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Production system with two stems with low, medium and high densities in a hydroponic tomato crop

Sistema de producción con dos tallos para baja, mediana y alta densidades en un cultivo de jitomate hidropónico

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Abstract

In the present work, a two-stem production management system was evaluated, for low density (2.6 plants m^{-2}), medium (3.5 plants m^{-2}) and high density (4.2 plants m^{-2}), in a tomato crop (*Solanum lycopersicum* L.) hydroponic. The evaluation consisted of making comparisons of the leaf area (LA), leaf area index (LAI), dry biomass, fresh biomass, and yield. An experimental trial was established with the cultivation of tomato in the spring-summer cycle of the year 2021, in the facilities of the National Institute of Agricultural and Livestock Forestry Research (INIFAP), San Martinito Experimental Field, Puebla. The experimental units were installed in a greenhouse with overhead ventilation. The transplant of the crop was carried out on April 27, 2021, using "*tepetzil*" as a substrate and a drip irrigation system. The results showed better growth and production variables in low density, followed by medium density, and finally, high density. The highest performance was presented by the density of 4.3 plants m-2, followed by the density of 3.5 plants m-2, and finally, the density of 2.6 plants m-2.

***Solanum lycopersicum* L., planting framework, Photosynthesis**

Resumen

En el presente trabajo se evaluó un sistema de manejo producción a dos tallos, para baja densidad (2.6 plantas m^{-2}), mediana (3.5 plantas m^{-2}) y alta (4.2 plantas m^{-2}), en un cultivo de jitomate (*Solanum lycopersicum* L.) hidropónico. La evaluación consistió en realizar las comparaciones del área foliar (AF), índice de área foliar (IAF), biomasa seca, biomasa fresca, rendimiento. Se estableció un ensayo experimental con el cultivo de jitomate de ciclo de primavera-verano del año 2021, en las instalaciones del Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP), Campo experimental San Martinito, Puebla. Las unidades experimentales se instalaron en un invernadero con ventilación cenital. El trasplante del cultivo se llevó a cabo el 27 de abril del 2021, utilizando "*tepetzil*" como sustrato y un sistema de riego por goteo. Los resultados mostraron mejores variables de crecimiento y producción en la densidad baja, seguida de la densidad media, por último, la densidad alta. El mayor rendimiento lo presentó la densidad de 4.3 plantas m^{-2}, seguida de la densidad 3.5 plantas m^{-2}, finalmente, la densidad 2.6 plantas m^{-2}.

***Solanum lycopersicum* L., marco de plantación, Fotosíntesis**

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Introduction

The tomato (Solanum *lycopersicum* L.) is the most important vegetable at national and international level, the crop is demanding due to its great consumption, harvested surface and economic value. It is cultivated in many regions, mainly in arid climates, and is consumed for fresh production and agro-industrial use. The production of tomato is in constant growth, due to the increase of cultivated areas and new technologies that allow higher yields. This crop is characterised by being intensive, and is grown all year round by small, medium and large producers (López, 2016).

The use of greenhouses or shade houses is a production alternative and a marketing opportunity for products grown under these systems, since they offer protection against adverse weather conditions to crops, giving them better quality and higher yields (Corella *et al*., 2013). Greenhouse cultivation has been complemented by other technologies, including hydroponics with or without substrate, in which the management of the nutrient solution and irrigation are among the most important aspects. This type of system has resulted in higher crop quality and yields, as well as efficient use of water and fertilisers (Salazar *et al*., 2014).

Tomato yield is influenced by planting density, which plays an important role in increasing or decreasing the number of plants per unit area, which is attributed to the effect on dry matter production. Therefore, it is important to assess which planting density may be the most appropriate to maximise yield.

The characterisation of production systems provides a framework within which new agricultural development strategies can be identified. Based on the above, the objective of the present study was to evaluate the two-stem management system for low, medium and high density hydroponic tomato in an intensive system, analysing the main growth and production variables, in order to obtain general deductions, both on a regional and global scale.

Materials and methods

Experimental site

The present investigation was carried out at the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), San Martinito experimental field, located at the Federal Highway Mexico-Puebla km 56.5, C.P. 74100 Santa Rita Tlahuapan, Pue., whose coordinates are: 19°20'49.9" north latitude and 98°33'57.1" west longitude and an altitude of 2538 m.

Establishment of the experimental units

The experiment was set up in a greenhouse with natural zenithal ventilation, with a N-S orientation and covered by a layer of 720-gauge plastic sheeting 12 m wide x 52 m long. A two-stem production system was established, considering each stem as a plant. The pots were arranged in six double-row beds, in a three-bowl arrangement. Saladette tomato seed (*Solanum lycopersicum* L.) cv. "*Montezuma* F1" (Harris Moran) was used during spring-summer.

Sowing was carried out on 17 February 2021, in 200-cavity polystyrene trays. Polyethylene bags of 40 x 40 cm (13 L) were filled with this substrate. Transplanting took place on 27 April, and the culture duration was up to 11 clusters per stem. The experiment was set up using a completely randomised block experimental design consisting of three planting densities as treatments: Treatment 1 (density of 2.6 plants m^2), Treatment 2 (density of 3.5 plants m^2) and Treatment 3 (density of 4.3 plants m^2). Analyses of variance for yield and leaf area were carried out using Tukey's mean comparison tests with a significance level (α = 95%), using the Statistical Analysis System (SAS, 2004).

Irrigation system and nutrient solution

The drip irrigation system consisted of the insertion of self-compensating drippers of 8 L h^{-1}, with adapters with four outlets, each of these with their respective tubes and stakes placed in each pot, with a semi-automated system for programming irrigation, with which 12 irrigations of one minute each were programmed. This watering time was increased according to the development and growth of the plants.

The universal solution of Steiner (1984) cited by Martínez-Ruiz et al., (2019; 2020; 2021) was applied. In the vegetative stage, N (NO_3-:11, meq L^{-1}) was decreased by 1 meq L^{-1} and K (K^+:7.5, me L^{-1}) was increased by 1 meq L^{-1} in the fruit set and fruit set stage (reproductive stage).

Leaf area of the crop

Leaf area was measured every 10 days, from the beginning to the end of the experiment. Four plants per treatment were taken at random and brought to the laboratory to measure the length and width of each leaf. Leaf area was estimated using allometric models, based on non-linear regressions, which correlate the characteristic leaf dimensions of: length, width and combinations between them (Martinez-Ruiz 2019 and 2021) and with density the leaf area index was obtained.

Biomass production

For the determination of fresh and dry biomass, the same plants whose leaf area was determined in the laboratory were used, and the fresh weight of each of the plant organs was measured: leaves + flowers, stem + rachis and fruits. Subsequently, they were placed in bags and dried in a drying oven "TECSA", at a temperature of 72 ºC, until a constant weight was obtained using an analytical balance model 1500-2M (KERN EW), the total biomass was obtained from the sum of the weights of all the organs of the plant.

Crop yield

To measure yield, eight plants per block were randomly selected, each pot was labelled and identified with coloured ribbons in each treatment, which were followed throughout the growing cycle. The tomatoes were cut as they reached maturity and the weight of each plant was recorded. At the end of the experimental trial, the weight of each of the measurements recorded for each plant during the whole crop cycle was integrated; the total weight was considered as the yield value per stem.

Results

Leaf area index (LAI)

The values obtained for LA and LAI in the three treatments are shown in Figure 1, where the evolution of the LAI is observed, which are similar in the initial stage (start of transplanting) up to 40 days after transplanting (DAT). However, after 40 DAT, the IAI increased exponentially, with values of 0.5 m^2 m^{-2} for density 2.6 plants m-2, 0.7 m^2 m^{-2} for 3.5 plants m^{-2} and 0.9 m^2 m^{-2} for 4.3 plants m^{-2}. This exponential trend was maintained, reaching 3.5 m^2 m^{-2}, 4.08 m^2 m^{-2} and 6.03 m^2 m^{-2} (for 2.6, 3.5 and 4.3 plants m^{-2}, respectively).

From 93 DAT onwards, fruit growth and development was affected, since, being in a fruiting stage, the increase in leaf area stopped until a plateau was formed (93 DAT). At 114 DAT the fruit harvest began; at this stage the LAI is affected by the fall of leaves in the senescence stage, this behaviour is also reflected in the cultivation of poblano chili under greenhouse conditions reported by Mendoza-Pérez et al. (2017). The maximum LAI values obtained were 4.35 m^2 m^{-2}, 6.04 m^2 m^{-2} and 8.71 m^2 m^{-2}, for density 2.6, 3.5 and 4.3 plants m^{-2} respectively.

The density 4.3 plants m^{-2} showed the highest value, due to a higher number of plants per unit area. This behaviour was similar to the results found by Ruelas-Islas et al. (2022), where the maximum values of leaf area index for a two-stem production system was 4.66 m^2 m^{-2}, for a density of 3 plants m^{-2} in hydroponic greenhouse cultivation.

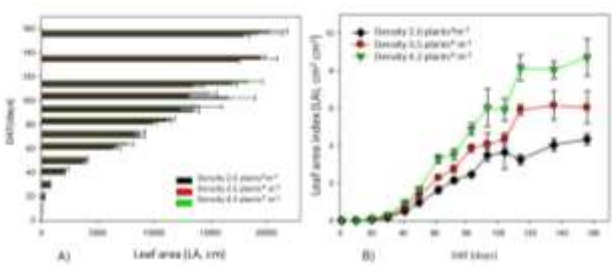

Figure 1 leaf area and leaf area index of the tomato crop in greenhouses

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DDT	Phenological stage	D	AF
41	Vegetative stage	2.6	1930.7 a
		3.5	1948.0 a
		4.3	2150.1 a
62	Flowering and fruit set	2.6	6336.6 b
		3.5	6579.1 a
		4.3	7687.1 a
93	Fruit development	2.6	13419 a
		3.5	11660 a
		4.3	14017 a
114	Beginning of harvest	2.6	12564 b
		3.5	16902 a
		4.3	18972 a
156	End of harvest	2.6	16717 b
		3.5	17262 ab
		4.3	20839 a

AF=leaf area (g plant^{-1}), D=density (plant m^{-2}), Means not sharing a letter are significantly different (Tukey, $p \leq 0.05$).

Table 2 Comparison of leaf areas for three different planting densities in hydroponic tomato cultivation in greenhouses

Fresh biomass

The accumulation of fresh biomass in the different planting densities of tomato is shown in Figure 2, where the partitioning of fresh matter in the different plant organs such as leaves (Figure 2A), stems (Figure 2B) and fruits (Figure 2C) and the production of total fresh biomass (Figure 2D) are presented. According to the phenology of the crop, the accumulation and distribution of fresh matter per organ showed a similar trend throughout the crop cycle for the three densities evaluated. In general, it can be seen that, from the beginning of the growth period, the leaves, together with the stems, show an exponential trend until reaching 120 DAT, after which the fruit is the organ that significantly increases its weight due to the full fruiting stage; this organ contributed considerably to the weight values for total fresh matter (Figure 2C).

Evaluations of the behaviour of fresh matter throughout the crop cycle are also mentioned by Juárez-Maldonado et al. (2015) in which they emphasise the same trends in timing. At 156 DAT (end of harvest) there were maximum values for leaves of 823.37 g plant^{-1} for density 2.6 plants m^{-2}, 845.01 g plant^{-1} for density 3.5 plants m^{-2} and 826.70 g plant^{-1} for density 4.3 plants m^{-2}. For stems, values found were 422.21 g, 468.11 g and 420.17 g plant^{-1}, respectively.

For the fresh biomass of fruits, Figure 2C shows an exponential growth from 93 DAT, where the stage of development and maturation of the fruits begins, as Peil and Gálvez (2005) point out when mentioning that "the first phase is of vegetative growth, then the fruits begin their development, where the remaining organs of the plant continue their decelerated growth, so that the fruits constitute the main organs of greater demand that compete among themselves and with the vegetative organs for the available assimilates".

The highest weight of fresh biomass resulted for the density 2.6 plants m-2, having better development conditions, however, it is observed that at the end of the cycle the density 3.5 plants m^{-2} increases its value in leaves, stem and fruits, this is due to the slower growth, but at the end of the cycle the growth of the plants was accelerated, so it showed higher weight. This crop, having an indeterminate growth, shows a continuous production of flower clusters and fruit production. This is corroborated by the total fresh matter data for all organs (Figure 2D).

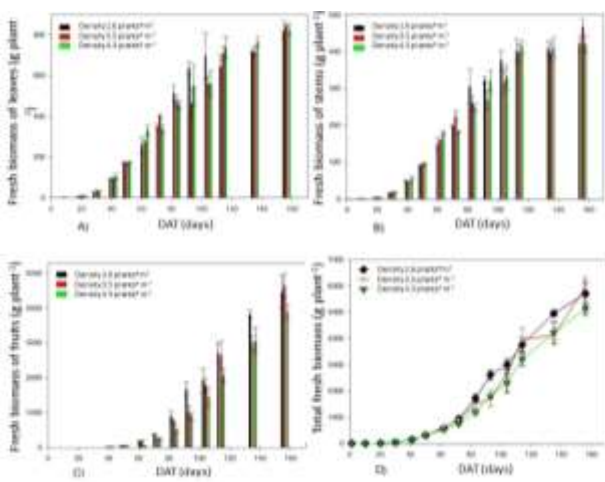

Figure 2 Fresh biomass of leaves A), stems B), fruits C) and total accumulation D) of the hydroponic tomato crop. DDT= days after transplanting

Dry biomass

Figure 3 shows the growth dynamics of leaves (Figure 3A), stems (Figure 3B) and fruits (Figure 3C), as well as the total dry matter (Figure 3D), resulting from the sum of the weights of the three organs. For the case of total dry biomass (Figure 3D), in the density 2.6 plants m^{-2}, its behaviour was of an exponential growth until 93 DAT, decelerating its development rate from those days after transplanting (fruit development), after 104 DAT it returns to its linear growth, until 120 DAT, then the development of the crop tends to stabilize, until the end of the cycle.

While the density 3.5 and 4.2 plants m^{-2} show the same exponential growth, from the beginning until reaching 114 DAT and a linear growth at 135 DAT. For the density 3.5 plants m^{-2}, an exponential increase was obtained in the course of the harvest until reaching its maximum value, while the density 4.3 plants m^{-2} maintains its linear growth. This indicates that the change in the increase in dry biomass at the harvest stage is influenced by nutrient demand, climatic conditions and planting density.

Similarly, it was found that at a density of 2.6 plants m^{-2}, 468.43 g plant^{-1} of total dry matter was accumulated, of which 24.90% was in leaves, 15.60% in stems and 59.50% in fruits. At the density 3.5 plants m^{-2}, the accumulation of total dry matter was 393.69 g plants m^{-1}, corresponding to 24.74% leaves, 17.23% stems and 58.03% fruits.

The density 4.3 plants m^{-2}, resulted in a total of 27.23% leaves, 16.96% stems and 55.81% fruits, corresponding to 27.23% leaves, 16.96% stems and 55.81% fruits, of 332.57 g plants m^{-1} of total dry matter. In this regard, Núñez *et al*. (2012) reported values of 46% for leaves and stems and 54% for fruits, slightly lower values for the densities 2.6 and 3.5 found in this research. Vargas *et al*. (2014) reinforce the results found in this study, who report that the greatest proportion of dry matter is destined to the fruits and a smaller proportion to the leaf tissues to foliar tissues.

Density m^2	Yield (kg plant $^{-1}$)		Performance (kg m^{-2})	
2.6	5.55	a	14.46	c
3.5	4.93	b	17.27	b
4.3	4.53	b	19.50	a

Means that do not share a letter are significantly different (Tukey, $p \leq 0.05$).

Table 3 Analysis of variance of yield for three planting densities of a hydroponic tomato crop in a greenhouse

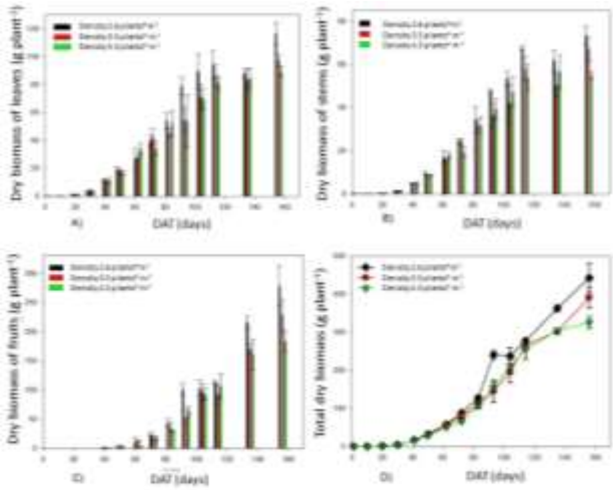

Figure 3 Dry biomass of leaves A), stems B), fruits C) and total accumulation D) of the hydroponic tomato crop. DDT = days after transplanting

Yield

During the time of the study, a total of nine fruit cuts were made and these were summed up to obtain the yield in each of the treatments. The density of 2.6 plants m^{-2}, showed a significantly higher weight per plant (Table 3), with a total of 5.55 kg plant^{-1}, followed by the density of 3.5 plants m^{-2} with a value of 4.93 kg plant^{-1} and, finally, the density of 4.3 plants m^{-2} with a value of 4.53 kg plant^{-1} and, finally, the density of 4.3 plants m^{-2} with a value of 4.53 kg plan^{-1}.

The highest yield was obtained at the high density, and the yields found were: 19.50, 17.27 and 14.46 kg m^{-2}, for densities 4.3, 3.5 and 2.6 plants m^{-2}, respectively. This is equivalent to: 144.55 t ha-1 for density 2.6 plants m^{-2}, 172.74 t ha^{-1} for density 3.5 plants m^{-2} and 195.05 t ha^{-1} for density 4.3 plants m^{-2}, finding significant differences between the three yields when expressing this variable with these units (Table 3). Mendoza-Pérez *et al*. (2018) reported close values, when increasing the number of stems, for a density of 3 plants m^{-2} in a similar hydroponic system. On the other hand, Grijalva, (2010) obtained a yield of 29.6 kg m^{-2} for a density of 3.78 plants m^{-2} worked to a single stem, grown in soil under greenhouse.

Conclusions

Under the conditions in which the present study was carried out, the crop showed higher yields at higher stocking densities, and the production of fresh matter, dry matter and leaf area index increased.

With this, it can be concluded that the density 2.6 plants m^{-2}, having higher fresh and dry biomass, yield per plant, as well as larger and higher quality fruits, was the treatment that presented better results. This was followed by density 3.5 plants m^{-2} and, finally, density 4.3 plants m^{-2}, where the plants and stems were more vigorous, but the fruits were smaller and developed more slowly.

The density 4.3 plants m^{-2} considerably increased the yield expressed in kilograms per surface area, compared to the other two treatments, and was 11.44% higher than the density 3.5 plants m^{-2} and 25.9% higher than the density 2.6 plants m^{-2}. Therefore, working this hydroponic system at different densities allows obtaining production of different quality, whose target market depends on the size of the fruit. Hydroponics continues and will continue to be a technology that allows higher yields and higher quality of harvested products.

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