J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 13 (8): 253 - 263, 2022

Journal of Soil Sciences and Agricultural Engineering

Journal homepage & Available online at: www.jssae.journals.ekb.eg

Study the Effect of Some Engineering Factors on the Performance of an Integrated Aquaponic Unit

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ABSTRACT

Aquaponic system is one of the modern systems that have been used to make the most of the water, in addition to integrating the agriculture of plants and fish together in one production system. It is an innovative, sustainable technology and environmentally friendly. The main objectives of this study are to evaluate the growth performance of Nile tilapia under the aquaponic system for a period of 42 days and to examine the effect of system type (aquaponic and hydroponic systems) and water flow rate of (0.5, 1.5 and 2.5 L/min) on the growth performance of lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT). The obtained results for fish indicated that fish weight, fish length and feed conversion ratio (FCR) were increased during the experimental periods. The results obtained for lettuce plants indicated that root length of the lettuce gradually increased with increasing water flow rates and growth period. the root growth rate was higher in aquaponic system than in hydroponic system. The nutrients consumption rate, water use efficiency and lettuce yield were increased with an increase in the water flow rate from 0.5 to 1.5 L/min and a decrease in the water flow rate from 1.5 to 2.5 L/min. The former parameters were higher in the hydroponic system than in the aquaponic system except for the rate of sodium consumption. The hydraulic loading rate was increased with increasing the water flow rate while the nutrient uptake time decreased with increasing the water flow rate.

Keywords: Aquaponic system, Hydroponic system, Water flow rate, Deep water culture technique, Nutrient film technique.

INTRODUCTION

The problem of water scarcity is the most important and biggest challenges facing most countries, especially in Egypt. Therefore, looking for a means by which water can be exploited optimally is the main objective of this research, especially in the case of cultivating fish and agricultural crops, each of which consumes large quantities of water using the application of the aquaponic system and the recirculating of fish farms water, which is one of the systems that enhances the concept of sustainability by adopting breeding the Nile tilapia fish in combination with the cultivation of lettuce plants, as these plants benefit from the dissolved waste in the aquaculture as an organic fertilizer without adding any additional chemical nutrients.

Aquaponic system is an integration of recirculating aquaculture systems (RAS) and hydroponic in one production system. RAS are designed so that large quantities of fish are raised in relatively small amounts of water and then the wastewater is reused after it has been treated to remove the resulting toxic waste. The main goal of the aquaponic is to reuse the nutrient released by the fish to grow plants. Plants grow using nutrients dissolved in wastewater. It is integrate the benefits from recirculating aquaculture systems (RAS) and hydroponic system. Aquaponic system allows for intensive and high quality production of vegetables without any impact on the environment whether pollution from chemical fertilizers and animal waste (Rakocy *et al*., 2006 and Pantanella, 2018).

Hydroponic is a method of growing plants without soil, using only water and chemical nutrients. Hydroponic plants are widely used in wastewater treatment systems because they effectively absorb compounds dissolved in wastewater as nutrients for plant growth. Plants grow by means of a nutrient solution in which sufficient amounts of micro and macro nutrients are dissolved to support their growth. Hydroponics is more efficient in terms of water and nutrient use than soil based farming (Maucieri *et al*., 2019).

Vegetables are perfect candidates for use in recycling hydroponic systems because they grow rapidly in response to high levels of nutrient in aquaculture water. Various types of vegetables such as: tomato, basil and lettuce have been successfully grown in aquaculture recirculating water (Rakocy *et al*., 2006).

Tilapia is one of the most popular freshwater and warm water fish that grows in aquaculture systems all over the world. Resistant to much diseases and copes well with stress, it performs best in warm temperatures and is able to withstand a wide range of water quality conditions such as: dissolved oxygen, water temperature, water pH and total dissolved solids (Diver and Rinehart, 2010).

The main objectives of this study are to:

1- Examine the effect of system type and water flow rate on the growth performance of lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT).
2- Determine the hydraulic loading rate and nutrient uptake time optimal for lettuce plants grown in deep water

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DOI: 10.21608/jssae.2022.151619.1093

culture technique (DWC) and nutrient film technique (NFT) for maximum crop yield.

3- Drive the benefits of using the smart control of the aquaponic and hydroponic system.
4- Evaluate the growth performance of Nile tilapia under the aquaponic system.
5- Utilizing the new technologies of aquaculture and renewable energy for water and energy saving.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at Agricultural Engineering and BioSystems Department, Faculty of Agriculture, Shebin El-kom, Menoufia University, Egypt during of the year 2020 from 21st October to 2nd December.

Experimental Setup and operation

Fig. 1. illustrates the design of the aquaponic system experiment which consists of fish tank, mechanical filter, biofilter, hydroponic subsystems, sump tank, submersible water pump, air pump, pipelines and ball valves.

Aquaponic system is equipped with a circular fiberglass fish tank. It was used for fish culture with dimensions of (120 cm diameter and 70 cm height). Fish tank with a particle trap in the middle for draining solids waste water with 3. 81 cm, in diameter. Mechanical filter is used to remove settleable solids and suspended solids from fish tank. It made from polyethylene (PE) with dimensions of (58 cm diameter and 95cm height). Biofilter is a place containing the media on which nitrifying bacteria grow that convert ammonia into nitrate. It consists of two circular polyethylene tanks, one containing gravel and the other containing on pieces of drip irrigation hoses with dimensions of (60 cm diameter and 90 cm height) for each tank. The height of the media in each tank was 60 cm.

Hydroponics subsystems are the part of the system where plants were grown by up taking overflow nutrients from wastewater. The plants are grown in two hydroponic systems deep water culture technique and nutrient film technique.

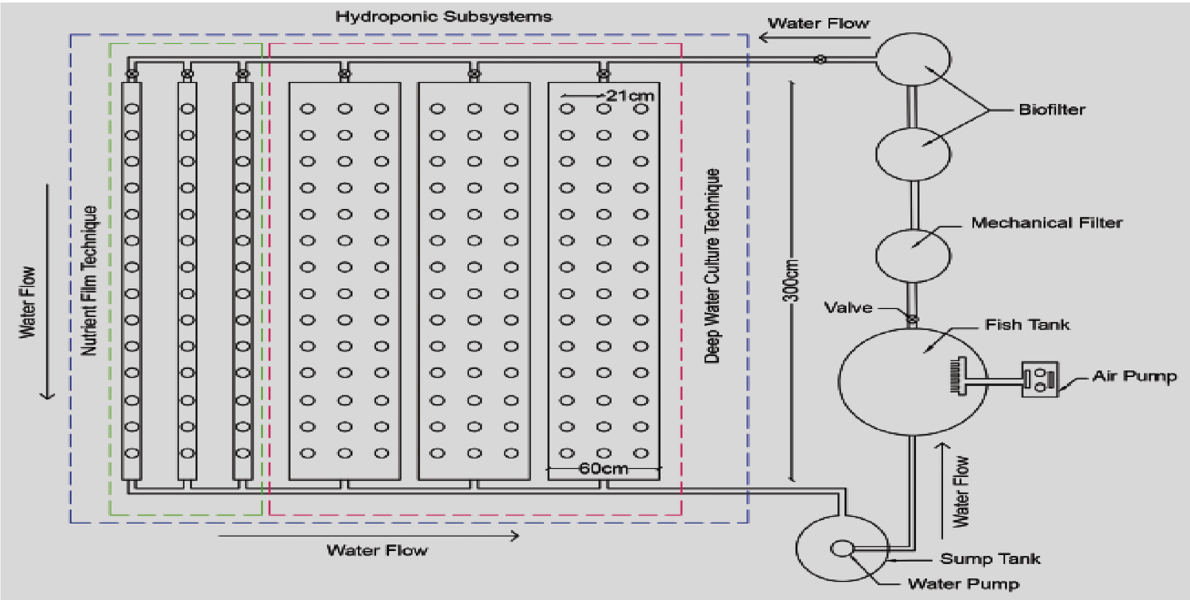

Fig. 1. Design of the experimental aquaponic system.

Deep water culture technique (DWC) consists of three rectangular fiberglass troughs which were used for lettuce plants culture. The troughs are covered with foam boards to assist the plants with dimensions of each foam board were 120 cm length, 60 cm width and 5 cm thickness. The foam boards were drilled with 5 cm diameter holes with spacing 21 cm between each hole in which plants are positioned. The plant spacing was 21 cm, and the depth of water used in each trough was 20 cm. Each trough provided with three air stones to maintain the concentrations of dissolved oxygen with dimensions of (300 cm length, 60 cm width and 30 cm depth).

Nutrient film technique (NFT) consists of three white polyvinyl chloride (PVC) pipes dimensions of (10.16 cm diameter and 300 cm length) for each pipe, with holes in the top of which plants are placed. The plants' roots develop inside the pipes. The pipes were drilled with 5cm diameter holes spacing at 21 cm between each hole, so that each line contains fourteen holes for the plants. The recommended slope was at a rate of 1% of pipe length.

The sump tank is the lowest point in the system and is a collection tank through which water is pumped into the fish tank, and the water is drained from the bottom of the plant. It's a circular polyethylene tank with a capacity of 500 litres. A submersible water pump is used to raise water from the sump tank to the fish tank. An air compressor (air pump) is used to inject air into water through air ducts and air stones located inside water tanks, thus increasing the dissolved oxygen levels in the water. Pipelines made of polyvinyl chloride 2.5 cm in diameter were installed to recirculate water between the fish tank and the aquaculture subsystems. And also, the water flow rate to regulate using ball valves with 2.54 cm in diameter.

Fig. 2. illustrates the design of the hydroponic experiment. The hydroponic system consists of the same components as the aquaponic system except for the fish tank, the mechanical filter and biofilter. The Fig. 2. shows that the system consists of solution tank, hydroponic subsystems, sump tank, water pump and air pump.

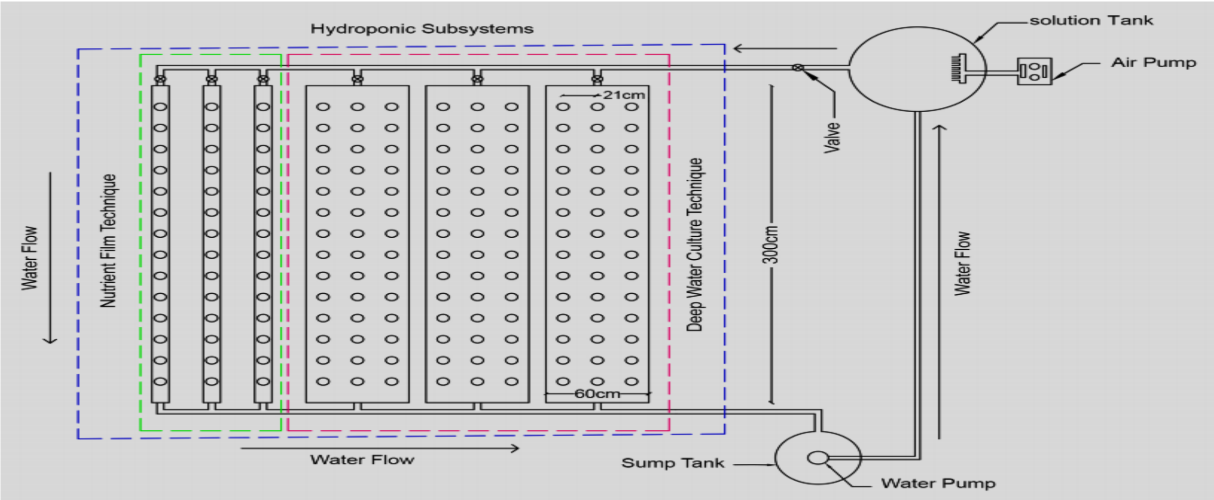

Fig. 2. Design of the experimental hydroponic system.

Fish and plant

Nile tilapias (Oreochromis niloticus) were obtained from the fish laboratory, Department of Poultry and Fish Production, Faculty of Agriculture, Menoufia University, Egypt. Number of 168 fish with average weight of 20.10 g and average total length of 10.50 cm were chosen to grow in the aquaponic system. Fish were fed four times daily at 9:00 am, 11:00 am, 13:00 pm and 15:00 pm, for six days a week with artificial diet contained 30% crude protein and 6.1% crude lipids provided by Screntj Egypt Company. The feed pellet diameter was 2 mm. The fish were feed rating at 4-6 % of body weight per day. Feeding was stopped during weighing process.

Three weeks old lettuce (Lactuca sativa) seedlings were transplanted in the experimental system from the trays to hydroponics troughs and pipes at planting density 25 plants in square meters. Lettuce seedlings were planted in plastic cups (5 cm, in diameter and 9 cm, in height) filled with a mixture of peatmoss and perlite in a ratio of 1:1.

Plants are fed in the case of the hydroponic system using the nutrient solution manufactured by Yara Company. The chemical composition of the solution as presented in table (1). A litre of solution (A) and a litre of solution (B) of the fed solution are placed for every 100 litres of pure water in the irrigation tank and the quantity may increase or decrease according to the plant's need of salts.

Table 1. Chemical composition of yara solution.

Solution	Fertilizer	Chemical Formula	Quantity
A	Nitrogen, Phosphorus, potassium with trace elements	N:P:K (12:12:36+TE)	850 G
	Potassium nitrate	KNO_3	350 G
	Magnesium sulphate	$MgSO_4.7H_2O$	400 G
	Water	H_2O	10 L
B	Calcium nitrate	$Ca(NO_3)_2.4H_2O$	1000 G
	Iron chelates	Fe-EDDHA 6%	35 G
	Water	H_2O	10 L

Smart aquaponic and hydroponic system

The smart system was used to continuously collect data from various sensors and monitor sensor information and control the system. In addition, the system can notify the user in the event of any malfunctions in the system and can automatically correct the problems. Generally, the smart automatic control system consists of a set of sensors to measure the process variables, actuating devices and controller, interface modules, communication system and power sources. The smart system developed in this work by integrating five modules such as: measurements sensor, mobile application, system rectification unit, central processing unit and cloud server.

The mobile application is built on the Android platform. Displays live sensor values and enables the user to remotely control the actuators using services from the cloud server. Furthermore, it allows the user to adjust the threshold values for each sensor with real time latency as shown in fig.3.

Fig. 3. Mobile application.

Treatments

An experiment was condacted to examine the effect of system type (aquaponic and hydroponic systems) and water flow rate (0.5, 1.5 and 2.5 L/min) on the growth performance of lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT). Three water flow rates 0.5, 1.5 and 2.5 L/min (Intermittent flow 4 minute 'on' and 8 minute 'off') were used in each culture type. The water flow rate was controlled by a ball valve and water flow rate sensor.

Aquaponic system

In this system the plants were fed using the aquaculture wastewater. The water flows by gravity from the aquarium into a mechanical filter that removes the solid waste, then passes through a biofilter that oxidizes ammonia to nitrate by nitrifying bacteria. The water then moves over the plant's growth beds as the plants absorb nutrients from it and eventually the water returns to the fish tank by the water pump as shown in fig. 4.

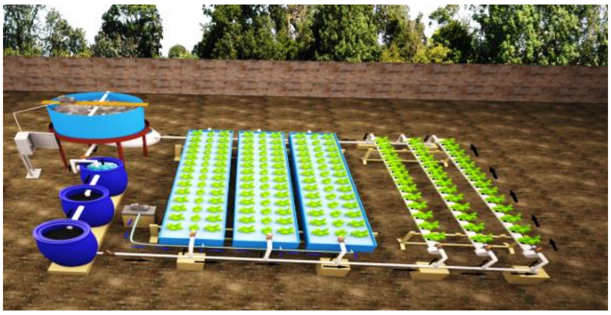

Fig. 4. Aquaponic system.

Hydroponic system

In this system, plants were fed with nutrient solution. The solution was pumping by the pump from the solution tank to the upper ends of the hydroponic, through pipes and then passes through plant growth troughs, where plants absorb nutrients from it, and finally the water returns to the solution tank as shown in fig. 5.

Fig. 5. Hydroponic system.

Sampling, measurements and instrumentation

Water samples were taken, from the fish tank at 9.30 am, once a week for measuring water temperature (T_W), nitrogen (N), dissolved oxygen (DO), ammonium (NH_4), water pH, ammonia (NH_3), and total dissolved solids (TDS). Water samples were also taken at inlet and outlet of the troughs and pipes at 9.30 am, once a week for measuring sodium (Na), nitrogen (N), water pH , Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), electrical conductivity (EC), DO and T_W.

N was measured by Automatic Kjeldahl Nitrogen Analyzer. NH_3 was measured by a HI700 Ammonia Low Range apparatus. $NH_4$was measured by photometer apparatus MD100. The water pH, DO, T_W, EC and TDS were measured by a Consort meter C933. P was measured by a spectrophotometer. K and Na were measured by a flame photometer. According to Burt and Soil Survey Staff (2014), Soluble Calcium (Ca) and Magnesium (Mg) were determined using the Versenate method and ammonium purpurate as an indicator for calcium and Eriochrome black T for calcium and magnesium.

Root length was measured by using ruler to study the behavior of root growth, their mass and length were measured. Fish were counted and weighed every two weeks to evaluate the growth and readjust the feed amount. Total length of the fish was also measured by ruler.

Calculations of the system

Consumption rate of nutrients

The consumption rates of nutrients were determined as the variances between the nutrients concentration at inlet and outlet of hydroponic subsystems by the following equation according to Khater (2006):

$$NC = \frac{(NC_{in} - NC_{out})}{\text{Number of plants}} \times Q \times 60$$

Where:

NC= the nutrients consumption rate, mg/plant .hr
NC_{in}= the nutrients concentration at inlet of the troughs and pipes, mg/L
NC_{out}= the nutrients concentration at outlet of the troughs and pipes, mg/L
Q= the water flow rate, L/min

Hydraulic loading rate

Hydraulic loading rate (HLR) was calculated according to Endut *et al*. (2010); Yang and Kim (2020) as follows:

$$HLR = \frac{Q}{A}$$

Where:

HLR= the hydraulic loading rate, m/day
Q= the water flow rate, m^3/day
A= the surface area of the troughs and pipes, m^2

Water use efficiency

The water use efficiency (WUE) is calculated by the following equation according to Djidonou *et al*. (2013):

$$\text{Water use efficiency } (Kg/m^3) = \frac{\text{Crop yield } (Kg/plant)}{\text{Crop water uptake } (m^3/plant)}$$

Fish growth performance parameters

The biological parameters such as: feed conversion ratio, daily weight gain, survival rate, specific growth rate and condition factor are used to evaluate tilapia growth performance according to Shoko *et al*. (2016) using the following equations:

a.Daily weight gain (DWG, g/day)

$$DWG = \frac{W_F - W_i}{t}$$

Where:

W_F = Average final weight of fish, g
W_i = average initial weight of fish, g
t = growth period, day

b. Specific growth rate (SGR, %/day)

$$SGR = \frac{[\ln(W_F) - \ln(W_i)]}{t} \times 100$$

Where:

W_F = Average final weight of fish, g
W_i = average initial weight of fish, g
t = growth period, day

c.Condition factor (K, %)

$$K = \frac{W}{L^3} \times 100$$

Where:

W = Average weight of fish, g
L = average length of fish, cm

d. Feed conversion ratio (FCR)

$$FCR = \frac{\text{Total feed consumed(g) or Feed intake (g)}}{\text{Tatal fish weight gain(g)}}$$

Statistical analysis

The obtained data were analyzed using the Statistical Package for Social Sciences (SPSS) software. Version 26 in which two and three way ANOVA are used.

RESULTS AND DISCUSSION

Water quality parameters in the fish tank

The parameters of water quality directly affect the health and well-being of fish in the aquaculture system.

There are basic considerations to improve aquaponic production. The water in the fish tank was analyzed to measure the parameters of water quality such as: pH, T_W, DO, TDS, TAN and N.

The results indicate that the average water pH, TW, DO, TDS, TAN and N in the fish tank were 7.55, 23.37 ℃,7.24 mg/L, 294.80 mg/L, 0.84 mg/L and 76.49 mg/L, respectively through the experimental period. The parameters of water quality in the fish tank which presented were remained within the suitable range for the Nile tilapia (Oreochromis niloticus) growth.

Nile tilapia growth

Fish weights and lengths were determined through the experimental periods. Furthermore, feed intake (FI), daily weight gain (DWG), feed conversion ratio (FCR), specific growth rate (SGR) and condition factor (K) were calculated as indicators of fish performance.

Fish weights and lengths

Fig. 6. represents the average individual fish weights and average total lengths through the experiment period. The average individual initial weight of the fish was 20.10 g, at the beginning of the experiment, while the average individual final weight was 52.23 g, at the end of the experiment. On the other hand the average individual initial total length of the fish was 10.50 cm, at the beginning of the experiment, while the average individual final total length was 13.88 cm, at the end of the experiment. Fish weight and length increased through the experimental periods. The Fish weight increased by almost 32.13 g and fish length increased its total length by 3.38 cm. It is concluded that there is a direct relation between fish weight and length through the experimental periods. These results were similar to the results found by Awad (2017).

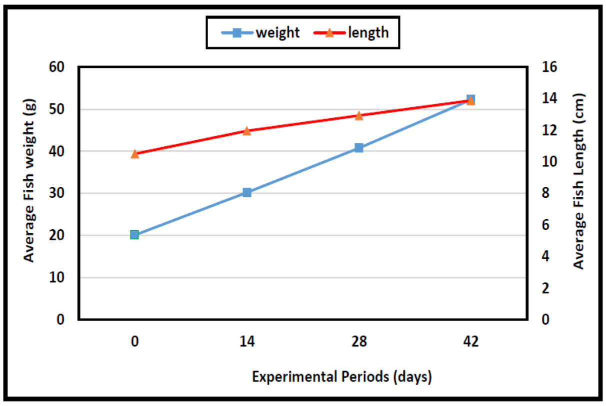

Fig. 6. The relation between average final weight and length through the experiment periods.

Factors affect in the growth of Nile tilapia

The K, SGR and DWG are most important factors indicating the efficacy of feed arrangement in the system. The survival rate was 100 % through the experiment periods. The condition factor (*K*) was increased from 1.74 to 1.95% during the experimental periods. While the *SGR* was decreased from 2.90 to 1.77 % /day as shown in Fig. 3.2. The measurements of *K* and *DWG* showed good environment for fish growth which reflected on the fish survival where no dead fish was found during the experimental periods. As shown in Fig. 7. decreasing SGR by the end of the experiment related to the increase in fish size which that leads to growth and feed efficiency decreasing that is also according the results of Jianga *et al.* (2015) and Liu *et al.* (2016).

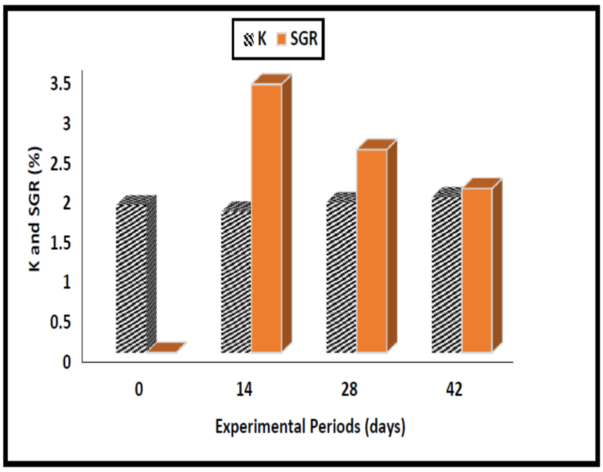

Fig. 7. Condition factor (*K*) and specific growth rate (*SGR*) of Nile tilapia reared in the aquaponic system for 42 day.

Factors affect the feed utilization of Nile tilapia

The feeding rate (FR) and feed conversion ratio (FCR) are also the efficacy of feed arrangement in the system. Feed conversion ratio and feeding rate indicated the response of fish to diet reflecting the fish growth during the experimental periods as shown in Fig.8.

Lower FCR clarifies that fish consumed the feed better. FCR became better at the beginning of the experiment (0-14 days) at the feeding rate of 6% of fish weight, which was (1.31). During the period of (14-28 days) by decreasing the feeding rate to 5% of the fish weight, the FCR was increased to (1.57) than the first two weeks (1.31). Furthermore, by the end of the experimental period (28-42 days), the FCR was (1.56).

Fig. 7. shows the adverse relationship between feeding rate and feed conversion ratio. The rate at which tilapia can grow is determined by a variety of factors, including genetics, ambient circumstances, health, food quantity and quality, and life stage. According to Somervilla *et al.* (2014), the water quality and feed affected FCR values, moreover, Tilapia FCR will be 1.4 - 1.8, if there are better conditions for fish.

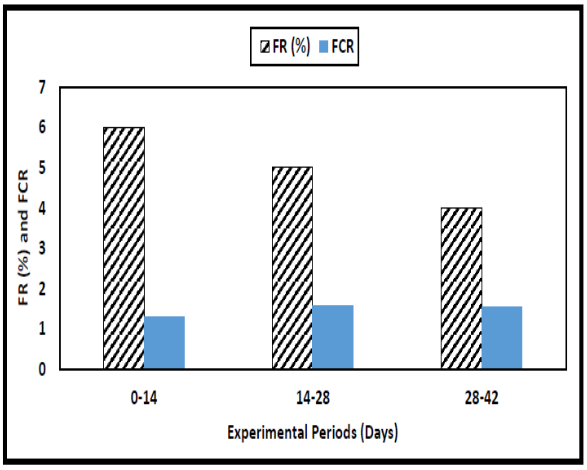

Fig. 8. Feed utilization for Nile tilapia (Oreochromis niloticus) reared in the aquaponic system for 42day.

Water quality parameters in the plant troughs

The water in the plant troughs were analyzed to determine the parameters of water quality such as: T_W, pH, EC and DO which affect plant growth in aquaponic and hydroponic system. Table (2 and 3) represents the average parameters of water quality at different sampling places (inlet and outlet) during the experiment period for all treatments. The average water temperature and water pH were significantly higher in the aquaponic system than in the hydroponic system. While, the average electrical conductivity and dissolved oxygen were higher in hydroponic system than aquaponic system for each culture type. These results agree with Yang and Kim (2020).

The T_W, pH and EC were significantly affected by system (S) but not affected by water flow rate (F), sampling places (Sp) and interactions between treatments. While, the DO was significantly affected by system, water flow rate, sampling places and interactions between (F×Sp) but not significant affected by interactions between (S×F), (S×Sp) and (S×F×Sp) are presented in table (2and 3). These results agree with the results of Hussain *et al.* (2014).He found that the T_w, pH and EC were not significant affected by water flow rate but not in DO.

Table 2. Summarizes the average parameters of water quality at different sampling places (inlet and outlet) of the deep water culture technique during the experiment period.

Deep water culture technique (DWC)								
	Aquaponic system				Hydroponic system			
Water quality parameters	Inlet	Outlet – Water Flow rate (L/min)			Inlet	Outlet – Water Flow rate (L/min)		
		0.5	1.5	2.5		0.5	1.5	2.5
Tw (ºC)	23.01	22.58	22.71	22.69	18.38	17.46	17.64	17.97
pH	7.50	7.42	7.46	7.44	6.69	6.64	6.64	6.66
EC (ds/m)	0.58	0.57	0.57	0.57	2.45	2.42	2.43	2.44
DO (mg/L)	6.82	5.66	5.82	5.98	7.04	5.40	6.17	6.30

ANOVA				
Treatments	Tw (ºC)	pH	EC (ds/m)	DO (mg/L)
System (S)	257.68**	222.74**	9114.09**	3.63*
Water Flow rate (F)	0.09^{ns}	0.02^{ns}	0.02^{ns}	3.99*
Sampling places (Sp)	3.00^{ns}	0.86^{ns}	0.36^{ns}	126.49**
S×F	0.04^{ns}	0.02^{ns}	0.01^{ns}	1.11^{ns}
S×Sp	0.34^{ns}	0.02^{ns}	0.09^{ns}	0.20^{ns}
F×Sp	0.09^{ns}	0.02^{ns}	0.02^{ns}	3.99*
S×F×Sp	0.04^{ns}	0.02^{ns}	0.01^{ns}	1.11^{ns}

Note: ns, ** mean no significant and significant at P ≤ 0.01 respectively.

Table 3. Summarizes the average parameters of water quality at different sampling places (inlet and outlet) of the nutrient film technique during the experiment period.

Nutrient film technique (NFT)								
	Aquaponic system				Hydroponic system			
Water quality parameters	Inlet	Outlet – Water Flow rate (L/min)			Inlet	Outlet – Water Flow rate (L/min)		
		0.5	1.5	2.5		0.5	1.5	2.5
Tw (ºC)	23.01	22.62	22.82	22.77	18.38	18.01	17.64	17.39
pH	7.50	7.36	7.43	7.39	6.69	6.60	6.66	6.67
EC (ds/m)	0.58	0.57	0.57	0.57	2.45	2.41	2.43	2.44
DO (mg/L)	6.82	5.20	5.38	5.55	7.04	5.04	5.98	6.47

ANOVA				
Treatments	Tw (ºC)	pH	EC (ds/m)	DO (mg/L)
System (S)	230.20**	211.22**	8992.35**	13.11**
Water Flow rate (F)	0.05^{ns}	0.12^{ns}	0.04^{ns}	7.86**
Sampling places (Sp)	2.33^{ns}	2.03^{ns}	0.36^{ns}	205.25**
S×F	0.13^{ns}	0.03^{ns}	0.03^{ns}	2.99^{ns}
S×Sp	0.46^{ns}	0.26^{ns}	0.12^{ns}	1.61^{ns}
F×Sp	0.05^{ns}	0.12^{ns}	0.04^{ns}	7.86**
S×F×Sp	0.13^{ns}	0.03^{ns}	0.03^{ns}	2.99^{ns}

Note: ns, ** mean no significant and significant at P ≤ 0.01 respectively.

Nutrients consumption rate in recirculating water system

Nutrients consumption rates such as: nitrogen, phosphorus, potassium, calcium, magnesium and sodium were determined through the growth period of lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT) for all treatments. The removal of nutrients from the water can be equated with uptake by plants. To reach this point the system should not leakage and free from algae. The results indicate that the nutrients consumption rates gradually increased with increasing growth period from 7 to 42 days after transplanting.

The results indicate that nitrogen consumption rate (N.C.R) ranged from 7.00 to 25.20, 8.40 to 42.00 and 7.00 to 21.00 mg/plant.hr in DWC and ranged from 16.80 to 50.40, 25.20 to 88.20 and 12.60 to 63.00 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. While in the case of hydroponic system the nitrogen consumption rate (N.C.R) ranged from 8.40 to 21.00, 12.60 to 50.40 and 7.00 to 28.00 mg/plant.hr in DWC and ranged from 21.00 to 67.20, 25.20 to 126.00 and 21.00 to 63.00 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively as shown in Fig. 9.

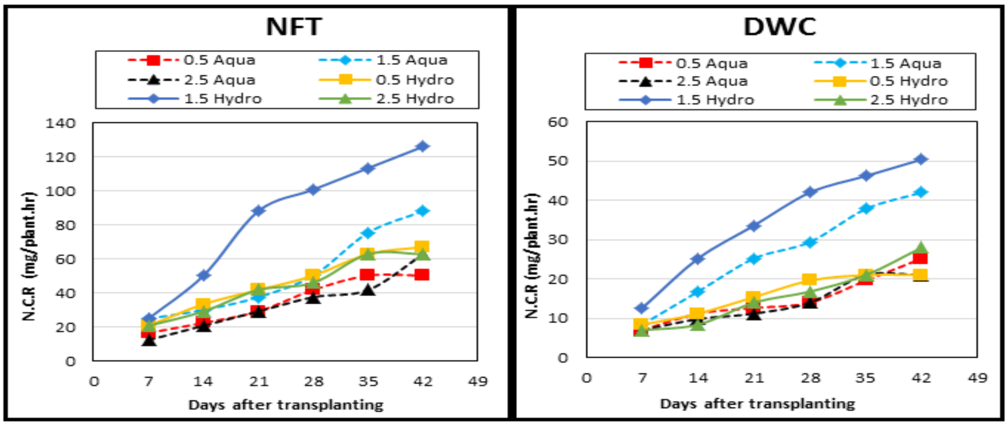

Fig. 9. Variation in nitrogen consumption rate (N.C.R) by lettuce plants throughout the experimental periods for all treatments.

Phosphorus consumption rate (P.C.R) ranged from 0.11 to 0.74, 0.11 to 0.86 and 0.10 to 0.57 mg/plant.hr in DWC and ranged from 0.51 to 1.03, 0.51 to 2.06 and 0.29 to 1.43 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. While in the case of hydroponic system it ranged from 0.23 to 0.90, 0.29 to 1.31 and 0.19 to 0.86 mg/plant.hr in DWC and ranged from 0.63 to 2.57, 0.69 to 3.43 and 0.57 to 2.00 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively as shown in Fig. 10.

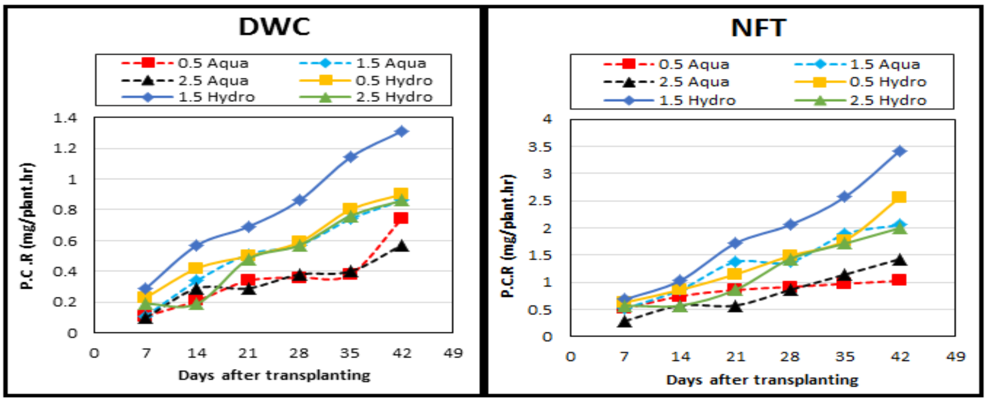

Fig. 10. Variation in phosphorus consumption rate (P.C.R) by lettuce plants throughout the experimental periods for all treatments.

Potassium consumption rate (K.C.R) ranged from 3.52 to 7.50, 5.35 to 15.39 and 3.00 to 7.97 mg/plant.hr in DWC and ranged from 8.85 to 17.85, 10.76 to 41.77 and 4.51 to 17.61 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. Whereas in the case of hydroponic system it ranged from 11.21 to 26.84, 16.94 to 67.45 and 10.64 to 30.56 mg/plant.hr in DWC and ranged from 25.31 to 73.99, 25.50 to 88.99 and 21.29 to 68.87 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively as shown in Fig. 11.

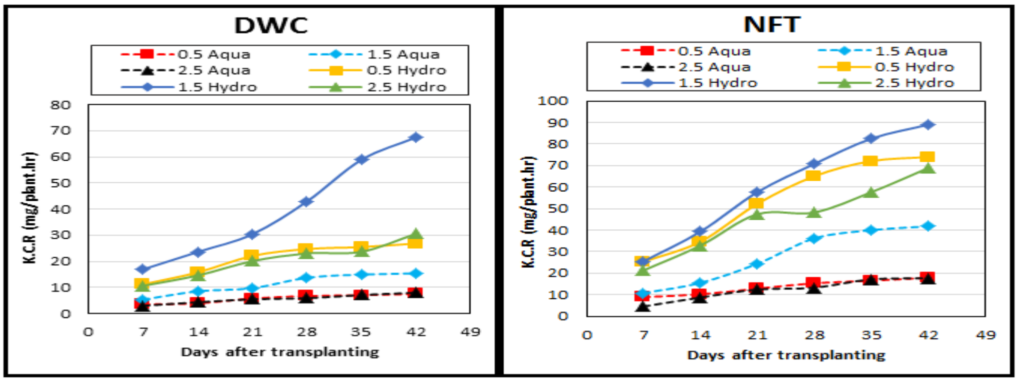

Fig. 11. Variation in potassium consumption rate (K.C.R) by lettuce plants throughout the experimental periods for all treatments.

Calcium consumption rate (Ca.C.R) ranged from 0.86 to 2.50, 1.07 to 3.32 and 0.71 to 2.32 mg/plant.hr in DWC and ranged from 2.14 to 6.00, 2.57 to 9.00 and 1.07 to 6.43 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. While in the case of hydroponic system it ranged from 1.14 to 2.86, 1.71 to 4.29 and 0.89 to 2.86 mg/plant.hr in DWC and ranged from 3.00 to 7.50, 3.86 to 10.93 and 2.14 to 6.96 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively as shown in Fig. 12.

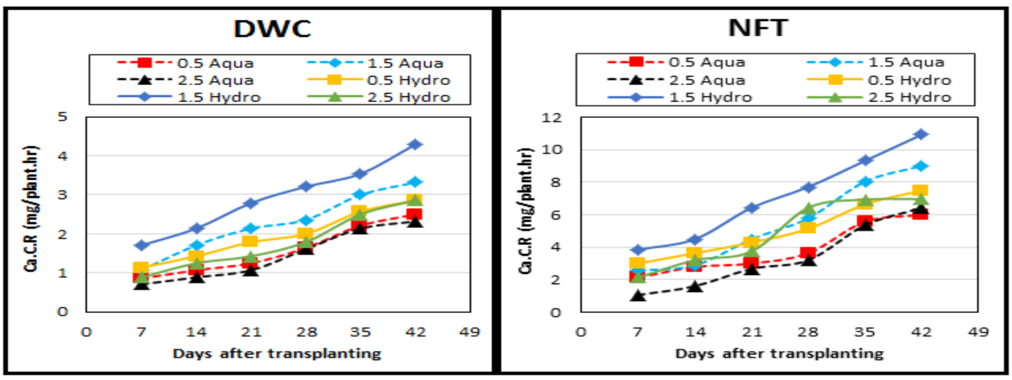

Fig. 12. Variation in calcium consumption rate (Ca.C.R) by lettuce plants throughout the experimental periods for all treatments.

Magnesium consumption rate (Mg.C.R) ranged from 0.36 to 1.79, 0.43 to 3.64 and 0.36 to 1.43 mg/plant.hr in DWC and ranged from 0.86 to 4.50, 0.96 to 7.39 and 0.54 to 4.29 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. While in the case of hydroponic system it ranged from 0.57 to 2.21, 0.75 to 4.29 and 0.54 to 1.96 mg/plant.hr in DWC and ranged from 1.29 to 5.14, 1.93 to 9.64 and 1.07 to 4.82 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively as shown in Fig. 13.

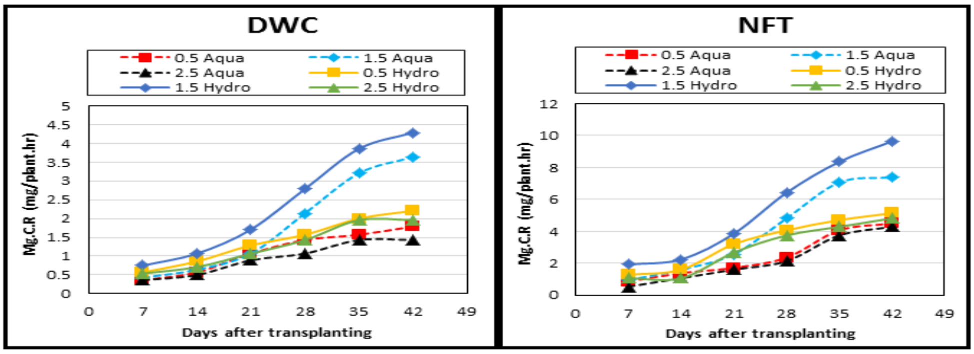

Fig. 13. Variation in magnesium consumption rate (Mg.C.R) by lettuce plants throughout the experimental periods for all treatments.

Sodium consumption rate (Na.C.R) ranged from 4.19 to 12.70, 5.25 to 26.79 and 2.88 to 11.41 mg/plant.hr in DWC and ranged from 10.70 to 38.10, 10.43 to 87.03 and 8.63 to 34.22 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. While in the case of hydroponic system it ranged from 2.38 to 11.05, 3.52 to 24.33 and 2.92 to 9.64 mg/plant.hr in DWC and ranged from 8.97 to 30.92, 15.94 to 66.54 and 8.75 to 28.91 mg/plant.hr in NFT at 0.5, 1.5 and 2.5 L/min water flow rate, respectively as shown in Fig. 14.

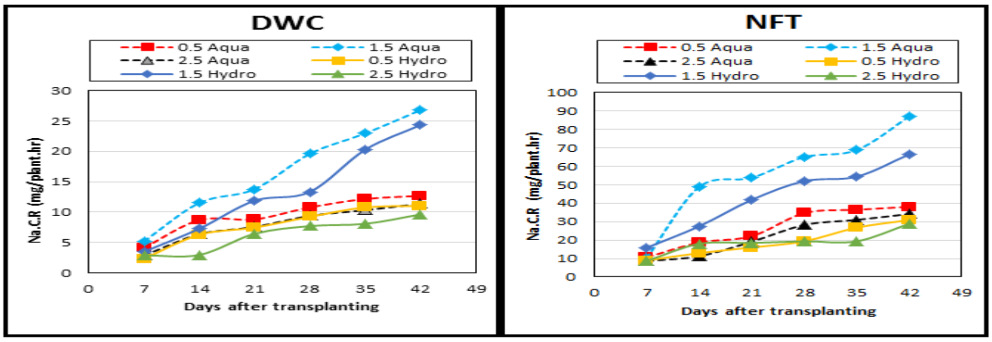

Fig. 14. Variation in sodium consumption rate (Na.C.R) by lettuce plants throughout the experimental periods for all treatments.

The nutrients consumption rates were significantly affected by system (S), water flow rate (F) and growth period (P). The results indicate that the nutrients consumption rates were increased with increasing the water flow rate from 0.5 to 1.5 L/min and decreased with increasing the water flow rate from 1.5 to 2.5 L/min. This is because the high flow rate may be reduce the contact time of plant roots with beneficial nutrients. So that increasing the velocity of water in troughs and pipes with increasing the water flow rate was decreased the rate of nutrients consumption. The best treatment was found at the highest value of nutrients consumption rate with the water flow rate 1.5 L/min. These results agree with the results of Khater (2016). He found that the nutrients consumption rates increased with increasing the water flow rate at 1.0 to 1.5 L/hr and decreased with increasing the water flow rate from 1.5 to 2 L/hr.

The results also indicate that the N.C.R, P.C.R, K.C.R, Ca.C.R and Mg.C.R were higher in aquaponic system compared to hydroponic system except for Na.C.R. These results agree with the results of Yang and Kim (2020).

Root length of the lettuce

The effect of system type and flow rate on the root length of the lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT) are presented in Fig15.

The root length of lettuce was not significantly affected by system. The results showed that the root length in aquaponic system was higher than of those in hydroponic system. In DWC, the root length was increased from18.82 to 19.76 cm and 18.54 to 19.52 cm in aquaponic and hydroponic system, respectively with increased from 0.5 to 2.5 L/min water flow rate after 42 days from transplanting. While in the case of NFT, the root length was increased from 16.70 to 17.88 cm and 16.30 to 17.58 cm in aquaponic and hydroponic system, respectively with increased from 0.5 to 2.5 L/min water flow rate after 42 days from transplanting.

The root length was significantly affected by water flow rate and growth period but not significantly affected by interactions between treatments. It was observed that when the water flow rate increased from 0.5 to 2.5 L/min in DWC, the length of root increased from 4.08 to 5.14 cm and 18.82 to 19.76 cm after 10 and 42 days, respectively from transplanting in aquaponic system. It is increased from 3.96 to 4.96 cm and 18.54 to 19.52 cm after 10 and 42 days, respectively from transplanting in hydroponic system. While in the case of NFT when the water flow rate increased from 0.5 to 2.5 L/min, the length of root increased from 3.98 to 5.06 cm and 16.70 to 17.88 cm after 10 and 42 days, respectively from transplanting in aquaponic system. It is increased from 3.88 to 4.58 cm and 16.30 to 17.58 cm after 10 and 42 days, respectively from transplanting in hydroponic system. These results agreed with those obtained results by Khater *et al*. (2015) and Ali (2016) whose found that the length of root was increased with increasing the water flow rate.

The results also indicate that the root length gradually increased with increasing water flow rate and growth period because the high water flow rate increases the solubility of dissolved oxygen inside the water, and thus the root obtains sufficient oxygen for respiration and growth. These results agree with the results of Baiyin *et al*. (2021).

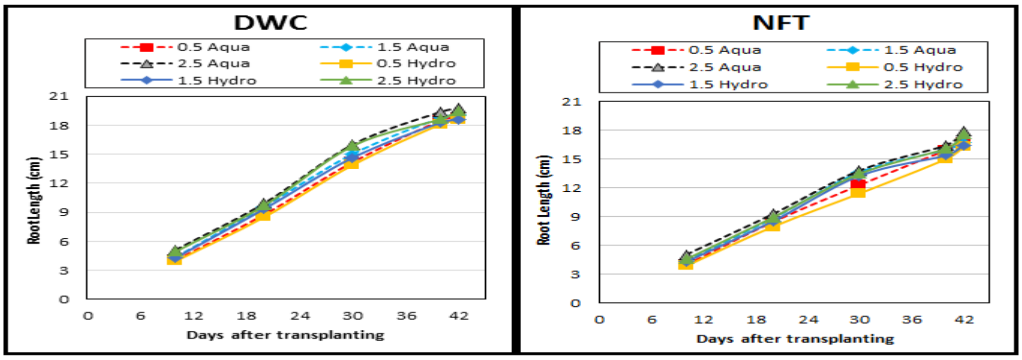

Fig. 15. Variation in root length for lettuce plants grown in DWC and NFT throughout the experimental periods for all treatments.

Hydraulic parameters of the lettuce plants.

Table 4. shows the effect of hydraulic conditions for operating the aquaponic and hydroponic system and their impact on the productivity of lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT). The results indicate that the hydraulic loading rate was increased with increasing the water flow rate. While, the nutrient uptake time decreased with increasing the flow rate because there is an adverse relationship between water flow rate and nutrient uptake time. These results agreed with those obtained by Endut *et al*. (2010) ;Yang and Kim (2020).

It was observed that when the water flow rate was increased from 0.5 to 2.5 L/min the hydraulic loading rate increased from 0.4 to 2 and 0.76 to 3.82 m/day in DWC and NFT, respectively. Meanwhile, the nutrient uptake time decreased from 12.8 to 4.2 and 3.8 to 1.7 min in DWC and NFT, respectively.

The hydraulic parameters affected positively on the yield of lettuce. The yield of lettuce was significantly affected by system (S), water flow rate (F) and interactions between treatments (S×F). In DWC, the highest total yield of lettuce was 297.74 and 312.02 g/plant after experimental period of 42 days in aquaponic and hydroponic system, respectively at a water flow rate of 1.5 L/min, hydraulic loading rate of 1.2 m/day and nutrient uptake time of 8.7 min. While in the case of NFT, the highest total yield of lettuce was 321.56 and 323.78 g/plant after experimental period of 42 days in aquaponic and hydroponic system, respectively at a water flow rate of 1.5 L/min, hydraulic loading rate of 2.29 m/day and nutrient uptake time of 2.6 min. The yield of lettuce was increased with increasing water flow rate from 0.5 to 1.5 L/min and decreased when flow rate was increased to 2.5 L/min. These results were in agreement with Hussain *et al*. (2014).

Table 4. Hydraulic conditions with operating the aquaponic and hydroponic system.

Water flow rate (L/min)	Hydraulic Loading Rate (m/day)		Nutrient uptake time (min)		Yield of lettuce (g/plant)			
					Deep water culture technique (DWC)		Nutrient film technique (NFT)	
	DWC	NFT	DWC	NFT	Aquaponic	Hydroponic	Aquaponic	Hydroponic
0.5	0.40	0.76	12.80	3.80	252.28	273.60	283.44	302.00
1.5	1.20	2.29	8.70	2.60	297.74	312.02	321.56	323.78
2.5	2.00	3.82	4.20	1.70	243.37	249.15	274.00	286.89

ANOVA

Yield of lettuce (g/plant)

Treatments	DWC	NFT
System (S)	21983.56**	18013.93**
Water Flow rate (F)	26555.52**	22476.28**
S×F	150.97**	1542.03**

Note: ** mean significant at P ≤ 0.01.

Water use efficiency

The most important indicator of the efficient used of irrigation water is identified by water use efficiency (WUE).This parameter is the ratio between crop yield (kg/plant) and crop water uptake (m^3/plant).Table 5 represents the water use efficiency for all treatments at the end of growing period. The results showed that the water use efficiency was significantly affected by system (S), water flow rate (F) and interactions between treatments (S×F).

The results indicate that the water use efficiency was 38.81, 45.81 and 37.44 kg/m^3 in deep water culture technique (DWC) and 42.09, 48.00 and 38.33 kg/m^3 in nutrient film technique (NFT) for 0.5, 1.5 and 2.5 L/min water flow rate, respectively with aquaponic system. Whereas in the case of hydroponic system, the water use efficiency was 62.29, 70.67 and 60.22 kg/m^3 in DWC and 66.37, 71.16 and 63.05 kg/m^3 in NFT for 0.5, 1.5 and 2.5 L/min water flow rate, respectively.

In DWC, the average water use efficiency was 40.69 and 64.40 kg/m^3 with aquaponic and hydroponic system, respectively. While in the case of NFT results show that the average water use efficiency was 42.81 and 66.86 kg/m^3 with aquaponic and hydroponic system, respectively.

The water use efficiency was increased in hydroponic system over those of aquaponic system. The water use efficiency was increased with increasing the water flow rate from 0.5 to 1.5 L/min and decreased with increasing the water flow rate from 1.5 to 2.5 L/min. These results were in agreement with Ali (2016). He found that the water use efficiency increased with increasing the flow rate at 1 to 1.5 L/hr and decreased with increasing the water flow rate from 1.5 to 2 L/hr.

Table 5. Water use efficiency for lettuce plants at the end of the growing period.

Water Flow rate (L/min)	Water Use Efficiency (kg/m^3) DWC Aquaponic	DWC Hydroponic	NFT Aquaponic	NFT Hydroponic
0.5	38.81	62.29	42.09	66.37
1.5	45.81	70.67	48.00	71.16
2.5	37.44	60.22	38.33	63.05
Mean	40.69	64.40	42.81	66.86
Treatments	ANOVA			
System (S)	4552.25**		18745.44**	
Water Flow rate (F)	271.16**		865.34**	
S×F	3.02**		6.99**	

Note: ** mean significant at P ≤ 0.01.

CONCLUSION

The experiment was conducted to evaluate the growth performance of Nile tilapia under the aquaponic system and to investigate the effect of system type (aquaponic and hydroponic system) and water flow rate (0.5, 1.5 and 2.5 L/min) on the growth performance of lettuce plants grown in deep water culture technique (DWC) and nutrient film technique (NFT) .

The obtained results can be summarized in the following points:

a.For fish

- The results indicate that the average water pH, water temperature (T_W), dissolved oxygen (DO), total dissolved solids (TDS), total ammonia nitrogen (TAN) and nitrogen (N) in the fish tank were 7.55, 23.37 °C, 7.24 mg/L, 294.80 mg/L, 0.84 mg/L and 76.49 mg/L, respectively during the experimental. The water quality parameters in the fish tank which presented were remained within the suitable range for the Nile tilapia (Oreochromis niloticus) growth.
- Fish weight and length increased during the experimental periods. The average individual initial weight and total length of the fish were 20.10 g and 10.50 cm, at the beginning of the experiment, respectively. While the average individual final weight and total length were 52.23 g and 13.88 cm, at the end of the experiment, respectively. The average fish weight and total length increased by almost 32.13 g and 3.38 cm, respectively after experimental period of 42 days.
- The condition factor (K) was increased from 1.74 to 1.95% during the experimental periods. While the specific growth rate (SGR) was decreased from 2.90 to 1.77 %/day.
- The measurements of condition factor (K) and Daily weight gain (DWG) showed suitable environment for fish growth so that no dead fish was found during the experimental periods.
- The feed conversion ratio (FCR) was increased from 1.31 to 1.57 during the experimental periods.

Finally, it could be concluded that the aquaponic system was suitable for the growth of Nile tilapia (Oreochromis niloticus) without any adverse effects. Further studies are necessary to determine the economic benefits of the system.

b. For plant

- The water quality parameters such as water temperature (T_W), water pH, electrical conductivity (EC) and dissolved oxygen (DO) in the plants troughs were significantly affected by system (S) but not significant affected by water flow rate (F) except for dissolved oxygen was significantly affected by water flow rate. The average water temperature and water pH were significantly higher in the aquaponic system than in the hydroponic system. While, the average electrical conductivity and dissolved oxygen were significantly higher in hydroponic system compared to aquaponic system for each culture type.
- There were significantly differences in the N.C.R, P.C.R, K.C.R, Ca.C.R, Mg.C.R and Na.C.R by lettuce plants through the growth period. The nutrients consumption rate were increased with increasing the water flow rate from 0.5 to 1.5 L/min and decreased with increasing the water flow rate from 1.5 to 2.5 L/min and the best treatment was obtained at the highest of nutrients consumption rate with the water flow rate 1.5 L/min. The nutrients consumption rates were higher in hydroponic system compared to aquaponic system except for Na.C.R.
- The root length was increased from18.82 to 19.76 cm and 18.54 to 19.52 cm in aquaponic and hydroponic system, respectively with increased from 0.5 to 2.5 L/min flow rate after 42 days from transplanting in the case of DWC. While in the case of NFT, the root length was increased from 16.70 to 17.88 cm and 16.30 to 17.58 cm in aquaponic and hydroponic system, respectively with increased from 0.5 to 2.5 L/min water flow rate after 42 days from transplanting.
- In DWC, the highest value of water use efficiency was (45.81 and 70.67 kg/m^3) obtained at a water flow rate of 1.5 L/min with aquaponic and hydroponic system, respectively. Whereas in NFT, the highest value of water use efficiency was (48.00 and 71.16 kg/m^3) obtained at a water flow rate of 1.5 L/min with aquaponic and hydroponic system, respectively.
- In DWC, the highest total yield of lettuce was 297.74 and 312.02 g/plant in aquaponic and hydroponic system, respectively at a water flow rate of 1.5 L/min, hydraulic loading rate of 1.2 m/day and nutrient uptake time of 8.7 min. While in the case of NFT, the highest total yield of lettuce was 321.56 and 323.78 g/plant in aquaponic and hydroponic system, respectively at a water flow rate of 1.5 L/min, hydraulic loading rate of 2.29 m/day and nutrient uptake time of 2.6 min. The yield of lettuce was increased with increasing water flow rate from 0.5 to 1.5 L/min and decreased with increasing the water flow rate from 1.5 to 2.5 L/min.

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دراسة تأثير بعض العوامل الهندسية علي أداء وحدة أكوابونيك متكامله

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قسم الهندسة الزراعية والنظم الحيوية ـ كلية الزراعة – جامعة المنوفية.

الملخص

في ضوء تغير المناخ والنمو السكاني يلعب نظام الأكوابونيك دورًا مهمًا في تحقيق الأمن الغذائي والتنمية الاقتصادية حيث تعتبر تقنية مبتكرة وصديقة للبيئة ومستدامة وأيضا أكثر إنتاجية من الزراعة القائمة على التربة. وهو من الأنظمة الحديثة التي تم استخدامها لتحقيق أقصى استفادة من المياه ، بالإضافة إلى التكامل بين استزراع الأسماك والنباتات معًا في نظام إنتاج واحد. وتنمو النباتات بإستخدام المغذيات المذابة في مياه الأستزراع السمكي كسماد عضوي. يهدف هذا البحث الي دراسة تقييم أداء نمو البلطي النيلي في نظام الاكوابونيك وأيضا معرفة تأثير نوع النظام (نظام الأكوابونيك ونظام الهيدروبونيك) و معدل التدفق (٠,٥ - ١,٥ - ٢,٥ لتر/ دقيقة) على أداء نمو نباتات الخس المنزرعة بتقنية الزراعة بواسطة المياه العميقة و تقنية الزراعة بواسطة الغشاء المغذي.تم إجراء هذه التجربة في قسم الهندسة الزراعية والنظم الحيوية ، كلية الزراعة ، شبين الكوم ، جامعة المنوفية خلال الفترة من الواحد والعشرون من شهر أكتوبر وحتي الثاني من شهر ديسمبر لعام ٢٠٢٠. وكانت أهم النتائج التي تم الحصول عليها بالنسبة للأسماك البلطي كما يلي : زيادة وزن وطول الأسماك خلال فترات التجربة. وزاد متوسط وزن السمكة وطولها الإجمالي بحوالي ٣٢,١٣ جم و ٣,٣٨ سم علي التوالي بعد فترة تجريبية مدتها ٤٢ يومًا. وأيضا تمت زيادة معامل الحالة من ١,٧٤ إلى ١,٩٥٪ وزيادة الوزن اليومية من ٠,٧٢ الي ٠,٨٢ جم/يوم زيادة معدل التحويل الغذائي من١,٣١ الي ١,٥٧ بينما انخفض معدل النمو النوعي من ٢,٩٠ إلى ١,٧٧ ٪ / يوم خلال فترات التجربة. وأيضا أهم النتائج التي تم الحصول عليها بالنسبة لنباتات الخس كما يلي : كانت هناك اختلافات معنوية في معدل إستهلاك نباتات الخس من النتروجين والفوسفور والبوتاسيوم والكالسيوم والماغنسيوم والصوديوم خلال فترة النمو وزاد معدل إستهلاك العناصرمع زيادة معدل التدفق المياه من ٠,٥ إلى ١,٥ لتر/ دقيقة وقلت مع زيادة معدل التدفق المياه من ١,٥ إلى ٢,٥ لتر/ دقيقة. وكان معدل إستهلاك العناصر أعلي في نظام الهيدروبونيك مقارنة بنظام الأكوابونيك باستثناء الصوديوم. و زاد طول الجذر من ١٨,٨٢ إلى ١٩,٧٦ سم ومن ١٨,٥٤ إلى ١٩,٥٢ سم في نظام الأكوابونيك والهيدروبونيك على التوالي مع زيادة معدل التدفق المياه من ٠,٥ إلى ٢,٥ لتر / دقيقة بعد ٤٢ يوم من الزراعة في حالة تقنية الزراعة بواسطة المياه العميقة. بينما في حالة تقنية الزراعة بواسطة الغشاء المغذي ، زاد طول الجذر من ١٦,٧٠ إلى ١٧,٨٨ سم ومن ١٦,٣٠ إلى ١٧,٥٨ سم في نظام الأكوابونيك والهيدروبونيك على التوالي مع زيادة معدل التدفق المياه من ٠,٥ إلى ٢,٥ لتر/ دقيقة بعد ٤٢ يوم من الزراعة. في تقنية الزراعة بواسطة المياه العميقة , كانت أعلى قيمة لكفاءة إستخدام المياه (٤٥,٨١ و ٧٠,٦٧ كجم/م٣) تم الحصول عليها عند معدل تدفق ١,٥ لتر/ دقيقة مع نظام الأكوابونيك والهيدروبونيك على التوالي. بينما في تقنية الزراعة بواسطة الغشاء المغذي ، كانت أعلى قيمة لكفاءة إستخدام المياه (٤٨,٠٠ و ٧١,١٦ كجم/م٣) تم الحصول عليها عند معدل تدفق ١,٥ لتر / دقيقة مع نظام الأكوابونيك والهيدروبونيك على التوالي. في تقنية الزراعة بواسطة المياه العميقة كان أعلى إنتاجية للخس هي ٢٩٧,٧٤ و ٣١٢,٠٢ جم / نبات في نظام الأكوابونيك والهيدروبونيك على التوالي عند معدل تدفق للمياه ١,٥ لتر/ دقيقة ومعدل تحميل هيدروليكي ١,٢ متر/ يوم وزمن امتصاص المغذيات ٨,٧ دقيقة. بينما في حالة تقنية الزراعة بواسطة الغشاء المغذي ، كان أعلى إنتاجية للخس هي ٣٢١,٥٦ و ٣٢٣,٧٨ جم/ نبات في نظام الأكوابونيك والهيدروبونيك على التوالي عند معدل تدفق للمياه ١,٥ لتر/ دقيقة ومعدل تحميل هيدروليكي ٢,٢٩ م/ يوم وزمن امتصاص المغذيات ٢,٦ دقيقة. وزاد إنتاجية الخس مع زيادة معدل التدفق المياه من ٠,٥ إلى ١,٥ لتر / دقيقة وقلت مع زيادة معدل التدفق المياه من ١,٥ إلى ٢,٥ لتر/ دقيقة.