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Performance of table tomato plants with irrigation shifts associated with rooting agent doses

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Abstract
This study aimed to evaluate the development and production of table tomato plants, cultivar BSDS0005, in a protected environment, using different irrigation schedules and doses of the rooting agent Raizal®. The experiment was conducted in a greenhouse at the Instituto Federal Goiano - Campus Morrinhos from June to October 2021. The design was randomized blocks with three replications arranged in a split-plot scheme, with three irrigation shifts (1, 2, and 3 days) in the plots and five doses of Raizal® rooting agent (0, 5, 10, 15, and 20 g plant^{-1}) in the sub-plots. 14.5 L pots of soil were used, arranged in double rows, 0.4 m between pots, 0.45 m between single rows, and 1.15 m between double rows. A drip irrigation system was used, with 2 L h^{-1} self-compensating emitters. Irrigation was managed by replenishing 100% of the crop evapotranspiration in each irrigation shift. The results show that the Raizal® was efficient at a dose of 10 g plant^{-1}, with better performance in flower abortion rate and yield. The two-day irrigation shift showed better performance in terms of root dry mass (18.14 g root^{-1}), flower abortion rate (57.41%), yield, and water use efficiency (0.077 m^3 kg^{-1} of fruit).

Keywords: drip. irrigation, evapotranspiration, *Solanum lycopersicum*

Introduction

Tomato plants can be grown in protected or unprotected environments (Lopes Sobrinho, 2020). A protected environment precisely controls growing conditions (Abdala, 2019). However, irrigation management often occurs empirically, damaging crop yields and water resources (Lima et al., 2017; Alves Júnior et al., 2021).

Water deficit in certain regions, in certain months of the year, or at certain stages of the crop is detrimental to tomato yield (Silva et al., 2018). When its greatest water demand occurs in the flowering and fruiting phases, this can reduce the quantity of fruit per plant. In this sense, proper water supply management must be conducted, with fertilization and irrigation shifts considering each phase of the tomato plant (Rodrigues et al., 2016). The efficient use of water contributes to the nutritional quality of tomatoes.

Several techniques contribute to tomato fruit yield and quality, such as rooting agents, foliar fertilization, fertigation, and cultivation in protected environments (Rodrigues et al., 2016). Rooting agents are synthetic or natural hormones that stimulate the growth of the plant embryonic root. Fertigation uses various non-phosphate, nitrogen, and potassium fertilizers to save water, fertilizer, and energy (Silva et al., 2018).

Among the irrigation systems, drip irrigation is the most suitable for growing table tomatoes because, in addition to saving water and energy, it minimizes diseases of the shoot, generating better yield and quality in the tomato harvest, as well as facilitating the application of agrochemical products (Silva et al., 2019).

Despite the need for frequent irrigation of tomato plants, it is essential to evaluate their performance under different irrigation shifts, whether or not associated with the use of rooting fertilizers (Marouelli & Silva, 2006). Adopting

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different irrigation shifts allows the farmer to manage water better, considering the climatic conditions and the soil where the tomato crop will grow.

This research is based on the hypothesis that using Raizal®, a rooting agent, associated with longer irrigation shifts in tomato cultivation, can lead to greater efficiency in water use. Based on the information presented, this research aimed to evaluate the development and production of table tomato plants, cultivar BSDS0005, subjected to irrigation shifts and doses of the rooting agent Raizal® in a protected environment.

Material and Methods

The experiment was conducted in a greenhouse at 17°49'19" S, 49°12'11" W, at approximately 885 m altitude, at the Instituto Federal Goiano, Campus of Morrinhos, Goiás. The greenhouse is 25m x 7m, with a 150-micron thick plastic roof and anti-aphid screens on the sides. According to Becker et al. (2018), the Köppen-Geiger system classifies the region's climate as Aw-type, a semi-humid tropical climate with rainy summers and dry winters.

Temperature and relative air humidity (**Figure 1**) were monitored using a digital thermo-hygrometer installed in the center of the greenhouse at a height of 2 meters, with data recorded every 15 minutes. The maximum daily temperature was 42.3° C at 92 days after transplanting (DAT), and the minimum was 4.6°C at 09 DAT, with relative air humidity ranging from 28 to 97% during the tomato cycle. Tomato evapotranspiration was obtained using weighing lysimeters on an electronic scale with a capacity of 40 kg and a precision of 2 grams, totaling 552 mm of evapotranspiration during the cycle.

The soil used in the experiment was classified as

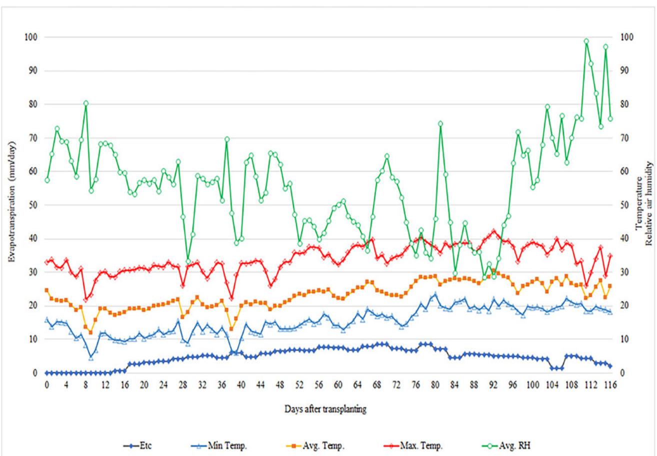

Figure 1 - Minimum, average, and maximum daily temperature (°C), relative humidity (%)indoors, in the greenhouse, and tomato evapotranspiration (mm day^{-1}) during the experimental period. Morrinhos - GO, June to October 2021.

having a clayey texture (44% sand, 8% silt, and 48% clay), with initial chemical attribute values of: Ca^{2+} = 2.2 $cmol_c$ dm^{-3}; Mg^{2+} = 1.3 $cmol_c$ dm^{-3}; K^+ = 104 mg dm^{-3}; Al^{3+} = 0.0 $cmol_c$ dm^{-3}; H+Al = 1.7 $cmol_c$ dm^{-3}; P = 31.0 mg dm^{-3}; S = 3.0 mg dm^{-3}; Zn = 2.8 mg dm^{-3}; B = 0.2 mg dm^{-3}; Cu = 6.4 mg dm^{-3}; Fe = 68.0 mg dm^{-3}, and Mn = 37.0 mg dm^{-3}; CEC = 5.47 $cmol_c$ dm^{-3}; Base Saturation = 68.0%; organic matter = 10.0 g kg^{-1}; $pHCaCl_2$ = 5.7.

The soil was corrected 30 days before transplanting. The soil correction and planting fertilizer dose was calculated per pot based on the number of plants criterion, considering a population of 26,315 plants per hectare.

According to the recommendations in the Bulletin IAC 215 (TRANI et al., 2015), 37.4 grams of lime, 5.6 grams of urea, 9.5 grams of potassium chloride, 97.8 grams of Yorin, and 1,140 grams of cattle manure were needed per plant for planting fertilizer, mixed into the soil using a rotating drum. Topdressing fertilizations were applied on the 7° DAT, 44° DAT, and 77° DAT, following the recommendations in the Bulletin IAC 215 (TRANI et al., 2015).

After correcting and fertilizing the soil, the pots with a capacity of 14.5 L each and dimensions of 33 cm in height, 29 cm in diameter at the top edge, and 17 cm in diameter at the base were filled with soil. TNT fabric was placed on the bottom of each pot to prevent soil leakage.

The experimental design was a randomized block design with three replications arranged in a split-plot scheme. The subdivided layout was implemented to facilitate the implementation of automated irrigation, with three irrigation shifts in the plots (1, 2, and 3 days) and five doses of the rooting agent in the subplots (0, 5, 10, 15, and 20 g plant^{-1}). Each subplot consisted of four plants.

The seeds of the BSDS0005 cultivar, which has determinate growth, half cuttings, and long shelf-life fruit, were purchased from Blue Seeds. The seedlings were grown in a commercial nursery. At 35 days after sowing, the seedlings were transplanted into the pots, arranged in double rows at a spacing of 0.4 m between pots, 0.45 m between single rows, and 1.15 m between double rows.

Drip irrigation was used with self-compensating emitters, using two outlet adapters, microtubes, and drip stakes, supplying water to two plants, with an average flow rate of 1.008 L h^{-1} per plant. Irrigation uniformity was measured before the experiment, showing a Christiansen Uniformity Coefficient of 93.53%.

From transplanting the seedlings to 14 DAT, irrigation was daily. From then on, irrigation shifts were differentiated until the final harvest at 116 DAT (1, 2, and 3 days). The water requirements of the plants were determined according to the daily mass variation of 10 lysimeters, which were used to determine crop evapotranspiration (ETc, mm day^{-1}) (Eq. 01) and irrigation times (Ti, min) (Eq. 02). Irrigation times and shifts were set using a Rain Bird irrigation controller.

$$ETc = \frac{Mw}{\left(\rho a \cdot \frac{\pi D^2}{4} \cdot IS\right)} \qquad \text{Eq.1}$$

$$Ti = 60 \cdot \frac{ETc.A}{q_{plant}} \qquad \text{Eq.2}$$

In which:

ETc - is the actual evapotranspiration of the crop (mm day^{-1});

Mw - is the mass of water evapotranspiration between two consecutive irrigations.

ña - specific mass of water (ña = 1.0 kg L^{-1});

D - diameter (m) of the top edge of the pot at ground level (D = 0.29 m);

IS - irrigation shift (day);

Ti - is the irrigation time (min);

A - is the area of soil in the pots that transfers water to the atmosphere (m^2);

q_{plant} - is the average flow rate of the emitters (L h^{-1}), applied per plant, obtained in an irrigation uniformity test.

After weighing the lysimeter pots, the water was replaced until the moisture content at field capacity was reached. Field capacity moisture was estimated at 0.5 cm^3 cm^{-3} after drying soil samples collected from additional lysimeters.

The first topdressing fertilization was applied at 7 DAT, then at 44 and 77 DAT, according to the technical recommendation in the Bulletin IAC 215 (Trani et al., 2015), using the same nutrient sources used in the seedling transplanting. Fertigation with Raizal® was performed at 14 and 50 DAT, at five doses: 0.0 (control), 5.0, 10.0, 15.0, and 20.0 g plant^{-1}.

The plants were supported using treated eucalyptus stakes, flat wire at a height of 2.2 m, ribbons, and bamboo stakes to support the weight of the tomato plants. Pest and disease control was conducted using the standard tomato crop management according to incidence. Five harvests were conducted, the first at 86 DAT and the last at 130 DAT.

The parameters assessed were plant height (PH, cm) at 30 and 50 days after transplanting (DAT), stem diameter (SD, mm), chlorophyll index (CI, SPAD index) at 30, 50, and 70 days after transplanting (DAT), leaf temperature (LT, °C) at 35 and 59 days after transplanting (DAT), flower abortion rate (FAR, %), root dry mass (RDM, g plant^{-1}), longitudinal fruit diameter (LFD, mm), transversal fruit diameter (TFD, mm), hydrogen potential (pH), soluble solids content (SSC, °brix), fruit yield (YIEL, t ha^{-1}), and water use efficiency (WE, m^3 kg^{-1} of fruit).

The relative chlorophyll index (SPAD index - *Soil Plant Analysis Development*) was obtained with a portable SPAD meter in three leaves per plant evaluated, located at the apex, middle, and lower third of the plants, totaling 12 readings per subplot. The diameter of the stem and the longitudinal and transverse diameter of the fruit were measured using a digital caliper with a precision of 0.1 mm. Leaf temperature was measured at 1 p.m. using a portable infrared thermometer positioned above the canopy of each plant. The readings were taken on three leaves of each plant; after the readings, the average leaf temperature was calculated.

After counting the flowers and fruit, the flower abortion rate was obtained. This was calculated by taking the difference between the number of fruits and flowers and converting it into a percentage using the following formula:

$$FAR = \left[1 - \left(\frac{TNF}{NF}\right)\right] \cdot 100 \qquad \text{Eq. 3}$$

Where FAR - flower abortion rate (%);

TNF - total number of fruits per subplot;

NF - number of flowers per subplot.

The pH of the fruit was obtained from the juice of six ripe fruits per subplot, two of each size (small, medium, and large), processed in a centrifuge, and analyzed using a benchtop pH meter. Based on the methodology of the Adolfo Lutz Institute (Zenebon et al., 2008), the soluble solids content was assessed using a digital refractometer, which was calibrated with distilled water. Approximately two drops of juice were placed on the prism of the refractometer to read the refractive index in brix (Zenebon et al., 2008).

The root dry mass was obtained after the end of the experiment by removing the roots from the pots, washing them, draining off excess water, storing them in paper bags, and sending them to an air-forced circulation oven at 65°C for four days.

The fruit yield was calculated based on the weight of commercial fruit, in grams of tomato per plant, counted every harvest and multiplied by the plant population per hectare, converting the result into tons per hectare.

Water use efficiency (m³ kg^{-1}) was obtained by estimating the volume of water applied per plant during the cycle (0.03463 m^3 plant) according to the ETc Excel spreadsheet as a function of the average flow rate per plant and the total irrigation time. Finally, the volume of water applied was divided by the production of commercial fruit (kg $plant^{-1}$) per subplot.

For statistical analysis, the variables were subjected to analysis of variance. The data for the irrigation shifts were compared using the Tukey test, and the doses of Raizal® were compared using regression equations using the SISVAR statistical software.

Results and Discussion

The summary of the analysis of variance (ANOVA) shows the mean squares of the treatments for each parameter evaluated (**Table 1**). Irrigation shifts influenced leaf temperature at 59 DAT (P = 0.001) and water use efficiency (P = 0.03). The doses of rooting agent (Raizal®) influenced the chlorophyll index at 50 DAT (P = 0.000) and 70 DAT (P = 0.000), leaf temperature at 59 DAT (P = 0.001), flower abortion rate (P = 0.006), root dry mass (P = 0.0000), and transversal fruit diameter (P = 0.0000).

The interaction between irrigation shifts (IR) and Raizal® doses (RD) influenced the chlorophyll indexes at 30 DAT (P = 0.0000), 50 DAT (P = 0.0000), and 70 DAT (P = 0.0000), leaf temperature at 59 DAT (P = 0.0000), flower abortion rate (P = 0.0000), root dry mass (P = 0.0000), fruit yield (P = 0.003), and water use efficiency (P = 0.0000).

The relative chlorophyll index at 30 DAT was influenced by the interaction between irrigation shifts and doses of Raizal® (P = < 0.001). As the dose of rooting agent increased, the plants irrigated daily showed higher chlorophyll indexes. The highest SPAD index (SPAD = 81.59) was observed in the 3-day irrigation shift (IS3) in the absence of the rooting agent, and the lowest (SPAD = 61.27) in the 1-day irrigation shift (IS1) with a dose of 10 g $plant^{-1}$ of Raizal® (**Table 2**).

The relative chlorophyll index at 50 DAT was lower than that obtained at 30 DAT, especially at lower doses of the Raizal®. The biggest decrease in the index occurred in the 3-day irrigation shift with the control dose (0 g $plant^{-1}$), probably due to the water deficit during this irrigation shift and the translocation of nitrogen in the plant, which, according to Almeida (2011), is redistributed via the phloem from the older leaves, causing a decrease in chlorophyll content at 50 days. The highest SPAD index (SPAD = 68.20) at 50 days was observed in the 1-day irrigation shift with the dose of 15 g of rooting agent and the lowest (SPAD = 52.11) in the 3-day irrigation shift with no rooting agent added.

The relative chlorophyll index at 70 days showed similar values to those obtained at 50 DAT, except for the 1- and 2-day irrigation shifts associated with the doses of 10 and 15 g $plant^{-1}$ of Raizal, which showed an increase in chlorophyll content compared to 50 days. The highest SPAD index (SPAD = 73.35) at 70 days was observed in a 2-day irrigation shift at a dose of 20 g $plant^{-1}$ of Raizal®, and the lowest (SPAD = 51.07) in a 1-day irrigation shift with a dose of 5 g $plant^{-1}$ of Raizal®.

The irrigation shifts influenced the leaf temperature (°C) at 59 DAT, with lower temperatures on average in the 2- and 3-day irrigation shifts. The highest leaf temperature (31.84°C) observed in the 1-day irrigation shift without the rooting agent is possible because the temperature assessment was conducted on the irrigation management date, and the plants in the 1-day irrigation shift received less water (1/3 of the total water). Consequently, they may have had greater water stress at the time of the measurements and, therefore, higher canopy temperatures.

The irrigation shift influenced the flower abortion rate (%). The 2-day irrigation shift showed the lowest percentage of flower abortion in almost all the doses applied, except for the 20 g $plant^{-1}$ of the rooting agent. The 1-day irrigation shift stood out with the lowest flower abortion rate. According to the Tukey test, the highest flower abortion rates (79.40% and 71.40%) occurred at doses of 10 and 0.0 g $plant^{-1}$, respectively, both in the 1-day irrigation shift, which may be associated with the high moisture content at field capacity (50%), being more harmful in the 1-day irrigation shift, with less development of the root system, due to the waterlogging of the soil at the base of the pots and, consequently, the lower absorption of phosphorus and less pollination of flowers observed in these treatments. The high soil humidity associated with the high clay content may have affected the abortion rate and, consequently, other parameters, such as yield, since they harm the tomato plant (Barros, 2019).

For root dry mass (g $root^{-1}$), the effect observed in the flower abortion rate was repeated, and the 2-day irrigation shift had the highest root dry mass in almost all the doses analyzed, except for the 20 g $plant^{-1}$ dose of the Raizal® and 1-day irrigation shift stood out. The highest root dry mass (27.99 g $plant^{-1}$) occurred in the 1-day irrigation shift at a dose of 10 g $plant^{-1}$ of Raizal®, and the lowest root masses were observed in the 3-day irrigation shift, especially at doses of 0.0 and 5.0 g $plant^{-1}$ of Raizal®.

Regarding fruit yield (t ha^{-1}), 2- and 3-day irrigation shifts were superior to 1-day irrigation shifts, with the highest yields observed at 10 and 15 g $plant^{-1}$ of Raizal® (P = 0.12). The highest yield, 16.26 t ha^{-1}, was obtained in the 3-day irrigation shift at a dose of 15 g $plant^{-1}$ of Raizal®,

Table 1. Summary of analysis of variance for plant height (PH, cm) at 30 and 50 DAT, stem diameter (SD, mm), chlorophyll index (CI, SPAD index) at 30, 50, and 70 DAT, leaf temperature (LT, °C) at 35 and 59 DAT, flower abortion rate (FAR, %), root dry mass (RDM, g root^{-1}), longitudinal fruit diameter (LFD, mm), transversal fruit diameter (TFD, mm), hydrogen potential (pH), soluble solids content (SSC, °brix), fruit yield (YIEL, t ha^{-1}), and water use efficiency (WUE, m^3 kg^{-1} of fruit) of table tomato, BSDS0005 cultivar, according to the doses of Raizal® (rooting agent) and irrigation shifts (IS). Morrinhos - GO, 2022

Variables	Source of variation				CV_{IS} (%)	CV_{RD} (%)	Overall average
	Block	Irrigation shifts(IS)	Raizal® doses(RD)	RD x IS			
	Mean squares						
PH 30 DAT	159.19^{NS}	32.69^{NS}	23.07^{NS}	16.45^{NS}	18.77	6.45	49.59
PH 50 DAT	281.30^{NS}	8,019^{NS}	11.30^{NS}	31.80^{NS}	11.82	4.68	95.41
SD 30 DAT	0.492^{NS}	0.728^{NS}	0.297^{NS}	0.276^{NS}	14.43	5.27	6.80
SD 50 DAT	0.310^{NS}	2,419^{NS}	0.093^{NS}	0.134^{NS}	11.01	6.17	9.58
SD 70 DAT	0.863^{NS}	0.027^{NS}	0.571^{NS}	1.159^{NS}	11.70	8.31	10.92
CI 30 DAT	73.04^{NS}	35.91^{NS}	16.22^{NS}	201.16**	10.15	7.05	70.85
CI 50 DAT	10.60^{NS}	6.862^{NS}	72.02**	69.36**	13.21	5.36	60.00
CI 70 DAT	75.70^{NS}	107.67^{NS}	148.37**	117.48**	18.20	5.14	61.92
LT 35 DAT	7.434^{NS}	12.66^{NS}	1.680^{NS}	2.156^{NS}	6.80	4.00	28.63
LT 59 DAT	0,539^{NS}	26.32**	1.405**	3.602**	2.38	1.64	29.20
FAR	466.87^{NS}	234.75^{NS}	106.45**	232.30**	11.36	7.76	61.37
RDM	56.23^{NS}	101.53^{NS}	174.16**	95.13**	33.07	12.26	15.22
LFD	7.451^{NS}	28.19^{NS}	12.85^{NS}	9.149^{NS}	18.72	10.06	38.67
TFD	2.458^{NS}	70.10^{NS}	81.63**	15.26^{NS}	10.83	9.33	45.49
pH	0.903^{NS}	0.735^{NS}	0.774^{NS}	0.787^{NS}	24.14	21.10	4.07
SSC	1.139^{NS}	1.699^{NS}	0.387^{NS}	0.337^{NS}	36.96	13.60	6.25
YIEL	9.131^{NS}	46.35^{NS}	12.85^{NS}	25.87**	35.48	24.58	10.29
WE	0.0002^{NS}	0.0070*	0.0005^{NS}	0.0020**	29.86	20.00	0.099

^{NS} not significant; * and ** significant at 5% and 1% probability by the F test; CV - coefficient of variation.

and the lowest yield of 5.94 t ha^{-1} in the 1-day irrigation shift with 10 g plant^{-1} of Raizal® (Table 2).

Water use efficiency (m^3 kg^{-1} of fruit) was higher in the 2- and 3-day irrigation shifts at doses of 10 and 15 g plant^{-1} of the rooting agent, requiring lower volumes of water per kilogram of fruit produced. These treatments required between 63 and 70 liters of water to produce 1.0 kg of tomatoes. The highest efficiency (0.063 m^3 kg^{-1} of fruit) occurred in the 3-day irrigation shift at a dose of 15 g plant^{-1} of Raizal®, and the lowest efficiency (1.147 m^3 kg^{-1}) in the 1-day irrigation shift with 10 g plant^{-1} of Raizal®.

There were changes in the relative chlorophyll index, which rose at 30 DAT and then fell at 50 and 70 DAT in most treatments, probably due to the translocation of nitrogen in the leaves as the reproductive phase began, demanding high amounts of nutrients. These changes in the SPAD index are probably related to a possible foliar nitrogen deficiency, even though the topdressing fertilization was applied at 44 DAT, which had no immediate effect and required time for the nutrients to be properly absorbed and translocated in biochemical and metabolic processes. According to Nogueira et al. (2018), up to 70 DAT is in high nutrient demand for the tomato plant, as it is in a period of full vegetative development, consuming large amounts of nitrogen and determining its yield potential.

On average, the 1.92% increase in the chlorophyll index in the 50 to 70 day phase demonstrates the plants positive response to nitrogen fertilization. It should be noted that the plants that suffered the greatest decrease in chlorophyll index were those without the rooting agent, especially at the 3-day irrigation shift. The decrease is less evident as the dose of Raizal® increases due to nitrogen in its composition, minimizing nutrient deficiency. The SPAD index is closely related to chlorophyll content and chlorophyll concentration to leaf nitrogen content since 70% of leaf nitrogen is found in the chloroplasts. As a result, a reduction in nitrogen content directly and proportionally affects the relative chlorophyll index (Ferreira et al., 2006; Paixão et al., 2020).

The lower leaf temperatures at 59 DAT, obtained with longer irrigation shifts, are consistent with the results obtained by Lage (2018), and longer irrigation shifts showed lower leaf temperature values due to plant adaptation. At high temperatures, the plant tends to close its stomata to avoid losing water to the outside environment, with the leaf position minimizing the incidence of radiation. As a result of the lower solar radiation index on the leaf limb, the lower the leaf temperature. It can be seen that the plant has a greater capacity for water replenishment in the shorter irrigation shifts than in the longer ones, so it remains with its stomata open for longer and receives more radiation on the leaf tissue, which consequently raises the leaf temperature (Almeida et al., 2020; Valeriano et al., 2020).

Table 2. Chlorophyll indexes (SPAD index) at 30, 50, and 70 days after transplanting (DAT), leaf temperature (°C) at 59 DAT, flower abortion rate (%), root dry mass (g root^{-1}), transversal fruit diameter (mm), fruit yield (t ha^{-1}), and water use efficiency (m^3 kg^{-1} of fruit) according to the doses of Raizal® (rooting agent) and irrigation shifts (IS). Morrinhos - GO, 2022

Variables	Irrigation	Doses of Raizal® (rooting agent) (g plant^{-1})					Mean
	Shifts	0	5	10	15	20	
Chlorophyll index 30 DAT (SPAD)	IS1	64.63b	69.43ab	61.27b	72.77a	77.44a	69.10
	IS2	68.89b	68.02b	80.31a	68.40a	71.39ab	71.40
	IS3	81.59a	79.79a	70.91ab	65.49a	62.44b	72.05
DMS: 11.34	Mean:	71.70	72.41	70.83	68.89	70.42	70.85
Chlorophyll index 50 DAT (SPAD)	IS1	54.61ab	58.15a	56.72a	68.20a	62.32a	60.00
	IS2	63.74a	64.82a	58.01a	57.40b	59.40a	60.67
	IS3	52.11b	57.29a	57.79a	63.55ab	65.87a	59.32
DMS: 10.22	Mean:	56.82	60.09	57.51	63.05	62.53	60.00
Chlorophyll index 70 DAT (SPAD)	IS1	69.55a	51.07a	67.02a	70.36a	58.76b	63.35
	IS2	56.84ab	59.84a	64.46a	63.44a	73.35a	63.58
	IS3	52.37b	56.78a	64.53a	60.46a	60.02ab	58.83
DMS: 13.92	Mean:	59.58	55.89	65.34	64.75	64.04	61.92
Leaf temperature 59 DAT (°C)	IS1	31.84b	28.88a	30.85b	31.39b	30.61b	30.72
	IS2	28.25a	28.21a	27.88a	28.16a	30.72b	28.65
	IS3	27.69a	28.77a	28.57a	28.40a	27.80a	28.25
MSD: 1.09	Mean:	29.26	28.62	29.10	29.32	29.71	29.20
Flower abortion rate (%)	IS1	71.40b	58.53a	79.40b	69.37a	47.92a	65.32
	IS2	54.80a	55.74a	52.03a	63.25a	61.20b	57.41
	IS3	61.02ab	64.28a	54.50a	65.64a	51.52b	61.39
MSD: 10.87	Mean:	62.42	59.52	61.98	66.08	56.88	61.37
Root dry mass (g root^{-1})	IS1	7.92b	12.98ab	15.38b	7.64b	27.99a	14.39
	IS2	16.65a	14.02a	26.32a	17.80a	15.88b	18.14
	IS3	8.31b	7.49b	20.38ab	16.52a	12.98b	13.14
MSD: 6.40	Mean:	10.96	11.50	20.70	13.99	18.95	15.22
Fruit yield (t ha^{-1})	IS1	10.30a	8.35a	5.94b	6.91b	10.78a	8.46
	IS2	11.47a	11.10a	12.66a	13.42a	11.16a	11.96
	IS3	7.59a	7.65a	13.06a	16.26a	7.67a	10.44
MSD: 5.74	Mean:	9.79	9.04	10.55	12.20	9.87	10.29
Water use efficiency (m^3 kg^{-1} of fruit)	IS1	0.123a	0.110a	0.147b	0.137b	0.087a	0.121
	IS2	0.080a	0.087a	0.070a	0.070a	0.080a	0.077
	IS3	0.120a	0.120a	0.070a	0.063a	0.123a	0.099
MSD: 0.04572	Mean:	0.10777	0.10555	0.09555	0.09000	0.09666	0.09911

For each characteristic evaluated, means followed by the same letter in the column do not differ by the Tukey test at 0.05 significance level. MSD - Minimum Significant Difference; IS1, IS2, and IS3 - Irrigation shifts of 1, 2, and 3 days, respectively.

Santos (2019) states temperatures above 30°C cause biochemical reactions that result in flower abortion and reduced fruit size. With a reduced number of seeds and temperatures above 34°C, there are extreme effects on reproductive structures. Excess and deficit humidity leads to the abortion of flowers, pollination, and nutrient absorption, directly impacting the yield capacity and quality parameters of the fruit (Reis et al., 2013; Abdala, 2019; Silva, 2019).

The root dry mass (RDM) stood out when irrigation was conducted every two days, compared to the other irrigation shifts. The only exception was at a dose of 20 g plant^{-1} of the rooting agent, and the 1-day irrigation shift stood out compared to the 2- and 3-day irrigation shifts, which had lower amounts of roots. Campos (2019) found results contrary to this study, reporting that daily water supply can induce less root development depending on the cultivar since it is not necessary for the root system to expand to meet water needs. When plants are subjected to periods of water stress, they can activate adaptive and tolerance mechanisms and increase their chances of survival. Water deficit/stress causes photoassimilates to be sent to the roots, which are used so that the roots can reach deeper layers of the soil and meet their water and nutritional needs, producing greater root mass (Xu et al., 2015; Brito et al., 2015).

On average, fruit yield (kg ha^{-1}) was higher in the 2- and 3-day irrigation shifts. This result was consistent with that obtained by Basílio et al. (2019), and irrigation shifts of up to five days were superior to the daily irrigation shift. This response varies according to the cultivar used, with some cultivars being more sensitive to water deficit and excess, but it is a consensus for tomato growing that both lack and excess water cause losses in fruit yield (Santos, 2019). The opposite was also observed in studies such as Zheng et al. (2013), Santiago et al. (2018), and Du et al.

(2018), and an increasing linear effect was identified as the irrigation rate increased, increasing tomato yields. According to Wang et al. (2015), despite causing yield losses, irrigation deficit increases the concentration of soluble solids in the fruit.

The higher water use efficiency (m^3 kg^{-1} of fruit) in the longer irrigation shifts is expected, corroborating the study of Monte et al. (2009), Basílio et al. (2019), Almeida et al. (2021), and Silva et al. (2021), who found similar results. Since this parameter is a ratio, the efficiency of which is reduced with the increase in the water supply provided within the ideal range for the crop and limiting irrigation below the recommended causes drastic losses in yield (Carvalho et al., 2011; Silva et al., 2013; Santos, 2019).

When analyzing the relative chlorophyll index according to the rooting agent doses, it is possible to see different responses depending on the irrigation shift. At 30 DAT, the 1-day irrigation shift showed a linear upward response as the dose of Raizal® increased, and this performance was maintained at 50 DAT. However, at 70 DAT, the relative chlorophyll index showed decreasing increases from the dose of 15 g plant of Raizal®, with a quadratic response in the 1- and 3-day irrigation shifts (**Figure 2** A,B,C).

On the other hand, in the 2-day irrigation shift, the chlorophyll index differed according to the application of Raizal® fertilizer: at 30 DAT, it remained stable, regardless of the dose of the rooting agent; at 50 DAT, the chlorophyll index decreased as the doses increased. However, at 70 DAT, it showed an increasing linear response from the lowest to the highest dose of Raizal®.

With the 3-day irrigation shift, the chlorophyll index was different: at 30 DAT, it showed a downward linear response to the increase in the rooting agent dose. However, this performance was not maintained at 50 and 70 DAT, with an increase in the relative chlorophyll index as the dose of Raizal® increased.

As for leaf temperature at 59 DAT, it can be seen that for 1-day irrigation shift, the temperature remained above 30°C, possibly due to lower root development, due to the high soil humidity in the pots, and lower absorption of nutrients such as potassium, which plays a role in the opening and closing of stomata. As a result, no verticalization of the leaves is necessary to reduce the incidence of radiation and lower temperatures. For the 2-day irrigation shift, there was initially a reduction in temperature up to the dose of 7.03 g $plant^{-1}$, rising again at the dose of 20 g $plant^{-1}$ of the Raizal®. This was the opposite effect to that observed in the 3-day irrigation shift, which showed an increase up to the estimated dose of 9.82 g $plant^{-1}$, with a reduction in leaf temperature at 20 g $plant^{-1}$. The 2- and 3-day irrigation shifts showed leaf temperatures below 30°C at the four lowest doses. The only exception is the 2-day irrigation shift with 20 g $plant^{-1}$ of Raizal®, which reached a similar temperature to the 1-day irrigation shift (Figure 2D).

Despite the reduction in chlorophyll indexes at 50 DAT, due to a possible delay in the availability of the

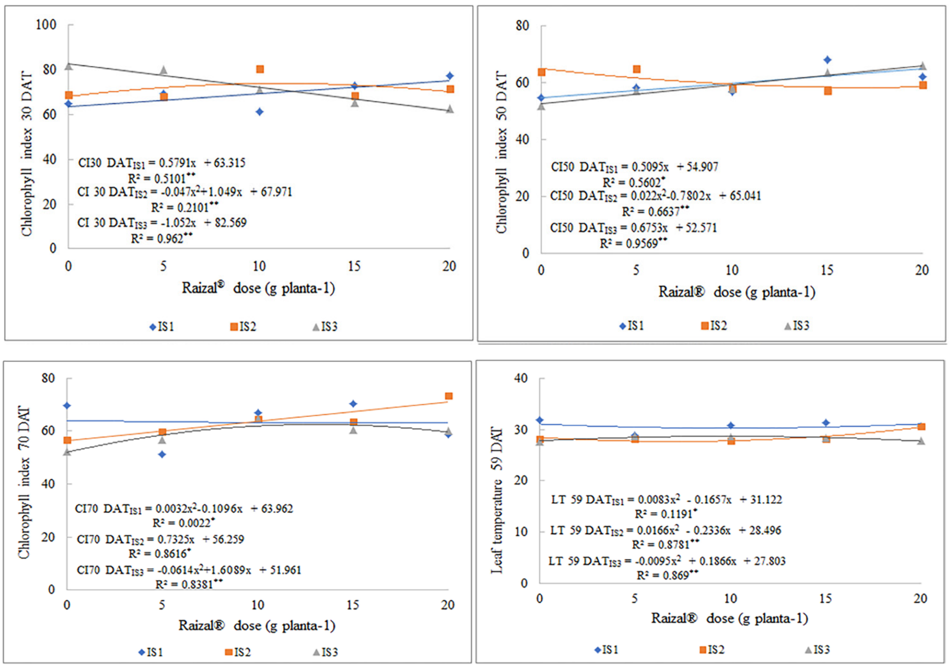

Figure 2. Chlorophyll index (SPAD) at 30 days (A), 50 days (B), and 70 days after transplanting - DAT (C), and leaf temperature (°C) at 59 days after transplanting (D) of tomato plants according to the doses of Raizal® and irrigation shifts (IS). Morrinhos - GO, 2022.

nutrients applied by the topdressing fertilization, the index proved to be responsive to the increase in doses of the Raizal®. The behavior in the 1- and 3-day irrigation shifts equations at 70 DAT is due, according to Godoy *et al.* (2008), to the supply of nutrients and photoassimilates to the flowers and the start of fruit development, concomitantly with vegetative growth.

The 10-30°C leaf temperature range is ideal for most plants, including tomatoes. However, for the tomato crop, heat stress begins at 30°C in an attenuated way, becoming more drastic when the temperature reaches 34°C, causing damage to the photosystem, with a reduction in growth rate, disturbances in flowering, and a decrease in yield capacity, justifying the low yield under high-temperature environments (Tardieu, 2013; Silva et al., 2020).

The flower abortion rate (%) performed differently depending on the irrigation shift and the Raizal® dose. 1-day irrigation shift initially showed an increase in flower abortion rate up to the estimated dose of 7.36 g plant^{-1}, with a reduction after that up to 20 g plant^{-1}. On the other hand, in 2- and 3-day irrigation shifts, the abortion rate increased according to the rooting agent dose (**Figure 3**).

The flower abortion rate is closely linked to leaf temperature. This can be seen by interpreting the data in Table 2 and comparing the trend lines in Figures 2D and 3. As the temperature increased, the abortion rate also increased, except for mitigating factors, such as the dose of 20 g plant^{-1} of Raizal® in the 1-day irrigation shift curve. The Raizal® provided a lower abortion rate, probably due to the high root concentration, as seen in Table 2. There is an increase in the supply of K, provided by the rooting agent, since the nutrient helps with translocation, assisting in the supply of nutrients demanded by the flowers (Branquinho & Decian, 2020).

The interaction between leaf temperature and flower abortion rate is well known. The yield capacity of a cultivar can only be achieved under ideal temperature conditions and is subject to interaction with the environment. Heat stress influences biochemical mechanisms, accelerating the production of ethylene, which increases the flower abortion rates, causing reductions of up to 42% in the number of flower buds and 26% in the number of fruits in some species (Wheeler & Braun, 2013; Silva et al., 2020). Lima (2020) observed an abortion rate of 14% of common bean flowers when subjected to four days of heat stress at 28°C (night) and 33°C (day). Tonhati (2018) observed that under heat stress conditions of 25-30.5°C (night) and 25-38.9°C (day), tomato plants showed a 12% higher total number of fruits and an 18% increase in the number of commercial fruits when using biostimulants.

Irrigation shifts and Raizal® doses influenced root dry mass (RDM, g root^{-1}). In the 1-day irrigation shift, the RDM increased as the doses of the rooting agent increased, reaching a maximum value with the application of 20 g plant^{-1}. In the 2- and 3-day irrigation shifts, the quadratic equation was the one that best fitted the data, and RDM reached maximum values at doses estimated at 10.4 and 12.8 g plant^{-1} of Raizal®, respectively, decreasing at doses of 15 and 20 g plant^{-1} (**Figure 4**).

The extra nitrogen supply provided by the rooting agent likely promoted greater root growth due to the nutrient role in biosynthesis and hormone signaling, especially auxins, which induce root growth. In addition, nitrogen controls root architecture, especially the growth of lateral roots (Lucio, 2019).

The different effect of the 1-day irrigation shift is due to the greater availability of water since highly mobile nutrients such as nitrogen are absorbed by mass

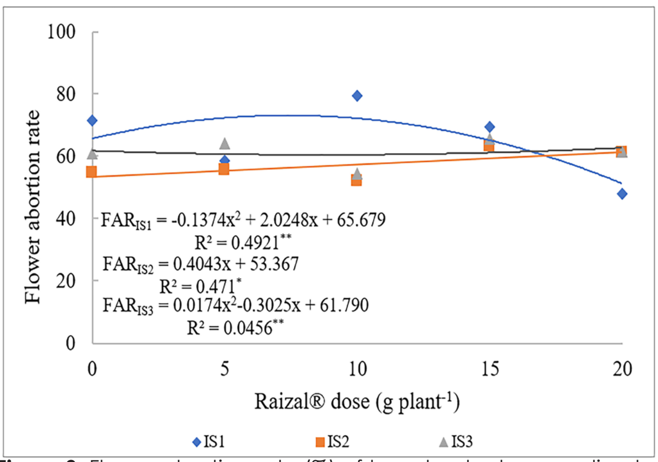

Figure 3. Flower abortion rate (%) of tomato plants according to the doses of Raizal® and irrigation shifts (IS). Morrinhos - GO, 2022.

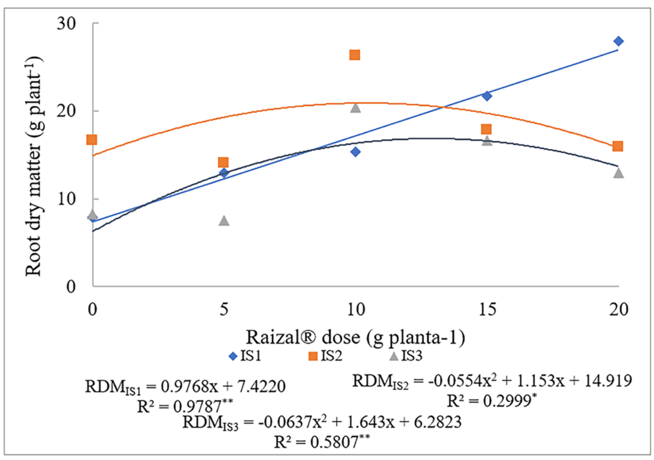

Figure 4. Root dry mass (g root^{-1}) of tomato plants according to the doses of Raizal® and irrigation shifts (IS). Morrinhos - GO, 2022

flow, with the N remaining in the soil solution. According to Lucio (2019), the movement of nitrogen in the soil occurs from areas of higher water potential to areas of lower potential, close to the root.

The transversal fruit diameter (mm) responded positively to the Raizal®, increasing as the dose of the rooting agent increased (**Figure 5**).

The response to the addition of increasing doses of Raizal® was due to the greater availability of macronutrients, such as nitrogen (N), which favored root development and photosynthetic rate; phosphorus (P), highly related to energy transformation in the plant and the formation of ATP (adenosine triphosphate); and potassium (K), which acts in the transport of sugars, organic acids, and fruit formation (Peres et al., 2020).

There was an effect of the rooting agent on fruit yield (t ha^{-1}) in each irrigation shift. In the 1-day irrigation shift, there was a decrease in yield up to the dose of 10 g $plant^{-1}$, responding positively at the higher doses, reaching the highest yield at the dose of 20 g $plant^{-1}$ of Raizal®. In the 2- and 3-day irrigation shifts, fruit yield responded positively to the rooting agent, reaching optimum doses of 11.3 and 11.5 g $plant^{-1}$ obtained by deriving the equations, respectively, but ceasing to be responsive at doses of 15 and 20 g $plant^{-1}$, with fruit yield declining after reaching the optimum dose (**Figure 6**).

The highest fruit yield at a dose of 10 g $plant^{-1}$ in the 2- and 3-day irrigation shifts is mainly due to the greater development of the roots in these treatments, making it possible to absorb nutrients from a greater volume of soil, with greater benefit from the Raizal®. 2- and 3-day irrigation shifts showed better results due to their larger root systems, and the longer intervals between irrigations induced root growth in the search for water absorption, which had influence in nutrient absorption during the draining periods of the reproductive phase, providing the plants with a larger effective root area.

Another factor that affected the yield performance of the cultivar was leaf temperature and flower abortion rate, as the 2- and 3-day irrigation shifts showed lower rates of these factors, especially at doses of 10 and 15 g $plant^{-1}$ of the Raizal®, which were consequently the doses with the highest fruit yield. Basílio et al. (2019) found similar results for tomato plants, in which the highest yields were obtained with irrigation shifts of 3 to 7 days, depending on the cultivar, generating a 32% increase in yield compared to the 1-day irrigation shift.

In terms of water use efficiency (m^3 kg^{-1}), the irrigation shifts had different effects: 1-day irrigation shift demanded a greater volume of water per kilogram of fruit, up to a dose of 10 g $plant^{-1}$ of the Raizal®, and was more efficient at doses of 15 and 20 g $plant^{-1}$. The 2-day irrigation shift remained stable in the water use efficiency equation. At the same time, the 3-day irrigation shift had optimum efficiency estimated at 10.3 g $plant^{-1}$ of Raizal®, requiring less water consumption per kilogram of fruit produced (m^3 kg^{-1}) (**Figure 7**).

On average, the 2-day irrigation shift was more efficient than the other irrigation shifts regarding water use efficiency. However, the 1-day irrigation shift was more efficient at a dose of 20 g $plant^{-1}$ of Raizal®, as it requires less water per kg of fruit, and the 3-day irrigation shift was more efficient at a dose of 10 g $plant^{-1}$ among the five doses of the rooting agent. The water use efficiency was similar to that observed by Santos et al. (2020), who showed that the ideal water level does not always result in the highest yield but consumes the least amount of water per kilogram of fruit produced. Due to the constant

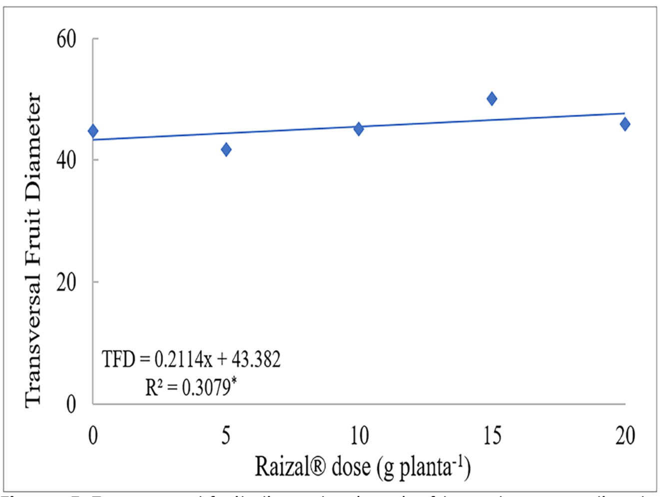

Figure 5. Transversal fruit diameter (mm) of tomato according to the doses of Raizal® and irrigation shifts (IS). Morrinhos - GO, 2022.

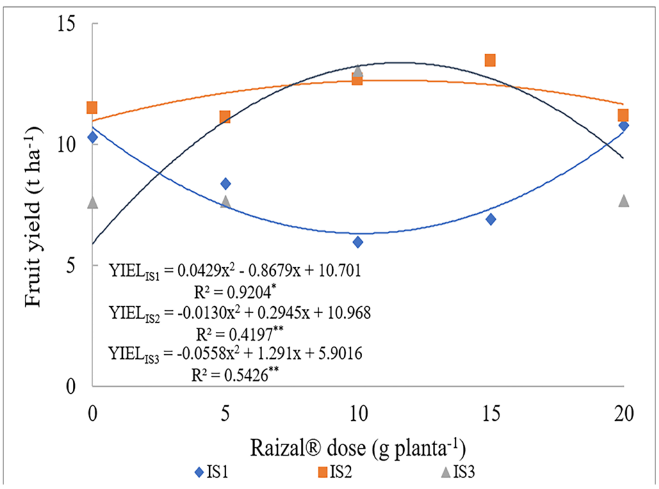

Figure 6. Fruit yield (t ha^{-1}) of tomato according to the doses of Raizal® and irrigation shifts (IS). Morrinhos - GO, 2022.

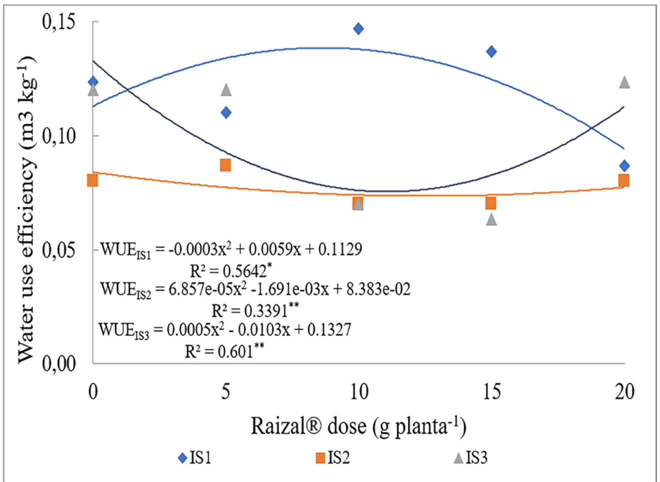

Figure 7. Water use efficiency (m^3 kg^{-1}) of tomato plants according to the doses of Raizal® and irrigation shifts (IS). Morrinhos - GO, 2022.

irrigation in the 1-day irrigation shift, there were probably greater daily water losses through direct evaporation, resulting in lower efficiency than 2- and 3-day irrigation shifts. On the other hand, using the rooting agent and the longer interval between irrigations (3-day irrigation shift), according to Wang et al. (2015), allows for greater efficiency in water use in the treatments with greater root mass.

Conclusions

The vegetative parameters of the tomato plants had no significant response to the irrigation shifts and the addition of the rooting agent, except the chlorophyll index.

Irrigation every two days proved more efficient for table tomatoes, cultivar BSDS0005, with a better response in the yield parameters analyzed and better efficiency in water use.

Using 10 g plant^{-1} of the Raizal® rooting agent, combined with irrigation shifts of 2 and 3 days, resulted in greater root dry mass and fruit yield of tomato.

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