Article

Proportion of drainage of the nutritive solution in the yield and quality of tomato in hydroponics

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Abstract

The limited availability of water, which is becoming more and more severe worldwide, demands a more efficient use of water in agricultural production. The closed hydroponic systems make a more efficient use of water, where the surplus nutrient solution is recovered, regenerated and reused in the same crop. The objective of this research was to know the effects on production and fruit quality with six percentages of drainage (%D): 25, 30, 40, 45, 55 and 60% D of the nutrient solution in a tomato crop. Pots with a fine pearlite substrate previously used were used. The research was carried out in 2016 in the Academic Unit of Agronomy of the Autonomous University of Zacatecas. The number, size, weight and yield of fruits, water productivity and fruit quality (electric conductivity, hydrogen potential, soluble solids, acidity and juice maturity index) were measured in two stages of production. There was a significant difference in yield and quality for treatments 3 and 4 and 1 and 2 respectively. With %D of 40% higher yield was obtained, but with 25% of drainage the content of salts and sugars in fruit was increased and the highest productivity is obtained with respect to the other percentages.

Keywords: *Lycopersicum esculentum* Mill, irrigation, recirculation, percentage of drainage.

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Introduction

Most greenhouse crops are developed using artificial substrates in hydroponic systems, these substrates are preferred to the soil for their physicochemical characteristics, since they can have better control over water, aeration, nutrition and distribution of roots (Ehret *et al*., 2001). These farming systems are characterized by not requiring soil, so they represent an alternative in places where it has been degraded or has physical or chemical deficiencies; in addition, they make it possible to make more efficient use of water (Moreno *et al*., 2015).

Hydroponics is used to develop plants in nutrient solution (SN) based on water and nutrients, with or without the use of a medium or substrate. The SN must have the adequate proportion of nutrients in ionic form (anions and cations), necessary for the plants to absorb them (Baca *et al*., 2016). Hydroponic systems are widely used for the production of greenhouse vegetables, have a high degree of efficiency in the use of water, the irrigation area is reduced because the radical growth does not need to grow in excess, since nutrients are available in the optimal amounts (López *et al*., 2011; Cuervo *et al*., 2012).

Hydroponic systems in which substrates are used are known as open, when the excess of SN that drains from these goes to the soil, infiltrating to the subsoil (AlShrouf, 2017) or in the best case is used outside the greenhouse in an alternative crop (Savvas, 2003). Open systems require a high consumption of water because they present a great waste of water, which represents a high cost and a negative impact on the environment (Pardossi *et al*., 2011; Sánchez *et al*., 2014; Moreno *et al*., 2015).

In closed hydroponic systems, where SN recirculation does exist, it is more efficient to use the water and nutrients that are applied for the growth and development of a crop, since the SN that drains from the system (drainage) is captured and used again in the same production system; however, an aspect that limits the reuse of SN and with this the efficiency in the use of water and nutrients is obtaining a lower yield, decrease in quality, accumulation of toxins (phytotoxicity) mineral deficiencies and risk of dissemination of microorganisms that cause disease in the crop root (Deniel *et al*., 2006; Sánchez *et al*., 2014). In a closed system, it is essential to maintain an adequate electrical conductivity (1.5 to 3.5 dS m^{-1}) during the cultivation cycle, which in the indeterminate tomato can be up to 11 months, which can be technically complicated and due to the cycle so long, plants are exposed to diseases for longer (Sánchez *et al*., 2014).

Substrate hydroponic systems have an average drainage percentage of 27% of the SN applied to the crop, from 20% later in the first irrigations of the day, to 40 or 50% in the central hours of the day, with an average during the day of 27%, maintaining this percentage range of drainage (20 - 50%) by means of frequency and time of irrigation, reduces the risk of accumulation of ions that in excess can be toxic for plants (Sengupta and Banerjee, 2012; Salazar *et al*., 2014). The time and the frequency of irrigation determine the amount of water applied to the crop, which is supplied by means of the irrigation system that, in the hydroponic systems, is usually by drip.

The amount of water applied and the frequency of irrigation directly affect the efficiency in the use of water; the substrate must also be taken into account when defining the frequency and time of irrigation since, depending mainly on its physical characteristics, it will retain more or less water in its porous space (Hao *et al*., 2013). Perlite is one of the most used substrates for tomato since it has good physical characteristics, such as moisture retention, aeration capacity, density and porosity (AlShrouf, 2017). The percentage of drainage must be handled properly and be the optimum to meet the needs of the plant and at the same time not cause a waste of water and nutrients (Sánchez *et al*., 2014).

Through the management of irrigation (frequency and irrigation times) the magnitudes of the drained SN are generated. There is little information on the percentage of SN drained with which the tomato plants have the best conditions for their growth, yield and fruit quality in a closed hydroponic system; Due to this, the objective of this research is to generate information in that sense.

Materials and methods

Location and environmental conditions of the place

The present work was carried out in a tunnel type greenhouse of 120 m^2, with passive climate control, in which a closed hydroponic system was established, in which three irrigation times were measured with one and two drippers, to obtain six percentage of drainage of the SN from the pots to a reservoir for recycling, the greenhouse is located in the Academic Unit of Agronomy of the Autonomous University of Zacatecas, at the coordinates: 22.72° north latitude and 102.68° west longitude, and altitude of 2 440 m.

Treatments and experimental design

Six SN drainage treatments were evaluated, resulting from the combination of three irrigation duration times (1, 2 and 3 min) and two streams of the emitters (2 and 4 L h^{-1}), the drainage percentages (%D) of the SN in the irrigation times mentioned and the flow of 2 L h^{-1} were: 25, 30 and 40, which correspond to treatments 1, 2 and 3, respectively; the combinations with the same irrigation times and the flow of 4 L h^{-1}, the% D were 45, 50 and 60, corresponding to treatments 4, 5 and 6, respectively. The frequencies of the irrigation varied between 20 and 30 min, depending on the stage of development of the plants.

Each treatment consisted of five repetitions, where each experimental unit consisted of six pots with 25 liters of fine perlite as a substrate and two tomato plants in each pot, having a density of 3 plants per square meter. Each row of six pots had an SN capture system that by gravity drove it from the pots to a container to determine the volume of the SN drained, with this value and the volume of SN applied per day, the was determined %D (Massa *et al*., 2010), the drained SN of each treatment was conducted to a deposit with a capacity of 1 000 L in which electrical conductivity and pH were measured, to restore SN in these parameters.

Plant material and production system

The variety of tomato (*Lycopersicum esculentum* Mill.) Used was the hybrid "El Cid", of indeterminate growth habit, of the saladette type. The transplant was performed 35 days after sowing. The pearlite was reused from four previous cycles for the production of tomato, cucumber (*Cucumis sativus* L.), tomato and tomato again. Perlite was disinfected before being used in each culture cycle with sodium hypochlorite at a concentration of 4 mg L^{-1} (Cayanan *et al*., 2009).

Handling the nutrient solution during the experiment

The SN Steiner was used in 75% of the first irrigations (between 28 and 32 irrigations) of each day, the drained SN of each treatment was stored in its respective reservoir, before the last eight irrigations of each day the SN drained was restored adding the necessary water to reduce the CE to 1.7 ±0.1 dS m^{-1} and the necessary amount of a 1 N solution of potassium nitrate to achieve an CE of 2 ±0.1 dS m^{-1} and the required amount of a 1 N solution of sulfuric or phosphoric acid to re-establish the pH at 5.5 ±0.1. Phosphoric acid was only used when the phosphorus content in the SN dropped to 35 ppm.

The water used to prepare the SN had: pH= 7.23, CE= 0.55 dS m^{-1}, concentration of soluble ions in mol_c m^{-3}: NO_3= 0.21, P-PO_4= 0.02, SO_4= 0.70, HCO_3= 3.60, Cl= 0.80, Ca= 1.85, Mg= 1.48, K= 0.26, Na= 2.09 and in mg L^{-1} the micronutrients: Fe= 0.03, Mn= 0.02, Zn= 0.01, Cu= 0 and B= 0.1.

The fertilizers used to prepare SN were calcium nitrate ($Ca(NO_3)_2 \cdot 0.2NH_4NO_3 \cdot H_2O$), potassium nitrate ($KNO_3$), potassium sulfate ($K_2SO_4$), magnesium sulfate ($MgSO_4 \cdot 7H_2O$), monopotassium phosphate (KH_2PO_4), phosphoric acid (H_3PO_4) and sulfuric acid (H_2SO_4). To provide the micronutrients, a fertilizer was used that contains a concentration of: 6.6, 2.6, 1.1, 0.9, 0.3 and 0.2%, Fe, Mn, Zn, B, Cu and Mo, respectively, whose concentration in the SN was: 1.98, 0.78, 0.33, 0.27, 0.09 and 0.06 mg L^{-1}, for the respective micronutrients; Fe, Mn, Zn and Cu were applied as a chelate with EDTA. The water used was directly from deep well, the presence in it of bacteria and fungi was negative.

Variables measured in the plant

In a plant of each experimental unit the following measurements were carried out.

Performance. It was expressed in kilograms produced per square meter; three fundamental performance components were also evaluated, which were:

Number of fruits per plant. The fruits harvested during the cycle that reached physiological maturity were counted and finally the average of the harvested fruits per plant was obtained.

Size of fruits. It was obtained at the time of harvest with a ScalaTM digital vernier in millimeters measuring the equatorial and polar diameters.

Weight of fruits. The fruits were weighed when harvested, the weighing was performed with a digital scale EK-200i with a precision of 0.01 g. The measurement of fruit size and weight allowed to classify the fruits in categories according to the following scale: 1a (>130 g), 2a (100-130 g), 3a (60-100 g) and 4a (<60 g).

Variables measured as fruit

Fruit samples were taken in two stages of production, with the same maturity index (color), in the fourth and in the eighth bunches, the samples were constituted by five fruits considering the same position of them in cluster. The fruits were crushed and ground in a Krups 267 juice extractor. After extracting the juice with an 80 mesh fiber, it was used to determine the following quality variables:

Total soluble solids (SST). A drop of the juice of the obtained sample was taken and placed in the sensor refractometer Atago, model N-1E, with a reading range of 0 to 32 °Brix.

pH and electrical conductivity. They were measured with a LAQUAtwin B-712 potentiometer for the pH test and a Laquatwin B-771 conductivity meter for electrical conductivity in a 50 mL sample of juice extracted from the fruits, the measurement accuracy was 0.01 in both properties.

Titratable acidity. It was determined by the method used by San Martin *et al*. (2012). This variable was expressed as a percentage (AT%) as a percentage of citric acid.

Maturity index (IM). For the determination of this parameter, it was calculated with the method used by San Martin *et al*. (2012), obtaining the relationship between SST and AT.

Variables measured in the nutrient solution

CE and pH. These parameters were measured with a PCE-CM 41 meter for electrical conductivity and a PCE-PH 22 meter for pH. These parameters were measured to regulate the nutrition of the crop and have a normal and balanced development and were measured both in the applied SN and in the drained.

To restore the pH, sulfuric and phosphoric acids were used, the amount applied was that required to lower the pH again to a value of 5.5.

Volume of solution applied. An extra dropper was installed in each experimental unit in a container to capture the solution applied in one day, at the end of the day it was measured with a graduated cylinder, obtaining the volume applied per day per plant.

Volume of drained solution. In each container (drainage tray) installed in each repetition the drained SN was collected and its volume was measured with the help of a graduated cylinder, per day and per experimental unit. This parameter also allowed to control the irrigation (frequency, between every 30 and 40 minutes, and number of irrigations, between 30 and 50) and the restoration of the pH and the CE of the SN.

Drainage percentage (%D). It was obtained by the relationship between the volume applied and the volume drained.

Water productivity. A record was made of the amount of SN applied for each treatment during the crop cycle. Subsequently, the ratio in kilograms per cubic meter of the amount of water applied and the amount of fruit produced with such quantity was obtained.

Statistical analysis

The data obtained were analyzed in an experimental design in randomized complete blocks and subjected to an analysis of variance (Anova) and a means test using the Tukey criterion, with ($\alpha \leq 0.05$). This analysis was carried out with the statistical program SAS (Stadistical Analysis System) version 9.4.

Results and discussion

Variables measured in the plant

Performance. The yield was greater in the treatments with 40 and 45% D with respect to the other treatments (Table 1), these yields are higher 14% than those obtained by Sánchez *et al*. (2014), where they evaluated open and closed hydroponic systems, the present investigation provided results a little lower than those obtained by Oztekin *et al*. (2008) and Nakano *et al*. (2010) since they did not find significant differences using different and new substrates and different open and closed hydroponic systems in tomato culture.

Number of fruits. The number of fruits per plant was not different among the treatments evaluated (Table 1). The number of fruits in the treatments oscillated with greater frequency between 40-50 fruits per plant during the 18 cuts made throughout the cycle (may to november), these results are similar to those obtained by Urrieta *et al*. (2012). The reason for not having differences is probably due to the fact that the number of fruits is strongly influenced by some morphological characteristics of the plants, among them the type of inflorescence and the number of flowers per bunch (Rivas *et al*., 2012).

Size of fruits. This variable was greater in the treatments with 40 and 45% D with respect to the other treatments (Table 1); however, the results of the six treatments are similar to those of Ucan *et al*. (2004). The size of the fruit is strongly related to the number of fruits, since, to a smaller number of fruits, the greater number of photoassimilates destined to each fruit, favoring larger fruit size (Ucan *et al*., 2004; Rivas *et al*., 2012).

Weight of fruits. The weight of the fruits was strongly related to the size, to larger size, greater weight, for this reason the weight of the fruits was also greater in the treatments with 40 and 45% D (Table 1), these treatments presented an average weight of superior fruit 23% with respect to the treatment with the lowest average weight of fruit, corresponding to the treatment with 25% D, which may be due mainly to that in this treatment there was greater stress in the plant affecting its yield (Sengupta and Banerjee, 2012; Sánchez *et al*., 2014).

Table 1. Yield and productivity of tomato fruits in hydroponics with different percentage of drainage of nutritive solution in 18 cuts made in the cycle.

Drainage percentage	Fruits per plant	Diameter (mm)		Weight per fruit (g)	Yield (kg m^{-2})	Water productivity (kg m^{-3})	Category and predominance (%)	
		Polar	Equatorial					
25	44.7a†	59.92b	48.98b	90.02b	12b	43.09a	3	75-100
30	45.81a	61.95b	48.84b	92.48b	12.7b	41.03a	3	75-100
40	44.9a	65a	51.8a	116.9a	15.7a	33.81b	2	80-100
45	44.5a	64.92a	51.5a	116.6a	15.5a	29.86b	2	80-100
55	46.54a	62.18b	49.97b	94.18b	13.5b	22.54c	3	80-100
60	44.3a	60.3b	49.45b	92.9b	12.3b	18.48c	3	75-100
DHS‡	2.29	2.26	1.79	22.2	3.54	3.97		

†= means followed with the same letter within columns do not present significant differences (Tukey, 0.05); ‡= DHS = significant honest difference.

The variables mentioned above (size and weight of fruits) it was determined that the fruits that predominated had weights of 60 to 100 g for the treatments with 25, 30, 50 and 60 %D and of category 2 (100-130 g) for treatments with 40 and 50 %D (Table 1), according to the scale established for the sizes (polar and equatorial diameters) and weights of the fruits.

Variables measured as fruit

Total soluble solids (SST). The treatment with 25 %D was statistically greater than the others in both stages of measurement; likewise, the treatment with 30 %D was also greater in the second stage, the results obtained varied from 4.85 to 5.99 °Brix (Table 2), these values are higher than those found by Rivas *et al*. (2012) from 4.57 to 5.10 °Brix in different tomato cultivars and Urrieta *et al*. (2012) from 4.81 to 5.33 °Brix using native varieties as plant material.

The SST are a parameter of fruit quality that varies with the electrical conductivity of the SN and the hydric stress of the fruit during its development (Cespedes *et al*., 2004), the greatest water stress condition in this investigation was presented in the treatments of 25 and 30 %D, the tomato fruits of plants under this type of stress store mainly ions and organic molecules such as fructose and glucose (Munns, 2002), which increases the SST. The results of the present investigation are in agreement with those found by Chang *et al*. (2012) who found that with SN drainage percentages lower than 30% or close, SST increase and as %D increases, SST decreases.

pH of juice. The pH in the juice did not have a significant difference in any of the treatments evaluated. The pH is an indicator of quality, the best values in tomatoes of quality for this variable are between 4 and 5 (Aguayo *et al*., 2004) and the results obtained in this investigation agree with the mentioned thing (Table 2), a juice of Fruits with lower acidity have greater acceptance, since this way their sweet and pleasant taste stands out more when consumed fresh (Urrieta *et al*., 2012).

Electric conductivity. In this variable values were found from 5.30 (treatment with 60 %D, Stage 1) to 6.32 (treatment with 25 %D, stage 2) (Table 2). The treatments with 25 and 30 %D presented higher CE, due to the accumulation of solutes (salts) in the substrate, the results found in this variable in all the treatments agree with those observed by San Martin *et al*. (2012), who found that there is a direct relationship between the accumulated salinity in the substrate and the electrical conductivity of the fruit; likewise, as %D is decreased, the accumulation of salts increases the CE in the root and also in the juice of the fruit (Sengupta and Banerjee, 2012).

Acidity titulable. The treatments tested showed no statistical differences in the two production stages (Table 2). The six treatments presented values from 0.15 to 0.32% acidity (Table 2), similar to those obtained by Bugarin-Montoya *et al*. (2002) (0.19-0.32%) with different concentrations of potassium in a closed hydroponic system, and slightly lower than those found by Rivas *et al*. (2012) (0.25-0.43%) using diverse cultivars.

Table 2. Quality of tomato fruits by effect of six percentages of drainage of the nutrient solution in a closed hydroponic system, in two stages of plant development.

Stage	Drainage percentage	SST	pH	CE	AT	IM
1	25	5.91a[†]	4.69a	6.05a	0.27a	21.88c
	30	5.42b	4.67a	5.7b	0.32a	16.93c
	40	5.08b	4.56a	5.66b	0.18a	28.22b
	45	4.9c	4.59a	5.68b	0.22a	22.36c
	55	4.98c	4.52a	5.57c	0.15a	33.2a
	60	4.85c	4.46a	5.3c	0.18a	26.95b
2	25	5.99a	4.55a	6.32a	0.28a	21.81c
	30	5.6a	4.59a	5.95b	0.19a	29.42a
	40	5.43b	4.51a	5.64b	0.27a	20.14c
	45	5.4b	4.61a	5.59c	0.25a	21.64c
	55	5.35b	4.37b	5.53c	0.19a	33.43a
	60	5.15b	4.62a	5.58c	0.22a	30.23a
DHS		0.4	0.26	0.35	0.3	4.42

[†]= means followed with the same letter within columns do not present significant differences (Tukey, 0.05). SST= total soluble solids; pH= hydrogen potential; CE= electrical conductivity; AT= titratable acidity; IM= maturity index; DHS= significant honest difference.

Maturity index. This index was higher in the treatment with 55 %D in the first stage and with 55 and 60 %D in the second stage, which is due to the combination of high values of SST with low AT, the results obtained in the six treatments varied between 16.9 and 33.4 for the IM (Table 2) with an average of 26.7. With values obtained in a range of 12 to 18, the maturity index is the one indicated for many tomato varieties (Bugarin-Montoya *et al*., 2002). According to Kader *et al*. (1978) when the IM is greater than 10 the tomato fruits are considered of better quality.

Variables measured in the nutrient solution

It is important to emphasize that these variables in the nutrient solution were only measured in order to carry an adequate plant nutrition and correct application of the same, in order to have a balance in the development of the plants.

CE and pH. In the applied SN, values were maintained between 1.7 and 2.6 dS m^{-1} and between 5.5 and 6 respectively, depending on the stage of development in which the crop was found as recommended by Putra and Yuliando (2015); Baca *et al*. (2016). The EC and the pH of the drained SN were increased during the cycle (Results not reported), with averages of 4.28, 4.19, 4.11, 4.04, 3.82, 3.77 and 4.32 dS m^{-1} CE for the six treatments and means of 6.65, 6.62, 6.79, 6.37, 6.58, and 6.5.

In the CE, these results are probably due to the fact that the plant absorbs more water than nutrients in proportion, and taking into account the amount of water lost through evaporation, the drained solution will have a concentration of solute (nutrients) greater than of water (solvent), thus increasing the electrical conductivity. Results similar to the present investigation found Chang *et al*. (2012) with different percentages of drainage and percentage of zero drainage, since the electrical conductivity increased when decreasing the percentage of drainage obtaining from 2-6 dS m^{-1} with percentages of 30 to 50%.

Water productivity The productivity obtained in the six treatments ranged between 18 and 43 kilograms of fruit produced per cubic meter of water applied (Table 1), although there was no difference in the number of fruits, if there was a significant difference for productivity , presenting the highest values with the lowest drainage percentages (25 and 30%) since they were in which the amount of water applied was lower and as the percentage of drainage increased the productivity of the water decreased. The productivity reflects an efficient use of water, in hydroponic systems and especially closed ones, water savings can be achieved from 30 to 40% (Komosa *et al*., 2011) or up to 46% (Dasgan and Ekici, 2005).

Conclusions

The percentage of drainage of the nutrient solution had an effect on the yield of tomato fruits, with 40 and 45% drainage the highest yields were obtained, with an increase of up to 25%.

The highest fruit yield was not due to the greater number of fruits, but to the larger size (polar and equatorial diameters) and fruit weight, the treatments with which these parameters were increased were with 40 and 45% drainage of the solution nutritious

Percentages of drainage of the nutrient solution lower than 40% favor some parameters of fruit quality such as the concentration of sugars (total soluble solids) and electrical conductivity in the juice of the tomato fruits, but the yield is reduced.

The electrical conductivity and the pH of the drained nutrient solution showed a greater increase in treatments with 25 and 30% drainage, thus increasing quality variables such as SST and CE.

The productivity of water measured in kg of tomato fruits per cubic meter of water, was higher in the treatments with lower percentage of drainage (25 and 30%), the higher percentage of drainage decreased productivity.

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