Article

Tomato water consumption in the greenhouse according to the number of stems

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Abstract

The low availability of water observed in the country's dams and the overexploitation of underground aquifers make it urgent to generate strategies to optimize this resource. One strategy is the optimization of irrigation by calculating water needs for irrigation scheduling. The objective of this study was to analyze the relationship between crop evapotranspiration (ETc) and crop coefficient (Kc) in tomato cultivation as a function of the number of stems, for the supply of irrigation water based on a drainage lysimeter and an atmometer. The work was carried out under controlled conditions using tezontle as a substrate and a drip irrigation system. The experiment consisted of three treatments, one (T1), two (T2) and three (T3) stems per plant. The drainage lysimeter method was used to measure daily crop transpiration (ETc) and an atmometer was used to estimate reference evapotranspiration (ETo). The accumulated transpiration of the crop was 352, 389 and 434 mm for T1, T2 and T3 and a Kc of 1.06, 1.16 and 1.32 for the same treatments, respectively, as well as the irrigation requirement of 1.04, 1.14 and 1.29 L plant^{-1}, both parameters determined in the stage of maximum water and nutrient demand. It is concluded that the daily measurements of transpiration in tomato with the drainage lysimeter allow to reliably calculate the water requirement of crops, in addition, the atmometer is an alternative to estimate the ETo for irrigation scheduling purposes in different crops.

Keywords: crop coefficient, leaf area index, irrigation requirement, protected agriculture.

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Introduction

The low availability of water observed in some dams of the Mexican Republic in recent years and the overexploitation of underground aquifers make it urgent to establish strategies to make rational and efficient use of this resource (López *et al*., 2010). Irrigation scheduling is a decision process aimed at determining the amount of water to be applied and the time of irrigation to minimize deficiencies or excess moisture in the soil that could cause adverse effects on crop growth, yield and quality. The scheduling of irrigations is usually done considering the days after sowing and transplanting or the experience of the producer (López *et al*., 2010).

Evapotranspiration is the sum of the water lost through the soil surface by evaporation and that lost through the transpiration of the plant (Vera *et al*., 2014) and to estimate it, the crop and environmental conditions are considered. Reference evapotranspiration (ETo) represents meteorological demand and crop coefficient (Kc) represents the ability of plants and soil to meet that demand (Jensen and Wright, 1978). The relationship of evaporation and transpiration in a crop varies according to its stages of development and growth, with the water requirement and the rate of transpiration being different for each crop, which depend on climatic conditions (Vera *et al*., 2014).

Another way to estimate the evapotranspiration of crops grown in greenhouse conditions is the use of simulation models. López-Cruz *et al*. (2017) recommends the use of the VegSyst and mod-VegSyst models to predict dry matter, nitrogen uptake and crop transpiration of greenhouse-grown tomatoes. Martínez Ruiz *et al*. (2019) developed a discrete time model (HortSyst) to describe photothermal time dynamics (PTI), total dry matter production (DMP), N uptake (N up), leaf area index (LAI) and evapotranspiration (ETc) for greenhouse crops.

The crop coefficient depends on the characteristics of each crop, therefore, it is specific to each one and depends on the phenological stage. It also depends on soil characteristics, moisture, agricultural practices and irrigation. Kc values are low in the initial stage and increase as the plant covers more soil (Fernández *et al*., 2012). To calculate the evapotranspiration of the crop, it is necessary to identify the growth stages, their duration and select the corresponding Kc for each stage.

The use of atmometers can be a viable tool to estimate the reference evapotranspiration (ETo) (Mendoza-Pérez *et al*., 2019), but at the same time, it requires appropriate calibration, local validation, as well as good operation and maintenance, all these components represent a reliable alternative for irrigation scheduling in agricultural crops either in the open field or under greenhouse conditions. The objective of this study was to analyze the relationship between crop evapotranspiration (ETc) and crop coefficient (Kc) in tomato cultivation as a function of the number of stems, for the supply of irrigation water based on a drainage lysimeter and an atmometer.

Materials and methods

Experimental site

The work was established in a zenith greenhouse under a hydroponic system in localized substrate, which is located within the Department of Hydrosciences of the College of Postgraduates, Montecillo *Campus*, State of Mexico, (19.46° north latitude and 98.90° west longitude at 2 244 m altitude). The greenhouse consists of three naves with metal structures and high-density polyethylene plastic covers, with 75% of transmissivity, equipped with a zenith ventilation system and provided with an anti-insect mesh on the side walls.

Cultivated material and planting frame

For the experiment, tomato seeds (*Solanum lycopersicum* L.) Saladette type from the Cid F1 cultivar of indeterminate growth were used. The seeds were sown on March 5 in germinating trays of 200 cells, transplanted on April 20, 2018. The material was grown in a greenhouse in a hydroponic system in black polyethylene bags (10 L) with red tezontle as substrate. The plantation was in a staggered arrangement, with separation of 40 cm between plants, in double rows 20 m long at 40 cm between lines, with a planting density of 3 plants m^{-2} in both treatments. Every eight days pruning of lateral shoots was carried out with T-67 pruning shears to keep the plant at one, two and three stems, the topping was made in the tenth bunch.

Establishment of treatments

The treatments were established according to the number of stems per plant: at one (T1), only the main stem was left, at two (T2), the main stem and one secondary stem were left, and at three stems per plant (T3), the main stem and two secondary stems were left. Each experimental unit was 6 m^2 with 18 plants, with four repetitions per treatment, with a total area of 159 m^2 per treatment, under a completely randomized experimental design.

Irrigation system

A drip irrigation system was installed, with a surface irrigation line of 16 mm in diameter with self-compensating droppers 40 cm apart and an operating pressure of 68.64 kPa. The nutrient solution type Steiner (1984) with an osmotic potential of -0.087 MPa and a pH of 6.5 was applied during the entire crop cycle.

Physical properties of the substrate

The physical properties of the tezontle were determined with the gravimetric method, which consisted of taking five samples of red tezontle with a defined volume to dry in a Tecnal-TE-395 oven at a temperature of 105 °C for 24 h, then the dry weight was determined, then the substrate was saturated with water and finally drained for 24 h. The following values of the evaluated properties were obtained: moisture retention capacity= 1.7 L, bulk density= 1.04 g cm^{-3}, total porosity= 41%, aeration= 59%, field capacity= 18%, permanent wilting point= 9%.

Measurement of crop transpiration

To measure the transpiration of the crop, control pots with 10 kg of tezontle and a water retention capacity of 0.17 L plant^{-1} were used. In each treatment, four repetitions of control pots were installed and covered with a white plastic on the surface of the pot in order to disregard the evaporation values of the substrate. In these pots a known volume of nutrient solution was applied from 9:00 am, which was allowed to drain for 1 h, then the drained nutrient solution was measured and the transpired volume per plant was obtained by difference (volume applied minus volume drained) (Figure 1). This procedure was repeated daily from 9:00, 11:00, 13:00, 15:00 and 17:00 h with a total of five daily measurements from transplantation to harvest of the tenth bunch.

Figure 1. **Measurement of evapotranspiration in control pots in a greenhouse.**

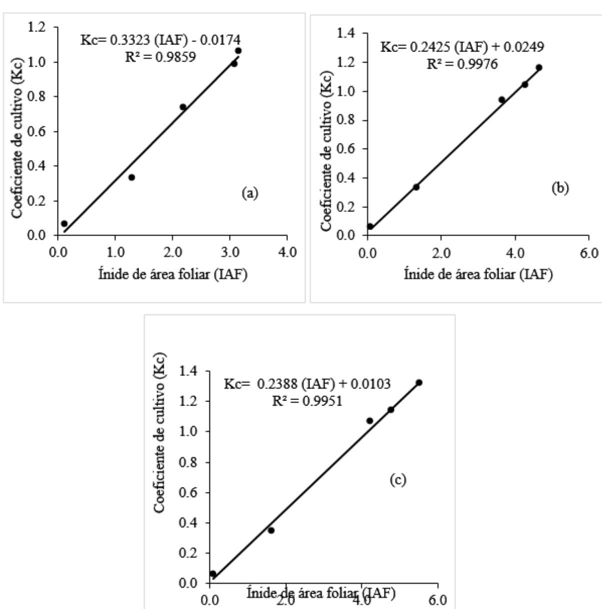

Figure 2. Crop coefficient in tomato as a function of the leaf area index for T1 (a); T2 (b); and T3 (c).

The daily evapotranspiration of the crop is considered equal to the difference between the amount of water applied and drained, which was calculated with equation 1. ETc= I-D 1). Where: ETc= daily evapotranspiration or transpiration of the crop; I= applied irrigation volume (L); D= drained water volume (L).

Reference evapotranspiration (ET_0) measured with an atmometer

To estimate the reference evapotranspiration, an ETogage model A atmometer (Loveland, Colorado, USA) was installed inside the greenhouse. This equipment was installed at a height of 1.2 m and the amount of water evaporated in the previous 24 h was measured manually at 8:00 am, using a glass tube with a graduated scale fitted on the outside of the equipment (Figure 3). The sheet of evaporated water was estimated by the change in two water levels of two consecutive readings. The period in the data collection was from April 24, 2018, to September 29, 2018.

Figure 3. Installation of the atmometer inside the greenhouse.

Atmometer description

The atmometer consists of a porous ceramic plate connected internally with a hose to a cylindrical reservoir of distilled water. This apparatus simulates the diffusion resistance of water vapor from the evaporating porous surface. A polytetrafluoroethylene membrane is usually placed over the plate to prevent water from entering through it (Mendoza-Pérez *et al*., 2019). In addition, it has two rigid two-inch stainless-steel wires at the top to prevent birds from perching on the meter (Figure 2). The model has a 300 mm water tank, made of white PVC to reflect solar radiation and prevent the transmission of heat to the water that is stored inside.

Crop irrigation needs

The water requirements of the tomato were calculated from the ETo values obtained from the atmometer and the crop coefficient (Kc) obtained from the ETc/ETo ratio by equation 2. ETc= ETo$*$Kc 2). ETc= evapotranspiration of the crop or net water demand of the crop (mm day^{-1}); ETo= reference evapotranspiration (mm day^{-1}); Kc= crop coefficient. The accumulated values for n elapsed days are expressed with the following relationship. $ETc_{accumulated}=\sum_{i=1}^{n} ETc$. Where: i is the number of days elapsed from the date of transplantation; ETc is the daily reference evapotranspiration of tomato.

Irrigation requirement per pot

The irrigation requirement was estimated from the values of evapotranspiration of the crop or the need for irrigation (ETc) and the planting density, with equation 3. $IR=\frac{ETc}{PD}$ 3). IR= irrigation requirement (L day^{-1} plant^{-1}); ETc= net water demand of the crop (mm day^{-1}); PD= planting density (number of plants ha^{-1}).

Crop coefficient

The crop coefficient by phenological stage was estimated from the values of evapotranspiration of the crop and the reference evapotranspiration of the atmometer by equation 4. $Kc=\frac{ETc}{ETo}$ 4). Kc= crop coefficient; ETc= evapotranspiration or transpiration of the crop; ETo= reference evapotranspiration.

Leaf area

Leaf area measurements were made with the destructive method, which consisted of extracting the plant from the pot, then separating the leaves and measuring the leaf area with an electronic meter (area meter model LI-3100, Decagon Device, Inc). They were performed in four repetitions of each treatment. Finally, the leaf area index (LAI) of the plant was calculated with equation 5, described by (Reis *et al*., 2013). $LAI=\frac{LA\ X\ NP}{TA}$ 5). Where: LAI is in m^2; LA is the average leaf area of three plants (m^2); NP is the number of plants per m^2, and TA is the total considered area of (1 m^2).

Yield

To determine the fruit yield, eight plants per treatment were first selected, then the fruits were harvested as they matured in each bunch of the plant and finally, they were weighed on a digital scale model 5 000 p with a resolution of 0.001g.

Statistical analysis

To determine significant differences in the variables evaluated, a mean comparison test was performed using the Tukey test with $p\leq 0.05$, with the Minitab statistical package.

Results and discussion

Treatment of one stem per plant (T1)

The accumulated values of reference evapotranspiration (ETo) measured with the atmometer were 76.8, 103.8, 87.3, 156.2 and 82.4 mm in the initial stage, vegetative development, beginning of fruiting, beginning of maturity and end of the crop, respectively (Table 1). For the accumulated values of ETc measured with the drainage lysimeter, they were 4.50, 34.6, 86.7, 165.5 and 60.6 mm in the same stages, respectively. In this sense, Rodríguez and Pire (2008) reported real daily evapotranspiration (ETr) values of 2.95 mm day^{-1} during the initial stage and 7.3 mm day^{-1} during the fruiting phase.

Table 1. Values of ETc, ETo, Kc and irrigation requirement for (T1).

DAT	Phenological stage	Length	ETc	Eto	Kc	IR
16	Initial	16	4.5	76.8	0.06	0.094
42	Vegetative development	25	34.6	103.8	0.33	0.462
72	Beginning of fruiting	31	86.7	87.3	0.99	0.932
125	Beginning of maturity	53	165.5	156.2	1.06	1.041
154	End of cultivation	29	60.6	82.4	0.74	0.697
	Total sum	154	351.9	506.5		

DAT= days after transplantation; ETc= accumulated evapotranspiration of the crop by stage (mm); ETo= accumulated reference evapotranspiration by stage (mm); Kc= crop coefficient; IR= irrigation requirement (L plant^{-1} day^{-1}).

On the other hand, (Flores *et al*., 2007) found a direct relationship between the transpiration of tomato and the global radiation that reaches the foliage inside the greenhouse. The same authors found that the evapotranspiration rate was 58 L h^{-1} around 14:00 h of the day. Finally, Martínez-Ruiz *et al*. (2019) reported similar values of ETc in tomato estimated with the HortSyst model.

The Kc values obtained for this crop were 0.06, 0.33, 0.99, 1.06 and 0.75 in the same stages (Table 1). These data are similar to those obtained by (Zamora *et al*., 2014) in the cultivation of tomato HC 3880 with an average Kc of 1.18. On the other hand, (Cerekovic *et al*., 2010) obtained values of initial Kc of 0.4, Kc of 1.18 in the middle stage and Kc of 0.7 at maturity in tomato grown in Mediterranean climate conditions. For this study, the irrigation requirement was 0.09, 0.46, 0.93, 1.04 and 0.69 L plant^{-1} day^{-1}, respectively (Table 1). However, Flores *et al*. (2007) reported irrigation requirement values of 0.55, 0.57, 0.92, 1 and 0.81 L plant^{-1} day^{-1} in the same stages.

Treatment of two stems per plant (T2)

The accumulated values of ETo obtained by the atmometer were 76.8, 103.8, 87.3, 156.2 and 82.4 mm; for the ETc measured with the drainage lysimeter, they were 4.4, 34.3, 91, 181.5 and 77.3 mm; the Kc values were 0.06, 0.33, 1.04, 1.16 and 0.94 in the same phenological stages, respectively (Table 2). The irrigation requirement was 0.09, 0.45, 0.97, 1.14 and 0.88 L plant^{-1} day^{-1} in the stages mentioned above. (Rodríguez-Cabell *et al*., 2020) in their research work they reported that, in the treatment where they applied 1.12 L plant^{-1} day^{-1}, the plant showed better physiological, productive and quality improvement response in fruit size.

Soto (2018) found ETc values from 1.9 to 2.3 L plant^{-1} day^{-1} in Cherry tomato of the Súper Suncherry cultivar, of indeterminate growth grown in greenhouse, and reports that as the photosynthetically active radiation increases, the evapotranspiration of the crop increases, therefore, the environmental conditions with very important variables for the development of agricultural crops.

Table 2. Values of ETc, ETo, Kc and irrigation requirement for (T2).

DAT	Phenological stage	Length	ETc	Eto	Kc	IR
16	Initial	16	4.4	76.8	0.06	0.09
42	Vegetative development	25	34.3	103.8	0.33	0.45
72	Beginning of fruiting	31	91	87.3	1.04	0.97
125	Beginning of harvest	53	181.5	156.2	1.16	1.14
154	End of cultivation	29	77.3	82.4	0.94	0.88
	Total sum	154	388.5	506.5		

DAT= days after transplantation; ETc= accumulated evapotranspiration of the crop by stage (mm); ETo= accumulated reference evapotranspiration by stage (mm); Kc= crop coefficient; IR= irrigation requirement (L $plant^{-1}$ day^{-1}).

Treatment of three stems per plant (T3)

Similarly, the accumulated values of ETo obtained were 76.8, 103.8, 87.3, 156.2 and 82.4 mm; ETcs measured with the drainage lysimeter were 4.6, 35.9, 99.3, 205.8 and 88.3 mm for the same stages (Table 3). These are lower than what was reported by Dauda and Olayaki-Luqman (2016), who estimated an ETc of 816, 775 and 617 mm day^{-1} as the same ETo (521.8 mm day^{-1}) for the Cherry, Roma and Jubilee tomato varieties. In the same way, Hanson and May (2006) estimated ETc values from 648 to 752 mm in different irrigation systems (surface and drip) with yields that ranged between 82 and 146 Mg ha^{-1} in tomato varieties for processing.

Table 3. Values of ETc, ETo, Kc and irrigation requirement for (T3).

DAT	Phenological stage	Length	ETc	Eto	Kc	IR
16	Initial	16	4.6	76.8	0.06	0.095
42	Vegetative development	25	35.9	103.8	0.35	0.479
72	Beginning of fruiting	31	99.3	87.3	1.14	1.068
125	Beginning of harvest	53	205.8	156.2	1.32	1.294
154	End of cultivation	29	88.3	82.4	1.07	1.015
	Total	154	433.9	506.5		

DAT= days after transplantation; ETc= accumulated evapotranspiration of the crop by stage (mm); ETo= accumulated reference evapotranspiration by stage (mm); Kc= crop coefficient; IR= irrigation requirement (L $plant^{-1}$ day^{-1}).

Likewise, they argued that the water application system directly influences the estimation of ETc, (decrease in soil evaporation) especially when drip irrigation systems are employed. They also found that average Kc values for an intermediate stage vary from year to year, with a range of values that ranged from 0.96 to 1.09. The Kc values found in this study were 0.06, 0.35, 1.14, 1.32 and 1.07 at each stage (Table 3). In this case, López *et al.* (2010) found Kc values of 0.3, 1.1 and 0.86 in vegetative stage, flowering and maturity-senescence in husk tomato in treatments where irrigation sheets equivalent to an ETo= 100% were applied and without plastic mulching, and when the crop was covered with plastic mulch, the crop coefficients decreased to 0.2, 0.71 and 0.56 of Kc for the same stages, respectively.

The authors mention that their findings were consistent with what found by Allen *et al*. (1998), who proposed Kc values for the initial, intermediate and final stages of 0.6, 1.15 and from 0.7 to 0.9 for the cultivation of tomato without plastic cover. On the other hand, studies reported by Zamora *et al*. (2014) showed Kc values in the intermediate stage of 1.32 in tomato of the Campbell variety. Rodríguez and Pire (2008); CONAGUA (2019), determined Kc values of 0.64 in the initial stage, 1.3 in the fruiting stage and 1.22 in the harvest stage for the same crop.

Finally, Dauda and Olayaki-Luqman (2016) estimated initial Kc values of 1.56, 1.39 and 1.18 with yields of 6, 5 and 4.2 Mg ha^{-1} for Cherry, Roma and Jubilee tomato varieties. These Kc values are different from other findings. However, Kang *et al*. (2003) mention that Kc values could vary from place to place depending on factors such as climate, soil type and crop, variety or irrigation method, which is why they emphasize the regional calibration of Kc for different environmental conditions.

Other studies conducted by Cerekovic *et al.* (2010) reported a strong relationship between Kc and the temperature of tomato *cv* Dracula grown in a semiarid environment, indicating that Kc and ETc can be modeled during at least three stages of the crop cycle. The results showed that the estimation of the maximum Kc can be adjusted to the prevailing weather conditions (relative humidity, wind speed and plant height).

Relationship between crop coefficient and leaf area index

The crop coefficients and the leaf area index allow achieving a better use of water resources. Figure 1 shows the relationship of Kc with the leaf area index evaluated from transplantation to harvest of the tenth bunch of the plant. These relationships indicate that Kc can be estimated from LAI measured in tomato. The Kcs for T1 (one stem) can be estimated by the equation Kc= 0.3323 (LAI) - 0.0174, for T2 (two stems) Kc= 0.2425 (LAI) + 0.0249 and for T3 (three stems) Kc= 0.2388 (LAI) + 0.0103.

Lopez *et al*. (2010) found in husk tomato grown in plastic mulch that, when the LAI value is equal to one, crop coefficient tends to approach the unit; however, in the absence of plastic mulch, this value tends to be greater than one, indicating that ETc exceeds ETo.

Relationship between crop evapotranspiration, leaf area index and yield

Table 4 shows a mean comparison test (Tukey with $p \leq 0.05$) where statistically significant differences were found between the variables of ETc, LAI and fruit yield in the treatments. Therefore, the total values of water consumption obtained throughout the crop cycle, without water limitations in the area explored by the roots, depend on the atmospheric demand, the duration of the crop cycle and the leaf area developed by the plant.

Table 4. Relationship between crop evapotranspiration, leaf area index and yield.

Treatments	ETc (mm)	LAI (m^2 m^{-2})	Yield (kg $plant^{-1}$)
T1 (one stem)	351.9 c	3.15 c	6.66 a
T2 (two stems)	388.5 b	4.66 b	6 b
T3 (three stems)	433.9 a	5.53 a	5.33 c

Different letters in each column indicate significant differences ($p\leq 0.05$).

From the point of view of crop water consumption, the aerial structure of the crop is what determines the amount of water transpired. In such a way that, as the leaf area index increases, the water consumption of the crop for the same atmospheric demand increases linearly until reaching a maximum under maximum canopy cover, then it begins to decrease per day (Mendoza-Pérez *et al*., 2018b).

In this research work it was found that, as the number of stems per plant increases, the number of fruits increases, however their size for export purposes decreases, therefore and according to the evaluation and analysis of the aforementioned variables, it is defined that the best treatment was T1 (one stem) per plant, since it showed lower value of evapotranspiration of the crop compared to the other treatments, in addition to showing better yield and size of harvested fruits (Table 4).

Conclusions

Daily transpiration measurements under controlled conditions make it possible to calculate the irrigation water requirement for the cultivation of tomato as a function of the number of stems per plant. In addition, it was found that as the number of stems per plant increases, Kc and LAI increase and, consequently, the evapotranspiration and water requirement of tomato increase; however, the size of fruits decreases. It was observed that the behavior of Kc in horticultural crops depends strongly on the temperature of the environment under controlled conditions and varies with management practices, so it is necessary to relate these values with stages of crop development.

Kc values can be estimated from LAI measured in tomato, for T1 (one stem) with the equation Kc= 0.3323 (LAI) - 0.0174, for T2 (two stems) Kc= 0.2425 (LAI) + 0.0249 and for T3 (three stems) per plant Kc= 0.2388 (LAI) + 0.0103. The atmometer is an alternative to estimate the reference evapotranspiration (ETo) for the scheduling of irrigation in different crops in order to optimize this water resource.

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