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Growth and Yield of Tomato (*Solanum lycopersicum* L.) as Affected by Hydroponics, Greenhouse and Irrigation Regimes

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This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climatic and technical factors influence tomato (*Solanum lycopersicum* L.) production in hydroponics and greenhouse, but there is not much research on management of red volcanic rock as substratum, as well as on water and nutrient solution. Therefore, the effect of the concentration of nutrient solution, irrigation frequency and the volume of substratum on growth, dry matter and fruit production was evaluated, and the economical impact was compared according to costs and yield. During 2007 and 2008, in the Experimental Field of the Universidad Autónoma Chapingo, Chapingo Mexico,

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concentrations of nutrient solution (100, 75, and 50%), irrigation frequency d^{-1} (1, 4, 7, and 10), and volumes of substratum $plant^{-1}$ (5, 10, and 15 L) were assessed in a completely randomized block design in a factorial treatment arrangement replicated three times. The results showed significant differences ($P < 0.05$) between years, concentrations of nutrient solution, irrigation frequency, and volumes of substratum in growth and yield of dry matter and fruit. In 2008, there was major growth and yield of dry matter and fruit, compared to 2007. Nutrient solution at 75% diminished the fruit yield by 4.8% compared to 100%. With 7 irrigations d^{-1} , stem thickness was reduced by 2.1, 1.8, and 1.7%, and the index of leaf area, and fruit yield, respectively, was compared to ten irrigations d^{-1} . There were no differences between 10 and 15 L in fruit yield. It is concluded that it is convenient to utilize the nutrient solution at 75% in seven irrigations d^{-1} and substratum volume of 10 L for tomato production in hydroponics and greenhouse in order to obtain the highest profit (73.9%).

Keywords: *Solanum lycopersicum* L.; irrigation; container; fruit yield; growth.

1. INTRODUCTION

Tomato is the second most important fruit vegetable with the highest production worldwide, followed only by “Nep vegetables”, including beet (*Beta vulgaris* L.), watercress (*Nasturtium officinale* T.), and radish (*Raphanus sativus* L.) [1]. In 2010, the main tomato producing countries were: China, USA, India, Turkey, and Egypt, with a production of one hundred and forty six million tons; Mexico occupied the tenth place with a production of 3 million tons. In 2009, Mexico exported one million tons, surpassing Spain and the Netherlands. There was a consistent growth in export between 2005 and 2009 [1]. In Mexico, based on amount and export value, tomato occupied the second place in agricultural products only surpassed by barley (*Hordeum vulgare* L.). In 2011, two million tons (mean yield of $41.67 t ha^{-1}$) were produced, with a value of ten trillion pesos [2], generating ten jobs per hectare on the average.

Vegetable production under protected systems, greenhouses, shade houses, and hydroponics allow cultivation in regions inappropriate for conventional agriculture by efficiently using natural resources particularly water and soil. In Mexico there are about four thousand hectares cultivated under greenhouse conditions [3], approximately, twenty percent use hydroponic system with absorbent substrata such as coconut fiber, perlite, rock wool, tezontle (red volcanic rock sand), vermicompost and their combinations [4,5] and a drip-irrigation system which supplies water at low tension and high frequency, creating optimum environment of moisture in soil [6] and substratum [7], which influences plant water absorption [8].

Hydroponics has advantages over cultivation in soil which is reflected in higher yield per unit area of land [9]. However, installation and operation costs are very expensive; besides, the expense of construction and maintenance of the greenhouse, and of the irrigation system, substrata, containers, and fertilizers must also be considered. Substrata are expensive and have to be brought up to date every year or every two years, as in the case of rock wool, one of the most used substrates; therefore, other types and volumes of substratum have been studied [10,11]. Tezontle is an alternative because of its low cost, it permits using cheap containers such as polyethylene bags and may last five or more years, but its handling as hydroponic substrate has been given little attention by researchers [4,12], especially, the minimum volume per plant to attain a balance of oxygen and water, for the root, considering

the quantity of water and frequency of drip irrigation application, with the purpose of utilizing the substratum [13]. The fertilizer in hydroponic system represent approximately thirty percent of tomato production cost which is between three hundred and four hundred thousand pesos per hectare per year.

Several Scientists had earlier reported on the concentration and balance of nutrient solutions that provide higher yield and fruit quality of tomato in hydroponics [14-16]. But it is possible to reduce the nutrient concentration in the solution, based on early replacement, as in the case of soil medium, where most of the nutrients exist in low concentrations and practically constant, because of the quick recovery, produced by the soil colloids [17,18].

Seedlings of husk tomato (*Physalis ixocarpa* Brot.) had higher growth (height, number of leaves, fresh and dry weight) by applying Universal Steiner nutrient solution by 50% in comparison to 75 and 100% [19]. In cherry tomato, the volume of the nutrient solution affected the number and weight of fruits, and fruit yield was higher with the application of 1500mL plant⁻¹ day⁻¹ [15]. On the other hand, in tomato, the highest irrigation frequency with reduction in irrigation water amount was more efficient for plant growth, regardless of the nutrient level [18], with one, four or eight irrigations a day there was no effect on leaf area [20], but four times a day has significant effect on fruit yield compared to twice a day, by 21% [4]. Likewise, tomatoes grown in containers with 14 L had higher relative water content in the leaf than plants grown in 7 or 35 L, as well as an increase in yield and quality by increasing substrate volume in 2 L plant⁻¹ [21].

The objective of the study was to compare the effect of different concentrations of nutrient solution, irrigation frequency, and volume of the substrate on growth, dry matter production, and fruit yield of tomato plants, as well as to compare the economic impact of the evaluated treatments according to their costs and output.

2. MATERIALS AND METHODS

The study was carried out in the Experimental Field of the Universidad Autónoma Chapingo, at Chapingo, Texcoco, State of Mexico (19° 29' 31.19" N, 98° 52' 20.86" W and 2,268 meters above sea level), characterized by sub humid climate with rainfall in summer annual with mean precipitation of 625 mm, and annual mean temperature of 15.1° C [22]. The experiment was established in hydroponics and greenhouse during the planting seasons of spring/summer of 2007 and 2008. A chapel-type greenhouse with a saddle roof and small lateral and front windows in the upper part, was used, covered with gauges of plastic, caliber 720 with 20% shade, 42 m length, 11 m width and 5 m high.

Imperial tomato hybrid (origin: Enza Zaden, 2006) was used for planting which has an indeterminate growth habit, a flattened half-round ball fruit without green shoulders, 250 g weight per fruit, good looking and firmness, intense red color, and excellent shelf life, with precociousness at harvest.

Thirty-six treatments were evaluated, combination of three concentrations of nutrient solution (100, 75, and 50%), four irrigation frequencies d⁻¹ (1, 4, 7, and 10), and three substrate volumes plant⁻¹ (5, 10, and 15 L); factorial arrangement in a complete randomized block design with three replications. The experimental unit consisted of six plants. A nutrient solution proposed by [23] was with the following mineral concentrations (mg L⁻¹): N 225.8, P 60, K 247.2, Ca 250.2, Mg 59.5, Fe 3.2, Mn 1, B 0.5, Cu 0.08, and Zn 0.08, applied by drip-irrigation and prepared with chemical fertilizers. Black plastic bags, caliber 600, were used

as containers. Daily irrigations were defined according to plant requirements in hydroponic system with absorbent substrata and container volume. Regardless of the number of irrigations, the daily dose of nutrient solution was 1.8 L plant^{-1} ; adjusted to drain between 10 and 25% of accumulated salts.

The seedbed was established in August 2007 and in May 2008. Sowing was done using plastic trays of 200 cavities with a mixture of peat-moss and perlite in 1:1 proportion as substrate. At the emergence of the first real leaf, irrigation with nutrient solution concentration by 50% was applied twice every day until transplant (33 days after sowing). The containers were filled with 5, 10, and 15 litres capacity with tezontle sand of particle size between 0.5 and 3 cm diameter. The greenhouse and the substratum were disinfected with quaternary ammonium salts and immediately irrigated with water until substrate saturation. Field density was three plants m^{-2} . After transplant and until the end of the crop cycle the plants were irrigated with nutrient solution by 50, 75, and 100% concentration based on treatment.

The plants were staked at ten days after transplanting, the plants were tied to a fixed wire with raffia from the base, and the free end of the stem was tied to the fixed wire. The axillary shoots and leaves frequently pruned, and the plant was cut above the sixth inflorescence. Insecticides and fungicides were sprayed biweekly to control pests and diseases.

At the beginning of the harvest of commercial fruits (three quarters of ripening process and ripe fruits), at 123 days after sowing (das), variables were measured (four tagged plants): 1) Plant height, measured from the ground level to the terminal point of the plant (cm). 2) Stem thickness assessed by the use a digital vernier caliper at the height between the first and the second raceme of the plant. 3) Leaf area was determined without taking destructive samplings; from one sample of 100 leaves, leaf area of each leaf was measured with an integrator LI-3000A (LI-COR, Lincoln, Nebraska, USA); subsequently, by means of linear regression, an expression was calculated for estimating leaf area, based on the data of leaf width and length, and finally the index of leaf area was calculated. 4) For yield of dry matter, dry weight of stem, leaf, and fruit was calculated in g m^{-2} , and they were separately placed in an oven at $70 \text{ }^\circ\text{C}$ 48 h for stem and leaf, and 72 h for the fruit until reaching constant weight. 5) Fruit yield, the fruits were harvested at 123, 133, and 143 das and the total were summed up and weighed in kg m^{-2} .

The production cost per hectare was calculated through the quantification of the costs associated with the activities made during the growing season (inputs, quantity and application): hybrid seed, chemical fertilizers to produce the nutrient solution, substratum, containers, insecticides, fungicides, bactericides, raffia, and labor. The economic income per hectare was calculated based on the fruit yield and price per kilogram.

The experiment was analyzed using the Statistical Analysis System package [24] and the mean comparison was carried using the Tukey test at 5% level of probability.

3. RESULTS AND DISCUSSION

Significant differences ($P < 0.05$) were observed between years, concentration of nutrient solution, irrigation frequency, and substrate volume (Table 1) for stem thickness, plant height, index of leaf area, and yield of dry matter and fruit, measured at 123 das. This indicates that between 2007 and 2008, there was a differential effect of quantity and distribution of precipitation, temperature, evaporation, and relative humidity, and of the

essential nutrients in watery solution, available for the plant [3]. It is related to irrigation frequency and substrate volume, as well as consequent nutrient absorption and water availability [25,13]. Similar results were observed by [19] at applying Universal Steiner nutrient solution by 25, 50, 75, and 100%, weekly variation of 25, 50, and 75% and a triple 18 solution on development of husk tomato seedlings in containers and greenhouse. [18] also detected that the highest irrigation frequency with reduction in irrigation water amount was more efficient for tomato plant growth, regardless of the nutrient level, as well as increase in fruit yield with the application of 1500 mL plant⁻¹ d⁻¹ of nutrient solution [15].

Table 1. Comparison of means of growth parameters and fruit yield of tomato in hydroponics and greenhouse. Chapingo, Mexico, 2007 and 2008

Years	Stem thickness (cm)	Plant Height (m)	Index of leaf area	Yield of dry matter (g m ⁻²)	Fruit yield (kg m ⁻²)
2007	1.47a	1.22b	2.24b	524.09b	8.92b
2008	1.39b	1.66a	3.19a	620.15a	11.51a
HSD (0.05)	0.01	0.01	0.05	7.87	0.24
Concentration of nutrient solution (%)					
100	1.47a	1.45a	2.91a	603.77a	11.31a
75	1.44b	1.43a	2.78a	572.49b	10.77b
50	1.38c	1.43a	2.46b	540.09c	8.55c
HSD (0.05)	0.03	0.02	0.17	25.01	0.43
R ²	0.88	0.90	0.90	0.97	0.90
V. C. (%)	4.73	1.33	7.31	5.04	3.45

Means with the same letter in each column are statistically equal (Tukey, P=0.05). HSD = Honest Significant Difference, R² = Determination coefficient, V. C. = Variation coefficient

3.1 Years of Evaluation

Plant height, leaf area, dry matter and fruit yield increased, respectively, by 36.1, 42.4, 18.3, and 29% in 2008, and there was decrease in stem thickness by 5.4% (Table 1). This was because in 2008 temperature was higher (17.5 °C on average), as well as solar radiation during the period of plant growth, in comparison with 2007 (mean temperature 15.6 °C) (Fig. 1). It became increasingly cloudy, and relative humidity was similar in both years, 70% on average [26]. This proves that environmental factors influence growth, development, and yield of plants, because they affect their physiology (photosynthesis and evapotranspiration) [27]. [28] Stated that solar radiation play a key role during fruit growth, as well as [29] posited that relative humidity has a positive influence on plant growth, owing to a direct action on hydric relations, and an indirect one on photosynthesis as a consequence of daily limitation in CO₂ availability. [30] Observed in tomato seedlings greater plant height, stem thickness, and leaf area with 16 °C of night temperature.

3.2 Concentration of Nutrient Solution

Nutrient solution at 100% presented greater stem thickness, but at 75%, it was reduced by 2%, and at 50% it diminished by 6.1% (Table 1); likewise, the index of leaf area decreased by 4.5% and 15.5%, respectively, at an application of 75% and 50%. This indicates that it could be viable to reduce the concentration of nutrient solution to 75% without significantly affecting height and index of plant leaf area, compared with 100%. This did not happen at

50%, which shows a negative effect. Similar results were observed by [19] when applying Universal Steiner nutrient solution at 50% to tomato seedlings.

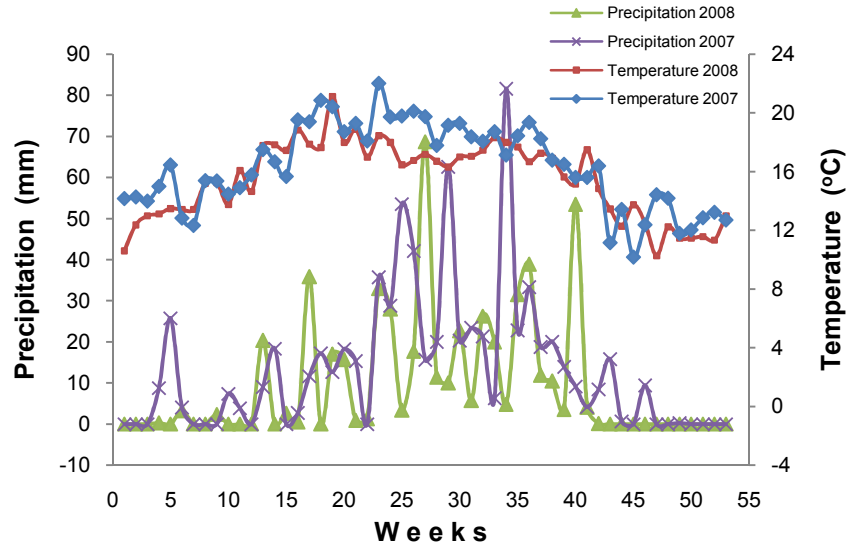


Fig. 1. Quantity and distribution of precipitation and temperature, weekly average, during the years 2007 and 2008. Meteorological Station of Colegio de Postgraduados, Texcoco, Mexico

Fruit and dry matter yields were higher with the nutrient solution at 100%, but there was a decrease by 4.7 and 5.1% with the concentration at 75%, and with nutrient solution at 50% the yield dropped by 24.4 and 10.5% (Table 1). This means that at lesser amount of nutrients in the solution, fruit and dry matter yield decreases significantly ($P < 0.05$), therefore, it is important to evaluate the economical impact, according to the rise in the price of inputs such as chemical fertilizers. [14] Observed similar results at combining high electrical conductivity (CE) at night with low CE during daytime, CE of control was 3-3.3 dS m⁻¹ using drip-irrigation and 4 dS m⁻¹ with drainage. [15] Also found increase in fruit yield applying 1500 mL plant⁻¹ day⁻¹ of nutrient solution.

3.3 Irrigation Frequency

The application of ten irrigations produced higher plant growth; one and four irrigations presented the least growth (Table 2). Practicing ten irrigations, nutrient solution was distributed and available for the plant during the day; whereas applying irrigation at 11:00 a.m., leaking was observed and less available nutrient solution during the day at the hours of highest temperature, causing water stress. Ten and seven irrigations were statistically equal ($P = 0.05$) for plant height and leaf area index, but not for stem thickness (Table 2). With seven irrigations, stem thickness and leaf area index diminished by 2.1 and 1.8%, respectively, compared to ten irrigations; therefore it is possible to apply seven irrigations, distributed over the day (9, 10:30, 12, 13, 14, 15, and 16 h) considering the hours of highest temperature, whenever there is a decrease in growth and the input of tomato is used efficiently. [20] noticed that with one, four or eight irrigations a day there was no effect on leaf area. This may be due to the plant not responding directly to the frequency of water application, but to

water potential in soil or substrate. With high irrigation frequency, the differences between values of the potential and between applications are absorbed, and normally are kept at an inferior threshold value, which could provoke water stress [31].

Table 2. Comparison of means of growth parameters and fruit yield of tomato with different irrigation frequency and substrate volume, Chapingo, Mexico. 2007 and 2008

Irrigation frequency	Stem thickness (cm)	Plant height (m)	Index of Leaf area	Yield of dry matter (g m ⁻²)	Fruit yield (kg m ⁻²)
Ten	1.46a	1.45ba	2.82a	577.62a	11.10a
Seven	1.43b	1.46a	2.77ab	587.00a	10.91a
Four	1.43b	1.42c	2.69b	571.98ba	9.95b
One	1.40c	1.43bc	2.59c	551.87b	8.90c
HSD (0.05)	0.02	0.02	0.07	16.51	0.51
Substrate volumen					
15 L	1.46a	1.44a	2.72ab	586.16a	10.65a
10 L	1.43b	1.45a	2.75a	572.98b	10.67a
5 L	1.39c	1.42b	2.68b	557.22c	9.32b
HSD (0.05)	0.02	0.01	0.07	11.56	0.36

Means with the same letter in each column are statistically equal (Tukey, P=.05). HSD = Honest significant difference

The yields of dry matter and fruit, irrigated ten and seven times, turned out to be statistically equal ($P=.05$) (Table 2); the greatest production was obtained with ten irrigations, followed by seven and four, and the lowest with one irrigation. A higher frequency of water applications provided higher availability of nutrients and water for the plants, particularly, at the hours of the day with the highest temperature, due to the adjustment of electrical conductivity of the substratum, acting on the percentage of drainage [32,9]. Fruit yield diminished by 1.7, 10.4, and 19.8% with seven, four, and one water applications in comparison with ten irrigations. This indicates that fewer than seven irrigations must not be utilized in tomato production in hydroponics and greenhouse. [4] Observed that distribution of nutrient solution four times a day has significant effect on tomato fruit yield compared to twice a day, by 21%. Likewise, [33] point out that the frequency of fertirrigation has an important influence on fruit yield.

3.4 Substrate Volume

Containers of 15 and 10 L capacity originated higher plant growth, yield of dry matter and fruit than those of 5 L (Table 2). Due to the fact that in small substrate volume retention capacity of nutrient solution is lower, which could cause water stress and changes in salt and pH concentrations between irrigations, in comparison with great volumes [31]; greater substrate volume favors nutrient absorption, water relation in the plant, and the distribution and accumulation of dry matter and fruit [34]. [20] found that the plants grown in containers with 14 L had higher relative water content in the leaf than plants grown in 7 or 35 L, as well as rise in tomato yield and quality at increasing substrate volume in 2 L plant⁻¹ [21].

With a substrate volume of 5 L, stem thickness diminished by 4.8% and plant height by 1.4%, compared to 15 L; in fruit yield there was no significant decrease with 10 L, for which it may be possible and economically convenient to use a container of 10 L capacity.

3.5 Interactions

The interaction between concentration of nutrient solution x substrate volume was significant ($P=0.05$); at increasing concentration and volume, dry matter yield grows at a maximum of 642 g m^{-2} with 100% of concentration and 15 L, and at a minimum of 532 g m^{-2} with nutrient solution at 50% and 5 L. The highest fruit yield was reached with nutrient solution at 100% and substrate volume of 15 L (Fig. 2) being statistically equal ($P=0.05$) to 75% and 10 L, with a reduction of 3.9%, equivalent to diminishing 470 g m^{-2} ; in a greenhouse of 1000 m^2 470 kg are reduced. According to the time of the year, the product price and the cost of fertilizers would turn out to be an alternative for tomato production, due to saving in the amount of fertilizers for preparing the nutrient solution. Dry matter and fruit yield was lower with nutrient solution at 50% and substrate volume of 5 L.

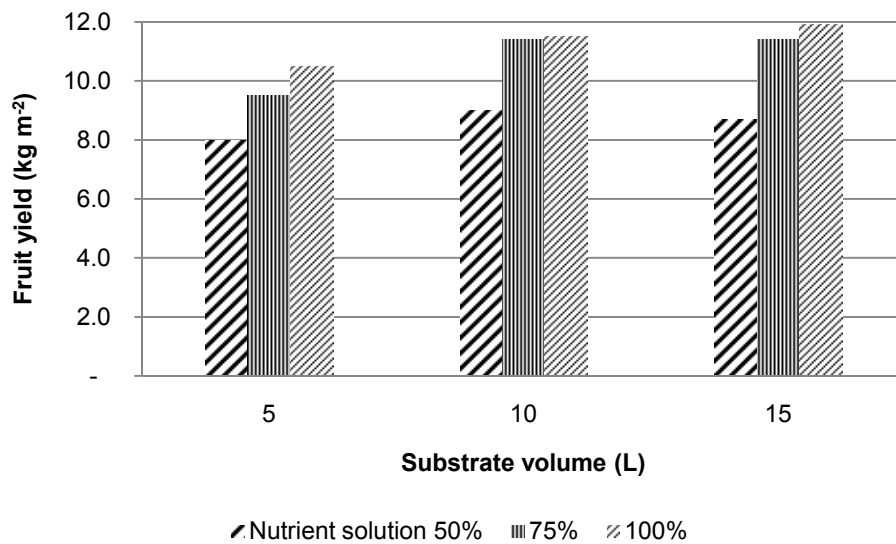


Fig. 2. Interaction concentration of nutrient solution x substrate volume for fruit yield of tomato (123 das)

The interaction between concentration of nutrient solution x irrigation frequency was significant ($P=0.05$), dry weight was affected by the lowest nutrient concentrations and irrigation frequency. With 50% of nutrients and one irrigation, dry weight diminished by 4.33% in comparison with 50% of nutrients and seven irrigations (547.70 g m^{-2}). When the concentration rises to 75% and 100% with seven irrigations, it increases by 13.91 and 17.65%, respectively, while there is hardly any response in frequencies of one and four irrigations a day (Fig. 3). The long intervals of irrigation produce water stress, causing that there is no response to the low nutrient concentration (lowest absorption rate) and only with higher concentration, a satisfactory rate of nutrient absorption is achieved in order to promote higher growth, according to the characteristics of the nutrient solution applied as mutual relation between anions and cations, nutrient concentration expressed with electrical conductivity, pH, the $\text{NO}_3^-/\text{NH}_4^+$ relation, and temperature [25]. [15] As well observed in Cherry variety tomato that the volume of nutrient solution affected number and weight of the fruits.

The fruit yield was found to increase with increasing concentration of nutrients and irrigation frequency, yield grows gradually until reaching the highest fruit yield (12.31 kg m^{-2}) applying nutrient solution at 100%, distributed in ten irrigations a day. However, it is feasible for tomato production in hydroponics and greenhouse to utilize nutrient solution at 75%, distributed in seven irrigations a day (11.71 Kg m^{-2}), since significant diminution in fruit yield has not been observed.

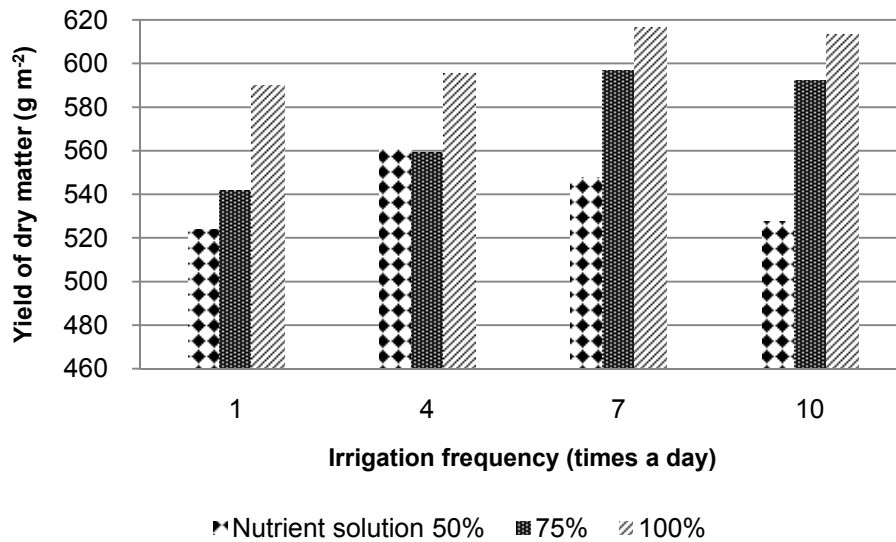


Fig. 3. Interaction concentration of nutrient solution x irrigation frequency for yield of dry matter of tomato (123 das)

3.6 Production Costs

In order to calculate the total cost of mean production per hectare of tomato in hydroponics and greenhouse (Table 3) the following items were considered: 1) Seed of Imperial variety, round fruit and indeterminate growth. 2) Nutrient solution proposed by [23], applied by spaghetti-type drip-irrigation ($1.8 \text{ L day}^{-1} \text{ plant}^{-1}$). 3) Tezontle substrate in black polyethylene bag, caliber 600, of 15 L. 4) Preventive and curative spraying: a) Insecticides: actara (a.i. Tiametoxam, talstar (a.i. Bifenthrin), orthene (a.i. Acephato) and decis (a.i. Deltamethrin); b) fungicides: ridomil gold bravo (a.i. Metalaxyl-M + Chlorothalonil), aliette (a.i. Aluminum phosetyl), cupravit mix (a.i. Copper oxychloride + Mancozeb) tecto (a.i. Thiabendazol) and interguzan (a.i. Quintozene + Thiram); and c) bactericides: agrygent (a.i. Gentamicin sulphate + Oxytetracycline hydrochloride).

In 2007, the total cost of the production ha^{-1} of tomato in hydroponics and greenhouse was 42263 U. S. dollars, and in 2008, 45167 U. S. dollars (increased by 6.9% compared to 2007) (Table 3). This rise occurred because of the widespread price rise in agricultural input (seed, bag, substratum, raffia, labor, and pesticides), cost of fertilizers, on the contrary, diminished by 3.7%. In 2007, fertilizer price increased, especially that of phosphoric acid, calcium, and potassium sulfate; whereas in 2008 prices diminished, and consequently the cost of nutrient solution was lower.

Table 3. Production costs of tomato in hydroponics and greenhouse, Chapingo, Mexico. 2007 and 2008

Description	Unit	Quantity (ha)	Unit price (US\$)		Cost (US\$)	
			2007	2008	2007	2008
Tomato seed	Piece	33400	0.1	0.1	2709	2967
Polyethylene bag	Piece	33400	0.1	0.1	3611	4385
Tezontle substrate	m ³	334	6.6	7.3	2193	2451
Nutrient solution	m ³	56.78	2.2	2.1	17766	17740
Raffia	kg	120	2.9	3.5	352	417
Labor	Wage	1440	8.5	9.3	12234	13346
Pesticides	Some	20	169.9	193.1	3398	3862
Total					42263	45167

US\$ 1 = 12.95 MEX\$. May 9th, 2014

In order to determine the profitability of tomato production in hydroponics and greenhouse we considered fruit yield and its market price to define income and total cost (expenditure). For 2007, considering the factors commonly used in tomato production in hydroponics and greenhouse in the State of Mexico, Mexico, nutrient solution at 100%, four irrigations a day and a container of 15 L, the other factors being kept constant, income of 48994 U. S. dollars was obtained (fruit yield of 104,700 kg ha⁻¹ and a price of 0.46 kg⁻¹ dollars) and the expenditure was 42255 U. S. dollars, which results in a profit of 6739 dollars. In 2008, under the same conditions, an income of 64941 U. S. dollars was calculated (Fruit yield of 128,200 kg ha⁻¹ and a price of 0.46 kg⁻¹) and expenditure of 45158 dollars, therefore, a profit of 19782 dollars was obtained, mainly due to a rise in fruit yield. This procedure was followed for each of the evaluated treatments, combination of three concentrations of nutrient solution (100, 75, and 50%), four irrigation frequencies (1, 4, 7, and 10) and three substrate volumes (5, 10, and 15 L) (data not presented) for determining the viability of modifying the factors of production, such as concentration of nutrient solution, irrigation frequency and substrate volume in order to reduce production costs without affecting the producer income.

In 2007, combinations of nutrient solution at 100%, one irrigation, and substrate volume of 5, 10, and 15 L presented loss of money: \$1020, \$1414, and \$701 U. S. dollars ha⁻¹, respectively, due to scarcity of water and nutrients; the greatest loss of money, however, was at diminishing the nutrient solution to 75 and 50%, combined with only one irrigation and substrate volume of 5 L (7873 and 4149 dollars ha⁻¹, respectively). In 2008, there was loss of money only with nutrient solution at 50% in one irrigation and substrate volume of 15 L (3279 dollars ha⁻¹) and with nutrient solution at 50%, four irrigations day⁻¹ and one container of 15 L (544 dollars ha⁻¹).

In 2007, higher profit was obtained with nutrient solution at 50%, seven irrigations and a substrate volume of 5 L, followed by 100% of concentration, 10 irrigations, and a container of 10 L; this indicates that it is indeed feasible modifying the factors of tomato production, the use of the inputs being efficient. In 2007, maximum profit of 47.2% was achieved with the best treatment (nutrient solution at 50%, seven irrigations, and substrate volume of 5 L), while in 2008, it was 73.9% with nutrient solution at 75% in seven irrigations and a container of 10 L.

4. CONCLUSION

Based on the results and the production costs of tomato in hydroponics and greenhouse, it is convenient to apply the nutrient solution at 75% in seven irrigations day⁻¹, with a substrate volume of 10 L in order to obtain good yield of dry matter and fruit of the plant, and the highest profit (73.9%).

As a result of increase in the cost of agricultural inputs (chemical fertilizers, containers, and pesticides) and to water shortage, the results of the present study contribute to increasing efficiency in tomato production and producer competitiveness.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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