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REGULAR ARTICLE

Substrate volume and nursery times for earliness and yield of greenhouse tomato

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ABSTRACT

In nurseries, seedling management can be an option to increase the yield and earliness of the harvest of *Solanum lycopersicum* L. in the greenhouse. The objective of this study was to evaluate substrate volumes and days in nursery of tomato seedlings evaluating root and seedling height, as well as, their effects on harvest earliness and yield. Two independent and consecutive experiments were carried out. The first experiment was done in the nursery where the volumes 22, 100, 150, 250, 350 and 450 cm^3 substrate and, 30, 40, 50 and 60 nursery days were evaluated. The control was 22 cm^3 and 30 days. The variables evaluated were: Seedling height, stem diameter, length and volume of the root and fresh and dry root weight. The second experiment was the cultivation of seedlings in composted maguey bagasse, agrolite and the normal soil as the control. The response variables were days till harvest after transplanting and total yield. Both experiments were conducted in a randomized complete block, with three repetitions and twenty plants per experimental unit. In the nursery, all variables increased with the increasing of substrate volume and nursery time. In cultivation, the highest total yield (8.20 kg plant^{-1}) were obtained with seedlings produced with 22 cm^3 volume of substrate and 30 nursery days. Seedlings with substrates volumes greater than 100 cm^3 and more than 40 days in the nursery began the fruit ripening and harvest 60 days after transplantation. The control initiated it at 90 days.

Keywords: Earliness; Yield; Nursery; *Solanum lycopersicum*; Substrate volume

INTRODUCTION

Tomato (*S. lycopersicum* L.) is the most cultivated and most important vegetable in the world (FAO, 2015). In Mexico, in the last 50 years, the cultivation of *S. lycopersicum* went from an extensive open air in-ground system to a hydroponic greenhouse system. The combination of advanced greenhouses, fertigation and soilless culture has helped tomato to achieve yields higher than 600 t ha^{-1} (Salazar et al., 2012). The initial investment under this production system is high, 70% of the cost is the greenhouse and drip irrigation, while the other 30% is inputs and labor of cultivation. On average, the time from tomato transplant to harvest is 90 days in warm regions and 105 days in temperate and cold regions. During this time, spending on inputs and labor is high and no sales incomes of the fruit are perceived (Martinez-Gutiérrez et al., 2014). This emphasizes the need to generate technologies to reduce the time from transplant to harvest. In intensive horticulture, a rarely unexplored option is the use of different sizes and shapes of containers for seedling production in the nursery, as well as, the time they can stay in this stage without affecting post-transplant survival, yield and the beginning of the harvest.

In Mexico, the agro industry that produces tomato seedlings (S. *lycopersicum* L.), in a nursery, usually uses expanded polystyrene containers of 200 cavities; each cavity containing 22 cm^3 of substrate volume. This small volume of substrate allows the productions and commercialization of larger quantities of seedlings per m^{-2}, use less substrate, reduce costs and facilitate the handling of containers in the nursery (Poorter et al., 2012). However, in these nurseries, the physiological and morphological parameters of the seedlings needed for optimal development are not considered, nor are the effects they can have on growth and yield after transplant (Sanchez et al., 2012; Urrestarazu, 2015). A small volume of cavity or container uses little substrate, reduces the availability of water and nutrients to the plant and restricts

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root growth (Poorter et al., 2012; Urrestarazu, 2015), causing hypoxia and etiolation of the shoot, factors that affect seedling quality and behavior after transplanting. In forest species, the type and size of the container is directly related to the root morphology and shoot development, it also influences greatly in the success of the crop (Muñoz et al., 2011; Thetford et al., 2005; South et al., 2005). In vegetables like tomato (*Solanum lycopersicum* L), Kemble et al. (1994) and Ruff et al. (1987) by increasing in 20% the container volume, the time from sowing to the anthesis was reduced. Nesmith et al. (1992) using small containers in nurseries for pepper (*C*apsicum *annuum* L.), cantaloupe (*Cucumis melo*) and tomato (*Solanum lycopersicum* L.) found lower volume root, water consumption and less nourished plants, this factors decreased post-transplant survival as well as quality and yield of fruit. Meanwhile, Cooper et al. (2002) reported that in tomato, by increasing the volume of the cavity, the flowering and harvesting earliness increased. Using seedlings originating from apical cuttings of 30 cm length, the tomato harvest began 70 days after transplant, a 50 days reduction compared to seedlings originating from seed (De Bruin and Sande, 1986; Juárez et al., 2000).

The objective of this study was to evaluate the effect of substrate volume and residence times in the nursery on yield and harvest earliness of S. *lycopersicum* L. in substrates and soil under greenhouses.

MATERIALS AND METHODS

Two experiments were conducted from April to November 2014. The first one was done in the nursery, the second one in cultivation for yield and earliness of harvest. Both were carried at the Interdisciplinary Center of Research for Regional Integral Development of the National Polytechnic Institute, Unit Oaxaca (CIIDIR-IPN-Oaxaca) in Santa Cruz Xoxocotlan, Mexico (17º 13 '21.28' LN, 96º 44 '33.19' LO and 1550 m) under a multi-tunnel greenhouse (Castilla, 2007) with a metal structure and a covering of white low density polyethylene. The plant material was tomato (S. *lycopersicum* L. cultivar El Cid) of indeterminate growth and "pear" or "saladette" fruit type, from Harris Moran Company®.

Experiment 1: Volume substrate and nursery days

The substrate used in the nursery was a mixture of peat *Sphagnum*® - perlite in 4:1 (v/v) and as containers "Styrofoam" cups of cylindrical type of Convermex® Company.

The experimental design was done in randomized complete block with three repetitions and a factorial arrangement of treatments, which were: Six volumes of substrate (22, 100, 150, 250, 350 and 450 cm^3) and four residence times in the nursery (30, 40, 50 and 60 days); the combination of cells of 22 cm^3 volume and 30 days in the nursery as control, 24 treatments in total. Each treatment had 60 seedlings, 20 were placed as a border against edge effect, and 40 in full competition, of which 20 were used for the first experiment and the other 20 were used for the second experiment. The sprinkler irrigation was done with a Swissmex® backpack hand sprayer of 15 L. Nutrient applications were made daily, using a solution of 75, 20 and 75 mg L^{-1} of N, P and K, respectively. The variables evaluated at the end of each residence time in the nursery were: Seedling height (cm) from the stem base to the apex; stem diameter (mm) measured with a digital vernier Serie 500 Mitutoyo® (USA), fresh and dry root weight (g) measured after 72 h in a stove with continuous flow at 70°C; and, root volume measured by water displacement and the main root length in cm.

Experiment 2: From transplant to harvest

A randomized complete block experimental design with a complete factorial arrangement of treatments of 6 x 4 x 3 was used to analyze six volumes of substrate, four residence times in the nursery and three culture systems: Agrolite, composted maguey bagasse (Martinez-Gutiérrez et al., 2015) and normal soil as the control, what generated 72 treatments with three repetitions and twenty plants per experimental unit. The substrates of composted maguey bagasse and agrolite had particles of 1.19 and 2.00 mm in diameter and black polyethylene bags of 18 L as containers. Each substrate corresponded with a treatment and soil functioned as control. The planting density was 3.5 plants m^2, using only one steam limited until the sixth raceme. Drip irrigation was used and the nutrient solution in mg L^{-1}: N = 250, P = 60, K = 300, S = 200, Mg = 75, Fe = 3, Mn = 0.5, B = 0.5, Cu = 0.1, Zn = 0.1 was applied at 100% concentration in the substrates and 50% in soil. The variables analyzed were earliness of harvest and total yield (kg $plant^{-1}$). Earliness of harvest was determined as the days required for the plant to reach commercial maturity of the fruit post-transplant, while total yield (kg $plant^{-1}$) was determined as the sum of the eight cuts, including commercial and noncommercial fruits.

In both experiments, an analysis of variance and comparison of means with the Tukey test ($P \leq 0.05$) was obtained, for each variable evaluated. Statistical analyzes were performed using SAS program, version 9.0 (SAS Institute, 2002). For the second experiment, the response surface methodology was used using a second-order polynomial model (Montgomery, 2006) and, to analyze it MATLAB® R2009a (Version R2009a, the MathWorks Inc., Massachusetts, USA) software was used.

RESULTS AND DISCUSSION

Substrate volumes and nursery days

Substrate volume, residence times in the nursery and their interaction showed significant effects ($P \leq 0.05$) in seedling height, stem diameter, length and volume of the root, and dry and fresh root weight (Table 1). The plants showed a higher growth when they spent more time in the nursery and with a greater volume of substrate.

Seedlings produced with 450 cm^{-3} of substrate and 60 days in the nursery were the tallest (56.55 cm) (Table 2). They also reached high values: Stem diameter (7.80 mm), length (59.50 cm) and volume (44.50 cm^{-3}) of the root and, fresh (42.50 g) and dry (4.14 g) root weight (Table 2). Seedlings of 14.26 and 16.97 cm height were obtained using volume of substrate of 22 and 100 cm^3 and 30 days in the nursery. These results were similar to the ones obtained by Sánchez et al. (2012) using substrate volumes of 36.8 and 85.9 cm^3 (14.39 and 16.29 cm, respectively). Seed companies for transplantation of *Solanum lycopersicum* L. recommend both heights. Seedlings produced in cells or containers of larger volumes show little root restriction; therefore, optimizing nutrients, water and light which promotes greater expansion of leaves, stems and roots (Oviedo et al., 2012; Oagile et al., 2016).

Using the smallest volume of substrate (22 cm^3) and least time in the nursery (30 days), the seedlings showed the lowest values for most variables evaluated.

Roots compete for water, nutrients, space and oxygen when they are confined in a container that restricts their growth. The geometry of the container also directly influences the availability of these resources (Nesmith and Duval, 1998). A consequence of the use of small containers for the propagation of seedlings is that as the seedlings grow, water demand increases and causes water stress response in the root growth, as well as, the decrease of seedlings appearance (Sanchez et al., 2006); which affects their quality and behavior after the transplant (Sakurai et al., 2007).

Total yield

The total yield varied in all factors evaluated, as well as their interactions. In earliness of harvest significant differences were found ($P \leq 0.05$) among substrate volume, culture systems and the interaction of substrates volumes and culture systems (Table 3). The residence time for seedlings of S. *lycopersicum* L. in the nursery did not affect harvest earliness which can in turn influence the cost of the plant, by staying for more than 30 days in the nursery.

The total yield of the fruits of *S. lycopersicum* L. was significantly lower in maguey bagasse and agrolite than in normal soil, and in the three culture systems, the total yield decreased by increasing the days in the nursery and the volume of substrate.

The second-order polynomial model was the most adjusted for the three culture systems with R^2 of 0.9904 for soil, 0.9915 for agrolite and 0.9694 for composted maguey bagasse (Table 4).

Response surface analysis showed that S. *lycopersicum* L plant, cultivated in soil with 22 cm^3 of substrate volume and 30 days in the nursery obtained the maximum yield, on average: 8.30 kg $plant^{-1}$ (Fig. 1a). By increasing the substrate volume 150, 250, 350 and 450 $cm^{3;}$ without altering the 30 nursery days, the average yield was similar (8.20 kg $plant^{-1}$) which means the total yield did not significantly increase. These results contradict what Cooper et al. (2002) mentioned, that a greater volume of substrate per seedling in nursery influences the fruit size and consequently, the total yield of the harvest (2002). However, it reinforces the results obtained by Sánchez et al. (2012) who did not find significant differences in average fruit weight and yield per plant in tomato, by increasing the volume of substrate in seedlings of 12.3 to 85.9 cm^3.

According to the response surface methodology, of the three culture systems the lower yield (3.8 kg $plant^{-1}$) was obtained on the substrate of agrolite and tomato seedlings that remained 60 days in the nursery with

Table 1: Analysis of variance and statistical significance of variables in root and seedling variables of *S. lycopersicum* L. in nursery stage

Variables	Means square			
	Substrate volume (SV) (5)‡	Nursery times (NT) (3)	SV*NT	Error (24)
Root				
Volume	517.26**	1004.12**	129.54**	1.059
Lenght	865.04**	1318.79**	81.59**	3.64
Fresh weight	426.45**	357.78**	83.98**	2.49
Dry weight	12.04**	0.67**	0.04**	0.01
Plant				
Seedling height	5235.21**	16856.20**	136.74**	50.36
Stem diameter	41.01**	32.92**	0.63**	0.492

‡In parenthesis are the degrees of freedom that correspond to each source of variation, **Highly significant with $P \leq 0.01$

Table 2: Seedling height and variables of root of *S. lycopersicum* L. as response to different substrate volumes and nursery times

Days	Substrate volume cm^3						CV
	22	100	150	250	350	450	
Seedling height (cm)							
30	14.26Cc*	16.97Bc	18.06BCb	20.84Bc	20.73Bb	27.74Ab	24.46
40	34.45Ca	31.99Cb	39.14Ba	41.81Bb	44.56Ba	53.16Aa	7.00
50	27.23Cb	39.65Ba	43.04Ba	42.97Bb	46.94Ba	55.18Aa	6.42
60	26.44Db	36.69Ca	43.26BCa	54.09ABa	48.89Ba	56.55Aa	13.22
CV	12.58	10.42	15.24	18.14	14.01	17.29	
Steam diameter (mm)							
30	3.00Bc	5.06Ab	4.99Ab	4.88Ab	5.26Ab	5.56Ab	12.61
40	4.27Db	5.73Ca	6.58Ba	6.57Ba	7.30Aa	7.97Aa	3.65
50	3.82Db	5.76Ca	6.24Ba	6.24Ba	6.96Aa	7.57Aa	9.01
60	5.13Ca	6.31Ba	6.43Ba	6.17Ba	6.89Ba	7.80Aa	8.91
CV	5.22	10.17	8.71	9.62	3.40	11.84	
Root length (cm)							
30	9.05Db*	12.15Cd	17.35Bc	18.75Bd	19.30Bc	22.05Ad	3.57
40	11.80Fb	20.00Ec	24.5Db	29.25Cc	34.00Bb	38.50Ac	7.76
50	20.65Fa	26.45Eb	29.9Da	40.25Cb	46.65Ba	55.40Ab	2.54
60	21.70Da	29.15Ca	31.00Ca	48.00Ba	47.55Ba	59.50Aa	3.49
CV	11.72	14.28	10.65	10.24	15.46	12.32	
Root volume (ml)							
30	2.95Ec	3.85Dc	5.05Cc	5.95Bc	6.40Bd	7.50Ac	5.00
40	8.55Eb	11.2Db	14.20Cb	15.40Cb	19.20Bc	21.25Ab	3.88
50	10.50Ea	13.8Da	16.70Db	21.75Ca	34.75Bb	42.50Aab	4.09
60	11.95Da	14.9Da	19.35Ca	22.40Ca	39.00Ba	44.50Aa	3.52
CV	6.89	10.91	7.42	5.23	8.03	10.75	
Fresh root weight (g)							
30	4.15Eb	6.15Dc	8.10Cc	9.85Bd	11.75Ad	12.80Ad	5.92
40	4.90Fab	7.00Ec	8.45Dc	12.40Cc	14.05Bc	16.55Ac	6.58
50	5.50Fa	9.20Eb	11.05Db	14.50Cb	19.40Bb	28.00Ab	6.16
60	5.95Ea	12.45Da	13.40Da	21.30Ca	31.00Ba	42.50Aa	8.77
CV	6.24	8.61	10.48	11.67	8.36	5.60	
Dry root weight (g)							
30	0.75Da	0.63Dc	1.45Cc	1.93Cb	2.67Bb	3.35Ab	1.23
40	0.13Fc	0.92Eb	1.55Db	2.14Ca	2.94Bb	3.42Ab	2.22
50	0.41Db	1.17Ca	1.66Ca	2.26Ba	3.17Aa	3.45Ab	0.67
60	0.62Fa	1.32Ea	1.75Da	2.38Ca	3.22Ba	4.14Aa	1.81
CV	5.33	8.54	9.41	9.30	5.75	5.83	

CV: Coefficient of variation, *: Values followed by different letters indicate statistically significant differences Tukey ($P\leq0.05$), upper case letters are compared horizontally and lowercase vertically

Table 3: Significance of factors: Volumes substrate, nursery times and culture systems and their interactions on the total yield and earliness of the harvest of *S. lycopersicum* L.

Factors	Total yield	Earliness of the harvest
Substrate volumes (SV)	*	*
Nursery times (NT)	*	NS
Culture systems (CS)	*	*
SV x NT	*	NS
SV x CS	*	*
NT x CS	*	NS
SV x NT x CS	*	NS

NS: Not significant, *: Significant with $P\leq0.01$

Table 4: Response surface analysis model fitting using LOESS (Cleveland, 1979) of each culture substrate of *S. lycopersicum* L.

Substrate	Data points	DFE	R^2	RMSE	SSE
Agrolita	24	16	0.9915	0.0986	0.1556
Maguey Bagasse	24	16	0.9694	0.1866	0.5568
Soil	24	16	0.9904	0.0958	0.1467

DFE: Degrees of freedom, R^2: Root squared, RMSE: Root mean squared error, SSE: Sum of squared error

450 cm^3 volume of substrate (Fig. 1b). Increased substrate volumes and two months of the seedling in the nursery caused larger quantity, length and fresh weight of roots (Table 2). However, in tomato this large amount of roots at the transplant were physiologically inactive as shown by Peterson et al. (1991) who indicate that restriction of the roots caused by a reduced volume in the nursery provoke loss of primary and post-transplant roots, increases the

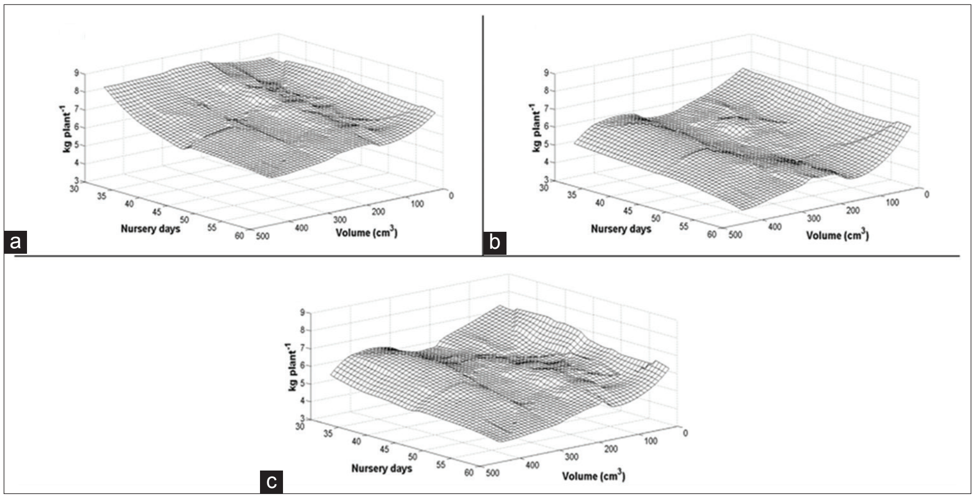

Fig 1. Response surface for the factors: Substrate volumes and residence time in the nursery and their effect on the total yield of tomato S. *lycopersicum* L., cultivated in: a) soil, b) agrolite and c) composted maguey bagasse.

number of secondary and adventitious roots, which are physiologically more active.

The total yield of S. *lycopersicum* L. in the composted maguey bagasse substrate and its behavior for substrate volume and residence time of the seedlings in the nursery (Fig. 1c), was similar to the one obtained in soil. This is probably due to the fragile management of fertirrigation in cultivation of substrates compared to the goodness of the soil, as Ojodeagua (2008) states when he compares the culture of S. *lycopersicum* L. in substrate of tezontle and normal soil.

Earliness of harvest

All volumes of substrate greater than the control (22 cm^3) persuaded tomato plants to start early ripening fruit (Fig. 2). Seedling of *S. lycopersicum* L. produced in containers of 22 cm^3 and 30 nursery days reached maximum yield (8.2 kg $plant^{-1}$); however, the fruit ripening and the beginning of the harvest lasted up to 90 days (Fig. 2). Volumes of substrate larger than 100 cm^3 stimulated fruit ripening and harvest began 60 days after transplantation, with a decrease of 30 days compared to the control (Fig. 2). This may be because by increasing the volume of the cavity and therefore the substrate, the flowering and harvest earliness are increased (Cooper et al., 2002; Sanchez et al., 2012). In addition, a larger volume of substrate improves the quality of seedlings, because it has better balance between shoot and root system and no stress post-transplant (Seabra et al., 2004; Oviedo et al., 2012).

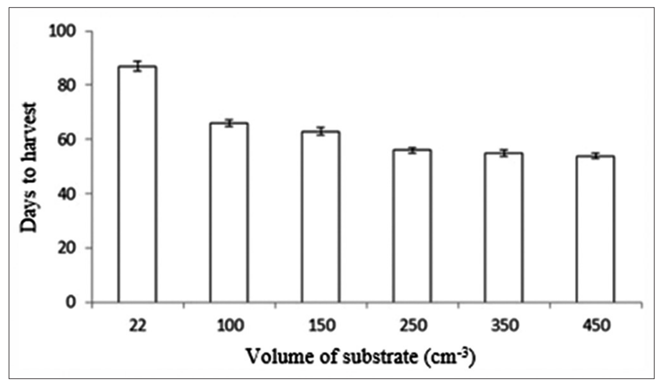

Fig 2. Substrate volume effect on days that *S. lycopersicum* L. harvest begins and greenhouse soil substrate. The vertical lines in bars indicate standard error (n = 3).

CONCLUSIONS

The tomato seedlings produced with a greater volume of substrate and nursery time were the tallest with greater diameter of the stem, length and volume of the root, and dry and fresh root weight. The seedling with lower volume of substrate and residence time in the nursery obtained the highest yield of the fruit, when increasing the volume of substrate and nursery time, yield did not increase.

Seedlings cultivated in normal soil obtained the greatest yield compared to the ones cultivated on agrolite and composted maguey bagasse.

Using seedlings produced with higher substrate volumes and residence times in the nursery, the time from transplant to harvest is reduced, which can be considered as a technological option to increase the culture cycles in greenhouse tomato; however, an economic analysis should be done before implementation.

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Author contribution

Gabino A. Martínez-Gutiérrez and Isidro Morales conducted the experiments and were responsible for the final review of the manuscript. Cirenio Escamirosa-Tinoco and Teodulfo Aquino-Bolaños designed the experiments and drafted the manuscript. Martín Hernández-Tolentino participated in the laboratory work and the data analysis. All authors read and approved the final manuscript.

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