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Evaluate the Growth and Production of Celery in Different Substrate Systems

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ABSTRACT
An experiment has been conducted in the rooftop garden of Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Dokki, Giza, Egypt during seasons of (2021/2022) and (2022/2023). The aim of this work was to evaluate the growth and production of celery in different substrate systems and under different planting densities. Two factors were under investigation in this work in relation to growth and yield of celery, their description were as follow: first, substrate systems (pot system and shallow beds system). Second, Planting density (15 plants per m^2 “D-A”, 18 plants per m^2 “D-B” and 21 plants per m^2 “D-C”). In pots system, each pot was filled with 5 liters from mixture of (coco peat: sand: perlite 2:1:1 v/v/v). In shallow beds system, the entire depth of the bed filled with 100 liters of the same substrate mixture. The obtained results indicated that regarding the impact substrate system on growth and yield of celery; celery plants grown in pots system recorded the highest values for plant height, number of leaves per plant, root fresh and dry weights, head weight and total heads weight/m^2 (yield/m^2). Regarding the impact of planting density on growth and yield of celery; density of 15 plants per m^2 recorded the highest values for plant height, number of leaves per plant, root fresh and dry weights, head weight. Whereas a density of 15 plants per m^2 recorded a higher head weight than a density of 18 plants per m^2, but the higher density (18 plant /m^2) resulted in a higher yield per m^2 (total heads weight/m^2).

Keywords: Celery, substrate culture, planting density, systems, rooftops gardens.

1. Introduction
The productivity of agriculture is significantly impacted by climate change. Green roof systems and urban horticulture should be key components in mitigating climate change vulnerability and generating food. Because of this, many cities all across the world are attempting to improve climate change adaptation by growing fresh vegetable on their rooftops (Abul-Soud *et al*., 2014). Vegetable crops can be grown on rooftop, which opens up possibilities for integrating agriculture into urban areas. By providing fresh food items, lowering family expenses for purchasing vegetable crops, enhancing air quality, absorbing carbon dioxide from the environment and mitigating the effects of climate change, rooftop agriculture can contribute to meeting the world's food needs. Rooftop farming will contribute to the sustenance of urban food systems and offer a unique chance to cultivate food effectively in otherwise underutilized areas (Chowdhury *et al.,* 2020).

The best growing method for starting a rooftop garden is soilless culture because rooftops have limited spaces, no soil, and unfavorable production conditions. soilless systems, which are often constructed of lightweight materials, can be easily adapted to fit any free spaces on rooftop. Furthermore, using a closed irrigation system, the nutritional solution is easily recirculated. The practice of collecting and reusing excess nutrient solution for irrigation is crucial for rooftop gardens as it stops water and nutrient solution from seeping through to the roof, and conserving both water and fertilizers (Metwally, 2016).

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Substrate culture is a branch of soilless culture. Utilizing substrate-based agriculture (substrate culture) is a logical alternative to the current soil based production. The use of different organic and inorganic substrates allows the plants the best nutrient uptake and sufficient growth and development to optimize water and oxygen holding (Verdonck *et al.,* 1982).

Celery is an indispensable member of many cuisines with its rich nutritional content and aroma. It is a vegetable that contains excellent natural fiber, minerals, and antioxidants, especially vitamin C and vitamin K, with a low glycemic index. Academic reports about the elementary composition of celery showed that it was rich in calcium, magnesium, copper, zinc, manganese, and selenium, especially in stalk parts. Celery contains potent antioxidants like phenolic compounds, flavonoids, essential oils. These antioxidants cannot be produced by the human body and should be taken in through the daily diet for a healthy body (Profir and Vizireanu, 2013; Ibrahim, 2016; Ruiz-De Anda *et al*., 2019). On the other hand, celery is a vegetable whose name is usually mentioned in conventional treatments, and nowadays, many researchers from different science sections have been interested in it. It's most popular aim for medicinal purposes is to eliminate body toxins from the kidney, liver, and spleen (Sowbhagya, 2014 and Asadi-Samani *et al.,* 2015). For that this work aimed to evaluate the growth and production of celery in different substrate systems and under different planting densities.

2. Materials and Methods

The experiment of this work has been conducted in the rooftop garden of Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Dokki, Giza, Egypt during seasons of (2021/2022) and (2022/2023).

Celery Seedlings (*Apium graveolens var dules*) were cultivated in tested substrate systems in the last week of October 2021 and replicated in the same time at 2022. The experiment extended until harvest time in January 2022 for first season and January 2023 for second season.

2.1. Description of substrate systems used in this work

Pots system; this system consisted of a wooden table (100cm length, 100cm width, and 10cm depth). The entire depth of the tables have been padded with black polyethylene sheets 0.7mm in thickness and equipped with drainage tube in one side, under this tube, plastic tank have been put under each table to collect the excess irrigation water. A number of black polyethylene pots have arranged on the entire depth of the table. Each pot was filled with 5 liters from mixture of (coco peat: sand: perlite 2:1:1 v/v/v). Each pot has holes in the bottom for release the excess drainage solution.

Beds system; this system consisted of a wooden table (same description of the wooden table in pot system) except in this system the entire depth of the table has been filled with 100 liters of mixture of (coco peat: sand: perlite 2:1:1 v/v/v)

In both systems a drip irrigation system have been used to deliver water and nutrients to plants, a slope about 1% have been made to collect the excess drainage solution and return it back to the tank using the drainage tube. The nutrient solution described by (El-Behairy, 1994) has been used in this experiment. The electrical conductivity (EC) adjusted at the range of 1.8 -2.00 m.mhos^2 throughout the experimental time. Digital EC meter was used to adjust the EC to the required level.

2.2. Treatments

The experiment was consisted of two factors, their description were as follow:

(A) Substrate systems
1. Pots system (substrate depth about 15cm).
2. Shallow beds system (substrate depth about 10cm).

(B) Planting density
1. Cultivate 15 plants per m^2 (D-A).
2. Cultivate 18 plants per m^2 (D-B).
3. Cultivate 21 plants per m^2 (D-C).

2.3. Measurements

Different measurements have been recorded during the experimental time; growth parameters such as: plant height, number of leaves and root fresh & dry weights. Yield parameters such as: head weight per plant and total heads weight per m^2, chemical parameters such as: nitrogen, phosphorus and potassium percentages in leaves.

Nitrogen, phosphorus and potassium % in leaves were determined according to methods described by (A.O.A.C., 1990).

2.4. Experimental Design and Statistical analysis

The experiment was arranged in split plot design with three replicates. Substrate systems were arranged in the main plots, while planting densities were arranged in the sub plots. The collected data were analyzed using ANOVA statistical analysis as described by (Snedicor and Cochran, 1980), and means were compared by determining the least significant difference (L.S.D) at a probability level of 0.05.

3. Results

3.1. Growth parameters

Data related to the impact of substrate systems and planting density on growth parameters such as plant height is illustrated in table 1, number of leaves is illustrated in table 2, root fresh weight is illustrated in table 3, and root dry weight is illustrated in table 4.

3.1.1. Plant height

Regarding the impact of substrate systems, data from both seasons illustrated that celery plants grown in pots system recorded a higher values for plant height than those grown in shallow beds system with significant difference between both of them.

Regarding the impact of planting density, data collected from both seasons indicated that D-A recorded the highest plant height value then D-B and finally D-C recorded the lowest value. There were significant differences among them.

Regarding the impact of interaction between substrate system and planting density, first season data indicated that interaction between pots and D-A recorded the highest plant height value, whereas interaction between shallow beds and D-C recorded the lowest value. On the contrary, there were no significant differences among interactions in the second season.

3.1.2. Number of leaves

Regarding the impact of substrate systems, data from both seasons indicated that celery plants grown in pots system recorded a higher number of leaves per plant than those grown in shallow beds system with significant difference between both of them.

Regarding the impact of planting density, data collected from both seasons indicated that D-A recorded the highest number of leaves per plant followed by D-B and finally D-C recorded the lowest number. There were significant differences among them.

Regarding the impact of interaction, there were no significant differences among interactions in both seasons.

3.1.3. Root fresh and dry weights

Concerning the impact of substrate systems, data from both seasons illustrated that celery plants grown in pots system recorded a higher values for root fresh and dry weights than those grown in shallow beds system with significant difference between both of them.

Concerning the impact of planting density, both seasons' data showed that D-A recorded the highest values for root fresh and dry weights then D-B and D-C respectively. Moreover, there were significant differences among them.

Concerning the impact of interaction, both seasons' data showed that interaction between pots and D-A recorded the highest values for root fresh and dry weights, whereas interaction between shallow beds and D-C recorded the lowest values for both parameters.

Table 1: Impact of substrate systems and planting density on plant height (cm) of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
	1st season (2021/2022)			
Pots	79.72	76.92	71.85	**76.16**
Shallow beds	76.39	73.03	63.07	**70.83**
Mean	**78.06**	**74.98**	**67.46**	
	2nd season (2022/2023)			
Pots	82.54	74.56	68.63	**75.24**
Shallow beds	79.07	70.96	61.00	**70.34**
Mean	**80.80**	**72.76**	**64.82**	

1st season			**2nd season**		
S	**D**	**S*D**	**S**	**D**	**S*D**
0.88	**1.62**	**6.88**	**3.09**	**2.59**	**N.S**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

Table 2: Impact of substrate systems and planting density on number of leaves per plant of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
	1st season (2021/2022)			
Pots	20.00	18.67	16.33	**18.33**
Shallow beds	18.33	17.67	14.33	**16.78**
Mean	**19.17**	**18.17**	**15.33**	
	2nd season (2022/2023)			
Pots	21.33	18.00	14.67	**18.00**
Shallow beds	19.00	16.33	13.33	**16.22**
Mean	**20.17**	**17.17**	**14.00**	

1st season			**2nd season**		
S	**D**	**S*D**	**S**	**D**	**S*D**
0.65	**0.80**	**N.S**	**0.86**	**0.74**	**N.S**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

Table 3: Impact of substrate systems and planting density on root fresh weight (g) of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
	1st season (2021/2022)			
Pots	445.57	399.19	349.51	**398.09**
Shallow beds	379.28	337.96	235.81	**317.69**
Mean	**412.43**	**368.58**	**292.66**	
	2nd season (2022/2023)			
Pots	416.63	378.93	312.33	**369.30**
Shallow beds	396.54	356.17	255.22	**335.98**
Mean	**406.58**	**367.55**	**283.78**	

1st season			**2nd season**		
S	**D**	**S*D**	**S**	**D**	**S*D**
6.99	**8.35**	**35.44**	**7.62**	**7.08**	**30.02**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

Table 4: Impact of substrate systems and planting density on root dry weight (g) of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
		1st season (2021/2022)		
Pots	81.38	68.41	57.70	**69.16**
Shallow beds	68.29	60.82	40.54	**56.55**
Mean	**74.84**	**64.62**	**49.12**	
		2nd season (2022/2023)		
Pots	84.00	72.18	53.03	69.74
Shallow beds	71.73	55.64	38.03	55.13
Mean	**77.86**	**63.91**	**45.53**	

1st season S	D	S*D	2nd season S	D	S*D
4.99	**1.57**	**6.68**	**5.57**	**4.50**	**19.08**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

3.2. Yield parameters

Data related to the impact of substrate systems and planting density on yield parameters such as: head weight per plant is illustrated in table 5 and total heads weight per m^2 (yield/m^2) is illustrated in table 6.

3.2.1. Head weight

Concerning the impact of substrate systems, data from both seasons showed that pots system recorded a higher head weight than shallow beds system with significant difference between both systems.

Concerning the impact of planting density, both seasons' data showed that the highest head weight was obtained from D-A followed by D-B and D-C respectively. Moreover, there were significant differences among treatments.

Concerning the impact of interaction, both seasons' data showed that interaction between pots and D-A recorded the highest values for head weight, while interaction between shallow beds and D-C recorded the lowest head weight values.

Table 5: Impact of substrate systems and planting density on head weight (g) of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
		1st season (2021/2022)		
Pots	860.23	805.67	586.35	**750.75**
Shallow beds	804.28	774.86	466.89	**682.01**
Mean	**832.26**	**790.26**	**526.62**	
		2nd season (2022/2023)		
Pots	846.81	829.72	549.11	**741.88**
Shallow beds	778.64	721.56	450.63	**650.28**
Mean	**812.73**	**775.64**	**499.87**	

1st season S	D	S*D	2nd season S	D	S*D
18.89	**17.72**	**75.16**	**17.47**	**12.34**	**52.37**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

3.2.2. Total heads weight per m^2 (yield per m^2)

Regarding the impact of substrate systems, data from both seasons illustrated that pots system recorded a higher total heads weight per m^2 than shallow beds system with significant difference between both systems.

Regarding the impact of planting density, first season data illustrated that the highest total heads weight per m^2 was obtained from D-B followed by D-A and D-C respectively. Moreover, there were significant differences among treatments. In the second season, the same trend was observed.

Regarding the impact of interaction, both seasons' data indicated that interaction between pots and D-B recorded the highest values for total heads weight per m^2, while interaction between shallow beds and D-C recorded the lowest total heads weight per m^2.

Table 6: Impact of substrate systems and planting density on total heads weight per m^2 (kg) of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
		1st season (2021/2022)		
Pots	12.90	14.50	12.31	**13.24**
Shallow beds	12.06	13.95	9.80	**11.94**
Mean	**12.48**	**14.22**	**11.06**	
		2nd season (2022/2023)		
Pots	12.70	14.93	11.53	**13.06**
Shallow beds	11.68	12.99	9.46	**11.38**
Mean	**12.19**	**13.96**	**10.50**	

1st season S	1st season D	1st season S*D	2nd season S	2nd season D	2nd season S*D
0.42	**0.34**	**1.45**	**0.31**	**0.22**	**0.94**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

3.3. Chemical parameters

Data related to the impact of substrate systems and planting density on chemical parameters such as: nitrogen % in leaves is presented in table 7, phosphorus % in leaves is presented in table 8 and potassium % in leaves is presented in table 9.

3.3.1. Nitrogen % in leaves

For the impact of substrate systems, both seasons' data illustrated that celery plants grown in pots system recorded a higher nitrogen % than those grown in shallow beds system with significant difference between both of them.

For the impact of planting density, both seasons' data indicated that the highest nitrogen % was recorded by D-A then D-B and finally D-C recorded the lowest nitrogen %. There were significant differences among them.

For the impact of interaction, first season data showed that there were no significant differences among interactions in the second season. On the other hand, data from second season showed that interaction between pots and D-A recorded the highest nitrogen %, whereas interaction between shallow beds and D-C recorded the lowest nitrogen %.

3.3.2. Phosphorus % in leaves

For the impact of substrate systems, data from first season illustrated that there was no significant difference between the two tested systems. On the other hand, data from second season presented that celery plants grown in pots system recorded a higher phosphorus % than those grown in shallow beds system with significant difference between both of them.

For the impact of planting density, both seasons' data indicated that the highest phosphorus % was recorded by D-A then D-B and finally D-C recorded the lowest phosphorus %. There were significant differences among them.

For the impact of interaction, data showed that there were no significant differences among interactions in both seasons.

3.3.3. Potassium % in leaves

Regarding the impact of substrate systems, both seasons' data illustrated that celery plants grown in pots system recorded a higher potassium % than those grown in shallow beds system with significant difference between both of them.

Regarding the impact of planting density, both seasons' data indicated that the highest potassium % was recorded by D-A followed by D-B and finally D-C recorded the lowest potassium %. There were significant differences among them.

For the impact of interaction, first season data indicated that interaction between pots and D-A recorded the highest potassium %, whereas interaction between shallow beds and D-C recorded the lowest potassium %. On the contrary, there were no significant differences among interactions in the second season.

Table 7: Impact of substrate systems and planting density on nitrogen (%) in leaves of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
		1st season (2021)		
Pots	2.39	2.14	1.82	**2.11**
Shallow beds	2.12	1.95	1.73	**1.93**
Mean	**2.25**	**2.04**	**1.78**	
		2nd season (2022)		
Pots	2.83	2.42	2.02	**2.42**
Shallow beds	2.22	1.91	1.79	**1.98**
Mean	**2.53**	**2.17**	**1.91**	

1st season S	D	S*D	2nd season S	D	S*D
0.04	**0.07**	**N.S**	**0.24**	**0.09**	**0.37**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

Table 8: Impact of substrate systems and planting density on phosphorus (%) in leaves of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
		1st season (2021/2022)		
Pots	0.517	0.480	0.430	**0.476**
Shallow beds	0.460	0.437	0.390	**0.429**
Mean	**0.488**	**0.458**	**0.410**	
		2nd season (2022/2023)		
Pots	0.503	0.453	0.450	**0.469**
Shallow beds	0.443	0.403	0.350	**0.399**
Mean	**0.473**	**0.428**	**0.400**	

1st season S	D	S*D	2nd season S	D	S*D
N.S	**0.039**	**N.S**	**0.024**	**0.018**	**N.S**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

Table 9: Impact of substrate systems and planting density on potassium (%) in leaves of celery grown on rooftops during seasons of 2021/2022 and 2022/2023.

Substrate systems (S)	Planting density (D) D-A	D-B	D-C	Mean
		1st season (2021)		
Pots	4.42	3.72	3.62	**3.92**
Shallow beds	3.76	3.49	2.44	**3.23**
Mean	**4.09**	**3.61**	**3.03**	
		2nd season (2022)		
Pots	4.86	4.08	3.88	**4.27**
Shallow beds	4.28	3.71	2.62	**3.54**
Mean	**4.57**	**3.89**	**3.25**	

1st season S	D	S*D	2nd season S	D	S*D
0.39	**0.24**	**1.02**	**0.21**	**0.39**	**NS**

D-A: 15 plants/ m^2, **D-B:** 18 plants / m^2, **D-C:** 21 plants / m^2

4. Discussion

The obtained results recorded that celery plants grown in pots system was superior in growth and yield parameters than those grown in shallow beds; celery plants grown in pots system recorded the highest values for plant height, number of leaves per plant, root fresh and dry weights, head weight and total heads weight/m^2 (yield/m^2). This could be a result to the more substrate depth in case of pots (substrate depth about 15 cm) than in case of shallow beds (substrate depth about 10 cm); the more substrate depth give the roots more free space to grow and this translated to a bigger plants. Kostopoulou *et al.*, (2011) stated that because container depth is strongly correlated with air availability, humidity, and water holding capacity, it is thought to be a significant factor determining plant and root shape. Additionally, Panayiotis *et al.,* (2011) studied the effects of two substrate depths (7.5 cm and 15 cm) on the physiology and growth of the native species *Dianthus fruticosus sub. fruticosus* were investigated. The findings showed that, over the course of the investigation, the deep substrate (15 cm) encouraged the growth of *Dianthus fruticosus sub. fruticosus*. Metwally, (2016) investigated the effect of using different substrate culture systems on growth and production of hot pepper; beds system (substrate depth 10cm), big pots system (substrate depth 15cm), small pots system (substrate depth 13cm) and horizontal bags system (substrate depth 10cm). Results indicated that hot pepper plants grown in big pots (substrate depth 15cm) system recorded the highest values regarding: plant height, number of leaves, aerial parts fresh and dry weights, root fresh and dry weights, yield per m^2 and highest nitrogen & phosphorus percentages in leaves.

Regarding the impact of planting density on growth and yield of celery; density of 15 plants per m^2 was superior than the other tested densities; celery plants grown under situation of 15 plants per m^2 recorded the highest values for plant height, number of leaves per plant, root fresh and dry weights, head weight. Paranjpe *et al*., (2008) revealed that the low planting density led to a higher leaf count per plant. Moreover, Lee *et al.,* (2002) examined how utilizing various plant densities (32, 48, and 64 plants per m^2) affected the cut chrysanthemum's growth. Data indicated that as plant density increased, the quantity of blooms per plant decreased.

Whereas a density of 15 plants per m^2 recorded a higher head weight than a density of 18 plants per m^2, but the higher density (18 plants /m^2) resulted in a higher yield per m^2 (total heads weight/m^2). This could be a result to increase number of plants per m^2, so even the head weight was smaller in case of (18 plant /m^2) but the high number of plants in the m^2 recover the reduction in head weight. De Hoog *et al.,* (2001) examined the impact of three various plant densities (five, seven, and ten per square meter) on the quantity and quality of roses cultivated in substrate culture. The maximum plant density produced the highest yield, according to the results. Moreover, Tribulato, *et al.,* (2003) conducted an experiment for studding the effect of different plant densities per m^2 on the production and quality of lily grown in soilless culture. 28, 37.5 or 45 bulbs of the Oriental hybrid ‘Star Gazer’ and the Asiatic hybrid ‘Elite’ were planted per m^2. Collected data showed that increasing plant density per m^2, increased total number of flowers/m^2. Furthermore, De-Camacaro *et al.,* (2004) found that in strawberry, the low plant density increased the yield per plant. nonetheless, high plant density produced the maximum yield/m^2.

5. Conclusion

It could be concluded that the pots system is more suitable for celery production on rooftops than shallow beds. Using density of 15 plants per m^2 is more suitable for celery production in pots system. Even so, it is possible to increase the plant density to 18 plants per m^2 to increase the total yield per m^2 regardless the head weight.

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