

**GROWTH RESPONSES OF STRAWBERRY (*FRAGARIA* × *ANANASSA* DUCH.)  
PLANTS GROWN AT DIFFERENT PLANTING DENSITY USING PVC PIPE  
UNDER PROTECTED CULTIVATION**

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**Abstract**

Production of strawberry cv. Sweet Charlie under soilless system (Horizontal and A-shape structures) at six different planting densities using two diameters of PVC pipes in a actively ventilated poly house was attempted. Significant differences were observed in growth parameters, namely number of leaves, petiole length, plant height, plant spread and crown diameter. The results showed that the plants grown at D<sub>3</sub> (20 plants/m<sup>2</sup>) significantly increased the number of leaves (9.76 and 12.49) and plant spread (24.44 and 25.69 cm) compared to other planting densities. The planting density significantly influenced the petiole length and plant height also in strawberry. The maximum petiole length (8.43 and 8.64 cm) and plant height (13.92 and 15.31 cm) were recorded from D<sub>3</sub> (12 plants/m<sup>2</sup>), however non-significant difference was observed between D<sub>3</sub> and D<sub>4</sub>. In future, these experimental results will prove very useful to find out most suitable plant geometry for better growth of strawberry.

**Introduction**

The modern cultivated strawberry (*Fragaria* × *ananassa* Duch., Rosaceae) is one of the most widely distributed soft fruits in the world due to its genotypic diversity, highly heterozygous nature and broad range of environmental adaptations (Childers *et al.* 1995, Sharma and Sharma 2004). Strawberries are widely considered a high value crop, so the use of new technologies related such as poly house, low tunnels, plastic mulches, plastic films and shading screens are increasing for obtaining higher productivity and quality of fruits. Due to its health properties, strawberry is being promoted for year-round production and this has been made possible through soilless cultivation. Greenhouse structures are expensive to set up and the plant size of strawberry is small, to make the greenhouse cost effective the vertical space needs to be utilized for high productivity by modifying the plant geometry (Linsley-Noakes *et al.* 2006). The increased demand for strawberries round the year is met through soilless cultivation (Morgan 2006). The volume and dimensions of containers not only affect aeration and water holding capacity of the media but also determine the production costs (Cantliffe *et al.* 2001). The yield of the strawberry is mainly related to the number of plants rather than the area. The optimum utilization of the greenhouse has been reported from various places across the world. The planting density can be increased three to four times by using a vertical system (Ozeker *et al.* 1999). The need of high density planting and appropriate plant geometry have become even more important when the crop area under cultivation is reducing with the increasing population and economic development. There is a challenge to meet the nutritional requirement from smaller area that too under changing global climate. Therefore, it is important to find out the most suitable plant geometry as well as optimal planting density within the system to maximize the utilization and distribution of light for strawberry cultivation under poly house conditions.

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### Materials and Methods

The experiment was conducted at Hi-tech greenhouse of Department of Horticulture, CCS Haryana Agricultural University, Hisar located at 215.2 m above sea level with co-ordinates of 29° 10' N latitude and 75° 46' E longitudes and 215-218 m from mean sea level in western Haryana during 2013-14 and 2014-15 growing seasons. The plants of strawberry cv. Sweet Charlie were planted under natural light condition during the first week of October. A set of PVC pipes of 1.5-2.0 m length was installed in an area of 2.0 × 1.0 m in both horizontal [12, 16 and 32 plants/m<sup>2</sup> (Figs 1, 5, 6)] and A-shape [20, 24, 24 and 28 plants/m<sup>2</sup> (Figs 2-4)] growing systems. Holes (30 mm) were made with the help of electric hand drill machine at 25 cm distance. In horizontal system, first plant was placed at 12.5 cm, while in A- shape growing system first plant was placed 30 cm above from the bottom end. The PVC pipes were filled with the mixture of artificial media (3:1:1, cocopeat + perlite + vermicompost). The fertigation system was open drip irrigation (with no circulation) using drippers installed on each hole in horizontal growing system and at the top of each PVC pipe in A-shape growing system. The transplanted plants were kept under uniform condition in poly-house during the study period where all the management practices were carried out as per the package of practices.



Figs 1-6. Strawberry plants in different structures. 1. 12 plants/m<sup>2</sup> (75 mm and 90 mm), 2. 16 plants/m<sup>2</sup> (75 mm and 90 mm). 3a. 20 plants/m<sup>2</sup> (75 mm). 3b. 20 plants/m<sup>2</sup> (90 mm), 4a. 24 plants/m<sup>2</sup> (75 mm), 4b. 24 plants/m<sup>2</sup> (90 mm), 5. 28 plants/ m<sup>2</sup> (75 mm and 90 mm), 6a. 32 plants/m<sup>2</sup> (75 mm) and 6b. 32 plants/m<sup>2</sup> (90 mm).

The number of leaves per plant was counted from the time of transfer to the end of growing season (October-March) at fortnightly interval and the average number of leaves per plant was calculated at each observation. Petiole length was calculated by measuring three randomly selected leaves per plant with the help of scale. The average of length was expressed as average petiole length in centimeters. The height of the plant was measured individually with a measuring scale from the crown level to the apex of primary leaves and result expressed as average height in centimeters.

The plant spread was calculated by measuring the canopy of plant in East - West (E-W) and North - South (N-S) direction with the scale and the average of both was expressed as plant spread in centimeters. The diameter of crown of plant was measured with the help of Vernier Calipers and expressed in millimeters.

The data were analyzed according to the procedure for analysis of completely randomized design (CRD) as given by Panse and Sukhtme (1984). The overall significance of difference among the treatments was tested, using critical differences (C.D.) at 5% level of significance. The results were statistically analyzed with the help of a windows-based computer package OPSTAT (Sheoran *et al.* 1998).

### Results and Discussion

The number of leaves per plant varied significantly with different planting density, PVC pipe diameter and pair-wise interactions between the treatments (Table 1).

**Table 1. Effect of different plant densities and PVC pipe diameter on number of leaves per plant in strawberry cv. Sweet Charlie.**

Planting density	PVC pipe diameter					
	2013-2014			2014-2015		
	75 mm	90 mm	Mean	75 mm	90 mm	Mean
12 plants/m <sup>2</sup> (D <sub>1</sub> )	8.11	9.33	8.72	10.82	12.65	11.73
16 plants/m <sup>2</sup> (D <sub>2</sub> )	7.89	8.02	7.96	10.73	11.77	11.25
20 plants/m <sup>2</sup> (D <sub>3</sub> )	9.24	10.29	9.76	11.74	13.23	12.49
24 plants/m <sup>2</sup> (D <sub>4</sub> )	8.89	9.51	9.20	11.32	12.80	12.06
28 plants/m <sup>2</sup> (D <sub>5</sub> )	8.60	9.33	8.96	10.85	12.72	11.78
32 plants/m <sup>2</sup> (D <sub>6</sub> )	7.73	7.99	7.86	9.50	11.63	10.57
Mean	8.41	9.08	8.74	10.83	12.47	11.65
CD (p = 0.05)	Planting density = 0.36			Planting density = 0.35		
	PVC pipe diameter = 0.21			PVC pipe diameter = 0.20		
	Pl. den. × P. dia. = 0.51			Pl. den. × P. dia. = 0.49		

The maximum number of leaves per plant (9.76 and 12.49) was obtained during 2013-14 and 2014-15, respectively from D<sub>3</sub> (20 plants/m<sup>2</sup>), which was significantly higher than the remaining plant densities, whereas, the minimum number of leaves (7.86 and 10.57) per plant was recorded from highest planting density (D<sub>6</sub>). The number of leaves per plant increased significantly with the increase in PVC pipe diameter and the plants grown in 90 mm PVC pipe produced higher number of leaves (9.08 and 12.47, respectively) than 75 mm PVC pipe (8.41 and 10.83, respectively) in both the years (2013-14 and 2014-15) of study. The data recorded during the period of study revealed that the plants were grown at D<sub>3</sub> in 90 mm PVC pipes resulted highest number of leaves (10.29 and 13.23) per plant, except D<sub>4</sub> (24 plants/m<sup>2</sup>) in 90 mm PVC pipe (12.80) during 2014-15.

The petiole length was significantly influenced by planting density and diameter of PVC pipe (Table 2). Among various densities, a significant increase in petiole length was observed at 20 plants/m<sup>2</sup>, which produced maximum petiole length (8.43 and 8.64 cm) and it was statistically at par with D<sub>4</sub> (8.24 and 8.33 cm), whereas, shortest petiole was recorded from D<sub>2</sub> (7.60 and 7.40 cm) in both growing seasons, respectively.

**Table 2. Effect of different plant densities and PVC pipe diameter on petiole length (cm) in strawberry cv. Sweet Charlie.**

Planting density	PVC pipe diameter					
	2013-2014			2014-2015		
	75 mm	90 mm	Mean	75 mm	90 mm	Mean
12 plants/m <sup>2</sup> (D <sub>1</sub> )	7.84	8.37	8.10	7.80	7.85	7.82
16 plants/m <sup>2</sup> (D <sub>2</sub> )	7.44	7.76	7.60	7.24	7.56	7.40
20 plants/m <sup>2</sup> (D <sub>3</sub> )	8.09	8.76	8.43	8.44	8.85	8.64
24 plants/m <sup>2</sup> (D <sub>4</sub> )	8.02	8.47	8.24	7.96	8.70	8.33
28 plants/m <sup>2</sup> (D <sub>5</sub> )	7.86	8.41	8.14	7.94	8.44	8.19
32 plants/m <sup>2</sup> (D <sub>6</sub> )	7.83	8.01	7.92	7.38	7.80	7.59
Mean	7.85	8.30	8.07	7.79	8.20	8.00
CD (P = 0.05)	Planting density = 0.41			Planting density = 0.34		
	PVC pipe diameter = 0.24			PVC pipe diameter = 0.20		
	Pl. den. × P. dia. = N.S.			Pl. den. × P. dia. = N.S.		

N.S. = Non-significant.

Plants grown in 90 mm PVC pipe produced higher petiole length (8.30 and 8.20 cm) compared to plants grown in 75 mm PVC pipe (7.85 and 7.79 cm), respectively. The interactive effects of plant density and pipe diameter were found non-significant. However, numerically maximum petiole length (8.76 and 8.85 cm) was observed at 20 plants/m<sup>2</sup>, when grown in 90 mm PVC pipe.

Data pertaining to plant height as influenced by PVC pipe diameter and plant density are presented in Table 3. The plants grown at 20 plants/m<sup>2</sup> density produced maximum plant height (13.92 and 15.31 cm), except D<sub>4</sub> (13.53 cm) during 2013-14, while minimum plant height was observed at 32 plants/m<sup>2</sup> (12.70 and 13.24 cm) which was statistically at par with D<sub>2</sub> (12.92 and 13.33 cm) during both the growing seasons, respectively. The plants grown in 90 mm PVC pipes were more tall (13.66 and 14.36 cm) than small size pipes (12.89 cm and 13.66 cm), respectively in 2013-14 and 2014-15. The perusal of data showed that interactive effect of treatments did not differ significantly. However, the plant height was more (14.44 cm and 15.82 cm) in plants grown in 90 mm PVC pipe at 20 plants/m<sup>2</sup> density.

The data concerning plant spread as affected by different planting densities and PVC pipe diameter are presented in Table 4. Significant difference was recorded between the two different sizes of pipes and among the all plant densities. During 2013-14, the plants grown at D<sub>3</sub> showed maximum plant spread (24.44 cm), which was statistically at par with D<sub>1</sub> (23.62 cm), whereas, the minimum plant spread (21.34 cm) was observed from the plants grown at D<sub>6</sub> (32 plants/m<sup>2</sup>). Similar trend was observed during the second year of experiment. In both growing seasons 90 mm pipe diameter gave higher plant spread (23.76 and 25.25 cm) as compared to 75 mm diameter (21.52 and 22.36 cm) during 2013-14 and 2014-15, respectively. The interactions between

planting densities and pipe diameter were also found to be significant. The plants grown at 20 plants/m<sup>2</sup> in 90 mm PVC pipe resulted maximum plant spread (26.17 and 27.82 cm) and were found superior to all the treatments except at D<sub>1</sub> in 90 mm PVC pipe during 2013-14.

**Table 3. Effect of different plant densities and PVC pipe diameter on plant height (cm) in strawberry cv. Sweet Charlie.**

Planting density	PVC pipe diameter					
	2013-2014			2014-2015		
	75 mm	90 mm	Mean	75 mm	90 mm	Mean
12 plants/m <sup>2</sup> (D <sub>1</sub> )	12.77	13.59	13.18	13.22	13.95	13.59
16 plants/m <sup>2</sup> (D <sub>2</sub> )	12.76	13.07	12.92	12.93	13.72	13.33
20 plants/m <sup>2</sup> (D <sub>3</sub> )	13.40	14.44	13.92	14.80	15.82	15.31
24 plants/m <sup>2</sup> (D <sub>4</sub> )	12.98	14.09	13.53	14.34	15.09	14.72
28 plants/m <sup>2</sup> (D <sub>5</sub> )	12.87	13.88	13.38	13.76	13.99	13.88
32 plants/m <sup>2</sup> (D <sub>6</sub> )	12.54	12.87	12.70	12.89	13.59	13.24
Mean	12.89	13.66	13.27	13.66	14.36	14.01
CD (p = 0.05)	Planting density = 0.45			Planting density = 0.41		
	PVC pipe diameter = 0.26			PVC pipe diameter = 0.24		
	Pl. den. × P. dia. = N.S.			Pl. den. × P. dia. = N.S.		

N.S. - Non-significant.

**Table 4. Effect of different plant densities and PVC pipe diameter on plant spread (cm) in strawberry cv. Sweet Charlie.**

Planting density	PVC pipe diameter					
	2013-2014			2014-2015		
	75 mm	90 mm	Mean	75 mm	90 mm	Mean
12 plants/m <sup>2</sup> (D <sub>1</sub> )	21.82	25.41	23.62	23.40	26.51	24.96
16 plants/m <sup>2</sup> (D <sub>2</sub> )	20.78	22.26	21.52	21.42	24.15	22.78
20 plants/m <sup>2</sup> (D <sub>3</sub> )	22.72	26.17	24.44	23.55	27.82	25.69
24 plants/m <sup>2</sup> (D <sub>4</sub> )	21.69	23.96	22.83	23.16	25.46	24.31
28 plants/m <sup>2</sup> (D <sub>5</sub> )	21.55	22.62	22.09	21.75	24.44	23.09
32 plants/m <sup>2</sup> (D <sub>6</sub> )	20.55	22.13	21.34	20.87	23.12	22.00
Mean	21.52	23.76	22.64	22.36	25.25	23.80
CD (p = 0.05)	Planting density = 0.69			Planting density = 0.62		
	PVC pipe diameter = 0.40			PVC pipe diameter = 0.36		
	Pl. den. × P. dia. = 0.97			Pl. den. × P. dia. = 0.88		

From the perusal of data in Table 5, it is evident that planting density, PVC pipe diameter and the interactions between the variants influenced significantly the crown diameter in strawberry. During 2013-14, the maximum crown diameter (15.33 mm) was obtained from the plants grown at D<sub>1</sub> followed by D<sub>2</sub> (14.72 mm), while minimum crown diameter (12.79 mm) was recorded at D<sub>5</sub> followed by D<sub>4</sub> (13.83 mm). The trend was similar during 2014-15 and the maximum crown diameter (17.08 mm) was recorded at 12 plants/m<sup>2</sup>, which were significantly superior to all the other planting densities, whereas, the minimum crown diameter (13.26 mm) was found at 28

plants/m<sup>2</sup>. Increasing trend in crown diameter was observed as PVC pipe size increased. In both growing seasons maximum crown diameter was observed in 90 mm PVC pipe (14.72 and 15.99 mm) as compared to 75 mm PVC pipe (13.67 and 14.52 mm), respectively. The plants grown at D<sub>1</sub> in combination with 90 mm PVC pipe gave maximum crown diameter (16.26 and 17.73 mm) and were found to be superior among all the treatments.

**Table 5. Effect of different plant densities and PVC pipe diameter on crown diameter (mm) in strawberry cv. Sweet Charlie.**

Planting density	PVC pipe diameter					
	2013-2014			2014-2015		
	75 mm	90 mm	Mean	75 mm	90 mm	Mean
12 plants/m <sup>2</sup> (D <sub>1</sub> )	14.39	16.26	15.33	16.43	17.73	17.08
16 plants/m <sup>2</sup> (D <sub>2</sub> )	13.98	15.45	14.72	15.30	17.05	16.17
20 plants/m <sup>2</sup> (D <sub>3</sub> )	13.73	14.62	14.17	14.39	16.15	15.27
24 plants/m <sup>2</sup> (D <sub>4</sub> )	13.58	14.08	13.83	13.62	14.60	14.11
28 plants/m <sup>2</sup> (D <sub>5</sub> )	12.48	13.10	12.79	12.86	13.66	13.26
32 plants/m <sup>2</sup> (D <sub>6</sub> )	13.87	14.83	14.35	14.53	16.75	15.64
Mean	13.67	14.72	14.20	14.52	15.99	15.25
CD (p = 0.05)	Planting density = 0.43			Planting density = 0.46		
	PVC pipe diameter = 0.25			PVC pipe diameter = 0.27		
	Pl. den. × P. dia. = 0.61			Pl. den. × P. dia. = 0.66		

In the present investigation, the results revealed that the vegetative growth of strawberry plant was influenced significantly by planting density. The maximum number of leaves, petiole length, plant height and plant spread was observed in the plants grown at D<sub>3</sub> (20 plants/m<sup>2</sup>) with A-shape planting system, except petiole length and plant height 2013-14, whereas, maximum crown diameter was recorded at D<sub>1</sub> (12 plants/m<sup>2</sup>) horizontal system. Vegetative growth of plants in terms of decreased at higher planting density during both the seasons. This might be due to the higher planting density increasing interplant competition for plant nutrients, which resulted reduced vegetative growth. Similar results were reported by Galletta and Himelrick (1990), Wilson and Dixon (1998) and Tariq *et al.* (2013) in strawberry. Paranjpe *et al.* (2008) reported that plants grown at higher planting density had smaller crowns and fewer leaves than lesser planting density. The present findings are also in close agreement with the results of De-Camacaro *et al.* (2004) and Linsley-Noakes *et al.* (2006), who recommended lower planting density for better growth in strawberry. The plant density turned out to have a great influence on growth in strawberry especially crown diameter (Jansen 1997). But contrasting results were postulated by Ahmad (2009) and Portela *et al.* (2012), according to them planting density had no significant influence on the morphological characters of strawberry.

Potentially, the PVC size (diameter) plays an important role in controlling the vegetative growth of the plant *i.e.* number of leaves, petiole length, plant height, plant spread and crown diameter, which significantly increased with the increase of PVC pipe diameter during both the years of investigation. The lesser growth in 75 mm PVC pipes might be due to with the growth of the plants the root development takes place and most of the space is occupied by vigorous root system of the plants, which reduces the aeration at higher planting density. These findings are in consonance to the findings of Cantliffe *et al.* (2008) and Cantliffe *et al.* (2003), who reported that larger volumes generally favor increased plant growth rates. NeSmith and Duval (1998) also reported the container size can affect growth of plants in soil less culture.

For maximum utilization of the greenhouse area, A-shape growing system is found to be the best option for commercial production as well as home gardening. Among the planting densities, significant differences were observed in growth parameters mainly due to differences in the root aeration and inter-plant competition. Better root aeration and light availability resulted in higher photosynthesis rate and better growth of the plants in A-shape structures.

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