horticultura brasileira

Research

SANTOS, MA; SILVA, AJP; SANTOS, DB; ALVES, MS; FREITAS, FTO. Water use efficiency of grape tomatoes subjected to different types of substrate, methods of conduction and irrigation management strategies. *Horticultura Brasileira* v.42, 2024, elocation e279426. DOI: http://dx.doi.org/10.1590/s0102-0536-2024-e279426

Water use efficiency of grape tomatoes subjected to different types of substrates, methods of conduction and irrigation management strategies

Moacir A dos Santos[1]; Alisson JP da Silva[1]; Delfran B dos Santos[2]; Marcio da S Alves[3]; Fabio TO de Freitas[4]

[1]IF Baiano, Governador Mangabeira-BA; moacir.santos@ifbaiano.edu.br; alisson.silva@ifbaiano.edu.br; [2]IF Baiano, Serrinha-BA; delfran.batista@ifbaiano.edu.br; [3]IF Baiano, Itaberaba-BA; marcio.alves@ifbaiano.edu.br; [4]Universidade Federal do Recôncavo da Bahia (UFRB), Cruz das Almas-BA; oibaf.freitas@hotmail.com

ABSTRACT

Considering the climate uncertainty, an increase in world population and the need to produce food under low water availability, studies showing alternatives for vegetable production, having in mind the rational use of water, are extremely necessary. The aim of this study was to evaluate the effects of the type of substrate, sprout thinning and irrigation management strategies on water use efficiency (WUE) and grape tomato (*Solanum lycopersicum* L.) yield in a protected environment. Tomatoes were grown with one, two, three and four stems. Additionally, the impacts of "fixed" and "variable" rates of irrigation on the crop productivity and water consumption of the plants were verified. The used substrates were: 100% local soil; 80% local soil + 20% carbonized rice husk; and commercial substrate Carolina Soil XVI®. Plant spacing was 1x0.7 m. The plants were arranged in a completely randomized experimental design in a protected environment. The 3x4x2 factorial scheme (3 substrates, 4 ways of conducting stems and 2 ways of managing irrigation) resulted in 24 treatments and five replications. Water use efficiency and plant yield were evaluated. No difference in the averages of the production variables in relation to irrigation management strategies was observed. The fixed and variable rate of irrigation did not influence productivity, both in mass and number of fruits. However, when grape tomato was grown with only one stem, the production was reduced, compared to the crop grown using two, three and four stems. WUE was 8.9 g/L when the crop was grown with 1 stem; when growing with 2 stems, an increase in WUE was noticed, 30.8% (11.6 g/L); from 1 to 3 stems an increase of 53.4% (13.7 g/L) was noticed, and from 1 to 4 stems, the authors observed an increase of 55.8% (13.9 g/L). An increase in the number of stems per cultivated plant resulted in greater WUE. The types of substrates influenced the total mass obtained; plants grown in commercial substrate showed an average of 14.9 g/L, whereas when growing in soil and mixture of soil + rice husk no significant variations were observed, 10.3 g/L and 10.1 g/L, respectively.

Keywords: *Solanum lycopersicum*, cultural practices, substrate, sprout thinning.

RESUMO

Eficiência do uso da água do tomate grape submetido a diferentes tipos de substrato, formas de condução e estratégias de manejo de irrigação

Diante das incertezas climáticas, aumento da população mundial e necessidade de produzir alimentos sob baixa disponibilidade hídrica, estudos que apontem alternativas para cultivo vegetal com racionalização na aplicação de água tornam-se extremamente necessários. Objetivou-se com o presente trabalho avaliar os efeitos do tipo de substrato, desbrota e estratégias de manejo de irrigação na eficiência do uso da água (EUA) e rendimento de frutos do tomate "grape" (*Solanum lycopersicum* L.) em ambiente protegido. Cultivou-se o tomate conduzido com uma, duas, três e quatro hastes. Adicionalmente, verificou-se as implicações do manejo de irrigação com turno de rega "fixo" e "variável" na produtividade e consumo hídrico da cultura. Os substratos utilizados foram: 100% de solo local; 80% de solo local + 20% de casca de arroz carbonizada; e substrato comercial Carolina Soil XVI®. As plantas foram dispostas em espaçamento de 1x0,70 m e distribuídas em delineamento experimental inteiramente casualizado. O esquema fatorial 3x4x2 (3 substratos, 4 formas de condução de hastes e 2 formas de manejar a irrigação) resultou em 24 tratamentos e cinco repetições. Avaliou-se a EUA e o rendimento das plantas. Os resultados obtidos indicam não haver diferença nas médias das variáveis de produção em função das estratégias de manejo de irrigação. O turno de rega fixo e variável não influenciou nas variáveis de produtividade, tanto em massa como em número de frutos. Já quanto à forma de condução, verificou-se que conduzir o tomate grape com apenas uma haste diminuiu a produção, comparativamente à condução com duas, três e quatro hastes. Ao cultivar-se com 1 haste obteve-se a "EUA" de 8,9g/L; elevando-se para 2 hastes houve um incremento de 30,8% (11,6 g/L) na "EUA"; já de 1 para 3 hastes a elevação é de 53,4% (13,7 g/L) e de 1 para 4 hastes o acréscimo é de 55,8% (13,9 g/L). O aumento no número de ramos por planta cultivada implicou em maior "EUA". Os tipos de substratos influenciaram a massa total de tomate obtida. As plantas cultivadas em substrato comercial apresentaram média de 14,9 g/L, enquanto o cultivo em solo e mistura de solo + casca de arroz não apresentaram variações significativas, sendo 10,3 g/L e 10,1 g/L, respectivamente.

Palavras-chave: *Solanum lycopersicum*, tratos culturais, substrato, desbrota.

Received on December 17, 2023; accepted on April 5, 2024

Water is one of the most precious resources. Brazil is the Country with the largest freshwater reservoir worldwide. Water availability is not uniform among the regions in the Country, though. Due to climate uncertainty and accelerated degradation of natural resources, water, this essential resource for life on Planet, is threatened since it is indispensable for performing various activities, such as agricultural, industrial, domestic, fishing, also tourism, navigation and electricity generation. Considering these activities, irrigated agriculture stands out, being the productive sector widely known as the one which demands the greatest world water resources. Approximately 70% of all freshwater withdrawals, surface water and groundwater, is used for irrigated agriculture (Dehghanipour *et al*., 2020). Given the above, studies aiming to contribute to the improvement of techniques for reducing irrigation water consumption, keeping or increasing crop productivity, are necessary (Costa *et al*., 2019a, 2020a; José *et al*., 2020; Quiloango-Chimarro *et al*., 2021).

An appropriate irrigation use depends on specific technical procedures, commonly called irrigation management, which is supposed to inform the operating time of the motor pump and/or the amount of water to be applied to the plants. When no irrigation management is used, crop productivity is compromised, due to an excess or lack of available water for the plant. The farmer tends to apply greater amount of water than necessary, depleting the soil water storage capacity, favoring percolation, nutrient losses through leaching and productivity reduction (Gava *et al*., 2016; Costa *et al*., 2018; 2020b; Quiloango-Chimarro *et al*., 2022; Almeida *et al*., 2022).

Irrigation management consists of determining the time, amount and how to apply water to crops, taking into consideration other aspects of productivity system such as phytosanitary control, meteorological, economic, soil and climate conditions and crop management strategies. Irrigation managements are based on atmospheric, soil and plant variables or the combination of them. These three ways contribute to an appropriate water use, considering the use of specific equipment, being chosen in relation to the conditions of the rural producer, such as physical conditions (soil, weather and water availability), plant, technical training and investment (Costa, 2019, 2023).

Irrigation management via soil involves to irrigate or not the crop, monitoring content, storage, tension or soil water availability. In order to obtain these variables, electronic sensors are becoming increasingly accessible and advantageous, allowing automatic measurements and also enabling the automation of systems judiciously.

Many studies on irrigation management techniques can be found in literature. These techniques intend to make the agricultural water use more efficient (Brito *et al*., 2012; Zoz, 2015; Blatchford *et al*., 2018), grow more food using less water (Tuong & Bhuiyan, 1999; Tabbal *et al*., 2002; Favati *et al*., 2009; Hooshmand *et al*., 2019), or improve water use efficiency (Heydari, 2014; Bogale *et al*., 2016; Nangare *et al*., 2016). The current concern in ensuring more production per volume of water, applied via irrigation, derives from the increase in demand for food and the need to conserve natural resources, with the technologies used in irrigation management (Brito *et al*., 2012; Christofidis, 2013; Mantovani *et al*., 2013).

A good water management plan for an irrigated crop shall not only consider the irrigation systems, but also the plants and soil, such as the various sprout thinning techniques and substrates which can influence water demand and irrigation frequency. Plants grown with different number of stems can present different leaf areas, which may affect transpiration and, consequently crop water demand. On the other hand, the source material of a substrate characterizes water retention in the region of the soil explored by the roots, as well as the frequency of irrigation (Chaves *et al*., 2021; 2022; José *et al*., 2019; Tapparo *et al*., 2019; 2022; Costa *et al*., 2015; 2019b; 2020c; Almeida *et al*., 2022).

Studies on variables related to efficiency and consumption of water in grape tomato crop are of great importance for tomato farming, considering that this small and sweet fruit has been more and more consumed lately, being an excellent choice to be grown, since allows early harvest (Abrahão *et al*., 2014; Vieira *et al*., 2014; Negrisoli *et al*., 2015; Eisele *et al*., 2022).

Tomato production has grown significantly over the last years. This tasty fruit can be easily found in the market; it has become popular and has been chosen by customers and farmers, due to these facts, such as earliness production, excellent added value, constant demand, unique flavor, durability of conservation and gastronomic versatility. Therefore, studies on grape tomato cultivation, taking into account the variables which can influence the productivity of the crop, are extremely important and necessary. The results shall allow recommendations on better management techniques for growing tomatoes, helping out farmers for choosing the best management technique (Espindula, 2002; Marouelli *et al*., 2014; Silva *et al*., 2017).

Given the above, this study aims to search how the effects of the types of substrate, sprout thinning and irrigation management strategies can affect water use efficiency and fruit yield concerning the grape tomato (*Solanum lycopersicum* L.) cultivation, drip irrigated, in a protected environment.

MATERIAL AND METHODS

The experiment was carried out at Instituto Federal Baiano (IF Baiano), in the municipality of Governador Mangabeira-BA (12º36'7"S, 39º2'34"W, 215 m altitude). The crop was grown in a greenhouse, arch type, 170 m². Rows of grape tomatoes were planted in a pest-free, rain-protected environment, 1x0.70 m spacing, 24 treatments and 5 replications, totalizing 120 plots. The experimental design used was randomized blocks, in a 3x4x2 factorial scheme. The plants were grown in 8-liter pots. A self-compensating dripper was installed in each pot (flow of 3.6 liters/hour – Irritec). The plants were fertigated with nutrients (macro and micronutrients) using synthetic fertilizers. The nutrients supplied during the "development" vegetative phase and "fruiting" are: N (111.95 and 164.10), P (61.99 and 93), K (156.11 and 371.27), Ca (80.06 and 108), Mg (23.54 and 33.30), S (47.96 and 64.67), B (0.221 and 0.3247), Cu (0.0325 and 0.045), Fe (2.00 and 2.00), Mn (1.18 and 1.75), Mo (0.0612 and 0.0612) and Zn (0.262 and 0.262), the amount of the nutrients presented above refer to g/1000 L water.

This study aimed to evaluate effects of irrigation frequency ("fixed" and "variable"), sprout thinning (plants with 1, 2, 3 and 4 stems) and substrates (commercial, 100% local soil and 80% local soil + 20% carbonized rice husk).

The experiment was carried out aiming to contribute to best agricultural water management practices in grape tomato Mascot F1, and also to identify the crop productivity variations in relation to the conduction model adopted in this study, the substrate used in crop and local irrigation management.

Tomato seedlings were sown in plastic trays. Sowing was carried out on April 2, 202; the seeds were planted at 0.5 cm depth. Definitive planting was performed 28 days after sowing with 48-cm high plants with 4-6 developed leaves.

The local soil was collected from the agricultural area of IF Baiano, Governador Mangabeira Campus and was classified, according to Sistema Brasileiro de Classificação de Solos [Brazilian Soil Classification System (SiBCS)], as Yellow Latosol, sandy clay loam (17.3% silt, 56.5% sand and 26.2% clay), pH 6.8, organic matter content 1.7%, CTC (T) 10.4 and appropriate macronutrient contents. The substrate Carolina soil class XVI contains peat, vermiculite and limestone. It also presents pH 5.5, electrical conductivity 0.7 mS/cm, maximum humidity 60% m/m, dry density 130 kg/m³. Hydraulic properties of the tested substrates were checked out for determining soil matrix potential (ψ) using the amount of water in soil (θ). An experiment on evaporation was carried out in order to obtain hydraulic properties through the inverse method using HYDRUS – 1D software, version 4.16.0110, (Simunek *et al*., 2013).

The variations in substrate water content were measured automatically using TDR probes (Time Domain Reflectometer, Campbell Scientific - Logan, Utah) at 15 min intervals. Water evaporation was quantified using the variation in the mass occurred inside the container, at 15 min intervals, with the aid of 60-kg and 120-kg capacity scales Alfa Instruments, bpth accurate to 0.02%.

The data obtained from the variation in substrate water content and evaporation were inserted in the HYDRUS-ID software to solve Richards' equation (Richards, 1931) in order to compute the soil water flow. For describing soil water retention and soil water conductivity curves, the authors used Mualem-Van Genuchten model (Mualem, 1976; Van Genuchten, 1991).

HYDRUS 1D software determines soil hydraulic parameters (θ_r, θ_s, α, n, **λ** and Ks) through the minimization between the variables "θ" or "h" observed and simulated in space and time. For this purpose, we used the total of the differences obtained between the observed and simulated values of θ or h, which shall be expressed using an objective function (Φ) (equation 1):

$$\Phi(\theta,\beta) = \sum_{j=1}^{m}\sum_{i=1}^{nj}\left[\theta_{TDR,j}(z_i,t_i) - \theta_{EST,j}(z_i,t_i,\beta)\right]^2$$

Cultural practices began at sowing. On the transplanting day, apical pruning was performed in order to stimulate side shoots, except for the plants conducted with only one vegetative stem.

Branches were managed by strings, by thinning the excess of shoots, and nutrition through fertigation and manual pollination.

Plants were irrigated using GS1 sensors (Decagon Devices, Inc., Hopkins CT, Pullman, USA) which, using an electrical signal, allow to determine the time and amount of water to be used for irrigation. At the fixed frequency, irrigation was activated when humidity reached the critical point (measured at 9 a.m.) and switched off when field capacity was reached. At the variable frequency the activation was carried out at any time of the day, as the substrate reached the humidity at the critical point (lower limit) (humidity of 0.3080 cm³/cm³ for soil, 0.2729 for soil + rice husk mix and 0.3577 for commercial soil), according to the reading of electrical sensors and, switched off when the field capacity reached humidity of 0.4454 cm³/cm³ for the soil, 0.4634 for soil + carbonized rice husk and 0.5473 for the commercial substrate. At fixed frequency, irrigation was activated every day at a fixed time (9 am), with a 24-hour "watering shift" between irrigations.

Thirty three days after the first flowers opened, the first ripe fruit appeared. Riped fruits were harvested once a week, being the first harvest on April 26, 2022. All the production was counted and weighed using a precision scale. The collected data during harvest were entered into a spreadsheet for analysis, for calculating water use efficiency (WUE) and fruit yield.

The number of fruits per plant was determined by counting the fruits of all the harvests of each treatment; fruit mass was determined by the sum of the weight of fruits of all the harvests of each treatment.

The irrigation WUE was determined by the ratio between production of fruits per plant (PFP, kg/plant) and the volume of water applied per plant (VAP, liter/plant), according to equation 2:

$$WUE\ (kg/liter) = \frac{PFP}{VAP}$$

For each type of managing, a value of WUE was determined, totalizing four values in relation to the number of stems used in each way of cultivation. Thus, WUE represents a response related to variation sources used in the experiment. The number of stems was a variation source used to study the influence of the stem in WUE of the tomato crop.

The obtained data were submitted to the variance analysis and average Tukey test ($p<0.05$) in order to identify the effect and the interaction of each factor.

RESULTS AND DISCUSSION

The lowest values related to number of fruits were verified in plants grown in pots filled with local soil (Table 1). When tomato was grown in soil + rice husk and in commercial substrate, the production (number and mass of fruits) did not change. When the plants were grown in soil, each plant produced an average of 255 fruits; when the plants were grown in soil + rice husk mix and commercial substrate, each plant produced an average of 322 and 338 fruits, respectively.

Table 1. Number of fruits obtained in tomato crop with different number of stems and types of substrates. Governador Mangabeira-BA, IF Baiano, 2022.

Type of substrate	N° of stems			
	1	2	3	4
100% soil	173a A	207ab A	313 bc A	327c A
80% soil + 20% rice husk	191a A	311b AB	377b A	407b A
Commercial substrate Carolina soil	240 a A	391 b B	347ab A	376 b A

*Averages followed by same lowercase letters in the lines do not differ from each other by Tukey test ($p<0.05$). Averages followed by the same uppercase letter in the columns do not differ from each other by Tukey test ($p<0.05$).

The substrate selection interferes with fruit production, especially due to the physical nature of the materials: density, porosity, water retention. The soil was placed in pots at an average density of 1.10 g/cm^3 and porosity of 32%. For the soil mixed with rice husk, after being placed in pots, the average density verified was 0.80 g/cm^3 and 42% porosity, whereas for the commercial substrate, the density was 0.13 g/cm^3 and porosity of 88%. The percentage of rice husk added in soil provided positive characteristics which were not in the soil: raised porosity and increased the substrate density favoring the distribution of water and nutrients in the root system, providing a suitable condition to develop the roots surrounded by a loose, uncompacted substrate. These characteristics were also presented in the commercial substrate.

When carbonized rice husk was added to the substrate, the beneficial effect is related to its physical characteristics which provide good drainage, low density and consequently, greater water retention capacity (Freitas *et al.*, 2013; Simões *et al.*, 2015).

Evaluating the effect of different methods for conducting stems for fruit production, we verified some differences in production. When the crop was grown with one stem, the lowest production was observed (Tables 1 and 2).

Plants conducted with more than one stem showed better results than plants grown with only one stem. This result can be justified by the greater number of stems and leaves, which favored an increase in photosynthetic activity and energy production. That means, a larger, well-nourished canopy, with an appropriate supply of water and light, generally allows greater production of flowers and fruits. The adopted spacing (0.7x1.0 m) provided sufficient space to develop all the stems.

The two irrigation management methods evaluated in this study did not influence significantly the production obtained in this experiment.

The obtained results showed that the watering shift (“fixed” and “variable”) did not influence the productivity, both mass and number of fruits. Based on the results, the authors noticed that in the two managements the evaluated substrates stored and retained sufficient water available to plants during irrigation intervals.

Both, in the variable and fixed rate irrigation, the available water to plants was constant, allowing development, nutrient translocation and production of flowers and fruits. The water was always available between lower limit and field capacity, due to real time monitoring, activating irrigation whenever humidity reached its critical value for the crop.

Table 2. Fruit mass (g) obtained in tomatoes with different number of stems grown in three different types of substrates. Governador Mangabeira-BA, IF Baiano, 2022.

Type of substrate	N° of stems			
	1	2	3	4
100% soil	1126a A	1355ab A	2040c A	1941bc A
80% soil + 20% rice husk	1243a A	1748ab AB	2065b A	2231b A
Commercial substrate Carolina soil	1540a A	2260b B	1937ab A	2023ab A

*Averages followed by same lowercase letters in the lines do not differ from each other by Tukey test ($p<0.05$). Averages followed by same uppercase letters in the columns do not differ from each other by Tukey test ($p<0.05$).

Although the rate of irrigation frequency does not cause significant differences in production, combined with the substrate, it implies relevant differences in water consumption. In the fixed irrigation frequency, carbonized rice husk substrate added to the soil, consumed approximately fewer than 80 liters water per each plant in relation to the same substrate in the variable frequency. In the soil, the fixed frequency also presented an advantage, since commercial substrate was advantageous and appropriate in variable frequency, saving approximately 20 liters per plant.

Based on the information obtained in this study, the authors could observe that the evaluated irrigation frequencies did not show any significant differences in relation to production parameters (number and mass of fruits), nevertheless these frequencies should be considered when it comes to water use efficiency. Irrigation management via soil promoted satisfactory results since it was easy to perform and also due to its data accuracy, allowing the producer to choose this management and tools (sensors) in his/her rural enterprise. In this case, the producer should accurately evaluate his/her work situation and economic reality to decide which frequency best suits.

The increase in number of stems per plant resulted in an increase of WUE (Figure 1). For each additional stem, the production increased 1.7 g for each liter of water. The average WUE of the experiment was 12 g/L with a range of 5 g/L, cultivation with 1 to 4 stems.

This result is justified by the higher productivity (13.9 g/L) obtained in plants with compound stems (4 stems), considering that the higher the yield, the higher the value of the numerator, consequently presenting a higher WUE. When just one stem was used, WUE was significantly reduced (8.92 g/L).

Perry *et al*. (2009) stated that the crops, environment and different management practices may influence the relationship between the agricultural production and water consumption. Thus, conducting plants with more stems, makes it possible to increase the production, without, necessarily, increase the volume of water to be used, providing, this way, an increase in WUE. According to Perry *et al*. (2009), any strategy to increase the harvested yield grown in irrigated substrates, also increase the irrigation water efficiency. Adopting management with composting stems, proof the efficiency of this strategy, producing more without using more water. An increase in mass in more than 600 g/plant using the same amount of water is quite possible using the conducting management with four stems.

The results showed that through the management of grape tomato stems it is possible to produce more using the same amount of water or obtaining the same production saving up water. Practically speaking, we consider that conducting a production with four stems instead of one, using one of the substrates analyzed (commercial), which consumed an average of 138 liters/plant, a saving of 49.5 liters of water per plant can be achieved and, converting this to one hectare, the savings exceed 700 thousand liters of water. For each additional stem, 16 liters of water per plant can be saved, without yield loss.

Increasing from three to four stems resulted in a quite small variation in the increase of WUE, according to Figure 1. The quadratic model explained the variation of WUE in relation to the number of stems evaluated in this study (1 to 4). The model obtained was well adjusted, since it showed R^2 of 99.6%, explaining a significant fraction ($p<0.05$) of the effect of the total variation in the number of stems on the response variable WUE. Cultivation with 1 stem showed WUE of 8.92 g/L, using 2 stems an increase of 30.78% (11.67 g/L) in WUE, using 3 an increase of 53.39% (13.68 g/L) could be noticed, and using 4 stems an increase of 55.82% (13.90 g/L) was verified. The difference in PA when cultivation was carried out changing 3 to 4 stems was only 2.4%, a small increase when compared to the difference between 2 to 3 stems, an increase of 22.61%.

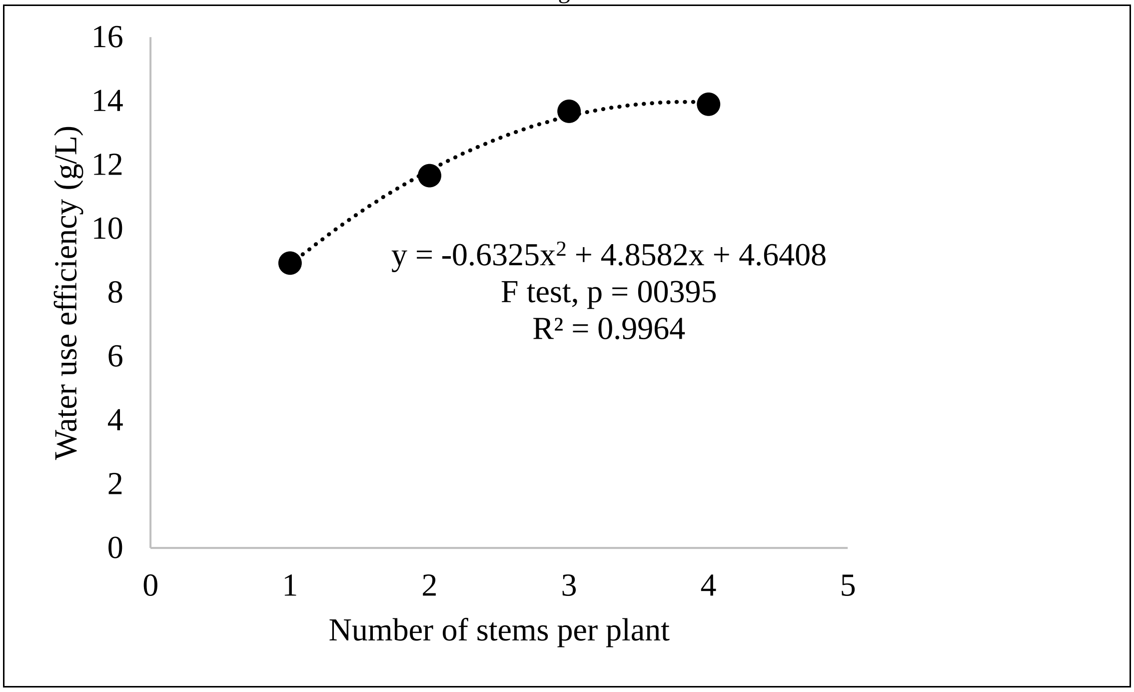

Figure 1. Water use efficiency in grape tomato cultivation in relation to the number of stems per plant. Governador Mangabeira-BA, IF Baiano, 2022.

Molden *et al.* (2003) states that WUE depends on many variables, including the crop genetic material, water management and agronomical practices. The gains in cultivation may be maximized using the stem conduction management strategy, taking into consideration spacing, which allows the development of all the stems, avoiding unnecessary energy use.

In crops in which fixed-frequency irrigation was evaluated, the total volume of water applied per plant was an average of 147 liters. In crops in which varying irrigation frequencies was tested, 173 liters per plant of water was applied. We observed that for a few days, especially those warmer days, the automatic system installed in the varied management condition was activated more than once a day as a result of the high-intensity water extraction by the plants and the programming to keep optimal substrate moisture levels. As a result, the number of irrigation events in the automatic system was greater. However, this difference in the volume of water applied as a result of different ways of management did not affect the WUE values. Fixed-frequency irrigation management presented WUE 12.06 g/L and with variable-frequency irrigation management 12.07 g/L. Viol *et al.* (2018), testing different irrigation depths and frequencies in the cultivation of Sweet Grape tomatoes in a greenhouse, found that the irrigation frequency did not influence any of the evaluated traits (mass and number of fruits), but the interaction depth versus frequency significantly affected water consumption, directly interfering with WUE values.

Martin *et al.* (2012) observed that higher WUE was reached with lower irrigation depths, being a good alternative to administrate water resources and that can be used in situation of water limitation. The authors highlight that minimizing water supply can result in minimal yield reductions, which are insignificant when compared to WUE gain.

Monte *et al.* (2013) report that the same commercial fruit production may be obtained reducing the water depth up to 40%, larger water depths promote greater water and energy consumption, without providing a significant increase in tomato commercial productivity. Therefore, increasing the water depth supplied does not significantly mean that fruit production will be increased.

Reaching high WUE is directly linked to two factors: (i) knowledge of the water holding capacity of the substrate; and (ii) the plant's ability to resist water depletion in soil. For this purpose, technical knowledge and appropriate management are necessary in order to avoid subjecting the plant to water stress, compromising its yield and consequently lowering WUE levels. We also shall take into consideration that excessive irrigation results in water waste, an increase in production costs and inappropriate management of available water resources.

Martin *et al.* (2012) highlighted that the deficit irrigation strategy can be an alternative to increase WUE, maintaining economic viability. This strategy needs more studies concerning different situations and different crops, though.

The irrigation frequency factor did not affect the final WUE result. However, the authors highlight that the study carried out experiments with irrigation frequency between 1 and 2 times a day; any variation below or above these values may compromise the productive result of the crop and WUE values. Adopting fixed frequencies greater than one day will greatly modify the water characteristics of the substrate, compromising its friability point, nutrient absorption, stomatal activity, among others, in addition to encouraging the plant to reach the wilting point before a new irrigation.

Managing irrigation with a fixed or variable frequency (12.06 g/L and 12.07 g/L) did not affect WUE result in the cultivation of Grape tomatoes in a greenhouse. Fixed-frequency irrigation, with a 24-hour interval between irrigations, with water supply at the beginning of the day (9 am), showed satisfactory results, as well as those obtained with variable frequency. We restate that although the irrigation schedule is fixed, it is important to take into account the irrigation schedule. Irrigating before sunlight avoids greater water losses through evaporation, consequently, reducing the risk of the plant suffering water stress, considering that moisture loss through evapotranspiration at high temperatures is greater.

In relation to substrates, we observed that WUE was superior in crops in which commercial substrate was used. This is due to the lower total volume of water applied in irrigation of crops in commercial substrates (138 L/plant), whereas in soil the volume was 156 L/plant and in the soil + rice husk mixture it was 187 L/plant.

Lima *et al*. (2012) highlighted that irrigation using lower water volume is considered efficient to increase WUE for many crops without resulting in serious reductions in yields. However, irrigation reduction shall be technically calculated, to avoid compromising vital functions of the plant, since keeping a plant in water stress compromises development and production.

The decrease in WUE values with an increase of the applied irrigation depth is a result of the reduction in the rate of water use by the tomato plant, taking into account the losses occurring in the system as the application of this resource increases.

The physical, chemical and biological properties of substrates directly impact the water retention and storage capacity and root development, influencing drainage, plant water availability, evaporation and consequently the water consumption and productive potential of plants.

According to Portela *et al*. (2001), an increase in substrate density allows lower water retention, due to porosity reduction (macroporosity). The mentioned authors also observed that an increase in substrate density provides lower water amount available in the systems. Thus, the commercial substrate showed to have the best characteristics related to retention and content of water available in relation to the other tested substrates. The commercial substrate has superior characteristics related to soil and the mixture rice husk + soil for porosity and density.

In relation to water retention capacity, the commercial substrate showed superior properties when compared with the others, it offered the plants better water access. The humidity of the commercial substrate is higher, both in lower and upper limits.

The soil and soil substrates mixed with rice husk did not show a significant effect on each other, with WUE of 10.3 g/L and 10.9 g/L, respectively. However, the commercial substrate differed significantly from the others, with WUE of 14.9 g/L. Testing new proportions and different mixtures in relation to the soil is essential, in order to analyze new conditions to increase yield and WUE.

In quantitative values, the commercial substrate presented 1 kg of fruit produced, for every 67.11 liters of water, whereas in the soil and in the soil + rice husk mixture, 97.08 L/kg and 99.10 L/kg were consumed, respectively. The commercial substrate saved approximately 31 liters of water (46%) for each kg of grape tomatoes produced.

According to Molden *et al*. (2010), practices which are not directly related to water management impact the water efficiency use due to interactive effects, such as the ones derived from soil fertility improvement, pest and disease control, selection of cultivars or access to better markets.

Improving water resource use efficiency contributes socioeconomically to the lives of the local and global population and, above all, advances in increasing WUE provide environmental preservation.

For Molden (1997), in an environment of increasing water scarcity and competition, increasing WUE is the most important goal of the Consultative Group on International Agricultural Research (CGIAR) in order to increase agricultural productivity, protect the environment and reduce poverty. Substantially increasing WUE used in agriculture is essential to achieve food and environmental security goals (Molden *et al*., 2003).

Improving WUE aims to produce more food, income, better livelihoods and ecosystem services (Molden *et al*., 2010). Studies aiming to increase PA besides enabling the rational use of water, makes it possible to reduce social inequality, manage and conserve soil and water sources, making better use of these resources.

More studies on grape tomato cultivation are important, especially the ones related to irrigation management. The authors look forward to investments on grape tomato research, as information on this crop is still scarce in literature.

Cultivation in a protected environment is a technology which is becoming more and more popular each day. This cultivation system is essential to increase WUE, avoid losses due to pests, disease, weather and mechanical damage. It is pretty important in order to increase “water productivity”, in addition to environmental and financial gains acquired without the use of pesticides.

When the appropriate irrigation management technique is applied, we noticed that the use of 1 to 4 stems resulted in an increase of water use efficiency (g/L).

In the three types of substrates, plants conducted with one stem showed lower production when compared to other conductions. Conducting plants with composting stems is a satisfactory and necessary alternative, combining higher income with high WUE.

Tomato production was greater when plants were grown with 2 stems in commercial substrate.

Managing irrigation via water sensing in soil at a fixed or varied frequency does not imply a distinction in the production of grape tomatoes and cultivating in a protected environment and pots proved to be an excellent alternative, as well as the spacing adopted proved to be satisfactory.

This study highlighted how substrates and their characteristics influence the yield and WUE. However, the rural producer, entrepreneur or researcher can use the 3 substrates, making a careful analysis of their work reality and the available inputs.

ACKNOWLEDGMENTS

The authors thank to Agristar do Brasil for making available the seeds, and to Instituto Federal Baiano and to Coordenação do Mestrado Profissional em Ciências Ambientais (Coordination of Professional Master in Environmental Science) for all the suport granted.

REFERENCES

ABRAHÃO, C; BÔAS, RLV; BULL, LT. 2014. Relação K: Ca: Mg na solução nutritiva para produção de minitomate cultivado em substrato. *Irriga* 214-224.

ALMEIDA, AM; COELHO, RD; BARROS, THS; COSTA, JO; CHIMARRO, CAQ; PIZANI, MAM; RAMÍREZ, AJF. 2022. Water productivity and canopy thermal response of pearl millet subjected to different irrigation levels. *Agricultural Water Management* 272: 107829.

ALMEIDA, IA; COLOMBO, A; ARAÚJO, ACS; ALMEIDA, RA; COSTA, JO; CHIMARRO, CAQ. 2022. Energy consumption reduction of a center-pivot with the use of a variable-frequency drive. *Revista Brasileira de Engenharia de Biossistemas* 16.

BLATCHFORD, ML; KARIMI, P; BASTIAANSSEN, WGM; NOURI, H. 2018. From global goals to local gains-A framework for crop water productivity. *ISPRS international journal of geo-information* 7: 414.

BOGALE, A; NAGLE, M; LATIF, S; AGUILA, M; MÜLLER, J. 2016. Regulated deficit irrigation and partial root-zone drying irrigation impact bioactive compounds and antioxidant activity in two select tomato cultivars. *Scientia Horticulturae* 213: 115-124.

BRITO, LTDL; CAVALCANTI, NDB; SILVA, ADS; PEREIRA, LA. 2012. Produtividade da água de chuva em culturas de subsistência no semiárido pernambucano. *Engenharia Agrícola* 32: 102-109.

CHAVES, SWP; COELHO, RD; COSTA, JO; TAPPARO, SA. 2021. Micrometeorological modeling and water consumption of tabasco pepper cultivated under greenhouse conditions. *Italian Journal of Agrometeorology* 1: 21-36.

CHAVES, SWP; COELHO, RD; COSTA, JO; TAPPARO, SA. 2022. Vegetative and productive responses of tabasco pepper to fertigation and plastic mulching. *Scientia Agricola* 79.

CHRISTOFIDIS, D. 2013. Água, irrigação e agropecuária sustentável. *Revista de Política Agrícola* 22: 115-127.

COSTA, JO. 2019. Spatial variability of water consumption of irrigated crops using remote sensing [Ph.D. Thesis]. *University of São Paulo*.

COSTA, JO; ALMEIDA, AN; COELHO, RD; FOLEGATTI, MV; JOSÉ, JV. 2015. Estimation models of micrometeorological elements in a protected environment. Water Res. *Irrigation Management* 4: 25-31.

COSTA, JO; COELHO, RD; BARROS, THDS; JÚNIOR, EFF; FERNANDES, ALT. 2018. Physiological responses of coffee tree under different irrigation levels. *Engenharia Agricola* 38: 648–656.

COSTA, JO; COELHO, RD; BARROS, THS; FRAGA JUNIOR, EF; FERNANDES, ALT. 2019b. Leaf area index and radiation extinction coefficient of a coffee canopy under variable drip irrigation levels. *Acta Scientiarum* 41: 1-8

COSTA, JO; COELHO, RD; BARROS, THS; FRAGA JÚNIOR, EF; FERNANDES, ALT. 2020b. Canopy thermal response to water deficit of coffee plants under drip irrigation. *Irrigation and Drainage* 69: 472–482.

COSTA, JO; COELHO, RD; BARROS, THS; FRAGA JUNIOR, EF; FERNANDES, ALT. 2020c. Tensiometry applied in the estimation of the water consumption of the coffee tree irrigated by drip irrigation. *Revista Geama* 6: 17-24.

COSTA, JO; COELHO, RD; JOSÉ, JV; CHIMARRO, CAQ; WOLFF, W. 2023. Mapping and quantification of water consumption in bean crops using the metric algorithm. In: VIII Inovagri International Meeting e XXXII CONIRD 1-12.

COSTA, JO; COELHO, RD; WOLFF, W; JOSÉ, JV; FOLEGATTI, MV; FERRAZ, SFB. 2019a. Spatial variability of coffee plant water consumption based on the SEBAL algorithm. *Scientia Agricola* 76: 93-101.

COSTA, JO; JOSÉ, JV; WOLFF, W; OLIVEIRA, NPR; OLIVEIRA, RC; RIBEIRO, NL; COELHO, RD; SILVA, TJA; SILVA, EMB; SCHLICHTING, AF. 2020a. Spatial variability quantification of maize water consumption based on Google EEflux tool. *Agricultural Water Management* 232: 106037.

DEHGHANIPOUR, AH; SCHOUPS, G; ZAHABIYOUN, B; BABAZADEH, H. 2020. Meeting agricultural and environmental water demand in endorheic irrigated river basins: A simulation-optimization approach applied to the Urmia Lake basin in Iran. *Agricultural Water Management* 241: 106353.

EISELE, TG; CONSTANTINO, LV; GIACOMIN, RM; ZEFFA, DM; SUZUKI, CH; GONÇALVES, LS. 2022. Genotipagem e fenotipagem de híbridos de tomate uva visando possíveis genitores para programa de melhoramento genético. *Horticultura Brasileira* 40: 352-359.

ESPINDULA, D. 2002. Uso racional de água e de energia elétrica na cafeicultura irrigada por pivô central e gotejamento. Viçosa, MG: UFV. 126 p. (M,Sc, Thesis)

FAVATI, F; LOVELLI, S; GALGANO, F; MICCOLIS, V; TOMMASO, T; CANDIDO, V. 2009. Processing tomato quality as affected by irrigation scheduling. *Scientia Horticulturae* 122: 562-571.

FREITAS, GAD; SILVA, RRD; BARROS, HB; MELO, AV; ABRAHÃO, WAP. 2013. Produção de mudas de alface em função de diferentes combinações de substratos. *Revista Ciência Agronômica* 44*:* 159-166.

GAVA, R; FRIZZONE, JÁ; SNYDER, RL; ALMEIDA, BM; FREITAS, PSL; REZENDE, R. 2016. Estratégias de manejo de déficit hídrico na irrigação da cultura da soja / Strategies of deficit water management in irrigation of soybean crop. *Revista Brasileira de Engenharia Biossistemas* 10: 305.

HEYDARI, N. 2014. Water productivity in agriculture: challenges in concepts, terms and values. *Irrigation and drainage* 6: 22-28.

HOOSHMAND, M; ALBAJI, M; ANSARI, NAZ. 2019. The effect of deficit irrigation on yield and yield components of greenhouse tomato (*Solanum lycopersicum*) in hydroponic culture in Ahvaz region, Iran. *Scientia Horticulturae* 254: 84-90.

JOSÉ, JV; OLIVEIRA, NPR; SILVA, TJA; BONFIM-SILVA, EM; COSTA, JO; SOUSA, HHF. 2019. Spatial-temporal dynamics of biome Cerrado using different vegetation indexes. *Australian Journal of Crop Science* 13:1438-1446.

JOSÉ, JV; OLIVEIRA, NPR; SILVA, TJA; SILVA, EMB; COSTA, JO; FENNER, W; COELHO, RD. 2020 Quantification of cotton water consumption by remote sensing. *Geocarto International* 35: 1800-1813.

LIMA, SCRV; FRIZZONE, JÁ; MATEOS, L; FERNANDEZ, MS. 2012. Estimativa da produtividade de água em uma área irrigada no sul da Espanha. *Revista Brasileira de Agricultura Irrigada-RBAI* 6: 51-60.

MANTOVANI, EC; DELAZARI, FT; DIAS, LE; ASSIS, IR; VIEIRA, GH; LANDIM, FM. 2013. Eficiência no uso da água de duas cultivares de batata-doce em resposta a diferentes lâminas de irrigação. *Horticultura Brasileira* 31: 602-606.

MAROUELLI, WA; LAGE, DAC; BRAGA, MB. 2014. Irrigação da cultura do tomateiro orgânico: Enfoque no manejo de doenças e de insetos-pragas. Brasília: Ed. Embrapa.

MARTIN, JD; CARLESSO, R; AIRES, NP; GATTO, JC; DUBOU, V; FRIES, HM; SCHEIBLER, RB. 2012. Irrigação deficitária para aumentar a produtividade da água na produção de silagem de milho. *Irriga* 1: 192-205.

MOLDEN, D. 1997. *Accounting for water use and productivity*. Colombo, SRI: Iwmi.

MOLDEN, D; OWEIS, T; STEDUTO, P; BINDRABAN, P; HANJRA, MA; KIJNE, J. 2010. Improving agricultural water productivity: Between optimism and caution. *Agricultural water management* 974: 528-535.

MOLDEN, D; RUST, HM; SAKTHIVADIVEL, R; MAKIN, I. 2003. A water-productivity framework for understanding and action. In: Water productivity in agriculture: Limits and opportunities for improvement. *Cabi Publishing* 1-18.

MONTE, JA; CARVALHO, DFD; MEDICI, LO; SILVA, LD; PIMENTEL, C. 2013. Análise de crescimento e produtividade da cultura do tomateiro sob diferentes lâminas de irrigação. *Revista Brasileira de Engenharia Agrícola e Ambiental* 17: 926-931.

MUALEM, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water Resources Research* 12: 513-522.

NANGARE, DD; SINGH, Y; KUMAR, PS; MINHAS, PS. 2016. Growth, fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.) as affected by deficit irrigation regulated on phenological basis. *Agricultural Water Management* 171: 73-79.

NEGRISOLI, R; CECHINATTO, FH; BISSOLI, MJ; ROSESTOLATO, LL; SABBAG, OJ. 2015. Viabilidade Econômica no Cultivo de Minitomate Sweet Grape no Município de Casa Branca-SP. *Enciclopédia Biosfera* 11(21).

PERRY, C; STEDUTO, P; ALLEN, RG; BURT, CM. 2009. Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. *Agricultural Water Management* 96: 1517-1524.

PORTELA, JC; LIBARDI, PL; VAN LIER, QDJ. 2001. Retenção da água em solo sob diferentes usos no ecossistema tabuleiros costeiros. *Revista Brasileira de Engenharia Agrícola e Ambiental* 5: 49-54.

QUILOANGO-CHIMARRO, C; COELHO, RD; COSTA, JO; ARRIETA, RG. 2021. Crop water stress index for predicting yield loss in common bean. *Irriga* 4: 687-695.

QUILOANGO-CHIMARRO, CA; COELHO, RD; HEINEMANN, AB; ARRIETA, RG; SILVA GUNDIM, A; FRANÇA, ACF. 2022. Physiology, yield, and water use efficiency of drip-irrigated upland rice cultivars subjected to water stress at and after flowering. *Exp. Agr*. 58.

RICHARDS, LA. 1931. Capillary conduction of liquids through porous mediums. *Physics* 1: 318-333.

SILVA, GU; PARIZI, ARC; GOMES, ACS; PIVOTO, OG; PECCIN, MD. 2017. Manejo de irrigação via solo e clima na cultura do milho (*Zea mayz* L.) na região de Alegrete-RS. *Revista de Ciência e Inovação* 2: 101-112.

SIMÕES, AC; ALVES, GK; FERREIRA, RL; ARAÚJO NETO, SE. 2015. Qualidade da muda e produtividade de alface orgânica com condicionadores de substrato. *Horticultura Brasileira* 33: 521-526.

SIMUNEK, J; SEJNA, M; SAITO, H; SAKAI, M; VAN GENUCHTEN, M. 2013. The HYDRUS-1D Software package for simulating the one-dimensional movementeries 3. *University of California* 3: 1-343.

TABBAL, DF; BOUMAN, BAM; BHUIYAN, SI; SIBAYAN, EB; SATTAR, MA. 2002. On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. *Agricultural Water Management* 56: 93-112.

TAPPARO, SA; COELHO, RD; COSTA, JO; CHAVES, SWP. 2019. Growth and establishment of irrigated lawns under fixed management conditions. *Scientia Horticulturae* 256: 1-7.

TAPPARO, SA; COELHO, RD; COSTA, JO; CHAVES, SWP; QUILOANGO-CHIMARRO, CA; OLIVEIRA, EDS. 2022. Relationships between leaf water potential and soil water potential in grasses subjected to water stress. *Revista Brasileira de Engenharia de Biossistemas* 16: 1-7.

TUONG, TP; BHUIYAN, SI. 1999. Increasing water-use efficiency in rice production: farm-level perspectives. *Agricultural Water Management* 40: 117-122.

VAN GENUCHTEN, MV; LEIJ, FJ; YATES, SR. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. *University of California Riverside.*

VIEIRA, DAP; CARDOSO, KCR; DOURADO, KKF; CALIARI, M; JÚNIOR, MSS. 2014. Qualidade física e química de mini-tomates Sweet Grape produzidos em cultivo orgânico e convencional. *Revista Verde de Agroecologia e Desenvolvimento Sustentável* 9: 100-108.

VIOL, MA; FERREIRA, ED; CARVALHO, J; LIMA, EM; REZENDE, FC. 2018. Resposta do tomate sweet grape cultivado em substrato comercial com diferentes lâminas e frequências de irrigação. *Revista Engenharia na Agricultura* 26*:* 269-276.

ZOZ, T. 2015. Avaliação de genótipos de cártamo quanto ao desempenho agronômico, divergência genética e produtividade da água. Botucatu, SP: UNESP. 64 p. (Ph.D. Thesis)

Author's ORCID:

Moacir A dos Santos: https://orcid.org/ 0000-0001-5109-0286

Alisson JP da Silva: https://orcid.org/ 0000-0002-1720-4216

Delfran B dos Santos: https://orcid.org/ 0000-0003-0670-9689

Marcio da S Alves: https://orcid.org/ 0000-0002-3893-3709

Fabio TO de Freitas: https://orcid.org/ 0009-0009-2970-9199