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NECESSIDADES HÍDRICAS DO TOMATEIRO INDUSTRIAL IRRIGADO POR GOTEJAMENTO ENTERRADO PARA AS CONDIÇÕES DE CERRADO DE GOIÁS

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1 RESUMO

O objetivo desta pesquisa foi determinar as necessidades hídricas e o coeficiente de cultivo do tomateiro para processamento industrial irrigado por gotejamento enterrado em área de Cerrado de Goiás. A pesquisa foi conduzida durante dois anos no Instituto Federal Goiano – Campus Morrinhos, Goiás, situada a 885 metros de altitude, 17º49'19" de latitude Sul e 49º12'11" de longitude Oeste. A evapotranspiração da cultura foi determinada utilizando-se cinco minilisímetros de pesagem cultivados com uma planta cada. O coeficiente de cultivo foi estimado através da razão entre a evapotranspiração da cultura de cada fase de desenvolvimento do híbrido e a evapotranspiração de referência estimada pela equação de Penman-Monteith. A demanda do tomateiro "híbrido BRS Sena" irrigado por gotejamento enterrado nas condições de Cerrado de Goiás foi de 490 e 427 mm nos dois anos de cultivo, respectivamente. As necessidades hídricas do "híbrido BRS Sena" variaram em função do ano de plantio e do seu desenvolvimento vegetativo e produtivo. Os coeficientes de cultivo médios estimados de dois anos de pesquisa para as condições de cultivo no Cerrado foram de 0,60-0,65 (0 – 10 dias após o transplantio); 0,88-1,00 (11 – 40 dias após o transplantio); 1,00-1,23 (41 – 70 dias após o transplantio); 1,07- 1,27 (71 – 97 dias após o transplantio) e; 0,71-0,83 (98 – 125 dias após o transplantio).

Palavras-chave: *Solanum* l*ycopersicom* L., gotejamento subsuperficial, manejo da irrigação, coeficiente de cultivo

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WATER REQUIREMENT OF INDUSTRIAL TOMATO IN SUBSURFACE DRIP IRRIGATION FOR THE CERRADO CONDITIONS, IN GOIAS, BRAZIL

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2 ABSTRACT

The aim this research was to mensure the water requirement and the crop coefficient of the industrial tomato, BRS Sena hybrid, irrigated by subsurface drip irrigation, in the Cerrado area of Goiás, Brazil. The research was conducted in two consecutive years, 2015 and 2016, in an Horticulture Experimental Area of the Federal Goiano Institute - Campus Morrinhos, Goiás, located at 885 meters of altitude, 17º49'19” south latitude and 49º12'11” west longitude. The crop evapotranspiration was mensured using five weighing mini-lysimeters, cultivated with one plant each. The crop coefficient was estimated through the ratio between the crop evapotranspiration of each hybrid development stage and the reference evapotranspiration estimated by the Penman-Monteith equation. Under cultivation conditions, the tomato required a replacement the 490 and 427 mm of the crop evapotranspiration accumulated, in the two years, respectively. The water needs of the hybrid vary depending on the year of planting and also on the basis of its vegetative and productive development. The estimated average crop coefficients from two years of research for cropping conditions in the Cerrado were 0.60-0.65 (0 – 10 days after transplanting); 0.88-1.00 (11 - 40 days after transplantation); 1.00-1.23 (41 – 70 days after transplantation); 1.07-1.27 (71 – 97 days after transplanting) and; 0.71-0.83 (98 – 125 days after transplanting).

Keywords: *Solanum* l*ycopersicom* L., subsurface drip irrigation, irrigation management, crop coefficient

3 INTRODUCTION

Water is one of the factors that most influences the development, productivity, and industrial quality of tomato fruits. Both excess and deficit water levels impair crop development and the quality of tomato fruits for industrial processing (NANGARE et al., 2016; SILVA et al., 2019).

Understanding tomato water demand for industrial processing is essential for irrigation planning and management in Cerrado cultivation areas. Quantifying crop irrigation depth and evapotranspiration requires knowledge of meteorological factors, such as rainfall, temperature, light, relative humidity, and wind speed, and plant characteristics, such as phenological stage, root system depth, absorption physiology, and water transfer to the atmosphere. These factors should be adopted on the basis of local research for each cultivar or hybrid and not on practices that have proven successful in other regions (PEREIRA; SEDIYAMA; VILLA NOVA, 2013; SILVA et al., 2019; SILVA et al., 2020).

Crop evapotranspiration (ETc) is a fundamental parameter in the design of irrigation systems and water management for crops (SILVA et al., 2019). The ETc value is generally calculated as a function of the crop coefficient (Kc), where the effects of meteorological conditions are represented by the reference evapotranspiration (ETo) and the characteristics of crop water consumption are represented by the crop coefficient (Kc) (ALLEN et al., 1998). Kc values vary with management conditions and crop characteristics; that is, Kc is an index that expresses the morphological (leaf area), physiological (metabolic intensity), and phenological (development stage) effects of a crop on its water consumption. To adapt irrigation management to local conditions, it is necessary to estimate Kc values at each location for each crop and growing season (PEREIRA; SEDIYAMA; VILLA NOVA, 2013).

Lysimetry is one of the most common and accurate methods for determining ETc and Kc in crops. However, lysimeters are generally large, stationary, and expensive structures with surface areas greater than 2 m2, making them difficult to use. An alternative is the use of small, portable lysimeters, such as those used by Grimmond, Isard, and Belding. (1992), Waugh et al. (1991), Misra, Padhi and Payero (2011), Gervásio and Melo Junior (2014) and Vilela et al. (2015), in which they achieved effective, accurate and reliable ETc results.

The use of mini-lysimeters to determine tomato water requirements has already been used, as in a study carried out by Reis, Souza and Azevedo (2009), who used small lysimeters (1.0 × 1.0 × 0.7 m) in a protected environment in Rio Largo, AL, with persimmon tomato plants and reported a high correlation between the ETc calculated by the average of four lysimeters and the ETc estimated via the Penman–Monteith equation with meteorological data measured inside the greenhouse. In Campinas, SP, which tests the irrigation frequency in Sahel tomato plants in a protected environment, Pires et al. (2009) used small weighing lysimeters with a capacity of 50 kg, with the mass variation measured on a precision scale of 0.01 kg, to calculate ETc and monitor irrigation.

In the literature, several Kc values are found for tomato crops, such as those established by Doorenbos and Pruit (1977), Allen et al. (1998), Marouelli, Silva and Oliveira (1991), Marouelli, Silva and Silva (1996), Marouelli and Silva (2002), Santana et al. (2011) and Marouelli, Silva and Silva (2012). However, few studies have investigated the Kc of industrial tomato plants irrigated by subsurface drip in Cerrado areas.

Thus, the objective of this research was to determine the water requirements and cultivation coefficient of tomato plants for industrial processing irrigated by buried drip irrigation under the edaphoclimatic conditions of the Cerrado in Goiás.

4 MATERIALS AND METHODS

The research was conducted in two consecutive years, from June to October 2015 and May to September 2016, at the Experimental Horticulture Area of the Instituto Federal Goiano, Morrinhos Goiás Campus, which is located at an altitude of 885 m, 17°49'19" South latitude and 49°12'11" West longitude, for a period of 125 days of cultivation in each experiment. The climate classification of the municipality, according to Köppen (1948), falls into the AW type, semihumid tropical, with a rainy summer and dry winter, an average annual temperature of 23.3°C and an average annual precipitation of 1346 mm.

During the experiments, meteorological variables were monitored by an automatic station located approximately 300 meters from the experimental area. The maximum mean daily wind speed (VV) recorded was 3.28 ms $^{-1}$ at 89 DAT and 3.5 ms $^{-1}$ at 102 DAT in 2015 and 2016, respectively (Figures 1 and 2). During the 2015 experimental period, the mean temperature (TMed) was 22.92°C, with 86 mm of precipitation, of which 30.6 mm occurred until 40 DAT, and 55.4 mm occurred in the final phase of the experiment. In 2016, the TMed was 22.54°C, with 27.6 mm of precipitation, of which 13 mm occurred until 25 DAT, and 14.6 mm occurred in the final 30 days of the experiment. In general, the highest temperatures coincided with the highest peaks of global solar radiation (Rg), which increased throughout both experiments (winter - spring) (Figures 1 and 2).

The ETc values were not recorded on days when it rained because of the difficulty in estimating the effective rainfall volume on the minilysimeters. Reference evapotranspiration (ETo) was estimated via the Penman–Monteith equation parameterized by Allen et al. (1998) via a spreadsheet developed for this purpose in Microsoft Excel®. The maximum ETo values calculated via the Penman equation Monteith coincided with the maximum Rg values. The maximum calculated ETo was 5.54 mm day $^{-1}$ and 6.03 mm day $^{-1}$ at 125 DAT in 2015 and 121 DAT in 2016, respectively. During the 125 days of the experiments, the accumulated ETo was 474.06 mm in 2015 and 492.24 mm in 2016 (Figures 1 and 2).

Figure 1. Precipitation values (PPs), global solar radiation (Rg), wind speed (VV), average temperature (TMéd) and reference evapotranspiration (ETo) during the experiment (01/06/2015--03/10/2015) in Morrinhos–GO

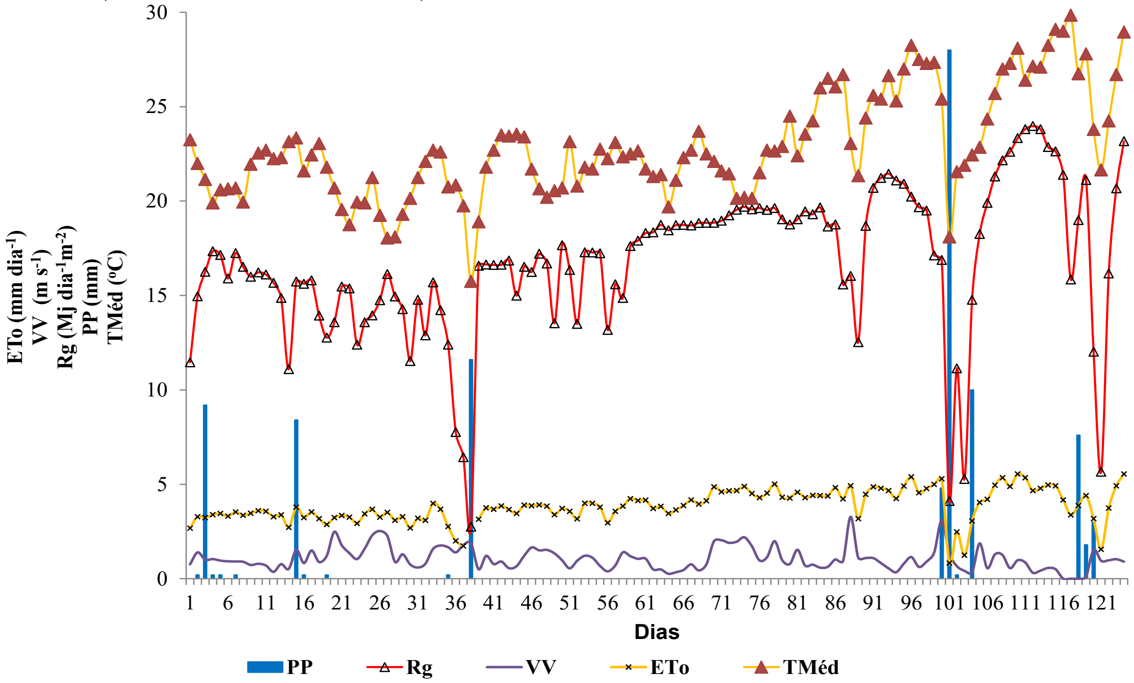
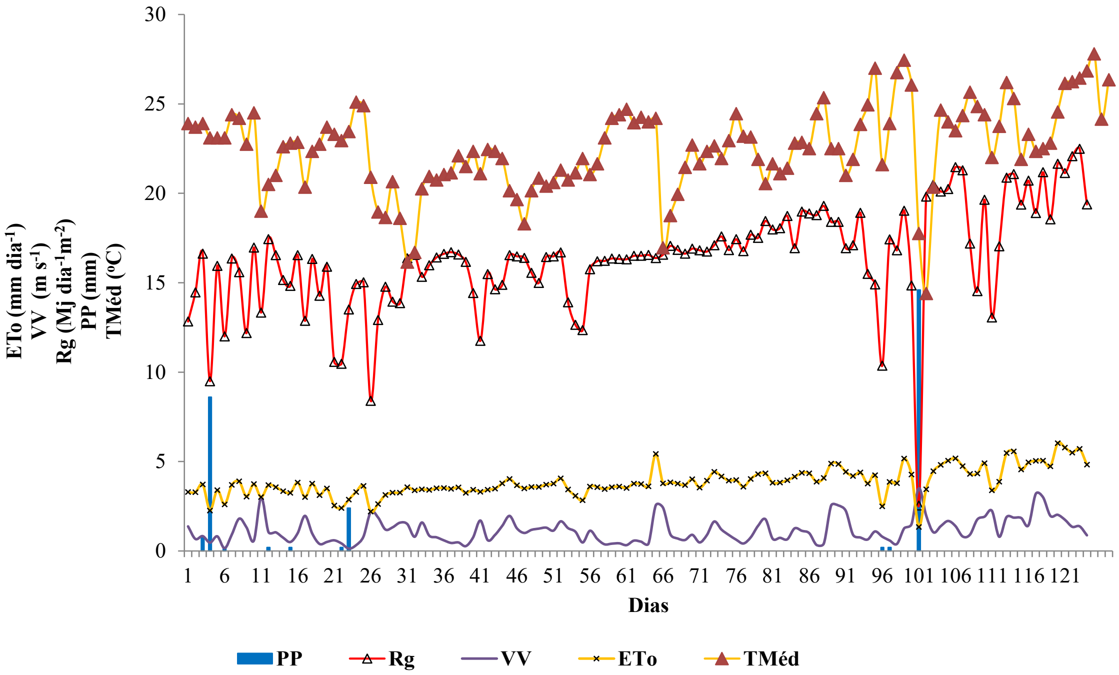
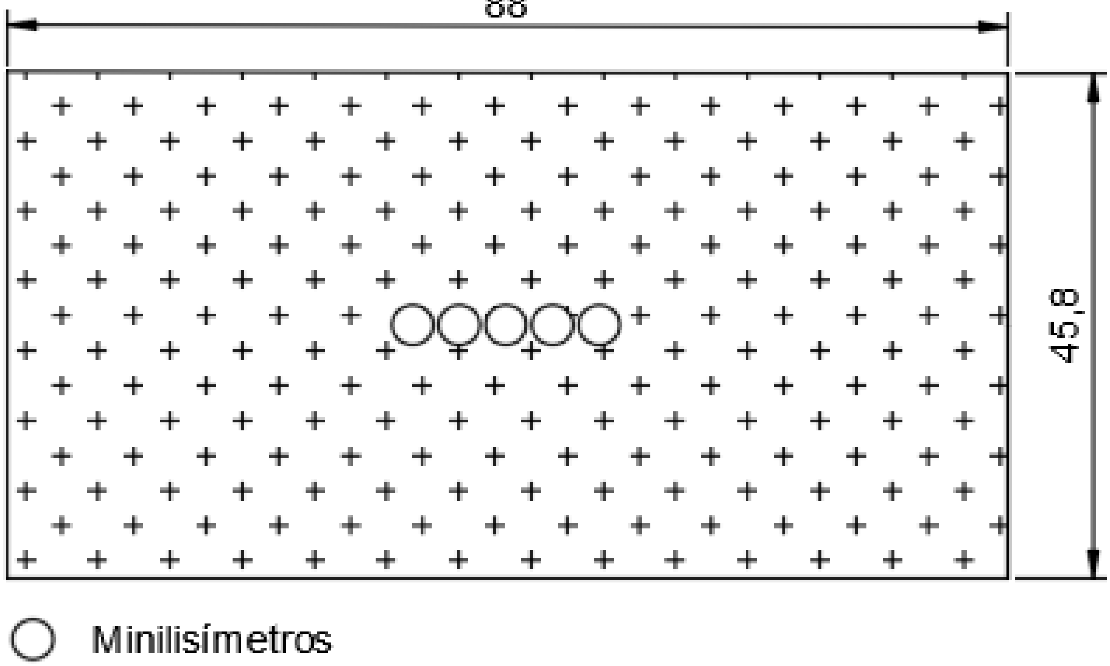


Figure 2. Precipitation (PP), global solar radiation (Rg), wind speed (VV), average temperature (TMéd) and reference evapotranspiration (ETo) values during the experiment (May 13, 2016, to September 16, 2016) in Morrinhos–GO



Tomato water requirements were determined via five plants grown in five 52-liter polypropylene minilysimeters with a 32.5-cm upper rim diameter. The minilysimeters were installed in the center of an experimental area of approximately 0.4 ha of tomato for industrial processing. Commercial industrial tomato "BRS Sena hybrid" plants were used in both experiments (Figure 3).

Figure 03. Sketch of the location of the mini-lysimeters within the experimental area with tomato plants, Morrinhos – GO



The mini-lysimeters were drilled at the base for water drainage. Thirteen uniform holes were drilled with a 1/2-inch drill bit in the same position as the base. After drilling, a dripper was installed in the center of each mini-lysimeter at a depth of 20 cm, the same depth as the subsurface dripper installed in the experimental area. The dripper was installed through holes on the sides of the mini-lysimeters with a diameter sufficient for the dripper line to pass through, a methodology also used by Silva et al. (2014) in jatropha.

To prevent water loss, the vessel wall was sealed with glue (Araldite®) to the dripper line. The minilysimeter dripper was connected to the experimental irrigation system via a threaded fitting for low-density polyethylene tubing. To ensure accurate water replenishment in all the minilysimeters, a flow test was performed on each dripper after installation, with five replicates lasting 10 minutes at an operating pressure of 150 kPa.

The lower internal base of the containers was subsequently lined with a bidim® geotextile blanket, followed by a small layer of zero-gravel gravel and medium-sieved sand to prevent soil loss during saturation and during the experiment. Only after this procedure were the mini-lysimeters filled with air-dried soil from the 0–15 cm layer of the experimental tomato plant area for industrial processing after limestone application. Initially, the mass of the container plus the dripperline, the geotextile blanket mass, the gravel mass, the sand mass, and the soil mass of each pot were determined, with each mini-lysimeter having the same mass of gravel, sand, and soil (Table 1). As 5.0 cm layers of soil were added to the lysimeters, weighing and light compaction were performed, with the soil being placed within 2 cm of the top rim of the containers. In the 2016 survey, the same lysimeters and soil used in the first survey were used.

Tabela 1. Data from mini-lysimeters and moisture determination at “field capacity ” , in Morrinhos – GO

Mini-lysimeter	MLG	MLGB	MLGBA	MLGBAS	MS	$M_{\theta cc}$	Bad	U_{cc}	Θ_{cc}
	kg							$(g\ g^{-1})$	$(cm^3\ cm^{-3})$
1	1.82	3.82	4.82	54.82	50	64.08	14.08	0.28	0.33
2	1.84	3.84	4.84	54.84	50	64.18	14.18	0.28	0.33
3	1.78	3.78	4.78	54.78	50	63.70	13.70	0.27	0.32
4	1.84	3.84	4.84	54.84	50	65.12	15.12	0.30	0.35
5	1.84	3.84	4.84	54.84	50	64.94	14.94	0.30	0.35

MLG – mass of lysimeter plus dripper (kg); MLGB – mass of lysimeter + dripper + geotextile blanket + gravel; MLGBA – mass of lysimeter + dripper + geotextile blanket + gravel + sand; MLGBAS - mass of lysimeter + dripper + geotextile blanket; + bidim + gravel + sand + soil; MS – mass of soil at natural moisture content (kg); Mθcc – mass of lysimeter + dripper + geotextile blanket + gravel + sand + soil + seedling mass, at field capacity; Ma – mass of water (g); Ucc – moisture content on the basis of mass at field capacity (gg $^{-1}$); Ɵcc – moisture content at field capacity on the basis of volume (cm ^{3} cm $^{-3}$); D – lysimeter diameter (cm);

Five days before the seedlings were transplanted, the mini-lysimeters were placed in a container with a water table for 24 hours to saturate the soil via capillary rise. They were then placed on wooden platforms to drain, and the top surface was sealed with plastic film to prevent evaporation. After 96 hours, they reached a constant mass, and there was no longer drainage at the base; thus, the lysimeters at field capacity were considered. This procedure was also used by Casaroli and Jong Van Lier (2008) and Silva et al. (2016) to determine soil moisture at "field capacity in pots."

Knowing the specific mass of the soil (r = 1.18 g cm $^{-3}$) in the 0--15 cm layer, the mass of the air-dry soil (MS) at natural humidity and the mass of water (MA) and the humidity at the field capacity of the minilysimeters were determined, as described by Libardi (2005) (Equation 01), on the basis of volume (Θ_{cc} cm ^{3} cm $^{-3}$) (Table 1). In general, the $\Theta_{cc\ values}$ of the minilysimeters were very close to the $\Theta_{cc\ value}$ determined by the van Genuchten equation, with data from the soil water retention curve of the 0--15 cm layer, where the moisture at field capacity was 0.36 m ^{3} m $^{-3}$ (-10 kPa).

$$\theta_{cc} = \frac{\rho}{\rho_a} \cdot U_{cc} \quad \therefore \quad \theta_{cc} = \frac{\rho}{\rho_a} \cdot \frac{M_a}{M_s} \qquad (01)$$

where θcc is the moisture content at “field capacity in containers”, which is based on volume (cm ^{3} cm $^{-3}$); ρa is the specific mass of water (1,0 gcm $^{-3}$); Ucc is the moisture content at “field capacity”, which is based on dry soil mass (gg $^{-1}$); and Ma and Ms are the masses of water and dry substrate in the containers, respectively (g).

The ETc calculation (Equation 2) was performed on the basis of the average mass of five minilysimeters at the field capacity moisture content ($M\theta_{cc}$) and the minimum moisture content at the current moisture content ($M\theta_a$), cultivated with one tomato plant in each lysimeter. ETc determinations in the lysimeters were carried out on Mondays, Wednesdays, and Fridays throughout the research period. When the amount of rainfall increased from the minilysimeters to the field capacity mass, irrigation was not carried out, and ETc data were not recorded.

$$ETc = \frac{40 \cdot \left(M_{\theta cc} - M_{\theta a}\right)}{\rho_a \cdot \pi \cdot D^2} \qquad (02)$$

where ETc is the plant evapotranspiration (mm); $M_{\theta cc}$ is the mass of the mini lysimeter + plant + soil at “field capacity” moisture content (g); $M_{\theta a}$ is the average mass, of five replicates, of the mini lysimeter + seedling +

soil at the current moisture content (g); ρ_a is the specific mass of water (1.0 g cm $^{-3}$ was considered); and D is the diameter of the edge of the container at ground level (cm).

The minilysimeters used to determine ETc were kept inside trenches dug in the soil at the center of the experimental area, with their upper edges flush with the soil surface. The trench walls were lined with wooden planks to prevent soil collapse. The minilysimeters were removed from the trenches only during weighing procedures to prevent their walls from being exposed to solar radiation and wind, which could lead to overestimations of the ETc values.

Mass measurements ($M_{\theta cc}$ and $M_{\theta a}$) were performed via a scale with a capacity of 100 kg and an accuracy of 0.01 kg. After weighing, the minilysimeters were irrigated again to reach field capacity moisture content. They were then placed back into the trench, where they remained until the next irrigation. Irrigation replacement in the minilysimeters was performed continuously, as in the field, using a subsurface dripper installed at a depth of 20 cm in the minilysimeters.

The fertilization of the plants in the minilysimeters followed the same recommendations for the crops in the surrounding experimental area. Fertilization was applied at a depth of 15 cm, proportional to the fertilization of a plant in the experimental area, according to soil analysis, aiming for an expected productivity of 130 t ha $^{-1}$ (CFSGO, 1988). Liming was only necessary in 2015; broadcasts were applied 51 days before transplanting. In the two years of research, base fertilization was carried out at a depth of approximately 15 cm immediately before transplanting the seedlings, and the top dressing was carried out via fertigation, with half being applied at 22 days after transplanting (DAT) (urea and potassium chloride - fertigation) and the other 50% at 35 DAT (calcium nitrate and potassium chloride - fertigation), when fertigation of the experimental area was also carried out.

Phytosanitary management was carried out in accordance with regional crop recommendations, aiming to keep the crop free of weeds, pests, and diseases, allowing it to reach its maximum potential for development, growth, and productivity. Pest and disease control applications were carried out preventively, weekly, alternating products with different active ingredients and modes of action at each stage of crop development, aiming to ensure that the crop reached its maximum productive potential.

The cultivation coefficient (Kc) was determined in five crop phases: initial (0–10 DAT), vegetative (11–40 DAT), flowering (41–70 DAT), fruiting (71–97 DAT), and maturation (98–125 DAT). The Kc estimate was performed through correlation analysis between the average ETc of the 5 minilysimeters for each hybrid development period and the Eto calculated by the Penman–Monteith equation parameterized by the FAO, corresponding to this period, considering the two years of research (ALLEN et al., 1998).

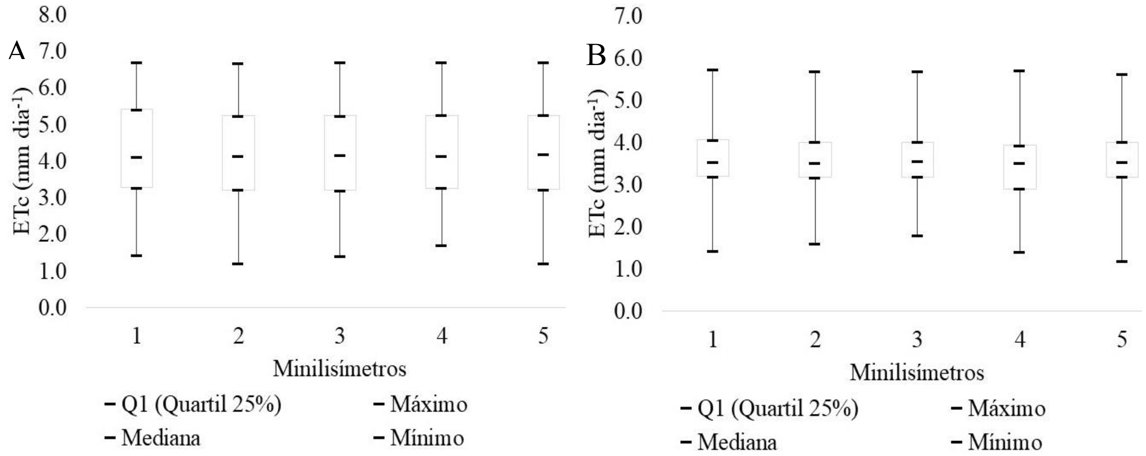
5 RESULTS AND DISCUSSION

In the first year of research, no typical begomovirus symptoms were observed in the crop. In the second year, despite intensified whitefly control, strong pest pressure occurred on tomato plants, culminating in a high incidence of viral disease symptoms caused by a complex of viruses of the begomovirus genus. Symptoms include wrinkling, deformation, leaf curling, decreased leaf area, and consequently reduced vegetative development, water and nutrient absorption, and lower plant productivity (INOUE-NAGATA, 2005). This explains the lower water consumption and Kc variation of the

BRS Sena hybrid tomato in 2016 than in 2015.

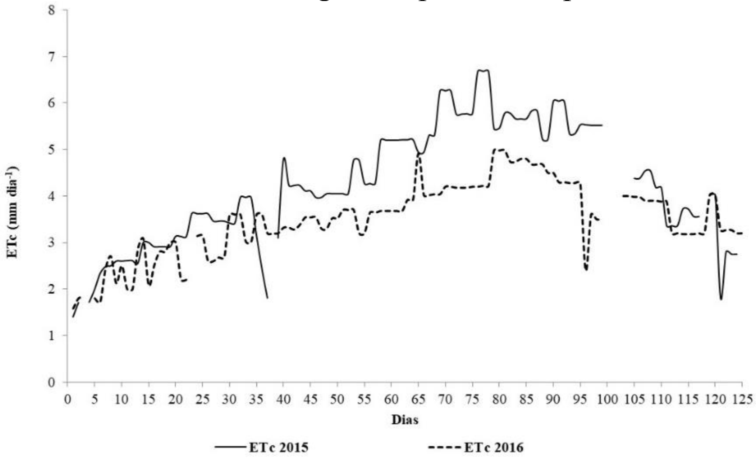
Figure 04 shows that crop evapotranspiration (ETc) was dispersed among the minilysimeters, in addition to temporal variability throughout the tomato development phases. The dispersion of the ETc data in the third and first quartiles, in the boxplot graph, was 2.13 and 0.87, 2.03 and 0.84, 2.04 and 0.83, 1.99 and 1.04 and 2.02 and 0.82, in 2015 and 2016, in the minilysimeters L1, L2, L3, L4 and L5, respectively. The largest ETc discrepancies occurred in minilysimeters L2 and L5 and in L1 and L5, respectively, in 2015 and 2016. The smallest quartile distances were observed in 2016 compared with 2015, and the lowest ETc values were recorded for the tomato plants in 2016 (Figure 04).

Figure 04. ETc variations in the five mini-lysimeters in 2015 (A) and 2016 (B) and in Morrinhos–GO



The amount of ETc accumulated during the crop cycle was 490.23 and 426.92 mm in 2015 and 2016, respectively (Figure 5), although the reference evapotranspiration (ETo) in 2016 was approximately 4% greater than that in 2015.

Figure 05. Accumulated ETc values during the experimental period in Morrinhos–GO



The lower plant water consumption in 2016 was certainly due to the reduced vegetative and productive development of the crop compared with that in 2015. As previously mentioned, in 2016, there was a higher incidence of virosis viracabosa and begomovirus. The manifestation of virus symptoms caused a reduction in the vegetative and productive development of the plants (INOUE-NAGATA, 2005). These findings indicate that the vegetative and productive development of tomato plants directly influences crop water consumption. Similarly, Silva et al. (2019) and Silva et al. (2020) evaluated the effects of irrigation levels on the productivity and vegetative development of the industrial tomato "BRS Sena hybrid" and reported that, in growing years with lower productivity and vegetative development, the crop water demand is lower.

These results are somewhat consistent with those reported by Silva et al. (2018) in Morrinhos, Goiás, who evaluated water replenishment in tomato plants for industrial processing. The authors recorded the highest yields for the "BRS Sena and Heinz 9992 hybrid" tomato, with ETc replenishments of 692.20 and 418.43 mm throughout the crop cycle, with ETc determined by a Class A tank and Kc from the FAO. The results also corroborate those reported by Basílio et al. (2019) in Morrinhos, Goiás, who evaluated irrigation intervals, ETo estimated via Class A tanks and Kc recommended by Marouelli, Silva, and Silva (1996). The authors reported ETc values of 421 and 535 mm in 2014 and 2015, respectively, for the industrial tomato hybrids “BRS Sena and Heinz 9992”.

The Kc values varied proportionally to the ETc and ETo values. Tomato plant evapotranspiration increased throughout the crop cycle until approximately 85 DAT, when it began to decrease until harvest. In the initial phase of the crop (up to 25 DAT), the crop consumed less water than ETo; however, from 25--100 DAT, the crop consumed more water than the reference crop did, and from then until harvest, it again consumed less water than ETo did in both years of research (Figures 5 and 6).

Figure 5. Ratio between crop evapotranspiration (ETc), reference evapotranspiration (ETo) and the crop coefficient (Kc) throughout the development of tomato plants (0--125 DAT in 2015) in Morrinhos–GO

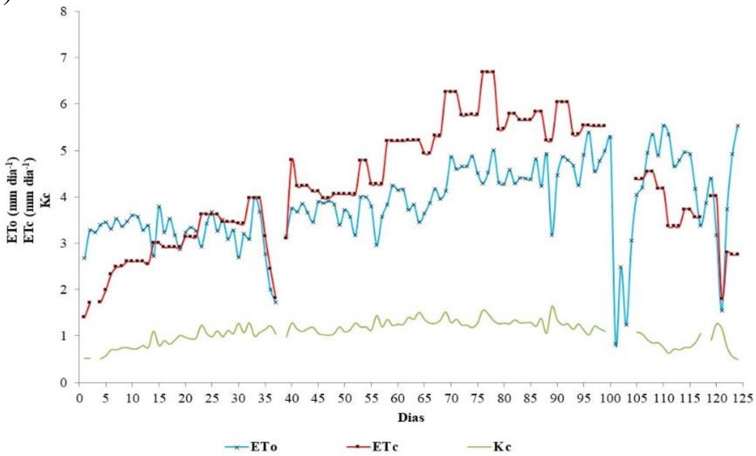
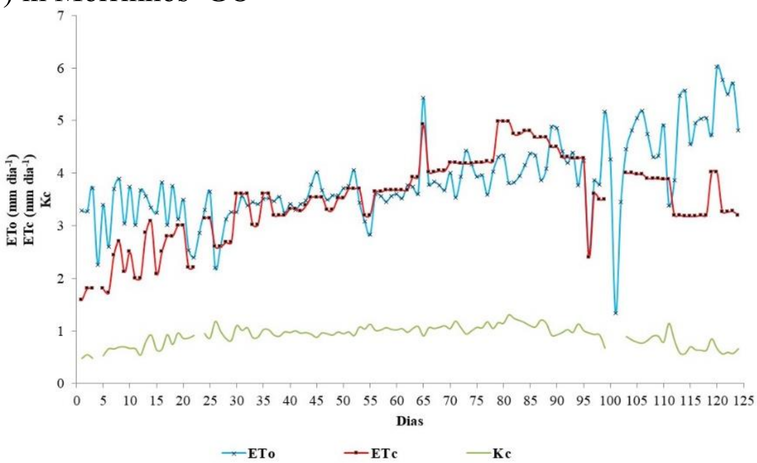


Figure 6. Ratio between crop evapotranspiration (ETc), reference evapotranspiration (ETo) and the crop coefficient (Kc) throughout the development of tomato plants (0--125 DAT in 2016) in Morrinhos–GO



Kc values were calculated by the ratio between the ETc and ETo values. In 2015, the tomato Kc values were greater than those in 2016. In general, the Kc values were higher than those recommended by Doorenbos and Pruit (1977), Santana et al. (2011) and Marouelli, Silva and Silva (2012) for tomato crops (Table 2).

Table 2. Cultivation coefficients for 2015 and 2016 and cultivation coefficients reported in the literature for Morrinhos–GO

Cultural Development	Kc 2015	Kc 2016	Kc DP [2]	Kc S [3]	Kc MSS [4]
0 - 10 DAT [1] (initial)	0.65	0.60	0.6	0.37	0.5
11 - 40 DAT (vegetative)	1.00	0.88	0.85	0.72	0.4
41 - 70 DAT (flowering)	1.23	1.00	1.15	1.03	1.0
71 - 97 DAT (fruiting)	1.27	1.07	0.9	1.1	1.0
98 - 125 DAT (maturation)	0.83	0.71	0.9	0.75	0.3

[1] DAT – Days after transplanting; [2] DP - Doorenbos & Pruit (1977); [3] S - Santana et al. (2011); [4] MSS - Marouelli; Silva; Silva (2012).

The Kc values varied from year to year due to weather variations and mainly due to plant development, which was lower in the second experiment than in the first experiment. This finding corroborates information from Allen et al. (1998), who reported that Kc varies mainly due to crop characteristics, soil variation, and small variation due to climate. The higher Kc values found, especially in the first experiment, compared with the literature values, may be related to the characteristics of the hybrid (BRS Sena), as it has a larger leaf area and leaf area index than the main industrial tomato cultivars and hybrids grown in the region. The results corroborate those reported by Silva et al. (2018) in Morrinhos, who reported that the industrial tomato plant “BRS Sena hybrid” presented a greater water demand (692.20 mm) than did the “Heinz 9992 hybrid” (418.43 mm) throughout its cycle, with productive potentials of 80.33 and 44.06 t ha $^{-1}$, respectively. According to the same authors, the hybrid (BRS Sena) has a greater water need than the other hybrids researched in the region do because of the greater vegetative and productive development, which justifies the discrepancy in the Kc values found in this research in relation to the values in the literature.

6 CONCLUSIONS

The water demands of the “BRS Sena hybrid” tomato plants irrigated by underground drip irrigation under the Cerrado de Goiás conditions were 490 and 427 mm in 2015 and 2016, respectively.

The water needs of the “BRS Sena hybrid” varied depending on the year of planting and its vegetative and productive development.

The estimated average crop coefficients from two years of research for the growing conditions in the Cerrado were 0.60--0.65 (0--10 days after transplanting), 0.88--1.00 (11--40 days after transplanting), 1.00--1.23 (41--70 days after transplanting), 1.07--1.27 (71--97 days after transplanting), and 0.71--0.83 (98--125 days after transplanting).

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