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# Flower abortion and yield of processing tomato according to irrigation depths[1]

## Abortamento floral e produtividade do tomateiro industrial em função de lâminas de irrigação

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*HIGHLIGHTS:*

*The number of flowers, the abortion rate, and the number of fruits per flower cluster directly influence processing tomato yield.*
*Deficient or excessive irrigation levels impair flowering and increase the abortion of flowers of the processing tomato.*
*Irrigation management is essential for the yield of processing tomato crops from the Brazilian Cerrado.*

**ABSTRACT:** This study aimed to evaluate the effect of irrigation depths applied by a subsurface drip system on flowering, fruiting, flower abortion and the influence of these variables on the yield of determinate growth tomato destined for industrial processing ("BRS Sena" hybrid). The experiment was carried out under a randomized block design, with four replicates. The influence of five irrigation depths; 50, 75, 100, 125, and 150% of the crop evapotranspiration was determined on the fresh and dry matter of flowers, the number of flowers and fruits per flower cluster, flower abortion rate, and the average weight of tomato fruits. The data were submitted to analysis of variance and regression. Irrigation replacements that ranged from 100 to 115% of the crop evapotranspiration (459 to 528 mm) provided a greater number of flowers, number of fruits per flower cluster, and lower abortion rate of tomato flowers. Irrigation depths greater than 115% of the crop evapotranspiration increased the average fruit mass; however, they reduced the number of flowers and fruits and increased the abortion rate of flowers in the crop. The number of fruits per flower cluster, the average fruit mass, and the flower abortion rate influenced between 53% and 66% the 'BRS Sena' yield.

**Key words:** *Solanum lycopersicum* L., water deficit, flowering

**RESUMO:** Objetivou-se neste estudo avaliar o efeito de lâminas de irrigação aplicadas por sistema de gotejamento subsuperficial na floração, frutificação, abortamento de flores e a influência destas variáveis na produtividade do tomateiro de crescimento determinado destinado ao processamento industrial (híbrido "BRS Sena"). O experimento foi conduzido no delineamento em blocos ao acaso, com quatro repetições. Avaliou-se a influência de cinco lâminas de irrigação de 50, 75, 100, 125 e 150% da evapotranspiração da cultura, sobre a massa fresca e seca das flores, número de flores e frutos por cacho floral, taxa de abortamento de flores e massa média de frutos do tomateiro. Os dados foram submetidos à análise de variância e de regressão. Reposições da irrigação que variaram de 100 a 115% da evapotranspiração da cultura (459 a 528 mm) proporcionaram maior número de flores, número de frutos por cacho floral e menor taxa de abortamento de flores do tomateiro. Lâminas de irrigação superiores a 115% da evapotranspiração da cultura aumentaram a massa média de frutos, entretanto reduziram o número de flores, frutos e elevaram a taxa de abortamento de flores da cultura. O número de frutos por cacho e frutos e a taxa de abortamento de flores, influenciam de 53 a 66% da produtividade do tomateiro híbrido 'BRS Sena'.

**Palavras-chave:** *Solanum lycopersicum* L., déficit hídrico, floração

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## Introduction

Water deficiency is one factor that limits gains in yield and quality of the raw material in the tomato industry, although excess water can also be harmful (Nangare et al., 2016; Ganeva et al., 2019; Ragab et al., 2019). The water deficit increases the flower abortion rate and reduces the fruit mass, directly interfering in yield (Silva et al., 2013; Nangare et al., 2016; Sivakumar & Srividhya, 2016; Ganeva et al., 2018; 2019; Giuliani et al., 2018). According to Ganeva et al. (2018; 2019), the combination of water deficit and high temperatures negatively impacts industrial tomato flowering and fruit formation. However, these negative impacts depending on the edaphoclimatic conditions and the tomato hybrid (Bacallao & Fundora, 2014).

Excessive irrigation affects soil aeration, increases nutrient leaching, and reduces tomato growth and gas exchange (Fiebig & Dodd, 2016; Silva et al., 2018; 2019). It is evident that the water replacement in the soil by irrigation, in quantity and at the right time, is decisive for crop success (Hott et al., 2018; Ragab et al., 2019).

Besides water requirements, the way water is applied can favor tomato crop. According to Martínez & Reca (2014) and Ayars et al. (2015), the subsurface drip irrigation system is highly viable for the crop, with significant yield gains and improved fruit quality. Besides promoting the most efficient use of water and nutrients, as they are applied where the highest concentration of roots of the crop is located, it reduces water losses through evaporation and the incidence of weeds and fungal diseases due to the lower humidity on the soil surface (Martínez & Reca, 2014). However, its use and research in Brazil are still incipient, mainly in the Cerrado region, the main tomato producing region for industrial processing. In this region, the cultivated areas are irrigated by the center pivot, and the lack of adequate irrigation management promotes economic, environmental, and social losses (Delazari et al., 2016).

Thus, this research aimed to evaluate the effect of irrigation depths (deficit and excess irrigation) on flowering, fruiting, flower abortion and the influence of these variables on tomato yield for industrial processing (BRS Sena hybrid), subsurface drip-irrigated in Cerrado areas from the Southern Goiás, Brazil.

## Material and Methods

The experiment was conducted in 2015 (June to October) and 2016 (May to September) in an experimental area at the Instituto Federal Goiano Campus Morrinhos, GO, Brazil (17º49'19.5" S, 49º12'11.3" W, and 885 m altitude). The climate is Aw-type, semi-humid tropical, with rainy summer and dry winter, according to classification of Köppen (1948).

The research was conducted in a Cerrado area of Oxisol, with soil bulk density of 1.16 g $cm^{-3}$, moisture at the field capacity of 0.36 $m^3$ $m^{-3}$ (-10 kPa), and a permanent wilting point of 0.23 $m^3$ $m^{-3}$ (-1500 kPa), in the 0-30 cm layer. The soil tillage was carried out conventionally in 2015; in 2016, the experiment was carried out under a no-tillage system. According to the soil analysis (Table 1), soil fertilization was carried out, aiming at a yield of 130 t $ha^{-1}$ (CFSGO, 1988).

In 2015, the lime was spread, followed by subsequent incorporation with disk harrow at 51 days before transplanting the seedlings. In 2016, it was not necessary to apply lime. In the two years of research, fertilization was carried out in the sowing furrow, three days before transplanting. The topdressing fertilization was carried out via fertigation, half of it at 22 days after transplanting (DAT) (urea and potassium chloride - fertigation) and another 50% at 35 DAT (calcium nitrate and potassium chloride - fertigation).

The seedlings of 'BRS Sena' tomato hybrid for industrial processing were transplanted 26 days after sowing in the planting furrow, with soil at the moisture content corresponding to the field capacity. Until 8 DAT, the plants were irrigated daily; from 8 to 25 DAT, they were irrigated on alternate days, replacing 100% of the crop evapotranspiration (ETc), to ensure the seedling survive. After 25 DAT, the plants were subjected to the proposed treatments.

The experiment was carried out under a randomized block design, with four replicates. Five irrigation depths of 50, 75, 100, 125, and 150% of the crop evapotranspiration (ETc) were applied. The experimental unit consisted of three rows of plants 5.5 m long, spaced 1.10 m apart. The central row was considered the useful area of the plot, and the two lateral rows were the borders. The plants were spaced at 0.30 m in the planting row, totaling 18 plants per row, 54 plants per plot. The blocks and plots were spaced 6 and 4 m apart, respectively.

The subsurface drip irrigation system was installed at a depth of 0.20 m, with one irrigation line for each row of plants, a self-compensating emitter per plant, and a flow rate of 2.2 L $h^{-1}$ (NaanDanJain brand; Amnondrip PCAS model), operating at a pressure of 150 kPa. ETc was determined by the weight variation of five weighing lysimeters, with a capacity of 52 L, diameter of 32.5 cm, and precision of 10 g, which were filled with air-dried soil from the experimental area (layer 0-15 cm) and grown with a tomato plant. The lysimeters were kept during the research period inside open trenches in the soil in the

**Table 1.** Chemical and physical soil attributes of the experimental area

| Layer (cm) | pH water | P | K | Na | Ca | Mg | Al | H + Al | Organic matter | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (mg $dm^{-3}$) | | | ($cmol_c$ $dm^{-3}$) | | | | (g $dm^{-3}$) | (g $kg^{-1}$) | | |
| 2015 | | | | | | | | | | | | |
| 0-20 | 5.7 | 2.6 | 44.0 | 9.0 | 2.9 | 1.2 | 0.0 | 2.6 | 31.1 | 486 | 100 | 414 |
| 20-40 | 5.5 | 1.5 | 35.0 | 8.0 | 1.8 | 0.8 | 0.1 | 2.9 | 26.0 | 494 | 121 | 385 |
| 2016 | | | | | | | | | | | | |
| 0-20 | 6.4 | 13.3 | 94.4 | 87.0 | 3.2 | 1.2 | 0.0 | 1.7 | 37.8 | - | - | - |
| 20-40 | 5.7 | 13.3 | 6.5 | 88.0 | 0.8 | 0.8 | 0.0 | 2.3 | 32.6 | - | - | - |

Methodology: pH - Electrode in suspension soil:water (1:2.5); P, K, and Na - Mehlich-1; Ca, Mg, and Al - 1 M Potassium chloride at pH 7.0; H + AL - 0.5 M Calcium acetate at pH 7.0; Organic matter - Wet oxidation (organic carbon content x 1.724) center of the experimental area so that its edge was on the same level as the soil surface. The walls of the trench were covered with wooden boards to prevent soil collapse. Lysimeters were removed from the trench only during weighing procedures on a scale to prevent their walls from being exposed to the sun and wind and avoid overestimation of ETc values. After weighing, the lysimeters were again irrigated to maintain soil moisture at in the field capacity and immediately placed back inside the trench, where they remained until the next irrigation. The irrigations, both in the treatments and weighing lysimeters, were carried out at intervals of two days.

The irrigation times for each treatment were calculated according to the ETc, wet strip width, spacing, dripper flow, and irrigation depths (treatments). The meteorological data were monitored in an automatic meteorological station, located about 300 m from the experiment. The reference evapotranspiration (ETo) values during the experimental period were calculated using the Penman-Monteith equation - FAO, as proposed by Allen et al. (1998).

At 45, 65, and 85 days after transplanting (DAT) of the seedlings, the fresh matter (FMF) and dry matter (DMF) of flowers per plant were determined using the average of two plants chosen at random from each experimental plot. After the flowers of the plants were separated from the other vegetative parts, the FMF was determined on a precision scale (1 mg). Subsequently, the flowers were packed in paper bags and taken to the air-forced circulation oven at 65 °C for 96 hours, when the DMF was determined using the same precision scale.

At 52 DAT, when the plants were in full bloom, the average number of flowers (NF) per flower cluster was evaluated. The evaluation consisted of identifying with colored wool cord and counting flowers in seven flower clusters in each experimental unit.

Five days before harvest (120 DAT), the number of fruits per flower cluster (NFT) was evaluated by counting the number of fruits that resulted from the flower clusters previously identified. When counting all fruits in the cluster, regardless of their characteristics, whether rotten, green, or ripe, were considered.

With the number of flowers in the flower cluster and the number of fruits that resulted in each treatment, the flower abortion rate (FAR) was determined according to Eq. 1.

$$\text{FAR} = \left[1 - \left(\frac{\text{NFT}}{\text{NF}}\right)\right] \quad (1)$$

where:

FAR - flower abortion rate, %;

NFT - total number of fruits counted in the flower cluster marked in each treatment; and,

NF - number of flowers counted and marked in the flower clusters of each treatment.

At 125 DAT (harvest), the average fruit mass (AFM) was also evaluated, calculated based on the mass of 30 fruits chosen at random in each experimental unit. Subsequently, the individual and combined effect of NFT, AFM, and FAR on tomato yield was also evaluated, using linear regression analyses.

The evaluated data were submitted to analysis of variance and regression for each year of evaluation ($p < 0.05$), using the SISVAR software (Ferreira, 2011).

## Results and Discussion

Maximum temperatures of 35.4 and 34.1 °C, minimum temperatures of 11 and 8.2 °C, precipitations of 86 and 27.6 mm, were recorded by the weather station, located 300 m from the experiment, in 2015 and 2016, respectively. The crop evapotranspiration (ETc) accumulated during the crop cycle (125 days) was 490.2 and 426.9 mm, and the reference evapotranspiration (ETo) was 474.1 and 492.2 mm, in the first and second year of the research, respectively. The irrigations were carried out with intervals of two days between one irrigation and the other, replacing the ETc proportionally to each proposed treatment (50, 75, 100, 125, and 150% of the ETc).

The effect of the treatments (F, $p \leq 0.05$) was observed for most of the variables analyzed, except for the average fruit mass (AFM) in 2016 (F, $p = 0.8449$) (Tables 2 and 3). It was also verified, through regression analysis, that treatments influenced ($p < 0.05$) the crop yield, except FAR in 2015.

In the first year of research, no typical symptoms of infection by *Begomovirus* species were found in the crop. In the second year, despite the intensification of whitefly control, there was a strong pressure of the pest in the tomato, which culminated in a high incidence of symptoms of virus caused by a complex of viruses of the *Begomovirus* genus, with typical symptoms of roughness, deformation, leaf rolling, decrease in leaf area and consequently less development, absorption of water and nutrients by plants, and lower yield (Inoue-Nagata,

**Table 2.** Summary of analysis of variance of fresh matter of flower (FMF), dry matter of flower (DMF), number of flowers per flower cluster (NF), number of fruits per flower cluster (NFT), flower abortion rate (FAR), and average fruit mass (AFM) of tomato plants according to the irrigation depths (% ETc) in 2015

| Source of variation | DF | Mean square | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FMF | | | DMF | | | NF | NFT | FAR | AFM |
| | | 45 DAT | 65 DAT | 85 DAT | 45 DAT | 65 DAT | 85 DAT | 52 DAT | 120 DAT | | 125 DAT |
| Depth (D) | 4 | 12.37** | 17.15* | 11.12** | 0.14** | 0.40* | 0.49** | 0.05* | 0.49* | 76.64* | 1731.67** |
| Block | 3 | $0.002^{ns}$ | $11.65^{ns}$ | 4.89** | 0.12** | $0.30^{ns}$ | 0.19** | 0.09** | $0.01^{ns}$ | $6.09^{ns}$ | 518.03* |
| Error | 12 | 0.001 | 5.29 | 3.66 | 0.009 | 0.10 | 0.01 | 0.01 | 0.13 | 32.66 | 91.93 |
| Total | 19 | 49.49 | 167.02 | 62.82 | 1.00 | 3.66 | 2.71 | 0.60 | 3.56 | 716.74 | 14557.00 |
| CV (%): | | 1.36 | 26.24 | 12.94 | 17.15 | 23.55 | 13.59 | 1.85 | 8.16 | 23.57 | 14.06 |
| | | $g\ plant^{-1}$ | | | $g\ plant^{-1}$ | | | - | - | % | $g\ plant^{-1}$ |
| Overall mean | | 2.37 | 8.77 | 4.27 | 0.54 | 1.33 | 0.84 | 5.85 | 4.42 | 24.25 | 68.18 |

**, *, and ns - Significant at $p \leq 0.01$, $p \leq 0.05$, and not significant, respectively, by the F-test; DF - Degrees of freedom; CV - Coefficient of variation; DAT - Days after transplant

**Table 3.** Summary of analysis of variance of fresh matter of flower (FMF), dry matter of flower (DMF), number of flowers per flower cluster (NF), number of fruits per flower cluster (NFT), flower abortion rate (FAR), and average fruit mass (AFM) of tomato plants according to the irrigation depths (% ETc) in 2016

| Source of variation | DF | Mean square | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FMF | | | DMF | | | NF | NFT | FAR | AFM |
| | | 45 DAT | 65 DAT | 85 DAT | 45 DAT | 65 DAT | 85 DAT | 52 DAT | 120 DAT | | 125 DAT |
| Depth (D) | 4 | 0.09** | 22.52** | 56.09** | 0.002** | 0.45** | 2.67** | 0.20* | 0.84** | 191.12** | 25.82$^{ns}$ |
| Block | 3 | 0.05* | 8.10* | 2.03$^{ns}$ | 0.001* | 0.19* | 0.26* | 0.03$^{ns}$ | 0.09* | 37.00$^{ns}$ | 17.18$^{ns}$ |
| Error | 12 | 0.01 | 1.81 | 0.86 | 0.0002 | 0.04 | 0.05 | 0.05 | 0.024 | 11.14 | 88.90 |
| Total | 19 | 0.61 | 136.14 | 240.82 | 0.014 | 2.81 | 12.04 | 1.47 | 3.93 | 1009.15 | 3754.52 |
| CV (%): | | 17.44 | 26.35 | 12.35 | 22.01 | 20.41 | 8.94 | 3.85 | 4.46 | 9.01 | 14.03 |
| | | g plant$^{-1}$ | | | g plant$^{-1}$ | | | - | - | % | g plant$^{-1}$ |
| Overall mean | | 0.56 | 5.11 | 7.53 | 0.07 | 0.94 | 2.47 | 5.62 | 3.54 | 37.03 | 67.22 |

**, *, and ns - Significant at p ≤ 0.01, p ≤ 0.05, and not significant, respectively, by the F-test; DF - Degrees of freedom; CV - Coefficient of variation; DAT - Days after transplant

2005). This fact explains the lower number of flowers, fresh and dry matter of flowers, and the number of fruits per flower cluster of the 'BRS Sena' tomato hybrid in 2016 when compared to 2015, which may justify not having any difference between the treatments regarding the average fruit mass (AFM) in 2016.

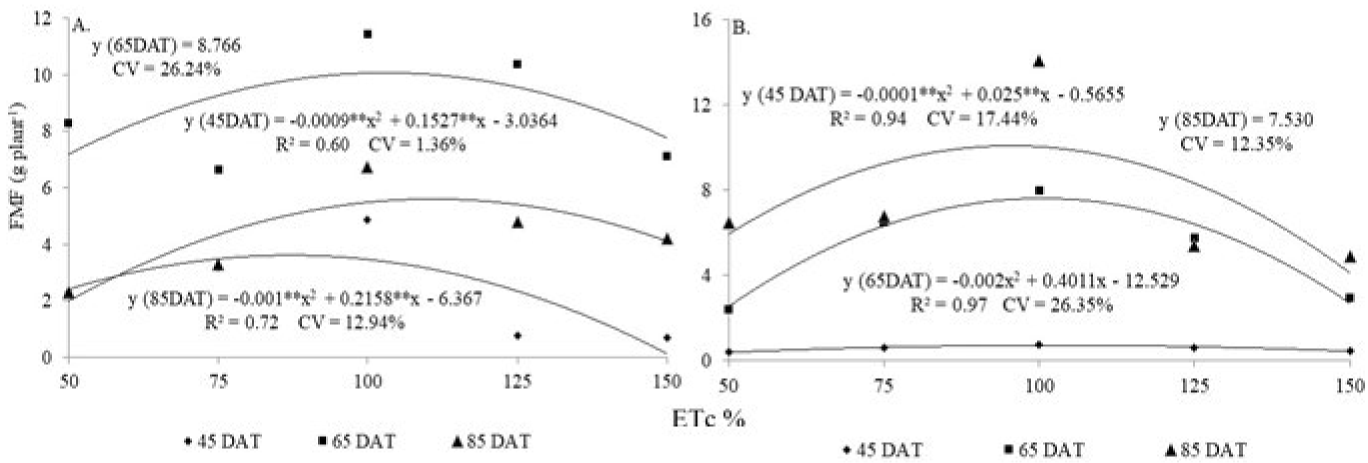
The percentages of replacement of irrigation influenced the fresh matter of flower (FMF). Both the water deficit and excess reduced the values of this variable, regardless of the period and year of assessment (Figure 1A). The highest FMF values in 2015 were estimated at 3.61 and 5.6 g plant$^{-1}$, with irrigation replacement of 87.08% (427.00 mm) and 110.89% (543.58 mm) of ETc, respectively, at 45 and 85 DAT. At 65 DAT, it was not possible to properly adjust the quadratic equation to the data ($y = -0.001^{*}x^2+0.2125^{ns}x-0.859$; $R^2 = 0.36$; CV = 26.24%) (Figure 1A), with a value mean FMF of 8.766 g plant$^{-1}$. While in 2016, the highest FMF values were estimated at 0.71 and 7.61 g plant$^{-1}$, with irrigation depths corresponding to 102.34% (436.89 mm) and 100.39% (428.57 mm) of ETc, respectively, at 45 and 65 DAT. While at 85 DAT, it was not possible to properly adjust the quadratic equation to the data ($y = -0.002^{**}x^2+0.3828^{**}x-8.191$; $R^2 = 0.43$; CV = 12.35%) (Figure 1B), when the plants produced FMF of 7.53 g plant$^{-1}$.

The FMF results are consistent with those found by Giuliani et al. (2018) in Italy, where they concluded that a higher incidence of flowers occurs with the replacement of 136% of ETc. There is a significant reduction in the dry mass of tomato plants as the plant water stress increases. The results are also consistent with those of Feibig & Dodd (2016) in the United Kingdom; they concluded that high soil water content impairs the development of tomato plants in the greenhouse due to less soil aeration and less nitrogen absorption. The results also corroborate those found by Silva et al. (2020) in Goiás, Brazil, where they found that deficit and excessive irrigation impair the growth and vegetative development of the 'BRS Sena' tomato hybrid.

The highest value of DMF at 85 DAT was estimated at 1.11 g plant$^{-1}$ in 2015, with 110.84% of ETc (543.34 mm). At 45 days and 65 DAT, it was not possible to properly adjust the equations to the DMF data ($y = -9E\text{-}05^{**}x^2 + 0.0162^{**}x-0.0529$; $R^2 = 0.52$; CV = 17, 15%; $y = -0{,}0002^{*}x^2 + 0.0364^{*}x-0.3162$; $R^2 = 0.45$; CV = 23.55%), with mean DMF values of 0.541 and 1.330 g plant$^{-1}$, respectively (Figure 2A). In 2016, the highest DMF values were estimated at 0.092 and 1.29 g plant$^{-1}$ with irrigations equal to 102.61% (438.04 mm) and 100.60% (429.46 mm) concerning the ETc, respectively. However, at 85 DAT the quadratic equation did not fit the DMF data ($y = -0.0004^{**}x^2+0.0807^{**}x-0.818$; $R^2 = 0.41$; CV = 8.94%) when the plants had an average DMF value of 2.471 g plant$^{-1}$.

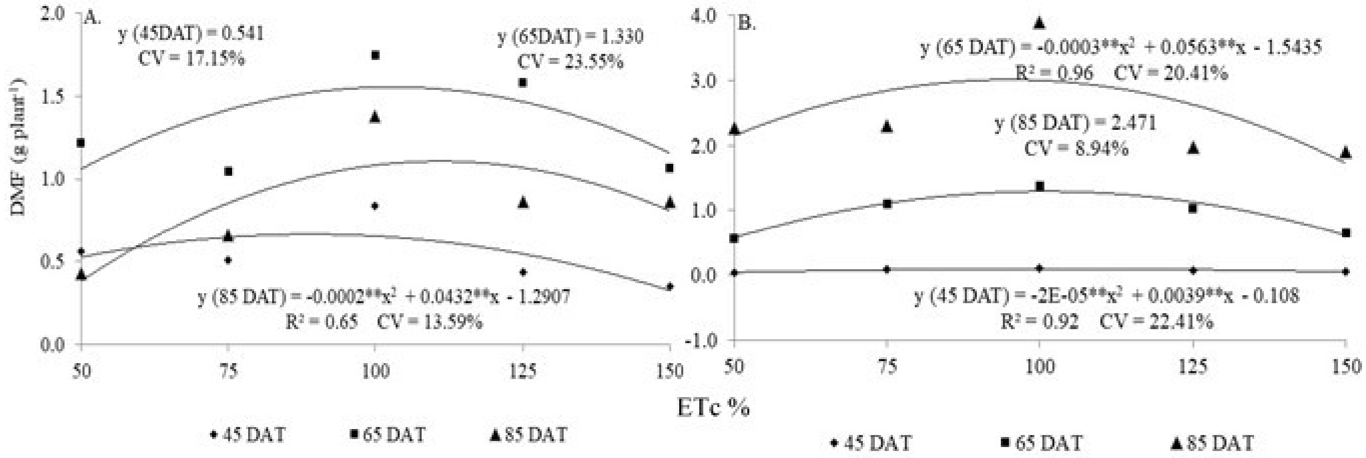
The results of the DMF are consistent with those found by Silva et al. (2013) with the Caline IPA 6 tomato cultivar in a greenhouse in Paraiba, Brazil, and with the results of Silva et al. (2018; 2019) in Goiás, Brazil, when they assessed the influence of irrigation depths on water stress and tomato yield.

The water deficit and excess decreased NF and NFT and increased FAR. In 2015, it was not possible to




** - Significant at p ≤ 0.01 by the F-test

**Figure 1.** Fresh matter of flowers (FMF) in 2015 (A) and 2016 (B) of tomato plants at 45, 65, and 85 DAT, according to the irrigation depths (ETc)




** - Significant at $p \leq 0.01$ by the F-test

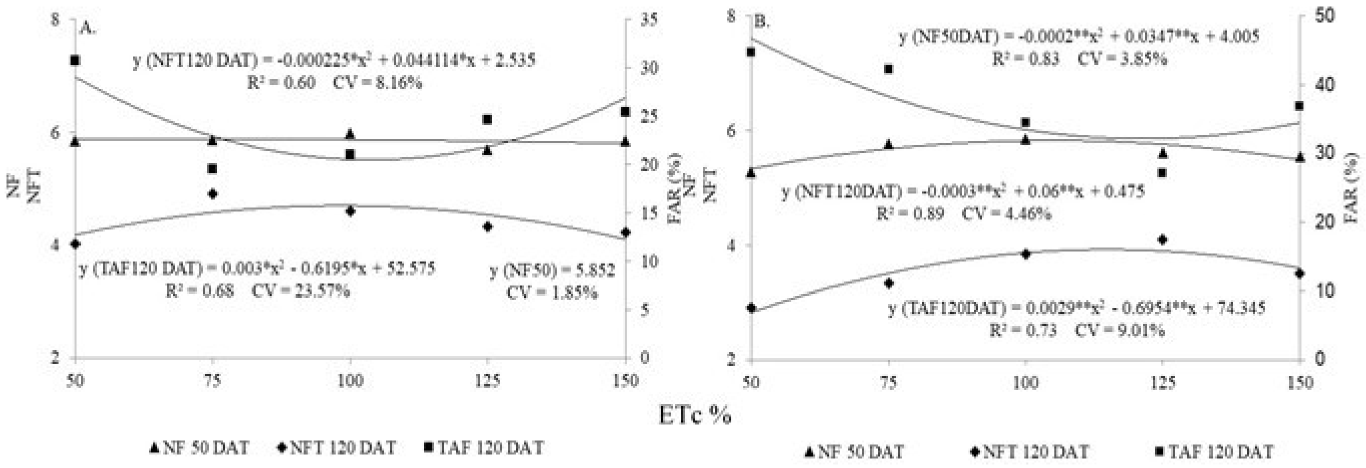
**Figure 2.** Dry matter of flowers (DMF), in 2015 (A) and 2016 (B), of tomato plants at 45, 65, and 85 DAT, according to the irrigation depths (ETc)

properly adjust the regression equation to the NF data ($y = -1E\text{-}05^{ns}x^2+0.0018^{ns}x+5.816$; $R^2 = 0.10$; CV = 1.85%), with an average value of 5,852 fruits per flower cluster. While in 2016, it was estimated at 5.82 flowers per cluster, with 104.65% of ETc (446.75 mm). The average number of flowers per cluster was 5.85 and 5.61 in 2015 and 2016, respectively (Figures 3A and B).

The NFT values behaved in a quadratic way according to the percentage of ETc replacement in the two years of evaluation. The highest NFT per flower cluster was estimated at 4.70 and 3.93, with irrigation depths corresponding to 98.03% (480.54 mm) and 115.01% (490.98) ETc, in the first and second years of research, respectively. The smallest FAR (20.46 and 36.85%) were obtained with replacements of 103.66% (508.62) and 114.42% (488.46 mm) of ETc, in 2015 and 2016, respectively (Figures 3A and B). In the two years of evaluation, the highest NF and NFT and the lowest FAR were obtained with irrigation depths ranging from 100 to 115% of the ETc.

The results found are consistent with those of Ganeva et al. (2019) in Bulgaria, in field conditions, where they concluded that water stress significantly reduces the number of flowers, the number of fruits per cluster, fruit mass and increases the rate of flower abortion, regardless of the genotype studied and which fruit cluster evaluated. The highest values of NF, NFT, and the lowest values of FAR under ideal conditions of irrigation (close to 100% of ETc) found in this research, certainly occurred due to the adequate conditions of soil moisture, which favored the $CO_2$ diffusion, transpiration, and contributed to the biomass accumulation. Facts also evidenced by Hott et al. (2018), in Espírito Santo, Brazil, who also concluded that deficit irrigations severely affected the number of flowers and fruits per plant, the shoot dry matter, and increased the flower abortion rate.

The results were also similar to those of Ragab et al. (2019), in Egypt, in field conditions, when they evaluated replacements of 100, 85, 70, and 55% of ETo in tomato plants (Marwa hybrid) and concluded that the deficit irrigation (55% of ETo), significantly reduced the number of flowers and fruits per plant, which increases the abortion of flowers and decreases the crop yield. According to the authors, facts occurred due to the lower performance of photosynthesis and accumulation of nitrogen, phosphorus, and potassium in tomato leaves. Results consistent with those of Sivakumar & Srividhya (2016) in India, under field conditions, which evaluated different soil moisture (50 and 100% of moisture corresponding to field capacity) in 10 tomato genotypes and concluded that the irrigation management with water deficit (50% of the moisture content in the field capacity)



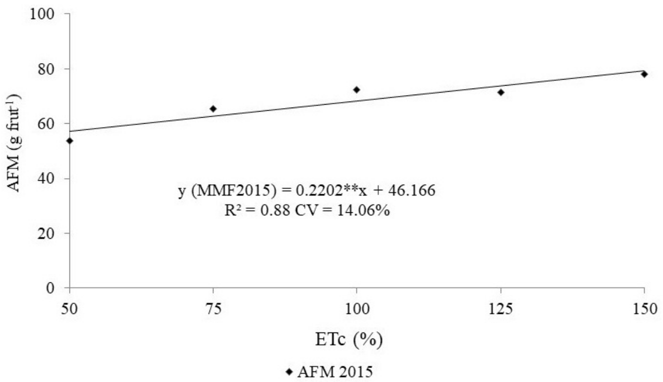

* and ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by the F-test, respectively

**Figure 3.** Number of flowers (NF), fruits (NFT), and flower abortion rate (FAR) per flower cluster in 2015 (A) and 2016 (B), according to the irrigation depths

increased the flower abortion and, consequently, occurring less quantity of fruits per flower cluster of tomato. Information that also corroborates with results of Bacallao & Fundora (2014) who concluded that the water deficit decreases the number of flowers and fruits, the average fruit mass, the fresh and dry matter of the plants, although under these conditions, the water use efficiency is higher.

In the first year of research, AFM increased linearly according to the irrigation depth (Figure 4), while in the second year of research, there was no significant effect.

The results found are consistent with those of Silva et al. (2019), under field conditions in Cerrado de Goiás, Brazil, and with those of Hott et al. (2018) in Espírito Santo, Brazil, where they found that deficient irrigations severely impair tomato yield. AFM results also corroborate those found by Nangare et al. (2016) in India under field conditions. When they evaluated irrigation replacements equal to 60, 80, and 100% of ETc, they concluded that deficit irrigation compromised the fruit size. Results that are also consistent with those verified by Sivakumar & Srividhya (2016) also in India, where they found that the water deficit (50% of the moisture content corresponding to the field capacity) decreased the size of the tomato fruits. The results also corroborate those found by Giuliani et al. (2018) in Italy, where they concluded that the reduction from 100 to 50% of the total irrigation required




** - Significant at $p \leq 0.01$ by the F-test

**Figure 4.** Average fruit mass (AFM) of tomatoes harvested at 125 DAT (2015), according to the irrigation depth (ETc)

for the crop caused a reduction from 43 to 50% in fruit yield, depending on the tomato genotype that was evaluated.

In general, excessive irrigation proved to be harmful to all variables analyzed, except AFM in 2015. This fact was also evidenced by Fiebig & Dodd (2016), who state that excessive irrigation affects soil aeration, increases nutrient leaching (nitrogen and potassium), reduces leaf growth, leaf area, plant height, and gas exchange of tomato plants. Information was also evidenced by Silva et al. (2018; 2019) in Goiás, Brazil when they assessed the effect of irrigation depths on the water stress index and tomato yield for industrial processing (BRS Sena hybrid) and proved that excessive irrigation does not favor the tomato.

The variables NFT, AFM, and FAR directly influenced the composition of the 'BRS Sena' tomato hybrid in both years of the research. Comparing the two independent variables individually concerning the yield using linear regression, there was significance ($p < 0.05$) ($R^2 = 0.29$ and 0.59), in 2015, ($R^2 = 0.39$ and 0.29) and 2016, with the variables NFT and AFM, respectively (Table 4). The two variables (NFT + AFM), when included in the multiple linear regression model to estimate tomato yield, showed a positive correlation ($R^2 = 0.63$ and 0.53; $p \leq 0.01$) in the two years of research, respectively, showing to be determinants in the yield (Table 4).

The association of the three main variables analyzed (NFT + AFM + FAR), through multiple linear regression concerning the yield, showed a highly positive correlation, in which these three variables were responsible for 66 and 53% of yield in the two years of research, respectively (Table 4).

It is known that the interaction of numerous factors contributes to tomato yield, such as edaphoclimatic conditions, hybrid used, and incidence of pests and diseases, as highlighted by Bacallao & Fundora (2014). The lesser influence of NFT, AFM, and FAR on tomato yield in the second year of research was possible due to the high incidence of viruses caused by a complex of *Begomovirus* genus on the crop this year influencing yield, regardless of the irrigation depths tested.

Anyway, the results evidenced in this research corroborate those found by Hott et al. (2018), Ragab et al. (2019), and Ganeva et al. (2019) in Brazil, Egypt, and Bulgaria, respectively,

**Table 4.** Simple and multiple linear regression analysis of yield (Yield t $ha^{-1}$) of the hybrid industrial tomato 'BRS Sena' according to the number of fruits per flower cluster (NFT), the flower abortion rate (FAR%), and of the average fruit mass (AFM - g $fruit^{-1}$) for two consecutive years (2015 and 2016)

| Variable | Model | $R^2$ | Standard error % |
|---|---|---|---|
| | 2015 | | |
| NFT | Yield = -62.0371 + 34.88833*NFT | 0.29 | 17.82 |
| FAR | Yield = 131.4842 - 1.56467$^{ns}$FAR | 0.13 | 19.62 |
| AFM | Yield = -15.5596 + 1.578988**AFM | 0.59 | 13.53 |
| NFT + AFM | Yield =-68.1099 + 1,360622**AFM | 0.63 | 13.18 |
| AFM + FAR | Yield = -10.1557 + 1.549703**AFM | 0.59 | 13.91 |
| NFT + FAR | Yield = -90.1254 + 39.15424*NFT | 0.29 | 18.29 |
| NFT + AFM + FAR | Yield = -147.595 + 26.32603NFT + 1.423187**AFM | 0.66 | 13.11 |
| | 2016 | | |
| NFT | Yield = 14.49571 + 8.717317**NFT | 0.39 | 6.96 |
| FAR | Yield = 70.21091 – 0.5875*FAR | 0.25 | 7.73 |
| AFM | Yield = -36.0546 + 1.279328*AFM | 0.29 | 7.54 |
| NFT + AFM | Yield = -39.9417 + 7.12652**NFT + 0.915936*AFM | 0.53 | 6.33 |
| AFM + FAR | Yield = -0.76184 + 0.975585*AFM | 0.40 | 7.15 |
| NFT + FAR | Yield = 27.59086 + 7.21832*NFT | 0.41 | 7.07 |
| NFF + AFM + FAR | Yield = -33.652 + 6.635192*NFT + 0.889167*AFM | 0.53 | 6.51 |

$^{ns}$, *, ** - Not significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F-test where they concluded that under conditions of water deficit, the tomato crop reduces the number of flowers and fruits, the average fruit mass and consequently directly affects yield. Thus, management that contributes to greater flowering, fruit set by flower cluster, average fruit mass, and lower flower abortion certainly contribute positively to the industrial tomato yield.

## Conclusions

1. Replacement of ETc that ranged from 100 to 115% (irrigation depth from 459 to 528 mm) provided a greater number of flowers, number of fruits per flower cluster, and lower rate of flower abortion of the 'BRS Sena' processing tomato hybrid.

2. Excessive irrigations, above 115% of the ETc, increased the average fruit mass; however, they reduced the number of flowers, fruits and increased the rate of flower abortion of the 'BRS Sena' processing tomato hybrid.

3. The number of fruits per flower cluster, the average fruit mass, and the rate of flower abortion influenced between 53 and 66% of the 'BRS Sena' processing tomato hybrid yield.

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