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The Potential of Soilless Culture Systems in Producing Tomato and Cucumber under Greenhouse Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author MAA-S designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MSAE and AMHH managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Assess The sustainable production of tomato and cucumber under greenhouse conditions for meeting the challenges of natural resources shortage, food security and economic.
Study Design: Two experiments performed in complete randomized blocks with three replicates.
Place and Duration of Study: Central Laboratory for Agriculture Climate (CLAC), Agriculture Research Center, Egypt, during two autumn seasons of 2018 and 2019 (tomato) and two spring seasons of 2019 and 2020 (cucumber).
Methodology: Different soilless culture systems for producing tomato and cucumber under greenhouse were investigated: Hydroponic systems (Nutrient film technique (NFT) and deep flow technique (DFT)); and substrate systems (Dutch bucket, pot, container, and horizontal bag). Vegetative characteristics, yield parameters, N, P, and K contents, and environmental impact assessment were measured.
Results: Substrate systems gave the highest vegetative growth characteristics, yield parameters, N, P and K contents of tomato and cucumber leaves, as well as the highest power use efficiencies compared to hydroponic systems. Container and bags systems gave the highest results of tomato and cucumber vegetative growth, respectively, but the highest yield and net profits records

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belonged to bags and pots respectively. Bags substrate system gave the highest net profit yield (10.1Kg/ plant and 21881 LE / greenhouse) of tomato plant under plastic house followed by container system that presented the highest yield (10.6 Kg/ plant) but the total cost mainly substrate cost contributed to reduce its net profit yield. While for the highest yield and net profit of cucumber, the pots system (8.1Kg/ plant and 13243 LE / greenhouse) followed container system (7.65Kg/ plant and 9045 LE / greenhouse) and bags system (7.15Kg/ plant and 10270 LE / greenhouse) were recommended. The lowest yield, the highest average power use, cost and efficiency and lowest total cost were estimated by NFT system in both of tomato and cucumber investigations.

Conclusion: The substrate systems presented more sustainability for tomato and cucumber production under plastichouse conditions. Bags substrate system gave the highest net profit yield of tomato plant under plastic house followed by container system that presented the highest yield but the total cost mainly substrate cost contributed to reduce its net profit yield. While for the highest yield and net profit of cucumber, the pots system followed container system and bags system were recommended. The lowest yield, the highest average power use, cost and efficiency and lowest total cost were estimated by NFT system in both of tomato and cucumber investigations.

Keywords: Economic assessment; food security; hydroponic; Power Use Efficiency (PUE); substrate culture; yield.

1. INTRODUCTION

Tomato and cucumber plantsare the major cash crops under plastichouse as well as under open field and low-tunnelsas a high profit yields not just in Egypt but also in the worldwide scale. The vital needs for using soilless culture systems in producing tomato and cucumber are mainly maximize the water use efficiency and sustainable development under the current critical situation of water shortage and climate change impactsThe vegetables under this study are from the major vegetable crops grown in Egypt, they are cultivated under different methods of cultivation, i.e. open fiels, low tunnels and plastic house conditions. Tomato and cucumber are grown successfully in different soilless culture systems under greenhouse [1,2].

For increasing the yield and quality of tomato and cucumber as well as decreasing the threatening on human and environmental health, soilless culture systems are promising to achieve goals besides increasing the water use efficiency[3,4,5].

Soilless culture could be used on different scales from micro (greenhouse farms) up to mega (commercial greenhouse farms) via Plenty of soilless culture systems (substrate and hydroponic) as a flexible modern technology provided a sustainable and environmental production method. Due to inadequate agricultural area and climatic factors in the world, an increasing trend of using soilless culture has been observed worldwide especially under the shortage of water and soil [6,7,8].

Several authors investigated the cultivation of different cucumber and tomato varieties in different soilless culture systems under outdoor and greenhouse conditions to avoid the environmental issue of soil fumigation, production problems and climate change impacts while maximizing the water, fertilizer and land use efficiencies as well as the yield and the quality. Soilless culture have an environmental impact through reducing the use of agriculture chemical while maximizing the water use efficiency and offer the potential for cultivated unsuitable soils as a sustainable impact. There were arguments among the scientists concerning the quantity and quality of tomato and cucumberyield when grown in soilless systems compared to soil cultivation[9,10,11,12,13].

The author [14]provided the relationship between the sustainable agriculture production in hydroponic system and power use efficiency while the power use efficiency in soilless culture play the same important role of water use efficiency in conventional agriculture. Soilless culture characterized by high water use efficiency regarding to minimizing the evaporation and to prevent deep percolation and runoff compared to conventional methods of cultivating cucumber and tomato that need a high requirements of irrigation water[15,16,17].

Someone [18] mentioned that increased yield values in both pots systems comparing with beds or horizontal bags systems could be a result to increase substrate depth; the substrate depth increased from 10cm in case of beds and horizontal bags to13cm and 15cm in case of small and big pots systems, respectively,and the more depth gave more space for roots to grow and this idea was supported by results that indicated that both small and big pots recorded higher root fresh and dry weight values than beds or horizontal bags systems.

Someone[19] reported that container depth is considered an important variable influencing plant and root morphology as it is directly related to water holding capacity, humidity and air availability. It has been suggested that the highest values of stem diameter, biomass,yield of cucumber fruit, fruit's number, fruit size and fruit diameter were obtained from substrate system.

Several authors reported that substrate culture system presented the highest vegetative growth characteristics and yield parameters as well as the contents of nitrogen, phosphorus and potassium of tomato plant [20,21,8].

The current study aimedto investigate the sustainable, environmental and the profitablesoilless culture systemto produce tomato and cucumber under plastichouse conditions.

2. MATERIALS AND METHODS

The current study were conducted in the experimental unit of Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Center (ARC), Egypt.Tomato and cucumber were grown during two autumn and spring seasons of 2018- 2019 and 2019 – 2020, respectively, in different soilless culture systems under plastichouse conditions.

2.1 Plant Material

Tomato (*Solanum lycopersicum*)cv. Agyad F_1 hybrid seeds were sown on 1st and 3rdAugust of 2018 and 2019, respectively, in polystyrene trays (209 holes). After 45 days from sowing the seeds (4 – 5thtrue leaf stage), the tomato seedlings were transplanted into different soilless culture systems regarding the specification of each system.

Cucumber, cv. Safa 62 F_1 hybrid (*Cucums sativus* L.) seeds were sown on 10thand 8th February 2019 and 2020, respectively, in polystyrene trays (84 holes). After the fifth true leaf stage, the transplants were planted in different soilless culture systems regarding to the specification of each system.

Tomato and cucumber seedlings were cultivated under plastichouse (9 m width, 40m length and 4.5m height)conditionsthat took a place in double rows. The final plant densities of tomato and cucumber were equal in all soilless culture systems (4 plants / m^2), the distance among the plants in-row or between the rows varied depending on each system specification while between the beds was130 cm.

All other agriculture practices of tomato and cucumber cultivations under plastichouse were in accordance with the standard recommendations for commercial growers by Agriculture Research center (ARC), Ministry of Agriculture (MOLAR), Egypt [22,23].

2.2 Soilless Culture System Materials

2.2.1 Hydroponic systems

1 - Nutrient film technique (NFT), polyethylene plastic sheet (black and white with 200 micron thickness) was used to created NFT plastic gullies (0.2 m width, 6.5 m length and 0.1 m height). The seedlings of tomato and cucumber were transplanted into net cups (11cm) filled by peat moss : perlite (1 : 1 *v/v*) substrate (200 ml) and arranged in the NFT plastic gullies as presented in Fig. 1 Tow gullies were established on rising bed (0.6 m width, 6.0 m length and 0.42 m height), each bed had a seperated tank (0.6 m width, 1.2 m length and 0.35 m height to create solution volume 250 L) and submersible pump (80 watt) forpumpingthe nutrient solution via polyethylene pipe 16 mm for both NFT gullies on the rising bed. The rising bed offered a slope 1 % for NFT plastic gullies for collecting the drainage by gravity down to the tank toperformed a close NFT system. The fertigation schedule was programmed to work 24 - 30 times per day depending upon the season and growth stage via digital timer (each time 10 min./hour). The plant distance between the plants in-row was 50 cm.

2 – Deep flow technique (DFT), we reused a cheese plastic bucket (20 L volume) to create inovative DFT system as Fig. 2 illustrated. The plastic buckets were modified to match the DFT specifications needs, drainage polyethylene pipe 16 mm was established in 5cm from the top edge and the plastic covered of the bucket was holed

to match two holes for the seedlings net cups, one for supplying the nutrient solution and another for air supply. PVC (48 mm) were used to collectsthe drainge from each DFT bucket to the tank for presenting the close system. The seedlings of tomato and cucumber were transplanted into net cups (11cm) that filled by peat moss : perlite (1 : 1 *v/v*) substrate (200 ml), each bucket had tow plants while the DFT buckets were arranged in one row on the rising bed to create the equal plant densities among the different soilless culture systems under the studies. The plastic bucket filled with nutrient solution and its cover use as a base for the seedling net cups. Each rising bed had also seperated tank and submersible pump (the same specifics as above). Air pump (35 watt) was used to supply air for all DFT plastic buckets through polyethylene pipe 8 mm to avoid O_2 deplation. The pumping of nutrient solution and air scheduled to work 4 and 8 times per day respectively depended upon the season and growth stage via digital timer (each time 15 min./hour).

2.2.2 Substrate systems

Rising beds (0.6 m width, 6.0 m length and 0.42 m height) were constructed to demonstratedifferent substrate systems, each bed was covered by black polyethylene sheet (400 micron) for recollecting drainage with a slope 1 % to presented close substrate system while had a seperate tank and submersible pump (80 watt) forpumping the nutrient solution as the same specification above.Tomato and cucumber plants were irrigated by using drippers 4 L/h. The fertigation schedule was programmed to work 4 - 8 times per day in substrate systems depended upon the season and growth stage via digital timer (each time 10 min/h). The final plant distances of tomato and cucumber were 50 cm in-row between the plants, 40 cm between the rows and 130 cmbetween the beds for all substrate system exept dutch bucketwhich had one row per bed.

The standard substrate peat moss: perlite (1:1 *v/v*) was used in all substrate systems but dutch bucket was filled by perlite substrate only as follows:

1 – Pots system, vertical plastic pots (12 L volume) were filled with standard substrate. The potswerearranged in two rows (12 pots/ row) wereperformed 24 plants / 2 rows / bed (one tomato and cucumberseedling / pot) to presenteplant density 4 plants /m^2.

2 – Dutch bucket, we also reused a cheese plastic bucket (20 L volume) to create dutch bucket system. The plastic bucket modified by holed a drinage hole (5 cm from the base of the bucket) and PVC pipe (1 inches) with elbow were constructed to collect the drainge from the bucket to PVC pipe (2 inches) to the tank to performeclose substrate system. The plastic bucket fwas illed by 5 cm of gravil to assist the drainage easily and then was filled by perlite substrate 100%. The plastic bucketwas arranged along the bed in one row, each bucketwas cultivated by two plants.

3 – Bags system, horizontal polyethylene (white outer and black inner side with 0.2 mm thickness) bags (0.25 x 1 m = 35 L volume) were filled with standard substrate. Drainage hole at the bottom along the bags to allow recollecting the leaching nutrient solution. The bags was arranged in tow rows (2 bags/ row). Twotomato and cucumberseedlings were cultivated in each bag. The final plant density was 4 tomato and cucumberplants /m^2.

4 – In the containers system, container was created by using black polyethylene sheet (0.6 mm). The bed system (0.6 x 6.0 x 0.15 m) was filled by 540 L of standard substrate. The tomato and cucumberseedlings were cultivated in two rows with the same plant densities. The container system mulched by silver/black polyethylene sheet (0.2 mm).

The different substrate systems (pots, dutch bucket, bags and container) that grown by tomato and cucumber were observed in Fig. 3.

The physical and chemical properties of perlite and peat moss : perlite that use in dutch bucket substrate system and the rest of soilless culture systems used in these studies for tomato and cucumber were illustrated in Table 1.

Bulk density (B.D),Total poor space (T.P.S), Water holding capacity (W.H.C),Air porosity (A.P), Organic matter (O.M).

Chemical nutrient solution [24] was applied as illustrated in Table 2. The electrical conductivity (EC) of nutrient solution for all soilless culture systems was adjusted by using digital EC meter to the required level for both of tomato (2.0 – 3.5 dsm^{-1}) and cucumber during the different growth stages (1.5 – 2.5 dsm^{-1}).

2.3 The Investigated Treatments

The investigation studied the tomato and cucumber production in different commercial soilless culture systems under greenhouse conditions as follows:

1. Nutrient film technique (NFT)
2. Deep flow technique (DFT)
3. Pot substrate (Pots).
4. Dutch bucket (Dutch)
5. Bag substrate (Bags).
6. Container substrate (container).

The experimental design was complete randomized blocks with threereplicates. Each replicate contained 24tomato or cucumber plants.

2.4 The Measurements

2.4.1 The vegetative and yield characteristics

The vegetative characteristics of tomato and cucumber: plant height (cm), No. of leaves, stem diameter (cm) and total leaves area(cm^2) were measured at 120and 60 days, respectively, after transplanting at both cultivated seasons of each plant. While fresh plant and dry plant weight were determined at the end of each season for both of tomato and cucumber.

The yield parameters were collected during the production season (average early and total yield (kg) per plant and m^2, average fruit weight (g), average No. of fruit / plant and estimated at the end of season for both tomato and cucumber.

Fig. 1. Tomato and Cucumber growth in NFT plastic gully

Fig. 2. DFT system construction (bucket, air supply and pumping solution)

Fig. 3. The different substrate systems under the current study

Table 1. Physical and chemical properties of used substrates

	Physical				Chemical		
Substrate	**B.D g/l**	**T.P.S %**	**W.H.C %**	**A.P %**	**E.C ds m^{-1}**	**pH**	**O. M %**
Peat: perlite	165.4	64.5	32.0	32.5	0.40	7.6	46.0
Perlite	123.0	58.0	48.0	10.0	0.15	7.7	0.0

Table 2. Chemical composition of nutrient solutions at 2.5 dsm^{-1}

Elements	Macronutrients (ppm)						Micronutrients (ppm)					
	N	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**B**	**Cu**	**Mo**
Concentration	200	60	300	180	50	69	3.0	2.0	0.1	0.3	0.1	0.2

2.4.2 The chemical analysis

The physical and chemical properties (Bulk density (B.D), total pore space (T.P.S), water holding capacity % (W.H.C) and air porosity % (A.P) of perlite and peat moss : perlite (1: 1 *v/v*) for both two experiments were estimated according to [25,26]. The pH of the potting mixtures were determined using a double distilled water suspension of each potting mixture in the ratio of 1:10 (w: v)[27] that had been agitated mechanically for 2 h and filtered through Whatman No.1 filter paper. The same solution was measured for electrical conductivity (EC dsm^{-1}) with a conductance meter that had been standardized with 0.01 and 0.1M KCl.

For N, P and K (%) contents of tomato or cucumber plants, three plant samples (15 full expended leaves) of each replicate were dried at 70 ^{o}C in an air forced oven for 48 h. Dried tomato and cucumberleaves samples were digested in mixture of $HClO_4$ and H_2SO_4 acidsaccording to the method described by [28]and N, P and K contents were estimated in the acid digested solution by colorimetric method (ammonium molybdate) using spectrophotometer and flame photometer [29]. Total nitrogen was determined by Kjeldahl method according to the procedure described by [30]. Phosphorus content was determined using spectrophotometer according to [31]. Potassium content was determined photo-metrically using Flame photometer as described by [29].

2.4.3 The environmental and economic study

The power use calculated according pump power (watt) x operation hours/ day (1.33 and 5 h/day for substrate and NFT systems respectively) x 240 (No. of days / season) while the cost of Kw is currently equal 0.55 LE [14].

The power use efficiency (Kg / Kw / season) = the average yield (Kg /m^2 /seasons) / the average power use / m^2 / season of both seasons [14]

The economic impact assessment was calculated regarding to standard greenhousespanarea (9 x 60 m)540 m^2 = 1200 tomato or cucumber plants. The investment cost take in consideration the cost of each system (pumps, tanks, plastic, substrate, timers and irrigation network) / Annual depreciation rate. The operation cost include the nutrient solution, IPM and power use.

2.4.4 The statistical analysis

Analysis of the data was done using SAS program for statistical analysis and the means that were significant were separated using Duncan's New Multiple Range Test at P≤0.05 [32].

3. RESULTS

3.1 The Effect of Different Soilless Culture Systems on Tomato Plant

3.1.1 Vegetative growth characteristics

In general, substrate culture systems (Container, bags, pots and dutch bucket) presented positive significant effects on vegetative characteristics of tomato plants compared to hydroponic systems (NFT and DFT). Tomato plants that were cultivated in container substrate system had the highest records of plant height (cm), stem diameter (cm), No. of leaves and total fresh plant weight (g),followed by bags substrate system,while NFT system gave the lowest values. The highest results of dry matter content (%) were recorded by DFT and dutch bucket systems while pots system presented the lowest record as Table 3. illustrated.

3.1.2 Yield parameters

Logically, regarding to the results of different soilless culture systems on tomato vegetative characteristics, substrate systems had a superior significant impact on tomato yield which recorded the highest significant results of total yield /plant (kg), early and total yield per m^2 (kg) and average No. of fruits / plant in both cultivated seasons compared to hydroponic systems as Figs. 4,5,6,7 illustrated.

The results of Figs. (4, 5,6) indicated that container substrate followed by bags substrate system recorded the highest significant results of tomato yield parameters (total yield /plant (kg), early and total yield per m^2 (kg) and average No. of fruits / plant) in both cultivated seasons. On the contrary, the lowest tomato yield parameters were given by NFT followed by DFT systems. The significant effects among the different soilless culture treatment were true in both cultivated seasons.

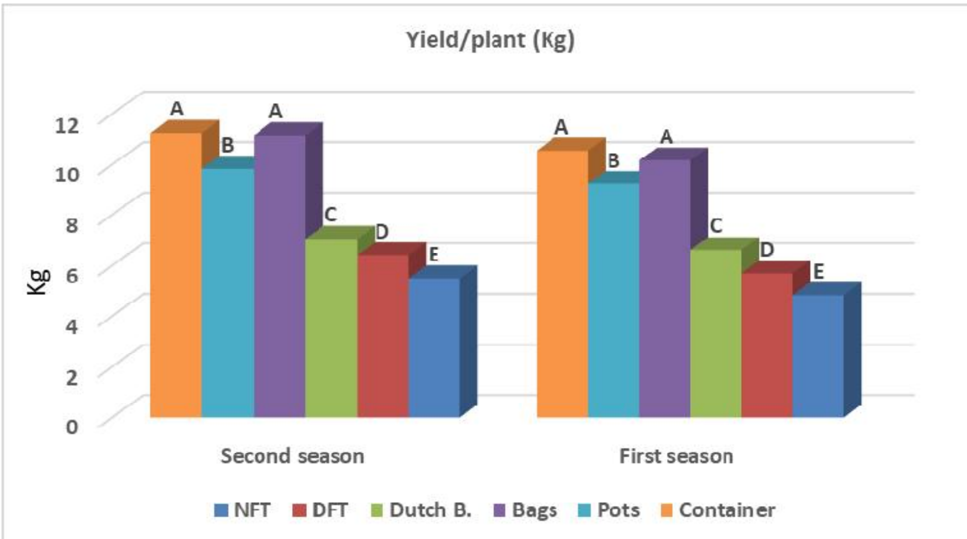

Fig. 4. The effect of different soilless culture systems on total yield /plant (kg) of tomato under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

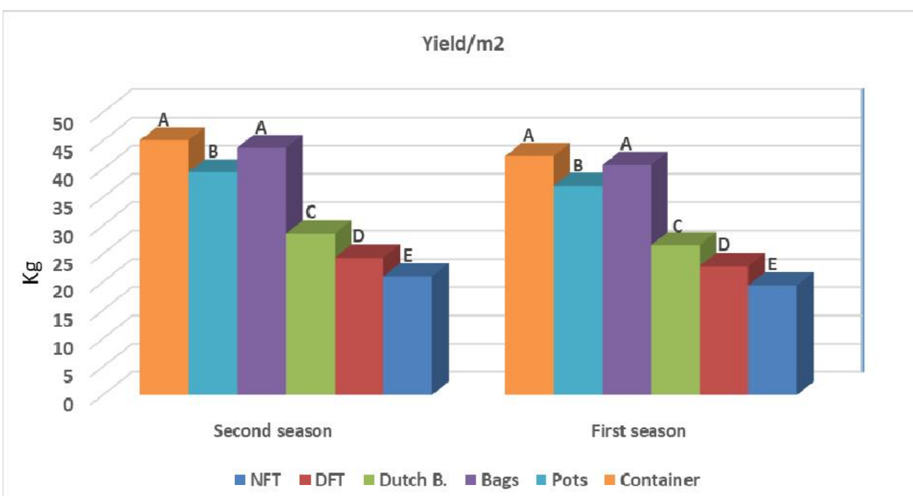

Fig. 5. The effect of different soilless culture systems on total yield per m^2 (kg) of tomatounder plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container).*

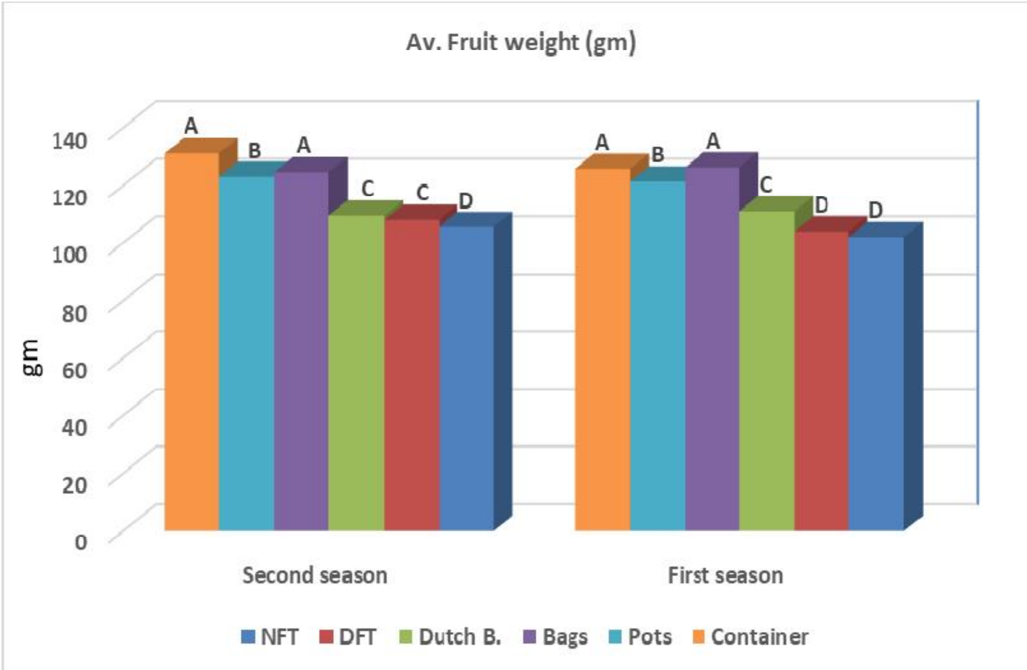

Fig. 6. The effect of different soilless culture systems on average fruit weight (gm) of tomato under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container).*

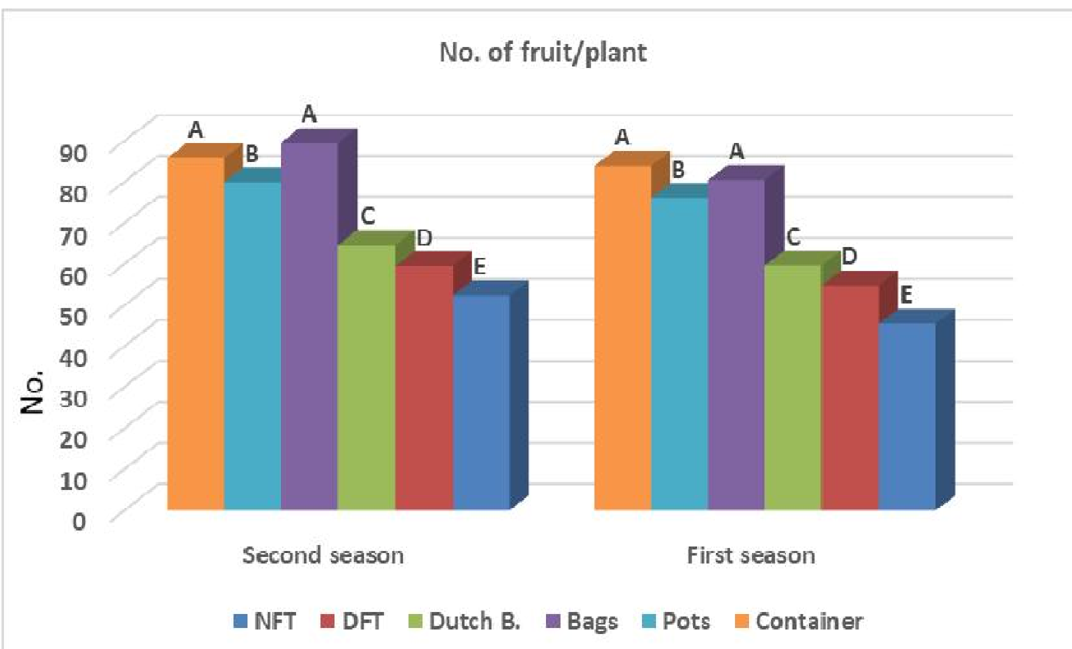

Fig. 7. The effect of different soilless culture systems on average No. of fruits / plant of tomato under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

3.1.3 N, P and K (%) contents of tomato leaves

Substrate culture systems (Bags, pots and container) illustrated supreme effect on the N, P and K contents of tomato leaves. The higher water and nutrient holding capacity of standard substarte peat moss : perlite (1:1 *v/v*) led to increase the N, P and K uptake compared to hydroponic systems such as NFT, DFT and dutch B. Container system recorded the highest values of N, P and K contents of tomato leaves,while NFT system gave the lowest records as Table (4) presented. Significant effect among the treatments were true in both cultivated seasons.

3.2 The Effect of Different Soilless Culture Systems on Cucumber Plant

3.2.1 Vegetative growth characteristics

The results of Table (5) indicated the same general observations on the effect of different soilless culture systems on cucumber as well as tomato plants. Substrate culture systems had the preferance of the cucumber vegetative characteristics (plant height (cm), stem diameter (cm), No. of leaves and total fresh plant weight (g)) compared to hydroponic culture systems.

Bags system gave the highest results of plant height and No. of leaves. Moreover, pots system recorded the highest values of stem diameter, total leaves area and fresh plant weightas well as dry matter content.

On the other hand, the lowest significant effects of vegetative characterictics in both cultivated seasons (plant height (cm), stem diameter (cm), No. of leaves and total fresh plant weight (g))were demonestrated by NFT system. Pots system showed the highest significant dry matter content followed by NFT system in both cultivated seasons as Table (5) presented. Otherwise, the lowest observed results of dry matter content (%) were varied from the first season to the second season by DFT and bags system respectively.

3.2.2 Yield parameters

In general, substrate systems (bags, pots and container) that recorded the highest significant vegetative growth characteristics had also the highest significant yield parameters in comparison to hydroponic systems (NFT, DFT and dutch bucket) that gave the lowest yield parameters. The obtained results of Fig. (8, 9, 10 and 11) observed that, pots system followed by container system presented the highest records of total yield /plant (kg), and total yield per m^2 , and average No. of fruits / plant but average fruit weight (g) was presented bycontainer system.

Moreover, the lowest yield parameters of cucumber were recorded by NFT followed by DFT system. The effects of different soilless culture treatments on cucumber yield parameters were significant in both cultivated seasons as Fig. (8, 9, 10and 11) illustrated. The most important yield parameters was the yield per plant as Fig. (8) observed.

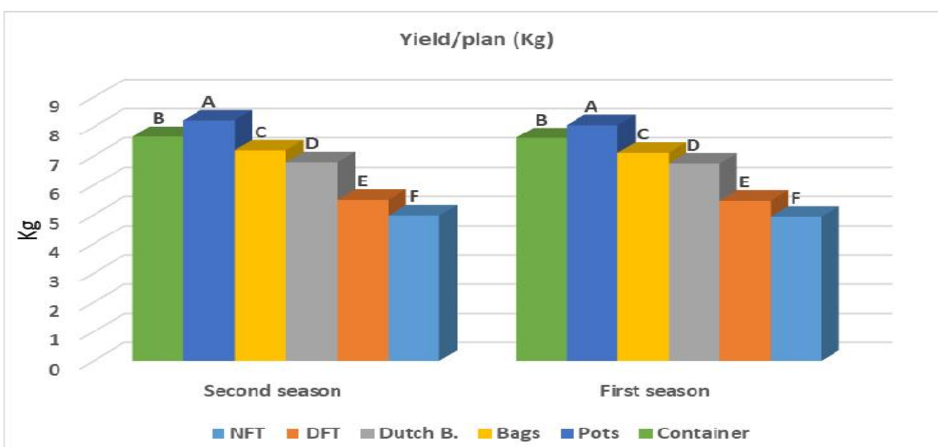

Fig. 8. The effect of different soilless culture systems on total yield /plant (kg) of cucumber under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

Table 3. The effect of different soilless culture systems on vegetative characteristics of tomato under plastichouse conditions

Soilless system	Plant height (cm)	Stem diameter (cm)	No. of leaves	Total leaves area (cm^2)	Fresh plant weight (g)	Dry matter(%)
First season 2018 / 2019						
NFT	254.40 F	1.42 D	37.37 D	3629.50 D	286.10 E	21.60 A
DFT	260.60 E	1.55 CD	40.50 C	4011.80 C	320.50 D	22.70 A
Dutch B.	279.10 D	1.66 C	41.10 C	4237.90 B	327.10 C	22.60 A
Bags	306.20 B	2.05 B	53.50 B	4462.50 A	464.30 B	16.91 B
Pots	293.90 C	2.00 B	51.80 B	4468.40 A	467.10 B	15.70 B
Container	314.30 A	2.45 B	59.59 A	4522.10 A	516.70 A	17.10 B
Second season 2019 / 2020						
NFT	256.60 F	1.53 D	34.20 D	3751.30 E	278.80 E	21.68 A
DFT	258.30 E	1.62 D	41.74 C	4086.30 D	322.40 D	22.87 A
Dutch B.	280.70 D	1.73 C	41.70 C	4263.30 C	335.70 D	22.81 A
Bags	309.70 B	2.19 B	53.83 B	4489.20 B	467.10 C	16.10 B
Pots	291.20 C	2.16 B	52.12 B	4528.60 B	486.60 B	15.95 B
Container	311.00 A	2.53 A	58.20 A	4649.20 A	519.70 A	17.22 B

** Similar letterswithin column indicate non-significant difference at 0.05 level; ** Capital letters indicate the significant difference of each factor (P<0.05); ***NFT(Nutrient film technique),DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags,pots and container)*

Table 4. The effect of different soilless culture systems on N, P and K (%) contents of tomato leaves under plastichouse conditions

Soillesssystem	First season 2018 / 2019			Second season 2019 / 2020		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
NFT	3.29 C	0.63 D	3.04 E	3.33 D	0.59 D	3.24 C
DFT	3.75 B	0.64 D	3.26 DE	3.78 C	0.64 CD	3.37 C
Dutch B.	3.86 B	0.69 C	3.54 CD	3.86 C	0.67 BC	3.45 C
Bags	4.44 A	0.77 B	3.82 BC	4.23 B	0.72 B	4.23 B
Pots	4.61 A	0.86 A	4.02 AB	4.61 A	0.91 A	4.54 A
Container	4.49 A	0.88 A	4.23 A	4.67 A	0.93 A	4.61 A

** Similar letterswithin column indicate non-significant difference at 0.05 levels; ** Capital letters indicate the significant difference of each factor (P<0.05); ***NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

Table 5. The effect of different soilless culture systems on vegetative characteristics of cucumber under plastichouse conditions

Soilless system	First season 2018 / 2019					
	Plant height (cm)	**Stem diameter (cm)**	**No. of leaves**	**Total leaves area (cm^2)**	**Fresh plant weight (g)**	**Dry matter(%)**
NFT	192.59 E	1.40 C	29.80 DE	5652.30 F	529.60 E	18.3 AB
DFT	202.83 D	1.59 B	28.20 E	6469.30 E	501.20 F	14.7 C
Dutch B.	238.20 C	1.64 B	34.60 B	6687.40 D	633.60 C	16.8 BC
Bags	259.12 A	1.96 A	38.70 A	6835.70 C	746.90 B	14.9 C
Pots	251.66 B	1.98 A	34.30 BC	7210.80 A	756.80 A	20.8 A
Container	233.66 C	1.94 A	31.9 CD	6867.20 B	599.60 D	17.9 AB
	Second season 2019 / 2020					
NFT	189.28 E	1.48 C	30.16 D	5703.10 E	534.40 D	18.51 B
DFT	204.65 D	1.60 B	28.94 D	6527.50 D	488.60 E	15.49 C
Dutch B.	236.12 C	1.63 B	34.93 B	6747.60 C	639.30 C	16.98BC
Bags	256.86 A	1.97 A	38.08 A	6930.60 B	724.30 B	15.06 C
Pots	253.92 B	1.97 A	36.05 B	7309.00 A	763.60 A	21.99 A
Container	236.09 C	1.95 A	32.57 C	6895.70 B	637.00 C	17.07BC

** Similar letters within columnindicate non-significant difference at 0.05 levels; ** Capital letters indicate the significant difference of each factor (P<0.05); ***NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

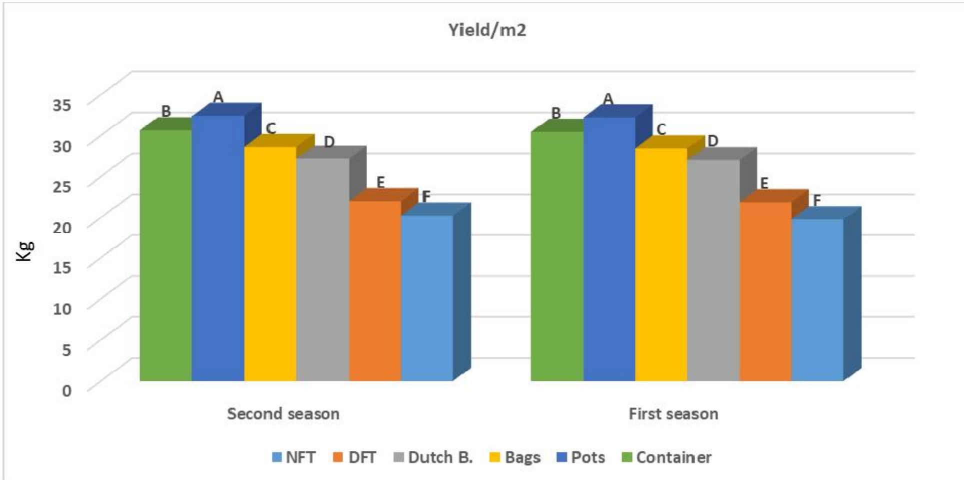

Fig. 9. The effect of different soilless culture systems on total yield per m^2 (kg) of cucumber under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container*

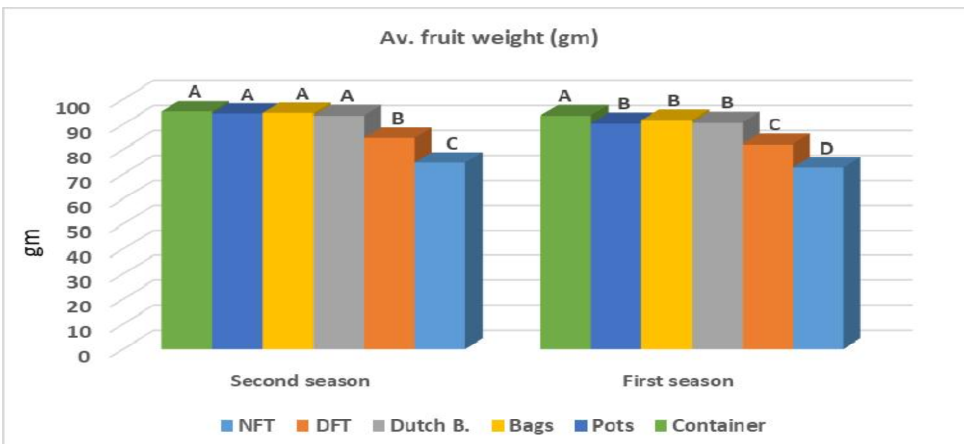

Fig. 10. The effect of different soilless culture systems on average fruit weight (g) of cucumber under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

3.2.3 N, P and K (%) contents of cucumber leaves

Table (6)presented the effect of different soilless culture systems on N, P and K (%) contents of cucumber leaves under plastichouse conditions. The revealed results indicated that similar results of the soilless systems effect on tomato nutrient leaves contents were obtained. Substarte systems encourage the nutrients uptake more than hydroponic systems did. Otherwise,pots system had the highest siginificant resultsof N, P and K contents of cucumber leaves and NFT system recorded the lowest values in both cultivated seasons.

3.3 The Environmental Impact Assessment of Different Soilless Culture Systems

3.3.1 The power use cost assessment and efficiency

Fig. 12.showed the average total power (Kw/m^2) consumed by different soilless culture grown tomato and cucumberand their average cost

(LE/m^2) under greenhouse condition during the two cultivated seasons. The obtained data indicated that both hydroponic systems (Flat and A-shape NFT) consumed more power and cost higher compared to substrate systems that's reflect on the power use efficiency. Hydroponic systems presented the highest values of average total consumed power and power cost during both cultivated seasons. Reducing the power use had not just an economic benefit, but also led to increase the sustainable ecology agriculture under greenhouse condition via reduce the environmental pollution and greenhouse gases (GHG's).

Concerning the average power use efficiency (Kg/kw) of different soilless culture systems, substrate systems had a different direction in contrary to the previous results which recorded the highest results of average power use efficiency compared to hydroponic systems. Container substrate had the highest significant average power use efficiency followed by bags system in producing tomato yield. For cucumber production, the highest power use efficiency observed by pots substrate system. On the other hand, the lowest power use efficiency results recorded by NFT system followed by DFT system as Fig. 14.illustrated. Needless to mentioned that the power use efficiency results between tomato and cucumber, tomato in general presented higher values compared to cucumber under the different soilless culture systems that indicated tomato needed less power for produce the same unit of yield comapred to cucumber.

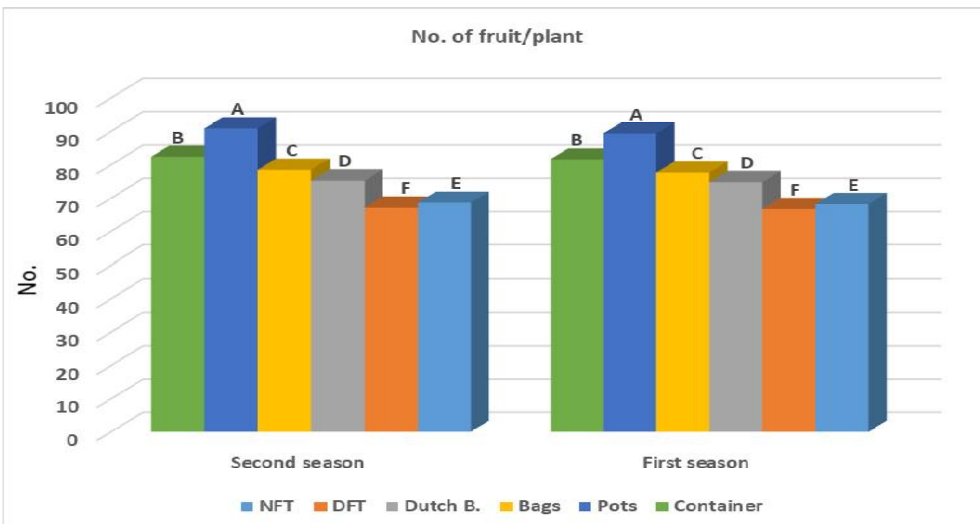

Fig. 11. The effect of different soilless culture systems on average No. of fruits / plant of cucumber under plastichouse conditions

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

Table6. The effect of different soilless culture systems on N, P and K (%) contents of cucumber leaves under plastichouse conditions

Soilless system	First season 2018 / 2019			Second season 2019 / 2020		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
NFT	2.94 C	0.37 C	3.04 B	2.96 D	0.38 C	3.06 B
DFT	3.18 BC	0.37 C	3.12 B	3.17 CD	0.37 C	3.11 B
Dutch B.	3.35 B	0.43 C	3.36 B	3.37 C	0.43 C	3.38 B
Bags	4.81 A	0.77 B	3.99 A	4.84 AB	0.78 B	4.02 A
Pots	4.84 A	0.89 A	4.46 A	5.04 A	0.89 A	4.52 A
Container	4.66 A	0.86 AB	4.18 A	4.69 B	0.86 B	4.24 A

** Similar letterswithin column indicate non-significant difference at 0.05 levels; ** Capital letters indicate the significant difference of each factor (P<0.05); ***NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container).*

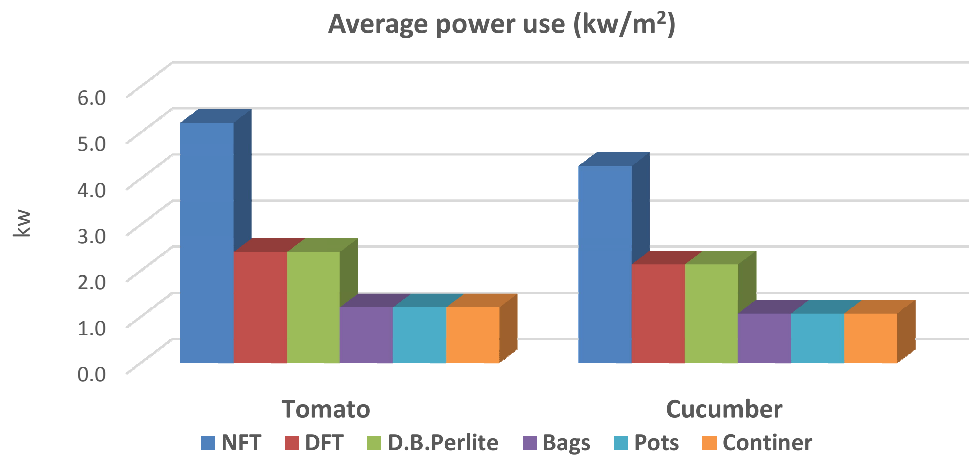

Fig. 12. Average power use (Kw/m^2) of different soilless culture grown tomato and cucumber under plastichouse condition.

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

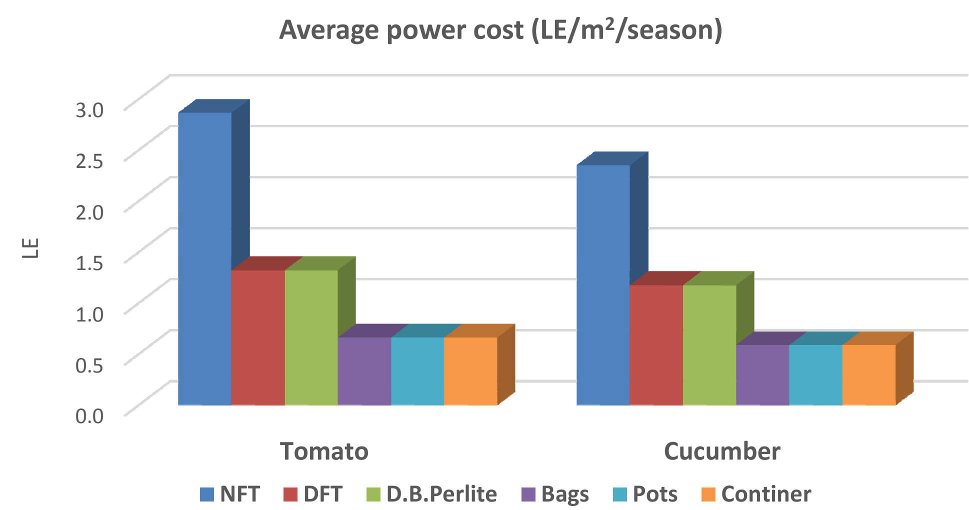

Fig. 13. Average power cost (LE/ m^2/ season) of different soilless culture grown tomato and cucumber under plastichouse condition.

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

3.2.2 The economic impact assessment

The obtained results of Table (7).Indicated that the use of different soilless culture systems both substrates and hydroponic systems achieved the netprofitable yield impact of growing tomato under plastic house conditions. Instead of the highest costs of substrate systems compared to hydroponic systems but had the highest net profit results. Bags substrate system yielded the highest return and net profit regarding to its result of the highest yield and moderate costs compared to NFT system that recorded the lowest investment and operation costs but presented the lowest yield resulted the lowest net profit. The highest investment cost of substrate systems regarding mainly to the high cost of standard substrate and short depreciation period.

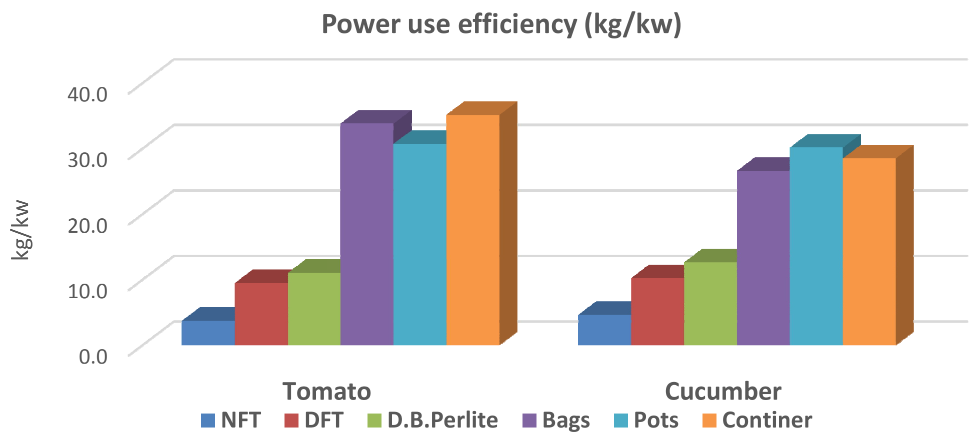

Fig. 14. The average power use effieciency (Kg/Kw) of different soilless culture grown tomato and cucumber under plastichouse condition

**NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags ,pots and container)*

Similar results presented in Table (8) the economic impacts of soilless culture systems on cucumber illustrated clearly the positive impacts of substrate systems on cucumber yield and profits. Pots substrate system observed the highest return and net profit while the NFT system gave the lowest values.

4. DISCUSSION

The study neglected the water use efficiency estimation of different soilless culture systems regarding to the well known knowledge of the positive water saving impact of soilless culture systems in food production. No deep perculation, no run-off and minimum evaporation were presented in different soilless culture systems. Otherwise, irrigation water for plant vegetative growth processes include the transpiration and yield.The minimum evaporation and leaching loss with maximum yield are the most vital factors for maximizing the water use effiency under soilless culture [6 ,15,16,17].

Resorting to soilless culture as an alternative method for matching the sustainable food production needs as well as minimize the negative impacts of soil, water and climate conditions is pivotal but the technolgy transfer, cost and the power needs eleminate the soilless culture expansion. Soilless culture is a method to avoid soil distenfiction, physical and chemical properties problems and water shortage while provide optimum conditions for roots and vegetative growth for maximum yield.Conserving the environmental (maximize the water, soil and chemical as well as minmize the greenhouse gases emissions) and sustainable (food security, social and economic) objectives.

Substrate culture systems introduced the highest vegetative growth characteristics compared to hydroponic systems that led to the highest yield parameters as a result of better nutrients uptakes that observed significantly in the N, P and K contents of tomato and cucumber leaves. While the relation between vegetative growth and yield is not always positive relationship. Container substrate system performed the highest vegetative growth characteristics besidessome yield parameters total yield per plant and per m^2 of tomato plants and average fruit weight of cucumberbut it didn't record the highest profityield per m^{2}by the same rate.

Substrate provided positive protection for tomato and cucumber roots by offer buffering stability for the roots against the temperature and moisture disturbances in the root zone. The standard used substrate under the current studies characterized by the high water and nutrient hold capacities besides suitable bulk density and air porosity that led to better root growth resulting better vegetative growth and definitly the yield. [33] mentioned thatthe soilless culture system which offers the optimum growth condition for the bare root vegetable seedlings success present the highest yield.

Table 7. The economic impact of tomato in different soilless culture systems under plastichouse conditions

Soilless system	Average cost and profitable impact (LE / Span)						
	Investment costs	**Operation cost**	**Total cost**	**Average yield (Kg)**	***Price EGP**	**Return EGP**	**Net profit EGP**
NFT	1545.8	12500	14,045.8	6600	2.8	18,480.0	4434.2
DFT	3803.3	12500	16,303.3	7692	2.8	21,537.6	5234.3
Dutch B.	6006.7	12500	18,506.7	8472	2.8	23,721.6	5214.9
Bags	4049.5	11600	15,649.5	13404	2.8	37,531.2	21,881.7
Pots	4225.0	11600	15,825.0	11808	2.8	33,062.4	17,237.4
Container	8001.7	11600	19,601.7	13,501.2	2.8	37,833.6	18,231.9

** Price EGP (Egyptian pound) calculated based on the average commercial (farm) price during the seasons of tomato; ** NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags, pots and container)*

Table 8. The economic impact of cucumber in different soilless culture systems under plastichouse conditions

Soilless system	Average cost and profitable impact (LE / Span)						
	Investment costs	**Operation cost**	**Total cost**	**Average yield (Kg)**	***Price EGP**	**Return EGP**	**Net profit EGP**
NFT	1030.5	9500	10,530.5	5976	2.5	14940	4409.5
DFT	2535.5	9500	12,035.5	6600	2.5	16500	4464.5
Dutch B.	4004.4	9500	13,504.4	8148	2.5	20370	6865.6
Bags	2699.7	8600	11,299.7	8628	2.5	21570	10270.3
Pots	2816.7	8600	11,416.7	9864	2.5	24660	13243.3
Container	5334.4	8600	13,934.4	9192	2.5	22980	9045.6

** Price EGP (Egyptian pound) calculated based on the average commercial (farm) price during the seasons of cucumber; **NFT (Nutrient film technique), DFT (deep flow technique) and substrate systems (Dutch bucket, horizontal bags, pots and container)*

Hydroponic system, especially NFT system suffered strongly from the temperature disturbance of the nutrient solution espicially during the cold nights or hot days under uncontrolled plastic house. Hydroponic systems such as NFT,DFT and dutch buckets consumed a huge power for presenting better management of nutrient solution temperature, dissolved O_2index (DOI), and pumping the nutrient solution for conserving the moisture around the roots stable and nutritional health state.

The volume of substrate per plant in different substrate systems play a role in increasingthe vegetative growth and yield parameters and N, P and K uptake that apeared strongly in leaves nutrient contents of tomato and cucumbercompared to hydroponic systems. The substrate volume per plant in substrate systems ranged from10 L / pot and dutch bucket, 15 L / bags, 22.5 L / container while both of NFT and DFT systems were 0.2 L. The increase of substrate volume led to increase the root zone volume, water and nutrient holding capacities as well as more balance for root zone temperature and moisture that provide a favorable environment for promotingtomato and cucumberroot growth as a results of increase in the absorption of nutrients[34,35].

The obtained results presented clearly that the selection of suitable soilless system in producing tomato and cucumber were very necessary to achieve the highest net profit under the plastic house conditions. The less power capacity and operation time use combined with higher yield demonstrated the maximum power use efficiency that fulfillment by substrate systems. [14,33] studied the importance of power consumption and cost relationship in soilless culture systems that depend mainly on the power that operating the system for performingthe sustainability of soilless culture in producing leafy vegetables and strawberry. Power use effiency is the other face of water use efficency for sustainable food production under greenhouse conditions and climate change impacts.

Bags system had the highest net profit of tomato production followed by container system that presented the highest yield but the total cost, mainly substrate cost, contribute to reduce its net profit yield. While for the highest yield and net profit of cucumber, the pots system followed container and bags were recommended.Bags substrate system gave the highest net profit yield (10.1Kg/ plant and 21881 LE / greenhouse) of tomato plant under plastic house followed by container system that presented the highest yield (10.6 Kg/ plant) but the total cost mainly substrate cost contributed to reduce its net profit yield. While for the highest yield and net profit of cucumber, the pots system (8.1Kg/ plant and 13243 LE / greenhouse) followed container system (7.65Kg/ plant and 9045 LE / greenhouse) and bags system (7.15Kg/ plant and 10270 LE / greenhouse) were recommended. The lowest yield, the highest average power use, cost and efficiency and lowest total cost were estimated by NFT system in both of tomato and cucumber investigations.

The lowest yield, the highest average power use, cost and efficiency and lowest total cost were estimated by NFT system.

Hydroponic systems in general consume higher power than substrate systems regarding the higher needs for pumping nutrient solution and supply airscheduling. Also, hydroponic systems consumed more power for optimizing the nutrient solution temperature to enhance the nutrient uptake and root growth that led to enhence the vegetative growth and therefore the yield. The environental impact and economic assessment results supported strongly the recommendations of this study.

5. CONCLUSION

The current study providedbesides the scientific investigation a technical guide to How to produce tomato and cucumber sustainability under plastichouse conditions in different soilless culture systems. The study recommended the use of bags substrate systems in producing tomato and and pots substrate system for cucumberto achieved the highest yield with economic and sustainable production. Substrate systems (pots, bags and container) in general consume less power than hydroponic systems (NFT, DFT and dutch bucket).

In general, the use of soilless culture systems in producing tomato and cucumberunder greenhouse conditions were profitable economicaly.The most important factor in defining the soilless system should be based on productive profitability (net profit), not yield. Also the power use efficiency and total investment costs of the soilless culture systems could be the limited factors regarding to the available conditions.

The need for more investigations to develop the use of soilless culture systems espicially reducing the substrate cost will provide more economic impact for container system. Also, improve the management of root zone conditions (temperature, moisture and DOI) in hydroponic systems (NFT and DFT) and enhence the power use efficiency may will improve the vegetative growth and yield parameters that resulte in increase the yield and the net profit.

Profit production, water, power and economic use efficiencies created the driving forces to promote the different soilless culture systems immplement in greenhouse under climate change impacts. The use of renew energy in provide the power needs of different soilless culture systems and precisely for hydroponic systems is neccessry.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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