Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v40n4p453-461/2020

DEFICIT IRRIGATION OF SUBSURFACE DRIP-IRRIGATED GRAPE TOMATO

Thaís G. Mendonça[1], Marília B. da Silva[1], Regina C. de M. Pires[2], Claudinei F. Souza[1*]

[1*]Corresponding author. Federal University of São Carlos - UFSCar/ Araras - SP, Brazil.
E-mail: cfsouza@ufscar.br | ORCID ID: https://orcid.org/0000-0001-9501-0794

KEYWORDS

TDR, water resources, irrigation management, water content.

ABSTRACT

Agriculture is one of the segments that most uses water and developments have been made to save irrigation water. Deficit irrigation is a technique that can contribute to production and water saving in agriculture. This study aimed to evaluate the viability of deficit irrigation in tomato production irrigated by subsurface drip in a greenhouse and estimate water saving. The experiment was conducted at the CCA/UFSCar, in Araras, São Paulo, Brazil, with grape tomato cultivation. It consisted of three treatments, 100 % water depth and deficit irrigation (75 and 50 % of water depth), with a randomized block design. Irrigation management was performed using mean soil moisture data collected through TDR probes installed in each treatment. Tomato plants were cultivated for 137 days and conducted vertically with one stem and six bunches. Fruit size, number and mass of fruits per plant, fruit pH and soluble solids were attributes measured and analyzed weekly. The deficit irrigation of 50 % treatment presented lower values in all attributes evaluated and 90.6 % of water saving. The 75 % treatment showed lower value only for pH and fruit diameter and 70.4 % of water saving. Deficit irrigation of 75 % was viable for tomato cultivation in greenhouse and for water saving in crop cycle.

INTRODUCTION

The search for a rational water use has recently intensified mainly because areas in regions that were generally unaffected by water deficiency registered a drop in rainfall levels and reduction in their reservoir levels (Almeida & Benassi 2015). Periods of droughts and floods have become more intense in the last eighty years, being necessary to seek ways to preserve the environment and use water consciously (Dias et al., 2013).

In order to increase productivity and reduce water use, researches on deficit irrigation have been developed. Deficit irrigation is the reduction in water application with the minimum possible impact on production (Padrón et al., 2014). This technique is advantageous where water deficit affects agricultural cultivation, in addition to enabling a lower incidence of diseases by maintaining low moisture around the crops (Geerts & Raes 2009).

Localized irrigation by means of subsurface drip irrigation has also contributed to the production and water use in agriculture. Subsurface drip has been stood out for reducing water evaporation, improving the efficiency of fertilizer application, reducing the total amount of water required, reducing the population of weeds and salt accumulation on the surface, among other advantages (Souza & Bizari, 2018).

When compared to other irrigation systems, subsurface drip has resulted in increased production and water use savings. In an experiment conducted by Enciso et al. (2015) in onion cultivation, subsurface drip resulted in a higher production and water savings of 44 % when compared to furrow irrigation. Leopoldo et al. (2013) obtained higher production of tomatoes with subsurface drip when compared to the cultivation with superficial drip.

The use of deficit irrigation together with subsurface drip irrigation may be viable for areas where water deficit may affect the production of crops that are more demanding in water and with greater phytosanitary risks, such as tomato plants.

Tomato is among the brazilian's most consumed vegetables. In 2017, tomato production was 4.2 million tons, with a cultivated area of 62,200 hectares (Coelho et al., 2018). Tomato is a crop that can be cultivated over the year in the field or in greenhouses. In addition, this crop demands a greater attention due to the incidence of diseases and pests.

[1] Federal University of São Carlos - UFSCar/ Araras - SP, Brazil.
[2] Agronomic Institute of Campinas - IAC/ Campinas - SP, Brazil.

Area Editor: Adunias dos Santos Teixeira
Received in: 8-24-2018
Accepted in: 5-9-2020

Tomato presents a water requirement that corresponds to 90 % of its mass, being determinant for fruit size and quality (Ho et al., 1987). Irrigation with lower water volumes may favor tomato plant production when cultivation is carried out with attention and without damaging the plants. The subsurface drip may also minimize mechanical damage to irrigation system during cultural practices and harvest, reduce disease incidence, and promote water and energy savings over crop cycle.

The hypothesis of this study is that deficit irrigation by means of subsurface drip contributes to water use efficiency (WUE) in grape tomato cultivation and fruit quality. Thus, this study aimed to assess the contribution of subsurface deficit irrigation on productivity and quality of fruits of grape tomato.

MATERIAL AND METHODS

The experiment was carried out in a 6.40 × 20 m simple arch greenhouse, 5 m high and covered with a transparent polyethylene film (150 µm of trickness) installed at the experimental area of the Center for Agricultural Sciences, Federal University of São Carlos (UFSCar), located in Araras, São Paulo State, Brazil. The geographical coordinates are 22°18′ S and 47°23′ W. The average altitude is approximately 600 m.

The predominant soil in the experimental area is a very clayey Red Latosol (Oxisol) according to the brazilian soil classification system (Mendonça et al., 2019). The analyses for characterizing soil physical and chemical attributes (Table 1) were conducted at the Laboratory of Soil Fertility and the Laboratory of Soil Physics of the UFSCar.

TABLE 1. Physical and chemical characteristics of the soil, 0-0.20 m depth.

Parameters	Units	Content
Sand	%	20
Silt	%	19
Clay	%	61
Field capacity	$m^3 m^{-3}$	0.33
Permanent wilting point	$m^3 m^{-3}$	0.17
Total porosity	$m^3 m^{-3}$	0.51
Bulk density	$kg m^{-3}$	1300
Soil particle density	$kg m^{-3}$	2650
Basic infiltration velocity	$cm h^{-1}$	13.20
pH H_2O	-	5.30
Phosphorus	$mg dm^{-3}$	62.00
Organic matter	%	25
Potential acidity	$mmol_c dm^{-3}$	33.00
Potassium	$mmol_c dm^{-3}$	3.70
Calcium	$mmol_c dm^{-3}$	35.00
Magnesium	$mmol_c dm^{-3}$	17.00
Sum of basis	$mmol_c dm^{-3}$	55.60
Cationic exchangeable capacity	$mmol_c dm^{-3}$	88.60
Base saturation	%	63
Sulfur	$mg dm^{-3}$	46.00
Boron	$mg dm^{-3}$	0.21
Copper	$mg dm^{-3}$	3.70
Iron	$mg dm^{-3}$	11.00
Manganese	$mg dm^{-3}$	42.3
Zinc	$mg dm^{-3}$	3.00

The experiment totalized a 137-day tomato crop cycle. It consisted of three treatments: application of a water depth to maintain soil moisture at 100 % of its available water capacity (AWC) (T1); deficit irrigation to maintain soil moisture at 75 % of its AWC (T2); and deficit irrigation to maintain soil moisture at 50 % of its AWC (T3).

Soil tillage was conducted by using a micro tractor with a rotary hoe. Liming was carried out with dolomitic limestone two months before seedling transplantation, as recommended by the Technical Bulletin 100 (Raij et al., 1997).

Twelve 0.30 m thickness beds were constructed in the experimental area. The experimental design was a randomized block design with four replications, totaling 12 plots (Figure 1). Each plot consisted of a 2.7 × 2.0 m (width × length) bed, corresponding to an area of 5.4 m^2. The useful area of each bed considered for the assessments was 2.1 m^2 (Figure 1).

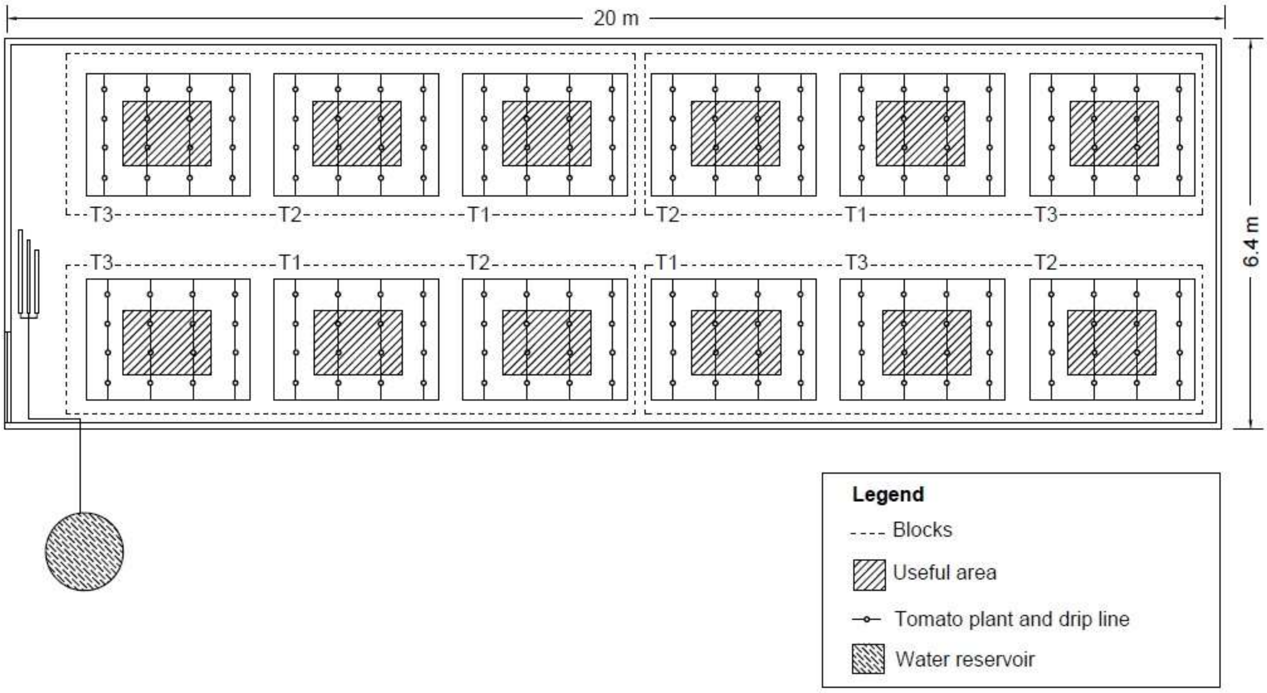


FIGURE 1. Sketch of experimental area with treatments distribution, blocks, useful area of the plots and drip line.

Irrigation was performed by subsurface drip by using drip tubes with non-compensating emitters spaced 0.50 m, flow of 1.6 L h^{-1}, and a service pressure of 100 kPa (Drip Plan, Drip Tech model) as water consumption of each treatment. Four drip tubes were installed 0.70 m apart from each other, at a depth of 0.20 m at each bed with four emitters in each line.

Four 0.20 m TDR probes were installed at each plot, two of them in the layer of 0–0.20 m and the other two in the layer of 0.20–0.40 m, close to two drippers of the useful area. At the ends of the planting rows, two wooden stakes with 2.5 m high and 0.50 m deep were also installed, being tied raffia to tutor and support tomato plants. At the center of the greenhouse, a meteorological station was installed to obtain temperature and relative humidity data throughout the experiment.

Tomato seedlings (*Solanum lycopersicum* L.) variety Milla, group grape were transplanted in the stage of four definitive leaves. These seedlings were transplanted on the drip line, spaced 0.50 m between plants and 0.70 m between rows.

Planting fertilization was carried out with simple superphosphate applied in the seedling pit, avoiding the contact with the roots, and potassium nitrate, applied in half-moon per plant and following the doses according to Raij et al. (1997).

Topdressing fertilization with nitrogen and potassium was divided into six applications and carried out at 22, 41, 60, 78, 102, and 123 days after transplanting (DAT) via fertigation by an injection pump. Potassium nitrate and calcium nitrate was used as nutritional sources.

In order to avoid the clogging of drippers by root intrusion, 0.125 mL of the herbicide trifluralin was injected per emitter at the 18th DAT. No recommendations were found in the literature regarding the volume of trifluralin to be applied in tomato or other vegetables. However, Dalri et al. (2015) and Lima et al. (2014) recommend the application of 0.250 mL per emitter for sugarcane and coffee, respectively. Thus, it was opted to use half of the dose suggested by these authors.

During the experiment, tomato plants were tutored by tying with straps the main stem in raffia at different heights. Plants were also sprouted thinning to keep them with only one stem. At 66 DAT, tomato plants were top lopped to limit plant height and the number of bunches (only six) (Guimarães et al., 2007). Systemic insecticide of the chemical group neonicotinoids (a.i. imidacloprid) and contact and ingestion insecticides of the group pyrethroid (a.i. deltamethrin) were also applied. Weed control was manual.

At the beginning of irrigation management (between 10 and 19 DAT), the effective root depth was considered as 0.10 m and subsequently as 0.30 m.

Regarding soil moisture, the Campbell Scientific* TDR100 was used for reading the probes installed in the useful area of beds. The values of the apparent dielectric constant of soil (Ka, dimensionless) were converted into soil volumetric moisture (θ, m^3 m^{-3}) according to [eq. (1)] (Souza et al., 2017). Readings were performed three times a week and the means of each treatment were considered in the reading of the day.

$$\theta = 5e\text{-}6 \times Ka^3 - 3e\text{-}4 \times Ka^2 + 0.0161 \times Ka + 0.0132 \quad (1)$$

TDR probes also provided the apparent electrical conductivity of soil (EC_{TDR}, dS m^{-1}), which was estimated by [eq. (2)] for the electrical conductivity (EC, dS m^{-1}) adjustment regarding the saturated paste (Souza et al., 2017).

$$EC = 0.0303 + (4.602 \times EC_{TDR}) - (0.07 \times \theta) \quad (2)$$

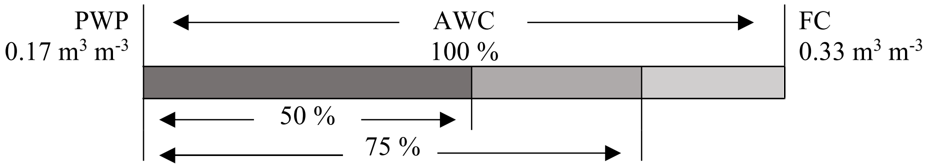
For the irrigation management of tomato plant, the available soil water capacity (AWC) was considered. According to Souza et al. (2016), AWC corresponds to the

* References to trademark does not constitute an endorsement by the authors.

amount of water available in the interval between field capacity (FC) and the permanent wilting point (PWP).

Irrigation management took into account AWC, being soil moisture increased according to the reference moisture of each treatment, i.e. 0.33 for T1, 0.29 for T2, and 0.25 m^3 m^{-3} for T3, corresponding to the restitution of 100 % of AWC and deficit irrigations of 75 and 50 % of AWC, respectively.

The treatment T1 corresponded to 100 % of AWC, the interval between PWP (0.17 m^3 m^{-3}) and FC (0.33 m^3 m^{-3}), i.e. the reference moisture for irrigation management of T1 (θ_{RT1}) was 0.33 m^3 m^{-3}. Proportionally, deficit irrigations were 75 and 50 % of AWC for T2 and T3, respectively (Figure 2).



PWP: permanent wilting point; FC: field capacity.

FIGURE 2. Available water capacity (AWC) scheme in soil experiment and proportion of soil moisture considered for each treatment.

Reference moisture for T2 and T3 was calculated from the available soil water (mm) for T1, as [eq. (3)].

$$AWC = (\theta_{FC} - \theta_{PWP}) \times z \times 1000 \quad (3)$$

Where:

AWC is the available soil water capacity for T1 (mm);

θ_{FC} is the soil moisture in the reference FC for T1 (m^3 m^{-3});

θ_{PWP} is the soil moisture in PWP (m^3 m^{-3}), and

z is the effective root depth (m).

Subsequently, 75 % of AWC for T2 and 50 % for T3 were considered, being these values substituted in [eq. (4)].

$$\theta_{RT} = \left(\frac{WD_T}{z \times 1000}\right) + \theta_{PWP} \quad (4)$$

Where:

θ_{RT} is the volumetric moisture of the reference soil for the treatment (m^3 m^{-3});

WD_T is the treatment water depth (mm);

θ_{PWP} is the soil moisture in PWP (m^3 m^{-3}), and

z is the effective root depth (m).

Reference moisture was 0.29 m^3 m^{-3} for T2 and 0.25 m^3 m^{-3} for T3, with a variation range from 0.17 to 0.29 m^3 m^{-3} and 0.17 to 0.25 m^3 m^{-3}, respectively.

Soil moisture value (θ) from [eq. (1)] was used in [eq. (5)] to calculate the treatment water depth (WD_T) to be applied on the day of reading with the TDR and reapplied the next day. The calculated water depth was divided into three irrigations over the day.

$$WD_T = (\theta_R - \theta) \times z \times 1000 \quad (5)$$

Where:

θ_R is the reference soil moisture for the treatment;

θ is the soil moisture obtained from [eq. (1)], and

z is the effective root depth (m).

At the end of the crop cycle, the total water depth applied to each treatment was obtained from the sum of the water depth applied daily.

Harvest started at 67 DAT and fruits were collected from plants located in the useful area of each bed. Fruits were selected according to their staining, i.e. those that presented a more intense red thus maintaining a pattern for the laboratory analysis of soluble solids and pH.

Quantitative and qualitative attributes of fruits were assessed in relation to the treatments. The quantitative attributes were the number of fruits per plant, average fruit mass, and productivity whereas the qualitative attributes were the diameter, length, soluble solids, fruit pH, and dry mass of leaves and stem. The number of fruits per plant, fruit mass per plant (by means of a precision balance), and fruit diameter and length (by means of a caliper) were assessed at each harvest.

Laboratory analyses were carried out at the Laboratory of Polymeric and Biosolvent Materials of the CCA/UFSCar, being obtained the values of soluble solids (%) with a portable refractometer (model RHB–32ATC) and pH with a bench pH meter (Denver Instrument*, model UltraBasic).

First, samples were divided into quartiles until obtaining smaller samples (approximately four fruits per sample), enough for the analyses. Thus, we worked with four samples and with a random tomato selection. Subsequently, samples were crushed in an IKA* analytical mill (model A11 Basic) at 28000 rpm.

To obtain the soluble solids value, a Pasteur pipette was used to collect part of the crushed material. Approximately three drops of the crushed material were placed on the refractometer slide, which, when directed against the light, allowed the reading of the percentage of soluble solids present in the material.

For pH analysis, the material was diluted to 10%. The procedure consisted of primarily in the analytical weighing of 2.5 mL of the ground material. Subsequently, the material was poured into a 25 mL volumetric flask by using a funnel, being filled with distilled water. The material was deposited in a 25 mL beaker and the pH was measured on a bench pH meter.

At the end of the experiment, tomato plant shoots from the useful area of plots were cut with a pruning shears. Shoots were divided into leaves and stalk (stem + bunch).

The material was weighed on a precision balance and then dried in an Ethik Technology* drying oven (model 400–8D) at 65 °C until constant weight. This material was packed in paper bags during drying.

Water use efficiency (WUE) (estimated in kg m^{-3}) was obtained by dividing the productivity (kg ha^{-1}) of each treatment by the water depth (mm) applied during the cycle.

From the results obtained, an analysis of variance (ANOVA) and a comparison of means with the Tukey's test at 5% significance were performed by means of software R version 3.2.0 (Carvalho et al., 2018).

RESULTS AND DISCUSSION

The average temperature inside the greenhouse during the experiment was 21.6 °C, with a minimum of 11 °C and a maximum of 27.7 °C. The average relative air humidity was 74.5 %, with a minimum of 48 % and a maximum of 97.7 % (Figure 3).

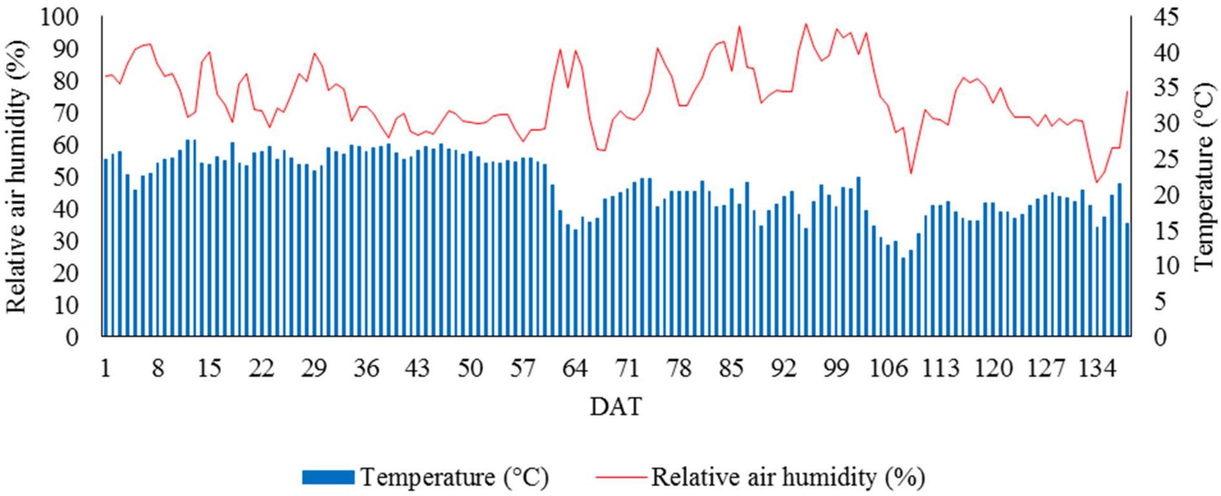
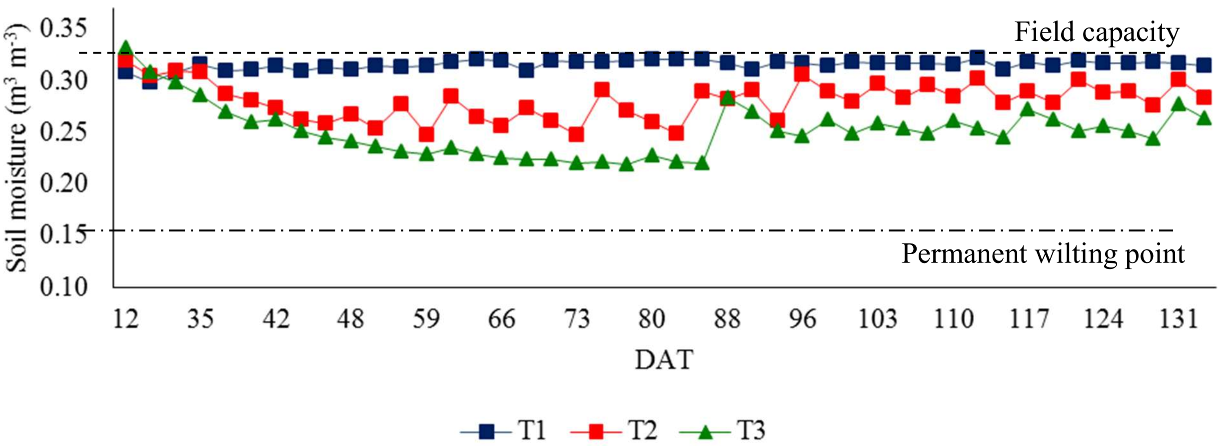


FIGURE 3. Average values of relative air humidity and internal temperature of greenhouse obtained through a weather station throughout the crop cycle.

A great variation of temperature and relative air humidity was observed since the crop cycle covered part of the summer and winter. These climatic factors had no interference with tomato production nor favored pest and disease proliferation that could affect the crop, probably due to the cultivation carried out in a greenhouse and the cultural treatments performed over the experiment.

Figure 4 shows that soil moisture was maintained between the permanent wilting point and field capacity in the layer of 0.20-0.40 m. T2 and T3 presented moisture values above their reference moisture. Water depth application was based on soil moisture readings performed every two days with a TDR, i.e. water depth was reapplied the day after moisture reading and hence soil moisture variation remained temporarily above the reference value, being readjusted from the data of the next reading.

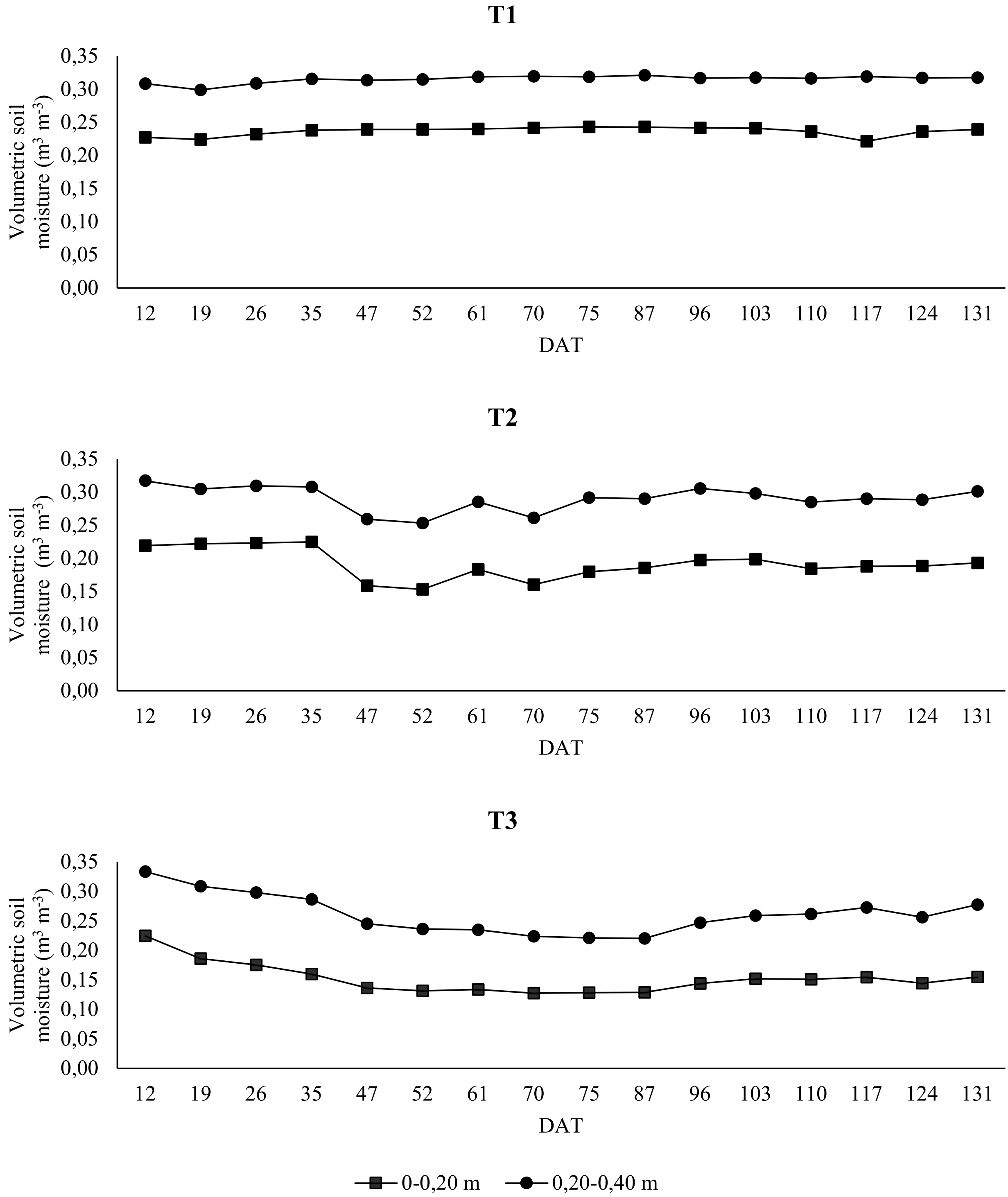


T1: Treatment with 100 % of AWC; T2: 75 % of AWC; T3: 50 % of AWC.

FIGURE 4. Volumetric soil moisture in layer 0.20 m to 0.40 m, obtained through TDR probes along the tomato cycle.

The total water depth applied was 1297 mm in T1, 471 mm in T2, and 234 mm in T3. When comparing the water depths of the deficit irrigation with that of full irrigation in T1, the total water depth in T2 was 36 % and in T2 was 18 % of that applied in T1.

Figure 5 shows the soil moisture profile of the layers 0–0.20 and 0.20–0.40 m. These results show that in the layer of 0–0.20 m, moisture was lower in relation to the layer of 0.20–0.40 m for all treatments. Subsurface drip irrigation allows the wet bulb formation close to the buried emitter and, consequently, makes it difficult the losses by evaporation from the soil surface. In an experiment conducted by Martínez & Reca (2014) with olive trees, subsurface drip resulted in lower evaporation losses when compared to surface drip due to the gravity effect, which caused the water to flow towards the surface more slowly, favoring also a better water redistribution close the root system.



T1: Treatment with 100 % of AWC; T2: 75 % of AWC; T3: 50 % of AWC.

FIGURE 5. Volumetric soil moisture considering the treatments (T1, T2 and T3) and the layers from 0 to 0.20 m and 0.20 to 0.40 m depth.

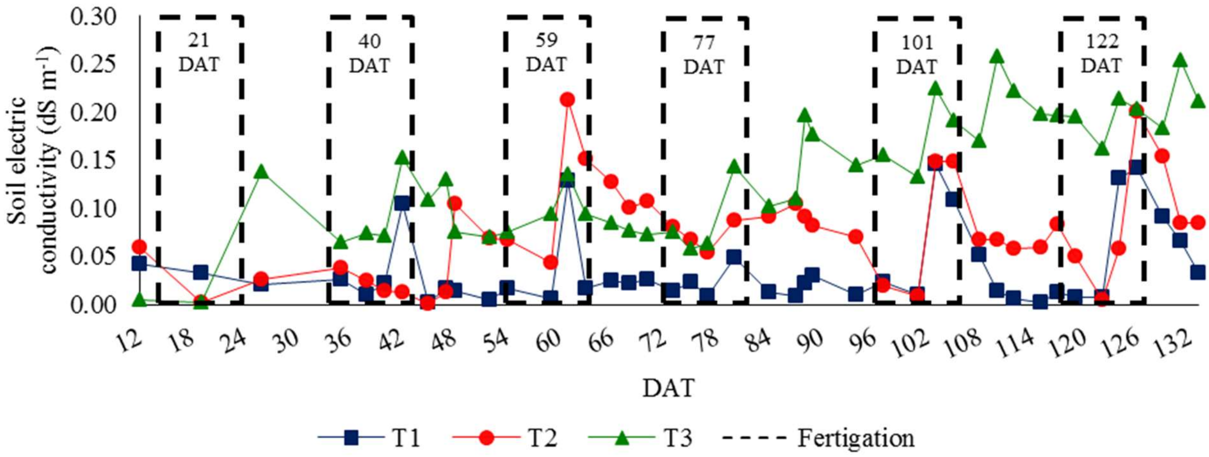
The values of apparent electrical conductivity of soil in the experiment are shown in Table 2. The average electrical conductivity was below the values indicated by Guedes et al. (2015), which is 2.5 dS m^{-1} for tomato crop, being the value unable to reduce crop production.

TABLE 2. Minimum, maximum and average values of soil electrical conductivity (dS m^{-1}) in crop cycle.

	T1	T2	T3
Minimum	0.002	0.002	0.002
Maximum	0.146	0.213	0.258
Average	0.036	0.076	0.134

According to Medeiros et al. (2012), the tomato is a crop sensitive to soil salinity caused by fertilizing salts. When working with six salinity levels in a clay-loam soil (1, 2, 3, 4, 5, and 6 dS m^{-1}), these authors observed a tendency of higher productivity in soils with lower salinity levels and obtained a maximum acceptable salinity of 1.3 dS m^{-1}. Considering the results obtained by Medeiros et al. (2012), the values shown in Table 2 were below the maximum acceptable salinity for all treatments.

Figure 6 shows the values of soil electrical conductivity in the layer of 0.20–0.40 m. T1 presented the lowest electrical conductivity when compared to the other treatments. This is due to the highest water depth applied in this treatment in relation to the other treatments, keeping the concentration due to salt dilution.



T1: Treatment with 100 % of AWC; T2: 75 % of AWC; T3: 50 % of AWC.

FIGURE 6. Soil electrical conductivity in the layer of 0.20 m to 0.40 m along the cycle and periods in which the fertigation was carried out.

Figure 6 also highlights the six days in which the tomato plants were fertigated. The occurrence of peaks in soil electrical conductivity is observed for all treatments soon after fertigation, in addition to a more pronounced tendency in increasing soil electrical conductivity over time in T3 when compared to the other treatments. The lowest applied irrigation water depth explains this behavior in T3 since the applied salts had a greater interaction with soil and a less interaction with soil solution due to the existence of a lower free water content (0.25 m^3 m^{-3}).

The quantitative analysis of tomato plants showed that the deficit irrigation of 50 % of AWC resulted in a reduction in the number of fruits per plant and hence the productivity. Table 3 shows the results of the analysis of variance (ANOVA) and comparison of means. T2 and T3 were statistically different regarding the average number of fruits per plant and T2 presented the highest average among the three treatments.

TABLE 3. Analysis of variance of the number of fruits per plant, mean mass of fruits and yeld and comparison of means by Tukey Test at 5 % significance.

Attributes	T1	T2	T3	p
Number of fruits per plant	94.06 ab	107.40 a	74.94 b	0.0055
Mean mass of fruits (g)	9.04a	7.49b	6.22c	$1.72e^{-12}$
Yeild (kg ha^{-1})	25.04 a	19.37 ab	12.98 b	0.0282

T1: Treatment with 100 % of AWC; T2: 75 % of AWC; T3: 50 % of AWC. Averages with the same letter (in horizontal) do not statistically differ between themselves by the Tukey test ($p < 0.05$).

All treatments differed statistically regarding the average fruit mass. T1 presented the highest mean whereas T3 presented the lowest mean, showing that deficit irrigation resulted in fruits with a lower mass.

The treatment T2 had no effect on tomato productivity, being statistically equal to T1 and T3. However, the average productivity of T1 was higher than T3, i.e. the deficit irrigation of 50 % of AWC reduced the productivity of grape tomato in 48 %.

Ismail & Almarshadi (2013) worked with deficit irrigation in alfalfa cultivation by means of subsurface drip irrigation using Watermark sensors and obtained savings in water use of 13 and 27 % for the treatments of 80 and 75 % of the field capacity, respectively. However, a productivity reduction was observed for both treatments. In this current study, deficit irrigation resulted in smaller water depths in tomato cultivation, but only in T2, no reduction in productivity was observed when compared to T1.

The qualitative analysis of tomato plants showed that T3 differed statistically from T1, except for soluble solids. Furthermore, T2 was similar to T1 for the most assessed parameters. Table 4 shows the results of analysis of variance (ANOVA) and comparison of means of the qualitative analyses. Regarding the fruit size, T2 statistically differed from T1 in fruit diameter and T3 in fruit length. No difference between treatments was observed considering in the percentage of soluble solids.

TABLE 4. Analysis of variance of diameter and length of fruits, soluble solids, pH and dry mass of leaves and stem, and comparison of means by Tukey Test at 5 % significance.

Attributes	T1	T2	T3	p
Fruit diameter (m)	2.12 a	1.95 b	1.87 b	$2.88e^{-12}$
Fruit length (m)	3.34 a	3.16 a	2.89 b	$1.43e^{-10}$
pH	4.14 a	4.10 b	4.12 b	0.000325
Soluble solids (%)	6.93 a	7.11 a	7.19 a	0.1372
Dry mass of leaves (kg)	0.073 a	0.066 a	0.043 b	$2.03e^{-5}$
Dry mass of stem (kg)	0.062 a	0.062 a	0.046 b	0.00581

T1: Treatment with 100 % of AWC; T2: 75 % of AWC; T3: 50 % of AWC. Averages with the same letter (in horizontal) do not statistically differ between themselves by the Tukey test ($p < 0.05$).

A difference was observed in the pH values between treatments, with a higher average in T1. However, no treatment presented values out of the recommended range for tomato. According to Pereira et al. (2018), the pH is an intrinsic factor of tomato capable of affecting the survival or growth capacity of microorganisms. In order to have no interference by bacteria and toxins in the fruit during storage, the pH value should be between 4.0 and 4.5; the obtained results are within this recommended range.

The deficit irrigation in T3 affected leaf and stem dry masses, resulting in smaller fruits, which shows that deficit irrigations using 50 % of AWC affect plant and fruit development.

Water use efficiency (WUE) for T1, T2, and T3 was 0.48, 1.03, and 1.39 kg m^{-3}, respectively. These results show that deficit irrigation increased WUE, but not at the same ratio that the productivity increased since T3 presented the highest WUE and the lowest productivity (Table 3) whereas T2 had the second highest WUE and a productivity similar to T1. Studying the deficit irrigation in alfalfa, Ismail & Almarshadi (2013) observed a reduction in productivity of plants irrigated with 70 and 85 % of the field capacity. However, the reduction in water supply increased WUE and water saving. According to these authors, this indicated that plants used water efficiently.

According to Hatfield & Dold (2019), WUE can be affected by irrigation water lost through drainage, canopy interception, soil type, cultural practices, and variety used. However, it can also increase when working with deficit irrigation. This increase can be observed in the results of T2 and T3, in which we worked with deficit irrigation, being observed an increase in WUE as the lowest water depth was applied during the irrigation. Possibly, subsurface irrigation also contributed to the WUE of treatments because it prevented water loss by evaporation and hence the use of a lower water depth over crop cycle.

WUE is not enough for recommending the use of deficit irrigation in grape tomato cultivation, being necessary to consider other factors that were assessed in our study such as the irrigation method, productivity, qualitative and quantitative attributes of crop and fruit, and water depth reduction. Considering these factors, WUE is more interesting to justify the recommendation in T2, a treatment capable of contributing to the reduction in water use in tomato cultivation and production of grape tomato.

From the obtained results, the use of deficit irrigation of 75 % of AWC is suggested in the cultivation of grape tomato irrigated by subsurface drip irrigation. This treatment was interesting due to the productivity, number of fruits, fruit length, soluble solids, and dry mass of shoot be similar to the results of the treatment with 100 % of AWC, in addition to resulting in the application of 36 % of its water depth. Deficit irrigation in the cultivation of grape tomato is not recommended when 50 % of AWC is used since despite the applied water depth is 18 % of the water depth applied in 100 % of AWC, the results show that this treatment was detrimental to quantitative and qualitative attributes of the crop. Deficit irrigation provided a reduction in water use over crop cycle and an increase in WUE. However, these results, together with the positive aspects that the treatment of 75 % of AWC presented, prove its viability in the cultivation of grape tomato, also contributing to water use reduction in agriculture.

CONCLUSIONS

Deficit irrigation performed by subsurface drip was viable for grape tomato cultivation and reduced water depth over crop cycle. A deficit irrigation of 75 % of AWC with subsurface drip is the most indicated system, resulting in 471 mm of applied water depth, which corresponds to 36 % of the water depth of 100 % of AWC and to a lower water use over crop cycle.

ACKNOWLEDGEMENTS

This work was supported by the brazilians research funding agencies FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) (Contracts # 17/08172-6), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior).

REFERENCES

Almeida DL, Benassi RF (2015) Water and electricity crisis between 2014-2015 in the Southeast. Revista Hipótese 1(2):65-76.

Carvalho RS, Bastos RG, Souza CF (2018) Influence of the use of wastewater on nutrient absorption and production of lettuce grown in a hydroponic system. Agricultural Water Management 203(1):311-321.

Coelho RG, Oliveira FDF, Souza EB, Azevedo JMA, Lima MO (2018) Desenvolvimento e características produtivas de tomate do tipo cereja em diferentes compostos orgânicos. Revista Espacios 39(26):29-41.

Dalri AB, Cruz RL, Faria RT, Azzonetto FM, Corbani RZ (2015) Use of trifluralin to control root intrusion in drippers buried under sugar cane crop. Irriga 20(1):82-91.

Dias MAFS, Dias J, Carvalho LMV, Freitas ED, Dias PLS (2013) Changes in extreme daily rainfall for São Paulo, Brazil. Climatic Change 116(3):705-722.

Enciso J, Jifon J, Anciso J, Ribera L (2015) Productivity of onions using subsurface drip irrigation versus furrow irrigation systems with an internet based irrigation scheduling program. International Journal of Agronomy 2015(1):1-6.

Geerts S, Raes D (2009) Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management 96(9):1275-1284.

Guedes RAA, Oliveira FA, Alves RC, Medeiros AS, Gomes LP, Costa, LP (2015) Estratégias de irrigação com água salina no tomateiro cereja em ambiente protegido. Revista Brasileira de Engenharia Agrícola e Ambiental 19(10):913-919.

Guimarães MA, Silva DJH, Fontes PCR, Caliman FRB, Loos RA, Stringheta PC (2007) Production and flavor of tomato fruits subjected to top-shoot and floral cluster pruning. Horticultura Brasileira 25(2):265-269.

Hatfield JL, Dold C (2019) Water-Use Efficiency: Advances and Challenges in a Changing Climate. Frontiers in Plant Science 10(1):1-14.

Ho LC, Grange RI, Picken AJ (1987) An analysis of the accumulation of water and dry matter in tomato fruit. Plant Cell and Environment 10(2):157-162.

Ismail SM, Almarshadi MH (2013) Maximizing productivity and water use efficiency of alfalfa under precise subsurface drip irrigation in arid regions. Irrigation and Drainage 62(1):57-66.

Leopoldo G, Andreau R, Etchevers P, Zabala SM, Chale W, Etcheverry M, Romay C, Salgado H (2013) Tomato (*Solanum lycopersicum* L.) yield response to water distribution with subsurface and superficial drip irrigation, grown under greenhouse. Revista de la Facultad de Agronomía (La Plata) 112(1):18-26.

Lima PLT, Colombo A, Lima LA, Thebaldi MS, Colares MFB, Gatto RF (2014) Doses and frequency of trifluralin as inhibitor of root intrusion in sub-surface drip irrigation of coffee plants. Irriga 19(1):25-34.

Martínez J, Reca J (2014) Water use efficiency of surface drip irrigation versus an alternative subsurface drip irrigation method. Journal of Irrigation and Drainage Engineering 140(10):1-9.

Medeiros PRF, Duarte SN, Uyeda CA, Silva EFF, Medeiros JF (2012) Tolerance of tomato crop to salinity of soil in protected ambient. Revista Brasileira de Engenharia Agrícola e Ambiental 16(1):51-55.

Mendonça TG, Berça AS, Souza CF (2019) Uso da água em tomateiro cultivado com cobertura morta em casa de vegetação. Revista Brasileira de Agricultura Irrigada 13(1):3236-3246.

Padrón RAR, Ramírez LR, Swarowsky A, Daboín JR (2014) Efecto del riego deficitario y diferentes frecuencias en la producción del cultivo de pimentón. Interciencia 39(8):591-596.

Pereira BM, Bravin GPO, Olivo AM (2018) Controle da qualidade aplicado no setor de hortifrúti de um supermercado como estratégia para atenuação de perdas. Colloquium Exactarum 10(1):27-40.

Raij B, Cantarella H, Quaggio JA, Furlani AMC (1997) Recomendações de adubação e calagem para o Estado de São Paulo. Campinas, Instituto Agronômico/Fundação IAC, 285p.

Souza CF, Faez R, Baccarin MF, Bacalhau FB, Pereira TS (2017) In situ monitoring of a controlled release of fertilizers in lettuce crop. Engenharia Agrícola 37(4):1-10.

Souza CF, Bizari DR (2018) Soil solution distribution in subsurface drip irrigation in sugarcane. Engenharia Agrícola 38(2):217-224.

Souza JM, Pereira LR, Reis EF, Bonomo R (2016) Variabilidade espacial da capacidade de campo e ponto de murcha permanente em argiloso amarelo coeso. Revista Brasileira de Agricultura Irrigada 10(5):875-882.