Journal of Agricultural Science; Vol. 11, No. 6; 2019
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Irrigation Depth and Nitrogen Fertilization on Production and Quality of Cherry Tomatoes

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Received: February 25, 2019 Accepted: March 31, 2019 Online Published: May 15, 2019

doi:10.5539/jas.v11n6p547 URL: https://doi.org/10.5539/jas.v11n6p547

Abstract

Nitrogen fertilization and water supply are determinant factors for production and physical-chemical quality of cherry tomato. The objective of this study is to evaluate the productivity and quality of cherry tomatoes, cultivar Carolina, produced under different irrigation depth and nitrogen treatments. The experiment was conducted in a protected environment in randomized blocks and a 5 × 3 factorial design with three replications. The treatments were integrated by the combination of five irrigation depth consisting of 50, 75, 100, 125 and 150% of replacement of the reference evapotranspiration (ETo), and three nitrogen treatments fertilization (common urea, urea with urease inhibitor and without the application of nitrogen). The productive and qualitative characteristics of tomato fruits were evaluated. Productivity was better responsive with the 125% ETo depth. The 100% ETo depth provided the highest titratable acidity. Nitrogen treatments did not promote differences in productivity and quality of tomatoes.

Keywords: evapotranspiration, irrigation management, nitrogen sources, water use efficiency

1. Introduction

Brazil is the eighth largest tomato producer in the world (FAO, 2015). This crop stands out because of its social and economic relevance. It may be cultivated in all regions of Brazil by the adoption of different techniques of cultivation and management during the whole year (Vilela, Melo, Boiteux, & Clemente, 2012). The mini-tomato (*Lycopersicum esculentum* Mill) is mainly produced in the Center-West and Southeast regions of Brazil (Cunha, Sandri, Vieira, Cortez, & Oliveira, 2014). These authors emphasized that farmers in these regions constantly need new crop, water and nutritional management options, which would make it possible to maximize profitability.

The cherry tomatoes have satisfactory market values according Maciel, Fernandes, Melo and Oliveira (2016). Thus, they have been more interested in farmers who spread their cultivation in a protected environment. However, for better yields and economic profitability, it is necessary that the factors inherent to nutrition, correct use of water, genetics and sanity be at adequate levels (Silva et al., 2013).

The water is one of the factors that present the greatest influence on tomato growth and development characteristics (Andrade, Noronha, Azevedo, Silva, & Santos, 2017). Santana, Vieira and Barreto (2010) mentioned water deficiency as the factor that affects tomato production the most. Andrade, Noronha, Azevedo, Silva, and Santos (2017) indicated that fruit quality also responds negatively to both water excess and deficit, as well as inadequate fertilization. According to Soares et al. (2012), one of the main demands of producers is precisely to know the water requirement of tomatoes, and alternatives sources of N.

Thus, irrigation should be adequately managed respecting the water requirement of the crop during its cycle, and the estimation of evapotranspiration is important in this determination (Xie & Zhu, 2013). Recent studies have been carried out to evaluate the effects of drip irrigation depth on productivity and/or quality of tomato fruits, be it for industrial processing (Moreira et al., 2012; Silva et al., 2013) or for *in natura* consumption (Campagnol, Abrahão, Mello, Oviedo, & Minami, 2014; Brito et al., 2015). However, studies correlating irrigation depth with the production and quality of cherry tomatoes are still scarce.

Allied to an adequate water availability, the supply of nutrients is also fundamental, especially when it comes to nitrogen. This nutrient is required in a greater quantity by plants, and its application may be cause N losses in soil, especially when the source is urea, which has high hygroscopicity, but is also very susceptible to losses by volatilization (A. A. Silva, S. T. Silva, Vasconcelos, & Lana, 2012).

Alternatives to reduce losses by volatilization are the use of slow or controlled sources of nitrogen. According to Caetano, Diniz, Benett, and Salomão (2015), studies using slow-release or polymer-coated urea are incipient and therefore need to be further investigated, especially in the cultivation of economically important vegetables such as tomatoes.

Among the determining factors in the production and quality of cherry tomatoes are nitrogen fertilization and an adequate water supply. Thus, the objective of this study is to evaluate the productivity and quality of cherry tomatoes, cultivar Carolina, produced under different irrigation depth and nitrogen fertilization treatments.

2. Method

This study was conducted at the State University of Goiás, Campus Santa Helena de Goiás, GO, in a protected environment. The area is located at 17°48′49″ S and 50°35′49″ W, at 595 meters of altitude. According to Köppen, the climate of the region is Aw, with annual rainfalls in a bimodal distribution and two well-defined seasons: dry season (May-October) and rainy season (November-April). The average temperature is 25 ºC, rainfall reaches approximately 1,500 mm annually, and the relative humidity is on average 53%.

The experimental design comprised completely randomized blocks (CRB) in a 5 × 3 factorial design with 3 replicates, totaling 15 treatments and 45 plots. The first factor was that an irrigation depth, composed of 50, 75, 100, 125 and 150% of the reference evapotranspiration (ETo), and the second factor was three nitrogen treatments: 1-common urea (CU); 2-urea with urease inhibitor (UI); 3-without nitrogen (WN).

The local irrigation system was by drip. With pressure and working flow of 15 mca and 1.8 L h^{-1}, respectively. Irrigation depth were obtained from evaporation data measured daily using a mini-evaporator built with PVC (polyvinyl chloride), 30 cm in diameter and 28.5 cm in height, making up a volume of 20 L, leveled using a 0.7 m high wooden stand (Salomão, 2012). It should be noted that the mini-evaporator was calibrated from June 11 to 30, 2016, due to the evaporation of the standard class A tank, as shown in Figure 1, and both were installed inside the protected environment.

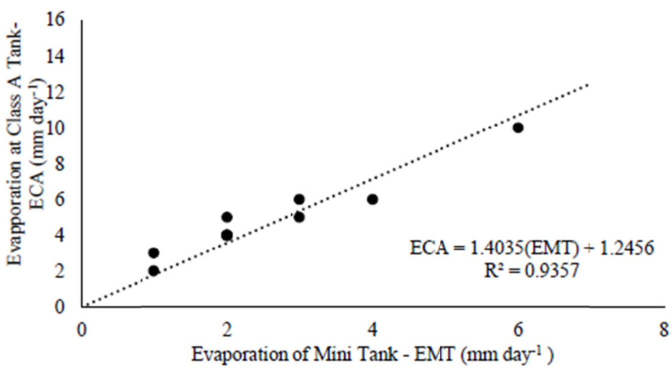

Figure 1. Calibration of the mini-evaporator with the standard class A tank, and its respective regression equation

The crop evapotranspiration (ETc) was obtained by the Equation 1:

$$ETC = Kp \times Kc \times (Ev \times f) \quad (1)$$

where, ETc = crop evapotranspiration (mm day^{-1}), Kp = tank coefficient, dimensionless (0.75 for protected environment); Kc = crop coefficient (Doorenbos & Kassam, 1994); Ev = evaporation of the mini-evaporator; f = evaporation correction factor for the standard class A tank (mm day^{-1}).

The crop coefficient (Kc) used varied according to the phenological phase of the crop (Table 1). For tomatoes, according to Doorenbos and Kassan (1994), the phases I to V correspond to the stages emergence of seedlings, post-emergence, flowering, reproductive and maturation, respectively.

Table 1. Tomato crop coefficient (Kc) for each stage of development, and number of days at each stage

Stage of Development	Number of Days per Phase	Kc values
Phase I (Initial)	10-15	0.5
Phase II (Development)	20-30	0.8
Phase III (Intermediary)	30-40	1.2
Phase IV (Last)	30-40	0.9
Phase V (Harvest)	-	0.6

Source: Doorenbos and Kassan (1994).

Tomato Carolina was a cultivar selected for this study. It has a habit of indeterminate growth, a cycle of 100 to 115 days, tolerance to some diseases and high productivity of tasty fruits. Twenty-five days after sowing, cherry tomatoes were transplanted into pots with a volumetric capacity of 6 L of substrate. A soil representative of the Brazilian Cerrado region was used, it classified as Oxisol with a clayey texture. The pots were arranged 1.0 m apart between rows and 0.50 m apart between plants, as recommended. Soil acidity and nutrient supply were corrected based on chemical analysis (Table 2), as recommended by Ribeiro, Guimarães and Alvarez (1999).

Table 2. Chemical characterization of the soil used as substrate for cherry tomato cultivation in a protected environment

Ca	Mg	Al	H+Al	CEC	K	P	V	pH	OM
------------------------ $cmol_c\ dm^{-3}$ ------------------------					------- $mg\ dm^{-3}$ -------		%	$CaCl_2$	$g\ dm^{-3}$
1.7	0.7	0.0	4.2	6.72	45.0	7.7	37.5	5.0	24.0

Note. Ca: calcium; Mg: magnesium; Al: aluminum; H+Al: hydrogen + aluminum; CEC: Cation exchange capacity; K: potassium; P: phosphorus; V: base saturation; pH: hydrogen potential in calcium chloride ($CaCl_2$); OM: soil organic matter.

Phosphate and potassium fertilization were performed for all treatments using the triple superfostate and potassium chloride sources, respectively. In contrast to nitrogen, different treatments (CU, UI and WN) were used according to the respective treatments. Both nitrogen and potassium were applied in cover using a split-plot design every 15 days throughout the crop cycle until the 8th week, according to Table 3. The phosphorus was applied at total dose at the time of transplanting tomato seedlings.

Table 3. Fertilization times and nutrient doses applied throughout the cultivation of cherry tomatoes in protected environment

Application Time	Application Date	Nitrogen Dose (kg ha^{-1} of N)	Potassium dose (Kg ha^{-1} of K_2O)	Phosphorus dose (Kg ha^{-1} of P_2O_5)
Transplantation	05/23/16	20	60	700
2nd	06/06/16	20	90	300
3rd	06/21/16	40	90	-
4th	07/04/16	40	120	-
5th	07/19/16	40	120	-
Total	-	160	480	1000

Note. The analyzed variables were productivity (Prod), fruit transverse diameter (TD), longitudinal fruit diameter (LD), number of fruits per plant (NF pl^{-1}), fruit mass per plant (FM pl^{-1}), total soluble solids (TSS), total titratable acidity (TTA), ratio and water use efficiency (WUE).

The TD and LDs of three representative fruits of each plant were measured using a digital caliper. For the determination of productivity (Prod) we counted NF pl^{-1} and obtained FM pl^{-1} on an analytical bullet. Afterwards, we extrapolated the results to yield per hectare, since the spacing adopted between plants was the same used in the field.

The TSS content was determined using a portable sugar refractometer and the results were expressed in ºBrix, and the TTA was obtained by titration with 0.1 N NaOH. The ratio of TSS per TTA, called ratio (TSS/TTA), was calculated for the different samples. These analyses were performed after extraction of the broth from five tomatoes randomly selected from each plot, manually macerated and sieved. The relation between the average productivity of each plot and the irrigation depth applied throughout the crop cycle determined the WUE.

Data were submitted to analysis of variance associated with F test at a significance level of 5%. For the evaluation of the irrigation depth, a regression analysis was used, and for the comparison between the nitrogen treatments, a Tukey test at 5% probability was performed. The statistical software SISVAR was used for statistical analyses (Ferreira, 2011).

3. Results and Discussion

Table 4 shows the F values and their significance for irrigation depth (IB), nitrogen treatments (NT) and their interactions according to productive characteristics: productivity (Prod.), fruit mass per plant (FM), number of fruits per plant (NF), and fruit quality parameters transverse diameter (TD), longitudinal diameter (LD), total soluble solids (TSS), total titratable acidity (TTA), and ratio and water use efficiency (WUE).

Table 4. F values of the analysis of variance of irrigation depth (IB), nitrogen treatments (NT) and their interactions (IB × NT) according to the qualitative and productive characteristics of cherry tomatoes, and water use efficiency

SV	DF	Qualitative Characteristics					Quantitative Characteristics			WUE (kg mm^{-1})
		TD	LD	TSS	TTA	Ratio	Prod.	FM pl^{-1}	NF pl^{-1}	
IB	4	3.08 *	5.87 ^{ns}	0.42^{ns}	0.014 *	12.82 ^{ns}	6,504.90 **	16.26 **	578.05 **	42.66 **
NT	2	4.11 *	9.53 *	0.60^{ns}	0.006 ^{ns}	10.83 ^{ns}	20,754.29 **	51.89 **	689.17 **	94.51 **
IB × NT	8	1.41 ^{ns}	4.27 ^{ns}	0.97^{ns}	0.005 ^{ns}	12.02 ^{ns}	1,080.53 ^{ns}	2.70 ^{ns}	2.35 *	5.78 *
Block	2	1.79	5.1	0.34	0.007	3.99	363.03	0.91	7.41	3.76
Residue	28	1.05	2.91	0.45	0.004	116.83	492.77	1.23	53.48	2.69
Total	44	-	-	-	-	-	-	-	-	-
CV (%)	-	4.58	5.81	10.89	12.44	18.79	18.91	18.91	28.08	21.48

Note. Productivity (Prod.), fruit mass per plant (FM pl^{-1}), number of fruits per plant (NF), fruit transverse diameter (TD), and qualitative fruit parameters longitudinal fruit diameter (LD), total soluble solids (TSS), total titratable acidity (TTA), Ratio (TSS/ATT) and water use efficiency (WUE). CV: Coefficient of variation; SV: source of variation; DF: degree of freedom; ns: not significant, ** and *, significant at 1% and 5%, respectively, by Tukey test.

Qualitative and quantitative characteristics had a significant effect on irrigation depth, except for the LD, TSS and Ratio variables. TD and TTA were significant at 5% probability. On the other hand, Prod, FM pl^{-1}, NF pl^{-1} and WUE were significant at 1% level. For nitrogen treatments, Prod., FM pl^{-1} and NF pl^{-1} were significant at 1% probability, and TD and LD were significant at 5% probability. In the interaction of factors between IB and NS, only the characteristics NF and WUE were significant at 5% probability.

The NF pl^{-1}, in function of the irrigation depth in the treatment with CU, presented a higher value with the depth of 126.24% of ETo, in which it reached the average of 37.41 of fruits per plant (Figure 2A). Regarding the UI treatment, the mean number of fruits per plant was 32.62 and the depth that allowed this average was 112% of the ETo. In the WN treatment, the fruit average was below the other treatments, reaching only 24.7 fruits per plant, requiring an irrigation depth of 118.38% of ETo. This low number of fruits found in the treatment without N (Table 5) reinforces the idea of the centrality of this nutrient for the increase in tomato fruit production.

Table 5. Test of means of the parameters Transversal diameter (TD), longitudinal diameter (LD), total soluble solids (TSS), total titratable acidity (TTA), ratio (TSS/ATT), productivity (Prod.), fruit mass per plant (FM pl^{-1}), number of fruits per plant (NF pl^{-1}) and water use efficiency (WUE) of cherry tomatoes cultivated in a protected environment using nitrogen treatments (NT) and irrigated with different irrigation depth

NT	TD (mm)	LD (mm)	TSS (ºBrix)	TTA (%)	Ratio	Prod. (t ha^{-1})	NF pl^{-1}	FM pl^{-1} (g)	WUE (kg mm^{-1})
WN	21.98 b	28.51 b	5.96 a	0.50 a	11.19 a	2.35 b	18.37 b	0.12 b	4.75 b
CU	22.21 ab	29.44 ab	6.29 a	0.52 a	12.21 a	4.36 a	28.57 a	0.22 a	8.84 a
UI	22.98 a	30.10 a	6.31 a	0.54 a	12.81 a	4.42 a	31.20 a	0.22 a	9.31 a
LSD	0.93	1.54	0.61	0.017	1.85	0.63	6.61	0.03	1.48

Note. CU: common urea, UI: urea with urease inhibitor, WN: without nitrogen; LSD: least significant difference. Means followed by the same lowercase letter in colun do not differ by Tukey test at 5% probability.

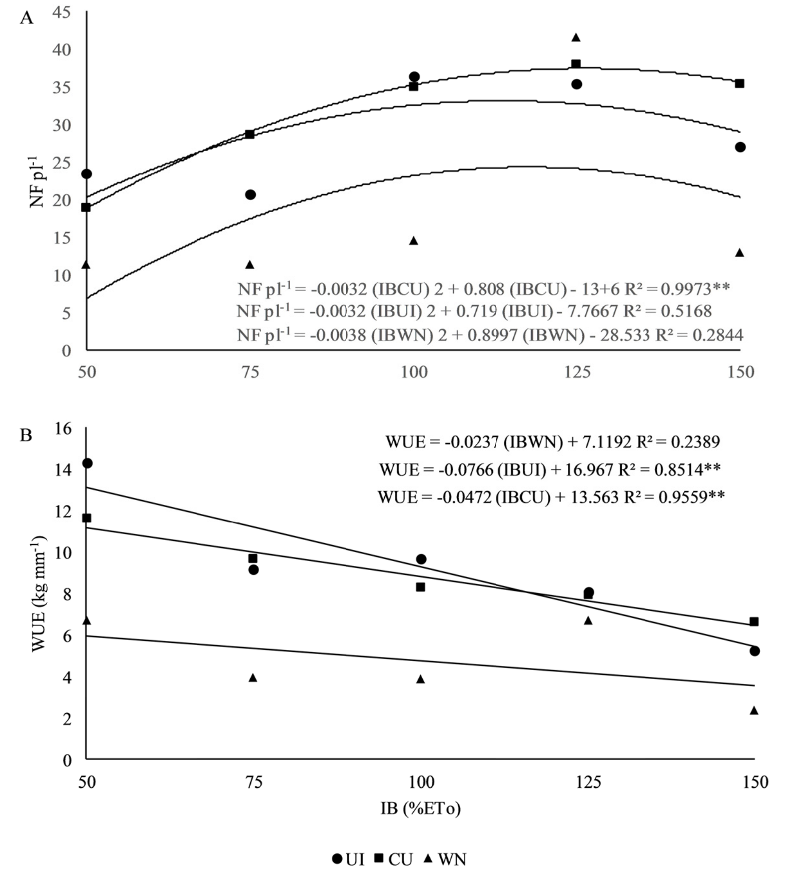

Figure 2. Avarege of numbers of fruits per plant (NF pl^{-1}) of cherry tomato (A) cultivated in a protected environment and water use efficiency (WUE) (B) in function of nitrogen treatments for each irrigation blade (IB) determined in function of the reference evapotranspiration (% ETo). UI: urea with urease inhibitor. CU: common urea. WN: without N

Santana, Vieira, and Barreto (2010) observed that smaller or larger irrigation depth in relation to the 100% replacement resulted in losses of productivity and number of fruits per plant, indicating as an optimal physical irrigation depth 460.17 mm, in which there were 30.56 fruits per salad tomato plant. The total depth applied to the cycle of the cherry tomato studied were 259.5, 389.25, 519, 648.75 and 778.5 mm, corresponding to 50%, 75%, 100%, 125% and 150% of ETo, respectively. In this study, this same irrigation depth as cited by Santana, Vieira and Barreto (2010), of 460.17 mm, resulted in 23.46 fruits per plant.

For TD, the data ranged from 25 to 33 mm (Table 5). For LD, cherry tomato fruits varied between 25.91 and 34.28 mm. Preczenhak et al. (2014) performed a characterization of mini-tomato genotypes, and the diameter varied between 20 and 40 mm. Tomatoes may be classified as small when they have between 20 and 25 mm, medium between 25 and 30 mm, large between 30 and 35 mm and giant when greater than 35 mm (Fernandes, Corá and Braz, 2007). In this study, therefore, the cherry tomato class would be between medium and large.

By observing Table 5, it was found that, for the TD and LD of the fruits, only the treatment with urease inhibitor differed from that without nitrogen. The factor irrigation depth influenced the TD of fruits. For higher values, an intermediate depth was required, in which it reached 22.15 mm in diameter using a 78.5% ETo depth regardless of the nitrogen treatment used (Figure 3A). Silva et al. (2013) analyzed the cultivation of the Caline IPA 6 tomato in a protected environment under different evapotranspiration replacement rates and observed that the transversal diameter maintained its averages between 28.5 and 45.5 mm for depth between 33 and 166% of ETo. In this study, the behavior was quadratic, with the vertex facing downwards, indicating that intermediate irrigation depth presented smaller fruits, were verified with application of these irrigation depth.

For the optimum irrigation depth, 127.06% of ETo, regardless of the nitrogen treatment, there was a mean fruit mass per plant of 212.75 g, as observed in the Figure 3C. On the other hand, Silva et al. (2013) found that the irrigation depth that provided the best yield of fruit mass per plant was the 128% of the ETo for the cultivar Caline IPA 6. A similar result was found in this study. Regarding productivity, the CU treatment obtained the best fit between the estimated and the observed data.

Feltrin, Pott, Furlani and Carvalho (2005) reported that the TTA reaches the maximum value when still with a yellow coloration, and this value reduces as the tomato fruit matures. Ferreira et al. (2010) stated that the tomato harvested in the first flowering tend to present a higher TTA, an observation also made by Vieira, Cardoso, Dourado, Caliari and Soares Júnior (2014) and observed in this study. The mean value of 0.374% TTA of cherry tomatoes in a conventional and organic cultivation was within the range found in this study, whose values varied between 0.30 and 0.68%, but did not show differences in function of nitrogen fertilization. For the TTA of 0.55%, a depth of 100% of ETo was applied regardless of the nitrogen treatment used (Figure 3B).

Regarding the physical-chemical quality of cherry tomatoes, TSSs reflect the sweetness of the product, indicate maturity/ripeness level and may be expressed in ºBrix (Pineli, 2009). Ramos et al. (2013) stated that fertilization, temperature, irrigation and the genetic influenced the character of the cultivar. According to Schwarz et al. (2013), a fruit with values higher than 3 ºBrix is recommended for marketing *in natura*. In this study, the content of TSS varied from 4.0 to 8.0 °Brix, with the lowest values observed in the treatment without addition of N (Table 5).

According to Moura et al. (2017), studies reporting the water use efficiency for cherry tomatoes are scarce. The WUE showed an inverse behavior of productivity; Santana, Vieira, and Barreto (2010) observed the same behavior upon analyzing the response of irrigated tomatoes to levels of water replacement in the soil. Based on the equations of each treatment of N (Figure 2B), it is observed that the reduction rate of WUE was 77, 47 and 23 g mm^{-1}, for UI, CU and WN, respectively. Efficiency of water use is directly related to productivity. The higher the productivity, as even water consumption, the greater the effectiveness of water use.

Abrahão et al. (2014) found different WUEs for cherry tomato cultivars: 'Swett Milion' had 29.1 kg m^{-3} and 'Sweet Grape' had 22.3 kg m^{-3}. According to Moura et al. (2017), the differences in water use efficiency values may be attributed to the cultivars studied, local climatic conditions and planting spacing, and in this study, it was observed that nitrogen fertilization also exerts a great influence.

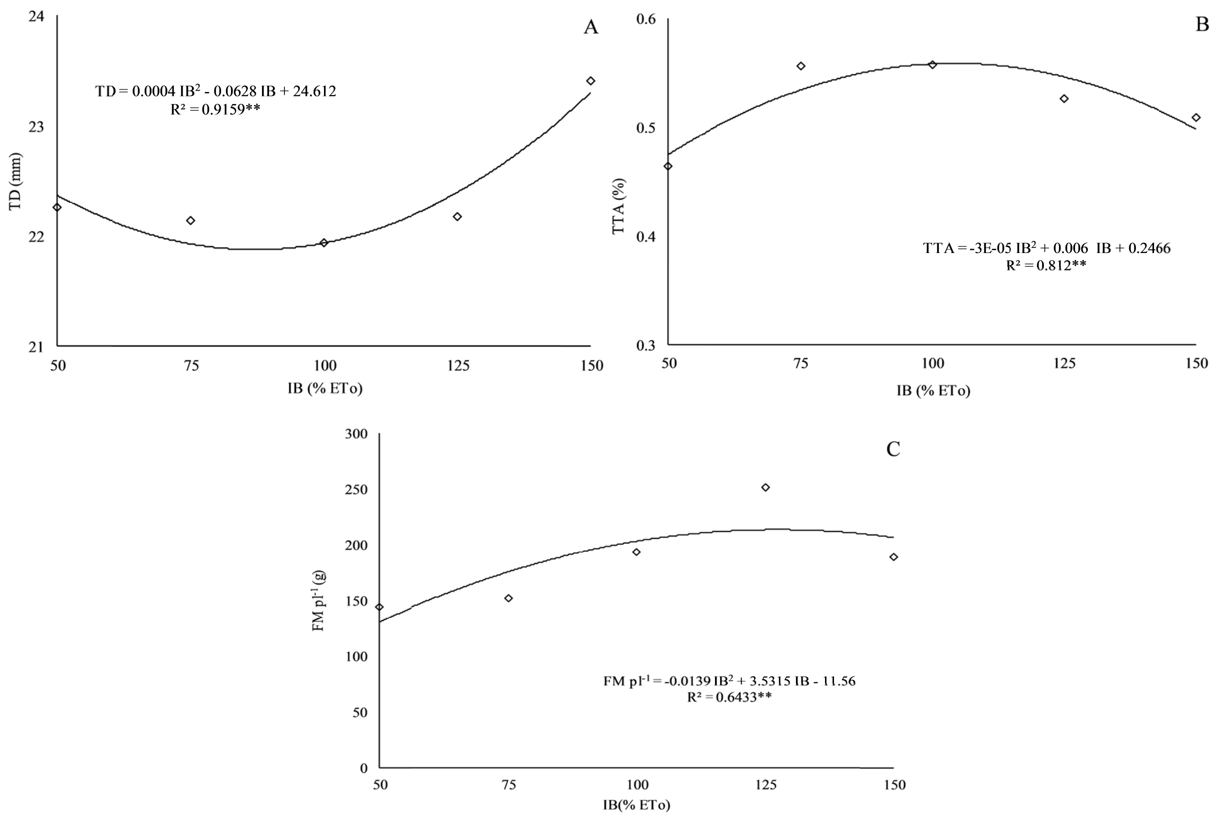

Figure 3. (A) Transverse diameter (TD) (B) total titratable acidity (TTA) and (C) fruit mass per plant (FM pl^{-1}) of cherry tomatoes cultivated in a protected environment according to nitrogen treatments and irrigation blade (IB), determined in function of reference evapotranspiration (ETo)

4. Conclusions

The irrigation depth that resulted in the highest productivity was the 117.67% of ETo. Only TTA among the physical-chemical characteristics of tomatoes showed an interference of irrigation depth. The 100% ETo depth provided slightly more acidic fruits. The irrigation depth equivalent to 100% of the ETo resulted in a superior quality in relation to the parameters that please the consumer market.

For the common urea, the irrigation depth of 126.24% ETo provided the highest number of fruits per plant. And for the urea with urease inhibitor, the depth that allowed the greatest response to this variable was the 112% of ETo. In the without nitrogen treatment, the irrigation depth that promoted the best response for all the analyzed characteristics was the equivalent to 118.38% of the ETo. The first two are more efficient in water use because they provide the greatest efficiency in the use of the water applied to the soil.

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