

TECHNICAL PAPER

EVAPOTRANSPIRATION AND CROP COEFFICIENT OF DRIP IRRIGATED WATERMELON IN PIAUI COASTLINE, BRAZIL

**EDSON A. BASTOS¹, CLÁUDIO R. SILVA², BRAZ H. N. RODRIGUES³,
ADERSON S. ANDRADE JR.¹, LÍVIA M. M. IBIAPINA⁴**

ABSTRACT: The knowledge of the evapotranspiration (ET_c) and crop coefficient (K_c) is fundamental to plan and to manage the irrigation of any crop. The aim of this study was to determine the daily and hourly evapotranspiration of drip irrigated watermelon (*Citrullus Lanatus*, var. Crimson Sweet) and crop coefficient (K_c) in each crop development phase. The experiment was carried out in an experimental area of 1.27 ha of Embrapa Mid-North, localized in Parnaíba (02°54'S, 41°47'W and 46 m above of sea), State of Piauí, Brazil, from September to November, 2006. Electronic weighing lysimeters of 1.5 m x 1.5 m wide and long and 1.0 m deep were used to obtain the evapotranspiration. The plants were drip irrigated with a lateral row per plant row and drippers spaced 0.5 m from each other. The reference evapotranspiration (ET_o) was estimated using the Penman-Monteith equation from the climatic data obtained by electronic sensors. The total evapotranspiration during the watermelon crop cycle cultivated in the state of Piauí was 233.87 mm, with mean values of 3.7 mm day⁻¹, minimum of 1.18 and maximum of 8.14 mm day⁻¹. The K_c of the drip irrigated watermelon was 0.18 in the initial stage of crop growth; 0.18 to 1.3, in crop development stage; 1.3 in the intermediate stage and 0.43 in the final stage.

KEY WORDS: *Citrullus lanatus*, lysimeter, water consume.

EVAPOTRANSPIRAÇÃO E COEFICIENTE DE CULTIVO DA MELANCIA IRRIGADA POR GOTEJAMENTO NO LITORAL DO PIAUÍ

RESUMO: O conhecimento da evapotranspiração e do coeficiente de cultivo (K_c) é fundamental para dimensionar e manejar a irrigação de qualquer cultura. O objetivo deste trabalho foi determinar a evapotranspiração (ET_c) diária e horária da melancia (*Citrullus lanatus* Schrad, var. Crimson Sweet) irrigada por gotejamento e o K_c em cada fase de desenvolvimento da cultura. O estudo foi conduzido em uma área experimental de 1,27 ha da Embrapa Meio-Norte, localizada em Parnaíba - PI (02° 54'S, 41° 47'W e 46 m de altitude), no período de setembro a novembro de 2006. Utilizaram-se quatro lisímetros de pesagem eletrônica de 1,5 m x 1,5 m de largura e comprimento com 1,0 m de profundidade para determinar a evapotranspiração. A cultura foi irrigada por gotejamento com uma linha lateral por fileira de planta e gotejadores espaçados a cada 0,5 m. A evapotranspiração de referência (ET_o) foi estimada com base na equação de Penman-Monteith a partir dos dados climáticos de sensores eletrônicos. A evapotranspiração total durante o ciclo da cultura da melancia cultivada no Piauí foi de 233,87 mm, com valores médios de 3,7 mm dia⁻¹, com mínimo de 1,18 e máximo de 8,14 mm dia⁻¹. O K_c da melancieira irrigada por gotejamento foi de 0,18 no estágio inicial; 0,18 a 1,3, no estágio de crescimento; 1,3 no estágio intermediário, e 0,43 no estágio final.

PALAVRAS-CHAVE: *Citrullus lanatus*, lisímetro, consumo hídrico.

¹ Eng^o Agrônomo, Pesquisador, Doutor em Irrigação, Embrapa Meio-Norte, Av. Duque de Caxias, 5650, Teresina - PI, Fone: (0XX86) 3089-9100 ramal 159, edson@cpamn.embrapa.br; aderson@cpamn.embrapa.br.

² Eng^o Agrônomo, Professor Adjunto, Universidade Federal de Uberlândia - MG, claudio@iciag.ufu.br.

³ Eng^o Agrônomo, Pesquisador Doutor em Irrigação, Embrapa Meio-Norte, UEP de Parnaíba - PI. braz@cpamn.embrapa.br.

⁴ Eng^o Agrônoma, Professora do Colégio Agrícola de Cocal - PI, liviamibiapina@hotmail.com.

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INTRODUCTION

Watermelon (*Citrullus lanatus* Thunb.) constitutes one of the major horticultural crops in Brazil. In 2006, the Brazilian annual production was 1.94 million tons with average yield of 20.9 t ha⁻¹ (FAO, 2008). The good uniformity of size, color and flavor provided that watermelon occupied the second place among the vegetables in Brazilian export volume, losing position only to the melon (VILELA et al., 2006).

In the Northeast region, the warm and dry climate provides the yield of excellent quality fruits, and it can be grown all year with the use of irrigation, generating employment and income, especially during the dry season, when the difficulties in this region are more patent (PEDROSA, 1997).

Although the production of Piauí is still small compared to the harvested area in the Northeast, the good acceptance of the fruits in the local market and the fast development cycle (60 days, on average) when compared to other cultures, have made the watermelon a good alternative for producers of irrigated perimeters (Irrigation District of the Coastal Tablelands of Piauí - DITALPI and Guadalupe Plateau Irrigation District), and some irrigated areas of the region of Teresina and Vale do Rio Gurguéia.

Traditionally, with respect to precipitation, the State of Piauí can be characterized in two seasons: dry and rainy seasons. The dry season, longer, takes approximately eight months, covering the months from May to October. In this period, there is a pronounced soil water deficit. Thus, it is necessary the use of irrigation. The first areas were irrigated by sprinkler or furrow, but recently, the area under drip has been increased, mainly because it consumes less water and facilitates weed control.

However, due to the confinement of the roots in a limited volume of soil, with low volume of water available to plants, drip irrigation management requires that the crop evapotranspiration (ET_c) is accurately determined and for maximum intervals of one day (CLARK & SMAJSTRLA, 1993).

Lysimeters have long been used in research for the direct measurement of evapotranspiration of a crop, varying in form and scale (MAREK et al., 2006). Due to advances in microelectronics, enabling the data acquisition in instantaneous scale, the high accuracy and low hysteresis, several authors have reported the use of weighing lysimeter as a standard tool in studies of water loss of crops, even to determine ET_c and crop coefficient (K_c) as well as the calibration of estimative agrometeorological models, according to a review by CAMPECHE (2002).

Electronic weighing lysimeter are being used for most crops, perennials, such as Tahiti lime (ALVES JR. et al., 2007; BARBOZA JR. et al., 2008), grapevine (MONTORO et al., 2008) castor oil plant (HELD et al., 2008) or annual cultures, such as bean (BASTOS et al., 2008 and FERREIRA et al., 2009).

Using electronic weighing lysimeters, MIRANDA et al. (2004), in the state of Ceará, determined that the total evapotranspiration during the crop cycle of drip irrigated watermelon (cv. Crimson) was 267 mm, with maximum values of 7.0 mm d⁻¹ during the intermediate phase, obtaining the values of crop coefficient (K_c) of 0.39, 1.31 and 0.70 for initial, intermediate, and final stages, respectively. ALLEN et al. (1998) comment that the crop evapotranspiration depends on climatic, plant and soil management factors. Thus, obtaining regionalized values can improve the accuracy in the planning of the irrigation.

The objective of this study was to determine the evapotranspiration and crop coefficient of watermelon, with a weighing lysimeter, in the climatic conditions of the coast of Piauí, Brazil.

MATERIAL AND METHODS

Details of the experimental area and culture

The study was conducted in 1.27 ha in the experimental field of Embrapa Mid-North, located in the city of Parnaíba, State of Piauí (03°05' S, 41°47' W and 46 m altitude), Brazil. The soil is classified as dystrophic Yellow Latosol, sharply drained, sandy texture (MELO et al., 2004). The annual mean temperatures of the site is 27.9°C with mean relative humidity of 75.4%, reference evapotranspiration of 5.4 mm and mean annual rainfall of 1,051.6 mm, however, concentrated from January to May (BASTOS et al., 2010).

The water content in the soil at field capacity was 0.18 m³ m⁻³ and 0.06 m³ m⁻³ in the permanent wilting point, determined based on undisturbed soil samples. Before planting, chemical analysis of the soil was made on layer 0-0.4 m deep for the correction of acidity and crop fertilization. Chemical analysis of the soil showed: pH = 5.8 (water); P = 1.55 mg dm⁻³; K⁺ = 0.05 cmol dm⁻³; Ca²⁺ = 1.08 cmol dm⁻³; Mg²⁺ = 0.80 cmol dm⁻³; H + Al³⁺ = 1.80 cmol dm⁻³; CTC = 3.74 cmol dm⁻³, and V = 51.26 %.

The foundation chemical fertilizer was based on soil analysis, applying: 72 kg ha⁻¹ of P₂O₅ (superphosphate), 34 kg ha⁻¹ of N (urea), 30 kg ha⁻¹ of K₂O (chloride potassium) and 6 kg ha⁻¹ of FTE BR-12. Coverage fertilizations were performed with nitrogen and potassium under fertigation at a dosage of 92.7 and 66 kg ha⁻¹ of N and K₂O, respectively.

Soil preparation consisted of plowing and harrowing, followed by plowing in rows spaced 2.0 m and 0.3 m depth. It was used a variety of Crimson Sweet watermelon with planting done on September 26th, 2006, leaving four seeds per hole, spaced 1.0 m between plants and 2.0 m between rows. The thinning of the plants was carried out when the seedlings had two definitive leaves, leaving one plant per hole. The phytosanitary control and the weeding were performed as needed, following the usual techniques recommendations of the culture.

There were two harvests at 63 and 70 days after planting, harvesting all the fruits of the lysimeters. To estimate the yield of fruits in the boundary, it was made a sample, harvesting four sub-areas (144 m²), each one containing six rows of 12 m.

Irrigation and lysimeters

The crop was drip irrigated with a lateral line per row of plants and drippers spaced every 0.5 m. The drippers had an average flow of 1.63 L h⁻¹ under a pressure of 150 kPa and 90% coefficient of uniformity (Cu), after a uniformity test done after the irrigation installation (Figure 1A). After planting, seven daily irrigations were performed aiming to raise the soil humidity at field capacity to promote crop establishment. After this period, it was adopted, as standard, an irrigation schedule of two days and the fertigations held at a frequency of three times a week, using an injection pump type TMB (Figure 1B).

In the center of the area, there were four weighing lysimeter, spaced 12 m from each other. Each lysimeter contained a plant with two drippers. Lysimeters were consisted of a fiberglass box of 9 mm thick, measuring 1.5 m long by 1.5 m wide, 1.0 m deep (Figure 1C and 1D). Each box was placed on a lever reducing mechanism connected to an electronic load cell (model SV 100, Alfa Instrumentos, São Paulo, State of São Paulo, Brazil) and an automatic data collection (CR model 23x, Campbell Scientific, Logan, UT, USA).

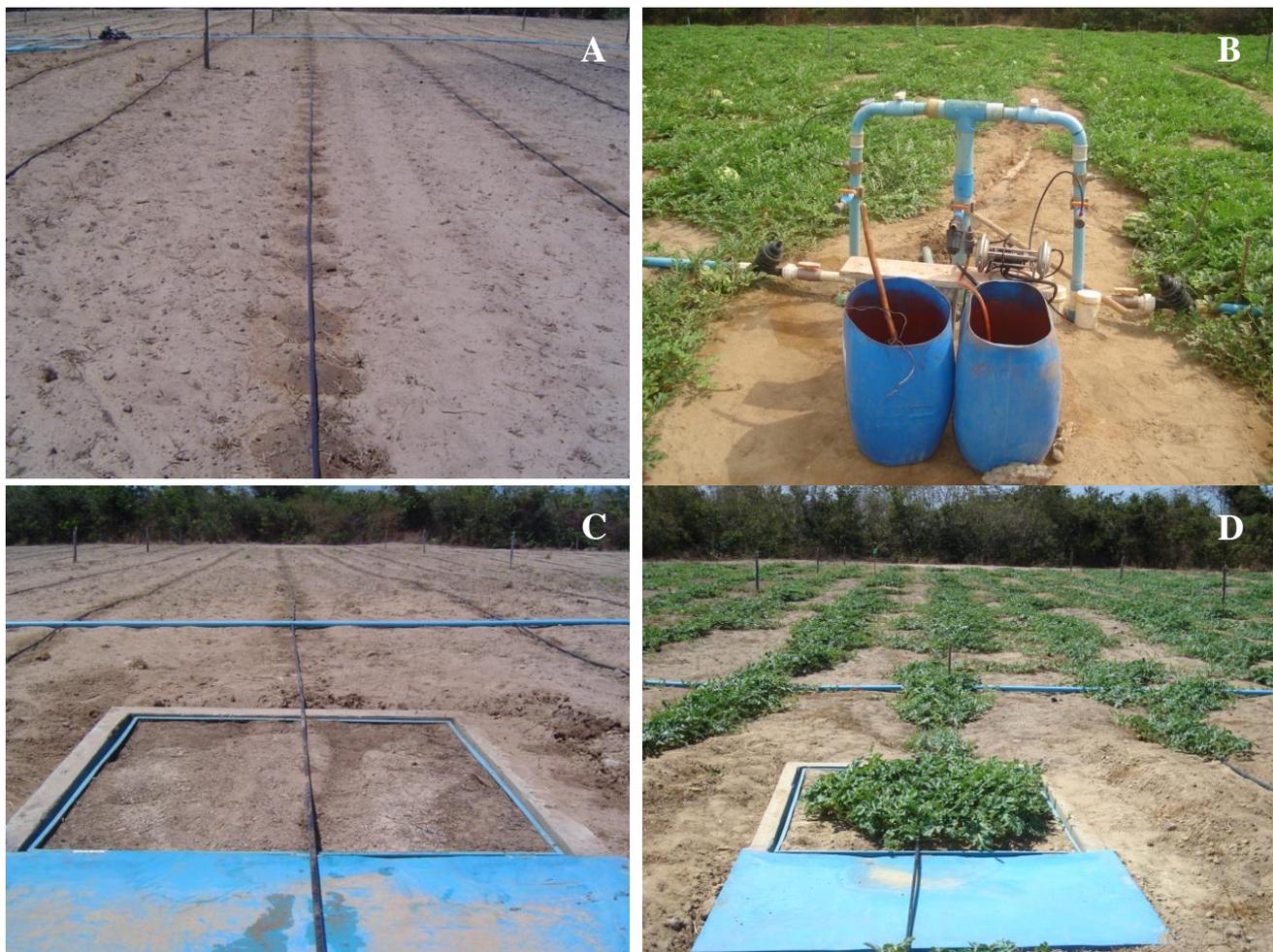


FIGURE 1. Photographs of the irrigation (A) and fertigation (B) systems and of one lysimeter at crop planting (C) and crop development (D). Parnaíba, State of Piauí, 2006.

The hourly mean values, in millivolt (mV), provided by each cell were converted into millimeters of water (mm) as the calibration equation performed for each lysimeter. Further details of lysimeter construction may be seen in BASTOS et al. (2008). The crop evapotranspiration (ET_c) was obtained by the difference between the current and previous reading of the lysimeter, apart from the rain, irrigation and drainage during the period.

Irrigation was made to maintain soil humidity close to field capacity, monitored by digital puncture tensiometers installed at 0.2 and 0.4 m deep on the lysimeters, as well as on four sites distributed randomly in the area. The tensiometer readings were made daily, in the morning, until the maturation stage of culture, when irrigation was suspended. The water depth was calculated by the product between reference evapotranspiration (ET_o), the crop coefficient (K_c) and the coverage area of the plant (A_c), whose adopted values were: 0.3, until 29 days after planting (DAP); 0.5, from 30 to 39 DAP; and 0.8, from 40 to 60 DAP.

The ET_o was estimated based on the Penman-Monteith equation parametrized by ALLEN et al. (1998) from the weather data provided by electronic sensors of temperature, relative humidity, solar radiation and wind speed installed in automatic data collection cited above.

The crop coefficients (K_c) were calculated for each day of the cycle ($K_c = ET_c ET_o^{-1}$). Then, it was determined mean values of ET_c and K_c considering the growing stages proposed by ALLEN et al. (1998): I) initial: planting up to 10% of ground cover; II) growth phase: from the end of the initial stage up to 80% of ground cover; III) intermediate: from 80% of ground cover to the beginning of fruit maturation; IV) final: from the beginning of maturation until harvest. For the final

phase, it was considered the K_c obtained on the day of harvest. And also, with daily values of K_c , a curve was adjusted between K_c and days after planting (DAP).

Early in the experiment, one of the lysimeters had electronic malfunctioning in load cell and, thus, their data were discarded. For the other lysimeters, the values of ET_c , obtained daily, were analyzed together (average data). To analyze the evolution of ET_c during the day, mean hourly values of ET_c were calculated in five representative days in the initial (I) and intermediate phase of culture (III).

RESULTS AND DISCUSSIONS

Climatic conditions during the experiment

No rainfall occurred during the experiment, fully justifying the technique of irrigation. The temperature was almost constant throughout the experiment (Figure 2). A similar profile was obtained with relative humidity. There was a decrease in global radiation at 39 days after planting (DAP) due to cloudiness. In general, the climatic conditions were highly favorable to the development of culture, resulting in 63 days from planting to harvest, lower than the value obtained by MIRANDA et al. (2004) with the same variety (70 days), in Ceará. Commercial production area was of 31.5 t ha^{-1} , with mean fruit weight of 9.0 kg in the lysimeters, values above the national average (20.9 t ha^{-1}). The average voltage of the soil water (0-0.4 m) for the entire crop cycle was low $\approx 20 \text{ kPa}$ (slightly smaller in the lysimeters $\approx 10 \text{ kPa}$). These low values indicate that irrigation provided good water availability to plants throughout the development cycle, a necessary condition to obtain the evapotranspiration of a culture according to ALLEN et al. (1998).

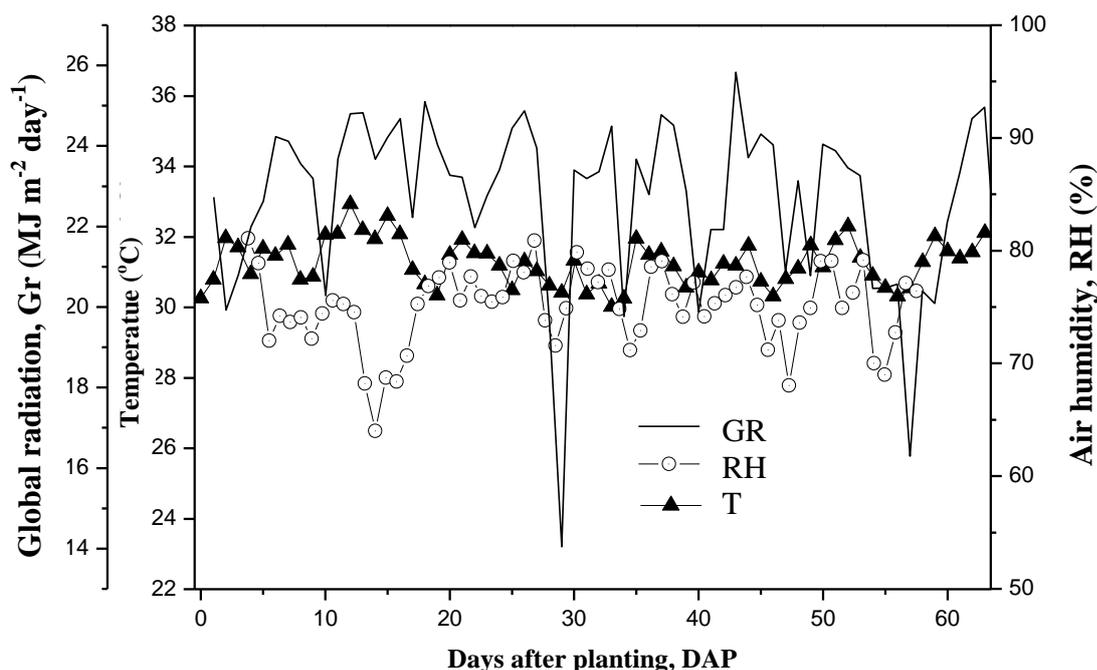


FIGURE 2. Climate conditions (daily global radiation, mean air humidity and temperature) observed during the experiment. Parnaíba, State of Piauí, 2006.

Crop evapotranspiration

Figure 3A shows the evolution of ET_c during the development cycle of culture. It was emphasized in the figure the four phenological phases proposed in the model of ALLEN et al. (1998). In the first, the phase I (initial), ET_c was low, with a value close to 1 mm day^{-1} , influenced by the small portion of the soil volume irrigated, by low evaporation of water from soil (dry surface) and small leaf area of plants. From the 30th day after planting (DAP) and approximately until the 40th DAP, ET_c increased dramatically (Phase II), reaching maximum values close to

9 mm day⁻¹, higher than the value obtained by MIRANDA et al. (2004), with 7.5 mm day⁻¹ for the same crop and irrigation system. From 40th DAP to 48th DAP (Stage III), there was some stabilization, around 8.3 mm day⁻¹, caused by the beginning of maturation culture.

In both phase I and phase III, the ETc peak occurred close to midday (10 to 14 h), however, with values of 0.16 mm hour⁻¹ for Phase I, and 1.02 mm hour⁻¹, for Phase III (Figure 3B). The standard deviations were higher to ETc-III, because as the perspiration were greater than the evaporation in this phase, variations of albedo, height, development and aerodynamic properties of the leaves of plants in each lysimeter may have caused deviations in the ETc. It was also observed in this figure that there was a low evapotranspiration in the morning (5 to 7 h) and at night (18 to 20h). SILVA et al. (2005) also found a nocturnal evapotranspiration in lime acid, of 17.4 and 13.4% of ETc for the summer and winter, respectively. Thus, this contribution to ETc should not be neglected in the sum of daily evapotranspiration.

From the 50th DAP, the ETc decreased, coinciding with the senescence of part of the leaves of the crop, and finally with the end of irrigation. In Table 1, it can be seen the aggregation of ETc at every stage of development. The total ETc was approximately 234 mm for a cycle of 63 days of culture. MIRANDA et al. (2004) obtained 267 mm for one cycle of 70 days under cultivation in Ceará.

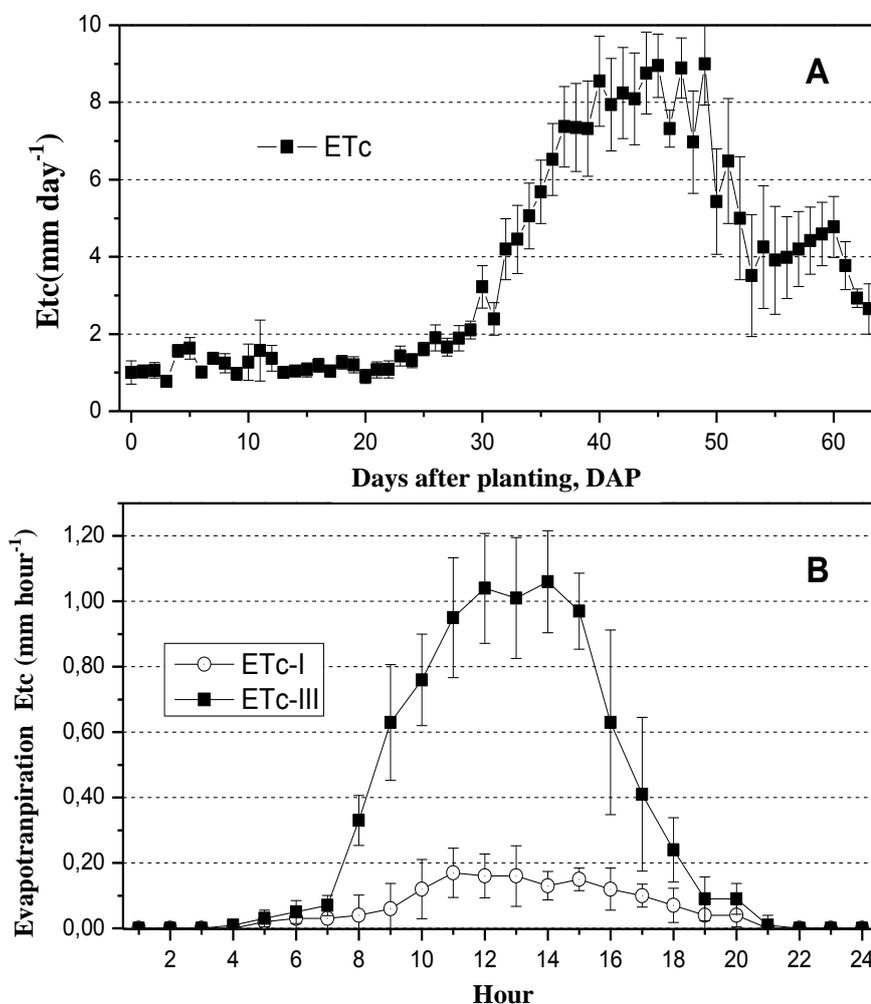


FIGURE 3. (A) Crop daily evapotranspiration (ETc) throughout watermelon growth cycle. Each point represents a mean of three values, and the bars represent the standard deviation. (B) Crop hourly evapotranspiration for initial (ETc-I) and intermediate (ETc-III) phase. Each point represents a mean value of 15 replications, and the bars represent the standard deviation.

TABLE 1. Watermelon crop evapotranspiration (ET_c) in each crop development stage. Parnaíba, State of Piauí, Brazil, 2006.

Phenological Phase	Duration	ET _c
	(day)	(mm)
I-Initial	20	23.67
II-Growth	20	76.15
III-Intermediate	8	65.16
IV-Final	15	68.89
TOTAL	63	233.87

Crop coefficient

The mean K_c values throughout the development of culture and the curves of K_c (adjusted manually and the curve obtained by MIRANDA et al., 2004) are shown in Figure 4. During the initial phase, the K_c was almost constant, with value of 0.2. According to ALLEN et al. (1998), when the culture is not fully covering the ground, K_c values are determined based on the frequency at which the soil is wet by rain or irrigation, ranging from 1.0 to 0.1. Considering that the crop is grown in wide row spacings, large amount of water is wasted when using conventional methods of irrigation such as furrow and sprinkler, especially in the early stages of culture (SRINIVAS et al., 1989). As drip irrigation, at this stage, wet a small volume of soil so that evaporation was low, and because the plants have little leaf area, K_c values were minimal at this stage. The same result was obtained by MIRANDA et al. (2004), but slightly higher, with a value of 0.3.

From 23rd DAP, K_c values increased linearly (0.06 day⁻¹), directly related to the fast development of the plant and increased transpiration rates. Thus, the highest crop coefficients at this stage are related to more intense metabolism of the crop. With the increasing influence of transpiration on the values of K_c, standard deviations increased directly influenced by the intrinsic characteristics of each plant in the lysimeters. At 40 DAP, there was stabilization close to the value of 1.3, being higher than the value obtained by MIRANDA et al. (2004), which was 1.15. It should also be noted that in this stage (intermediate), K_c values are greater than those proposed by ALLEN et al. (1998), who recommend K_c equal to 1.0. These differences are explained, partially, by the different climatic conditions. While the FAO K_c values were determined for a subtropical climate, the values from this study were obtained under a tropical climate, with the occurrence of high air temperature and solar radiation (Figure 2). From 48 DAP there was a gradual decline in values, directly caused by the beginning of senescence in culture.

In general, it is observed that the K_c values obtained by MIRANDA et al. (2004) are overestimated in the initial phase, and underestimated in the intermediate phase, compared to values obtained in this study. This fact highlights the importance of obtaining regionalized values of K_c to increase efficiency in water use. Possibly, the fact that MIRANDA et al. (2004) used a spacing of 2 x 0.75 m, leaving two plants per hole, and consequently the air temperatures were higher than the place where the experiments were conducted by MIRANDA et al. (2004) contributed to the differences between these K_c values.

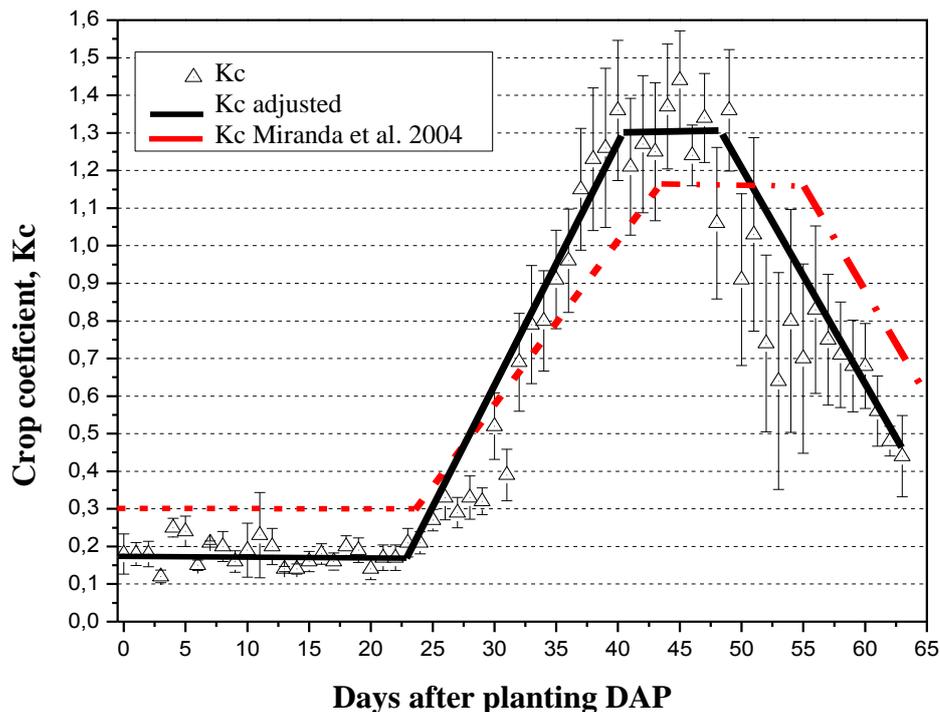


FIGURE 4. Crop coefficient throughout the watermelon growth cycle and Kc curves (the adjusted curve from points and the curve obtained by MIRANDA et al., 2004). Each point represents the mean of three values and the bars represent the standard deviation.

CONCLUSIONS

The total evapotranspiration during the crop cycle of watermelon grown on the coast of Piauí and drip irrigated was of 233.87 mm, with a mean of 3.7 mm day^{-1} .

The ETC quantitatively starts at 7am, ending at 20 h.

The crop coefficient (Kc) of drip irrigated watermelon, in the conditions of soil and climate of the coast of Piauí, is 0.18 in the initial stage, 0.18 to 1.3 in the growth stage, 1.3 in intermediate stage, and 0.43 in the final stage of culture.

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