ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.6, p.425-432, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n6p425-432

Irrigation strategies in production of cherry tomatoes under water scarcity conditions[1]

Estratégias de irrigação na produção de tomates cerejas sob condições de escassez hídrica

Kleyton C. de Sousa[2]*, Raimundo N. T. Costa[2], Kenya G. Nunes[2] & Alexsandro O. da Silva[2]

[1] Research developed at Universidade Federal do Ceará, Programa de Pós-Graduação em Engenharia Agrícola, Fortaleza, CE, Brazil
[2] Universidade Federal do Ceará/Centro de Ciências Agrárias/Programa de Pós-Graduação em Engenharia Agrícola, Fortaleza, CE, Brazil

HIGHLIGHTS:

The red cultivar of the cherry tomato requires more water than the orange cultivar.
The coefficient of sensitivity to water deficit assists the management of water resources for irrigation purposes.
Cherry tomato is well adapted to water deficit-conditions and is appropriate for production in semiarid conditions.

ABSTRACT: Controlled water deficit in the phenological phases of cherry tomato can be used without significantly impairing crop yield. The objective was to determine the coefficients of sensitivity to water deficit in cherry tomatoes and to understand the effects of this deficit in agronomic variables and water use efficiency for different irrigation strategies based on phenological stages. The experimental design used was randomized blocks in a split-plot scheme, with four replicates. The primary treatments distributed in the plots were as follows: control without induction of water deficit (W1) and induction of water deficit in the vegetative stage (W2), in the flowering stage (W3), in the fruiting stage (W4), in the maturation stage (W5), and in all phenological stages (W6). The secondary treatments comprised two cherry tomato cultivars, orange and red, placed in the subplots. Water deficit was established at 50% of crop evapotranspiration. Cherry tomato is recommended for production in semiarid regions owing to their adaptability to controlled water deficit based on the coefficient of sensitivity to water deficit, which assists in the management of water resources for irrigation and the maintenance of crop productivity. The vegetative stage is recommended for the deficit irrigation strategy. However, water deficit should not be implemented in the flowering stage, which is considered the most critical stage for the application of water deficit in both cultivars.

Key words: *Lycopersicum esculentum* var. *cerasiform*, water use efficiency, water deficit, phenological stages

RESUMO: O déficit hídrico controlado nas fases fenológicas do tomate cereja pode ser utilizado sem comprometer abruptamente a produtividade da cultura. Objetivou-se determinar os coeficientes de sensibilidade ao déficit hídrico e compreender os efeitos desse déficit nas variáveis agronômicas e na eficiência do uso da água para diferentes estratégias de irrigação baseadas em estádios fenológicos. O delineamento experimental foi em blocos ao acaso, em esquema de parcelas subdivididas, com quatro repetições. Os tratamentos distribuídos nas parcelas foram: controle sem indução de déficit hídrico (W1), e indução de déficit hídrico na fase vegetativa (W2), na fase de floração (W3), na fase de frutificação (W4), na fase de maturação (W5), e em todos os estádios fenológicos (W6). Os tratamentos secundários foram duas cultivares de tomate cereja: cultivares laranja e vermelha, colocadas nas subparcelas. O déficit hídrico foi estabelecido em 50% da evapotranspiração da cultura (ETc). O tomate é recomendado para produção em regiões semiáridas devido à sua adaptabilidade ao controle do déficit hídrico, tendo como base o coeficiente de sensibilidade ao déficit hídrico, que auxilia no manejo dos recursos hídricos para irrigação e na manutenção da produtividade da cultura. A fase vegetativa é recomendada para a estratégia de irrigação deficitária. No entanto, o déficit hídrico não deve ser utilizado na fase de floração, que foi considerada a mais crítica para a aplicação da estratégia em ambas as cultivares.

Palavras-chave: *Lycopersicum esculentum* var. *cerasiform*, eficiência no uso da água, déficit hídrico, estádios fenológicos

• Ref. 256090 – Received 05 Sept, 2021
* Corresponding author - E-mail: kleyton@ufc.br
• Accepted 07 Jan, 2022 • Published 02 Feb, 2022
Editors: Lauriane Almeida dos Anjos Soares & Carlos Alberto Vieira de Azevedo

Introduction

Tomato is one of the most cultivated vegetables worldwide (Zanin et al., 2018). Among the tomato cultivars, cherry tomato (*Lycopersicum esculentum* var. *cerasiforme*) stands out for its high added value and serving as an income alternative for small and medium farmers (Soldateli et al., 2020). The intensity of water stress, however, is a factor that affects tomato crop yield and fruit quality (Wang et al., 2011).

In the coming years, the number of areas subjected to water stress is estimated to increase (Çelik et al., 2017). In this context, measures must be sought to minimize the adverse effects of this abiotic factor. One of the ways to maintain satisfactory crop production is the application of controlled deficit in irrigation management that considers the phenological stages.

According to Davies et al. (2011), deficit irrigation is the application of water at a level below the amount required to obtain a full harvest. It is believed that the application of controlled water deficit in some phenological stages of cherry tomatoes grown in a semiarid region does not drastically impair productivity.

One of the indicators to quantify crop responses to water stress is the water deficit sensitivity factor (Ky), which quantifies the relationship between relative yield reduction and evapotranspiration deficit (Doorenbos & Kassam, 1979). The production response to water deficit is an important tool for production planning (Pejic et al., 2017). Furthermore, the water deficit sensitivity factor aids in determining the proper management of water for the crop, with a view to maximizing water use efficiency.

Considering the aforementioned findings, studies on water deficit strategies for cherry tomato cultivation in semiarid regions remain scarce, despite being a crop of considerable economic interest for the region. The objective of this study was to determine the coefficients of sensitivity to water deficit and to understand the effects of this deficit on agronomic variables and water use efficiency for different irrigation strategies based on phenological stages in two cherry tomato cultivars cultivated in a semiarid region.

Material and Methods

The experiment was conducted in an open area in the municipality of Pentecoste (State of Ceara, Brazil) at the coordinates 03° 49' 08" S and 39° 20' 02"W, an altitude of 48 m, between June and December 2019. According to the Köppen classification, the climate of the region is of the BShw type, hot and semiarid, with irregular rains distributed from February to May. Climatological data were obtained from an agrometeorological station located near the experimental area. The mean air temperature and relative air humidity were 31.0 ± 0.9 °C and 51.1% ± 5.4%, respectively, during the cultivation cycle. No rainfall was recorded during the experimental period.

The soil in the area was classified as Fluvent Entisol (USDA, 1999, 2014), with a loose texture. The physical and chemical attributes of the soil (Table 1) were determined using samples collected from the 0 to 0.20 m depth soil layer before the start of the experiment.

The Curu River is the water source used for irrigation, having electrical conductivity of 0.75 dS m^{-1} and pH of 6.8.

The experimental design used was randomized blocks, in a split-plot scheme, with six primary treatments in the plots, two secondary treatments in the subplots, and four replicates.

The primary treatments consisted of periods of water deficit induction as follows: control treatment without induction of water deficit (W1), induction of water deficit in the vegetative stage (W2), in the flowering stage (W3), in the fruiting stage (W4), in the maturation stage (W5), and in all phenological stages (W6).

The secondary treatments consisted of two cherry tomato cultivars (red and orange). Water deficit was established as 50% of the crop evapotranspiration (ETc) applied in the treatment without deficit.

The area of the experimental plot and the subplots was 11.0 and 5.5 m^2, respectively, with each subplot consisting of 11 plants, the three central plants being considered useful and the rest, borders.

A drip irrigation system was used with a flow rate of 1.6 L h^{-1}, a service pressure of 10 mca, and spacing between emitters of 0.30 m. The system presented a coefficient of distribution uniformity of 97.7% and a water application efficiency of 92.8%.

Irrigation was carried out daily and divided into two applications, according to the crop water requirement, based on the evaporation of a Class A tank installed near the experimental area. At 8:00 hours, 70% of the required water depth was applied and the other 30% at 15:00 hours. Until 10 days after transplanting (DAT), irrigation was carried out based on the water depth required by the crop to ensure the establishment of seedlings in all experimental plots. After that period, different treatments were applied.

Reference evapotranspiration (ETo) was calculated as the product of the evaporation of the tank (ECA) and the tank coefficient (Kt = 0.65). Crop evapotranspiration (ETc) was obtained from the product of the ETo value and the crop coefficient (Kc). ETc correction for the localized system was estimated (ETc × 0.1 × $\sqrt{Pw}$, where Pw is the percentage of wet

Table 1. Physical and chemical attributes of the soil in the experimental area

<table>
<tr><th rowspan="2">Depth
(m)</th><th colspan="5">Granulometric composition (g kg^{-1})</th><th rowspan="2">Class
textural</th><th rowspan="2">Soil density
(g cm^{-3})</th></tr>
<tr><th>Coarse sand</th><th>Thin sand</th><th>Silte</th><th>Clay</th><th>Natural clay</th></tr>
<tr><td>0-0.2</td><td>52</td><td>319</td><td>432</td><td>197</td><td>160</td><td>Loamy</td><td>1.25</td></tr>
<tr><th rowspan="2">pH</th><th>EC</th><th>C</th><th>N</th><th>ESP</th><th>BS</th><th>Organic matter</th><th>$P_{Assimilable}$</th></tr>
<tr><th>(dS m^{-1})</th><th colspan="2">(g kg^{-1})</th><th colspan="2">(%)</th><th>(g kg^{-1})</th><th>(mg kg^{-1})</th></tr>
<tr><td>7.0</td><td>0.38</td><td>9.4</td><td>1.05</td><td>2.00</td><td>90</td><td>16.45</td><td>37</td></tr>
<tr><th colspan="8">Assortment complex (cmol$_c$ kg^{-1})</th></tr>
<tr><th>Ca^{2+}</th><th>Mg^{2+}</th><th>Na^+</th><th>K^+</th><th>$H^+ + Al^{3+}$</th><th>Al^{3+}</th><th>S</th><th>CEC</th></tr>
<tr><td>11.2</td><td>1.60</td><td>0.31</td><td>0.57</td><td>1.49</td><td>0.10</td><td>13.70</td><td>15.2</td></tr>
</table>

Soil, water, vegetable tissue, and fertilizer analysis was conducted at a laboratory in Federal University of Ceara or shaded area). The Kc values for cherry tomatoes at different phenological stages followed those obtained by Doorenbos & Kassam (1979), with values of 0.5, 0.8, 1.25, 0.9, and 0.65 for the initial, vegetative, flowering, fruiting, and maturation phases, respectively.

Cherry tomato seeds of orange and red cultivars were sown in Styrofoam trays with 162 cells (volume of 31 cm^3) filled with substrate containing 90% bovine manure and 10% vermiculite. The trays were kept in a greenhouse covered with 50% sombrite screen, which remained for 32 days after sowing (DAS), at which time the plants had three to four definitive leaves. At 16 DAS, the seedlings were thinned, leaving one plant per cell.

The seedlings were transplanted at 32 DAS to the experimental area, with a spacing of 0.5 m between plants and 1.0 m between rows. The soil that received the seedlings was properly prepared by removing invasive plants and revolving at a depth of 0.30 m, using a leveling grid. The beds were constructed using a terracer, with subsequent incorporation of 2.0 kg m^{-1} of bovine manure. No cultivation was carried out in this area for a 10-year period, followed by the cultivation of a cycle of cowpea and then cherry tomatoes.

As the red cherry tomato cultivar has an indeterminate growth habit, they were managed with two stems and vertical staking. Pruning to eliminate thieving branches started at 26 DAT, occurring weekly after this period. The orange cherry tomato cultivar has a determined growth habit, eliminating the need for staking. For both cultivars, heaping was performed at 26 DAT and topdressing fertilization at 50 DAT with bovine manure.

The plants were grown in an organic production system. Phytosanitary control was carried out by monitoring the insect population through adhesive traps and weekly application of a natural pesticide based on azadirachtin, extracted from the Indian neem (*Azadirachta indica* A. Juss), at a concentration of 0.01%, diluted in water at pH 6.8. At 10 and 25 DAT, manual weeding was performed.

The crop cycle, calculated as the period from transplanting to final harvest, was 105 and 116 days for the orange and red cultivars, respectively. The vegetative stage in both cultivars was of 11 days, whereas the flowering, fruiting, and maturation stages took 12, 13 and 52 days for the orange cultivar and 26, 16, and 45 days for the red cultivar, respectively.

After harvesting the fruits, the following agronomic variables were evaluated: mass of commercial fruits per plant (MCF, measured in grams per plant), total fruit mass per plant (MTF, measured in grams per plant), number of commercial fruits per plant (NCF), number of total fruits per plant (NTF), and productivity (PROD, measured in t ha^{-1}).

MCF and MTF variables were measured on a digital scale. Productivity was estimated as the product of the MCF and the number of plants in the stand (20,000 plants ha^{-1}).

The irrigation water productivity (WPir) was calculated as the ratio of the total yield of commercial fruits (kg ha^{-1}) and the amount of water applied by irrigation (m^3 ha^{-1}) in each treatment at the end of the cycle (Pereira et al., 2009).

The coefficient of sensitivity to water deficit (Ky) was quantified by the relationship between the relative yield drop and the relative evapotranspiration deficit (Doorenbos & Kassam, 1979). Mathematically, Ky is described as Eq. 1:

$$Ky = \frac{\left[1 - \left(\frac{Yr}{Ym}\right)\right]}{\left[1 - \left(\frac{ETr}{ETm}\right)\right]} \qquad (1)$$

where:

Yr - real crop yield obtained in treatments subjected to water deficit;

Ym - maximum crop yield obtained in treatment without water deficit;

ETr - real evapotranspiration of the crop obtained in treatments submitted to water deficit; and,

ETm - maximum evapotranspiration of the crop obtained in treatment without water deficit.

Water deficit sensitivity coefficients were classified according to the methodology recommended by the Food and Agriculture Organization of the United Nations (FAO) by Bulletins 33 (Doorenbos & Kassam, 1979) and 66 (Smith & Steduto, 2012).

Data were analyzed for normality of residues by the Shapiro-Wilk test and for homogeneity by the Bartlett test. Next, an analysis of variance was performed using F test, and in the event of a significant effect, the mean values were compared using Tukey's test. MCF and PROD variables underwent a Box-Cox transformation before the analysis of variance. R software (version 3.6.1; R Core Team, 2019) was used for all statistical tests.

RESULTS AND DISCUSSION

The red cultivar required more volumes of water per crop cycle, with 18.9, 20.6, 9.5, 18.2, 27.8, and 17.8% more water volume per plant (L per plant) in W1–W6 treatments, respectively, than required by the same treatments for the orange cultivar (Table 2).

Table 2. Water volume per plant and mean values of crop evapotranspiration (ETc) by phenological phases during cultivation of cherry tomatoes cultivars

Treatments	Water volume (L per plant per cycle)	
	Orange cultivar	Red cultivar
W1	95.24	113.23
W2	87.18	105.17
W3	86.05	94.19
W4	88.12	104.15
W5	74.90	95.71
W6	50.54	59.53
Phenological phases	**ETc (mm per day)**	
	Orange cultivar	**Red cultivar**
Vegetative	3.12	2.12
Flowering	4.37	4.36
Fruiting	3.14	3.30
Maturation	2.42	2.36

W1 - Control treatment without induction of water deficit; W2 - Induction of water deficit in the vegetative stage; W3 - Induction of water deficit in the flowering stage; W4 - Induction of water deficit in the fruiting stage; W5 - Induction of water deficit in the maturation stage; W6 - Induction of water deficit in all phenological stages

The differences in water volume for irrigation between the cultivars may be explained by the duration of the phenological phases and the duration of the cycle, which were different in some phases for the cultivars studied.

When the mean values of ETc by phenological phases were analyzed (Table 2), the highest evapotranspiration rates were in the flowering phase for both cultivars, indicating that this phase requires a greater demand for water. The maturation phase had lower ETc values, with 44.6 and 45.9% lower demand in relation to the flowering phase for orange and red cultivars, respectively.

The variations in ETc values were due to the specific crop coefficients for each phase and the variations in atmospheric demand that influence the evapotranspiration process, such as wind speed and relative air humidity (Farahani et al., 2008).

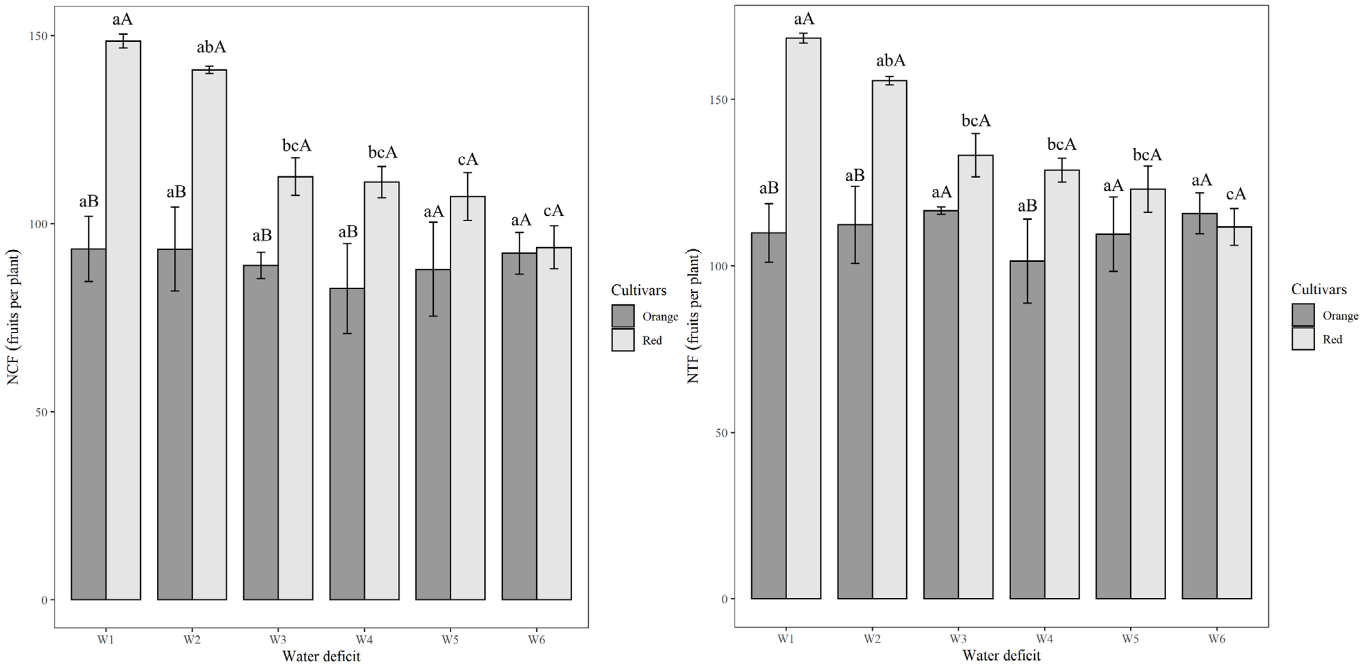
No significant effect (Table 3) was observed in the interaction between the water deficit factor in the phenological phases and the cultivar factor ($p > 0.05$) for the evaluated variables, except for NCFs ($p \leq 0.05$) and NTFs ($p \leq 0.01$). However, observation of the effects of the water deficit factor alone showed significant differences ($p \leq 0.001$) in the commercial fruit mass, total fruit mass, productivity, and WPir. In addition, a significant difference ($p \leq 0.01$) was observed for the cultivar factor alone on WPir.

The variable number of commercial fruits (NCF) responded to the deficit in the phenological phases and to the cherry tomato cultivars (Figure 1A), so that the highest average recorded was for the red cultivar without application of water deficit, with a value of 148.46 fruits per plant. With the application of the deficit in the vegetative phase for the red cultivar, there were no significant differences in relation to the control treatment. The lowest average for the red cultivar was 93.67 fruits per plant, which did not differ statistically from the application of water deficit in the stages of flowering, fruiting and maturation. For the orange cultivar, the highest mean was also for the control treatment (93.31 fruits per plant), but there was no statistical difference for the other treatments.

Table 3. Summary of the analysis of variance for the variables number of commercial fruits per plant (NCF), number of total fruits per plant (NTF), mass of commercial fruits per plant (MCF), mass of total fruits per plant (MTF), productivity (PROD) and irrigation water productivity (WPir)

SV[1]	DF[4]	Mean square					
		NCF	NTF	MCF	MTF	PROD	WPir
Block	3	34.8	18.5	1.39x10^{10}	27259	2222.4	1.6864
Water deficit (a)	5	1090.7*	917.6*	8.14x10^{10***}	48578***	13024.9***	7.4857***
Residue (a)	15	270.5	256.9	2.43x10^{9}	5450	389.4	0.3042
Cultivars (b)	1	10281.4***	8010.9***	1.81x10^{8ns}	47107^{ns}	29.1^{ns}	13.7067**
a x b	5	762.4*	1000.3**	5.05x10^{9ns}	4771^{ns}	805.7^{ns}	1.7583^{ns}
Residue (b)	18	208.4	231.3	7.27x10^{9}	13277	1164.7	1.2560
CV% (a)[2]		15.77	12.94	14.33	10.59	14.33	8.18
CV% (b)[3]		13.84	12.28	24.79	16.53	24.79	16.63

[1]Sources of variation; [2]Coefficient of variation of the plot; [3]Coefficient of variation of the subplot; [4]Degrees of freedom; *, **, ***, and ns: significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, and not significant by F test, respectively



W1 - Control treatment without induction of water deficit; W2 - Induction of water deficit in the vegetative stage; W3 - Induction of water deficit in the flowering stage; W4 - Induction of water deficit in the fruiting stage; W5 - Induction of water deficit in the maturation stage; W6 - Induction of water deficit in all phenological stages
Means followed by the same lowercase letter and by the same uppercase letter do not differ statistically by Tukey test at $p \leq 0.05$ between water deficits and cultivars, respectively; Vertical bars represent the standard error of the mean (n = 4)

Figure 1. Number of commercial fruits per plant (NCF) (A) and number of total fruits per plant (NTF) (B) of cultivars of cherry tomatoes submitted to water deficit at different phenological phases

Overall, the red cultivar showed better results in all treatments when compared to the orange cultivar, except for the treatments with deficit in all phenological phases and at maturation, in which they were statistically equal.

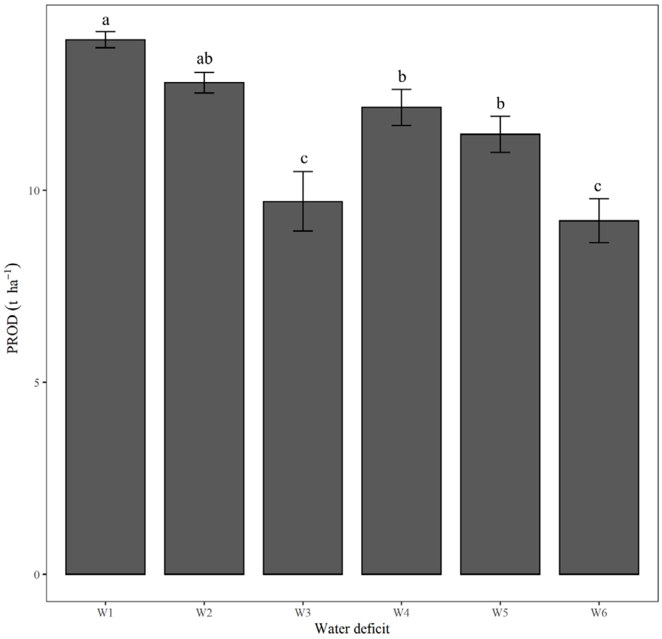
For the variable NTF (Figure 1B), the orange cultivar did not show statistical differences between water deficit treatments. For the red cultivar, the control treatment showed the best performance, with 168.31 fruits per plant, which did not differ statistically from the water deficit treatment in the vegetative stage. However, a reduction in NTFs at 20.8, 23.5, 26.9 and 33.6% was observed when plants were subjected to water deficit in the flowering, fruiting, and maturation stages and in all phenological stages, respectively, in comparison with the ideal water conditions.

For the orange cultivar, the highest average NTF was recorded for the control treatment, which did not differ statistically from other treatments. The red cultivar showed better performance in all treatments when compared to the orange cultivar, except for deficit treatments in all phenological phases and in maturation stages, in which the results were statistically equal for both cultivars.

Similar to this study, Sento-Sé et al. (2014) observed variations in the number of fruits obtained in hybrid mini tomatoes cultivated in semiarid conditions.

The yields of cherry tomatoes were not affected by the cultivars used, but the deficit treatment in the phenological stages resulted in statistically significant differences (Figure 2).

The lowest yields obtained were for the application of deficit in all phenological stages (9.21 t ha^{-1}) and in the flowering period (9.71 t ha^{-1}). Conversely, plants under control conditions produced the highest yields of fruits (13.92 t ha^{-1}), with the second-best performance observed in the application of deficit in the vegetative phase (12.80 t ha^{-1}), followed by water deficit applied in the fruiting phase (12.16 t ha^{-1}) and maturation phases (11.46 t ha^{-1}).



W1 - Control treatment without induction of water deficit; W2 - Induction of water deficit in the vegetative stage; W3 - Induction of water deficit in the flowering stage; W4 - Induction of water deficit in the fruiting stage; W5 - Induction of water deficit in the maturation stage; W6 - Induction of water deficit in all phenological stages
Means followed by the same letter do not differ statistically by the Tukey test at $p \leq 0.05$; Vertical bars represent the standard error of the mean (n = 8)

Figure 2. Productivity (PROD) of cherry tomatoes submitted to water deficit at different phenological phases

Bogale et al. (2016) and Coyago-Cruz et al. (2019) also reported a decrease in production from cherry tomato plants under water stress when compared to that from plants without water deficit.

The productivity of cherry tomato in the present study is consistent with the results of the study by Nangare et al. (2016), who reported that the phenological stages of tomato plants have different responses to deficit irrigation. In the context of fruit productivity, data suggest that water deficit in the vegetative phase can promote water savings for producers, with a small decrease in production.

There was no significant effect of WPir on the interaction between water deficit treatments and cultivars ($p > 0.05$); however, there was a significant effect of water deficit ($p \leq 0.001$) and cultivar ($p \leq 0.01$) alone (Table 3).

For the isolated effects among water deficit treatments, the highest WPir value occurred with a water deficit of 50% of ETc during all phenological phases (W6), with an average value of 8.38 kg m^{-3}. The lowest value was obtained when the same level of water stress was applied during the flowering phase (W3), with a WPir of 5.38 kg m^{-3}. The other treatments showed average values close to that of the treatment without water deficit (6.73 kg m^{-3}) and did not differ statistically using the Tukey test ($p \leq 0.05$) (Figure 3A).

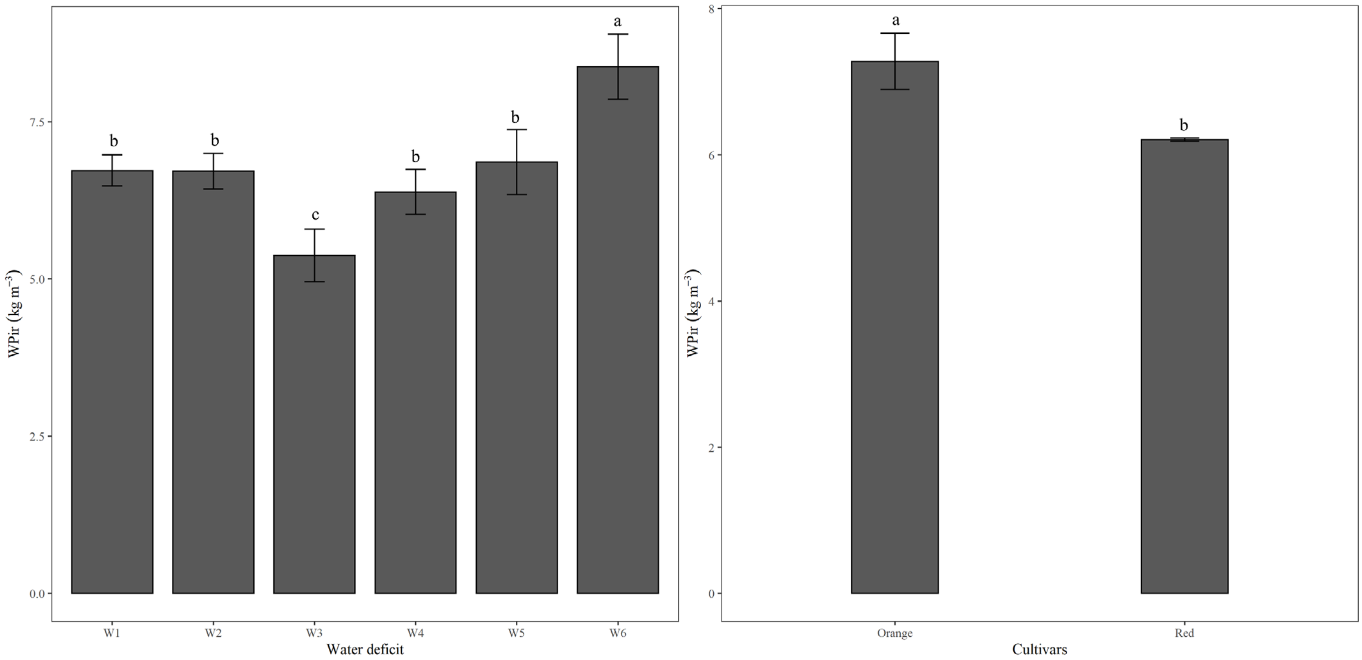
Regarding cultivar types, the orange cultivar showed superior performance over the red cultivar in relation to WPir (Figure 3B). This result may reflect the fact that the orange cultivar requires less water to maintain higher levels of productivity than the red cultivar.

Zhang et al. (2017) explained water use efficiency as the ratio between photosynthesis and transpiration at the physiological level; however, for agronomic analyses, it is more easily defined as the ratio between the biomass produced by the plant and the water used during its cycle.

According to Mukherjee et al. (2010), water use efficiency is an indicator that reflects the effective use of water resources in agricultural production. When water is insufficient for production, this indicator is a significant factor in choosing irrigation management practices.

Regarding water restrictions in various phenological phases, water deficit in the flowing phase showed significant differences compared with that in other phases. In a similar study, Kusçu et al. (2014) studied tomato crops in a subhumid environment and found no significant differences in the four phases of the crop under water stress. However, the authors observed that the tomato plants subjected to water deficit in the flowering phase showed substantial reduction in the efficiency of water use.

For tomato crops, the smaller the amount of water applied through irrigation depths, the greater the efficiency of water use (Santana et al., 2010). Sá et al. (2005), in turn, demonstrated that efficiency in water use showed an increasing linear response with increased water tension in the soil. Similar results were observed in the present study when comparing W1 and W6 treatments, which explains the better efficiency



W1 - Control treatment without induction of water deficit; W2 - Induction of water deficit in the vegetative stage; W3 - Induction of water deficit in the flowering stage; W4 - Induction of water deficit in the fruiting stage; W5 - Induction of water deficit in the maturation stage; W6 - Induction of water deficit in all phenological stages
Means followed by the same letter do not differ statistically by the Tukey test at $p \leq 0.05$; Vertical bars represent the standard error of the mean (n = 8)

Figure 3. Productivity of irrigation water (WPir) for cherry tomatoes submitted to water deficit at different phenological phases (A), and for cultivars of cherry tomatoes (B) submitted to water deficit at different phenological phases

recorded for the W6 treatment, with an increase of 24.6% in relation to W1.

However, when this water reduction was applied in the vegetative, flowering, fruiting, and maturation phenological phases, the same effect was not observed, as in both cultivars, plants under water stress in the flowering phase received lower depth of irrigation compared to those in the vegetative and fruiting stages, which showed a lower WPir. This shows the sensitivity to the effect of irrigation water on different phenological stages in relation to the application of constant depths throughout the cycle.

In the flowering and fruiting growth phases, tomato plants show the maximum demand for water (Alvarenga, 2004). This maximum demand under deficit likely resulted in less productivity without, however, a large decrease in the volume of water applied, resulting in a lower WPir value.

Other authors found different values for water use efficiency in tomato plants. Silva et al. (2019), with a 100% ETc supply for the red cherry tomato cultivar produced in a semiarid region, obtained a water use efficiency of 2.87 kg m^{-3}, a value lower than that obtained by the same treatment and cultivar in this study (6.12 kg m^{-3}).

In both cultivars, Ky values increased with the induction of deficit in the following order: vegetative, fruiting, maturation, flowering, and all phenological stages (Table 4).

Ky is used to indicate the sensitivity of plants to water deficit at any stage of their cycle (Azevedo et al., 2016) or in the entire cycle. It quantifies the effects of stress caused by a shortage of available water in the soil in relation to the decrease in potential productivity during the crop cycle (Silva et al., 2014).

The yield response to water deficit is an important tool for production management, and a higher Ky value reflects higher losses in crop yield caused by water deficit (Pejic et al., 2017).

When considering specific stages in the development of cherry tomato, plants subjected to water stress during the flowering period showed higher Ky values. In contrast, plants

Table 4. Mean values of the composition of the water deficit sensitivity coefficients (Ky) for cherry tomatoes cultivars under water deficit in different phenological phases in semiarid region

Deficits in the phases	Real yield (t ha^{-1})	Maximum yield (t ha^{-1})	Ratio between real and maximum evapotranspiration	Deficits in productivity	Evapotranspiration deficits	Ky
			Orange cultivar			
Vegetative	12.83	13.96	0.50	0.08	0.50	0.16
Flowering	8.96	13.96	0.50	0.36	0.50	0.73
Fruiting	12.57	13.96	0.50	0.10	0.50	0.20
Maturation	12.06	13.96	0.50	0.14	0.50	0.28
At all stages	8.68	13.96	0.50	0.38	0.50	0.76
			Red cultivar			
Vegetative	12.77	13.87	0.50	0.08	0.50	0.16
Flowering	10.46	13.87	0.50	0.25	0.50	0.49
Fruiting	11.75	13.87	0.50	0.15	0.50	0.31
Maturation	10.86	13.87	0.50	0.21	0.50	0.43
At all stages	9.73	13.87	0.50	0.30	0.50	0.59

subjected to water stress in the vegetative phase recorded lower values in relation to the other phases. These results were observed for both cultivars.

Comparing the Ky values between the cultivars for the same treatment, the application of 50% ETc in the flowering stage and in all phenological stages of the orange cultivar caused higher Ky values compared to that in the red cultivar, which led to greater sensitivity and, consequently, decreased yield for the orange cultivar under these conditions.

For both cultivars, water demand during the flowering phase was higher because of higher Kc values than of the other phases. However, the correlation of the higher crop coefficient with higher Ky values may promote an incorrect understanding of the data, as the crop coefficient values for the maturation phase are lower than those for the vegetative and fruiting phases. Moreover, the results showed that the Ky value for the water stress applied in the maturation phase was higher than that of the other phases.

With the application of 50% ETc in the fruiting (W4) and maturation (W5) phases, the red cultivar showed greater sensitivity compared to the orange cultivar. In the vegetative phase, the Ky values were the same for both cultivars.

The Ky values obtained for cultivars in all treatments were less than 1.0, which indicates that they are not very sensitive to water deficit, according to the classification of the FAO Bulletin 66 (Smith & Steduto, 2012), or have low sensitivity, according to FAO Bulletin 33 (Doorenbos & Kassam, 1979).

Carvalho et al. (2016) stated that plant species with Ky < 1.0 are adaptable to water deficit. This behavior was observed for both cultivars with water deficit applied in the phenological phases. It is understood that the decrease in productivity is less than the restriction of the evapotranspirative deficit, with the consequent decrease in irrigation.

The Ky values obtained for cherry tomatoes in this study differ from those of Doorenbos & Kassam (1979) for tomato cultivation in general, which were 0.4, 1.1, 0.8, 0.4, and 1.05 for vegetative, flowering, fruiting, maturation, and at all phenological phases, respectively.

For tomato crops grown in the semiarid region of the Mediterranean, Patanè & Cosentino (2010) calculated a Ky value of 0.76 for marketable fruit yield, with the application of water stress throughout the cycle and based on 50% ETc. This value coincides with that found in this study for the orange cultivar and is close to that of the red cultivar (Ky = 0.56), both produced with the same deficit and in semiarid conditions.

Gatta et al. (2007) reported a Ky of 0.55 for tomato crops, which is similar to the Ky value found for the red cultivar in this study (Ky = 0.56).

Differences in Ky values can occur due to differences in the cultivation sites and differences in the varieties and types of tomato being grown. Irmak (2015) reiterated that the Ky values, as well as the production functions of agricultural cultivars, vary for different crops and for the same crop according to growth stage, climatic conditions, and soil water. The author also indicated that the quantification of Ky for different climatic conditions and local management practices is necessary for the planning and robust evaluation of agricultural production correlated with water use.

CONCLUSIONS

1. Cherry tomato is recommended for production in semiarid regions owing to its adaptability to controlled water deficit based on the coefficient of sensitivity to water deficit (Ky), which assists in the management of water resources for irrigation and the maintenance of crop productivity.

2. In a semiarid climate with water scarcity, the water deficit irrigation strategy is recommended during the vegetative stage in the cultivation of cherry tomato. However, water deficit should not be implemented in the flowering stage, which is considered the most critical stage for the application of water deficit in both cultivars.

LITERATURE CITED

Alvarenga, M. A. R. Tomate: produção em campo, em casa-de-vegetação e em hidroponia. 1.ed. Lavras: UFLA, 2004. 400p.

Azevedo, B. M. de; Bomfim, G. V.; Nascimento Neto, J. R. do; Viana, T. V. A.; Vasconcelos, D. V. Irrigation depths and yield response factor in the productive phase of yellow melon. Revista Brasileira de Fruticultura, v.38, p.1-13, 2016. https://doi.org/10.1590/0100-29452016802

Bogale, A.; Nagle, M.; Latif, S.; Aguila, M.; Müller, J. Regulated deficit irrigation and partial root-zone drying irrigation impact bioactive compounds and antioxidant activity in two select tomato cultivars. Scientia Horticulturae, v.213, p.115-124, 2016. https://doi.org/10.1016/j.scienta.2016.10.029

Carvalho, D. F.; Oliveira Neto, D. H. de; Felix, L. F.; Guerra, J. G. M.; Salvador, C. A. Yield, water use efficiency, and yield response factor in carrot crop under different irrigation depths. Ciência Rural, v.46, p.1145-1150, 2016. https://doi.org/10.1590/0103-8478cr20150363

Coyago-Cruz, E.; Meléndez-Martínez, A. J.; Moriana, A.; Girón, I. F.; Martín-Palomo, M. J.; Galindo, A.; Pérez-López, D.; Torrecillas, A.; Beltrán-Sinchiguano, E.; Corell, M. Yield response to regulated deficit irrigation of greenhouse cherry tomatoes. Agricultural Water Management, v. 213, p.212-221, 2019. https://doi.org/10.1016/j.agwat.2018.10.020

Çelik, Ö.; Ayan, A.; Atak, Ç. Enzymatic and non-enzymatic comparison of two different industrial tomato (*Solanum lycopersicum*) varieties against drought stress. Botanical Studies, v.58, p.1-16, 2017. https://doi.org/10.1186/s40529-017-0186-6

Davies, W. J.; Zhang, J.; Yang; Dodd, I. C. Novel crop science to improve yield and resource use efficiency in water-limited agriculture. Journal of Agricultural Science, v.149, p.123-131, 2011. https://doi.org/10.1017/S0021859610001115

Doorenbos, J.; Kassam, A. H. Yield response to water. 1.ed. Rome: Food and Agriculture Organization of the United Nations, 1979. 193p.

Farahani, H. J.; Oweis, T. Y.; Izzi, G. Crop coefficient for drip-irrigated cotton in a Mediterranean environment. Irrigation Science, v.26, p.375-383, 2008. https://doi.org/10.1007/s00271-007-0101-0

Gatta, G.; Giuliani, M. M.; Monteleone, M.; Nardella, E.; Cro, A. Deficit irrigation scheduling in processing tomato. In: Lamaddalena, N.; Bogliotti, C.; Todorovic, M. Scardigno, A. (eds.). Water Saving in Mediterranean Agriculture and Future Research Needs. Bari: CIHEAM. 2007. p.277-289.

Irmak, S. M. ASCE. Interannual variation in long-term center pivot-irrigated maize evapotranspiration and various water productivity response indices. I: Grain yield, actual and basal evapotranspiration, irrigation-yield production functions, evapotranspiration-yield production functions, and yield response factors. Journal of Irrigation and Drainage Engineering, v.141, p.1-17, 2015. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000825

Kusçu, H.; Turhana, A.; Demir, A. O. The response of processing tomato to deficit irrigation at various phenological stages in a sub-humid environment. Agricultural Water Management, v.133, p.92-103, 2014. https://doi.org/10.1016/j.agwat.2013.11.008

Mukherjee, A.; Kundu, M.; Sarkar, S. Role of irrigation and mulch on yield, evapotranspiration rate and water use pattern of tomato (*Lycopersicon esculentum* L.). Agricultural Water Management, v.98, p.182-189, 2010. https://doi.org/10.1016/j.agwat.2010.08.018

Nangare, D. D.; Singh, Y.; Kumar, P. Suresh; Minhas, P. S. Growth, fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.) as affected by deficit irrigation regulated on phenological basis. Agricultural Water Management, v.171, p.73-79, 2016. https://doi.org/10.1016/j.agwat.2016.03.016

Patanè, C.; Cosentino, S. L. Effects of soil water deficit on yield and quality of processing tomato under a Mediterranean climate. Agricultural Water Management, v.97, p.131-138, 2010. https://doi.org/10.1016/j.agwat.2009.08.021

Pejic, B.; Adamaic, D.; Maksimovic, L.; Mackis, K. Effect of drip irrigation on yeld, evapotraspiration and water use eficiency of sweet basil (*Ocimum basilicum* L.). Ratarstvo i Povrtarstvo, v.54, p.124-129, 2017. https://doi.org/10.5937/ratpov54-14808

Pereira, L. S.; Cordery, I.; Iacovides, I. Coping with water scarcity: addressing the challenges. 1.ed. Dordrecht: Springer, 2009. 357p.

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2019. Available on: <http://www.r-project.org/>. Accessed on: Jun. 2020.

Sá, N. S. A. de; Pereira, G. M.; Alvarenga, M. A. R.; Mattioli, W.; Carvalho, J. de A. Comportamento da cultura do tomateiro sob diferentes tensões do tomateiro sob diferentes tensões de água no solo em ambiente protegido. Revista Brasileira de Engenharia Agrícola e Ambiental, v.9, p.341-347, 2005. https://doi.org/10.1590/S1415-43662005000300008

Santana, M. J. de; Vieira, T. A. Resposta do tomateiro irrigado a níveis de reposição de água no solo. Irriga, v.15, p.443-454, 2010. https://doi.org/10.15809/irriga.2010v15n4p443

Sento-Sé, G. V. T.; Gomes, A. da S.; Gonçalves, F. M.; Silva, M. C.; Costa, N. D.; Yuri, J. E.; Resende, G. M. de. Desempenho de cultivares de mini tomate em condições de verão do Submédio do Vale do São Francisco. Horticultura Brasileira, v.31, p.1017-1022, 2014. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/110198/1/Jony-4.pdf

Silva, A. R. A. da; Bezerra, F. M. L.; Farias, C. A. S. de; Amorim, A. V.; Carvalho, L. C. C. de; Pereira Filho, J. V. Coeficientes de sensibilidade ao déficit hídrico para a cultura do girassol nas condições do semiárido cearense. Revista Brasileira de Agricultura Irrigada, v.8, p.38-51, 2014. https://doi.org/10.7127/rbai.v8n100185

Silva, B. A. da; Rabelo, J. da S.; Costa, R. N. T.; Silva, A. O. da; Almeida, A. V. R. de. Response of the cherry tomato to watering and ground cover under organic cultivation. Australian Journal of Crop Science, v.13, p.214-220, 2019. https://doi.org/10.21475/ajcs.19.13.02.p1220

Smith, M.; Steduto, P. Yield response to water: the original FAO water production function. In: Crop yield response to water. Rome: Food and Agriculture Organization of the United Nations, 2012. Cap.2, p.6-13.

Soldateli, F. J.; Batista, C. B.; Godoy, F.; Mello, A. C.; Soares, F. dos S. O.; Bergmann, M. D.; Ethur, L. Z. Crescimento e produtividade de cultivares de tomate cereja utilizando substratos de base ecológica. Colloquium Agrariae, v.16, p.1-10, 2020. https://doi.org/10.5747/ca.2020.v16.n1.a342

USDA - United States Department of Agriculture. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Washington: NRCS, 1999. 871p.

USDA - United States Department of Agriculture. Keys to soil taxonomy. 12.ed. Washington: NRCS, 2014. 372p.

Wang, F.; Kang, S.; Du, T.; Li, F.; Qiu, R. Determination of comprehensive quality index for tomato and its response to different irrigation treatments. Agricultural Water Management, v.98, p.1228-1238, 2011. https://doi.org/10.1016/j.agwat.2011.03.004

Zanin, D. S.; Resende, J. T. V.; Leist, A. R.; Oliveira, J. R. F.; Henshel, J. M.; Lima Filho, R. B. Selection of processing tomato genotypes resistant to two spotted spider mite. Horticultura Brasileira, v.36, p.271-275, 2018. https://doi.org/10.1590/S0102-053620180221

Zhang, H.; Xiong, Y.; Huang, G.; Xu, X.; Huang, Q. Effects of water stress on processing tomatoes yield, quality and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District. Agricultural Water Management, v.179, p.205-214, 2017. https://doi.org/10.1016/j.agwat.2016.07.022