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SESAME CROP COEFFICIENTS USING CROP EVAPOTRANSPIRATION BY WATER BALANCE AND, REFERENCE EVAPOTRANSPIRATION BY PENMAN-MONTEITH[1]

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1 SUMMARY

To determine sesame BRS 196 CNPA G4 coefficients - Kc, at semiarid conditions, an experiment, irrigated with 100% of crop evapotranspiration - ETc, was installed at Embrapa Cotton, Barbalha County, Ceará State, Brazil, in 2012. It was measured, with a Diviner 2000® probe, each 10 cm soil depth, volumetric soil water content in three replications. The ETc (mm d^{-1}) was calculated by the soil water balance equation [$ETc = I - Rs \pm D/C \pm \Delta h$, where I = irrigation flows (mm d^{-1}), Rs = runoff (mm d^{-1}), D/C = water drainage flows (mm d^{-1}) and, Δh = soil water storage variation (mm d^{-1})]. It was determined soil water retention curves and parameters (by Richards Plates and by van Genutchen method, respectively) and the saturated soil hydraulic conductivity (by infiltrometer method), too. To estimate the reference evapotranspiration – ET_0, data required by Penman-Monteith equation were obtained from the weather station of the National Meteorological Institute, Barbalha County, Ceará State, Brazil. It was concluded that the soil water balance method was able to determine the crop coefficient values for each phenological phase of the sesame BRS 196 CNPA G4, being equal to 0.63 (planting/establishment), 0.83 (growth), 0.97 (development/floration) and 0.56 (maturation).

KEYWORDS: *Sesamum indicum* L., water flows, water consumption.

2 INTRODUCTION

The sesame crop, today little known in Brazil, may become an alternative for the grains production by the Brazilian Northeast and the Savannah farmers, since as viewed as a

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functional food and to have good market prospects, especially its oil (GRILO JUNIOR; AZEVEDO, 2013).

This crop presents good yield under semi-arid conditions of the Brazilian Northeast, but it is believed to obtain, under irrigation, a significant increase in yield, as attested by Milani et al. (2006) and Uçan et al. (2007). However, for the adoption of a sesame crop irrigated system urges the need to conduct research about your water consumption.

However, according to Souza et al. (2013), only the rainfall data are not sufficient to predict the amount of available water in the soil for crops since these inform as only the entry of water into the soil. It is necessary to know also the soil water balance.

To calculate the soil water balance for one culture is necessary to compute the entries of soil water via rainfall or irrigation, i. e. infiltration from the surface, and the outputs, represented by internal drainage, evapotranspiration and surface runoff in a soil volume based on the crop root system configuration, in a certain period of time (ALLEN et al., 2006; REICHARDT; TIMM, 2012).

The estimation of crop evapotranspiration - ETc, in turn, is based on the losses of water from the plant-soil system to the atmosphere through the processes of evaporation and transpiration (ALBUQUERQUE et al., 2002; ALLEN et al., 2006).

Information on sesame crop evapotranspiration - ETc and crop coefficients - Kc values that could subsidize irrigation management are scarce, as even the tabulated crop coefficients (Kc) values (initial Kc, middle Kc, end Kc), usually found in FAO reports (ALLEN et al., 2006), were obtained in regions outside Brazil, being more related, therefore, to a condition of sub-humid climate, not stressed cultures, reaching maximum production; however it is known that in actual field conditions, even in the same local and crop condition, these vary depending on local as well as the season conditions. For more arid conditions, such as the northeast semi-arid, with higher wind speeds, and many other factors outside of that standard condition, the use of those coefficients need corrections.

So, to ease the correction calculations, it is better to determine, *in situ*, the Kc, using methods that have been validated by research, such as the methods of the soil water balance to determine ETc and of Penman-Monteith for the estimation of ET_0. The soil water balance method is characterized by to require bit parameters to its determination, and provides reliable values (FERNANDES et al., 1999). The Penman-Monteith method is the recommended by the FAO (ALLEN et al., 2006) to provide relatively accurate and consistent ET_0 results in any geographic and climatic context.

Thus, this study aimed to calculate the crop coefficients in each phenological phase of the irrigated sesame BRS 196 CNPA G4 crop cycle in the semiarid soil-climate conditions by the soil water balance method.

3 MATERIALS AND METHODS

The experiment was carried out in the Embrapa Cotton Experimental Station, located in the Barbalha County, Ceará State, Brazil (Geographical coordinates: 07°19' S, 39°18' W and 409 m above the mean sea level – RAMOS et al., 2009), in the period from August 04th to November 7th, 2012. Soil at the site is classified as Fluvic Neossol, with surface layer predominantly clay-loamy, of medium fertility, but with low organic matter content, whose chemical characterization (0-20 cm), was as follows: pH of 6.8, 95.3, 49.2, 2.8, 1.4 and 0.0 $\text{mmol}_c\ \text{dm}^{-3}$ of calcium, magnesium, sodium, potassium and aluminum, respectively, 5.4 mg dm^{-3} of phosphate and 12.3 g kg^{-1} of organic matter. Soil texture, in turn, at the surface layer

(0-30 cm) was characterized as Clay Loamy (33.67, 20.17 and 46.16% of sand, silt and clay, respectively) and at the 30-60 cm depth layer as Clay-sand Loamy (59.98, 15.10 and 24.92% of sand, silt and clay, respectively). The other soil physical characteristics of the experimental area (0-30 and 30-60 cm soil depth layers) are organized in Table 1.

The region climate is, according to Koppen's classification, "CSa" type, semi- humid, with hot and dry summer (4-5 months), with maximum and minimum temperatures average of 31.5 °C and of 20.5 °C, air relative humidity average of 63% and annual rainfall average of 1,000 mm, distributed in the months from March to June (RAMOS et al., 2009), whose obtained values at the place and time of the experiment are shown in Figure 1.

The water used for irrigation was of an artesian well, located near the experiment, classified as "C_2S_1", presenting medium salinity and low sodium concentration which may be used for irrigation whenever there is a moderate degree of leaching and special care in soil management.

Table 1. Soil physical characteristics in the experimental area. Barbalha County, Ceará State, Brazil. 2012.

Caracteristics	0 a 30 cm	30 a 60 cm
Bulk density (g cm^{-3})	1.74	1.44
Global density (g cm^{-3})	2.72	2.72
Porosity (%)	35.82	47.04
Water content in 0.10 atm (m^3 m^{-3})	45.90	32.10
Water content in 0.33 atm (m^3 m^{-3})	35.10	25.10
Water content in 1.00 atm (m^3 m^{-3})	28.72	17.76
Water content in 5.00 atm (m^3 m^{-3})	22.73	12.55
Water content in 10.0 atm (m^3 m^{-3})	20.27	11.61
Water content in 15.0 atm (m^3 m^{-3})	18.55	9.98
Available water content (m^3 m^{-3})	16.55	15.12

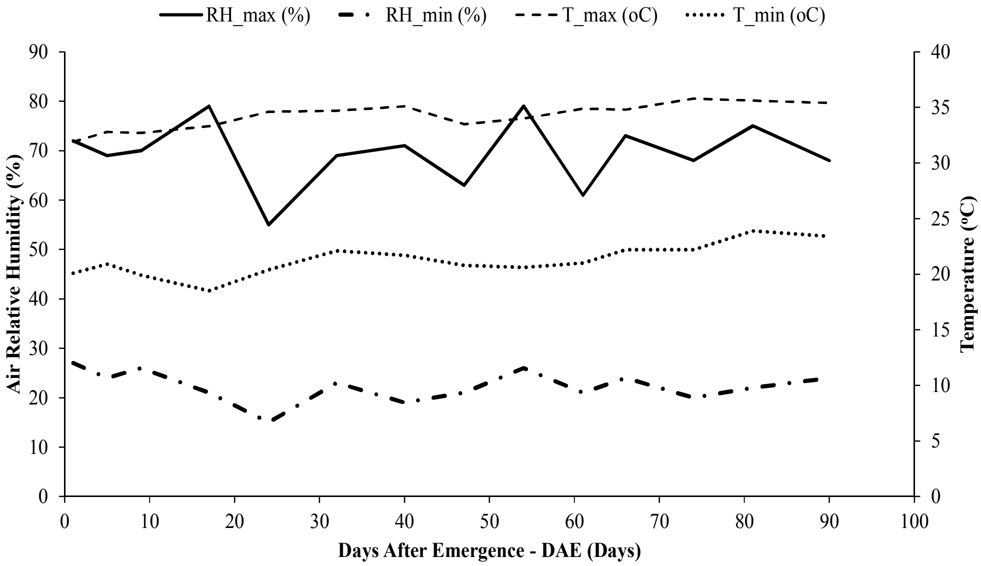

Figure 1. Maximum (T_max) and minimum (T_min) temperatures and maximum (RH_max) and minimum (RH_min) air relative humidities average values, obtained at the place and time of the experiment. Barbalha County, Ceará State, Brazil. 2012.

The experimental area measured 6.912 m^2 and was irrigated based in 100% crop evapotranspiration, which corresponds to an applied total net water depth of 567.50 mm, with three replications. The soil tillage system was moldboard plough/harrow disc. Basal fertilization was taken at the bottom of the planting furrow as chemical soil analysis and recommendations for the culture in the region. It was used in basal fertilization (on August 04th, 2012) 300 kg ha^{-1} of Monoammonium Phosphate fertilizer - MAP (11% N and 46% P_2O_5). Nitrogen was fractionated into two more times (44.5% of the dose after thinning and 44.5%, 25 days later, on September 05th and 27th, 2012, respectively), each time applying 100 kg $ha^{-1}$of Urea N fertilizer (45% N), while the K was all applied after thinning (on September 05th, 2012) at the rate of 50 kg ha^{-1} of Potassium Chloride (60% K_2O). Topdressing fertilization was made in the lateral furrows of planting rows. Sowing was held on August 4th, 2012 with five seeds per hill and at an average depth of 2 cm, using the BRS 196 CNPA G4 sesame cultivar (ARRIEL et al., 2010), 0.70 x 0.20 m spaced, with final density of 8-10 plants per meter of row. The thinning was done in 2 steps: first, when plants had 4 leaves (pre-thinning) and the second when 15 cm tall (final thinning). The weed control was performed with 3 hand weedings.

Irrigations, in the total number of 22 in the cycle, were performed using conventional sprinkler system, considering a 75% irrigation system efficiency, using sprinklers with 5.0 x 4.6 mm nozzle, with a 0.34 MPa service pressure, 18 x 12 m spaced, with a 10.54 mm h^{-1} average precipitation, applying water until 0.40 m, which according to Amaral; Silva (2008), corresponds to the required soil profile effective depth by the root system of the sesame. Before planting, irrigations were performed in the entire area in order to bring the soil at field capacity and promote germination. Later, irrigations were performed every 3 and 4 days, due to clay-loamy soil textural characteristics of the area favoring slow water infiltration. From the beginning of the maturation stage (67 days after emergence - DAE) to the cycle finishing, irrigations became weekly.

The water application uniformity tests were performed on September 9th, 2012 (clean ground, before plants emergence) and on September 28th, 2012 (50 DAE – development/floration phase) in four replicates per date, using 9 rain gauges per test, equally spaced (3 m x 3 m) within the area covered by 4 sprinklers, as Gomes (1994). With the collecting of the measured water volume of each rain gauge, obtained using a graduated recipient in millimeters, it was possible to determine the average precipitation sprinkler (mm h^{-1}) by dividing the average collected volume (mm) per gauge by the irrigation time (in hours). The average precipitation sprinkler considered in the irrigation calculations was derivated from all these tests and repetitions.

At each irrigation event, the water replacement ($ETc = ET_0 * Kc$) was a function of ET_0 estimated by the Penman-Monteith method, from respective period, using weather data from automatic weather station of the National Meteorological Institute – INMET, in Barbalha County, Ceará State, Brazil, distant 500 m from experimental area and, of crop coefficients (Kc) given in FAO-56 (ALLEN et al., 2006). The Kc average for the different stages of growth, were as follows: Phase I – planting/establishment - the period between emergence and 10% ground cover (1-5 DAE): 0.63. The values around average were obtained by the simplified equation by Albuquerque et al. (2002); Phase II - growth - period 10% ground cover to the beginning of flowering (6-32 DAE): 0.79. The values around average were obtained by the equation $Kc = 0.0147 + 0.5125 * DAE$; Phase III – development/floration - the period between flowering and early maturation (33-66 DAE): 1.10; and, Phase IV - maturation - the period from early to late maturation (67-90 DAE): 0.25. The values around average were obtained by the equation $Kc = -0.0425 + 4.075 * DAE$.

The period of study of the soil water balance was from August 10th to November 7th, 2012, totaling 90 days and it was divided into 13 sub-periods, 1 with 9 days, 4 with 8 days, 5 with 7 days, 1 with 5 days and 2 with 4 days. The non-uniformity of the sub-periods in number of days was due to soil volumetric water readings present some gaps.

The soil water balance was performed according to the methodology presented by Reichardt; Timm (2012), Equation (1), for the 0 to 0.50 m soil depth, using data of daily readings (mm 10 cm^{-3} of soil) at each 0.10 m soil depth (at 0.10, 0.20, 0.30, 0.40, 0.50 and 0.60 m) of access Diviner 2000® probe tubes (SENTEK, 2000), randomly installed in the plots. The Diviner 2000® probe calibration equation is shown in Figure 2. Before the readings, the probe normalization it was done through readings in air and water.

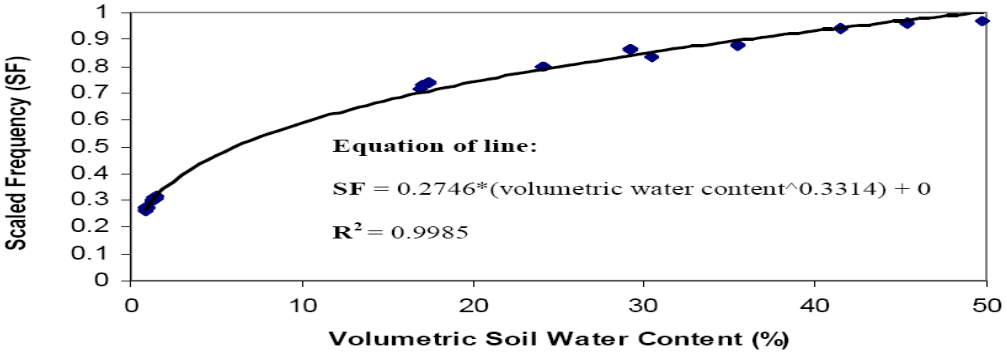

Figure 2. Diviner 2000® probe calibration equation (SENTEK. 2000).

$$ETc = (P + I) \pm D/C \pm R_s \pm \Delta SF \pm \Delta h \pm \Delta p \qquad (1)$$

where: ETc – crop evapotranspiration (mm); P - rainfall (mm), zero in driving time from work (RAMOS et al., 2009); I - irrigation (mm); D/C – deep drainage (-) or capillary rise (+) (mm) below the root zone contingency of crop; R_s – run-off (mm), null given the area is plan; ΔSF - sub-surfaces flows (mm) (minimum values usually being considered only on soils under conditions of high slope); Δh - soil water storage variation (mm) in the operating area of the roots (0-40 cm for Sesame) and, Δp - plant water content variation (mm).

The deep drainage or capillary rise components (D/C) of soil water were calculated by the Darcy-Buckingham equation [Equation (2)], simplified by Reichardt; Timm (2012):

$$D/C = -\overline{K}(\theta)\frac{\Delta H_t}{\Delta z} \qquad (2)$$

where: $\overline{K}(\theta)$ is the unsaturated soil hydraulic conductivity (mm d^{-1}), depending on soil volumetric water content; and, $\frac{\Delta H_t}{\Delta z}$, the soil water total potential gradient.

The soil water storage variations (mm), determined by the difference of the soil volumetric water content values, obtained at the initial and the final time of each considered period, were measured at 0 to 0.40 m depth (0.0 cm to L), effective depth sesame roots, according to Equation (7), and the variation of the deep drainage and capillary rise (D/C - mm) in the layer of 0.30 to 0.50 m, according to equations (2) to (6). The average unsaturated soil hydraulic conductivity $\overline{K}(\theta)$, the soil water total potential variation (ΔH_t) and the soil water storage variation (Δh) were obtained by numerical integrations using the trapezoidal graphical method (REICHARDT; TIMM, 2012):

$$\overline{K}(\theta) = K_0 \frac{(\theta_{(L-z)ft} + \theta_{(L+z)ft} + \theta_{(L-z)it} + \theta_{(L+z)it})}{4} \tag{3}$$

$$|\Psi_{\mathrm{m}}| = \frac{\{[(\theta_s - \theta_r)/(\theta - \theta_r)]^{\wedge}1/m - 1\}^{\wedge}1/n}{\alpha} \tag{4}$$

$$H = |\Psi_{\mathrm{m}}| - z \tag{5}$$

$$\Delta H_t = \frac{(H_{(L-z)it} + H_{(L-z)ft})}{2} - \frac{(H_{(L+z)it} + H_{(L+z)ft})}{2} \tag{6}$$

e

$$\Delta h = [\mu(\theta_0 \ldots \theta_L)_{ft}] - [\mu(\theta_0 \ldots \theta_L)_{it}] * \Delta Z \tag{7}$$

where: $\overline{K}(\theta)$ is the unsaturated soil hydraulic conductivity (mm d^{-1}), K_0 is the saturated soil hydraulic conductivity (mm d^{-1}), L is the considered layer (cm) for the soil water balance (effective depth crop roots), z (negative values) is the multiple of the depths (cm) where the volumetric soil water contents (m^3 m^{-3}) were measured, $\theta_{(L-z)ft}$ is the volumetric soil water content (m^3 m^{-3}) at L - z (cm) on final time, $\theta_{(L+z)ft}$ is the volumetric soil water content (m^3 m^{-3}) at L + z (cm) on final time, is the volumetric soil water $\theta_{(L-z)it}$ content (m^3 m^{-3}) at L - z (cm) on initial time, $\theta_{(L+z)it}$ is the volumetric soil water content (m^3 m^{-3}) at L + z (cm) on initial time, ΔH_t is the soil water total potential variation at L - z to L + z (mm) soil depth, $H_{(L-z)it}$ is the soil water total potential (mm) at L - z (cm) soil depth on initial time, $H_{(L-z)ft}$ is the soil water total potential (mm) at L - z (cm) soil depth on final time, $H_{(L+z)it}$ is the soil water total potential (mm) at L + z (cm) soil depth on initial time, $H_{(L+z)ft}$ is the soil water total potential (mm) at L + z (cm) soil depth on final time, Δz is the depth variation between L - z and L + z (cm) for the deep drainage and capillary rise, ΔZ is the depth variation between 0,0 – L (cm) for the soil water storage variation, μ is the symbolic notation of the mean, $(\theta_0 \ldots \theta_L)_{ft}$ are the volumetric soil water content (m^3 m^{-3}) measured at each z, from 0,0 to L soil depth (cm) on final time, $(\theta_0 \ldots \theta_L)_{it}$ are the volumetric soil water content (m^3 m^{-3}) measured at each z, from 0,0 to L soil depth (cm) on initial time, $|\Psi_{\mathrm{m}}|$ (absolute values) is the matricial potential (kPa), θ_s is the saturated volumetric soil water content (m^3 m^{-3}), θ_r is the residual volumetric soil water content (m^3 m^{-3}) and, α, m and n are water soil retention curve parameters (dimensionless) since θ< <1, θ<m<1 and n>1, according van Genutchen (1980) model.

The water soil retention curves, obtained from laboratory and field soil matricial potential (kPa) and volumetric water content (m^3 m^{-3}) data at 0-30 and 30-60 cm depths

(Figure 3) were determined at the UFCG Irrigation and Salinity Laboratory, Campina Grande, Paraíba State, Brazil, using Richards plates. The water soil retention curves data were fitted by polynomial regression, as van Genuchten (1980) model, determined by SWRC software (Soil Water Retention Curve - Beta 3.0 version -. DOURADO NETO et al., 2000), with the obtained parameters and the soil saturated hydraulic conductivity (K_0) values, determined in the experimental area, by the infiltrometer method, organized in Table 2.

To estimate the saturated soil hydraulic conductivity - K_0 were held on October 17th 2012, three infiltration tests at different points of the experimental area with 25 and 50 cm diameter infiltrometers, both with 30 cm high, 15 cm buried in the ground surface as Bernardo et al. (2009), being considered the stable infiltration rate (SIR) as the saturated soil hydraulic conductivity.

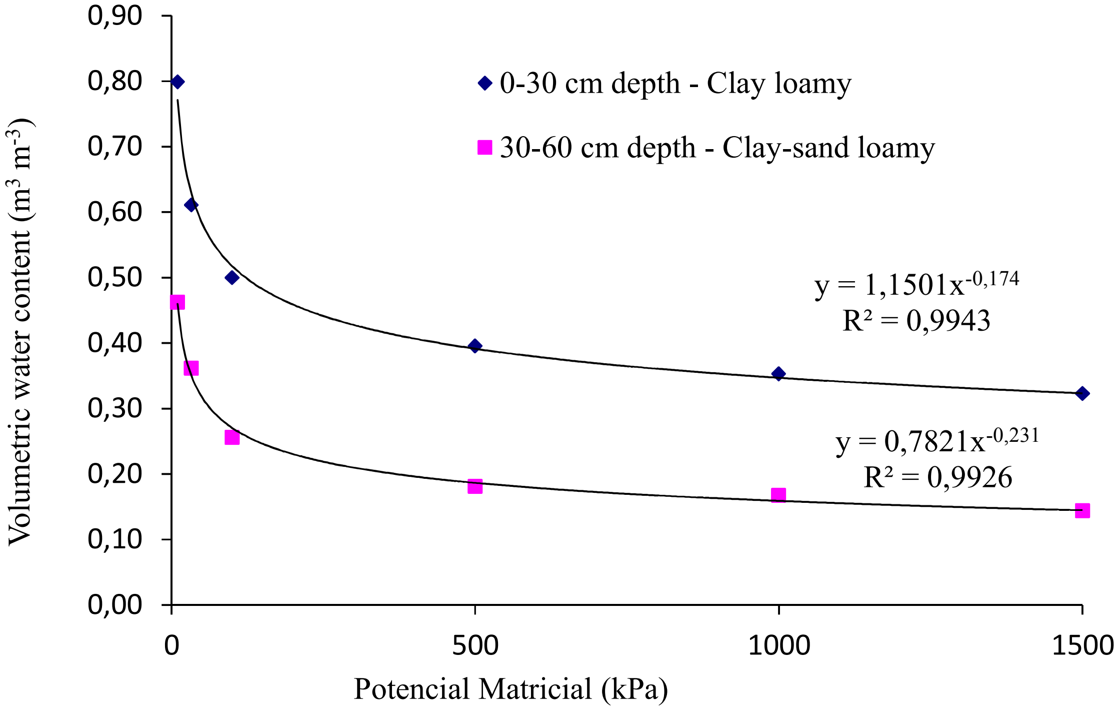

Figure 3. Soil water retention curves at 0-30 and 30-60 cm depths. Barbalha County, Ceará State, Brazil. 2012.

Table 2. Soil water retention curves parameters and soil saturated hydraulic conductivity (K_0 - mm d^{-1}) determined at 10 to 50 cm depths. Barbalha County, Ceará State, Brazil. 2012.

Parameters	Depths (cm)				
	10	20	30	40	50
α	1.4690	1.4690	1.4690	0.0693	0.0693
m	0.0947	0.0947	0.0947	0.0728	0.0728
n	2.9170	2.9170	2.9170	5.3548	5.3548
θr	0.0950	0.0950	0.0950	0.0560	0.0560
θs	0.8600	0.8600	0.8600	0.3240	0.3240
K_0	19.070	19.070	19.070	19.070	19.070

The reference evapotranspiration was determined in the 100% crop evapotranspiration level by FAO-Penman-Monteith method, as equations (8) and (9) (ALLEN et al., 2006):

$$ETo = \frac{0{,}408\,\Delta(Rn - G) + \gamma\left(\dfrac{900}{T + 273}\right)U_2\,(e_s - e_a)}{\Delta + \gamma\ (1 + 0{,}34U_2)} \qquad (8)$$

where: ET_o is the reference evapotranspiration (mm d^{-1}); Rn is the net radiation at crop surface (MJ m^{-2} d^{-1}); G is the soil heat flux density (MJ m^{-2} d^{-1}), considered insignificant when using daily calculations; T is the air temperature at 2 m height (ºC); U_2 is the wind speed at 2 m height (m s^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the current vapor pressure (kPa); Δ is the slope vapor pressure curve (kPa ºC^{-1}); γ is the psychrometric constant (kPa ºC^{-1}).

$$\Delta \;=\; \frac{4098\left[0{,}6108\ e^{\left(\frac{17{,}27\,\bar{T}}{\bar{T} + 237{,}3}\right)}\right]}{\left(\bar{T} + 237{,}3\right)^2} \qquad (9)$$

The psychrometric constant (γ) = 0,0622 kPa $^{o}C^{-1}$ since it is a function of atmospheric pressure, which varies very little throughout the year (95.03 kPa), and also of the water evaporation latent heat, that is little affected by temperature, being recommended an average value of 2.45 MJ kg^{-1}.

The crop coefficients – Kc, were obtained for each sesame BRS 196 CNPA G4 phenological phase, by the relationship between the crop evapotranspiration (ETc) values, estimated by the soil water balance (REICHARDT; TIMM, 2012), and the reference evapotranspiration (ET_0) values, determined by the FAO-Penman-Monteith method, according to Equation (10) (ALLEN et al., 2006), i. e.:

$$Kc = \frac{ETc}{ET_0} \qquad (10)$$

4 RESULTS AND DISCUSSION

The water balance components in the soil cultivated with sesame BRS 196 CNPA G4 during the study period are presented in Table 3 and Figure 4.

Table 3. Water balance components in soil cultivated with sesame BRS 196 CNPA G4 during the period from August 10th to November 7th , 2012. Barbalha County, Ceará State, Brazil.

Sub-periods (DAE - Phase)	I (mm d^{-1})	Δh (mm d^{-1})	D/C (mm d^{-1})	ETc (mm d^{-1})
-	39.5	-	-	-
1 (2 to 5 - P/E)	19.8	-3.7	3.8	5.0
2 (6 to 9 - G)	15.8	3.7	4.5	6.0
3 (10 to 17 - G)	31.6	0.5	8.2	5.0
4 (18 to 24 - G)	44.7	-6.1	11.8	7.2
5 (25 to 32 - G)	35.6	14.2	10.7	7.6
6 (33 to 40 - D/F)	94.8	14.6	6.4	14.5
7 (41 to 47 - D/F)	34.2	-11.7	-3.4	2.7
8 (48 to 54 - D/F)	52.7	9.2	-3.8	8.3
9 (55 to 61 - D/F)	54.0	15.0	-4.2	9.3
10 (62 to 66 - D/F)	30.3	-6.1	-4.6	3.9
11 (67 to 74 - M)	28.9	-14.6	-3.7	1.3
12 (75 to 81 - M)	54.0	20.3	-2.8	10.2
13 (82 to 90 - M)	31.6	-10.9	-2.4	2.0

I = irrigation; Δh = soil water storage variation; D/C = deep drainage (negative values) or capillary rise (positive values); ETc = crop evapotranspiration; P/E = Planting/Establishment; G = Growth; D/F = Development/Floration; M = Maturation.

The highest ETc values on the growth and development/floration phases can be explained by the fact that, according to Weiss (1983), in sesame, the maximum water absorption occurs at flowering, gradually decreasing thereafter, leading thus to an increase in evapotranspiration at this phase. Moreover, on these phases and on maturation, greater irrigation volumes occurred, which, as already mentioned, caused an increase in ETc. These higher values of ETc under major irrigation volumes occur due to increased evaporation in the surface layers, as observations of Cruz et al. (2005). The ETc decreasing at end of cycle probably occurred, according to Lima et al. (2006) due to leaves senescence, reducing the leaf area and, thus the exposed area to transpiration (Table 3, Figure 4).

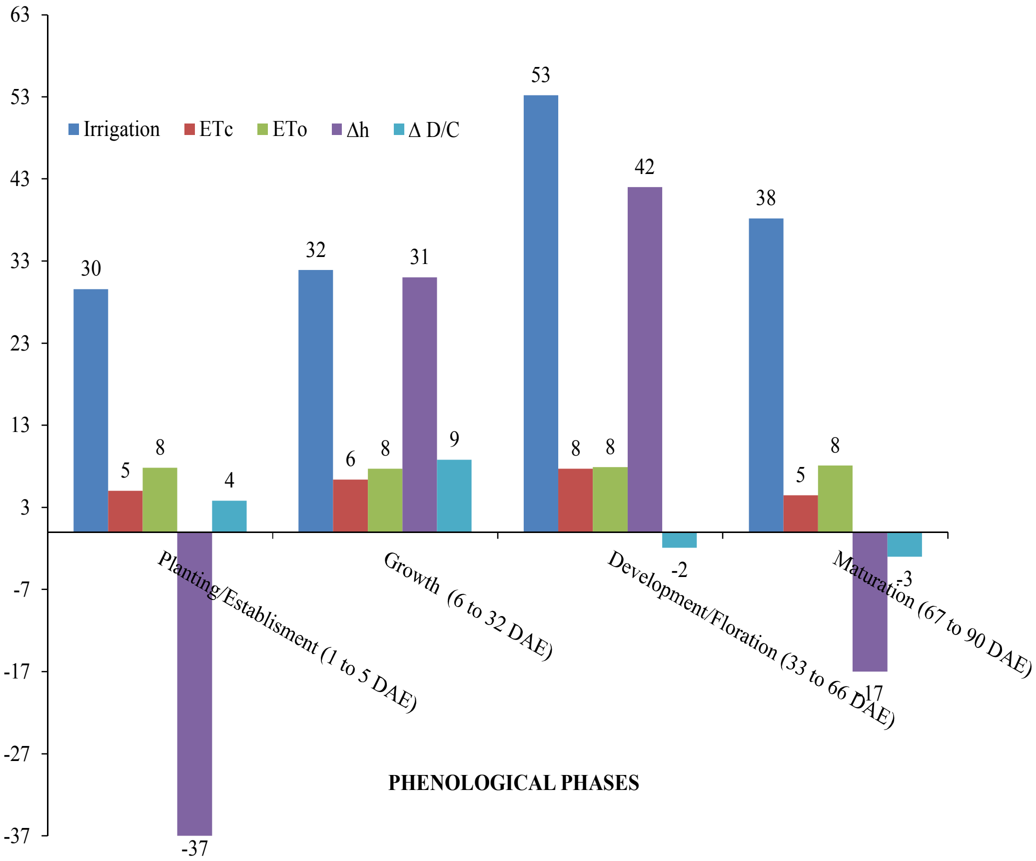

Figure 4. Irrigation (I), crop (ETc) and reference (ET_0) evapotranspiration, soil water storage (Δh) and soil drainage rates (D/C) daily averages for the different sesame BRS 196 CNPA G4 phenological phases. Barbalha County, Ceará State, Brazil. 2012.

The average ETc results in the experiment ranged from 1.3 to 14.5 mm d^{-1}, very different from those obtained by Chandrakar et al. (1994), in the Chhattisgarh region, India, in a sesame experiment under irrigation and by Amaral; Silva (2008), with the same sesame BRS 196 CNPA G4, irrigated too, in Barbalha County, Ceará State, Brazil.

The soil water storage variation (Δh) showed positive values in sub-periods 2, 3, 5, 6, 8, 9 and 12 with 3.7, 0.5, 14.2, 14.6, 9.2, 15.0 and 20.3 mm d^{-1}, respectively. The sub-periods 1, 4, 7, 10, 11 and 13 showed negative values with -3.7, -6.1, -11.7, -6.1, -14.6 and -10.9 mm d^{-1}, respectively (Table 3).

The soil water drainage rates (D/C) values were positive in sub-periods 1 to 6 - during planting/establishment and growth phases (totaling 4.5 mm), i. e., capillary rise (C), and negative in sub-periods 7 to 13 - development/floration and maturation phases (totaling -2.5 mm), indicating deep drainage (D). For the development/floration phase, where the largest amount of irrigation (53 mm) occurred, was provided higher deep drainage values, despite soil texture of the area having low infiltration capacity (Table 3, Figure 4), which agrees with the results of Azevedo et al. (2006), where the increases of the irrigation water amounts resulted in similar increases of the soil water drainage rate. The low soil water drainage rate values found in this study may be due to the low hydraulic conductivity (Table 3) or, according to Fernandes et al. (1999) to the normal difficulties encountered in the estimation of this term of the soil water balance equation.

It is also observed in Figure 4, that the period of highest sesame water requirement occurred in the development/floration phase, as agreed by Weiss (1983), with a total of 53 mm, with the lower water requirement occurring on planting/establishment phase with 30 mm. The applied water total volume was 567.5 mm. Interesting was the volume demanded by the growth phase to be smaller than the maturation ones, but Uçan et al. (2007) point out that the sesame is tolerant to lack of water in the soil during growth phase. This total irrigation amount is within of the suggested by Milani et al. (2006) who claim that sesame is very productive in regions with rainfall between 400-650 mm .

Regarding to the ET_0 values, they were higher than ETc during planting/establishment and maturation phases, indicating that on these phases the Kc value is smaller than on ones (Figure 4, Table 3).

Finally, from the relationship between the ETc values, calculated by the soil water balance, and the ET_0 values, estimated by the Penman-Monteith method, were obtained, *in situ*, for each sesame BRS 196 CNPA G4 phenological phase, the respective crop coefficients - Kc which are distributed in Table 4.

Table 4. Kc mean values for sesame BRS 196 CNPA G4 phenological phases in the Barbalha County, Ceará State, Brazil. 2012.

Phenological phase	Period (DAE)	Duration (Days)	Kc
I - Planting/Establishment	1 to 5	5	0.63
II - Growth	6 to 32	27	0.83
III - Development/Floration	33 to 66	34	0.97
IV – Maturation	67 to 90	24	0.56

Notably, the sesame BRS 196 CNPA G4 Kc value for phase III (development/floration phase) (Table 4) obtained in this study, approaches for less to the reported by Allen et al. (2006) and, for more, to the found by Amaral; Silva (2008). The Kc value of the phase IV (maturation phase) (Table 4), in turn, was nearly twice that found by Allen et al. (2006). According Albuquerque et al. (2002) and Allen et al. (2006), even for the same crop, the Kc value is not constant, it changes depending on climatic as well as season conditions and crop characteristics throughout its cycle.

5 CONCLUSIONS

1. The soil water balance method was able to determine the Kc value for each phenological phase of the sesame BRS 196 CNPA G4;
2. The sesame BRS 196 CNPA G4 evapotranspiration was higher in the development/floration phase, and smaller during planting/establishment and maturation ones;
3. The sesame BRS 196 CNPA G4 crop coefficient values were 0.63 (planting/establishment), 0.83 (growth), 0.97 (development/floration) and 0.56 (maturation).

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