Asian Journal of Crop Science

ISSN 1994-7879

OPEN ACCESS Asian Journal of Crop Science

ISSN 1994-7879
DOI: 10.3923/ajcs.2020.130.140

Research Article
Effects of Container Sizes and Nutrient Solution Concentrations on Growth and Yield of Chilli

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Abstract
Background and Objective: Management of high substrate volume in soilless culture is crucial to avoid increases use of water and fertilizer, manpower, pollution problem and for optimal growth and yield of vegetable crops. This study was conducted to determine the effects of different container sizes combined with fertilizer concentration on chilli growth and yield attributes. **Materials and Methods:** This study was performed in a split plot design with 5 replications. Treatments comprised of 1.5 and 2.5 dS m^{-1} fertilizer concentration subjected to 2805, 6831 and 10557 cm^3 container size. Dry matter production was carried out at 30, 60, 90 and 120 days after transplanting, while yield attributes were obtained upon harvesting at 120 days. The effects due to the treatment combinations were analyzed using analysis of variance (ANOVA) and mean comparison was done using Least Significant Different (LSD) at $p \leq 0.05$. **Results:** Treatment of EC 1.5 dS m^{-1} subjected to 2805 cm^3 container showed a reduction of plant growth, root morphology and yield compared to the control treatment of EC 2.5 dS m^{-1} in 6831 cm^3 container, especially in photosynthesis rate and stomatal conductance. A similar yield over the control was found in the 10557 cm^3 container. Therefore, 6831 cm^3 container size with EC 2.5 dS m^{-1} can be recommended for chilli production in soilless culture. **Conclusion:** The use of EC 2.5 dS m^{-1} in 6831 cm^3 container in soilless culture for chilli production is optimum and practical management practice.

Key words: Chilli, soilless culture, fertilizer concentration, container size, root morphology, photosynthesis rate

Citation: Nurul Idayu Zakaria, Mohd Razi Ismail, Yahya Awang, Puteri Edaroyati Megat Wahab and Zulkarami Berahim, 2020. Effects of container sizes and nutrient solution concentrations on growth and yield of chilli. Asian J. Crop Sci., 12: 130-140.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In Malaysia, vegetables are crucial food crops with a planted area of about 63,569 hectares and total annual production[1] of about 1,195,647 t in 2016. The production of high value vegetable crops such as chilli (*Capsicum annuum* L.) under the family of Solanaceae[2] is related to problems of poor physical soil properties and soil borne diseases[3]. Management system to improve the level of self sufficiency of chilli in Malaysia which is currently at 51.4% can be achieved with a soilless culture system[4]. In soilless culture, there is a higher requirement of a soilless substrate which increased the production cost and reducing the volume of a substrate could potentially improve the utilizing efficiency of this resource. The size of the container and a volume of the substrate determine the roots development[5] as well as water, nutrient and oxygen availability. The size of the root system and nutrient are related where container size determines the root size while available nutrients limit the plant size[6]. Therefore, careful management of nutrient concentration[7] in a limited root system is important to avoid toxicities due to over fertilization[8] and prevent wastage[9].

Nutrient availability in the limited physical space of soilless substrate significantly interferes with plant physiology, growth and yield. The plant grown in a small container with a high concentration of nutrient supply had efficient nutrient uptake[10] and affected N, P and K in the plant organ[11] but had a reduction of root, leaf and total plant growth. On the other hand, plants grown in the large containers had larger roots and shoot independent of a low or high amount of nutrients[12,13] and showed that leaf growth was dependent on the available space of root growth because with roots is the primary site of synthesis of growth substances[14]. When nutrient solutions were applied at a constant rate, large container size can retain more nutrients and provides high nutrient pool than the small rooting space. Besides, plant root ability is primarily to sense the available rooting space independent of the available nutrients[15].

Container size significantly affected photosynthesis rate and capacity of the source and sink organ in cotton plants[16]. On the other hand, low fertilizer concentration of 0, 1.0 and 2.0 dS m^{-1} on vinca plant (*Catharanthus roseus*) grown in different container size improved the CO_2 assimilation and transpiration rate but decreased with 4 dS m^{-1} electrical conductivity (EC) probably[17] because of high salt concentration and sodium accumulation in the plant tissue[18]. In general, the interaction between the EC of nutrient solution in different container sizes on chilli growth and yield has been not well documented. The benefit of optimal nutrient concentration for chilli will depend on the different container sizes. Therefore, the objective of the present study was to determine the effects of nutrient solution concentration combined with different container sizes on chilli growth, root morphology, physiological response and yield.

MATERIALS AND METHODS

Experiment site, treatments combination and experiment design: The experiment was conducted under a rain shelter at the Institute of Tropical Agriculture Protected Complex, Taman Pertanian Universiti, Universiti Putra Malaysia for 4 months from July to October, 2010. Seeds of chilli plants (*Capsicum annuum* var Kulai) were raised in peat moss and seedlings consisted of four true leaves were transplanted into white polybag containing a mixture of coconut coir dust and empty fruit bunch compost (70:30, v:v) after 4 weeks of germination. The nutrient solution concentration given via drip irrigation system was based on Cooper[19] formulation presented in Table 1-3.

Table 1: Amount and EC of nutrient solution supplied to the chilli plants used by the local grower's practice

Days	Amount of nutrient solution (mL/day)	EC of nutrient solution (dS m^{-1})
1-7	300-500	1.2
8-14	400-600	1.3
15-21	700-800	1.4
22-28	800-1200	1.5
29-35	1200-1500	1.6
36-49	1500-1800	1.8
50-70	1800-2000	2.0
71-120	>1800	2.0-2.8

Source: Standard amount of irrigation recommended by extension agency, Department of Agriculture, Malaysia, EC: Electrical conductivity

Table 2: Nutrient concentrations (mg L^{-1}) for Cooper standard solutions used in this study

Nutrients	Concentration (mg L^{-1})
N (Nitrogen)	200.0
P (Phosphorus)	60.0
K (Potassium)	300.0
Ca (Calcium)	170.0
Mg (Magnesium)	50.0
Fe (Ferrum)	12.0
Mn (Manganese)	2.0
B (Boron)	1.5
Zn (Zinc)	0.1
Cu (Cooper)	0.1
Mo (Molybdenum)	0.2

Table 3: Composition of concentrated nutrient solution used for the fertilizer stock solution

Fertilizer/salts	Formula	Weight of salt (g) in 30 L water
Stock A		
Calcium nitrate	$Ca(NO_3)_2.4H_2O$	6668.67
Ferrum EDTA	$CH_2N(CH_2.COO_2)_2$ FE Na	526.67
Stock B		
Potassium dihydrogen phosphate	KH_2PO_4	1753.33
Potassium nitrate	KNO_3	3886.67
Magnesium sulphate	$MgSO_4.7H_2O$	3420.00
Manganese sulphate	$MnSO_4.H_2O$	40.67
Boric acid	H_3BO_3	11.33
Copper sulphate	$CuSO_4.5H_2O$	2.60
Zinc sulphate	$ZnSO_4.7H_2O$	2.93
Ammonium molybdate	$(NH_4)_6MO_7O_{24}.4H_2O$	2.47

Table 4: Treatments combination with the specification of the polybag used in this experiment

		Specification of polybag			
EC (dS m^{-1})	Container volume (cm^3)	Polybag dimension (long×wide×height (cm))	Polybag size	Quantity of growing media mixture (kg)	Ratio of CCD:EFB (kg:kg)
1.5	2805	17×15×11	12×12″	0.60	0.42:0.18
	6831	27×23×11	20×20″	1.43	1.0:0.43
	10557	27×23×17	20×20″	1.86	1.3:0.56
2.5	2805	17×15×11	12×12″	0.60	0.42:0.18
	6831	27×23×11	20×20″	1.43	1.0:0.43
	10557	27×23×17	20×20″	1.86	1.30:0.50

EC: Electrical conductivity, CCD: Coconut coir dust, EFB: Empty fruit bunch

The experiment was conducted as a factorial experiment design with 2 different EC of nutrient solution (1.5 and 2.5 dS m^{-1})×3 container size (2805, 6831 and 10557 cm^3) as presented in Table 4. The EC 2.5 dS m^{-1} as a control in this experiment was based on previous study by Mokhtari *et al.*[20]. The container size of 2805, 6831 and 10557 cm^3 were chosen based on the lowest, highest and similar yield, respectively obtained in the previous experiment. The experiment was arranged in split plot design with 5 replications. The main plot was the EC level while the subplot was container size.

Data collection: Plant height was measured from the ground level to shoot tip using a measuring tape. Stem diameter was measured with vernier calipers and total leaf area using leaf area meter (Li-3000, Li-cor Inc., Lincoln, NE, USA). Five readings were taken per measurement in each treatment at 30 and 120 days. Five plants representing 5 replications were sampled from each treatment at 30, 60, 90 and 120 days and partitioned into leaves, stems and roots before oven dried at 65°C for 72 h for determination of dry weight using an electrical weighing balance (TX3202L, Shimadzu Corporation). The root: shoot ratio was calculated based on dry weights of shoot and root parts using the equation[21]:

$$\text{Root:Shoot ratio} = \frac{\text{Total root dry weight}}{\text{Total shoot dry weight}}$$

Photosynthesis rate, stomatal conductance, intercellular CO_2 and transpiration rate was performed at 90 and 120 days on the abaxial surface of 3rd or 4th fully expanded leaves from the tip between 10:00-11:00 am using a portable infrared gas analyzer model Li-6400XT (Li-cor Inc., Lincoln, NE, USA). The measurement was taken from 4 plants at a CO_2 flow rate of 400 μmol m^{-2} sec^{-1} and the saturating photosynthetic photon flux density (PPFD) was 900 mmol m^{-2} sec^{-1}. Relative chlorophyll content was taken on the third uppermost fully expanded leaves using a SPAD-502 meter (Minolta Corp., Ramsey, N.J.). Measurement was taken from 5 plants per treatment at the following growth stages: 14, 30, 60, 90 and 120 days.

Roots from 3 representative plants from each treatment were scanned and analyzed using the root image analyzer (WinRhizo STD 1600+ Scanner, Regent Instruments Inc., Quebec, Canada) to estimate total root length and root surface area at different growth stages 30, 60, 90 and 120 days. The macronutrient content including nitrogen (N), phosphorus (P) and potassium (K) of the shoot samples were analyzed. Four to five leaves of third and fourth leaves from the tips were sampled from three representative plants from each treatment at 30 and 90 days. The N and P content was determined using the automated ion analyzer system (QuikChem® FIA+ 8000 Series, Lachat Instruments), while K was analyzed by using an atomic absorption (AA) spectrophotometer (3110, PerkinElmer).

Mature fruits were harvested from ten representative plants from each treatment at fruit ripening stage until 120 day after transplanting (DAT). Total numbers of fruits were calculated and total fruit fresh weight was weighed using an electronic balance. Fruit length was measured using a ruler and fruit diameter was determined by using vernier caliper. The harvest index was calculated as the ratio between fruit biomass and total plant biomass from five representative plants from each treatment as described by Hunt[22].

Statistical analysis: Two-way analysis of variance was used to test for main effects and interaction of nutrient concentration and container size using statistical analysis system[23]. Least Significant Different (LSD) at $p \leq 0.05$ was used to test for significant differences between treatment means.

RESULTS

Plant height, stem diameter and leaf area: There was no significant interaction between fertilizer concentration and container size on plant height, stem diameter and leaf area. At 120 DAT, container size of 2805 cm^3 did not affected plant height however, significantly reduced stem diameter and total leaf area with their respective values of 1.34 cm and 4528.51 cm^2 which were 10 and 38% lower than that of 6831 cm^3 container as shown in Table 5. Plants grown in 10557 and 6831 cm^3 container size had similar stem diameter (1.43 and 1.49 cm) and total leaf area (7821.83 and 7251.07 cm^2). The EC 1.5 dS m^{-1} contributed to lower plant height (85.80 cm), stem diameter (1.32 cm) and total leaf area (4579.07 cm^2) with a reduction of 15, 23 and 46% compared to EC 2.5 dS m^{-1}. This implied that optimum nutrient concentration was important for plant growth and development.

Dry matter production and root to shoot ratio: Generally, there was a significant interaction between nutrient concentration and container size only on leaf and total plant dry weight at 120 days. Container size was significantly ($p \leq 0.05$) affected leaves shown in (Fig. 1a), stem (Fig. 1b), root (Fig. 1c) and total (Fig. 1d) plant dry weight in Fig. 1. The use of 2805 cm^3 container restricted to root and shoot growth which was apparent at 60 days and after 120 days, leaves, stem, root and total plant dry weight with the respective values of 20.56, 66.09, 10.19 and 96.74 g were reduced by 46, 17, 24 and 26% compared to 6831 cm^3 container. The 10557 cm^3 containers did not increase those measured parameters compared to 6831 cm^3 container from 30-120 days. EC 1.5 dS m^{-1} significantly ($p \leq 0.05$) reduced leaves (23.3 g) and stem (62.34 g) dry weight (Fig. 1e, f) about 45 and 31%, respectively but did not affected the root (12.4 g) dry weight, as shown in Fig. 1g. The lowest total plant dry weight was also recorded in EC 1.5 dS m^{-1} with the value of 97.77 g which was 33% lower than EC 2.5 dS m^{-1} as shown in Fig. 1h. Therefore, root growth was dependent more on container size compared to the nutrient concentration.

There was no significant ($p>0.05$) interaction between container size and fertilizer concentration on root: shoot ratio as shown in Table 6. At 60 days, the lowest root to shoot ratio was found in 2805 cm^3 container (0.0582) and it was 30% significantly reduced compared to 6831 cm^3 container (0.0827). At 120 DAT, root to shoot ratio were significantly increased in EC 1.5 dS m^{-1} with the value of 0.1471 which was 42% higher than EC 2.5 dS m^{-1} with the value of 0.1039.

Table 5: Effect of container size and EC of nutrient solution on height, stem diameter and leaf area of chilli

	Days after transplant (DAT)					
	Plant height (cm)		Stem diameter (cm)		Leaf area (cm^2)	
Treatments	30	120	30	120	30	120
Container volume (cm^3)						
2805	53.28^a	90.95^a	1.11^a	1.34^b	692.32^a	4528.51^b
6831	54.16^a	95.40^a	1.07^a	1.49^a	730.19^a	7251.07^a
10557	53.97^a	94.30^a	1.09^a	1.43^{ab}	715.82^a	7821.83^a
EC (dS m^{-1})						
1.5	49.23^b	85.80^b	0.95^b	1.32^a	635.26^b	4579.07^b
2.5	58.38^a	101.3^a	1.23^a	1.52^a	790.30^a	8488.54^a
F-test						
Volume	NS	NS	NS	*	NS	*
EC	*	***	*	NS	*	**
Volume×EC	NS	NS	NS	NS	NS	**

Means followed by the same letters within a column are not significantly different at $p \leq 0.05$ by LSD test, *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$, NS: Non-significant

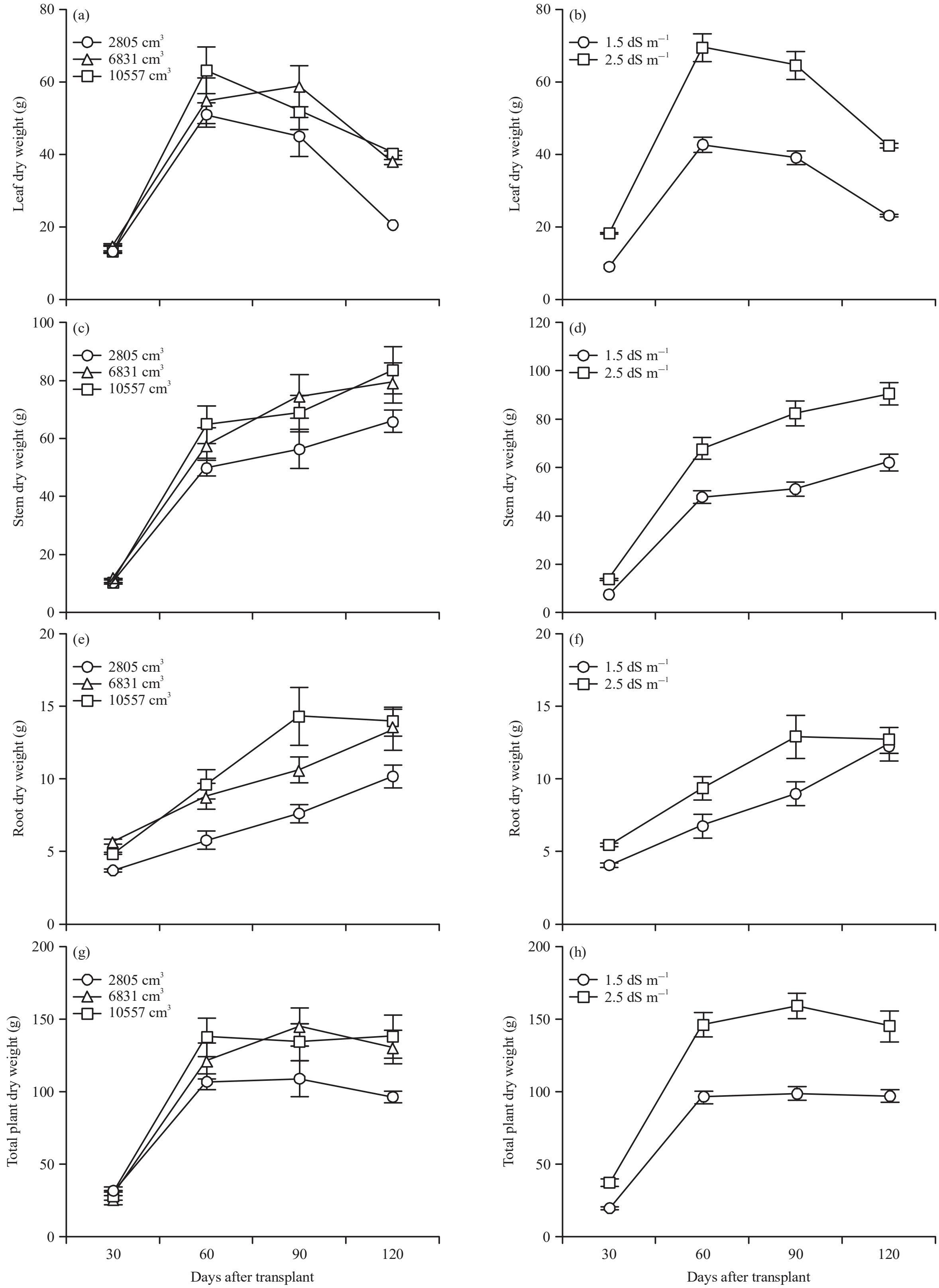

Fig. 1(a-h): Effect of container size and EC of nutrient solution on (a, b) Leaves, (c, d) Stem, (e, f) Root and (g, h) Total plant dry mass of chilli

Vertical bars represent ± SE of the mean (n = 5)

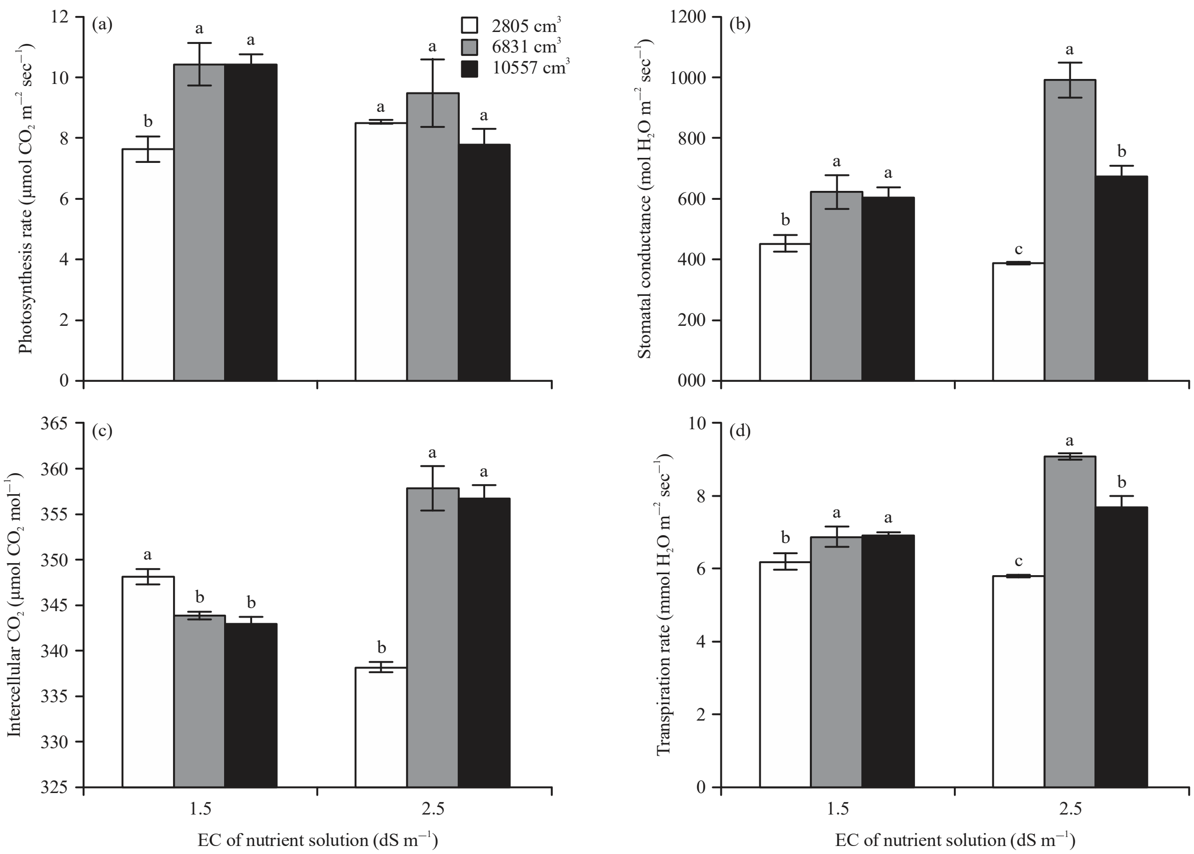

Fig. 2(a-d): Effect of container size and EC of nutrient solution on (a) Photosynthesis rate, (b) Stomatal conductance, (c) Intercellular CO_2 concentration and (d) Transpiration rate of chilli plants at 90 days after transplant

Mean values with different letters are significantly different ($p \leq 0.05$)

Table 6: Effect of container size and EC of nutrient solution on root:shoot ratio of chilli

	Root:shoot ratio			
	Days After Transplant (DAT)			
Treatments	30	60	90	120
Container volume (cm³)				
2805	0.1610[a]	0.0582[b]	0.0856[b]	0.1177[a]
6831	0.2413[a]	0.0827[a]	0.0873[b]	0.1331[a]
10557	0.2169[a]	0.0773[a]	0.1134[a]	0.1258[a]
EC (dS m⁻¹)				
1.5	0.2403[a]	0.0764[a]	0.1023[a]	0.1471[a]
2.5	0.1725[a]	0.0689[a]	0.0885[a]	0.1039[b]
F-test				
Volume	NS	*	*	NS
EC	NS	NS	NS	*
Volume×EC	NS	NS	NS	*

Means followed by the same letters within a column are not significantly different at $p \leq 0.05$ by LSD test, *$p \leq 0.05$

Photosynthesis rate, stomatal conductance, intercellular CO_2 concentration, transpiration rate: There was a significant interaction between fertilizer concentration and container size on photosynthesis rate, stomatal conductance, intercellular CO_2 concentration and transpiration rate. At 90 days, 2805 cm^3 container at EC 1.5 dS m^{-1} significantly ($p \leq 0.05$) reduced photosynthesis rate (7.64 µmol CO_2 m^{-2} sec^{-1}), stomatal conductance (452 mol H_2O m^{-2} sec^{-1}), increased intercellular CO_2 (348.13 µmol CO_2 mol^{-1}) and reduced transpiration rate (6.20 mmol H_2O m^{-2} sec^{-1}), as presented in Fig. 2a and d. Photosynthesis rate (8.53 µmol CO_2 m^{-2} sec^{-1}) was not affected by container size of 2805 cm^3 at EC 2.5 dS m^{-1} but 2805 cm^3 container significantly ($p \leq 0.05$) reduced stomatal conductance (387.75 mol H_2O m^{-2} sec^{-1}), intercellular CO_2 (338.25 µmol CO_2 mol^{-1}) and transpiration rate (5.82 mmol H_2O m^{-2} sec^{-1}). Lower stomatal conductance (674.38 mol H_2O m^{-2} sec^{-1}) and transpiration rate (7.70 mmol H_2O m^{-2} sec^{-1}) at EC 2.5 dS m^{-1} was found in 10557 cm^3 container compared to 6831 cm^3 container with the respective value of 992.5 mol H_2O m^{-2} sec^{-1} and 9.09 mmol H_2O m^{-2} sec^{-1} which had the greatest value.

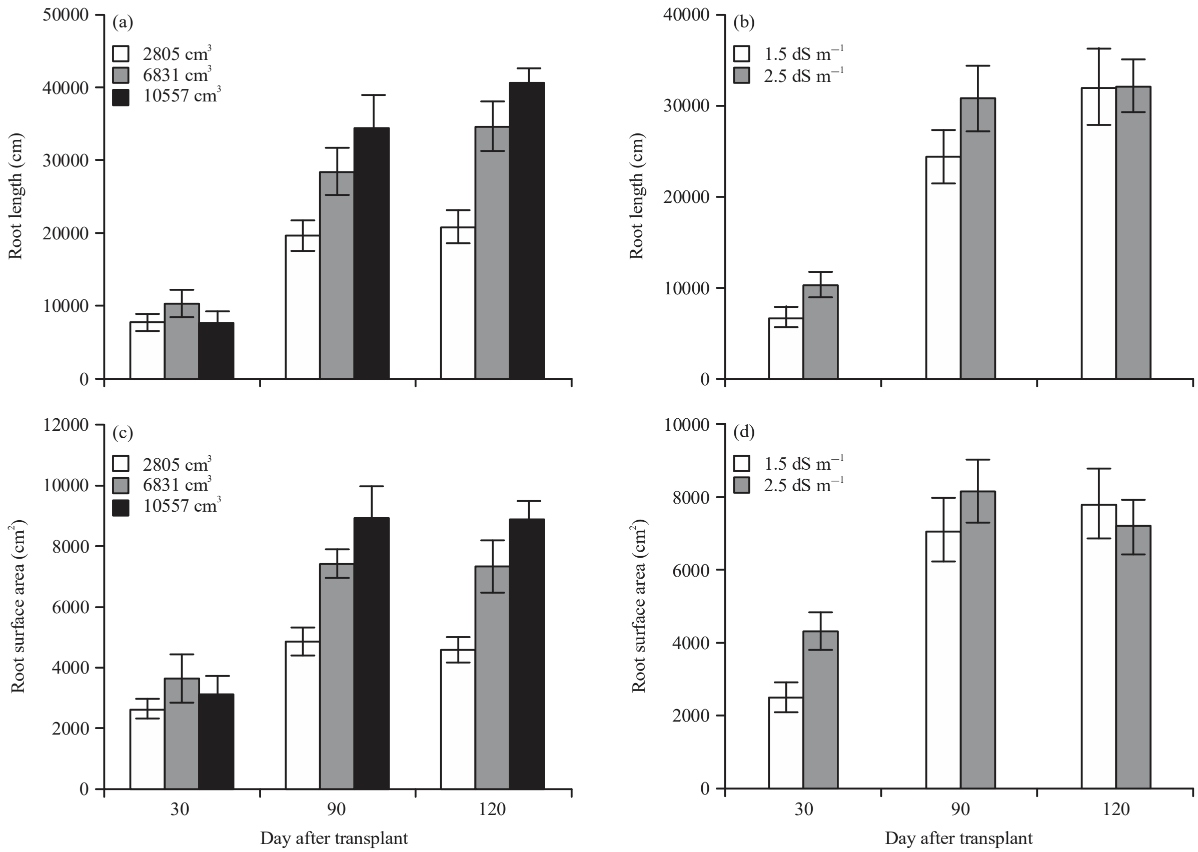

Fig. 3(a-d): Effect of container size and EC of nutrient solution on (a, b) root length and (c, d) Root surface area on chilli plants
Vertical bars represent±SE of the mean (n = 3)

Root length and root surface area: There was no significant interaction between fertilizer concentration and container size on root length and root surface area. At 120 days, the container size of 2805 cm^3 significantly ($p\leq 0.05$) reduced root length (Fig. 3a) and root surface area (Fig. 3b). This is reflected by lower value of root length (20999.70 cm) and root surface area (4607.57 cm^2) with a reduction of about 40 and 38%, respectively compared to container 6831 cm^3 in Fig. 3a-b. However, 10557 cm^3 containers showed similar root length (40701.18 cm) and root surface area (8926.23 cm^2) with 6831 cm^3 container with the values of 34744.62 cm and 7376.29 cm^2, respectively. Fertilizer concentration had a significant ($p\leq 0.05$) effect on root length and root surface area only at 30 DAT (Fig. 3c, d). At 30 DAT, the lowest root length and root surface area was recorded in EC 1.5 dS m^{-1} with the respective value of 6873.53 cm and 2332.90 cm^2 which was 34 and 42% lower than EC 2.5 dS m^{-1} with the values of 10402.29 cm and 4029.27 cm^2. However, from 90 days onwards, those measured parameters were similar with EC 2.5 dS m^{-1}. This implied improvement of root growth under EC 1.5 dS m^{-1}.

Leaf nutrient analysis: There was no significant interaction between fertilizer concentration and container size on N, P and K content in the leaves (Table 7). Container size had no significant ($p>0.05$) effect on N, P and K at 30 days. After 90 days, 2805 cm^3 container had higher N (5.81%) and P (0.51%) content compared to 6831 cm^3 containers but no effect on K content (4.53 %). Different EC of nutrient solution did not significantly ($p>0.05$) affected N, P and K content in the leaves after 90 days.

Yield production and fruit characteristics: There was no significant interaction between fertilizer concentration and container size on yield traits. Container size of 2805 cm^3 significantly ($p\leq 0.05$) reduced fruit fresh weight (910.23 g/plant), fruit number (91.3) and fruit length (15.55 cm/fruit) of chilli which were 17, 18 and 5%, respectively lower compared to 6831 cm^3 container (Table 8). Container size of 10557 cm^3 had similar fruit fresh weight (1040.56 g/plant), fruit number (111.4) and fruit length (16.35 cm/fruit) compared to 6831 cm^3 container with the respective value of 1090.22 g/plant, 111.2 and 16.29 cm/fruit.

Table 7: Effect of container size and EC of nutrient solution on leaves nutrients content of chilli

	Days after transplant (DAT)					
	Nitrogen (%)		Phosphorous (%)		Potassium (%)	
Treatments	30	90	30	90	30	90
Container volume (cm³)						
2805	4.26a	5.81a	0.70a	0.51a	4.81a	4.53a
6831	3.61a	5.61b	0.53a	0.44b	4.26a	4.83a
10557	4.59a	5.51b	0.47a	0.41c	5.19a	4.87a
EC (dS m⁻¹)						
1.5	3.83a	5.61a	0.71a	0.48a	5.17a	4.87a
2.5	4.48a	5.67a	0.43b	0.43a	4.33a	4.62a
F-test						
Volume	NS	*	NS	*	NS	NS
EC	NS	NS	*	NS	NS	NS
Volume×EC	NS	NS	NS	NS	NS	NS

Means followed by the same letters within a column are not significantly different at $p\leq 0.05$ by the LSD test, *$p\leq 0.05$, NS: Non-significant

Table 8: Effect of container size and EC of nutrient solution on yield traits of chilli

	Yield traits				
Treatments	Fruit fresh weight (g/plant)	Fruit number	Fruit length (cm/fruit)	Fruit diameter (cm/fruit)	Harvest index
Container volume (cm³)					
2805	910.23b	91.3b	15.55b	1.66a	0.1874a
6831	1090.22a	111.2a	16.29a	1.65a	0.1616b
10557	1040.56a	111.4a	16.35a	1.64a	0.1601b
EC (dS m⁻¹)					
1.5	872.68b	85.6b	15.87b	1.64a	0.1974a
2.5	1154.66a	123.6a	16.25a	1.66a	0.1419b
F-test					
Volume	***	**	***	NS	**
EC	***	***	***	NS	**
Volume×EC	NS	NS	NS	NS	NS

Means followed by the same letters within a column are not significantly different at $p\leq 0.05$ by LSD test, *$p\leq 0.0$, **$p\leq 0.01$, ***$p\leq 0.001$, NS: Non-significant

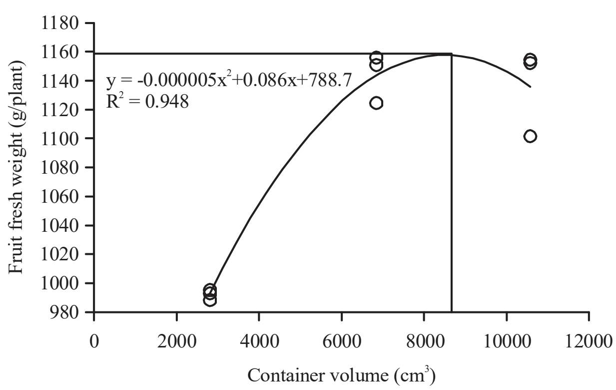

Fig. 4: Relationship between fruit fresh weight with container size of chilli plants

Fruit diameter was not affected by container size while the harvest index was significantly ($p\leq 0.05$) greater in 2805 cm³ container with the value of 0.1874. Chilli grown in 1.5 dS m⁻¹ fertilizer concentration showed significant ($p\leq 0.05$) reduction of fruit fresh weight (872.68 g/plant), fruit number (85.6) and fruit length (15.87 cm/fruit) which were 24, 31 and 2%, respectively lower compared to EC 2.5 dS m⁻¹. There was a similar fruit diameter but significantly higher harvest index in EC 1.5 dS m⁻¹ with the value of 0.1974 compared to EC 2.5 dS m⁻¹.

Relationship between fruit fresh weight and size of container: A quadratic relationship between fruit fresh weight and container size was significant at $p\leq 0.05$ as presented in Fig. 4. Based on regression, the relationship demonstrated that fruit fresh weight was increased by the increasing volume of a substrate from 2805-6831 cm³ and the maximum fruit fresh weight of chilli can be obtained by using 8500 cm³ container volume. However, substrate volume larger than 8500 cm³ will reduce fruit fresh weight of chilli. The equation for the relationship was:

$$\text{Fruit fresh weight} = -0.000005x^2+0.086x+788.7 \text{ with } R^2 = 0.94^* \ (n = 9)$$

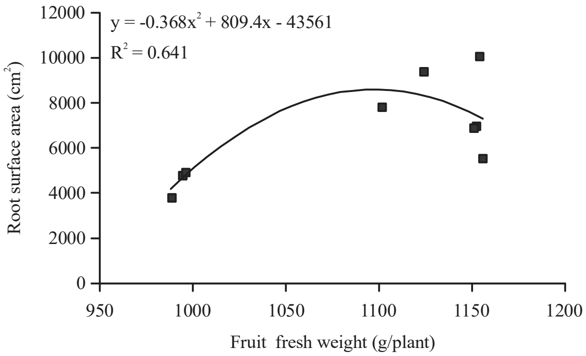

Fig. 5: Relationship between root surface area and fruit fresh weight

Relationship between root surface area and fruit fresh weight: A significant ($p \leq 0.05$) quadratic relationship was obtained between the root surface area and fruit fresh weight presented in Fig. 5. The equation for the relationship was:

$$\text{Root surface area} = -0.368x^2+809.4x-43561 \text{ with } R^2 = 0.64^* \ (n = 9)$$

DISCUSSION

In current study, chilli grown in EC 2.5 dS m^{-1} with container size of 10557 cm^3 had similar stem diameter, leaf area, dry matter production, photosynthesis rate, root morphology and yield in comparison to the container size of 6831 cm^3. This demonstrated that high substrate volume in 10557 cm^3 which can retain a high capacity of moisture content did not contribute to any yield increment probably due to a similar amount of water and nutrient application in both containers. This was consistent with the mathematical function that showed a quadratic relationship between container size and fruit fresh weight (Fig. 4). The positive effects of 6831 cm^3 container on growth and yield could be explained through an ample amount of nutrients in EC 2.5 dS m^{-1}. The other possible reason was due to higher nutrient availability within the shallow depth of substrate in 6831 cm^3 container which improved nutrient uptake with greater root length and root surface area. This was consistent with a positive relationship between root surface area and fruit fresh weight (Fig. 5).

Low EC of nutrient solution (1.5 dS m^{-1}) reduced plant height, leaf area and leaves and stem dry matter production of chilli. This finding was contradicted to the previous study by Kang and Chon[17], who found that dry matter production of vinca plants was increased in 1.0 dS m^{-1} compared to EC 2.0 and 4.0 dS m^{-1}. The EC 1.5 dS m^{-1} improved root to shoot ratio and not affected root length and root surface area but hampered yield by 24% compared to 17% yield reduction in 2805 cm^3 container. The reduction of yield in EC 1.5 dS m^{-1} in 2805 cm^3 container can be explained through a reduction of photosynthesis rate and a reduced supply of major elements such as N, P and K in the nutrient solution. In addition, O'Brien and Brown[24] stated that available space of root growth provides greater access and flexibility to water and nutrients uptake by the root. Given the observed greater effects of container size on root morphology and yield than those provided by EC of nutrient solution (Fig. 3a, d), it was suggested that container size effects cannot be mediated by selecting an appropriate nutrient concentration and container size are very important factors for chilli production in soilless culture.

For instance, 2805 cm^3 container supplied with EC 2.5 dS m^{-1} showed a reduction of stem diameter, leaf area, dry matter production, root to shoot ratio and root morphology with 17% yield reduction but improved the harvest index. The negative impact of reducing container size was reported in many plant species. For example, reduction of container size in the previous studies by Ronchi *et al.*[25] on coffee, Yeh and Chiang[26] on hydrangea and Van Iersel[27] on salvia resulted in a reduction of leaf area and dry matter production which in agreement with 2805 cm^3 container used in this study. The present work showed plants subjected to 2805 cm^3 container with EC 2.5 dS m^{-1} did not suffer from nutrient stress provided the improvement of N, P and K content in the leaves which showed the efficient mechanism of nutrient uptake. Besides, the photosynthesis rate was not affected by container size due to optimum nutrient concentration in EC 2.5 dS m^{-1}. On the other hand, 2805 cm^3 plants supplied with EC 1.5 dS m^{-1} showed a reduction in photosynthesis rate, stomatal conductance and higher intercellular CO_2 concentration which indicated a decreased in carboxylation efficiency[28]. The negative impact of 2805 cm^3 container on growth and yield could be explained with the reduction of root surface area that caused severe root restriction. The reduction of plant growth in small container could also be explained by Yong *et al.*[10] and Peterson *et al.*[29], who reported the loss of growth hormones and metabolites originated from the roots. In addition, Pezeshki and Santos[30] stated that mechanism of feedback inhibition causing accumulation of photosynthates in the sink organ. Furthermore, Shi *et al.*[31] demonstrated stomatal factors as an adaptation of plant grown in small container to reduced water loss[32]. On the other hand, it was found the involvement of non-stomatal factors such as reduction of rubisco activity of plant grown in small container[25,33].

CONCLUSION

This study demonstrated that EC of nutrient solution and container size significantly affected the growth, biomass production, photosynthesis rate, root morphology and yield of chilli. The result from this study revealed that EC 2.5 dS m^{-1} with a container size of 6831 cm^3 was optimum fertilizer concentration and container size and can be recommended for chilli production in soilless culture. In 6831 cm^3 container, yield improvement could be obtained, through improved stem diameter, leaf area, dry matter production, photosynthesis rate and root morphology. Container size of 2805 cm^3 can also be considered based on improvement on the harvest index and 57% substrate saving which merits further studies, despite this container size, reduced growth performance was observed.

SIGNIFICANCE STATEMENT

This study discovered the possibility of optimizing container size and saving fertilizer concentration while promoting better growth and yield of chilli. This study reveals the combined effects of different fertilizer concentrations along with container size on plant growth and yield. The findings can be beneficial for horticulturists and agronomists as well as farmers in managing fertilizer concentration for vegetable crops. This study will help the researchers to uncover the critical areas of optimum container size that many researchers were not able to explore. Thus, a new theory on the utilization of container size with an optimum nutrient concentration of chilli in the soilless culture production system for promoting economically feasible may be arrived at.

ACKNOWLEDGMENTS

This work was supported by Ministry of Higher Education, Malaysia under Malaysia Research University Network (MRUN) grant (Vot No: 5539120) entitled "Elucidating Human Exposure to Chemical through Food Chain". The authors sincerely thank Universiti Putra Malaysia for financial support of this project under Graduate Research Fellowship. The authors also would like to thanks Mr. Muhammad Adzan Mastor, Mrs. Nik Amelia Nik Mustapha, Mr. Desrafiel Abd Majid and Mrs. Norhasimah Sulaiman for assistance during this experiment conducted.

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