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Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2019 16(3): 2866-2881. **OPEN ACCESS**

The sustainable production of lettuce and celery ecologyically in deep water culture

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To match the growing food demands, under climate change risks and lack of natural resources as a result of high population and urbanization, soilless culture could create a successful strategy to win not just in hunger war but also to achieve the sustainable and ecology food production. The investigation was carried out at Central Laboratory for Agriculture Climate (CLAC), Agriculture Research Center, Egypt during two successive autumn seasons of 2017 and 2018 in deep water culture system under net-house conditions. The aims of study were investigating the use of different air (O_2) supply systems (turning and flushing, pumping air and deep flow technique (DFT) combined with different sources of nutrient solutions (Chemical, vermi-liquid and chemical + vermi-liquid (1:1)) for producing ecology lettuce and celery yields. The experiment performed in complete randomized blocks design. The yield characteristics and nutrient contents (N, P and K (%) of lettuce and celery beside the dissolved oxygen index (DOI) of different air supply systems and nutrient solution sources were measured. The obtained results indicate that using air pumping led to decrease the power use (kw/season) and its cost while increase DOI of different nutrient solution sources in deep water culture systems resulted the highest yield of lettuce and celery followed by DFT while turning and flushing system recorded the lowest yield of lettuce and celery. Vermi-liquid had a negative impact on DOI while presented positive impact regarding to free chemical nutrient use, root growth and root: vegetative ratio. The application of chemical a nutrient solution gave the highest yield of lettuce and celery compared to other nutrient solutions sources as a logic result of satisfying the plants nutrient requirements. The interaction effect of air pumping combined with chemical solution followed by chemical + vermi-liquid (1:1) presented the highest yield of lettuce and celery. The highest N and K (%) contents of lettuce and celery were obtained by the use of air pumping m, chemical nutrient solution and the combined treatment between both of them. The application of vermi-liquid presented a high significant promotion on the roots growth of both lettuce and celery. The study recommended that implementing air pumping combined with chemical + vermi-liquid (1:1) as a nutrient solution in deep water culture for producing ecology and sustainable lettuce and celery. Deep water culture as an inexpensive and simple soilless culture system could attribute strongly in ecology production of leafy vegetables such as lettuce and celery. On the other hand, the use of vermi-liquid as a nutrient solution reduce the chemical use and environmental risk while sustained the vegetable production.

Keywords: Soilless culture, deep water culture, Air supply, dissolved oxygen index (DOI), vermi-liquid, chemical, nutrient solution, lettuce, celery, food security.

INTRODUCTION

To produce more sustainable food considering the environmental conditions (soil, water, recycling organic wastes and chemical fertilizers), climate change impacts and to match the growing population needs, soilless culture is a vital agricultural practice and success strategy.

Deep water culture as the most economic and simple soilless culture method was developed independently by Jensen and Collins (1985) in Arizona and Massantini (1976) in Italy. Deep Water Culture or Direct Water Culture (DWC) is one of the most effective and economic hydroponic method for growing a mass production of lettuce heads or other leafy vegetables on a floating raft of expanded plastic that sustains plants roots in a well-aerated solution full of nutrients and water. Integrated system of DWC with cooling the nutrient solution stops the bolting of lettuce offer the possibility for producing large scale production of lettuce in the Caribbean. Bradley and Marulanda (2000) reported the use of simplified hydroponic technology which reduces the land requirement for crops by 75% or more and water used by 90% with negligible effect on environment. Lettuce is the most hydroponically cultivated leafy crop in the world take a place about 99% of their hydroponic leaves and sold 40%approximately more expensive than a lettuce grown traditionally. Celery is a promising leafy vegetables recently in hydroponic especially in DWC (Barbosa et al., 2015). Gislerød and Adams (1983), Morard and Silvestre (1996) and Papadopoulous et al., (1999) mentioned the concentration of oxygen in the nutrient solution depends on crop demand and nutrient solution temperature (reverse relationship). The depletion of O_2 in hydroponic systems produces an increase in the relative concentration of CO_2 in the root environment. A decrease bellow 3 or 4 mg L-1 of dissolved oxygen, inhibits root growth and produces changes to a brown color, which can be considered as the first symptom of the oxygen lack. The supply of pure, pressurized oxygen gas (oxyfertigation) to the nutrient solution is an oxygen-enriched method often used for research purposes not for commercial targets (Chun & Takakura, 1994).

Vermicomposting had more attention in Egypt since the first study (Abul-Soud et al., 2009) that spread the word for recycling the different organic agricultural residues and urban wastes in Egypt via specific epigic earthworms. The use of vermicomposting outputs such as vermicompost, vermi-tea and vermi-liquid took a lot of efforts during the last decade to presented many investigations conducted locally. Extract during vermicomposting process is known as vermi-liquid (vermicompost extract). Vermicomposting derived liquids contain valuable essential nutrients, growth promoters and humic substances that encourage the plant growth. Mainly, use an animal manure and agricultural waste for producing the vermi-Liquid (Gutiérrez-Miceli et al, 2011 and Pant et al., 2009). Available plant nutrients that present in these liquids are valuable and have the potential to be used as nutrients solution in hydroponics culture. Quaik et al., 2012 reported that vermicomposting leachate, this bio fertilizer showing promising results in various dilutions, The using of vermi-liquid, vermi-tea and compost-tea as an organic nutrient solution sources for different vegetable crops; sweet pepper (Abul-Soud et al., 2014), snap bean (AboSedera et al., 2015), strawberry (Abul-Soud et al., 2015a) lettuce (Abul-Soud 2015, Abul-Soud et al., 2015 band Abul-Soud et al., 2017), spinach , Molokai (Abul-Soud and Mancy 2015), celery and cabbage (Abul-Soud 2015) mainly in different substrate culture systems.

Reduce the energy inputs (injection, cooling, heating and air supply) and chemical nutrient solution in producing lettuce and other leafy vegetable crops constitutes a real dilemma for researchers as well as the growers to achieve the sustainable and ecology objectives. The study objected to maximize the yield of leafy vegetables (lettuce and celery) while secure the ecology and sustainable production under the soil, water and fertilizer shortages via enhancing air supply and use friendly environment, sustainability nutrient solution and power use in deep water culture technique.

MATERIALS AND METHODS

The investigation was carried out in the experimental station of Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Center (ARC), Egypt, during two autumn seasons2017 and 2018 in deep water culture system under double span nethouse conditions

Plant material:

Lettuce (*Lactuca sativus*) cv. Othilie -RZ*F1 hybrid* (Batavia green lettuce) and celery *Agium gravealens var. dulace)* cv. Royal crown *F1 hybrid* seeds were used in the experiment.

Seeds of celery were sown in the first week of September while seeds of lettuce were sown twice in the last week of September and the first week of November in both seasons (2017 and 2018) in polystyrene trays. After the fourth true leaf stage (3 weeks for Batavia lettuce – 6 weeks for celery), one seedling of each lettuce or celery was planted in plastic net cups (size 9 cm) filled by perlite. Seedlings were transplanted into holed foam plates that cover the deep water culture surface in the middle of October in both seasons (2017 and 2018). The final plant spacing was 20 cm in the row and between the plants to create plant density 21 plant/m^2. Batavia green lettuce cultivated twice during the celery season for prevent the interruption between the different season time for each plant type (Batavia green lettuce 30 – 35 days while celery 60 – 75 days) and plant density in the deep water culture system.

All other agriculture practices of lettuce and celery cultivations were in accordance with the standard recommendations for commercial growers by Agriculture Research center (ARC), Ministry of Agriculture, Egypt.

The vermicomposting process:

The vermi composting output (vermi-liquid) offered via vermin culture and vermicomposting research unit, CLAC. For producing vermi-liquid, vertical indoor fattening trays was used. Plastic boxes (64 boxes) arranged in four stands (4 shelves/ stand)) while a plastic tank laid in the bottom to collect the vermi-liquid during the vermicomposting process.

Each plastic box (38 x 54 x 20 cm) was contained 250 g of epigic earthworm (*Lumbriscus Rubellus* (Red Worm), *Eisenia Fetida* (Tiger Worm), *Perionyx Excavatus* (Indian Blue) and *Eudrilus Eugeniae* (African Night Crawler). The vermicomposting process, mixing well and adjust the moisture of the different raw organic materials: vegetables and fruits wastes + rabbit manure + cattle manure in the rate of 1:1:1 (*v/v*) before feeding earthworm. The feeding of earthworm in rate 1:1 daily depending on the earthworm biomass with two days fasting every week. Moisture content was adjusted regularly in the range of 60 – 70 %.

The vermi-liquid was collected weakly according to the vermicomposting process (Abul-Soud et al., 2009 and Abul-Soud and Mancey 2015 and Abul-Soud et al., 2017).

System materials

A simple construction basin (1.2 x 3.6 x 0.3 m) were established by blocks and cement on concrete base to presented reservoir deep water culture to hold a sufficient amount of water (1.296 m^3) for the more nutrient solution stability and the less maintenance, and monitoring.. The inner sides and bottom of experimental reservoir were covered by black polyethylene sheet (1mm) for creating deep water culture. The basin filled by water till 25 cm to performed real cultivation water volume 1.08 m^3. Foam polystyrene (high density) plates (0.6 * 1.2 m) were holed in distances 20 cm among the holes to offer place for the net cups with the lettuce and celery plants. Foam plates cover the water surface of DWC.

The different treatments of nutrient solution sources were applied. Chemical nutrient solution (Abul-Soud et al., 2017), vermi-liquid and chemical + vermi-liquid were applied. The EC of nutrient solutions were adjusted by using EC meter to the required level (1.8 dsm^{-1}).The chemical composition of different nutrient solution sources presented in Table (1).

Different air supply systems for offering sufficient O_2 and to prevent O_2 depletion (air pump, turning and flushing and deep flow technique (DFT) via submersible water pump) were established and tested before transplanting the seedlings. The different pumps were programmed via digital timer to work during the day (18 times (15 min./hour) from 06:00 to 00.00).

The investigated treatments

The study investigated two factors combined together:-

First, three different air supply systems : Air pump (105 watt / 3 deep water culture), turning and flushing by using submersible pump (40 watt / deep water culture) and deep flow technique by using submersible pump (40 watt/ deep water culture). The different air supply systems are illustrated in Fig. (1, 2 and 3).

Second, three different sources of nutrient solutions: chemical nutrient solution (Ch.N.S.) (control), vermi-liquid (Ver. L.) as organic source of nutrient solution and chemical nutrient solution + vermi-liquid (Ch.N.S. + Ver. L.) (1 : 1) .

The measurements

The vegetative and yield characteristics:

The average measurements of two lettuce cultivation per season were determined and presented at the end of growing seasons (4-5 weeks from transplanting). Celery vegetative and yield data were estimated at the end of growing seasons (9-10 weeks from transplanting).

Table (1): The chemical composition of different sources of nutrient solutions.

Nutrient source	Macronutrients (ppm)					Micronutrients (ppm)					
	N	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo
Ch. N.S.	160	40	240	150	48	3.0	0.8	0.4	0.5	0.25	0.02
Ver.-L.	145	92	191	87	56	8.7	1.9	0.29	0.28	0.15	0.04
Ch. + Ver.-L	150	65	226	118	51	5.9	1.3	0.35	0.40	0.20	0.03

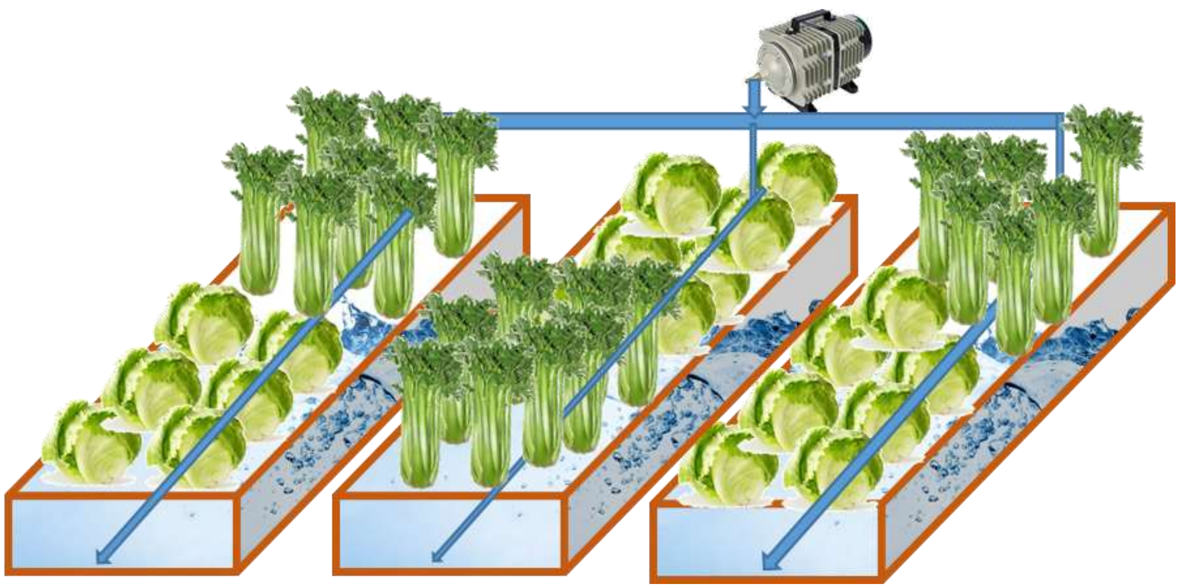

Figure 1: Air supply system via air pump (105 watt) in deep water culture (DWC)

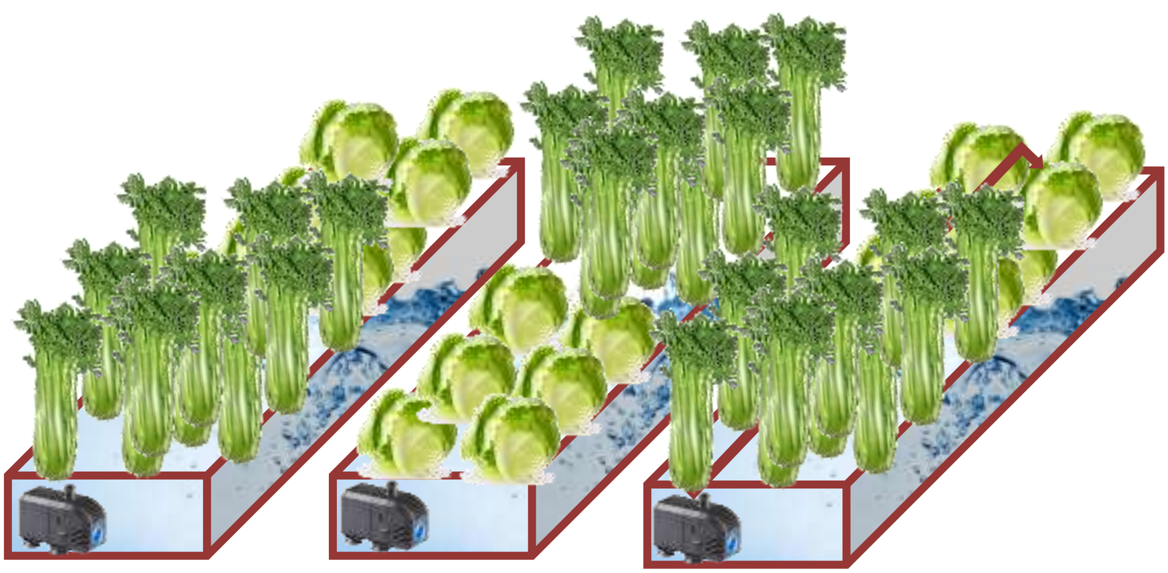

Figure 2: Air supply system turning and flushing via submersible p pump (40 watt) in deep water culture (DWC).

Figure 3: Air supply system deep flow technique (DFT) via submersible pump (40 watt) in deep water culture (DWC).

Plant height (cm), number of leaves, total plant weight (g / plant), average fruit (head) weight (g / plant), root weight (g / plant), total yield (Kg /season/m^2), root / vegetative ratio (%) and dry matter content (%) were measured for both lettuce and celery during the both cultivated seasons.

The chemical analysis

For N, P and K (%) contents of lettuce and celery, five plant samples at the harvest stage of each plot were dried at 70 ^oC in an air forced oven for 48 h. Dried plant samples were digested in mixture of $HClO_4$ and H_2SO_4 acids according to the method described by Allen (1974) and N, P and K contents were estimated in the acid digested solution by colorimetric method (ammonium molybdate) using spectrophotometer and flame photometer Chapman and Pratt, (1961). Total nitrogen was determined by Kjeldahl method according to the procedure described by FAO (1980). Phosphorus content was determined using spectrophotometer according to Watanabe and Olsen (1965). Potassium content was determined photo-metrically using Flame photometer as described by Chapman and Pratt (1961).Dissolved oxygen index (DOI) was measured by using digital DOI meter.

The different nutrient solutions composition were chemically analyzed according Chapman and Pratt, (1961), FAO (1980) and Watanabe and Olsen (1965).

The environmental study:

Chemical nutrient use and power use efficiency were determine regarding each treatment of air supply and nutrient solution source. The chemical nutrient solution was estimated at the end of each season. Chemical nutrient solution cost about 180 LE / season while the vermi-liquid cost 40 LE / season.

The power use calculated according pump power (watt) x operation hours/ day (4.5 hr/day) x 75 (No. of days / season) while the cost of Kw is currently equal 0.55 LE.

The power use efficiency (Kg / Kw / season) = the average yield (Kg /m^2 /seasons) / the average power use / m^2 / season of both seasons for both lettuce and celery.

The maximum and minimum temperature were determined by central lab. For agricultural climate (CLAC) under the net house by using Agro meteorological station.

The statistical analysis:

The experimental design was complete randomized blocks with 3 replicates. Analysis of the data was done by computer, using SAS program for statistical analysis and the differences among means for all traits were tested for significance at 5 % level (Snedicor and Cochran 1981).

RESULTS AND DISCUSSION

The effect of air supply systemand nutrient solution source onlettuce plant

Vegetative, yield and root growthcharacteristics

Table (2 and 3) presented the effect of different air supply systems and nutrient solution sources on vegetative and yield characteristics of lettuce in both cultivated seasons. Air pumping as an air supply system had a significant positive effect that recorded the highest results of number of leaves, total plant weight (g/plant), head weight (g), total yield weight (Kg/ season / m^2), dry matter (%), average root weight (g/plant) and root : shoot ratio (%) of lettuce plant. These results may explained through the positive effect of air pumping on increasing DOI that led to enhance the vegetative and root growth which reflect on the yield positively. The increasing rate of vegetative and root growth had the same significant trend of DOI.

The effect of different nutrient solutions on lettuce as illustrated in Table (2 and 3) observed that the use of chemical nutrient solution gave the highest values of vegetative, yield and root growth characteristics. These results were expected and acceptable referring to the balance and sufficient nutrients composition. Otherwise, there was no significant difference between Ch. N.S and Ch. N.S + Ver.-L treatments that encourage the use of Ch. N.S + Ver.-L in producing lettuce in DWC system environmentally. The lowest data of number of leaves, total plant weight (g/plant), head weight (g) and total yield weight (Kg/ season / m^2) but the highest average root weight (g/plant) and root : shoot ratio (%) of lettuce plant were gave by Ver.-L treatment as nutrient solution source. The use of Ver.-L illustrated a strong significant effect on root growth and root: shoot ratio. Increasing the rate from 0 (Ch. N.S treatment) to 50 % (Ch. N.S + Ver.-L) up to 100 % (Ver.-L treatment). Three expected factors could be used to explain these results, first: the negative impact of vermi-liquid on DOI that push the root growth of lettuce plants to compensate the O_2 depletion in DWC that in contrast with Morard and Silvestre (1996) and Papadopoulous et al., (1999) who reported that DOI level less than 3 or 4 mg L-1 led to inhibits root growth and produces changes to a brown color, which can be considered as the first symptom of the oxygen lack, second: the components of vermi-liquid could encourage more the root growth at the expense the vegetative growth while the third factor referring to the unbalance of nutrient composition and amounts that satisfy for lettuce plant nutrient requirements. Many studies investigated the use of vermi-liquid in substrate culture such as Quaik et al, 2012, AboSedera et al., 2015and Abul-Soud et al., 2015 a and b who observed the valuable of available plant nutrients of vermi-liquid and the potential nutrients solution in various dilutions with different plants like legumes crops, snap bean, lettuce and strawberry in substrate culture.

However, regarding the interaction effect among the different treatments of air supply system and nutrient solution sources, the obtained results indicated that air pumping combined with Ch. N.S presented the highest values of number of leaves, total plant weight (g/plant), head weight (g) and total yield weight (Kg/ season / m^2) followed by the interaction treatment air pumping combined with Ch. N.S + Ver.-L while the lowest records gave by turn & flu. + Ver.-L. On the other hand, the highest results of root weight and root : shoot ratio recorded by air pumping combined with Ver.-L while turn & flu combined with CH. N.S had the lowest data as Table (2 and 3) shown.

N, P and K (%) contents of lettuce head

The effect of air supply systems and nutrient solution sources on the N, P and K (%) contents of lettuce as Table (3) showed. Concerning the air supply system, the presented data indicated that the applying of air pumping treatment had the highest N, P and K (%) contents of lettuce as a result of increasing DOI while turn & flu. treatment illustrated the lowest N, P and K (%) contents. Increasing DOI depending on the air supply system efficiency led to increase N, P and K (%) contents of lettuce.

The treatment of Ch. N.S had a superior significant effect on N and K (%) contents of lettuce. The easily available, balanced nutrients and optimum pH of Ch. N.S treatment affect significantly on increasing N, P and K (%) contents in lettuce leaves (Abul-Soud 2015). Ver.-L treatment gave the highest value of P content of lettuce head. The results provided environmentally the use of Ch. N.S + Ver.-L as nutrient solution source to reduce the chemical nutrient solution use while observed average N, P and K (%)contents with high lettuce yield (Table 3).

Table (2): The effect of different air supply systems and nutrient solution sources on vegetative and yield characteristics of lettuce.

Air Supply system	First season 2017 / 2018				Second season 2018 / 2019			
	Nutrient source				Nutrient source			
	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)
	Number of leaves							
Turn. & Flu.	21.0 b	16.9 d	19.1 c	19.0 B	22.0 ab	17.0 e	19.3 d	19.4 B
Air pump	23.0 a	19.7 bc	20.3 bc	21.0 A	23.0 a	20.0 cd	21.0 bc	21.3 A
DFT	21.2 b	16.9 d	20.3 bc	19.4 B	22.0 ab	17.0 e	20.0 cd	19.7 B
Mean (A)	21.7 A	17.8 C	19.9 B		22.3 A	18.0 C	20.1 B	
	Total Plant weight (g / plant)							
Turn. & Flu.	184.4 c	149.3 d	159.4 d	164.4 C	178.1 c	157.0 c	169.6 c	168.2 C
Air pump	233.4 a	226.6 a	222.7 ab	227.6 A	243.9 a	242.2 a	232.8 ab	239.6 A
DFT	202.2 bc	200.9 bc	199.1 c	200.7 B	222.4 ab	213.1 b	212.5 b	215.9 B
Mean (A)	206.7 A	192.3 B	193.7 B		214.8 A	204.1 A	205.0 A	
	Average Head weight (g / plant)							
Turn. & Flu.	140.1 b	96.6 d	128.7 c	121.8 C	133.9 e	105.6 f	137.5 e	125.7 C
Air pump	169.4 a	143.6 b	162.8 a	158.6 A	177.1 a	155.0 c	172.8 ab	168.3 A
DFT	140.8 b	129.4 c	141.0 b	137.1 B	159.1 bc	139.0 de	152.3 cd	150.1 B
Mean (A)	150.1 A	123.2 C	144.2 B		156.7 A	133.2 B	154.2 A	
	Total yield (kg /season / m^2)							
Turn. & Flu.	5884.1 b	4057.2 d	5405.3 c	5115.6 C	5625.0 d	4436.1 e	5773.3 d	5278.2 C
Air pump	7114.8 a	6031.9 b	6839.0 a	6661.9 A	7436.1 a	6509.5 b	7259.6 a	7068.4 A
DFT	5913.2 b	5436.2 c	5922.0 b	5757.1 B	6683.5 b	5837.9 cd	6397.4 bc	6306.3 B
Mean (A)	6304.0 A	5175.1 C	6055.4 B		6581.6 A	5594.5 B	6476.8 A	
	Dry matter (%)							
Turn. & Flu.	6.33 bcd	6.46 bc	6.10 d	6.30 B	6.40 a	6.56 a	6.33 a	6.43 A
Air pump	6.13 d	7.73 a	6.23 cd	6.70 A	6.23 a	6.53 a	6.46 a	6.41 A
DFT	6.40 bc	6.53 b	6.26 cd	6.40 B	6.16 a	6.23 a	6.36 a	6.25 A
Mean (A)	6.29 B	6.91 A	6.20 B		6.26 A	6.44 A	6.38 A	

* Similar letters indicate non-significant at 0.05 levels. ** Capital letters indicate the significant difference of each factor (P<0.05)
*** Small letters indicate the significant difference of interaction (P<0.05)

Table (3): The effect of different air supply systems and nutrient solution sources on root growth parameters and N, P and K content (%) of lettuce.

Air supply system	First season 2017 / 2018				Second season 2018 / 2019			
	Nutrient source				Nutrient source			
	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)
	Average root weight (g / plant)							
Turn. & Flu.	44.30 de	52.70 cd	30.70 e	42.57 B	44.13 ef	51.43 de	32.17 f	42.58 B
Air pump	64.00 bc	83.00 a	59.86 bc	68.96 A	66.80 bc	87.20 a	59.96 cd	71.32 A
DFT	61.40 bc	71.50 ab	58.03 bcd	63.64 A	63.20 bcd	74.11 ab	60.23 bcd	65.83 A
Mean (A)	56.57 B	69.11 A	49.53 B		58.04 B	70.90 A	50.79 B	
	Root: shoot ratio (%)							
Turn. & Flu.	24.00 c	35.11 a	19.20 d	26.11 B	24.63 b	32.63 a	18.90 c	25.39 B
Air pump	27.33 bc	36.53 a	26.77 bc	30.21 A	27.37 b	36.00 a	25.67 b	29.68 A
DFT	30.27 b	35.46 a	29.00 b	31.58 A	28.40 b	34.63 a	28.27 b	30.43 A
Mean (A)	27.20 B	35.69 A	24.98 B		26.80 B	34.42 A	24.28 C	
	N (%)							
Turn. & Flu.	3.04 c	2.54 g	2.63 f	2.74 B	3.34 c	2.75 h	2.82 g	2.97 C
Air pump	3.25 a	2.72 e	3.14 b	3.03 A	3.58 a	2.95 e	3.39 b	3.31 A
DFT	2.85 d	2.69 ef	2.78 de	2.78 B	3.24 d	2.87 f	2.98 e	3.03 B
Mean (A)	3.05 A	2.65 C	2.85 B		3.39 A	2.86 C	3.06 B	
	P (%)							
Turn. & Flu.	0.45 f	0.62 d	0.56 e	0.54 B	0.47 f	0.60 d	0.53 e	0.53 B
Air pump	0.59 de	0.90 a	0.66 c	0.71 A	0.57 d	0.88 a	0.64 c	0.70 A
DFT	0.38 g	0.77 b	0.48 f	0.54 B	0.40 g	0.75 b	0.49 f	0.54 B
Mean (A)	0.47 C	0.76 A	0.57 B		0.48 C	0.74 A	0.55 B	
	K (%)							
Turn. & Flu.	1.27 bc	1.04 g	1.10 f	1.14 C	1.34 c	1.07 i	1.13 h	1.18 C
Air pump	1.33 a	1.13 e	1.30 ab	1.25 A	1.41 a	1.20 f	1.37 b	1.33 A
DFT	1.25 c	1.11 ef	1.18 d	1.18 B	1.29 d	1.16 g	1.25 e	1.23 B
Mean (A)	1.28 A	1.10 C	1.19 B		1.35 A	1.15 C	1.25 B	

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor (P<0.05)
*** Small letters indicate the significant difference of interaction (P<0.05)

Table (4): The effect of different air supply systems and nutrient solution sources on vegetative and yield characteristics of celery.

Air supply system	First season 2017 / 2018				Second season 2018 / 2019			
	Nutrient source				Nutrient source			
	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)
	Plant height (cm)							
Turn. & Flu.	59.3 bc	34.3 f	60.7 b	51.4 B	62.40 c	33.83 g	58.33 d	51.52 B
Air pump	60.3 b	42.3 e	65.7 a	56.1 A	64.00 bc	42.50 f	66.37 a	57.74 A
DFT	57.0 c	47.0 d	64.7 a	56.2 A	58.27 d	48.46 e	66.40 ab	57.71 A
Mean (A)	58.9 B	41.2 C	63.7 A		61.56 B	41.60 C	63.82 A	
	Number of leaves							
Turn. & Flu.	22.0 ab	19.7 c	21.3 abc	21.0 B	19.33 b	17.66 ce	18.66 bc	18.55 A
Air pump	23.3 a	17.0 d	21.0 bc	20.4 B	22.00 a	17.00 e	18.33 bce	19.11 A
DFT	23.0 ab	22.0 ab	23.0 ab	22.7 A	19.33 b	18.60 bc	18.66 bc	18.88 A
Mean (A)	22.8 A	19.6 B	21.8 A		20.22 A	17.77 B	18.55 B	
	Total Plant weight (g / plant)							
Turn. & Flu.	557.0 f	526.0 g	932.7 c	671.9 C	547.43 f	520.83 f	893.60 c	653.96 C
Air pump	871.3 d	795.0 e	1396.0 a	1020.8 A	845.43 d	787.33 e	1299.73 a	977.50 A
DFT	859.7 d	849.0 d	1131.3 b	946.7 B	826.66 de	835.66 d	1008.27 b	890.20 B
Mean (A)	762.7 B	723.3 C	1153.3 A		739.84 B	714.61 B	1067.20 A	
	Average Head weight (g / plant)							
Turn. & Flu.	472 e	233 fg	696 c	467 C	455.7 e	239.2 f	664.9 c	453.3 C
Air pump	775 b	258 f	969 a	667 A	730.4 b	282.3 f	894.1 a	635.6 A
DFT	637 d	229 g	758 b	541 B	609.6 d	242.3 f	682.9 c	511.6 B
Mean (A)	628 B	240 C	807 A		598.6 B	254.6 C	747.3 A	
	Total yield (kg / m^2)							
Turn. & Flu.	9919 e	4900 fg	14616 c	9811 C	9571 e	5022 f	13963 c	9519 C
Air pump	16278 b	5418 f	20338 a	14011 A	15339 b	5929 f	18775 a	13347 A
DFT	13380 d	4818 g	15918 b	11372 B	12803 d	5089 f	14341 c	10744 B
Mean (A)	13192 B	5045 C	16957 A		12517 B	5346 C	15693 A	

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor (P<0.05)
*** Small letters indicate the significant difference of interaction (P<0.05)

The obtained results of Table (3) throughout the both cultivated seasons of interaction effect observed thatAir pumping combined with Ch. N.S had the highest values of N and K (%) content of lettuce leaves followed by air pumping combined with Ch. N.S + Ver.-L. treatment while the lowest data gave by turn & Flu. combined with Ver.-L. Air pumping combined with Ver.-L. recorded the highest P content of lettuce leaves.

The effect of air supply system and nutrient solution source on celery plant

Vegetative, yield and root growth characteristics

The results of plant height (cm), number of leaves, total plant weight (g/plant), head weight (g), total yield weight (Kg / m^2), dry matter (%), average root weight (g/plant) and root : shoot ratio (%) were observed in Table (4 and 5). Air pumping had a similar significant effect and trend of lettuce on vegetative, yield and root growth characteristics of celery. The results support strongly the positive impact of increasing DOI in DWC on vegetative, yield and root growth characteristics of celery. The highest treatment effect (air pumping) on DOI of air supply system had the highest values of plant height (cm), number of leaves, total plant weight (g/plant), head weight (g), total yield weight (Kg / m^2), dry matter (%), average root weight (g/plant) and root : shoot ratio (%) while the contrast (turn & Flu.) was true.

Regarding to the effect of nutrient solution source, applying Ch. N.S + Ver.-L treatment as a nutrient solution source observed the highest values of plant height (cm), total plant weight (g/plant), head weight (g) and total yield weight (Kg / m^2) while the lowest results gave by Ver.-L treatments. The Ver.-L treatments had the highest data of dry matter (%), average root weight (g/plant) and root: shoot ratio (%) while the lowest records gave by Ch. N.S treatment that recorded the highest values of number of leaves. The obtained results provided anther evidence on the positive significant effect of Ver.- L treatment on encouraging the root growth of celery plants in DWC as Table (4 and 5)illustrated.

Nonetheless, Table (4 and 5) presented the interaction effect of different air supply systems and nutrient solution sources on vegetative and yield characteristics beside the root growth parameters of celery in both cultivated seasons. The revealed data showed that interaction treatment of air pumping combined with Ch. N.S + Ver.-L illustrated significant effect mainly on total plant weight (g/plant), head weight (g) and total yield weight (Kg / m^2). These results translated easily to economic benefits as yield quality and quantity. Otherwise, the lowest total plant weight (g/plant), head weight (g) and total yield weight (Kg / m^2) values observed by turn & Flu. combined with Ver.-L.

3.2.2 N, P and K (%) contents of celery leaves

Needless to mention that the effects of air supply systems and nutrients solution sources and their interaction on N, P and K (%) contents of celery leaves were similar effects and trends of lettuce leaves as Table (6) illustrated.

The Environmental and cost impact assessment of different treatments

The power use cost assessment and efficiency

The attracting of saving power and chemical nutrient use are very irresistible for many researchers concerning sustainable agriculture. Fig. (4 a and b) illustrated the effect of air supply system on the average power use (Kw) and the average power cost (LE/season) during the season. The implement of turn & flu and DFT recorded the highest power use (13.50 kw per season = 3.13 Kw / m^2/ season) while air pumping gave the lowest power use (11.81kw per season = 2.73 Kw / m^2/ season). The difference between water pump that use in both systems turn & flu and DFT compared to air pump is just 5 watt but the calculation during the season had a significant impact on the power use. Moreover, the cost of power use (LE/season) also promote the use of air pump as an air supply system as a result of its lowest cost compared to the other treatments of air supply. The importance of decreasing power inputs in hydroponic lettuce observed by Frantz et al., 2010 who reported that conserving power use with keeping high yield production is essential for keeping growers competitive in local, regional, and national markets.

Reducing power use had a lot of benefits on different scales while increasing the sustainable and ecology objectives of the study and reduce the environmental pollution and GHG's.

The power use efficiency (Kg / kw) of different treatments and crops observed a shock results, instead of cultivated lettuce twice during the season of celery but the power use efficiencies of celery with different treatments were higher than lettuce. Celery in general had excellence power use efficiency compared to lettuce. The impact of different interaction treatments on the average power use efficiencies of lettuce and celery were presented in Fig. (5). The obtained results indicated that interaction treatment air pumping + Ch. N.S recorded the highest power use efficiency of lettuce followed by air pumping combined with Ch. N.S + Ver.-L with no significant difference. For celery, the highest power use efficiency were gave by air pumping combined with Ch. N.S + Ver.-L followed by air pumping + Ch. N.S with significant difference. The interaction treatment DFT + Ver. L had the lowest power use efficiencies for both lettuce and celery as Fig. (5) Showed.

The environmental impact and cost assessment

The chemical nutrient solution use

Looking to alternate the use of chemical nutrient solution or minimized it gave anther sustainable indicator for this investigation. The utilize of vermi-liquid as a nutrient solution (100 %) or as an alternative part (50 %) of chemical nutrient solution achieve strongly the ecology impact. Vermi-liquid as a vermicomposting outputs was used in many studies to reduce the chemical nutrient use either in soil or in substrate culture (AboSedera et al., 2015,Abul-Soud et al., 2015a,Abul-Soud 2015, Abul-Soud et al., 2015 b and Abul-Soud et al., 2017, Abul-Soud and Mancy 2015,Abul-Soud et al., 2015maintioned that the use of vermicomposting technique in recycling the organic wastes if urban and agricultural residues for producing vermicompost as organic fertilizer and vermi-liquid as an organic nutrient solution led to reduce the direct and indirect the environmental and financial.

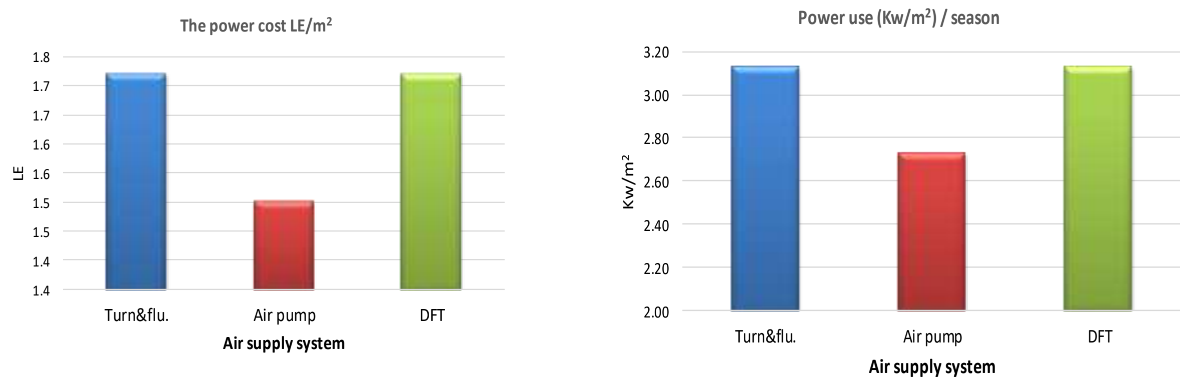

Figure (4 a and b): Effect of air supply system on the average power use (Kw) and the average power cost (LE/season) during the season.

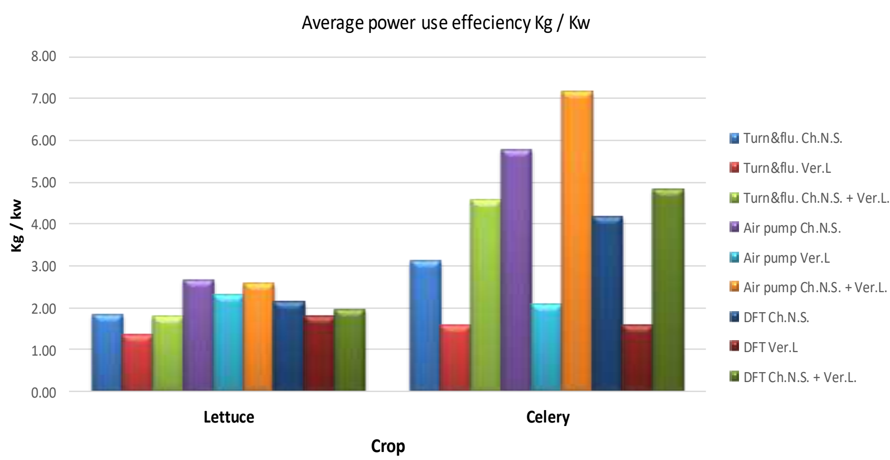

Figure. (5): Effect of interaction air supply systems and nutrient solution sources on the average power use effeciency (Kg / Kw) of lettuce and celery.

Table (5): The effect of different air supply systems and nutrient solution sources on dry weight (%) and root growth parameters of celery.

Air supply system	First season 2017 / 2018				Second season 2018 / 2019			
	Nutrient source				Nutrient source			
	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)
	Dry matter (%)							
Turn. & Flu.	6.4 e	11.7 a	8.9 d	8.9 A	6.6 d	11.1 a	8.1 c	8.59 A
Air pump	6.5 e	9.4 c	8.2 d	8.0 C	6.9 d	7.9 c	8.4 c	7.74 C
DFT	6.8 e	10.6 b	8.1 d	8.5 B	6.9 d	9.7 b	8.3 c	8.28 B
Mean (A)	6.6 C	10.6 A	8.3 B		6.80 C	9.56 A	8.27 B	
	Avergae root weight (g / plant)							
Turn. & Flu.	84.7 h	96.0 h	222.3 g	204.7 C	91.7 h	281.6 e	228.7 f	200.7 C
Air pump	292.7 e	537.3 b	619.7 a	353.6 B	115.0 g	505.0 b	405.7 c	341.9 B
DFT	236.7 f	427.3 c	373.0 d	405.0 A	217.0 f	593.3 a	325.3 d	378.6 A
Mean (A)	134.3 C	483.2 A	345.7 B		141.2 C	460.0 A	319.9 B	
	Root : shoot ratio (%)							
Turn. & Flu.	15.0 g	55.3 c	25.3 f	31.9 C	17.0 f	54.0 c	25.3 e	32.1 C
Air pump	11.0 h	67.3 b	30.7 e	36.3 B	13.7 g	64.3 b	31.3 d	36.4 B
DFT	26.0 f	73.0 a	33.3 d	44.1 A	26.7 e	71.0 a	32.3 d	43.3 A
Mean (A)	17.3 C	65.2 A	29.8 B		19.1 C	63.1 A	29.7 B	

* Similar letters indicate non-significant at 0.05 levels.

** Capital letters indicate the significant difference of each factor (P<0.05)

*** Small letters indicate the significant difference of interaction (P<0.05)

Table (6): The effect of different air supply systems and nutrient solution sources on N, P and K content (%) of celery.

Air supply system	First season 2017 / 2018				Second season 2018 / 2019			
	Nutrient source				Nutrient source			
	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)	Ch. N.S	Ver.-L.	Ch.N.S.+ Ver.-L.	Mean (B)
	N (%)							
Turn. & Flu.	2.41 c	1.67 h	1.97 g	20.2 C	2.21 c	1.70 g	1.83 f	1.92 C
Air pump	2.88 a	2.07 ef	2.49 b	2.48 A	2.58 a	1.96 e	2.32 b	2.29 A
DFT	2.33 d	2.05 f	2.11 e	2.16 B	2.12 cd	1.89 ef	2.05 d	2.02 B
Mean (A)	2.54 A	1.93 C	2.19 B		2.31 A	1.85 C	2.07 B	
	P (%)							
Turn. & Flu.	0.48 g	0.69 c	0.61 e	0.59 C	0.46 h	0.69 c	0.61 e	0.59 C
Air pump	0.64 d	0.85 a	0.65 d	0.71 A	0.63 e	0.83 a	0.65 d	0.70 A
DFT	0.57 f	0.80 b	0.60 e	0.66 B	0.56 g	0.76 b	0.58 f	0.63 B
Mean (A)	0.56 C	0.78 A	0.62 B		0.55 C	0.76 A	0.61 B	
	K (%)							
Turn. & Flu.	4.45 bc	2.59 g	3.10 f	3.37 C	4.65 ab	2.65 e	3.05 d	3.45 C
Air pump	4.75 a	3.53 e	4.52 b	4.27 A	4.84 a	3.29 d	4.70 ab	4.28 A
DFT	4.37 c	3.47 e	3.86 d	3.90 B	4.47 b	3.22 d	3.63 c	3.77 B
Mean (A)	4.52 A	3.19 C	3.82 B		4.65 A	3.05 C	3.79 B	

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor (P<0.05)
*** Small letters indicate the significant difference of interaction (P<0.05)

Also mitigate greenhouse gases (GHG's) and sequestrate CO_2 into vermicomposting outputs. The use of vermi-liquid (100 %) as a nutrient solution presented 0 use of chemical nutrient solution while applying Ch. N.S + Vermi-liquid decreased the use of chemical nutrient solution to 50 % compared to the Ch. N.S treatment as Fig. (6a) showed. The first season (2017/2018) consumed higher nutrient solution regarding to higher temperature during the first season compared to the second season that effect on the water requirements. The cost of different nutrient source (Fig. 5 b) varied strongly referring the rate use of chemical nutrient solution. The highest cost nutrient source was presented by Ch. N.S treatment (180 and 165 LE in first and second season respectively) followed by Ch. N.S + Ver.-L (110 and 100 LE in first and second season respectively) while Ver.-L the lowest cost of nutrient solution (40 LE in both cultivated seasons). Needless to mentioned the hundreds of studies and reports that investigated the importance of reducing the chemical fertilizers use on the environment (air, water and soil pollution, energy, GHG's and etc.), sustainable and public health scales.

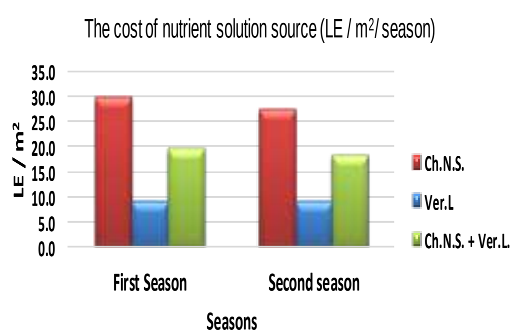

Figure. (6 a and b): Effect of nutrient source on the chemical nutrient solution use (L/ season) and the cost (LE/ m^2/season) during the cultivated seasons.

The obtained results of concerning the cost of interaction treatments among air supply systems and nutrient solution sources indicated that the main cost was the nutrient solution source not the air supply power. The interaction cost of air supply systems and nutrient solution sources as observed in Fig. (7) supported the need to reduce the cost of nutrient solution source. Regardless the other operation, infrastructure cost and the yield production of lettuce and celery, increasing the chemical nutrient solution (from 0 to 100 %) led to increase strongly the cost of use deep water culture in producing food as sustainable and ecologically method. In general, the costs of different treatments during the cultivated seasons were not affected by better climatic condition that affected on the water requirements of lettuce and celery. The climate condition control inside greenhouse to sustain the production

The effect of different air supply and nutrient source on DOI

The obtained results in Fig. (8) presented the use of air pump as an air supply system had the highest DOI followed by DFT treatment while the lowest DOI record gave by turn & flu treatment. The DOI of different air supply treatments in second season recorded higher results compared to the first season regarding the variation of temperature during the two season. This result agreed with Morard and Silvestre (1996) and Papadopoulous et al., (1999) who reported that increasing the nutrient solution temperature led to decrease the DOI.

The effect of nutrient solution source on DOI in both cultivated seasons as Fig. (9) indicated that the use of Ver.-L treatment had a negative impact on DOI data, Ch. N.S treatment recorded the highest DOI in both cultivated seasons followed by Ch. N.S + Ver.-L while the lowest records gave by Ver.-L. treatment. The negative impact of Ver.-L on DOI results could be explained to its contents of bio activities and organic substances that resulted in consume more O_2. Decreasing Ver.L. rate from 100 % to 0 % led to increase the DOI from 4.1 and 4.43 to 6.43 and 7.53 in first and second season respectively.DOI level less than 3 or 4 mg L-1 led to inhibits root growth and produces changes to a brown color, which can be considered as the first symptom of the oxygen lack. The supply of pure, pressurized oxygen gas (oxyfertigation) to the nutrient solution is an oxygen-enriched method often used for research purposes not for commercial targets (Chun & Takakura, 1994).

The revealed interaction data among the different treatments showed that air pump combined with Ch. N.S treatment had the highest DOI in both seasons while the lowest DOI results presented by turn&flu combined with Ver.-L treatment as Fig. (10) Illustrated. The impact of DOI on lettuce and celery growth and yield is observed clearly through their results.

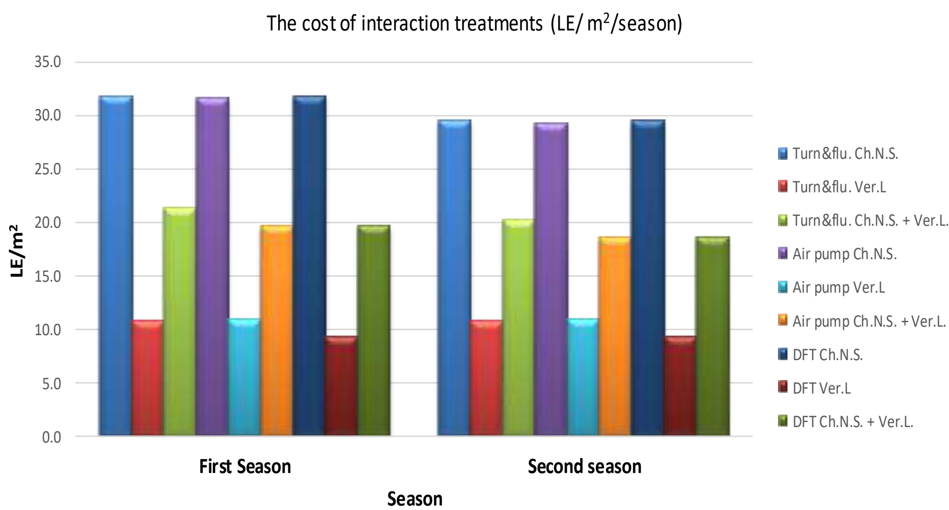

Figure. (7): The interaction cost of air supply systems and nutrient solution sources (LE/m^2) during the cultivated seasons

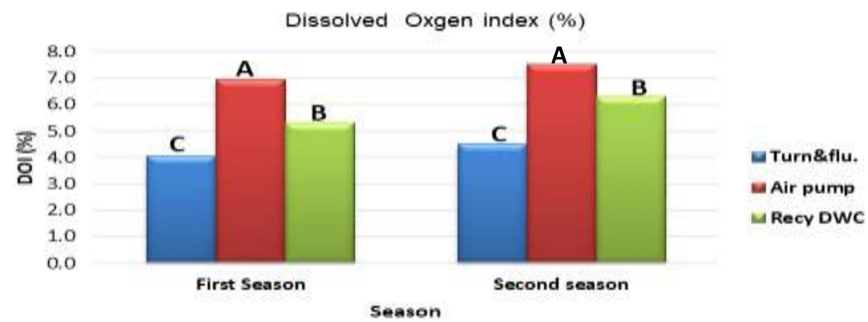

Figure. (8): Effect of air supply systems on DOI during the two cultivated seasons

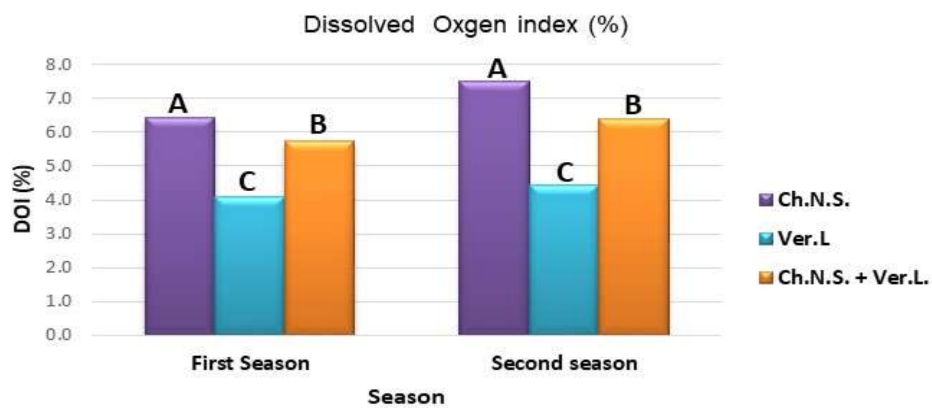

Figure. (9): Effect of nutrient solution sources on DOI during the two cultivated seasons.

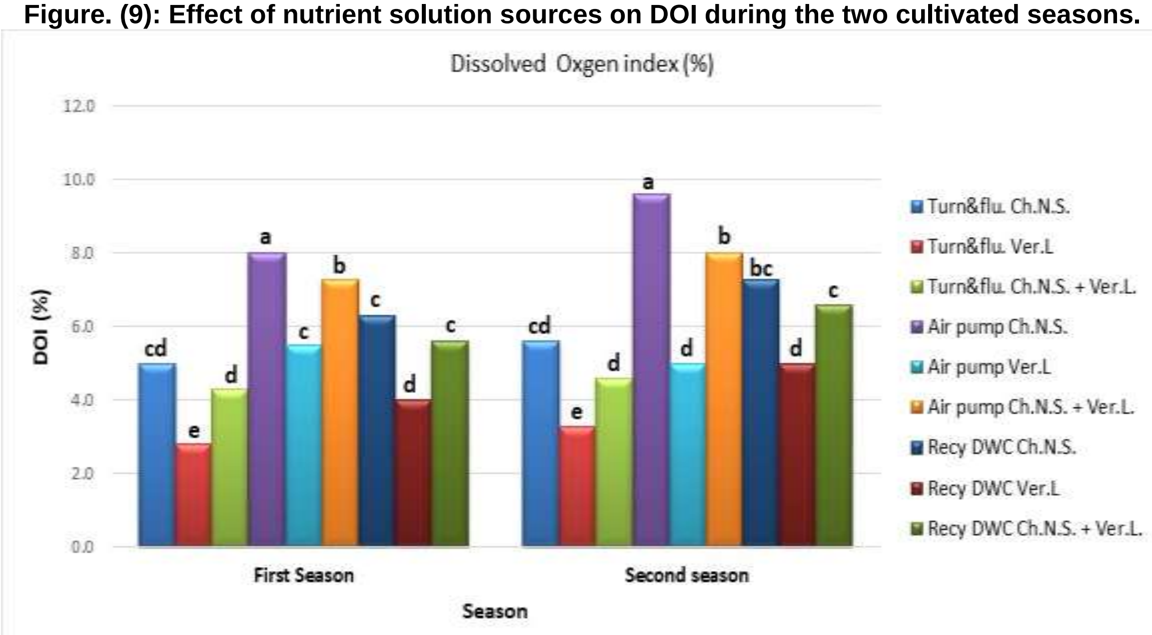

Figure. (10): Effect of air supply system and nutrient solution source on DOI during the two cultivated seasons.

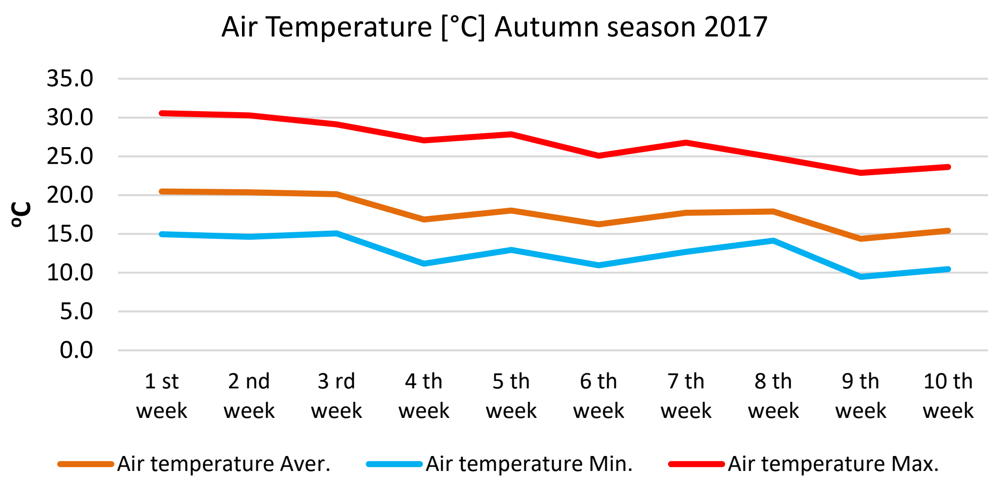

Figure. (11): Weekly air temperature (Maximum, minimum and average) (°C) during the first season (November 2017 – January 2018).

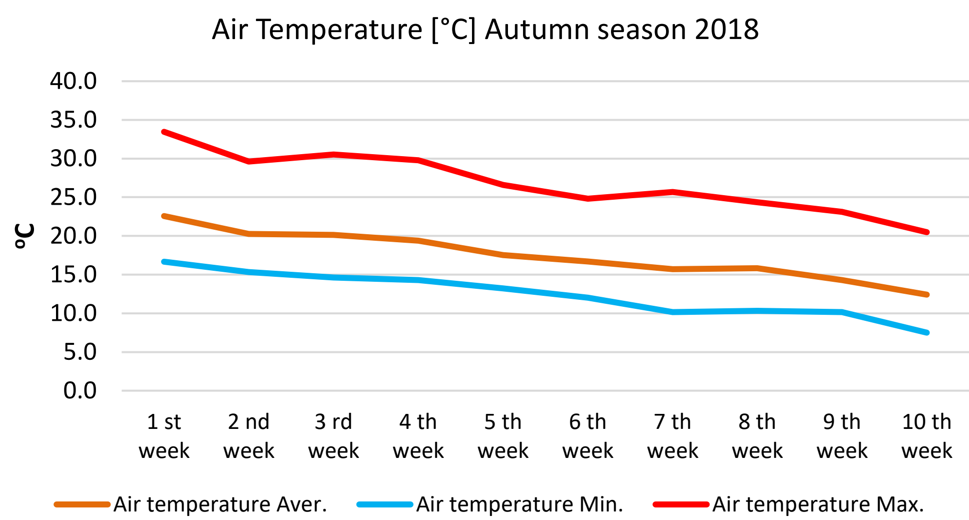

Figure. (12): Weekly air temperature (Maximum, minimum and average) (°C) during the first season (November 2018 – January 2019).

Climatic data

The variation of temperature (Maximum, minimum and average) between the two cultivated seasons affected strongly not just on DOI of nutrient solution in DWC as Fig. (11 and 12) presented (Morard and Silvestre (1996) and Papadopoulous et al., (1999) but also presented real reduction in the cost of nutrient solution source. Cooler climate during the growing season of lettuce and celery in general gave higher yield while decrease the water requirement of lettuce and celery.

CONCLUSION

The use of deep water culture in producing leafy vegetables should be developed under Egyptian conditions to offer sustainable production of leafy vegetables (lettuce and celery) ecologically. Providing well-aerated, environmentally and economic nutrient solution under the regional climate condition (warm autumn and winter) for enhancing the nutrients uptake, reduce the environmental cost, increase the yield and economic impact of DWC system are urgent to satisfy the food security needs and sustainable development under climate change impacts.

Nonetheless, the study provided the

alternative and successful method for the often argue among researchers, growers and clients about the use of chemicals in DWC or the use of aquaponic in producing leafy vegetables ecologically. Implement air pumping combined with Ch. N.S + Ver.-L present the possibility to grow sustainable, economic and healthier food with reduction of power use and environmental cost. While encouraging the environmental management of organic wastes and agricultural residues through vermicomposting technique.

More investigations need to enhance the power use and to investigate the effects of vermi-liquid on DOI and root growth of different plants in different soilless systems. The power use during the hot days for cooling the green house, the use of solar energy to provide the power needs and develop smart automation control for saving power, nutrients and water should be studied.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEGEMENT

The author appreciated the greet support that provided by CLAC and "Integrated environmental management of urban organic wastes using vermicomposting and green roof (VCGR) project" No. 1145, funded by Science and Technology Development Fund, Egypt.

AUTHOR CONTRIBUTIONS

AMA designed and supervised the experiment activities plus wrote the manuscript. ZYM performed the experiment and analyzed the data. MSAE performed the experiment and analyzed the data. MHM performed the experiment and collect the data. AMH collected the data and follow up the experiment. All authors read and approved the final version.

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