MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/

ISSN-Print: 1687-384X
ISSN-Online: 2636-3062

Misr J. Ag. Eng., 39 (2): 299 – 322

DOI: 10.21608/mjae.2022.112353.1061

NUTRIENTS CONSUMPTION OF LETTUCE PLANTS IN HYDROPONIC AND AQUAPONIC SYSTEMS

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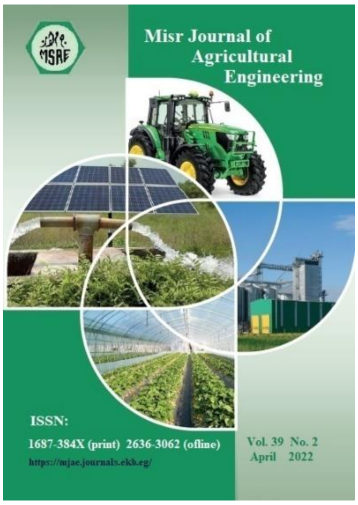

Keywords:
Aquaponic; Aquaculture; Hydroponic; Fish; Lettuce plant; Nutrients; Water use efficiency.

ABSTRACT

Aquaponics is the combined culture of fish and plants in recirculating aquaculture systems, considered to be an innovative, eco-friendly and sustainable technology. So, the main aim of this work is to study the effect of flow rate and culture system on nutrients consumption rate and lettuce productivity in hydroponic and aquaponic systems. To achieve that, two nutrients sources (effluent fish farm and stock nutrient solution), three systems of hydroponics (deep water, A shape and gutter systems) and three flow rates are 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ were compared. Also, water use efficiency of lettuce plants was determined. The various water quality parameters and plant growth were studied for treatment under study. The obtained results indicated that the highest values of N, P, k, Ca and mg consumption rate were found with gutter hydroponic system and 1.5 L h^{-1} $plant^{-1}$ of flow rate for lettuce plants grown in nutrient solution. The fresh weight of whole plant for lettuce plants grown in gutter hydroponic system was better than those grown in different culture system. The highest value of the water use efficiency of lettuce plants was 46.11 kg m^{-3} was found with nutrient solution for gutter hydroponic system.

1. INTRODUCTION

Aquaponics is the integration of aquaculture and hydroponic systems which is a promising sustainable food production method. Fishes are fed with complete diets and their excreta are broken down by bacteria into useful plants nutrients for normal growth of plants and the filtered water is returned back to the fish culture tank. **Hu *et al.* (2012)** believed that aquaponics will become one of the widely accepted methods of sustainable food production in the near future because of the current and escalating extent of soil degradation, water scarcity and climate-related challenges plaguing agricultural productivity in every corner of the world. And also no pesticides or antibiotics are used at any stage; therefore, the aquaponic production system can be regarded as a part of the organic agriculture **(Rakocy, 1999)**. Recirculation aquaculture and hydroponics technology when integrated lessen the use of water resources and increases the productivity of the system by yielding fresh healthy fish and vegetables, fruits and herbs.

The increased demand for food from a growing world population is intensifying the pressures on natural resources and ecosystems. Recent studies suggest that the planetary boundaries of biosphere integrity, nitrogen (N) and phosphorus (P) cycles have been or are soon to be overtaken. Overtaken planet boundaries can lead to unpredictable consequences, as deep changes of the ecosystem balance. Solutions urge to be found. The potential for more efficient resource use through the tightening nutrient cycles and reduction of waste may explain the increasing interest in aquaponics **(Love *et al.*, 2014)** as an innovation for the rapid expanding sectors of recirculating aquaculture systems and hydroponic productions **(Pulvenis, 2016)**.

Healthy plant growth requires the presence of additional macro and Micro nutrients (i.e., potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), Sulphur (S), iron (Fe), boron (B), copper (Cu), zinc (Zn), manganese (Mn), and molybdenum (Mo)) in specific proportion and concentration in the water **(Resh, 2012 and Sonneveld and Voogt, 2009)**. To date, the mass balance dynamics and budget of these nutrients, with the exception of N, P, K **(Wongkiew *et al.*, 2017 and Khater *et al.*, 2021)**, have not yet been fully studied in aquaponic systems while these data are fundamental for better system sizing, design and feed formulation **(Delaide *et al.*, 2016)**.

Three types of beds are most frequently used in aquaponics: nutrient film technique (NFT); ebb-and-flow (EAF); and deep water culture (DWC or RAFT) beds. EAF beds composed of heavy substrate (e.g; clay balls, perlite, etc) and siphon bells seem to be less practical for maintenance **(Rakocy and Hargreaves, 1993)** and there is only a few reports on their production performance compared to DWC or NFT **(Lennard and Leonard, 2006)**. Aquaponics is a new research field and a theoretical lower environmental footprint compared to conventional farming methods is expected but there is a lack of data establishing it. Namely, the water and energy used but also the expectable plant yields are not yet well documented and need to be compared to RAS and hydroponic systems. The ability of aquaponic systems to produce the same yield and quality as conventional one need to be also reported.

Integrated systems use water more efficiently through the interacting activities of fish and plants. The addition of water to a fish tank to satisfy the oxygen requirements depends on the oxygen consumption of the fish, the oxygen concentration in the inlet water and the lowest acceptable concentration in the outlet water **(Lekang, 2007)**. Hence effective HLR can be employed to achieve optimal growth for the fish and plants **(Khater *et al.*, 2015)**.

The rate of change in nutrient concentration can be influenced by varying the ratio of plants to fish **(Rakocy *et al.*, 2006)**. However, since the relative proportions of soluble nutrients made available to the hydroponic plants by fish excretion do not mirror the proportions of nutrients assimilated by normally growing plants, the rates of change in concentration for individual nutrients differ. The disparity in accumulation or reduction rates of different nutrients quickly results in suboptimal concentrations and ratios of nutrients, thereby reducing the nutritional adequacy of the solution for plants. Theoretically, the nutrient content of a diet can be manipulated to make the relative proportions of nutrients excreted by fish more similar to the relative proportions of nutrients assimilated by plants. With such a diet, there would be an optimal ration of fish to plants and optimal nutrient supplementation **(Seawright *et al.*, 1998)**.

Due to gradually increasing of production costs, it is required to maximize the utilization of available resources. Nutrients in the recycling water is considered one of these resources, therefore, the main aim of this work is to study the effect of flow rate and culture system on nutrients consumption rate and lettuce productivity in hydroponic and aquaponic systems.

2. MATERIALS AND METHODS

The main experiment was carried out in a greenhouse at Fish Farms and Protected Houses Center, Faculty of Agriculture Moshtohor, Benha University, Egypt (latitude 30° 21` N and 31° 13` E). During the period of November and December 2020 season.

2.1. Materials

2.1.1. System Description

Fig. 1 illustrates the experimental setup. It shows the system which consists of fish tanks, screen filter, biological filter, oxygen generator, oxygen mixer, hydroponic units, pumps and pipelines made of polyvinyl chloride were installed to connect components of system to recirculate the water.

2.1.1.1. Fish farm

Four fish tanks are an octagonal in shape and made from concrete has to openings for both settleable and suspended solids. The water volume used in each tank is 150 m^3 and has a height of 2.0 m. Each tank is provided with a particle trap in the center for water drain waste solids. The first opening allows for 1-15% of the total flow, the second opening allows for 85 – 99% of the total flow.

Two drum screen filters used in this system which has dimensions of 1.20 m in diameter and 2.0 m long. The filter was made from stainless steel at private company for steel industry. The fine mesh silk 60 micron was used a media of screening. The filter was driven by one motor of one kW power and 1500 rpm and a gearbox was used to reduce the rotation speed 500 times to give the recommended rotating speed (3 rpm).

Trickling biological filter used in this system, has 8.0 m in long, 4.0 m width and 4.0 m high. The filter was made from concrete. Used plastic sheets were used as a media. The total volume of media used in this system is 96 m^3.

Pure oxygen used in this system source of oxygen gas was oxygen generator. Adding pure oxygen gas to water by oxygen mixer. The water and oxygen enter the top of the oxygen mixer, as the water and oxygen move downward. Oxygen generator is used to provide the oxygenation system with its requirements of pure oxygen. It is consists of air compressor (Model BOGE – Flow rate 15 $m^3\ h^{-1}$ – Head 10 bar – Power 25 kW, Germany), Refrigeration unit, Filtration unit, 1 m^3 stainless steel tank for storage air, oxygen generator (Model BOGE – Flow rate 10.75 $m^3\ h^{-1}$ – Head 6.25 bar – power 1 kW, Germany) and 1 m^3 stainless steel tank for storage oxygen pure.

2.1.1.2. Hydroponic systems

Hydroponic systems consist of three types of hydroponic systems (deep water, A shape and gutter systems). The deep water system consists of six rectangular concrete tanks covered by polyethylene sheet with 1 mm thickness that used for lettuce plants culture. Dimensions of each tank are 17.5 m long, 1.2 m wide and 0.3 m high. The ground slope of tanks was 2 %. The tanks were covered with foam boards to support the plants. Fig. 2 shows the deep water system.

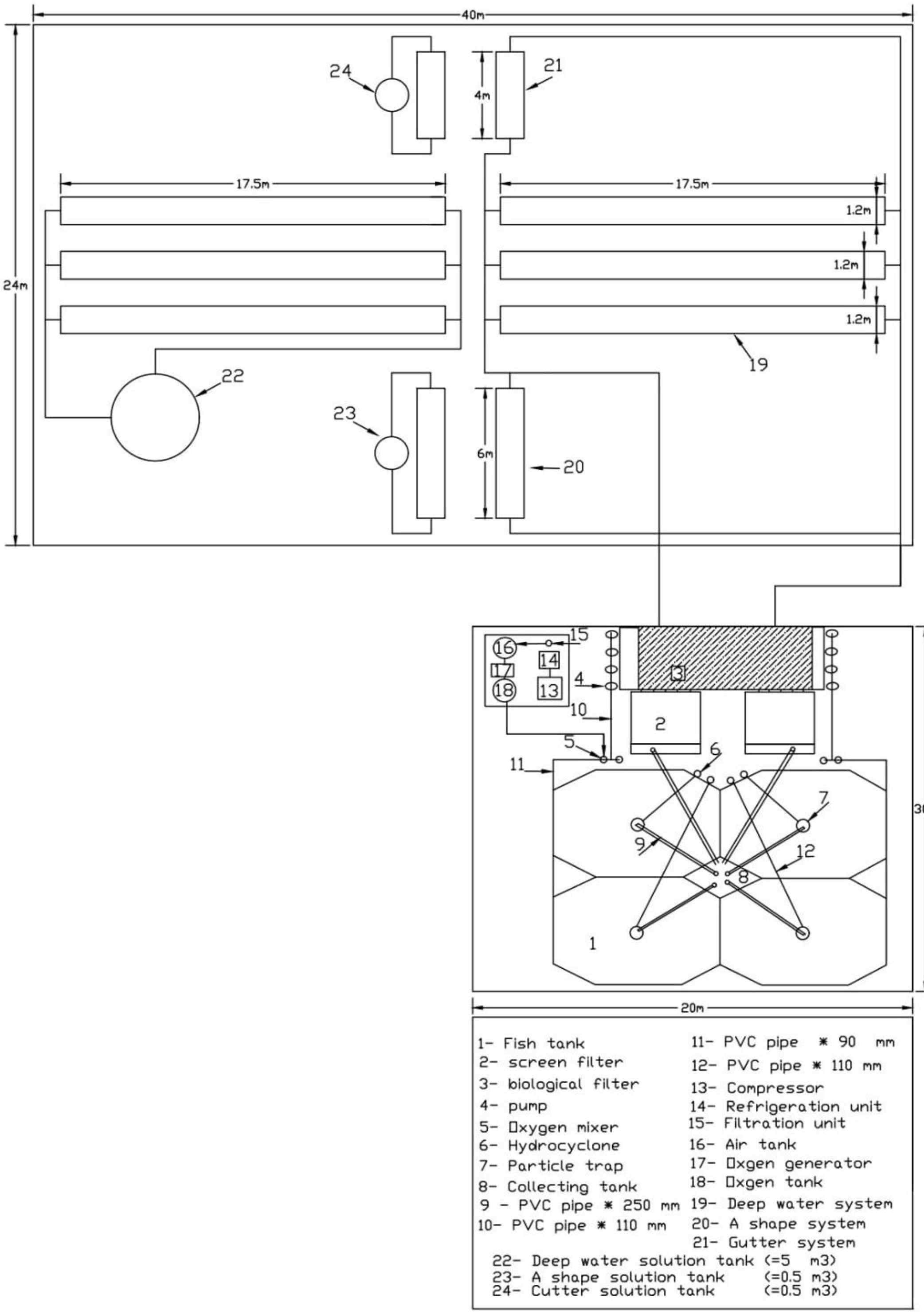

Fig. 1: The experimental setup

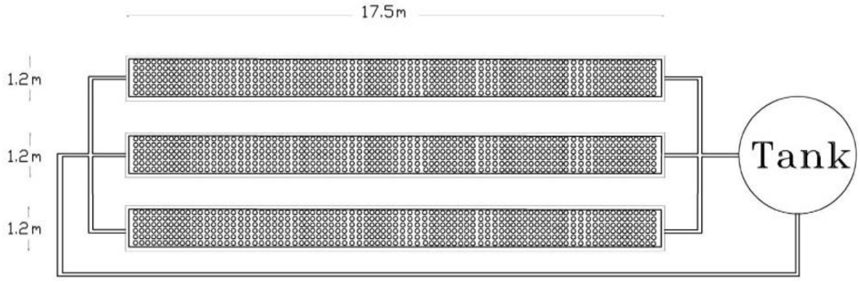

Fig. 2: The deep water system

The two A shape system consists of three stands made of iron. Dimensions of each stand are 1.2 m wide and 1.7 m high. Each A shape consists of nine polyvinyl chloride (PVC) pipe, the dimensions of pipe are 110 mm in diameter and 6.0 m long. The slope of pipes was 2 %. Small tubes (16 mm) were used to provide tanks with solution in a closed system. Fig. 3 shows the A shape system.
The two gutter system consists of three stands made of iron. Dimensions of each stand are 1.2 m wide and 1.0 m high. Each gutter system consists of three gutters made of PVC. The dimensions of each gutter are 4.0 m long, 0.15 m wide and 0.10 m high. The slope of gutters was 2 %, small tubes (16 mm) were used to provide tanks with solution in a closed system. Fig. 4 shows the gutter system.

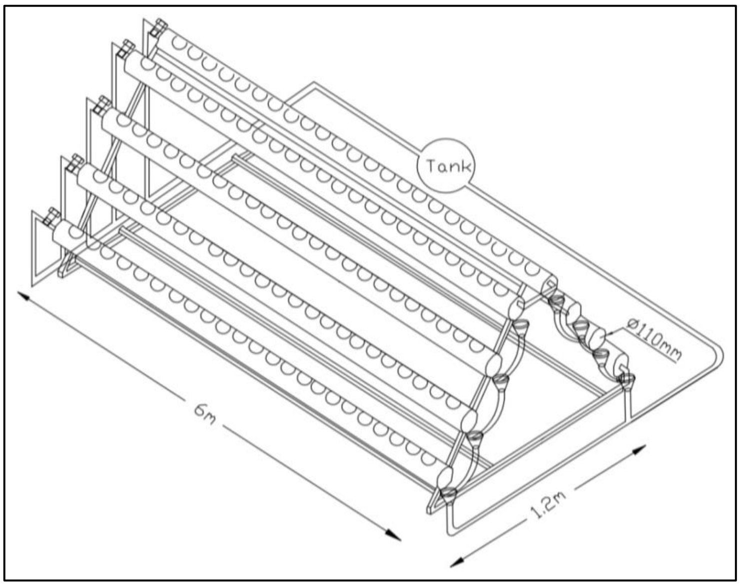

Fig. 3: A shape system.

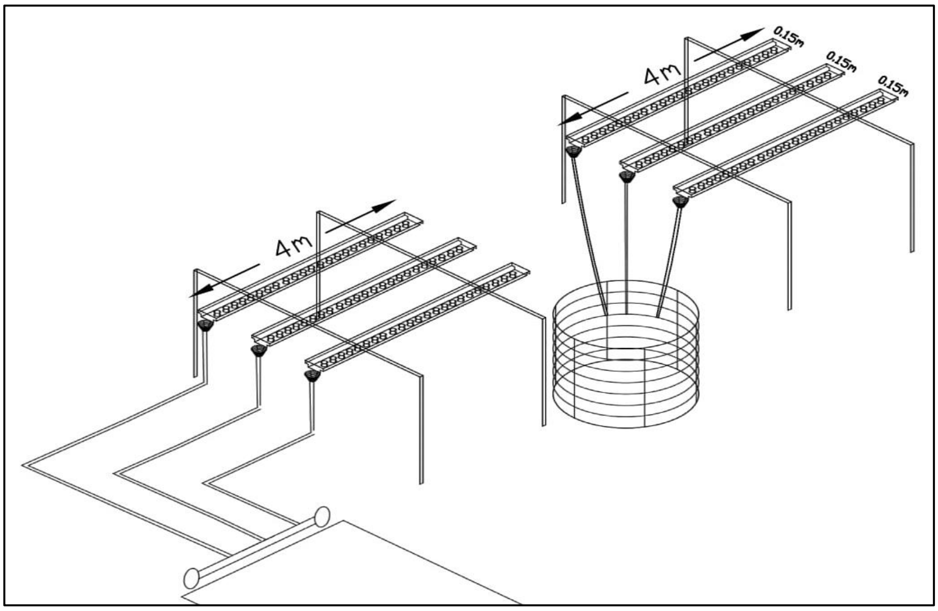

Fig. 4: Gutter system

The circular polyethylene tank of the nutrient solution system was used for collecting the drained solution by gravity from the ends of the three systems. The nutrient solutions were prepared manually according to **(Khater, 2006)** by dissolving appropriate amounts of

$Ca(NO_3)_2$, 236 g L^{-1}, KNO_3, 101 g L^{-1}, K2SO4, 115 g L^{-1}, KH_2PO_4, 136 g L^{-1}, $MgSO_4$, 246 g L^{-1} and chelates for trace elements into preacidified groundwater (from the following ppm concentration are achieved in this formulation: N = 210, P = 31, K = 234, Ca = 200, Mg = 48, S = 64, Fe = 14, Mn = 0.5, Zn = 0.05, Cu = 0.02, B = 0.5, Mo = 0.01). pH and Electrical Conductivity (EC) were further adjusted to 6.5–7.0 and 800 – 840 ppm, respectively, after salt addition. The average air ambient temperature was 25.97 ± 4.37 °C and the average water temperature was 24.03 ± 3.92 °C. The average relative humidity was 65.4% and the light intensity was 338.55 ± 40.06 W m^{-2}.

2.1.2. Plant and fish species

2.1.2.1. Lettuce plants

Lettuce seedlings were gown in the plastic cups (7 cm diameter and 7 cm height) filled with peat moss. The cups were irrigated daily using water with nutrient solution. Two weeks old lettuce seedlings were planted at 25.0 plant m^{-2} in the experimental tanks **(Khater and Ali, 2015)**.

2.1.2.2. Nile Tilapia fish

Tilapia nilotica fingerlings (an individual weight of 79.23 g), which were used in the beginning of experiment. The fish was weighed every ten days and the flow rate was adjusted according to the growth rate. The daily feed rates at different fish sizes were applied according to **Rakocy (1989)** and the feed pellet diameter was prepared according to **Jauncey and Ross (1982)**. Feeding was stopped during weighing process.

2.2. Methods

2.2.1. Treatments

The treatments were arranged in a split-split plot design in three replications. The treatments include: two nutrients sources (effluent fish farm and stock nutrient solution), three systems of hydroponics (deep water, A shape and gutter systems) and three flow rates are 1.0, 1.5 and 2.0 L h^{-1} per plant.

2.2.2. Measurements

2.2.2.1. Water parameters measurements

Water pH, EC and water temperature were measured daily. Water samples were taken from influent and effluent of the hydroponic units for measuring total nitrogen (Ammonia (NH_3), Nitrite (NO_2) and Nitrate (NO_3-N)), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) which were measured every ten days at 10 am during the experimental period. Water pH measured by pH Meter (Model ORION 105 –Range 0.0 – 9999.9 ppm ± 0.5 ppm, USA). Water temperature and EC measured by EC Meter (Model ORION 230A –Range 0.0 – 19.99 ± 0.05, USA). Ammonia (NH_3), Nitrite (NO_2) and Phosphorus (P) measured by a Spekol 11 (Model SPEKOL 11 –Range 0. 1 – 1000 concentration ± 1 nm λ, UK). Nitrate (NO_3-N) content was measured by using salicylic acid as described by **Chapman and Partt (1961)**. Potassium (K), Calcium (Ca) and Magnesium (Mg) measured by flame photometer (Model Jenway PFP7 –Range 0. 1 – 999.9 ppm ± 0.2 ppm, USA).

The nutrient consumption rates were calculated as the differences between the nutrients at inlet and outlet of culture units by the following formula **(Khater *et al.*, 2015)**:

$$C_{Nc} = \frac{Nc_{in} - Nc_{out}}{\mathrm{n}} \times Q \times 24 \quad (1)$$

Where:

C_{Nc} is the nutrients consumption rate, mg day^{-1} plant^{-1}

Nc_{in} is the nutrients at inlet of the hydroponic unit, mg L^{-1}

Nc_{out} is the nutrients at outlet of the hydroponic unit, mg L^{-1}

Q is the discharge, L h^{-1}

n is the number of plants

2.2.2.2. Plant samples

The fresh weight of whole lettuce plant was measured every ten days during the experimental period.

2.2.2.3. Water use efficiency

Water use efficiency (WUE) was determined by the following formula:

$$WUE = \frac{\text{fresh weight of shoot (kg)}}{\text{plant water uptake (m}^3\text{)}} \qquad (2)$$

Where: WUE is water use efficiency, kg m^{-3}

3. RESULTS AND DISCUSSION

3.1. Water quality parameters:

Table 1 shows some water quality parameters for different source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} plant^{-1}) during the growth period. Water temperature did not show any variation throughout the experimental period for the values of culture systems. It varied within a narrow range (23.05 ± 0.48 to 24.43 ± 0.63 ^{o}C). Water temperature is one of the important factors responsible for optimum fish and plant growth. The Electrical Conductivity water during the growth period ranged from 675.36±153.67 to 1183.58±66.37 mg L^{-1}. The water pH during the growth period range from 6.35 ± 0.11 to 6.77 ± 0.12, with no marked variation among the treatments at time of sampling. Different culture systems did not show any significant effect on water pH which was found in desirable limits for fish as well as plant growth. The highest value of ammonia-N generation rate was 0.026±0.002 mg L^{-1} with found of Deep water system at 1.0 L h^{-1} flow rate. Ammonia-N generation rate depends on the feeding rate in the system which was adjusted after each sampling as per the fish body weight. Lowest Nitrite-N concentration was observed in A shape hydroponic system at 1.0 L h^{-1} flow rate (0.0.29 ± 0.03 mg L^{-1}) as compared to other treatments. The highest value of Nitrate-N concentration was 174.33±3.59 mg L^{-1} with found of A shape system at 1.0 L h^{-1} flow rate for nutrient solution source, while, the lowest value of Nitrate-N concentration was 10.93±4.59 mg L^{-1} with found of deep water system at 2.0 L h^{-1} flow rate for effluent fish farm.

Table 2 shows some water quality parameters for different source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} plant^{-1}) during the growth period. The phosphorus concentration values were ranged from 7.40 ± 0.97 to 26.91 ± 2.27 mg L^{-1}. Potassium, calcium and magnesium concentrations also ranged from 39.03 ± 8.97 to 87.58 ± 9.09, 18.66 ± 8.75 to 64.67 ± 7.97 and 19.20 ± 4.23 to 42.92 ± 2.85 mg L^{-1}, respectively, for all treatments.

Table 1: Some water quality parameters

Parameter	Flow Rate, L h^{-1}	Hydroponic system					
		A Shape		Gutter		Deep Water	
		NS	EFF	NS	EFF	NS	EFF
Temperature, ˚C	1.0	24.43±0.63	23.81±0.63	24.07±0.47	23.86±0.58	23.05±0.48	23.78±0.59
	1.5	24.40±0.62	23.82±0.63	24.07±0.47	23.86±0.59	23.07±0.52	23.80±0.59
	2.0	24.41±0.61	23.82±0.63	24.08±0.46	23.88±0.60	23.08±0.53	23.79±0.59
EC, mg L^{-1}	1.0	1129.73±89.96	689.94±23.38	1134.07±33.03	695.50±117.78	1126.20±26.61	675.36±153.67
	1.5	1156.73±91.01	706.41±114.98	1163.85±88.99	712.42±119.76	1157.77±87.06	690.99±155.73
	2.0	1183.58±66.37	719.43±195.15	1184.52±92.42	722.27±117.16	1182.33±65.16	703.29±200.69
pH	1.0	6.38±0.10	6.70±0.14	6.37±0.11	6.22±0.28	6.37±0.09	6.75±0.14
	1.5	6.40±0.11	6.71±0.13	6.35±0.11	6.72±0.14	6.39±0.12	6.77±0.12
	2.0	6.37±0.15	6.72±0.13	6.36±0.11	6.72±0.14	6.37±0.09	6.76±0.12
NH_3, mg L^{-1}	1.0	-	0.025±0.001	-	0.023±0.001	-	0.026±0.002
	1.5	-	0.024±0.001	-	0.024±0.002	-	0.023±0.001
	2.0	-	0.024±0.001	-	0.024±0.001	-	0.023±0.003
Nitrite, mg L^{-1}	1.0	-	0.29±0.03	-	0.38±0.04	-	0.32±0.05
	1.5	-	0.35±0.06	-	0.36±0.02	-	0.39±0.01
	2.0	-	0.31±0.05	-	0.29±0.07	-	0.33±0.05
Nitrate, mg L^{-1}	1.0	174.33±3.59	10.94±5.70	161.16±4.75	14.31±3.99	149.08±11.24	12.71±6.66
	1.5	165.59±4.37	14.39±2.51	163.03±4.58	13.30±2.67	144.57±8.93	14.82±3.67
	2.0	169.72±3.64	13.63±2.79	149.53±6.80	15.00±2.21	155.51±3.36	10.93±4.59

Table 2: Some water quality parameters

Parameter	Flow Rate, L h^{-1}	Hydroponic system					
		A Shape		Gutter		Deep Water	
		NS	EFF	NS	EFF	NS	EFF
Phosphorus, mg L^{-1}	1.0	25.63±2.79	8.31±1.06	24.60±3.05	8.13±1.22	22.97±3.17	7.57±1.26
	1.5	26.91±2.27	8.72±1.12	25.01±2.68	8.44±1.09	23.16±2.81	7.99±1.14
	2.0	26.04±2.65	7.92±0.99	24.33±2.78	8.00±1.24	22.57±2.44	7.40±0.97
Potassium, mg L^{-1}	1.0	86.06±6.14	41.77±9.82	77.61±5.18	41.62±10.09	64.55±10.39	39.03±8.97
	1.5	87.58±9.09	44.18±10.95	78.41±4.96	41.18±10.05	65.62±12.19	39.23±8.65
	2.0	86.78±7.91	44.50±10.94	78.41±5.80	41.54±9.94	68.76±11.88	39.54±7.79
Calcium, mg L^{-1}	1.0	64.67±7.97	22.31±8.85	55.88±12.33	24.01±8.06	48.15±4.63	22.49±8.77
	1.5	63.03±10.35	21.72±7.56	54.81±14.36	23.05±6.18	51.22±5.12	19.91±8.77
	2.0	62.01±11.76	23.05±7.15	55.14±13.01	24.53±7.70	52.76±7.15	18.66±8.75
Magnesium, mg L^{-1}	1.0	42.92±2.85	24.52±2.67	39.64±5.80	24.14±4.42	34.92±3.42	20.26±3.50
	1.5	41.12±6.18	24.68±1.87	38.84±6.43	24.30±3.89	35.64±5.02	19.20±4.23
	2.0	40.06±5.91	23.18±2.64	37.36±7.15	23.98±5.38	38.44±4.60	20.58±4.62

3.1. Nutrients consumption rate:

3.1.1. Nitrogen consumption rate:

Figs. 5a, b and c show the nitrogen (N) consumption rate by lettuce plants during the growth period in source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$). The results indicate that the nitrogen (N) consumption rate by lettuce plants grown in different culture system increases with increasing plant age. It could be seen that the nitrogen (N) consumption rate by lettuce plants increased from 8.59 to 28.74, 10.96 to 29.65 and 5.24 to 24.67 and 4.82 to 19.11, 6.51 to 21.07 and 3.82 to 16.49 mg $plant^{-1}$ day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system.

For gutter hydroponic system, the nitrogen (N) consumption rate by lettuce plants increased from 8.81 to 28.73, 10.36 to 29.93 and 7.58 to 26.95 and 4.35 to 20.33, 6.84 to 23.63 and 3.70 to 18.48 mg $plant^{-1}$ day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ in nutrients solution and water discharged of the fish farm, respectively. For deep water hydroponic system, the nitrogen (N) consumption rate by lettuce plants increased from 9.00 to 26.95, 13.44 to 27.61 and 7.63 to 23.44 and 6.06 to 16.43, 9.76 to 20.46 and 5.40 to 14.20 mg $plant^{-1}$ day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ in nutrients solution and water discharged of the fish farm, respectively.

The highest value of the nitrogen (N) consumption rate by lettuce plants (29.93 mg $plant^{-1}$ day^{-1}) was found with nutrient solution for gutter hydroponic system. However, the lowest value of the nitrogen (N) consumption rate by lettuce plants (14.20 mg $plant^{-1}$ day^{-1}) was found with effluent fish farm for deep water hydroponic system at the end of growth period.

Regarding the flow rate, the results indicate that the highest values of the nitrogen (N) consumption rate by lettuce plants were found with 1.5 L h^{-1}. They were 29.64, 29.93 and 27.61 and 21.07, 23.63 and 20.45 mg $plant^{-1}$ day^{-1} with found in A shape, gutter and deep water hydroponic systems, respectively for nutrients solution and water discharged of the fish farm at the end of experimental growth period. These results agreed with those obtained by **Genuncio *et al.* (2012)** whose found that the highest values of nutrients consumption rate of plant were found with a flow rate of 1.5 L h^{-1} $plant^{-1}$. Regarding the hydroponic systems, the results indicate that the nitrogen (N) consumption rate by lettuce plants increased from 6.52 to 23.29, 6.86 to 24.68 and 8.55 to 21.52 mg $plant^{-1}$ day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, A shape, gutter and deep water systems for all treatments.

3.1.2. Phosphorus consumption rate:

Figs. 6a, b and c show the phosphorus (P) consumption rate by lettuce plants during the growth period in source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$). The results indicate that the phosphorus (P) consumption rate by lettuce plants grown in different culture system increases with increasing plant age. It could be seen that the phosphorus (P) consumption rate by lettuce plants increased from 6.70 to 21.05, 8.17 to 26.05 and 5.97 to 17.72 and 3.39 to 15.58, 4.71 to 21.02 and 3.19 to 13.17 mg $plant^{-1}$ day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5

and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system.

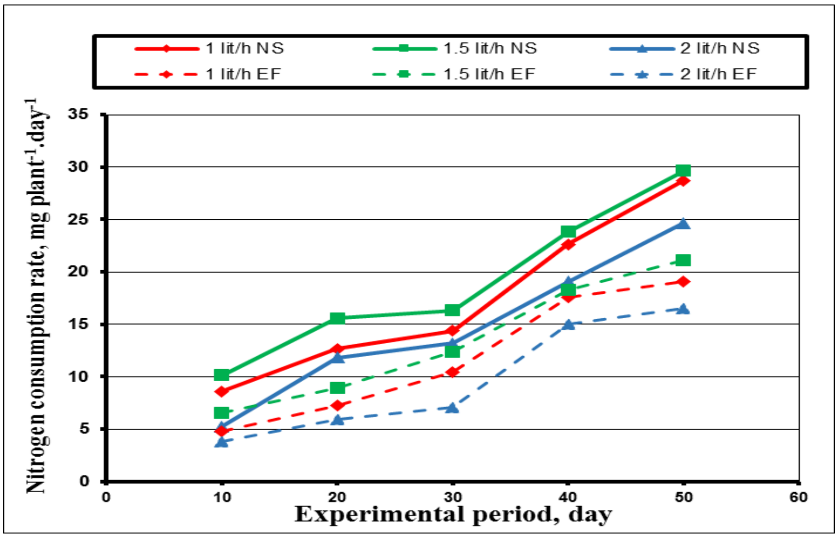

Fig. 5a: The nitrogen consumption rate by lettuce plants grown A shape system

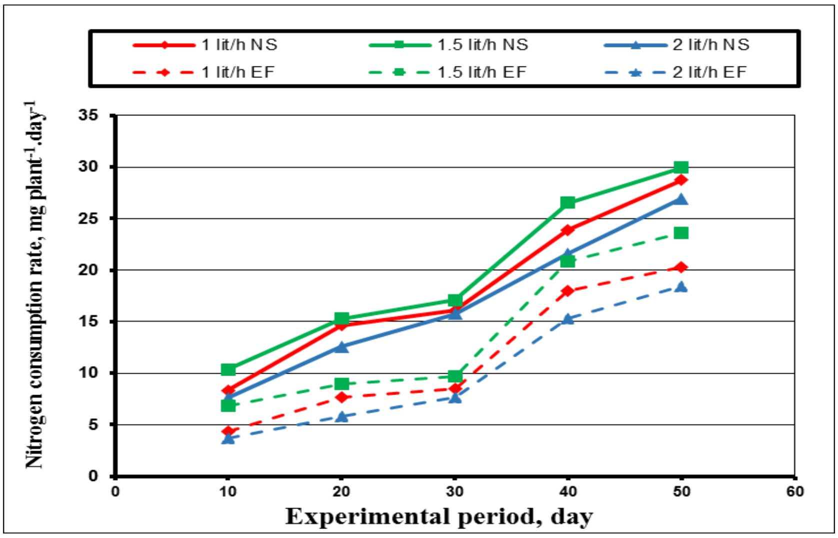

Fig. 5b: The nitrogen consumption rate by lettuce plants grown gutter system

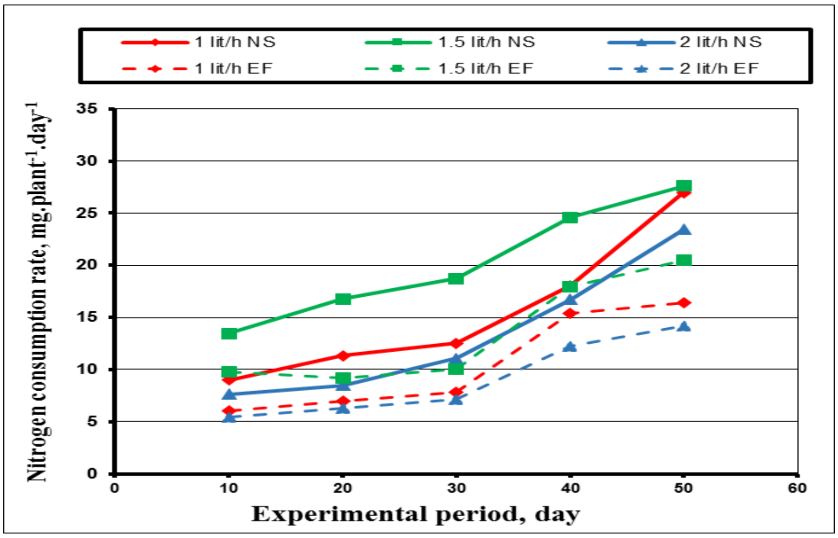

Fig. 5c: The nitrogen consumption rate by lettuce plants grown deep water system

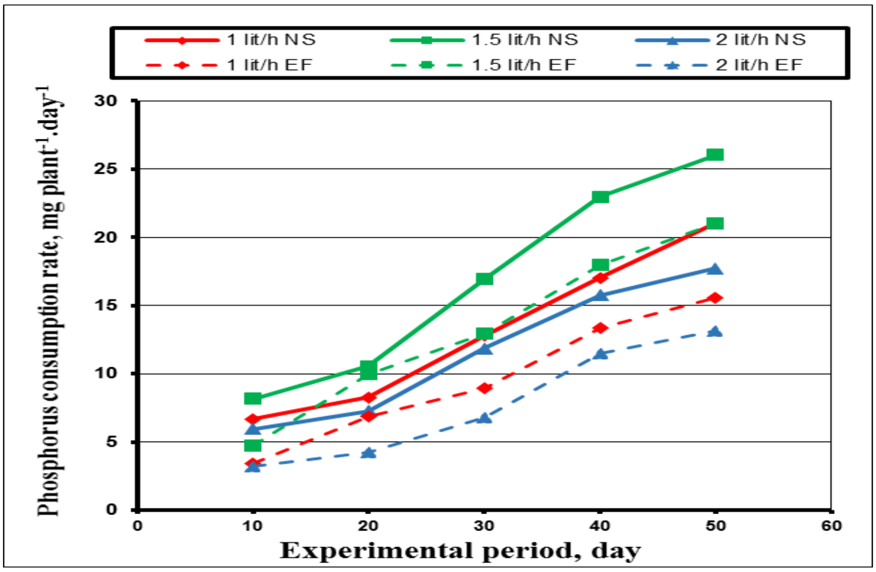

Fig 6a: The phosphorus consumption rate by lettuce plants grown A shape system

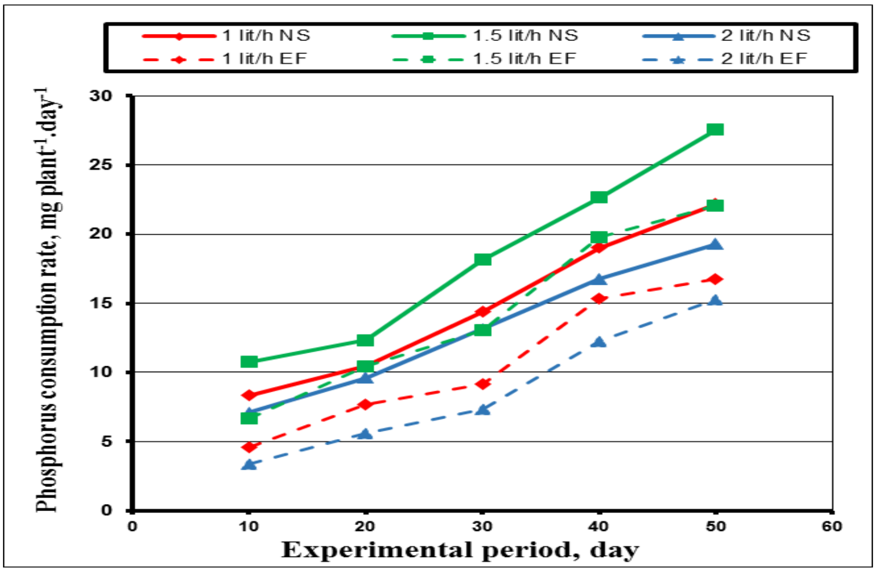

Fig. 6b: The phosphorus consumption rate by lettuce plants grown gutter system

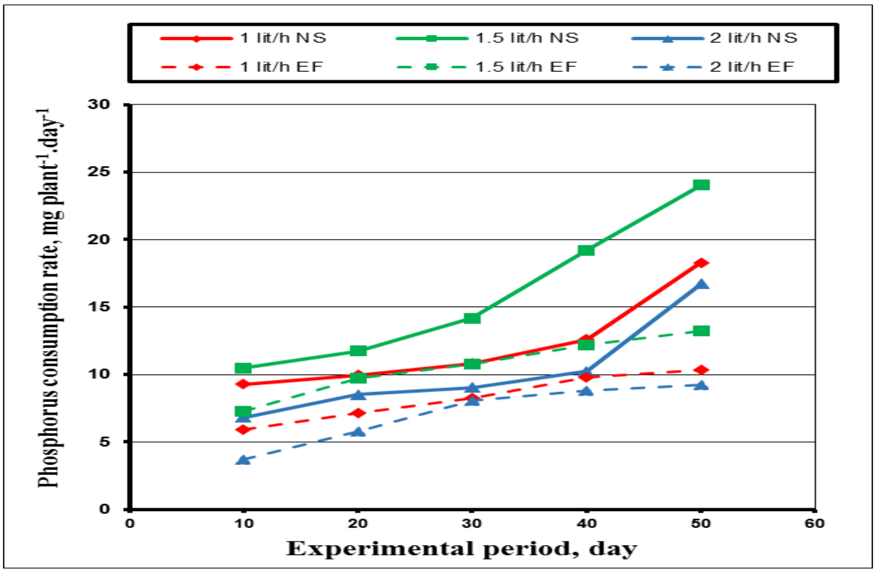

Fig. 6c: The phosphorus consumption rate by lettuce plants grown deep water system

For gutter hydroponic system, the phosphorus (P) consumption rate by lettuce plants increased from 8.33 to 22.17, 10.75 to 27.54 and 7.10 to 19.30 and 4.61 to 16.73, 6.69 to 22.04 and 3.39 to 15.29 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively. For deep water hydroponic system, the phosphorus (P) consumption rate by lettuce plants increased from 9.28 to 18.27, 10.47 to 24.03 and 6.82 to 16.71 and 5.92 to 10.34, 7.27 to 13.25 and 3.72 to 9.22 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively.

The highest value of the phosphorus (P) consumption rate by lettuce plants (27.54 mg plant^{-1} day^{-1}) was found with nutrient solution for gutter hydroponic system. However, the lowest value of the phosphorus (P) consumption rate by lettuce plants (9.22 mg plant^{-1} day^{-1}) was found with effluent fish farm for deep water hydroponic system at the end of growth period.

Regarding the flow rate, the results indicate that the highest values of the phosphorus (P) consumption rate by lettuce plants were found with 1.5 L h^{-1}. They were 26.05, 27.54 and 24.03 and 21.02, 22.04 and 13.25 mg plant^{-1} day^{-1} with found in A shape, gutter and deep water hydroponic systems, respectively for nutrients solution and water discharged of the fish farm at the end of experimental growth period. These results agreed with those obtained by **Ali *et al.* (2015)** whose found that the highest values of nutrients consumption rate of plant were found with a flow rate of 1.5 L h^{-1} plant^{-1}. Regarding the hydroponic systems, the results indicate that the phosphorus (P) consumption rate by lettuce plants increased from 5.36 to 19.10, 6.81 to 20.51 and 7.25 to 15.30 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, A shape, gutter and deep water systems for all treatments.

3.1.3. Potassium consumption rate:

Figs. 6a, b and c show the potassium (K) consumption rate by lettuce plants during the growth period in source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} plant^{-1}). The results indicate that the potassium (K) consumption rate by lettuce plants grown in different culture system increases with increasing plant age. It could be seen that the potassium (K) consumption rate by lettuce plants increased from 38.14 to 46.56, 39.65 to 53.80 and 34.39 to 44.58 and 19.34 to 31.23, 22.85 to 36.92 and 17.32 to 25.90 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system.

For gutter hydroponic system, the potassium (K) consumption rate by lettuce plants increased from 38.96 to 55.89, 41.37 to 63.21 and 36.14 to 47.73 and 24.10 to 35.38, 28.21 to 37.34 and 19.68 to 32.23 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively. For deep water hydroponic system, the potassium (K) consumption rate by lettuce plants increased from 31.97 to 46.32, 34.70 to 58.12 and 31.12 to 42.20 and 14.17 to 27.21, 17.26 to 38.37 and 9.33 to 24.19 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively.

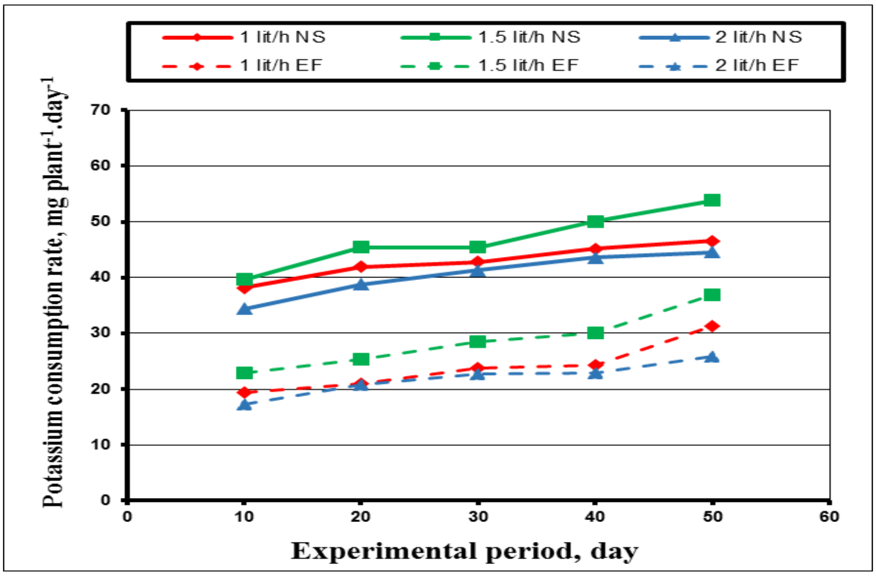

Fig. 6a: The potassium consumption rate by lettuce plants grown A shape system

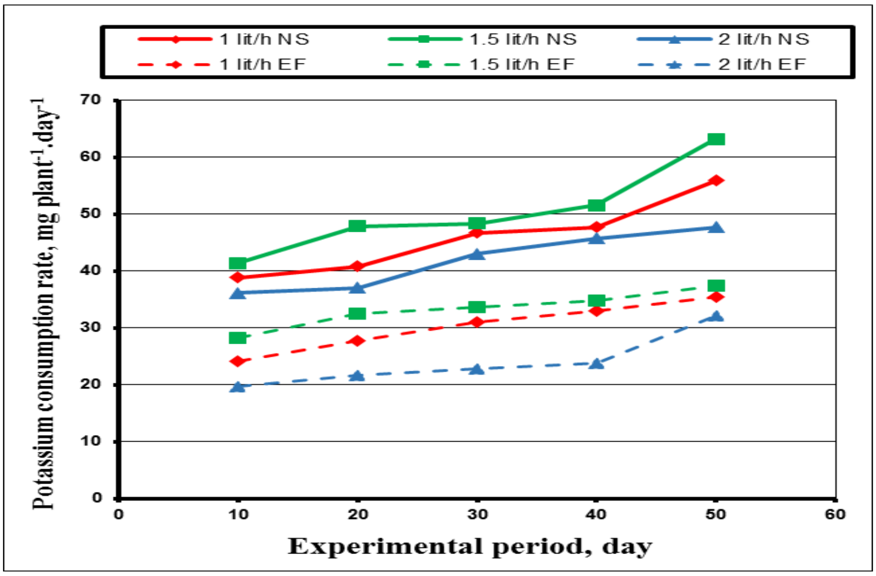

Fig. 6b: The potassium consumption rate by lettuce plants grown gutter system

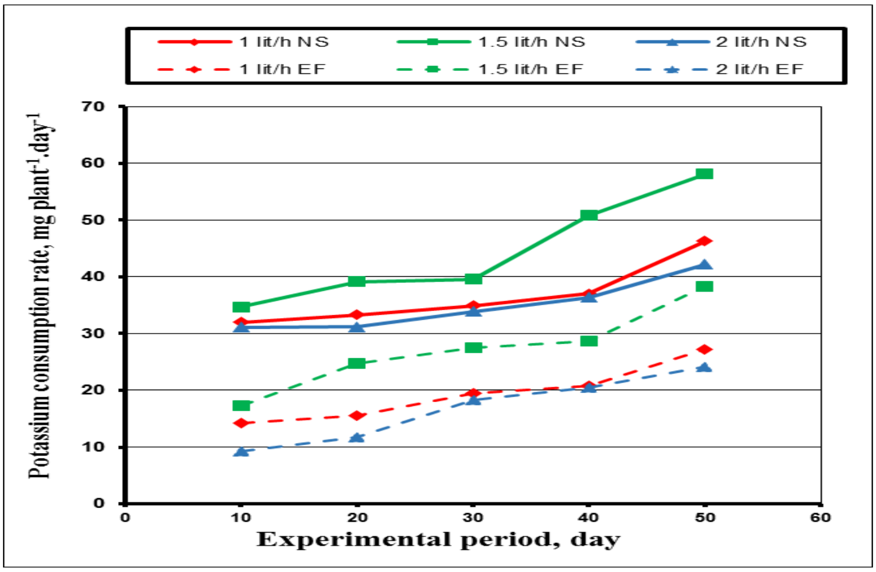

Fig. 6c: The potassium consumption rate by lettuce plants grown deep water system

The highest value of the potassium (K) consumption rate by lettuce plants (63.21 mg plant^{-1} day^{-1}) was found with nutrient solution for gutter hydroponic system. However, the lowest value of the potassium (K) consumption rate by lettuce plants (24.19 mg plant^{-1} day^{-1}) was found with effluent fish farm for deep water hydroponic system at the end of growth period.

Regarding the flow rate, the results indicate that the highest values of the potassium (K) consumption rate by lettuce plants were found with 1.5 L h^{-1}. They were 53.80, 63.21 and 58.12 and 36.92, 37.34 and 38.37 mg plant^{-1} day^{-1} with found in A shape, gutter and deep water hydroponic systems, respectively for nutrients solution and water discharged of the fish farm at the end of experimental growth period. These results agreed with those obtained by **Khater (2016)** who found that the highest values of nutrients consumption rate of plant were found with a flow rate of 1.5 L h^{-1} plant^{-1}. Regarding the hydroponic systems, the results indicate that the potassium (K) consumption rate by lettuce plants increased from 28.61 to 39.83, 31.39 to 45.28 and 23.10 to 31.39 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, A shape, gutter and deep water systems for all treatments.

3.1.4. Calcium consumption rate:

Figs. 7a, b and c show the calcium (Ca) consumption rate by lettuce plants during the growth period in source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} plant^{-1}). The results indicate that the calcium (Ca) consumption rate by lettuce plants grown in different culture system increases with increasing plant age. It could be seen that the calcium (Ca) consumption rate by lettuce plants increased from 4.17 to 14.32, 5.66 to 16.39 and 3.69 to 12.08 and 2.71 to 8.18, 3.55 to 9.92 and 2.63 to 7.93 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system.

For gutter hydroponic system, the calcium (Ca) consumption rate by lettuce plants increased from 4.97 to 13.59, 6.33 to 14.14 and 4.46 to 11.42 and 2.85 to 8.81, 4.09 to 10.29 and 2.67 to 6.45 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively. For deep water hydroponic system, the calcium (Ca) consumption rate by lettuce plants increased from 5.45 to 9.82, 8.07 to 12.20 and 5.38 to 8.31 and 3.56 to 6.08, 5.01 to 8.88 and 2.81 to 5.68 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively.

The highest value of the calcium (Ca) consumption rate by lettuce plants (16.39 mg plant^{-1} day^{-1}) was found with nutrient solution for A shape hydroponic system. However, the lowest value of the calcium (Ca) consumption rate by lettuce plants (5.68 mg plant^{-1} day^{-1}) was found with effluent fish farm for deep water hydroponic system at the end of growth period.

Regarding the flow rate, the results indicate that the highest values of the calcium (Ca) consumption rate by lettuce plants were found with 1.5 L h^{-1}. They were 16.39, 14.14 and 12.20 and 9.92, 10.28 and 8.88 mg plant^{-1} day^{-1} with found in A shape, gutter and deep water hydroponic systems, respectively for nutrients solution and water discharged of the fish farm at the end of experimental growth period.

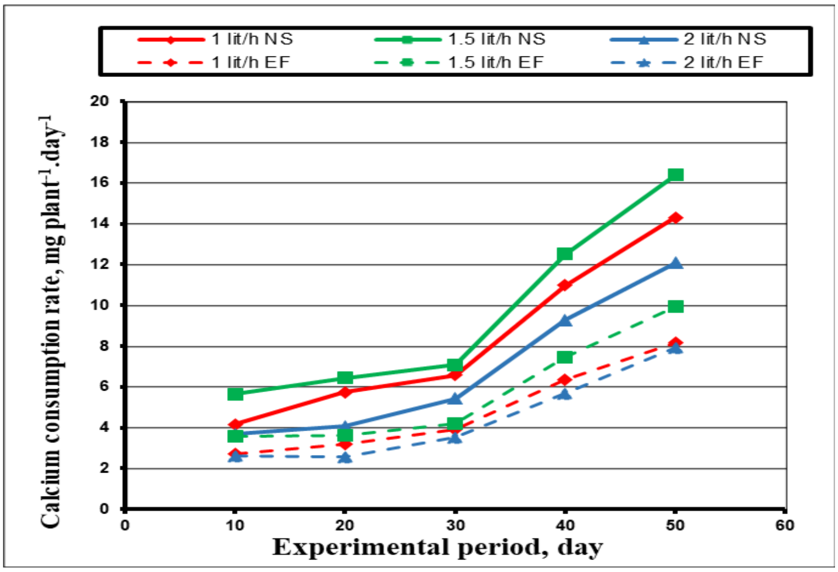

Fig. 7a: The calcium consumption rate by lettuce plants grown A shape system

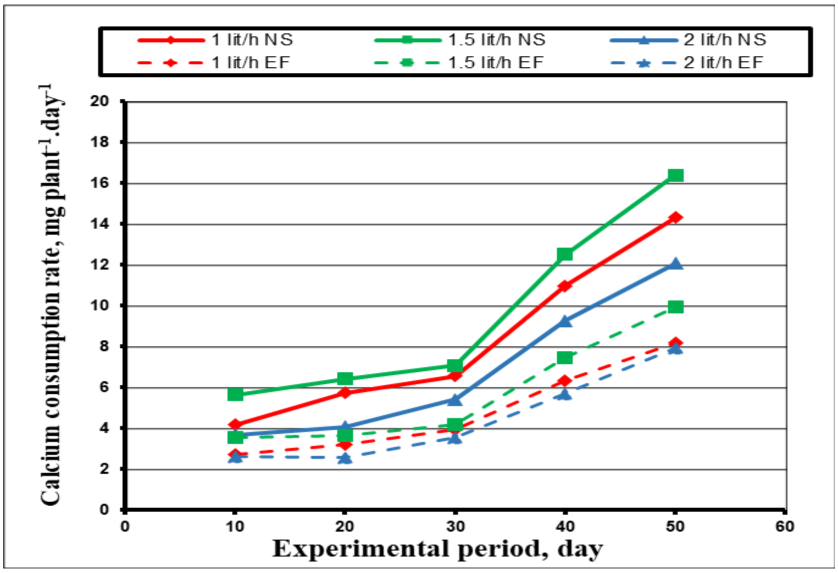

Fig. 7b: The calcium consumption rate by lettuce plants grown gutter system

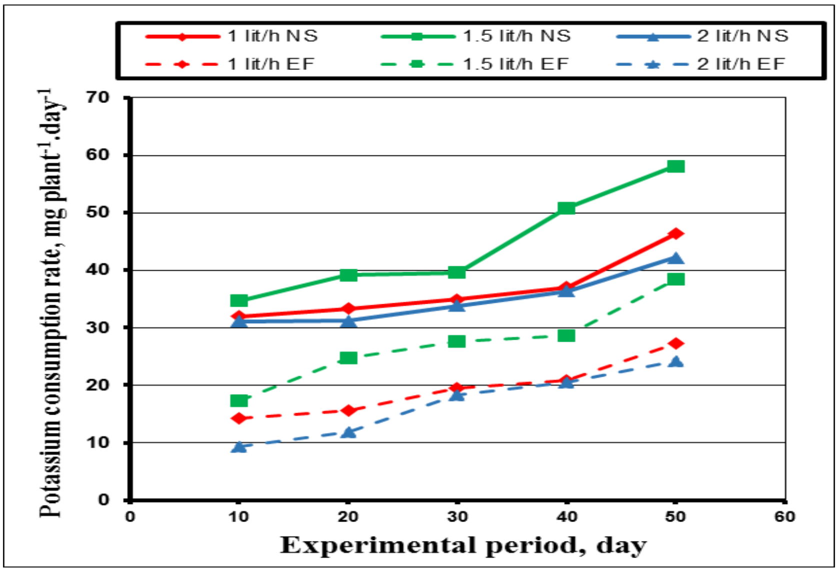

Fig. 7c: The calcium consumption rate by lettuce plants grown deep water system

Regarding the hydroponic systems, the results indicate that the calcium (Ca) consumption rate by lettuce plants increased from 3.73 to 11.47, 4.23 to 10.78 and 5.05 to 8.49 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, A shape, gutter and deep water systems for all treatments. These results agreed with those obtained by **Khater (2006)** who found that the highest values of nutrients consumption rate of plant were found with a stock nutrients solution.

3.1.5. Magnesium consumption rate:

Figs. 8a, b and c show the magnesium (Mg) consumption rate by lettuce plants during the growth period in source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} plant^{-1}). The results indicate that the magnesium (Mg) consumption rate by lettuce plants grown in different culture system increases with increasing plant age. It could be seen that the magnesium (Mg) consumption rate by lettuce plants increased from 6.98 to 14.55, 8.64 to 15.90 and 6.18 to 13.90 and 4.76 to 11.25, 5.42 to 12.55 and 3.49 to 10.18 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system.

For gutter hydroponic system, the magnesium (Mg) consumption rate by lettuce plants increased from 7.08 to 14.86, 9.03 to 16.53 and 6.10 to 14.26 and 4.95 to 10.92, 6.76 to 13.55 and 3.70 to 10.05 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively. For deep water hydroponic system, the magnesium (Mg) consumption rate by lettuce plants increased from 8.00 to 14.60, 10.54 to 16.28 and 6.28 to 13.30 4.20 to 7.31, 6.04 to 10.60 and 3.76 to 6.09 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} plant^{-1} in nutrients solution and water discharged of the fish farm, respectively.

The highest value of the magnesium (Mg) consumption rate by lettuce plants (16.53 mg plant^{-1} day^{-1}) was found with nutrient solution for gutter hydroponic system. However, the lowest value of the magnesium (Mg) consumption rate by lettuce plants (6.09 mg plant^{-1} day^{-1}) was found with effluent fish farm for deep water hydroponic system at the end of growth period.

Regarding the flow rate, the results indicate that the highest values of the magnesium (Mg) consumption rate by lettuce plants were found with 1.5 L h^{-1}. They were 15.90, 16.53 and 16.28 and 12.55, 13.55 and 10.60 mg plant^{-1} day^{-1} with found in A shape, gutter and deep water hydroponic systems, respectively for nutrients solution and water discharged of the fish farm at the end of experimental growth period. Regarding the hydroponic systems, the results indicate that the magnesium (Mg) consumption rate by lettuce plants increased from 5.91 to 13.06, 6.27 to 13.36 and 6.47 to 11.37 mg plant^{-1} day^{-1}, when the lettuce plant age increased from 10 to 50 days, respectively, A shape, gutter and deep water systems for all treatments. These results agreed with those obtained by **Khater and Ali (2015)** whose found that the highest values of nutrients consumption rate of plant were found with a stock nutrients solution.

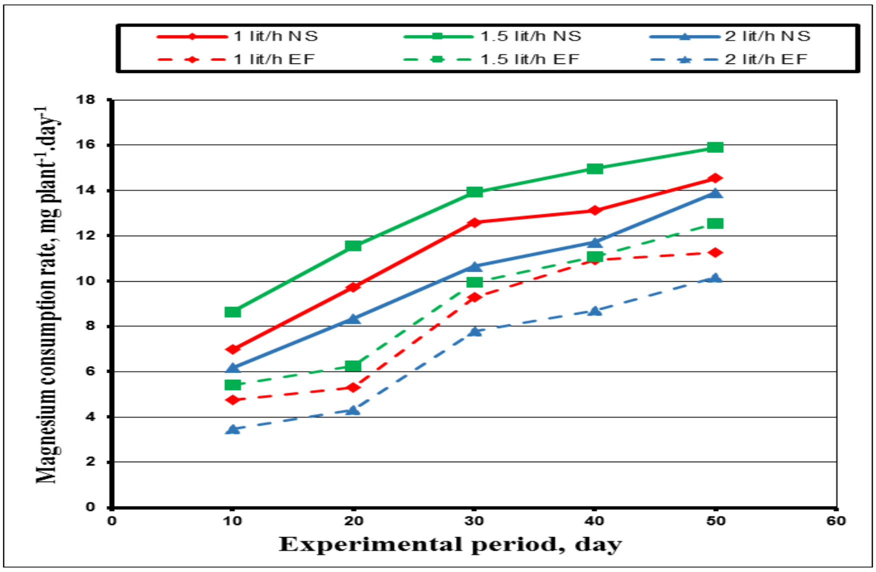

Fig. 8a: The magnesium consumption rate by lettuce plants grown A shape system

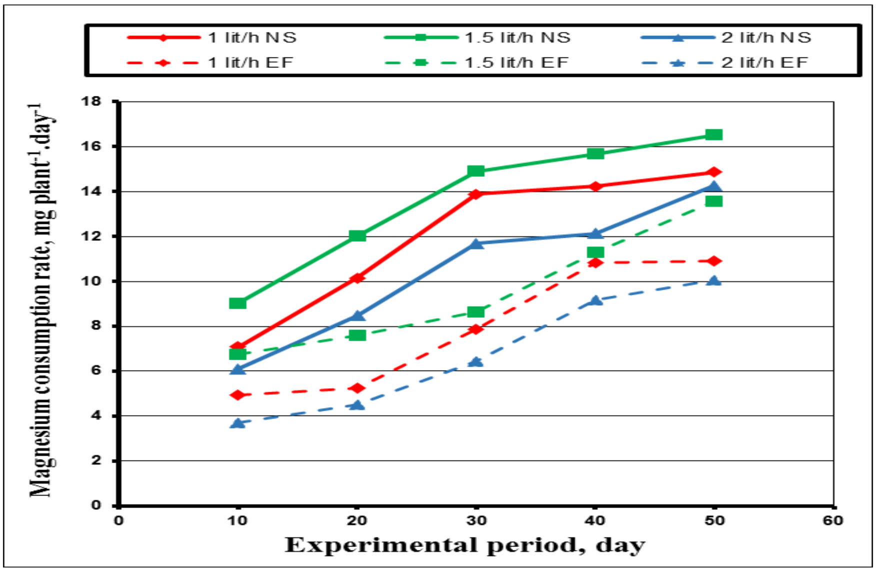

Fig. 8b: The magnesium consumption rate by lettuce plants grown gutter system

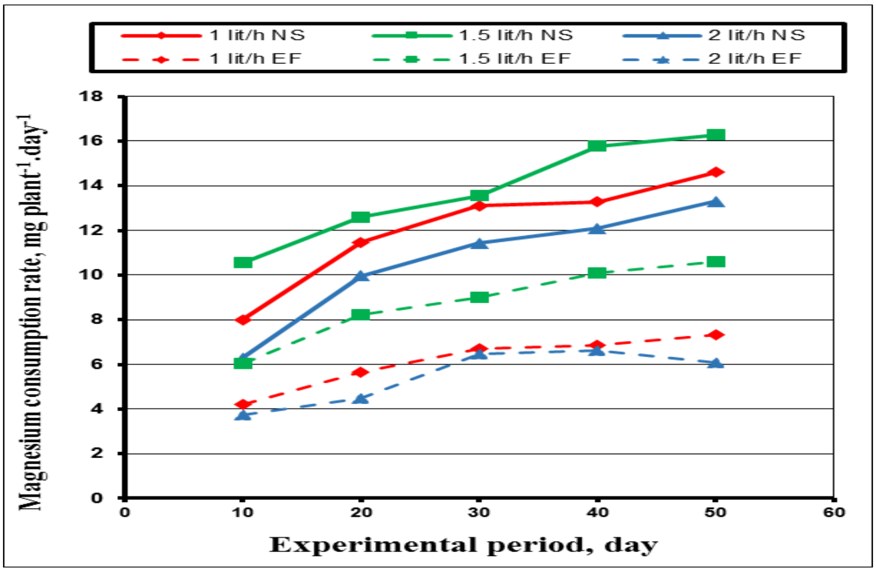

Fig. 8c: The magnesium consumption rate by lettuce plants grown deep water system

3.2. Whole plant weight:

Figs. 9a, b and c show the whole plant weight of lettuce plants grown during the growth period in source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$). The results indicate that the whole plant weight of the lettuce plant grown in different culture system increases with increasing plant age. It could be seen that the whole plant weight of lettuce plants increased from 99.19 to 288.17, 155.14 to 370.99 and 107.79 to 297.14 and 68.92 to 266.75, 92.35 to 314.25 and 85.91 to 251.88 g $plant^{-1}$, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system.

For gutter hydroponic system, the whole plant weight of lettuce plants increased from 130.33 to 319.71, 186.26 to 408.69 and 160.56 to 342.17 and 111.25 to 299.14, 149.78 to 371.87 and 91.94 to 276.55 g $plant^{-1}$, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ in nutrients solution and water discharged of the fish farm, respectively. For deep water hydroponic system, the whole plant weight of lettuce plants increased from 58.11 to 258.12, 122.63 to 344.73 and 58.49 to 262.31 and 47.27 to 246.82, 69.47 to 295.58 and 86.13 to 235.52 g $plant^{-1}$, when the lettuce plant age increased from 10 to 50 days, respectively, at 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$ in nutrients solution and water discharged of the fish farm, respectively.

The highest value of the whole plant weight (408.69 g $plant^{-1}$) was found with nutrient solution for gutter hydroponic system. However, the lowest value whole plant weight (235.52 g $plant^{-1}$) was found with effluent fish farm for deep water hydroponic system.

Regarding the flow rate, the results indicate that the highest values of whole plant weight were found with 1.5 L h^{-1}. They were 318.83, 277.63 and 356.89 and 315.85, 288.39 and 259.31 g $plant^{-1}$ with found in A shape, gutter and deep water hydroponic systems, respectively for nutrients solution and water discharged of the fish farm at the end of experimental growth period. These results were in agreement with **Khater (2006)**. Regarding the hydroponic systems, the results indicate that the average whole plant weight of lettuce plants increased from 101.55 to 298.23, 138.35 to 336.35 and 73.68 to 273.85 g $plant^{-1}$, when the lettuce plant age increased from 10 to 50 days, respectively, A shape, gutter and deep water systems for all treatments.

Multiple regression analysis was carried out to obtain a relationship between the whole weight of lettuce plants as dependent variable and different both of culture system, flow rate (1.0, 1.5 and 2.0 L h^{-1}) and experimental period (1 to 50 day) as independent variables. The best fit for this relationship is presented in the following equation:

$$W = a + bT + cQ \qquad (7)$$

Where:

W is the whole weight of lettuce plant, g

T is the lettuce plant age, day

Q is the flow rate, L h^{-1}

The constants of these equation and coefficient of determination are listed in Table 3.

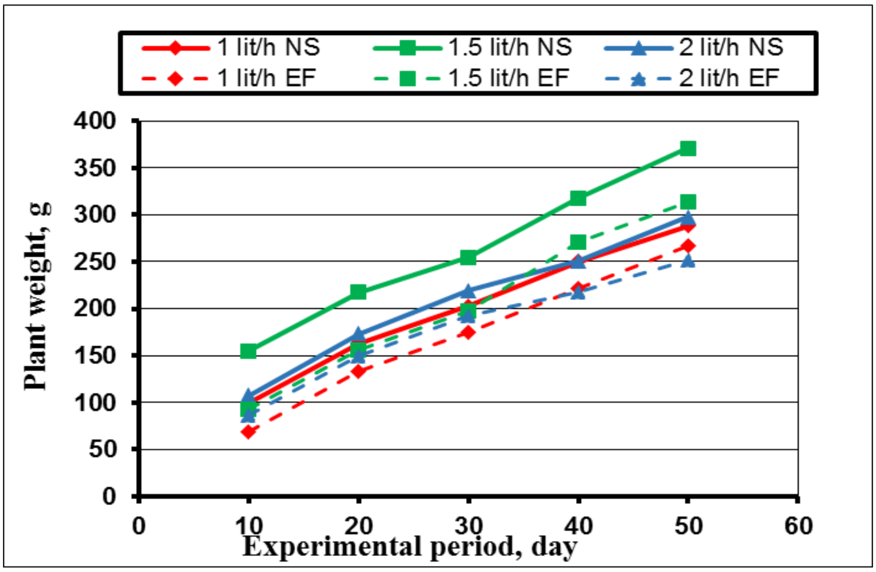

Fig. 9a: The whole plant weight of lettuce plants grown A shape system

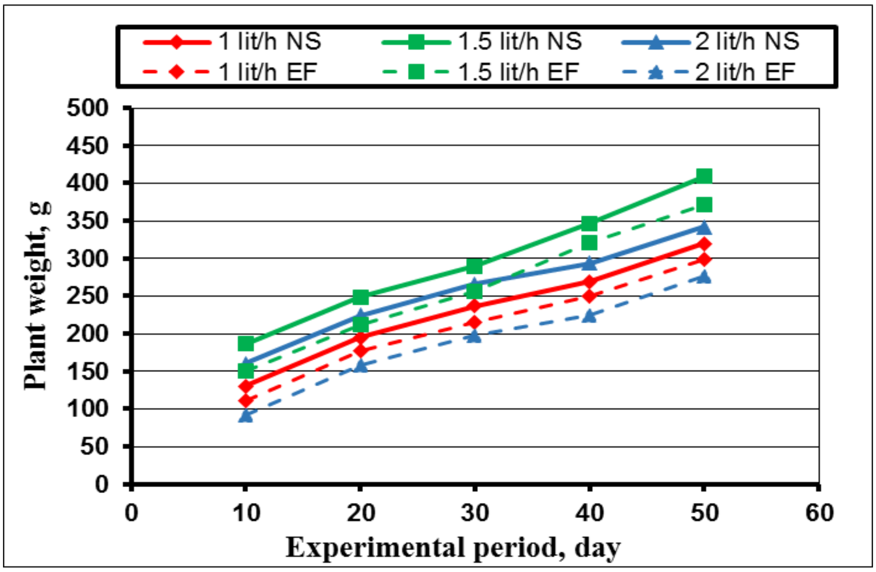

Fig. 9b: The whole plant weight of lettuce plants grown gutter system

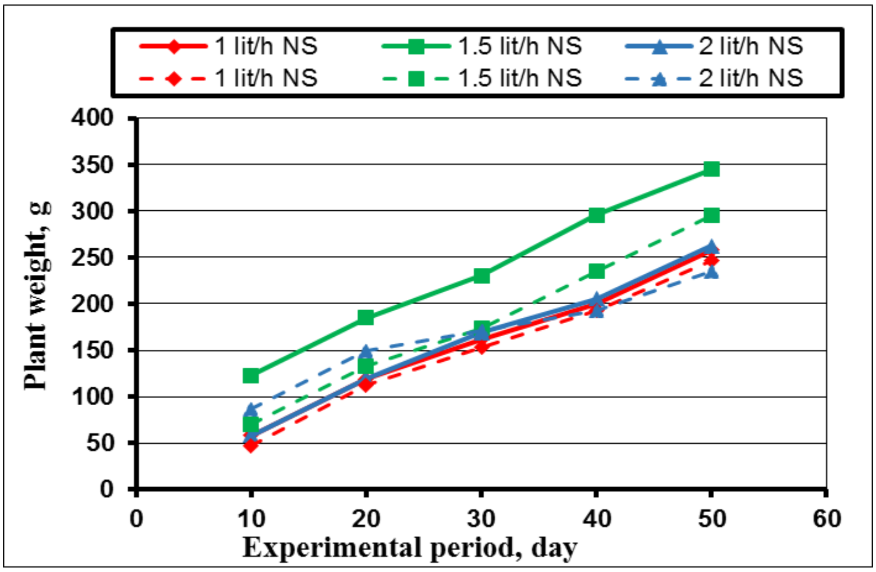

Fig. 9c: The whole plant weight of lettuce plants grown deep water system

Table 3: The constants a, b, c and coefficient of determination for whole lettuce plant weight

Hydroponic System	Nutrients Source	Constant			R^2
		A	B	c	
A Shape	NS	65.53	4.85	9.05	0.86
	EFF	31.68	4.81	6.75	0.92
Gutter	NS	77.74	4.76	27.05	0.86
	EFF	107.85	4.79	-20.37	0.83
Deep Water	NS	27.81	5.09	3.54	0.80
	EFF	3.44	4.59	16.80	0.92

NS: nutrient solution - EFF: effluent fish farm

3.3. Water use efficiency:

Fig. 10 shows water use efficiency of lettuce plants grown in different source of nutrients (stock nutrient solution and effluent fish farm), different hydroponic systems (A shape, Gutter and Deep water systems) and different flow rates (1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$) at the end of experimental period. The results indicate that the water use efficiency of lettuce plants values 29.96, 43.10 and 30.77 and 27.58, 34.32 and 26.45 kg m^{-3} for 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$, respectively, in nutrients solution and water discharged of the fish farm, respectively, for A shape hydroponic system. For gutter hydroponic system, the water use efficiency of lettuce plants values were 34.80, 46.11 and 37.11 and 32.67, 41.77 and 29.47 kg m^{-3} for 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$, respectively, in nutrients solution and water discharged of the fish farm, respectively. While, the water use efficiency of lettuce plants values were 27.52, 36.36 and 27.85 and 25.63, 31.31 and 25.84 kg m^{-3} for 1.0, 1.5 and 2.0 L h^{-1} $plant^{-1}$, respectively, in nutrients solution and water discharged of the fish farm, respectively, for deep water hydroponic system.

The highest value of the water use efficiency of lettuce plants (46.11 kg m^{-3}) was found with nutrient solution for gutter hydroponic system. However, the lowest value of the water use efficiency of lettuce plants (25.63 kg m^{-3}) was found with effluent fish farm for deep water hydroponic system.

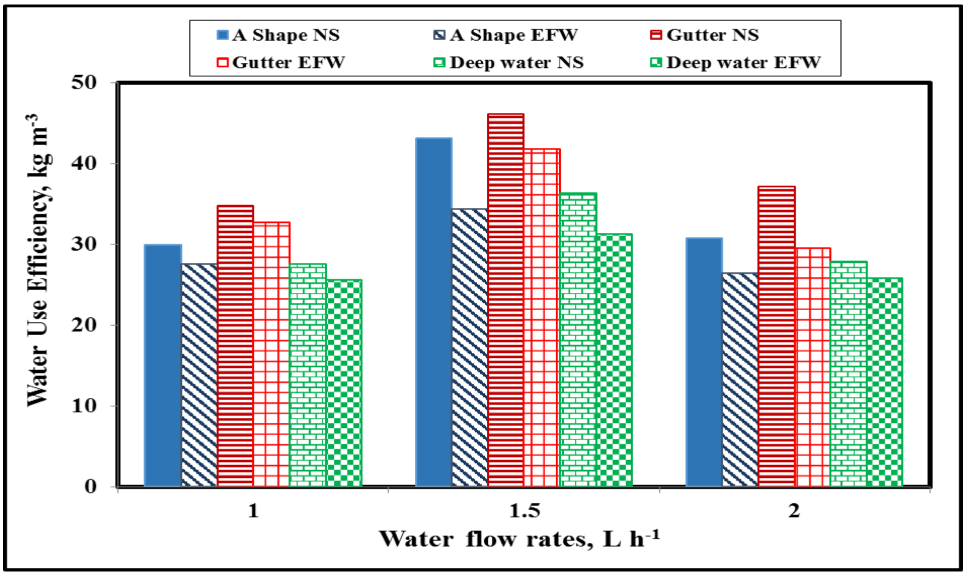

Fig. 10: water use efficiency of lettuce plants

4. CONCLUSION

The experiment was carried out to study the effect of flow rate (1.0, 1.5 and 2.0 L h^{-1}) and culture system (A shape, gutter and deep water) on nutrients consumption rate and lettuce productivity in hydroponic and aquaponic systems. The obtained results can be summarized as follows:

- The highest values of N, P, k, Ca and mg consumption rate were found with gutter hydroponic system and 1.5 L h^{-1} $plant^{-1}$ of flow rate for lettuce plants grown in nutrient solution. While, the lowest values of N, P, k, Ca and mg consumption rate were found with deep water hydroponic system and 2.0 L h^{-1} $plant^{-1}$ of flow rate for lettuce plants grown in water discharged of the fish farm.
- The highest value of the whole plant weight (408.69 g $plant^{-1}$) was found with nutrient solution for gutter hydroponic system. However, the lowest value whole plant weight (235.52 g $plant^{-1}$) was found with effluent fish farm for deep water hydroponic system.
- The highest value of the water use efficiency of lettuce plants (46.11 kg m^{-3}) was found with nutrient solution for gutter hydroponic system. However, the lowest value of the water use efficiency of lettuce plants (25.63 kg m^{-3}) was found with effluent fish farm for deep water hydroponic system.

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استهلاك المغذيات لنباتات الخس تحت نظم الزراعة المائية

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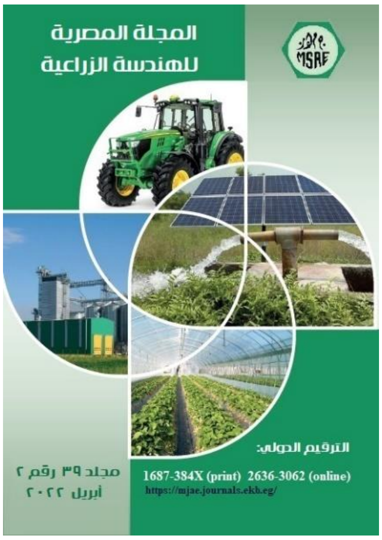

الكلمات المفتاحية:
الزراعة المائية؛ الأسماك؛ الخس؛ المغذيات؛ كفاءة استخدام المياه.

الملخص العربي

يهدف هذا البحث إلى دراسة تأثير معدل السريان ونظام الزراعة على معدل استهلاك المغذيات وانتاجية الخس في نظم الزراعة المائية . وتم إجراء هذه التجربة في وحدة المزرعة السمكية والبيوت المحمية – كلية الزراعة بمشتهر – جامعة بنها – محافظة القليوبية لدراسة تأثير مصدران للمحلول المغذى (المحلول المغذى المجهز صناعيا والمياه الخارجة من المزرعة السمكية) وثلاث نظم للزراعة وهي نظام زراعة على شكل حرف A ونظام الزراعة في المجاري (Gutter) ونظام الزراعة في العميق (Deep water)، وثلاثة تصرفات للمياه وهي ١,٠ و١,٥ و٢,٠ لتر لكل نبات في الساعة . وكانت أهم النتائج المتحصل عليها كما يلي: كان اعلى معدل استهلاك كلا من النيتروجين والفوسفور والبوتاسيوم والكالسيوم والماغنسيوم مع نظام الزراعة في المجرى (Gutter) ومعدل تصرف ١,٥ لتر لكل نبات في الساعة لنباتات الخس النامية في المحلول المغذى المجهز صناعيا. وكان الوزن الكلى لنبات الخس في نظام الزراعة في المجرى (Gutter) أفضل مقارنة بباقي المعاملات. وكانت أعلى قيمة لكفاءة استخدام المياه لنباتات الخس هي ٤٦,١١ كجم م$^{-3}$ لنظام الزراعة في المجرى (Gutter) لنباتات الخس النامية في المحلول المغذى المجهز صناعيا مقارنة بباقي المعاملات.