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Using deep water culture as one of the important hydroponic systems for saving water, mineral fertilizers and improving the productivity of lettuce crop

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***Abstract*---**Two experiments was carried out during for two successive seasons of 2020/2021 and 2021/2022 2021at the research farm of National Research Center (NRC) at Nubaryia Region, Al Buhayrah Governorate, Egypt., to Study of the performance of the deep water culture as one of the most important hydroponic systems in comparison with drip irrigation systems in open fields and under greenhouses on productivity, water productivity, fertilization productivity and some quality characteristics of lettuce. The experiment was arranged in a complete randomized block design with three replicates for each cultivar [two cultivars, CHE: CHEROKEE RZ (81-36) and AFI: AFICION RZ (81-82)] in each farming system [three farming systems, (Deep Water Culture (DWC) as hydroponic system, Drip Irrigation in Greenhouse (DIGH) with sandy soils, Drip Irrigation in Open Field (DIOF) with sandy soils)]. The study concluded that, by using the DWC, the vegetative growth characteristics were improved, productivity and water productivity increased, and the quality of the

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lettuce crop been improved. It was also possible to save more than 50% of the fresh irrigation water and mineral fertilizers required for fertilizing lettuce plants compared to the traditional farming systems, which are the soil farming system with drip irrigation, whether under greenhouses or open fields. DWC technology has huge potential for agricultural production under conditions of arid and semi-arid regions, i.e. reduced crop water consumption, possibility to grow all kinds of vegetable crops, ease of management, short crop growth cycle and improved plant growth, yield and quality as well as ensuring healthy quality of fresh product. The results of the study confirmed that the production of water lettuce (DWC) is a suitable, effective and sustainable alternative to the production of lettuce by traditional soil-based methods in light of the limited and scarcity of water sources in Egypt.

***Keywords*---**Deep Water Culture, Hydroponic Systems, Saving Water, Mineral Fertilizers, Lettuce.

Introduction

In areas that suffer from drought problems, which are known as arid and semi-arid areas with high population density and limited water resources, and with these previous conditions, great and high pressure is created on the agricultural sector in order to reduce the water consumption of fresh water for irrigation (Hozayn *et al.*, 2016; Abdelraouf *et al.*, 2020 a, b). The current and limited water resources in Egypt are suffering from severe shortage and scarcity, and this suffering increases with the increasing rate of population growth. This makes sense with the turbulent competition for limited water resources, and most modern irrigation technologies also compete to increase water productivity as well as improve and increase crop productivity and quality (Marwa *et al.*, 2017). Increasing the water productivity of crops is a necessary goal in order to increase the large and increasing demand for food in order to provide it in line with the continuous and turbulent rise in the population growth rate (Okasha *et al.*, 2013; Bakry *et al.*, 2012; Abdelraouf and Ragab 2018 a,b,c; Eid and Negm, 2019). It is necessary and obligatory to apply the best techniques, systems and new methods of irrigation, as well as the various and related techniques, and to be one of the important concepts that must be disseminated, adopted and followed, as well as applied in dry and semi-arid areas, as in Egypt, in order to provide large quantities and volumes of irrigation water for the cultivation of other areas (El-Habbasha et al., 2014). It is very important and necessary to reduce water consumption and save irrigation water through modernization, development and innovation of sustainable irrigation techniques. (El-Metwally *et al.*, 2015 and Abdelraouf and Abuarab 2012).

Majid et al. (2021) stated that the expansion of the Earth's population led to the great over-use of land and water resources, which was ultimately reflected in their lack and scarcity. The constant and changing climatic conditions as well as the irregular weather behavior over the years have exacerbated the current challenges and problems of land and water scarcity, and these risks continued to harm agricultural production. The use of the latest and most appropriate technologies with advanced methods and methods of crop production will undoubtedly increase our ability to face dealing with these problems and the current challenges of lack of these resources. There are many farming systems and soilless or liquid farming can be an excellent and wonderful alternative to traditional soil based farming systems. It was found that the deep water planting system is the easiest, cheapest and most preferred with regard to the duration of the crop, which reduced the period required for plant growth by 15 days. As also observed, larger values of most photosynthesis coefficients with the deep water cultivation system, which was ultimately reflected in higher yield/plant per system. The quality of the crop grown in the deep water farming system also improved, which was also reflected by the higher values of chlorophyll, total soluble solids content, protein and crude fiber content. Deepwater agriculture has also proven to be the most promising and best system for adoption within the framework of protected agriculture due to its simplicity, ease of operation, high productivity, and economic feasibility.

The results of previous and current studies confirm the possibility of maximizing crop productivity per cubic meter of water and per square meter of soil by using most soilless culture systems (Zayd et al., (1989). The need and necessity to use soilless culture has become more demanding and important in desert and dry lands than it was before, in order to increase water productivity and water use efficiency. In addition to the continuation of repeated crop cultivation and poor soil fertility, which in turn reduced the chances of soil fertility, which was accumulated due to microbes. This situation resulted in poor productivity and quality characteristics. In addition, the cultivation of traditional crops in soil (traditional open field cultivation) is difficult because it requires a large area and also large volumes of irrigation water in addition to a large number of workers (Abou-Hadid et al., 2004). Soilless cultivation can be an alternative cultivation technique to traditional cultivations that are difficult in the soil. Soilless farming is perhaps one of the most numerous and intensive ways to grow and produce crops along with greenhouses. The growth of the crop can only continue under the conditions of conventional cultivars if some form of soil sterilization or crop rotation and other difficult treatments occur. Steam sterilization is expensive, not economically feasible and ineffective, and the use of methyl bromide is prohibited and prohibited in many European Union countries. But production will inevitably continue when moving towards a new form of agriculture, which is soilless farming or alternative soil farming. The use of soilless culture has increased dramatically during the past decade until now because it contributes to the intensification of horticultural production and provides large and high yields even in dry areas with adverse conditions for plant growth (Zayd et al., (1989).

Soilless cultivation is widely used in protected agriculture, to improve control over the growing environment of cultivated plants and to avoid times of uncertainty in the presence and weakness of water and nutrients in the root zone of the soil. Also, this system overcomes the problem of salinity, as well as the accumulation of salts, pests and disease causes. In hydroponics, there is a great potential to use the water source to prepare the nutrient solution limited by the quality of the water. In the current and coming years, the demand and need for soilless culture will increase as a result of the relationship and link between the use of methyl bromide and ineffective alternatives in soil disinfection (FAO, 1990). El-Shinawy and Gawish (2006) also reported that the productivity of lettuce crop was higher under the conditions of hydroponic cultivation compared to the cultivation of sandy soil. Coronel et al. (2009) also confirmed that the yield of the crop was greater in lettuce grown in hydroponic (220.75 g plant^{-1}) than that grown organically (44.50 g plant^{-1}) or conventional (63.50 g plant^{-1}).

What was studied by Abou–hadid et al., (1996) concluded that the effect of the EC level of the nutrient solution on the amount of fresh weight of some lettuce cultivars and confirmed that EC levels had a significant effect on the productivity of the three cultivars under study. The most important hydroponic technology used by the community is Deep Water Culture (DWC). DWC is a hydroponic technology that delivers and supplies plants with nutrients directly to the plant roots. This DWC technology ensures that the rootstock of the plant is always immersed in the nutrient solution (Saaid et al., 2013). Hydroponics is the cultivation of plants that use water as a means of cultivation without the need to use soil. One of the simplest hydroponics is the Deep Water Culture (DWC) (Nursyahid et al., 2021).

If the goal is to produce more sustainable agricultural food, taking into account the environmental conditions (water, soil, recycling of organic agricultural waste, as well as chemical fertilizers), and avoiding the effects of climate change in order to meet the nutritional needs of the growing population rate, soilless culture is an effective agricultural method and practice Energetic and successful strategy. Deepwater aquaculture was developed as the most economical and simplest soilless culture method by Jensen and Collins (1985) in Arizona and Massantini (1976) in Italy.

Deep Water Culture or Direct Hydroponic Culture (DWC) is one of the most effective and economical hydroponics methods for growing large production of heads of lettuce or other leafy greens on a floating raft made of stretchy plastic that keeps the rootstocks in a good solution. Aerated and filled with nutrients and water. It was confirmed and reported by Bradley and Marulanda (2000) that the use of simple hydroponic techniques which reduces the land needs and requirements of crops by more than 75% and the water required for irrigation by 90% with the least impact on the environment. Lettuce is the most hydroponically grown leafy crop in the world, occupying about 99% of its hydroponic leaf and selling about 40% more expensive than conventionally grown lettuce in DWC (Barbosa et al., 2015).

The concentrations of calcium, phosphorous, zinc, copper, magnesium and boron in the DWC-harvested lettuce samples were almost twice the concentrations in the sand-grown lettuce samples. The performance of the DWC system was better by producing a higher yield of lettuce with higher nutritional content with more water consumption compared to the sand layer system (Salem, 2019).

Lettuce (*Lactuca sativa L.*) is a green leafed plant that belongs to the family Asteraceae. It is a cool season vegetable that thrives in temperatures from 7°C to 24°C and is most commonly eaten and consumed in salad mixtures. Lettuce outperforms all other vegetables except potatoes in the United States of America in terms of production area and crop value. Lettuce is highly nutritious and a rich source of Vitamin C, minerals and fiber. Lettuce has also been used as a medicine for many ailments including stomach problems, infections and urinary tract pain since ancient times. Nowadays, consumption of organic vegetables, including lettuce, is rising due to rapid population growth, rapid urbanization, and increasing health concerns. However, one of the important factors limiting vegetable cultivation is the insufficient land area and water scarcity in dry areas (Sapkota et al., 2019).

The aim of the study was to study the performance of the DWC as one of the most important hydroponic systems compared to the soil cultivation inside the greenhouses with drip irrigation and the open field cultivation of two cultivars of lettuce (*Lactuca sativa L*) in order to save irrigation water and mineral fertilizers and improve the quality properties under arid Egyptian conditions.

Materials and Methods

Experimental site and metrological data

Field experiments were conducted during 2020/21 and 2021/22 at the research farm of National Research Center (NRC) (latitude 30^{o} 30' 1.4'' N, longitude 30^{o} 19' 10.9'' E, and 21 m+MSL (mean sea level) at Nubaryia Region, Al Buhayrah Governorate, Egypt. The metrological data for experiment site has an arid climate with cool winters and hot dry summers. The data of maximum and minimum temperature, relative humidity and wind speed were obtained from the nearest local weather station.

Physical and chemical properties of the soil and irrigation water

The physical and chemical properties of the soil and irrigation water displayed in details as shown in Table (1). The Irrigation water was obtained from an irrigation channel passing through the experimental area. The main physical and chemical properties of soil were determined in situ and in the laboratory at the beginning of the field trial.

Irrigation system components

The irrigation network for drip irrigation in greenhouse with sandy soils and drip irrigation in open field with sandy soils consists of a centrifugal pump with a discharge of 45 m^3/h with other components of the main control unit. It was the main line of PVC pipes with a diameter of 110 mm. The branch lines of PVC pipes with a diameter of 75 mm were also directly connected to the main line. Manifold lines was made from Polyethylene pipes with a diameter of 50 mm were connected to the laterals. Emitters was built in the laterals with a diameter of 16 mm and a length of 40 m and the emitter discharge was 4 liters per hour at an operating pressure of 1.0 bar and a distance of 25 cm between the emitters. The system of deep water culture as hydroponic system was simple construction basin (20 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 and for the more nutrient solution stability and the less maintenance, and monitoring and the volume of nutrient solution tank was 2 m^3. 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 18 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.

Table (1): Main physical and chemical characteristics of the soil and chemical analysis of irrigation water

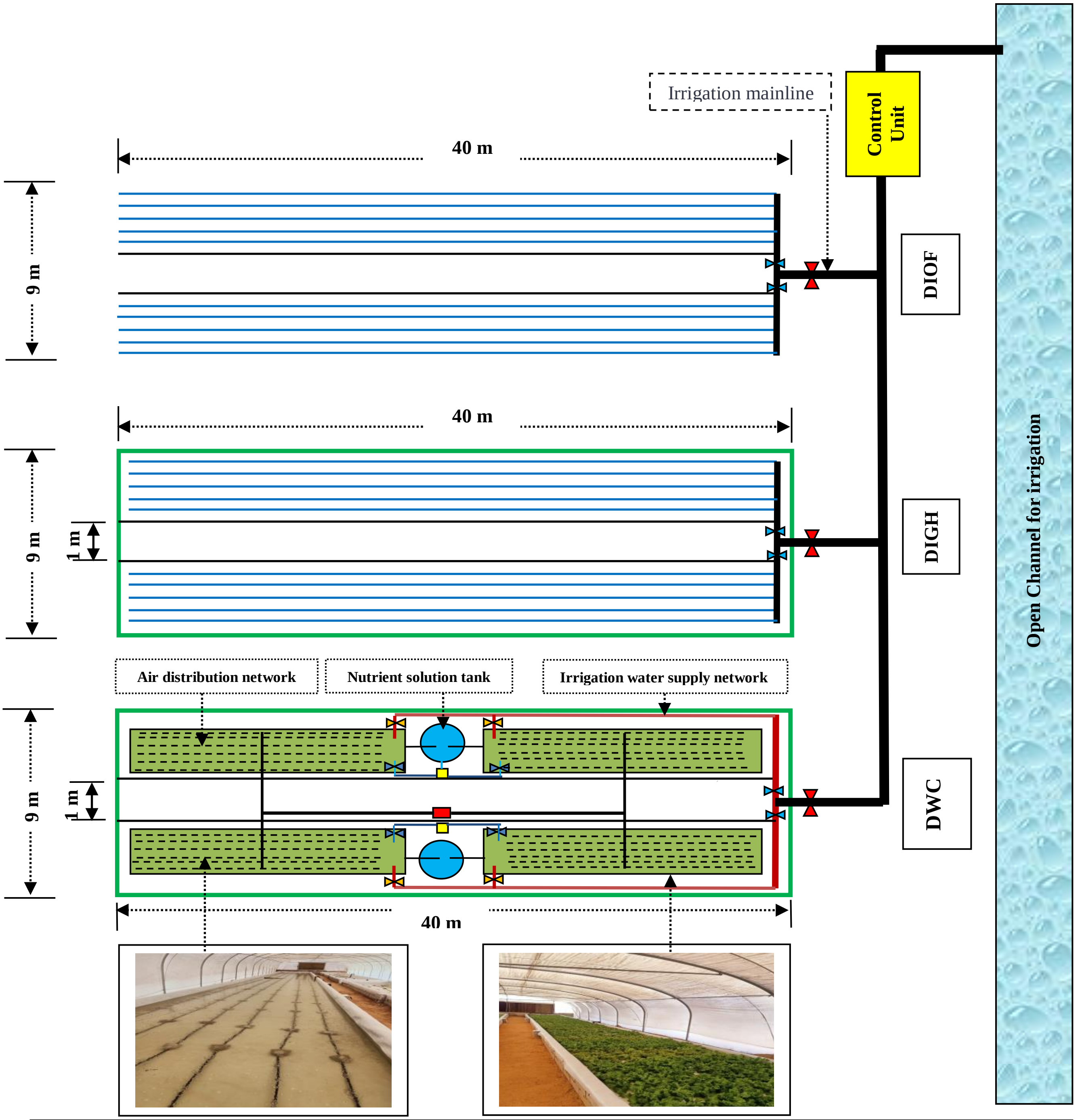
Soil characteristics of open field	Soil layer (cm)		
	0–20	20-40	40-60
Physical parameters			
Texture	Sandy	Sandy	Sandy
Course sand (%)	49.83	55.74	35.69
Fine sand (%)	47.80	40.72	60.50
Silt + clay (%)	2.37	3.64	3.81
Bulk density (t m^{-3})	1.66	1.67	1.68
Chemical parameters			
EC (dS m^{-1})	2.97	0.52	0.57
pH (1:2.5)	7.11	7.63	8.11
Total $CaCO_3$ (%)	7.44	2.36	4.66
Organic matter (%)	0.41	0.44	0.35

Soil characteristics of greenhouse	Soil layer (cm)		
	0–20	20-40	40-60
Physical parameters			
Texture	Sandy	Sandy	Sandy
Course sand (%)	48.87	55.63	44.70
Fine sand (%)	48.69	40.83	51.49
Silt + clay (%)	2.51	3.54	3.81
Bulk density (t m^{-3})	1.66	1.67	1.68
Chemical parameters			
EC (dS m^{-1})	2.08	0.48	0.51
pH (1:2.5)	6.55	7.12	8.22
Total $CaCO_3$ (%)	7.41	2.30	4.54
Organic matter (%)	0.47	0.51	0.38

Item		Irrigation water
pH		6.33
EC, (ds/m)		0.47
Anions (meq./L)	HCO_3^- &CO_3^{2-}	0.13
	Cl^-	2.86
	SO_4^{2-}	1.25
Cation (meq./L)	Ca++	1.1
	K+	0.21
	Mg+	0.50
	Na+	2.52
Nitrogen, (%)		< 0.03
Potassium, (%)		0.16

Experimental design

The experiment was arranged in a complete randomized block design with three replicates for each cultivar [two cultivars, CHE: CHEROKEE RZ (81-36) and AFI: AFICION RZ (81-82)] in each farming system [three farming systems, (Deep Water Culture (DWC) as hydroponic system, Drip Irrigation in Greenhouse (DIGH) with sandy soils, Drip Irrigation in Open Field (DIOF) with sandy soils)] as shown in Figure (1) and installing and testing of the ventilation network for DWC system shown in Figure (2).



DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in GreenHouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, Two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)]

Figure (1): Layout of the experimental design

(a) Installation and preparation of the ventilation network for planting ponds

(b) Testing the ventilation net before planting with porous polyurethane hoses

Figure (2): Installing (a) and testing (b) of the ventilation network for DWC system

Fertilization method

The soil was plowed 2-3 times and then the following fertilizers are added to it per hectare for lettuce plants were added at a rate of 36 m^3 organic manure and 12 m^3 poultry blue, 48 kg N (240 kg ammonia sulfate), 72 kg P_2O_5 (480 kg superphosphate), 48 kg K_2O (96 kg potassium sulfate), 12 kg MgO (120 kg magnesium sulfate).The chemical composition of different nutrient solution sources for DWC presented in Table (2).

Table (2): The chemical analysis of the nutrient solution at EC 2.5 dS/m

Macro elements, ppm					Micro elements, ppm				
N	P	K	Ca	Mg	Fe	Zn	Mn	Cu	B
230	42	304	155	46	4.62	0.134	0.720	0.124	0.251

Estimation of irrigation requirements

The applied water was calculated and estimated using drip irrigation system with sandy soil cultivation, which was obtained through equation (1) and gross irrigation requirements for deep water culture system was estimated by means of a meter for the discharge of water to the agricultural units. Irrigation requirements for lettuce for two seasons were estimated as shown in Table (3). The Penman-Monteith equation was used to estimate the ETo based on daily weather station (Allen et al., 1998).

$$IR = [ET_O \times Kc] / I_E - R + LR \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where IR is the gross irrigation requirements in mm/day, ET_O is the reference evapotranspiration in mm/day, Kc is crop factor, I_E is irrigation efficiency in %, R is rainfall in mm, and LR is the amount of water required for the leaching of salts in mm.

Table (3): Estimation of irrigation requirements for lettuce under the three farming systems

Deep Water Culture (DWC) as hydroponic system		Drip Irrigation in Greenhouse (DIGH) with sandy soils		Drip Irrigation in Open Field (DIOF) with sandy soils	
Gross irrigation requirements for DWC was estimated by means of a meter for the discharge of water to the agricultural units (m^3 ha^{-1}/ season)		Gross irrigation requirements was estimated by equation (1) with ETo calculation, a dependence was obtained on the climatic factors inside the greenhouses (m^3 ha^{-1}/ season)		Gross irrigation requirements was estimated by equation (1) ETo calculation, a dependence was obtained on the climatic factors in the open fields (m^3 ha^{-1}/ season)	
2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
1020	1020	2600	2640	2880	2850

Plant material

Two cultivars of lettuce are [CHE: CHEROKEE RZ (81-36) and AFI: AFICION RZ (81-82)] were sown in foam trays (84 cells) filled with a mixture of peat moss and vermiculite (1:1 v/v) media 30 days before transplanting date on 15th October for transplanting date of mid-November in both seasons of 2020/2021 and 2021/2020 and trays were then kept in the open field and greenhouses at the same date. All agricultural practices required for lettuce production in open field and greenhouses were carried out.

Evaluation parameters

Vegetative growth: *(1)Total leaves number/head:* The average number of leaf per head was counted in 4 replicates for each cultivar in each transplanting date using the above randomly selected heads, *(2) Head fresh weight:* The above mentioned heads were also used to record the average fresh weigh of head after removing the yellow and damage outer leaves for obtaining clean heads, *(3) Head dry weight:* The same heads which weighed for recording the head fresh weight were used to record the average head dry weigh after drying at 65 ^{o}C for 72 hours in an oven supplied with fan.

Salinity of the root zone : The salt concentration were measured (ppm) for three farming systems either in the cultivation systems with sandy soil or in the deep water culture during plant growth stages of lettuce plant during the two growing seasons.

Total yield of head lettuce: Total fresh weight of lettuce heads produced from a square meter was determined and expressed as total fresh weight of heads in kilogram which produced from one square meter (kg/m^2) and then, converted to ton ha^{-1}.

Water productivity of lettuce "$WP_{lettuce}$": The $WP_{lettuce}$ was calculated according to James (1988) as follows by equation 3:

$$WP_{lettuce} = Ey/Ir \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $WP_{lettuce}$ is water productivity of lettuce (kg $_{lettuce}$ /m^3_{water}), Ey is the economical yield (kg $_{lettuce}$ /ha) and Ir is the amount of applied irrigation water (m^3_{water}/ha).

Fertilizers productivity of lettuce "NPK Productivity $_{lettuce}$ ": The NPK Productivity $_{lettuce}$ were calculated according to the following equations 3,4, 5:

$$\text{Nitrogen Productivity of lettuce "}NP_{lettuce}\text{"} = Ey/N_{kg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\text{Phosphorus Productivity of lettuce } PP_{lettuce} = Ey/P_{kg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\text{Potassium Productivity of lettuce } KP_{lettuce} = Ey/K_{kg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where $NP_{lettuce,}$ $PP_{lettuce}$ and $KP_{lettuce}$ are water NPK productivity of lettuce (kg $_{lettuce}$ / kg $_{NPK}$), Ey is the economical yield (kg $_{lettuce}$ ha^{-1}).

Quality of lettuce: Mineral nutrient contents (nitrogen, phosphorus, potassium and calcium) were determined in both leaf and root tissues of lettuce plant. Leaf and root samples were dried at 65 °C for 72 hours or to a constant weight in an oven supplied with fan. Dried samples were ground to a fine powder using a stainless steel blender and then used to determine nutrient contents on a dry weight basis. A weight of 0.2 g of dried samples was digested using wet digestion method by using concentrated sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) 30%. The clear digested was quantitatively transferred to 50 ml volumetric flask and completed carefully to 50 ml using distilled water and then filtered through Whatman filter paper No. 42 as described by Wolf (1982). Afterwards the digested samples were used to determine nutrient contents. Total nitrogen and phosphorus contents in leaves and roots of lettuce were determined using the modified micro Kjeldah method and colorimetrically by ammonium metavanidate method using spectrophotometer (SPECTRONIC 20D, Milton Roy Co. Ltd., USA), respectively, according to the procedure described by Cottenie *et al.* (1982). Total potassium content was measured using flame photometer method (JENWAY, PFP-7, ELE Instrument Co. Ltd., UK) as described by Chapman and Pratt (1982). While, calcium and magnesium contents were determined in leaves and roots of lettuce using Atomic Absorption spectrophotometer (Analyst 200, PerkinElmer, Inc., MA, USA), according to Chapman and Pratt (1982).

Statistical analysis

All data generated were tabulated and subjected to statistical analysis using the analysis of variance method ANOVA with M-Stat package software. Least significant differences test (LSD) was used to compare the significant differences among mean of the treatments at 0.05 level of probability according to the method described by Snedecor and Cochran (1980).

Results and Discussions

Vegetative growth

Table (4) shows the vegetative growth results of two lettuce cultivars with deep water culture performance compared to the two systems of greenhouse cultivation and cultivation in sandy open soils. The individual effect of the performance of the DWC system as one of the most important hydroponic systems had a clear and effective effect on vegetative growth, with it achieving the highest results for the components of vegetative growth for both lettuce cultivars compared to the two terrestrial farming systems, whether under greenhouses or in open fields with drip irrigation.

The results of Table (4) also showed that there were no significant differences between the vegetative growths of the two lettuce cultivars. The results of the interaction between the cultivation systems and the two lettuce cultivars showed that the highest vegetative values were achieved when planting in the deep hydroponic system and with both cultivars without distinction during the two growing seasons.

Table (4): Effect of different transplanting dates, lettuce cultivars and their interaction effect on number of leaves/head, head fresh and dry weights

Treatments		No. of leaves/head		Head fresh weight, gm		Head dry weight, gm	
		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Farming systems (FS)	DWC	22.2	22.4	175.8	171.7	18.5	18.3
	DIGH	18.9	18.8	163.3	158.0	16.8	16.6
	DIOF	15.5	15.5	165.7	154.2	13.3	13.0
Cultivars	AFI.	18.8	19.0	167.9	161.0	16.5	16.3
	CHE.	18.9	18.8	168.6	161.6	15.9	15.6
DWC	AFI.	21.7	22.0	177.3	173.3	18.7	18.5
	CHE.	22.7	22.7	174.3	170.0	18.2	18.0
DIGH	AFI.	19.0	19.3	162.3	157.0	16.5	16.3
	CHE.	18.7	18.3	164.3	159.0	17.1	16.9
DIOF	AFI.	15.7	15.7	164.0	152.7	14.2	14.1
	CHE.	15.3	15.3	167.3	155.7	12.3	11.9

DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in Greenhouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, Two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)]

Salinity of the root zone

Figure (3) shows the level of salinity within the root spreading area, whether in the deep water system or within the root spreading area in sandy soil inside the greenhouse and also within the sandy soil in open fields. It is clear from Figure (3) that the highest level of salinity exposed to the root zone was with cultivation in the open field, followed by the level of salinity in the greenhouse, while the lowest level of salinity was with cultivation in deep water of the hydroponic system. This may be due to the fact that cultivation in open sandy lands was subjected to more difficult conditions. One of the most important of these conditions was an increase in the rate of evaporation resulting from high temperature and wind speed, which led to an increase in the accumulation of salts inside the root zone.

From the figure (3) it was also clear that the level of salinity in the root spreading area increased with the increase in the volume of the added irrigation water, which was associated with an increase in the growth rate of plants grown in the open lands and greenhouse systems, while in the deep water system evaporation did not occur and the evaporation process had no significant effect on the evaporation rate Because the upper water surface is covered with foam in addition to the continuous monitoring of the salinity level in the deep water system to avoid rising or falling below the permissible range and not causing severe damage to the quality of the nutrient solution.

The salinity level of the drip irrigation system with sandy soil inside the greenhouses was an intermediate level between the open sandy soil cultivation system and the deep water system. This may be due to the fact that the cultivation of sandy lands inside the greenhouses was characterized by the ease of controlling the temperature reduction with cooling cells, as well as the low wind speed, which led to a positive effect on the decrease in evaporation rate, which led to a decrease in the level of salinity inside the greenhouses compared to the open cultivation system, which with it increases Stressing the cultivated plants to the increase in temperature and wind speed.

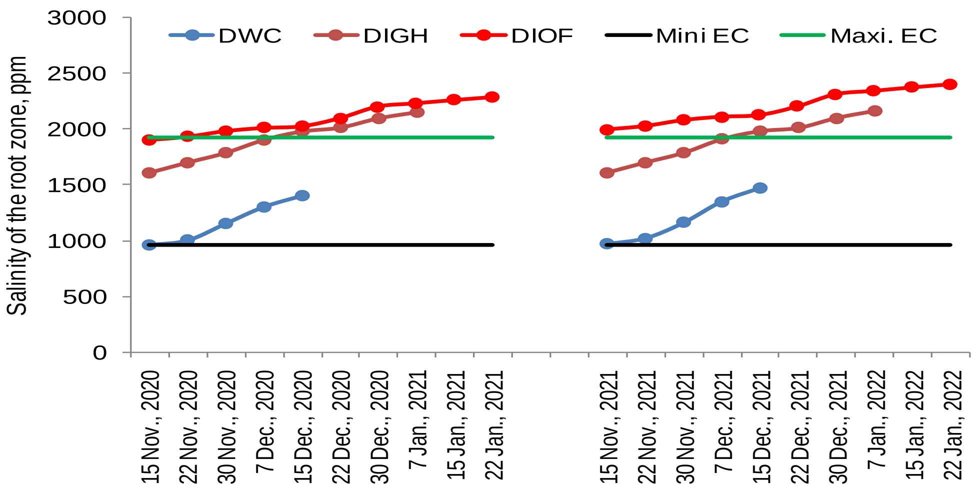


Figure (3): Measuring electrical conductivity of the root zone during two growing seasons of lettuce in both soil cultivation systems and with the deep water culture (DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in Greenhouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)])

Lettuce head yield

Figure (4) and Table (5) shows the head yield results of two lettuce cultivars with deep water culture performance compared to the two systems of greenhouse cultivation and cultivation in sandy open soils. The individual effect of the performance of the DWC system had effective effect on lettuce head yield, with it achieving the highest results for the lettuce head yield for both lettuce cultivars compared to the two soil farming systems, whether under greenhouses or in open fields with drip irrigation.

The results of Figure (4) and Table (5) also showed that there were no significant differences between the head yield of two lettuce cultivars under the three farming systems conditions. The results of the interaction between the cultivation systems and the two lettuce cultivars showed that the highest head yield of lettuce were achieved when planting in the deep hydroponic system and with both cultivars and there were no significant differences for both growing seasons.

All previously shown results clearly demonstrated that producing lettuce using DWC positively affects not only vegetative growth but also head yield compared to soil grown plants. In this respect, Vanachter and Leuven (1995) concluded that DWC cropping system could be used for growing a variety of crops including lettuce. It was of major importance and it is possible to grow up to 8 crops of heavy head lettuce on a year round basis. Also, Vital *et al.* (2002) indicated that DWC system for growing lettuce was efficient as cultivation technique. DWC technique had an enormous latent potential for agriculture production under conditions of arid and semi-arid regions, i.e. reducing crop water consumption, possibility to grow all kind of vegetable crops, easy to management, short growth cycle of crop and improvement of plant growth, yield and quality as well as earliness (Zolnier *et al.,* 2004) in addition, ensuring the sanitary quality of the fresh product (Carrasco *et al.,* 1999). Plants produced from DWC technique significantly had a higher vegetative growth rate than soil cultivated plants as mentioned by Kim *et al.* (1995); El-Behairy *et al.* (2001) and El-Shinawy and Gawish (2006) on head lettuce, In the same regards, El-Behairy *et al.* (2001); El-Shinawy and Gawish (2006) and Coronel *et al.* (2009) on head lettuce, They stated that DWC growing plants gave the highest yield and better quality in comparison with soil cultivation.

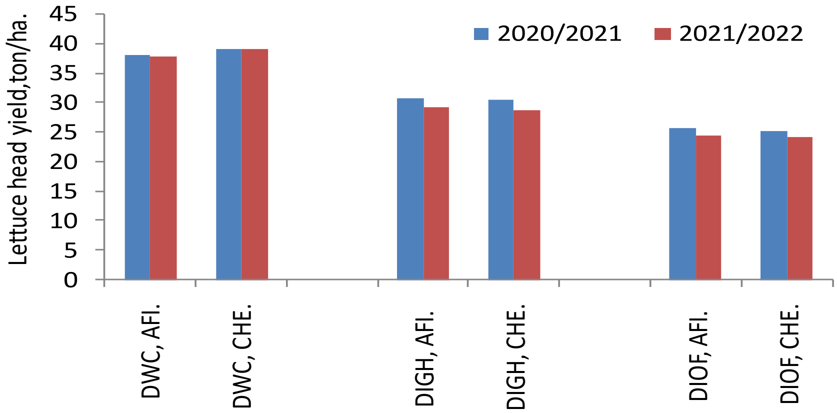


Figure (4): Effect of deep water culture and lettuce cultivars on the yield of lettuce (DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in Greenhouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)])

Water Productivity of lettuce

Figure (5) and Table (5) shows the water productivity of lettuce results of two lettuce cultivars with deep water culture performance compared to the two systems of greenhouse cultivation and cultivation in sandy open soils. The individual effect of the performance of the DWC system had effective effect on water productivity of lettuce, with it achieving the highest results for the water productivity of lettuce for both lettuce cultivars compared to the two soil farming systems, whether under greenhouses or in open fields with drip irrigation.

The results of Figure (5) and Table (5) also showed that there were no significant differences between the water productivity of lettuce of two lettuce cultivars under the three farming systems conditions. The results of the interaction between the cultivation systems and the two lettuce cultivars showed that the highest water productivity of lettuce were achieved when planting in the deep hydroponic system and with both cultivars and there were no significant differences for both growing seasons.

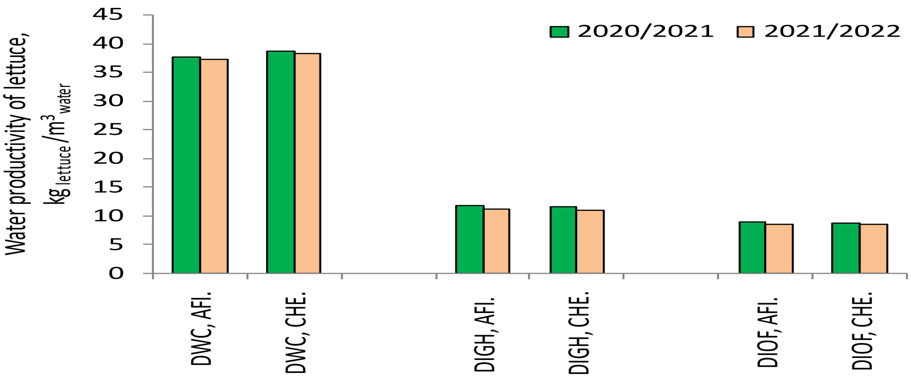


Figure (5): Effect of deep water culture and lettuce cultivars on the water productivity of lettuce (DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in Greenhouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)])

Table (5): Effect of deep water culture and lettuce cultivars on the yield and water productivity of lettuce

Treatments		Yield, (ton ha^{-1})		Water productivity of lettuce, ($kg_{lettuce}$ / m^3_{water})	
		2020/2021	2021/2022	2020/2021	2021/2022
Farming systems (FS)	DWC	38.8	38.6	38.1	37.8
	DIGH	30.6	29.0	11.8	11.0
	DIOF	25.6	24.4	8.9	8.6
LSD at 5%		3.4	3.1		
Cultivars	AFI.	31.6	30.6	19.4	19.0
	CHE.	31.7	30.7	19.7	19.2
LSD at 5%		NS	NS		
DWC	AFI.	38.3	38.0	37.6	37.3
	CHE.	39.3	39.1	38.6	38.3
DIGH	AFI.	30.8	29.2	11.8	11.1
	CHE.	30.5	28.7	11.7	10.9
DIOF	AFI.	25.7	24.5	8.9	8.6
	CHE.	25.4	24.2	8.8	8.5
LSD at 5%		1.2	1.0		

DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in GreenHouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)]

Fertilizers productivity of lettuce

Table (6) shows the fertilizers productivity of lettuce results of two lettuce cultivars with deep water culture performance compared to the two systems of greenhouse cultivation and cultivation in sandy open soils. The individual effect of the performance of the DWC system had a clear and effective effect on fertilizers productivity of lettuce, with it achieving the highest results for the fertilizers productivity of lettuce for both lettuce cultivars compared to the two farming systems, whether under greenhouses or in open fields with drip irrigation.

The results of Table (6) also showed that there were no significant differences between the fertilizers productivity of lettuce of the two lettuce cultivars. The results of the interaction between the cultivation systems and the two lettuce cultivars showed that the highest fertilizers productivity of lettuce values were achieved when planting in the deep hydroponic system and with both cultivars and there were no significant differences for both growing seasons.

Table (6): Effect of water deep culture and lettuce cultivars on the fertilizers productivity of lettuce

Treatments		NP lettuce ($Kg_{lettuce}$ /Kg_N)		PP lettuce $Kg_{lettuce}$ /kg_P		KP lettuce $Kg_{lettuce}$/kg_K	
		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Farming systems (FS)	DWC	1618.1	1606.3	1078.7	1070.9	1618.1	1606.3
	DIGH	638.2	603.1	425.5	402.1	638.2	603.1
	DIOF	531.6	507.0	354.4	338	531.6	507.0
Cultivars	AFI.	924.3	901.4	616.2	600.9	924.3	901.4
	CHE.	934.3	909.5	622.8	606.4	934.3	909.5
DWC	AFI.	1597.2	1584.7	1064.8	1056.5	1597.2	1584.7
	CHE.	1638.9	1627.8	1092.6	1085.2	1638.9	1627.8
DIGH	AFI.	641.0	609.0	427.3	406.0	641	609.0
	CHE.	635.4	597.2	423.6	398.2	635.4	597.2
DIOF	AFI.	534.7	510.4	356.4	340.3	534.7	510.4
	CHE.	528.5	503.5	352.3	335.7	528.5	503.5

DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in GreenHouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)]

Mineral nutrient contents of lettuce leaves

Figure (6) and Table (7) shows the mineral nutrient contents of leaves of lettuce results of two lettuce cultivars with deep water culture performance compared to the two systems of greenhouse cultivation and cultivation in sandy open soils. The individual effect of the performance of the DWC system had effective effect on mineral nutrient contents of leaves, with it achieving the highest results for the mineral nutrient contents of leaves for both lettuce cultivars compared to the two soil farming systems, whether under greenhouses or in open fields with drip irrigation.

The results of Figure (6) and Table (7) also showed that there were no significant differences between the mineral nutrient contents of leaves of two lettuce cultivars under the three farming systems conditions. The results of the interaction between the cultivation systems and the two lettuce cultivars showed that the highest mineral nutrient contents of leaves of lettuce were achieved when planting in the deep hydroponic system and with both cultivars and there were no significant differences for both growing seasons.

Plant yield, depend mainly on the availability of plant macro and micro nutrients. These nutrients should be provided through suitable sources on adequate amounts and forms in a right time to ensure that plants have adequate amounts of the nutrients required for both plant vegetative growth and high yield. The increment of yield in DWC technique grown plants is most likely due to more uniform water and better nutrients supply as reported by Abou-Hadid *et al.* (1989). This could be a result of good supplying of nutrients in available form through nutrient solution which increases the uptake of nitrogen which in turn encourage the vegetative growth which also known as the quality nutrient as well as all other nutrients (Lester *et al.*, 2006). Also Graves (1983) added that the highly response of the crop grown in DWC is probably related to better nutrition of the plants and the continuous supply of aerated water and attributed to reduction of tissue water deficits (Newton and Sahraoui, 1996). On the other hand, this may be also due to that immersing lettuce roots in the nutrient solution all the time makes buffer for the temperature during winter and early spring where the water collects the heat during the day time slowly and release it also slowly during the night. This makes the root active most of the day which stimulate the uptake of water and nutrients that increase vegetative growth and consequently the yield (El-Behairy, 2003 and Singer *et al.,* 2009).

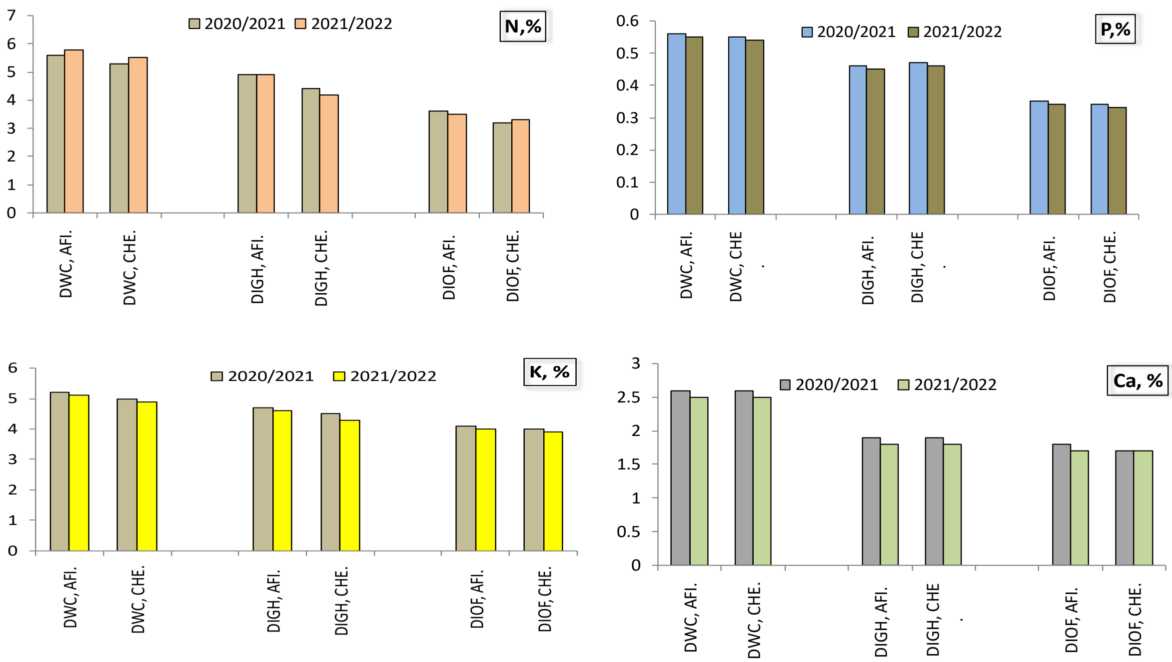


Figure (6): Effect of water deep culture and lettuce cultivars on the mineral nutrient contents of lettuce leaves (DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in Greenhouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)])

Table (7): Effect of water deep culture and lettuce cultivars on the mineral nutrient contents of lettuce leaves

Treatments		N, %		P, %		K, %		Ca, %	
		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Farming systems (FS)	DWC	5.5	5.7	0.56	0.55	5.1	5.0	2.6	2.5
	DIGH	4.7	4.6	0.47	0.46	4.6	4.5	1.9	1.8
	DIOF	3.4	3.4	0.35	0.34	4.1	4.0	1.8	1.7
Cultivars	AFI.	4.7	4.7	0.46	0.45	4.7	4.6	2.1	2.0
	CHE.	4.3	4.3	0.45	0.44	4.5	4.4	2.1	2.0
DWC	AFI.	5.6	5.8	0.56	0.55	5.2	5.1	2.6	2.5
	CHE.	5.3	5.5	0.55	0.54	5.0	4.9	2.6	2.5
DIGH	AFI.	4.9	4.9	0.46	0.45	4.7	4.6	1.9	1.8
	CHE.	4.4	4.2	0.47	0.46	4.5	4.3	1.9	1.8
DIOF	AFI.	3.6	3.5	0.35	0.34	4.1	4.0	1.8	1.7
	CHE.	3.2	3.3	0.34	0.33	4.0	3.9	1.7	1.7

DWC: Deep Water Culture as hydroponic system, DIGH: Drip Irrigation in GreenHouse with sandy soils, DIOF: Drip Irrigation in Open Field with sandy soils, The two Cultivars of lettuce are [CHE: CHEROKEE RZ (81-36), AFI: AFICION RZ (81-82)]

Conclusion

By using the deep water system as one of the most important hydroponic systems, vegetative growth characteristics were improved, productivity and water productivity increased, and the quality of the lettuce crop been improved. It was also possible to save more than 50% of the fresh irrigation water and mineral fertilizers required for fertilizing lettuce plants compared to the traditional farming systems, which are the ground farming system with drip irrigation, whether under greenhouses or open fields.

DWC technology has huge potential for agricultural production under conditions of arid and semi-arid regions, i.e. reduced crop water consumption, possibility to grow all kinds of vegetable crops, ease of management, short crop growth cycle and improved plant growth, yield and quality as well as ensuring healthy quality of fresh product.

The use of deep water culture in producing leafy vegetables should be developed under Egyptian conditions to offer sustainable production of leafy vegetables (lettuce) 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.

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