evaporation (*E*).

The model SimDualKc (Rosa *et al*., 2010), considered separately soil evaporation and crop transpiration, analysing the way the water of precipitation and irrigation water are used by the crop. SimDualKc carried out the soil water balance at the level of the plot, using daily time periods and offering different approaches to estimate deep percolation, capillary rise and surface runoff. The model can simulate the use of mulches and cover crops active. Results on the determination of dual coefficients, the fraction of ground cover (f_c) and a number of variables such as readily evaporable water (*REW*) and the total water evaporable or maximum depth of water can be evaporated in the soil (*TEW*) for vegetables under the conditions of the study area, which until now have not been considered in this type of crop and are not available in the literature are estimated from the calibration and validation of the model for subsequent use in management of alternative irrigation scheduling in conditions of scarcity of water.

The calibration process and validation of this useful tool, allowed to reach the execution of the objective of this consistent work in estimating the necessities of water of these vegetables using the methodology of the dual cultural coefficients with the purpose of to improve the administration of the watering and to generate alternative calendars of watering.

METHODS

The research was conducted at the Experimental Station of Irrigation and Drainage, located in the municipality Alquízar, Artemis Province (latitude 22° 46 'N, longitude 82° 37' N and 6 m in height). The experiments that form were developed during the period between the 80s and 90s ò of this century. Climatic characterization for this period (1985-1998) is shown in Fig 1. The reference evapotranspiration (ET_o) was calculated using the FAO-PM method (Allen *et al*., 1998).

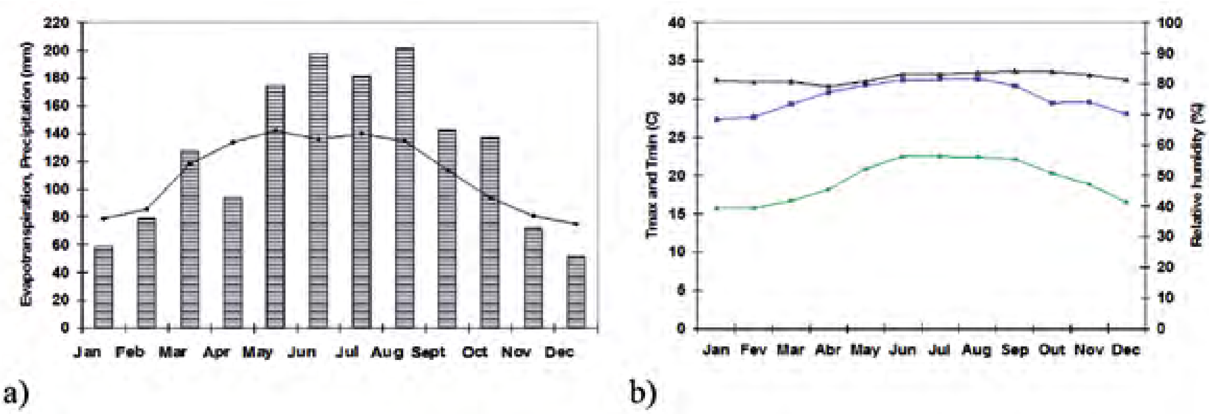


FIGURE 1. Climatic data: a) monthly precipitation ( ) and monthly reference evapotranspiration, ET_o, b) ( ) maximum ( ) and minimum ( ) temperature, and mean relative humidity ( ).

The ground where the research was conducted is classified as red Ferralitic compacted, or Rhodic Ferralsols, according to FAO / UNESCO, which is characterized by clayey, deep and very permeable. The observations of soil water potential were made

[1] ZAMORA, E., CHATERLÁN, Y., OSORIO, M., PÉREZ, R., LAMBERT, M., DUARTE, C., LEÓN, M., CISNEROS, E., REY, R. y GIRALT, E.: Informe final del proyecto: Ajuste de coeficientes para el pronóstico de riego en Cuba, Archivo Técnico Consejo Científico IIRD. La Habana, 34pp., (in Spanish), 2004.

using the gravimetric method, in the case of garlic, onion and carrot to a depth of 0.30 m, and 0.40 for pepper, with 3 replicates at each depth. The TAW was 27 mm for crops onion and garlic, 31 mm for carrots and 40 for the pepper. In all cases studied, the cultures were irrigated through an irrigation system for high frequency micro-spraying; micro sprinklers 41 L/h.

The model calculates the ETc SimDualKc using data on soil, climate, crop and irrigation system. The weather data include the maximum and minimum temperature, average wind speed, rainfall, and ET_o or calculated using ET_o temperatures. Data on culture include the identification of the duration of the phases of the crop cycle, the evolution of cover soil, root growth and crop height during the cultural cycle, and the selection of the corresponding tabulated K_{cb}, the adjustment of K_{cb} tabulated for specific climatic conditions of the study region, the daily calculation of the values of $K_{e,}$ and calculate daily ET_c. Using this method runs the simulation model of soil water balance, from which we derive proposals for irrigation scheduling.

The methodology for its determination using the estimated coefficients dual culture (Allen *et al*., 1998, 2005) is the adoption of the following formulation:

$$ET_c = (K_s K_{cb} + K_e) ET_o \tag{1}$$

All observations for these vegetables were used to calibrate the model under the conditions of the experimental area and derive the dual crop coefficients and other outcome variables of interest.

In order to evaluate the goodness of fit of the model predictions SimDualKc, there were a series of statistical analysis that can have a good perception of trends set in the model using a regression forced to the origin. The indicators used were: regression coefficient (*b*), coefficient of determination (R^2), the mean square error (*RMSE, mm*), the maximum absolute error (*AAE, mm*), the mean relative error (*ARE, %*), modeling efficiency (*EF*) and the rate of adjustment (D_{IA}). The selected indicators are based on applications previously made (Chaterlán *et al*., 2011).

RESULTS AND DISCUSSION

The calibration consisted of finding the dual cultural coefficients for the different stages of development of these vegetables from the adjustment of the parameters taken from observed values set ($K_{cb,}$ p, *TEW, REW*) by minimizing the differences between the observed and simulated values of soil moisture content. Table 1 shows the calibrated values. For its part, the validation was the use of these calibration values in the simulation of other experimental results in the same place in different time periods.

TABLE 1. Calibrated crop coefficients (K_{cb}) and depletion fractions for no stress (p), and dates of crops growth stages for the calibration and validation experiments

Parameter				
	Crop coefficients and depletion fractions for no stress			
	Onion	**Garlic**	**Carrots**	**Sweet pepper**
K_{cini}	0.15	0.15	0.15	0.15
K_{cmid}	0.95	0.95	0.95	0.95
K_{cend}	0,65	0.65	0.80	0.75
p_{ini}	0.50	0.40	0.40	0.40
p_{dev}	0.50	0.50	0.40	0.40
p_{mid}	0.50	0.50	0.40	0.50
p_{end}	0.60	0.50	0.40	0.50
REW (mm)	5	5	5	5
TEW (mm)	15	25	15	24
Z_e ***(m)***	0.10	0.10	0.10	0.10
	Crop growth stages			
Period length	Onion	Garlic	Carrots	Sweet pepper
Initial	20/11-20/12	04/12-24/12	22/11-08/12	16/12-20/01
	25/12-24/01	23/12-12/01	20/11-04/12	05/12-09/01
Development	21/12-29/01	25/12-28/01	09/12-17/01	21/01-19/02
	25/01-05/03	13/01-16/02	05/12-11/01	10/01-08/02
Mid season	30/01-20/03	29/01-09/03	18/01-11/02	20/02-14/03
	06/03-24/04	17/02-27/03	12/01-30/01	09/02-04/03
End season	21/03-17/04	10/03-08/04	12/02-11/03	15/03-18/04
	25/04-24/05	28/03-26/04	31/01-16/02	05/03-07/04

Cal – calibration year; Val – validation year

The graphic representation of the observed and simulated variation of the moisture of soil water during the growth cycle of these vegetables is presented from Figure 2 to Figure 5.

The results obtained related to the K_{cb} coefficients, significantly improve (while comparing average K_c, Chaterlán *et al.,* 2011) the estimated fractional precipitation water and irrigation used by these vegetables during the cultivation cycle and the amount of water that is consumed by the plant by respiration and the portion which is consumed by the evaporation from the ground.

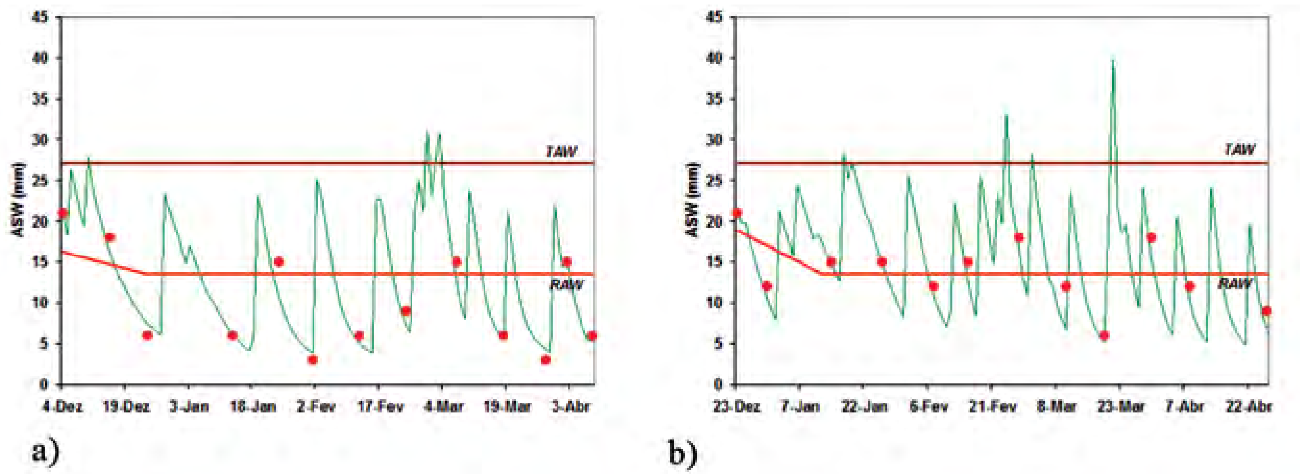


FIGURE 2. Comparison between the values observed ( ) and simulated ( ) of the humidity of the water available in the soil (ASW) for the crop of garlic: a) calibration, b) validation.

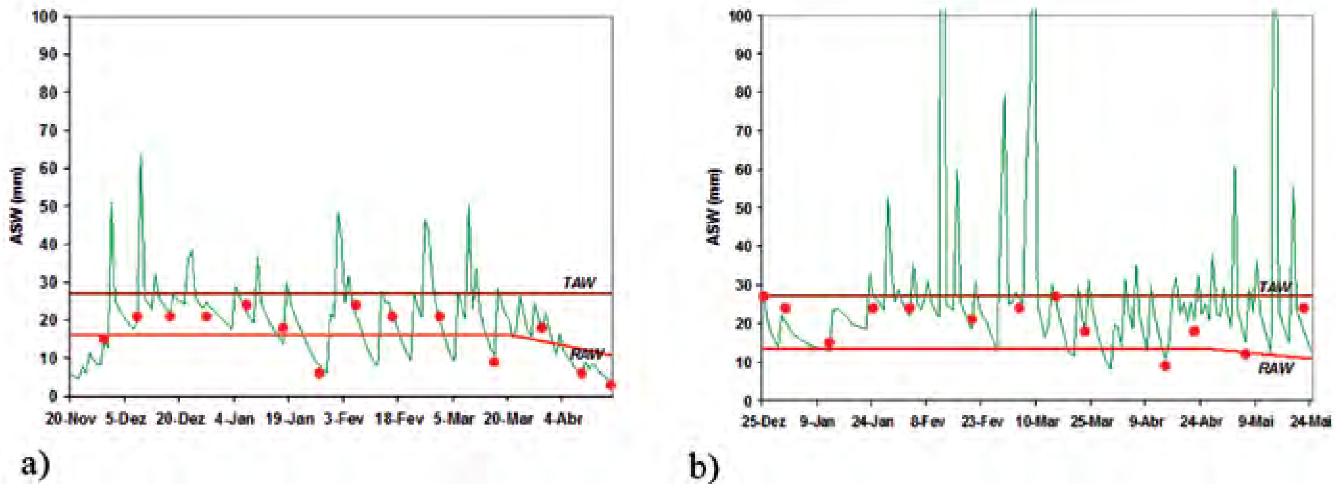


FIGURE 3. Comparison between the values observed ( ) and simulated ( ) of the humidity of the water available in the soil (ASW) for the crop of onion: a) calibration, b) validation.

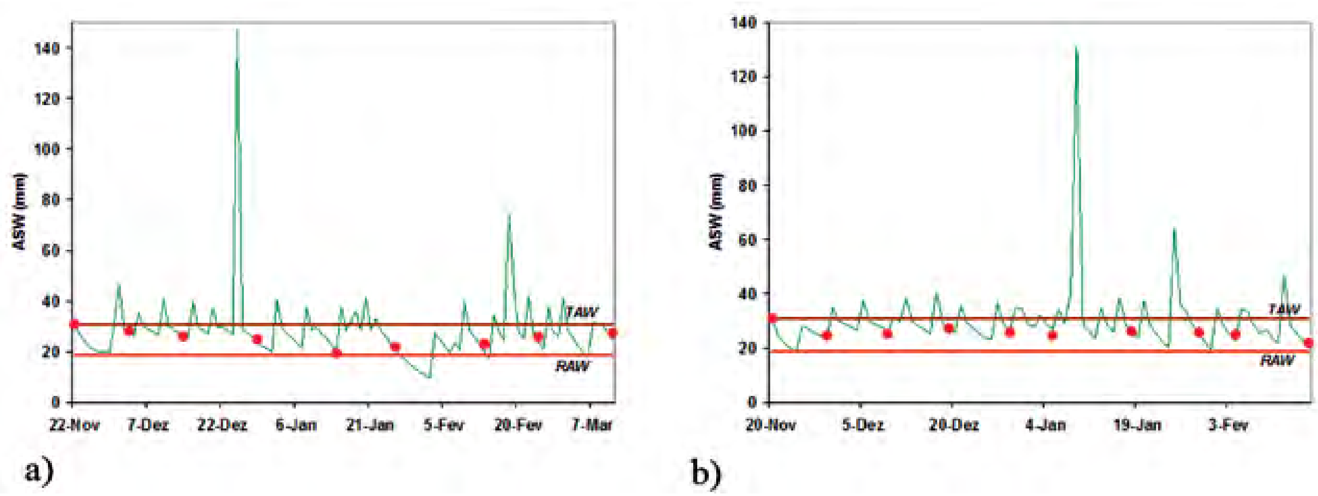


FIGURE 4. Comparison between the values observed ( ) and simulated ( ) of the humidity of the water available in the soil (ASW) for the crop of carrots: a) calibration, b) validation.

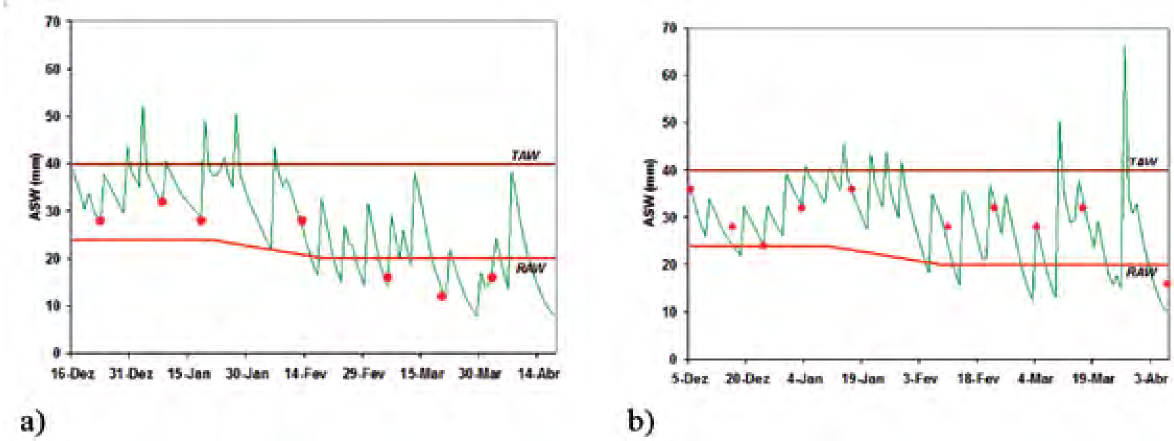
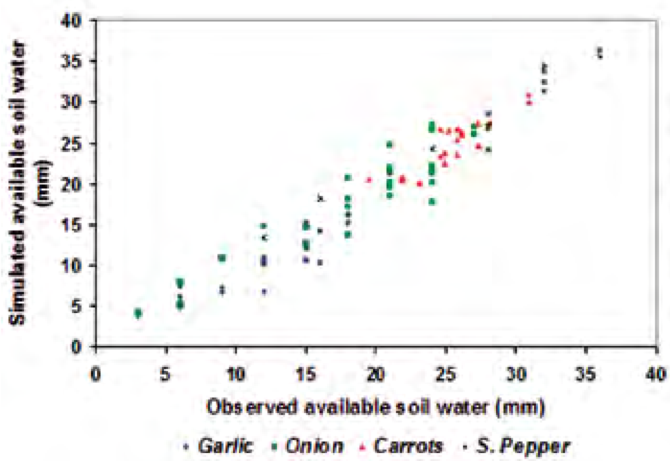


FIGURE 5. Comparison between the values observed ( ) and simulated ( ) of the humidity of the water available in the soil (ASW) for the crop of pepper: a) calibration, b) validation.

The results of the quality indicators adjustment calculated are summarized in Figure 6 and Table 2. From these results, the regression coefficient *(b)* is close to 1.0, then the co variation is close to the variation of the observed values which means that simulated and observed values are statistically close, the coefficient of determination *(R^2)* ranged from 0.74 and o.97 indicating that most of the variation in observed values explained by the model. The values of the residual error estimate available soil water in the case of the root mean square error, *RMSE (mm)* varies between 1.31 and 2.85 and the average absolute error, *AAE (mm)* of 1.23 and 2.40, representing approximately 7% *TAW* in all of the vegetables tested, show a good fit. As a whole these indicators confirm a good agreement between simulated and observed values.



Indicators the adjustment	b	R^2	RMSE (mm)	AAE (mm)	ARE (%)	EF	d_{IA}
Garlic	0.91	0.92	1.95	1.51	15.2	0.81	0.96
Onion	0.98	0.82	2.43	2.02	10.2	0.83	0.98
Carrots	0.98	0.93	1.51	1.30	5.0	0.69	0.93
S. Pepper	0.99	0.96	2.02	1.60	7.3	0.88	0.98

FIGURE 6. Regression between the observed and simulated values of the water content in the soil and indicators for the data related to the calibration and validation of the model for vegetables: garlic, onion, carrots and sweet pepper.

TABLE 2. Indicators de quality of the adjustment the model by using the calibrated values of REW, TEW, Ze, Kcb e p

Parameter	b	R^2	EMQ (mm)	EM_a (mm)	EM_r (%)	EF	d_{IA}
Garlic							
Calibration	0.92	0.93	1.72	1.32	16.7	0.91	0.98
Validation	0.90	0.90	2.17	1.70	13.6	0.70	0.94
Onion							
Calibration	0.98	0.92	2.01	1.64	7.5	0.92	0.98
Validation	0.98	0.74	2.85	2.40	12.8	0.73	0.97
Carrots							
Calibration	0.95	0.86	1.70	1.57	5.8	0.73	0.93
Validation	1.00	0.80	1.31	1.02	4.2	0.64	0.93
S. Pepper							
Calibration	0.99	0.97	1.36	1.23	6.8	0.97	0.99
Validation	0.98	0.94	2.67	1.96	8.3	0.78	0.96

CONCLUSIONS

- The implementation of this new methodology in Cuban investigations, allows to note that the results obtained regarding the coefficients K_{cb} and K_e significantly improve (as compared with the K_c means Chaterlán *et al*., 2011) the estimated fractional precipitation and irrigation water used by vegetables during the growing season and the amount of the water that is consumed by plant transpiration and the portion that is consumed by evaporation from the soil, providing a range of alternatives for evaporation control mulches and soil with active coatings.
- Statistically, the results obtained from linear regression forced origin and indicators for estimating the residual errors indicate a good fit between the values of soil moisture estimated by the model and the observed data.
- It is appropriate to note that these are preliminary results, which are intended to clarify in future work where we have other experimental tests that allow for the validation of the values obtained here in other agricultural settings.

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