Egypt. J. Aquat. Biol. & Fish., Vol. 10, No.3: 85 - 97 (2006) ISSN 1110 - 6131

AQUAPONIC PRODUCTION OF NILE TILAPIA (*OREOCHROMIS NILOTICUS*) AND BELL PEPPER (*CAPSICUM ANNUUM* L.) IN RECIRCULATING WATER SYSTEM

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Key words: Aquaponics, integrated, hydroponic, Nile tilapia, pepper.

ABSTRACT

Aquaponics is the combined culture of fish and hydroponic plants in recirculating systems. An integrated fish and hydroponics bell pepper system was evaluated for application in Central Laboratory for Aquaculture Research at Abassa, Sharkia Governorate. The system was constructed from readily available materials, and designed to minimize capital costs, energy, water use, and the technological skills needed for operation. Nile tilapia (*Oreochromis niloticus*) and bell pepper (*Capsicum annuum* L. 'Godeon') were cultured for 180 days in a closed system containing 1160 L of water for each unit. Six units were used with three treatments (all three treatments were in duplicated) to determine the effect of the integration between plant number /m^2 to fish density (100 fish /m^3) on fish performance. Each unit consists of 500 L fish rearing tank, hydroponic tank (2 m^2), filter and sump. Treatments were T_1 (fish culture with 10 plant/m^2), T_2 (fish culture with 15 plant/m^2) and T_3 fish culture without plant (control). Water quality suitable for fish production was maintained by aeration, mechanical and biological filtration, hydroponics vegetable production unit and the addition of make-up water. Fish metabolites, and wasted feed served as nutrient sources for pepper production. The results showed that T_1 (fish culture with 10 plants /m^2) gave the best significant ($P<0.05$) fish production 20.1 kg / m^3, followed by T_2 (fish culture with 15 plants /m^2) 17.95 kg / m^3 and the lowest ($P<0.05$) was T_3 fish culture without plant (control) 16.3 kg / m^3. Also T_1 (fish culture with 10 plants /m^2) was higher in average yield of marketable bell pepper 11.34 kg/m^2 ($P>0.05$) than T_2 (fish culture with 15 plants /m^2)

which produced 9.43 kg/m^2. Under the condition of the present study, results show in general that units integrated with hydroponic pepper T_1 and T_2 resulted in best economic efficiency, and T_1 was better than T_2.

INTRODUCTION

The use of recirculating water in aquarium systems presents a problem of nutrient accumulation as a result of fish excrement and waste feed. These waste products include ammonia, which is in a non-ionized form is toxic to fish (Alabaster and Lloyd, 1982). Biofilters are often employed to facilitate the digestion of these waste products and ammonia is converted to nitrite then oxidized to nitrate. The accumulation of the end products is controlled by partial flush or by chemical filtration (Spotts, 1970). Partial flush is usually employed in large aquaria or fish culture system where reconditioning by other methods is relatively expensive. However, this method has a large water requirement and may increase pollution problems if the nutrient waste is discharged into the environment. Recirculating aquaculture-hydroponic systems are designed to provide an artificial, controlled environment that optimizes the growth of fish (or other aquatic species) and hydroponics plants, while conserving water resources (Rakocy and Hargreaves, 1993). In such systems, the fish and plants are grown in a mutually beneficial, symbiotic relationship. Un-ionized ammonia-nitrogen is produced as an intermediate by-product of protein metabolism by the fish and high concentrations of this nitrogen can cause mortality. However, some forms of nitrogen can be used as a plant nutrient, and are removed from the water by the plant roots as the water circulates through the hydroponics unit. Thus, a harmful by-product of fish production becomes a beneficial input for plant production (Rakocy *et al.*, 1993). The present study was conducted to determine the production of Nile tilapia (*Oreochromis niloticus*) and bell pepper (*Capsicum annuum* L. 'Godeon') in aquaponic system, using different number of plant for maintaining water quality at acceptable range for fish production.

MATERIALS AND METHODS

The present study was conducted in a greenhouse at Central Laboratory for Aquaculture Research at Abbassa, Sharkia Governorate, Agriculture research center, Egypt, during one growing season 180 days (from 2nd October 2004 to 30 March 2005). Three recirculating treatment tanks for fish culture were performed. The first system (T_1) was integrated with 10 bell pepper (*Capsicum annuum* L. 'Godeon') plants/m^2, the second (T_2) was integrated with 15 bell pepper plants/m^2, and the third (T_3) fish culture without bell pepper, as a control. All three treatments were carried out in duplicated. The aquaponic system(Fig. 1) used in this experiment was consisted mainly of fish rearing fiberglass tank of 500 L total water volume, filtering unit, hydroponic system for bell pepper plants (2 m^2) and sump. The deep-water hydroponic unit was designed to allow the fish effluent to flow over the plant roots so essential nutrients can be extracted by the plant. The hydroponic tanks (2 m long by 1 m wide by 25 cm deep) and a raft system, consisting of floating sheets (2 m long by 1 m wide by 5 cm thick) of polystyrene, were installed. The filter unit consisted of 120 L. plastic drum containing 80 L. gravel. The sump was a 40 L. plastic tank. Total system water volume was 1160 L (1.16 m^3). One air pump and air stones were used to aerate the fish rearing tanks. Each tank was provided with one water heater (200 watt). A single 32 wt submersible pump was lifting 300 L of water / hour from the sump to the fish rearing tank. Mono sex Nile tilapia (*Oreochromis niloticus*) fingerlings were used in this experiment with an initial average weight of 10.5 gm / fish. Fish stoking density was 100 fish / m^3. The experimental integrated systems were operated with fish for 15 days in order to acclimate the biofilter and establish steady-state bacterial biomass with consequent nutrient build up in the system. The bell pepper seedlings obtained from the greenhouses of the Ministry of Agriculture were then introduced into the system.

Using normal operating procedures, effluent from the fish-rearing tank flowed into the filter. Effluent from the filter tank was discharged into the hydroponics tank and discharged into a sump, from which the treated water was pumped back to the rearing tank. The fish was fed two times daily on a complete pelleted diet containing 25 % protein. The daily feeding rate was calculated as a percentage of the estimated fish biomass and was gradually reduced from 4 to 1.2 % as the fish grew. All fish were harvested after 180 culture days. No pesticides or fungicides were used during the whole period of the experiment.

Water quality parameters including pH, dissolved oxygen (DO) and water temperature were measured daily at 6 a.m. and 12 p.m. by using pH/mV meter model 3505 and oxygen meter WPA20WAP scientific instrument, respectively. NH_3, NO_2, NO_3 and P were measured biweekly by C 99 and C 200 Series Multiparameter Bench Photometers. Mean total yield of pepper (kg/ m^2), mean yield of marketable fruit (kg/m^2), Market fruit weight (g) and Plant height (cm) were determined. Additionally, fish from each tank were weighed every two weeks to evaluate growth in weight and survival.

Statistical analysis

Statistical analysis for the experimental results carried out by using SAS program (SAS Institute, 1990). Differences between averages were determined by using Duncan's multiple range test (Duncan, 1955).

RESULTS AND DISCUSSION

Fish performance:

The averages of live body weight of Nile tilapia are presented in Table (1). Data show that the averages of initial weight for all treatments were 10.3 - 10.5 g with insignificant differences between all the treatments, indicating the accuracy of randomization process among the experimental treatments. The results of fish growth showed that all treatments of fish gave satisfactory growth during the experimental period since live body weight values increased progressively with age advancement. All the tested growth parameters {gain, average daily gain (ADG), specific growth rate (SGR)} showed that the highest average of final body weight (FBW) was observed by T_1 (fish culture with 10 plants/m^2) 207g / fish, followed by T_2 (fish culture with 15 plants/m^2) 189g / fish, while using fish culture without plant T_3 (control) exhibited the lowest final weight (170g / fish). The same trend was observed for gain, ADG, and SGR. Statistical analysis showed that (fish culture with 10 plants/m^2) T_1 resulted in significantly ($P<0.05$) higher value of BW, ADG and SGR than that of fish culture without plant T_3 (control), but not significantly higher than T_2 (fish culture with 15 plants/m^2). Also no significant difference was observed between T_2 and T_3 in FBW, ADG and SGR.

Data of Table (1) showe that the integration between fish culture and hydroponics bell pepper (T_1 and T_2) exhibited significantly ($P<0.05$) better FCR (1.81 and 1.86, respectively) than that of fish cultured without plant (control) 2.2. There were no significant differences ($P>0.05$) between T_1 and T_2 in this trait. The same trend was observed for feed fed.

Fish survival was 97, 95 and 96% for T_1, T_2 and T_3 respectively (Table 1). The losses, which did occur, were the result of fish jumping out of the rearing tank, and from injuries incurred during stocking. There were no significant differences ($P>0.05$) among treatments in survival rates.

Results of Table (1) show the effect of integration between fish culture and hydroponics bell pepper on total fish production. It is obvious that T_1 (fish culture with 10 plants/m^2) surpassed all treatments applied. Meanwhile, fish culture without plant (control) gave the lowest total fish production. Differences between treatments were significant ($P<0.01$). These results may be attributed to integration between fish culture and hydroponics bell pepper. In the integration system, wastes from fish culture provide nutrients required by plants, while the nutrient uptake by plants can improve water quality and increase fish production (Rakocy 1989). Chaves *et al.* (2000) showed that introducing lettuce in the fish system decrease nutrient concentration when compared to system which did not have any plants. Also T_1 (fish culture with 10 plants/m^2) had significantly ($P<0.05$) higher fish production than T_2 (fish culture with 15 plants/m^2). This may be due to the fact that this ratio between plants number (10 plants / m^2) to fish density (100 fish / m^3) was optimum.

Pepper production:

Data in Table (2) shows that increasing number of plant / m^2 reduced mean total yield of pepper; T_1 (fish culture with 10 plants/m^2) was higher ($P >0.05$) than T_2 (fish culture with 15 plants/m^2). The same trend was observed for Mean yield of marketable ripe fruit. With regard to the effect of plant number / m^2 to fish culture density on marketable pepper weight (table 2) data shows that T_1 (fish culture with 10 plants/m^2) was significantly ($P<0.05$) higher than T_2 (fish culture with 15 plants/m^2). The same trend was observed with Plant height. This results may be due to that this ratio between plants number (10 plants / m^2) to fish density (100 fish / m^3) was optimum. Rakocy (1989) determined the optimum ratio between the fish feeding rate and plant growing area. At this ratio (57g of feed / m^2 of plant growing area / day) the nutrient accumulation rate decreased and the hydroponics tanks were capable of providing sufficient nitrification. The incorporation of hydroponics into a recirculating aquarium system offers two potential benefits: (1) the provision of a secondary crop or animal feedstuff and the depletion of harmful fish waste products (Clarkson and Lane, 1991). Chaves *et al.* (2000) suggested that fish culture water might be used to fertigate hydroponically grown lettuce with minor nutrient supplementation. The lettuce produced equal to that with a standard nutrient solution and did not present perceptible symptoms of nutrient deficiencies.

Water Quality:

As given in Table (3), the averages of water temperature, pH, dissolved oxygen and water ammonia, nitrite and nitrate content were suitable for growth of Nile tilapia, *Oreochromis niloticus*. In this respect, Degani *et al.* (1988) observed that the optimum water temperature for *O. aureus* ranged between 24 and 31°C. As presented in the same table pH was maintained at average values between 8.17- 8.45 (Table 3). These values considered being high for a hydroponic system, but in an aquaponic system pH must be maintained above 7.0 to promote nitrification (Rakocy *et al.*, 2004). Fish excrete large quantities of ammonia, which must be oxidized to nitrate to prevent toxicity. Ammonia, nitrite and nitrate concentration remained within safe limits for fish culture (Table 3). According to this study, when pepper was stocked at a density of 10 plants / m^2 (T_1) the integrated system discharged 51% and 52.6% (NO_3 and phosphate, respectively) less than a fish recirculating system without plant (control), while, when pepper was stocked at a density of 15 plants / m^2 (T_2) the integrated system discharged 69% and 39.5% NO_3 and phosphate, respectively less than a fish recirculating system without plant (control). These results are in agreement with those of HongXin *et al.* (2001) who reported that the hydroponic vegetable's the maximal purification rate of ammonia-N, nitrite-N, nitrate-N, total-N, phosphate-P and COD was 57.46%, 51.72%, 3.7%, 10.67%, 9.72% and 21.78%, respectively. Nutrients concentrations were lower than the levels normally found in hydroponics system, but they were generally acceptable for aquaponic system because nutrients were produced daily, excreted directly by the fish or generated from the mineralization of organic matter (Rakocy *et al.*, 2004).

Daily make-up water averaged 20 L or 4 % of system volume. Water loss was attributed to sludge removal, evaporation and transpiration.

Economic Efficiency:

A projected cost and return analysis was compiled using the system design and yield data (Table 4). Operator labor (approximately 180 h /year) and land rental were not included in cost estimates as the system was designed to be operated on a youth or a family use basis. Production figures were based on one crop of fish and one crop of pepper per one season (6 months). As presented in Table (4) results of total costs including the variable and fixed costs for the treatments applied in L.E. were found to be 157; 162; and 125 L.E./unit for the T_1; T_2; and T_3 groups respectively. These results revealed that the total costs of T_3 were the lowest due to the fact that there is no hydroponic unit and pepper seedling in this system. On the other hand, the total costs of T_2 were the highest due to the costs of higher number of pepper seedlings 60 plant/unit than T_1 (40 plants/unit). Net returns in L.E per unit were 114.6; 74.99 and 21.7 L.E./unit for the T_1; T_2 and T_3 groups, respectively, (Table 4). Percentages of net returns to total costs were 72.99%; 46.3% and 17.4% for the T_1; T_2 and T_3 groups, respectively. Under the condition of the present study, results show in general that units integrated with hydroponic pepper T_1 and T_2 resulted in higher economic efficiency compared to the control. These results are in full agreement with results of Adler *et al.* (2000) who concluded that treatment of fishery effluent using hydroponic crop production represents a potentially profitable secondary enterprise to aquaculture producers.

CONCLUSIONS

Based on results obtained in this study and on the economical evaluation it could be concluded that the integration of the hydroponic vegetables production unit into the closed recirculating fish culture system was the key to the success achieved in this study. The hydroponic unit not only contributed to the maintenance of water quality suitable for good fish growth, but the subsequent pepper harvest was essential for the favorable economic projections developed for the culture system. However, from the economical point of view fish culture with 10 plant/m^2 (T_1) seemed to be the best in terms of ratio of returns to total costs.

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Table (1): Growth performance and feed utilization of Nile tilapia grown in a closed, recirculating fish and Bell pepper production system.

Item	T_1 (10 plant/m^2)	T_2 (15 plant/m^2)	T_3 (control)
Initial Weight g/ fish	$10.5^a \pm 0.16$	$10.3^a \pm 0.16$	$10.5^a \pm 0.16$
Final Weight g/ fish	$207^a \pm 4.76$	$189^{ab} \pm 4.76$	$170^b \pm 4.76$
Total Gain g/ fish	$196.5^a \pm 4.76$	$178.7^{ab} \pm 4.76$	$159.5^b \pm 4.76$
SGR (%/d)	$1.66^a \pm 0.02$	$1.615^{ab} \pm 0.02$	$1.55^b \pm 0.02$
Feed fed g/ fish	$355.6^a \pm 2.71$	$332.3^a \pm 2.71$	$350.3^b \pm 2.71$
FCR (g feed/ g gain)	$1.81^b \pm 0.06$	$1.86^b \pm 0.06$	$2.2^a \pm 0.06$
Survival rate (%)	$97^a \pm 1.41$	$95^a \pm 1.41$	$96^a \pm 1.41$
Total production (kg/m^3)	$20.1^a \pm 0.19$	$17.95^b \pm 0.19$	$16.3^c \pm 0.19$

a,b,c: Figures in each row having the same superscript are not significantly different ($p>0.05$).

Table (2): Yield of Bell pepper grown hydropnically in a closed, recirculating fish and Bell pepper production system.

Treatment	Mean total yield[a] of fruit (kg/ m^2)	Mean yield[a] of marketable fruit (kg/m^2)	Marketable ripe fruit (%)	Market fruit weight (g)	Plant height (cm)
T_1 (10 plant/m^3)	$11.93^a \pm 0.58$	$11.34^a \pm 0.60$	$95^a \pm 0.71$	$63^a \pm 2$	$105^a \pm 3$
T_2 (15 plant/m^3)	$10.25^a \pm 0.58$	$9.43^a \pm 0.6$	$92^a \pm 0.71$	$45^b \pm 2$	$78^b \pm 3$
T_3 (control)	-	-	-	-	-

a Fresh weight basis.

a,b: means with different superscript in the same column are significantly different ($P<0.05$).

Table (3): Average of water quality parameters through the experimental period.

Treatment	Water temperature °C	pH	DO_2* (mg/L)	NH_3** (mg/L)	NO_2*** (mg/L)	NO_3**** (mg/L)	P# (mg/L)
T_1 (10 plant/m^2)	26.5^{a} ± 0.21	8.17^{b} ± 0.05	6.8^{a} ± 0.21	0.41^{b} ±0.03	0.006^{a} ± 0.002	8.42^{b} ±0.16	1.8^{b} ±0.22
T_2 (15 plant/m^2)	26.2^{a} ±0.21	8.34^{ab} ± 0.05	6.6^{a} ±0.21	0.31^{b} ±0.03	0.005^{a} ±0.002	5.31^{c} ±0.16	2.3^{b} ±0.22
T_3 (control.)	26.0^{a} ± 0.21	8.45^{a} ± 0.05	6.7^{a} ±0.21	0.75^{a} ±0.03	0.014^{a} ±0.002	17.28 ^{a}±0.16	3.8^{a} ±0.22

*DO_2 : Dissolved oxygen.

**NH_3 : Ammonia

***NO_2: Nitrite

****NO_3: Nitrate

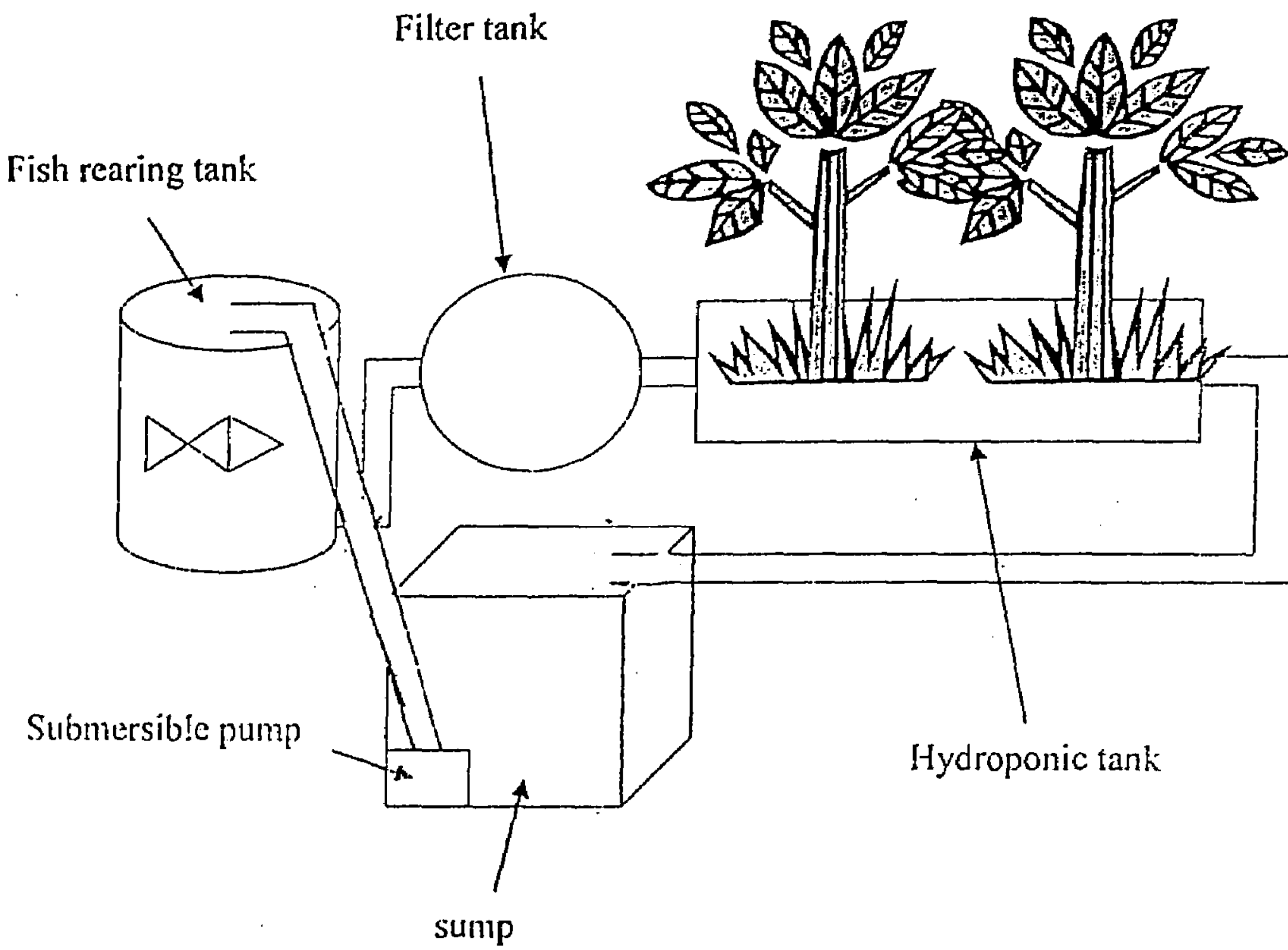
P : phosphate

Table (4) Economic efficiency for one season (6 month) of integrated fish and hydroponic pepper production system.

Items	Treatments		
	T_1 (10 plant/m^2)	T_2 (15 plant/m^2)	T_3 (control)
(1)Variable costs, L.E/unit.			
a- Costs of tilapia fingerlings:	15	15	15
b- Commercial diets	60	55	59
c- seedlings	20	30	-
d- electricity (300 kWh)	21	21	21
Total Variable costs, L.E/unit	116	121	95
Fixed costs, L.E/ unit – depreciation*			
a- culture tanks and plastic drum	35	35	25
b- submersible and air pumps	3.5	3.5	3.5
c- pip and fittings	2.5	2.5	1.5
Total fixed costs, L.E/unit	41	41	30
Total operating costs Variable & fixed	157	162	125
(2) Revenue (L.E.)**			
Fish sales	180.9	161.55	146.7
Bell pepper sales	90.72	75.44	-
Total	271.6	236.99	146.7
Net return, L.E/ unit.	114.6	74.99	21.7
%Net returns to total costs	72.99	46.3	17.4

* Equipment was depreciated at a fixed rate based on the expected life of the individual item.

** The economical evaluation of results was carried out according to market prices during 2004 – 2005 years in L.E.



Figer (1): aquaponic system unit.