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Nutrient cycle and sludge production during different stages of red tilapia (*Oreochromis* sp.) growth in a recirculating aquaculture system

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Abstract

The nutrient cycle of input feed and sludge production was evaluated for five stages of red tilapia growth in a recirculating aquaculture system. Five weight groups of red tilapia, 20±0.00 (20), 39.70±0.44 (40), 80.38±0.41(80), 113.62±1.92 (120), and 177.67±1.81 (180) g in triplicates were selected as treatments and randomly introduced to the experimental units (75 fishes/unit) and cultured for a 3-week period. The body weight and biomass of the fish were correlated with the assimilation rates of some minerals supplied by the input feed. It was estimated that red tilapia could capture on average, 11.46% Fe, 13.43% Zn, 6.81% Mn, 3.55% Cu, 26.81% Ca, 20.29% Mg, 32.53% N, 7.16% K, and 15.98% P of input feed during a culture period (from 20–200 g). The sludge settled over the hydroponic troughs could capture average rate of 23.93% Fe, 86.05% Mn, 46.17% ZN, 21.49% Cu, 15.71% Ca, 88.87% Mg, 5.55% N, 5.85% K, and 17.90% P of input feed in each experimental unit. The dry matter of sludge showed significant differences ($P<0.05$) among treatments and ranged from 5.00% to 10.00% of dried input feed. The concentrations of total nitrogen, phosphorus, and magnesium in water were not significantly different ($P>0.05$) among experimental fish groups at the end of experimental period and continuously increased during the 21-day experimental period. The electroconductivity (EC) of water continuously increased during the experimental period. The pH of water decreased in all treatments at the end of experiment. The results of this study predicted the fate of input feed nutrients in a representative recirculating system where the particular diet was used. It was also demonstrated that the aquaculture effluent carries out a large amount of nutrients, including solids form which can be accumulated in the hydroponic(s) troughs.
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Keywords: Nutrients cycle; Input feed; Sludge production; Red tilapia; Recirculating system

1. Introduction

The natural feeding strategy of fish species (i.e., herbivore, carnivore, omnivore, and filter feeder,

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etc.), fish stocking density, total fish biomass, input feed rate (fertilizer/feed used quantity and application method), water quality, and water management influence the assimilation of nutrients by fish and wastewater production (Tacon, 1995). Wastewater accumulates while feed is continuously added in a fish culture system. Wastewater effluent comprises mainly faeces, uneaten food, and bacterial biomass which are organic and rich in nutrients (Gloger et al., 1995). The total dissolved solid (TDS) generates (produces) due to feed leaching and bacterial degradation of faecal materials. Total suspended solid (TSS), including faecal materials and biomass of bacteria, is typically separated from water by the solid separation unit, which is then discharged from the culture system in the form of sludge (Coffin, 1993). These wastes, in one hand, can negatively impact on the adjacent environment owing to release of output effluents into the surrounding area. On the other hand, aquaculture wastes can be used to irrigate and fertilize terrestrial plants and reduce the use of inorganic fertilizer in agricultural lands, for example, in the climatic Mediterranean region (Maria et al., 1996). Wastewater processing or purification by plants in greenhouses or specific treatment systems has also become increasingly popular in response to water shortages (Gloger et al., 1995). Over the past 3 decades, in aquaculture practices, the hydroponic(s) plant compartments with different experimental design were integrated in the aquaculture systems in both warm and moderate climates to alleviate the accumulation of nutrients especially, N compounds in the culture system (Naegel, 1977; Lewis et al., 1978; Sutton and Lewis, 1982; Pierce, 1980). Closed recirculating systems appeared to be the most appropriate aquaculture system for integration with hydroponics since nutrients can be maintained at the concentrations which are sufficient for hydroponics plant culture (Nair et al., 1985; Rakocy et al., 2000). In aquaponic research, there has been strong interest to normalize the ratios between plants, fish, daily input feed, as well as the kind of integrated plant biofilter into the system (McMurtry et al., 1990; Rakocy, 1994). In some works, raft hydroponics itself has been integrated and made the main compartment for waste removal in the culture system without use of the bacterial biofilters (Gloger et al., 1995). In this respect, contribution of lettuce to waste treatment compartment have been well addressed (Rakocy, 1995). During fish development (growth), the stand biomass of fish is increased per unit of the experimental system. It is generally accepted that the rate of sludge production and feed nutrients assimilation in a culture system, depending on the life cycle of the fish, which can be varied during the time in an experimental culture system. Therefore, identification of such items can be crucial in this sense. At this study, it was tried to qualify and quantify the fate of input feed nutrients associated with physical and biological factors involving in a recirculating fish culture system. Thus, the main objective of this study was to evaluate the cycle of feed nutrients and sludge production, with an emphasis on characterization of wastewater production in different stages of red tilapia growth.

2. Materials and methods

The fate of nutrients that come from input feed was evaluated in different stages of red tilapia growth in a representative recirculating aquaculture system. Five weight groups of red tilapia, 20±0.00 (20), 39.70±0.44 (40), 80.38±0.41(80), 113.62±1.92(120), and 177.67±1.81 (180) g with 75 pieces of fish were selected as treatments in triplicates and randomly introduced to experimental units. It was estimated that the mean individual fish weight in each group would reach the next mean individual weight group after a 21-day culture period. For example, 20-g fish would grow to 40 g after a 3-week culture period. Therefore, the duration of the study was a 3-week experimental period. The experimental system consisted of a fiberglass tank (110 W×84 L×100 H cm) equipped with three raft hydroponic troughs (110 L×30 W×5 D cm) and a submersible water pump (Model Aqua, 1500). The water pump was used for recycling the water from the fish tank through the hydroponic troughs and finally to the fish tank (Fig. 1).

The hydroponics troughs were used to limit penetration of light to the fish tank and reduce algal growth and as a bed for water recycling (providing the similar condition to fish in an aquaponic system without use of plants). At the day of experimental

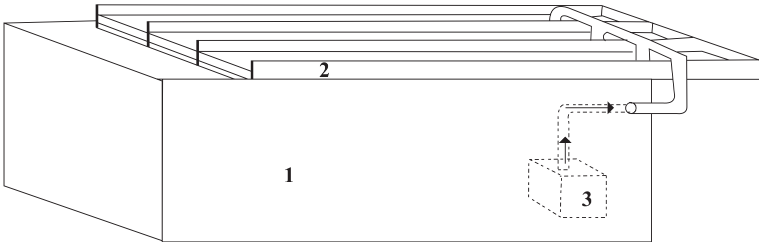

Fig. 1. Schematic feature of the system: 1—the fish tank, 2—the hydroponic troughs, 3—the water pump.

commencement, each rearing tank was stocked with 75 red tilapia juveniles.

2.1. Water supply

Each tank was filled with 640 L of tap water and aerated continuously with two circular air stones (3 L min^{-1}). The characteristics of water supply were the following: aged tap water: pH 7.17; Ec=0.16 mmhos; Ca=5 mg L^{-1}; Mg=2, 5 mg L^{-1}; K=0.00041 mg L^{-1}; P=0.00031 mg L^{-1}; Fe=0.578 mg L^{-1}; Mn=0.033 mg L^{-1}; Zn=0.00015 mg L^{-1}, and Cu=0.00013 mg L^{-1}.

2.2. Feed and feeding

The feed was a commercial diet floating pellet (Car-gill Company) with 24% protein, 6% fat, 6% fiber, and 11% moisture. The fish were fed twice a day ad libitum at 09:00 and at 13:30 h. The mineral content of feed was measured before initiation of the study. The characteristics of feed are given in Table 1.

2.3. Sampling and water quality measurement

Dissolved oxygen (DO) and water temperature (*T*) in fish rearing tanks were measured twice a week by YSI Model 57 meters. Electroconductivity (EC) was determined twice a week using EC meter model HANA instrument conductivity meter HI 8033. Two 100 ml of water were sampled from fish tanks to determine the pH using Orion model 410A pH meter. Total ammonia (NH_4^++NH_3) was measured weekly (taking two samples of water from the fish rearing tanks with 10 times dilution, using distilled water) (Parsons et al., 1984). Nitrite (NO_2^+) was measured weekly (APHA, 1980).

2.4. Fish weight measurement

The individual and biomass of fish were measured at the beginning and end of the study using gravimetery and correction for water values.

2.5. The sampling and dry fish weight measurements

Before start of experiment, from each fish group acclimated with the experimental feed for 1 month, five fishes were sampled and weighed then cut into small pieces and were put inside a dry dish. The dish containing piecemeal fish was put inside an oven at 70 °C, and dry weight was recorded. The samples were reweighed until getting the fixed weights for each fish sample; this process was done for fish sampled at the termination of the experimental period (APHA, 1980).

Table 1
The (mean±S.D.) percentage (%) of minerals[a] (nutrients) in dry experimental feed

Fe (%)	Mn (%)	Zn (%)	Cu (%)	Ca (%)	Mg (%)	N (%)	P (%)	K (%)
0.1094±0.0574	0.003±0.0014	0.0056±0.00007	0.0024±0.000005	1.74±0.226	0.428±0.037	3.40±0.226	1.48±0.091	0.53±0.0014

[a] Fe (ferrous), Mn (manganese), Zn (zinc), Cu (cupper), Ca (calcium), Mg (magnesium), N (nitrogen), P (phosphorus), and K (potassium).

2.6. Measurement of sludge rate accumulated in hydroponic troughs

The sludge (water, uneaten feed and fecal matter, and bacterial biomass) was gathered from each of the hydroponics troughs and dropped inside a plastic container, and the net weight of sludge was calculated by subtracting the weight of plastic container from the total weight. After homogenizing the sludge, two samples were taken, each containing 300 ml, and both were weighed and dried on an oven at 70 °C to get the fixed dry weight. The dry weight of sludge was measured by gravimetry (APHA, 1980).

2.7. Measurement of total solid in water

After harvesting the fish at the end of experiment, the water in each fish tank was disturbed with a big fishing scoop net. Water was sampled in duplicates (homogenized water) by two 500-ml beakers, each containing 300 ml of water, and deposited on an oven at 70 °C to get the fix weight for the beaker and the sum of dissolved and suspended solid in water. The dry total solid (TSO) was measured by gravimetry (APHA, 1980).

2.8. Nutrients (minerals) content of the dry fish, feed, and sludge measurements

The dry fish, feed, and sludge were pulverized and homogenized prior to mineral composition analysis process. A 0.25 g of dry feed, fish flesh, and sludge (four replicates) were taken and digested by Kejeldahl method (HACH, Cat. No.23130-18, Instruction Manual). After digestion, the volume of digested samples was brought up to 100 ml using distilled water. The concentration of total nitrogen (modified Bertholet method) and phosphorous in each sample was measured using an auto analyzer (Chemlab-System 4). The percentage of K, Fe, Ca, Mg, Zn, and Cu in the dried samples was then measured with an atomic absorption spectrophotometer (Model Perkin-Elmer AAS 3110). The percentage of elements in dry samples was measured using the following equation:

$$A\% = n \times 0.04$$

where

A = percentage of element
n = auto analyzer reading

The mean feed nutrients accumulated in body of the fish calculated using the fish growth rate (final mean fish weight−initiation mean fish weight)×A% and extended to the fish biomass considering density of 75 fishes per unit of system.

2.9. Concentration of dissolved minerals in the water

The concentration of dissolved nutrients in the fish tank was determined weekly by auto analyzers and atomic absorption device. The unit of measurement was reported in mg L^{-1}.

2.10. Data analysis

The percentage values were normalized by arc sine transformation then analyzed statistically. Data were subjected to one-way ANOVA, significant differences between the means were compared with the Duncan's

Table 2
Mean percentage of total feed nutrients recovered by different weight groups of red tilapia after the 21-day experimental period

Fish groups (g)	Zn (%)	Fe (%)	Cu (%)	Mn (%)	Ca (%)	Mg (%)	N (%)	P (%)	K (%)
20	0.75±0.038	10.01±0.068	27.21±0.013	5.34±0.072	34.66±0.270	8.85±0.145	27.87±0.225	14.08±0.613	6.85±0.057
40	8.33±0.047	6.30±0.080	30.41±0.021	6.04±0.057	33.65±0.037	4.23±0.009	31.22±0.006	19.14±0.051	7.00±0.054
80	9.83±0.096	6.18±0.025	8.10±0.064	5.57±0.081	22.10±0.137	5.37±0.183	36.56±0.329	20.36±0.090	8.00±0.015
120	38.38±0.078	11.55±0.084	1.37±0.097	5.79±0.141	33.77±0.209	5.98±0.102	34.48±0.151	19.16±0.096	8.59±0.055
180	0.015±0.0046	0.019±0.088	0.065±0.045	0.02±0.053	9.85±0.074	5.03±0.004	32.53±0.031	7.18±0.039	5.38±0.019

Table 3
The concentration of (mean±S.D.) of macroelements (nutrients) in water in different fish groups after week 1 and 3

	Nutrients	Ca (mg L^{-1})	Mg (mg L^{-1})	N (mg L^{-1})	P (mg L^{-1})	K (mg L^{-1})
First week						
Fish groups	20	13.00±2.00	1.20±0.32	0.10	10.55±1.20	5.00±1.70
	40	14.33±2.10	1.30±0.40	0.10	13.3±3.00	4.50±1.00
	80	12.70±1.85	1.47±0.97	0.10	9.71±6.80	5.00±1.13
	120	12.67±2.10	1.50±0.51	0.10	5.00±6.25	4.00±0.58
	180	15.00±1.17	1.90±0.98	0.10	2.59±0.70	4.78±0.21
Third week						
Fish groups	20	24.67±1.53	3.43±1.81	10.96±3.96	13.13±1.80	6.40±1.30
	40	27.00±2.00	3.13±1.89	8.38±8.71	16.60±1.10	6.83±1.80
	80	22.00±3.50	3.83±0.85	4.17±1.12	19.33±4.80	5.94±1.60
	120	27.00±2.10	3.98±1.96	12.40±1.10	15.63±1.70	7.00±2.00
	180	24.67±1.86	4.70±0.17	9.48±3.33	18.49±4.01	8.33±1.20

new multiple range test, and statistical significance were tested at a 0.05 probability level (SPSS Microsoft version 10.0).

3. Results

3.1. Feeding rate and nutrients added to experimental units

The mean rates of feed consumption and mean value of feed nutrients added to treatments are reported in Table 2.

3.2. Nutrient recovery by biomass of fish in different treatments

The mean percentage of feed nutrients recovered by red tilapia biomass (75 fishes) is listed in Table 2. These data show that the 120-g fish group recovered higher Zn, Fe, and K compared to other fish groups. The retention of Cu, Ca, and Mg in body of 20-g fish group was higher than other fish groups, with the rates of 27.21%, 34.66%, and 80.85%, respectively. The input feed N and P recovery by 80-g fish group was higher compared to other fish groups.

3.3. Water quality parameters

The concentration of total ammonia (NH_4^++NH_3) in water had fluctuation during the experimental period. Concentration of total ammonia was between 4.73–14.87 mg L^{-1} among experimental fish groups at the end of experimental period. Concentration of nitrite (NO_2^+) in water increased during the experimental period, it was between was 3.75 to 9.77 mg L^{-1} among experimental fish groups at the end of experimental period. Inorganic N varied and was between 4.17 to 12.4 mg L^{-1} among the experimental fish groups at the end of experimental period. The EC of water increased during the experimental period. The EC of water was between 0.40–0.50 mmohs/cm among the experimental fish groups at the end of

Table 4
Percentage (mean±S.D.) of macro- and microelements (nutrients) of feed accumulated in water in different fish groups at the end of the experimental period

Fish groups (g)	Fe (%)	Mn (%)	Zn (%)	Cu (%)	Ca (%)	Mg (%)	N (%)	P (%)	K (%)
20	6.40	6.40	6.40	6.40	6.23	80.90	10.19	28.04	38.17
40	6.40	6.40	6.40	6.40	5.31	57.86	7.28	33.13	38.04
80	6.40	6.40	6.40	6.40	5.21	23.09	2.90	30.94	26.55
120	6.40	6.40	6.40	6.40	4.10	51.94	6.54	18.93	23.68
180	6.40	6.40	6.40	6.40	6.03	49.41	6.22	27.88	35.07

Table 5
The mean (mean±S.D.) computed sum of total dry solid (DSO) in fish tanks, dry sludge (DSL) accumulated inside the hydroponic troughs in each experimental fish groups, and feed consumption (FC) values at the termination of the experimental period

Fish groups (g)	FC (g)	DSL (g)	DSO (g)
20	2025	182.50±16.90[bc]	349.1±22.62[a]
40	2167	113.50±44.00[ab]	444.8±21.97[b]
80	2702	159.41±1.33[ab]	334.8±25.86[a]
120	3579	169.1±27.80[ab]	436.2±24.79[b]
180	2868	224.1±72.46[c]	440.0±69.32[b]
Total	13,341.00	848.61	2004.90

Values with the same superscript letters in a column are not significantly different at the 0.05 level.

experiment. The pH of water was between 5.89–6.77 among the experimental fish groups at the end of experimental period.

3.4. Concentration of macroelements in water

The concentrations of P in water increased in all fish groups during the experimental period. It was between 5.9–14.5 mg L^{-1} at the end of the experiment. The concentration of Mg in water increased in all fish groups during the experimental period. Concentration of Mg was between 3.34–4.70 mg L^{-1} at the end of experimental period. The concentration of Ca in water fluctuated during the experimental period. The concentration of Ca was lower in 80-g fish group compared to other fish groups at the end of experimental period. The concentration of Ca in 40- and 120-g fish groups was higher compared to other fish groups with the rate of 27.00 mg L^{-1}. The concentration of K in water in 80-, 120-, and 180-g fish groups increased and in 20- and 40-g fish fluctuated during the experimental period. The concentration of K in the treatment with 180-g fish was higher than other fish groups with the rate of 39.33 mg L^{-1} at the end of experiment (Table 3). The recovery of feed nutrient by water as percent at the end of experimental period is listed in Table 4.

3.5. Faecal materials (sludge)

The data given in Table 5 show the dried weight of total sludge (TSL) accumulated in the hydroponic troughs, and total solid (TSO) accumulates in the water at the end of experiment. A large amount of sludge settled inside the hydroponic troughs during the 21-day experimental period. The quantity of dry TSL and TSO showed significant differences ($P<0.05$) among experimental fish groups.

3.6. Mineral content of dry sludge

Percentage of minerals (macro and micro) in dry sludge was not significantly different ($P>0.05$) among experimental fish groups. These rates averaged 0.33% for Fe, 0.03% for Mn, 0.045% for Zn, 0.007% for Cu, 4.10% for Ca, 0.384% for Mg, 2.61% for N, 3.89% for P, and 0.24% for K. The mean percentage of feed nutrients recovered by sludge was calculated for different experimental fish groups and listed in Table 6.

4. Discussion

In this experiment, different weight classes of red tilapia (different size, age, and biomass) were fed a diet with constant dietary nutrient. The results indicated that the body weight of red tilapia (with considering biomass increase/unit of culture system) affected the assimilation rates of some minerals supplied by the feed input. Retention of feed nutrients in the body of red tilapia associated with nutrient content of water was recorded and discussed as well

Table 6
Mean nutrients recovered by sludge as percent of input feed nutrients in different fish groups

Fish groups (g)	Zn (%)	Fe (%)	Cu (%)	Mn (%)	Ca (%)	Mg (%)	N (%)	P (%)	K (%)
20	27.08	92.50	73.19	26.96	21.14	8.06	23.64	6.91	4.07
40	20.95	89.17	60.08	22.89	18.26	8.39	15.93	4.56	6.83
80	21.43	97.07	39.64	17.73	16.55	8.07	14.94	4.39	5.08
120	27.84	93.84	61.95	22.14	22.049	11.00	19.44	6.59	7.31
180	23.93	86.05	46.17	21.49	15.71	88.87	17.90	5.55	5.85

(Rafiee et al., unpublished data). The recovery of feed nutrients by different weight groups of red tilapia varied, indicating the differences in the nutrient requirement of red tilapia during different stages of its growth in the culture system. It was estimated that red tilapia could capture on average, 11.46% Fe, 13.43% Zn, 6.81% Mn, 3.55% Cu, 26.81% Ca, 20.29% Mg, 32.53% N, 7.16% K, and 15.98% P of feed input during a culture period (from 20–200 g). A recovery of 5.00% Fe, 36.00% Zn, 3.00% Mn, 16.50% Cu, 95.00% Ca, 20.50% Mg, 44.00% N, 24.00% K, and 55.00% P of feed nutrients have been reported for red tilapia with the biomass of between 151–1804 g in different experimental trials (Seawright et al., 1998). Average retention of 16% of feed P by fish and shrimp (Avnimelech and Ritvo, 2003), rates of 32% of feed N assimilation (Quillere et al., 1993), and between 40–43.2% of input feed have been reported in the fingerling and breed of tilapia in conventional systems as well (Siddiqui et al., 1988; El-Sayed, 1990). Rates of 20% N recovery for a male population in recirculating systems without using plant (Suresh and Lin, 1992), 31% with a mixed population (Rakocy et al., 2000), 37.4% for a male population (Zweig, 1986), and 29% by fish and shrimp (Avnimelech and Ritvo, 2001) have also been reported. These findings demonstrate differences in feed nutrients recovery by fish which can be related to differences in the diet compositions, chemical form of minerals in a fish diet, the quantity of minerals, the current physiological state of fish (rate of gain, live weight, and age), and the design performance of the experiment (Tacon, 1995). Scientists have reported that between 20–40% of nitrogen content of feed is excreted by fish in the form of ammonia N. If so, it is considered that 39.29% of the feed N is excreted as ammonia N by fish and released to the culture system (Rafiee et al., 2002). It is concluded that about 28% of feed N must remain in the feacal solid and release to the culture system. These findings are comparable to the reports of 26% recovery of input feed N by fecal solid (Lin and Nash, 1996) and 24% of feed N accumulation in the sediments of intensive shrimp pond (Funge-Smith and Briggs, 1998). As a conclusion, in a tilapia culture system, large amount of feacal waste generates, meaning large quantities of feed nutrients released to the culture system. It was calculated that on average 88.54% Fe, 93.19% Mn, 86.57% Zn, 96.44% Cu, 73.19% Ca, 79.71% Mg, 67.47% N, 92.84% K, and 84.02% P of input feed were released to the representative culture system as metabolite wastes. It has been reported that about 75% of feed N and 80% of the feed P are not recovered in the harvested fish and settled in the pond bottom in a ground pond fish culture system (Avnimelech and Lacher, 1979). These data pointed to the fact that the main sources of wastes are derived from feacal materials and uneaten feed that are sources of energy and nutrients for growth of biological organisms (i.e., bacteria, fungi, and algae). These matters and biomass of microorganisms build up the total suspended solid (TSS) and the total dissolved solid (TDS) in a culture system. In a recirculating aquaponic system, for removal of solids and water treatment, the effluent from fish tank is passed through a clarifier then is flowed to the hydroponics areas, thus solid removal should be considered as the major concern because, in a integrated fish–plant culture system, nutrient concentration must be well regulated to provide suitable nutrient solution for fish and plant growth. It has been estimated that the solid removal by clarifier averaged 21% of the dry weight of feed input during a production cycle (Rakocy et al., 2000). Twarawska et al. (1996) determined that 35.3% of feed input (as aquaculture waste) can be captured as settling and nonsettling solids by using a particle trap and particle separation (17% removal) in combination with a microscreen drum filter (17.7% removal) in a tilapia culture system. Mudrak (1981) determined that 204 to 359 L (kg) of sludge was produced per 100 kg of feed application. It has been reported that sludge production in a culture system varied from 3.00 to 4.00 kg with the dry matter of 8.00% to 12.00%, while the input feed is between 2.00–3.00 kg (Rakocy, 1995). During long storage of fish in the culture system, dry matter of sludge exceeds to 40.00% (Bergheim and Forsberg, 1993). At this study, supplementary feed in the fish tanks was between 2.05–3.57 kg, and dry matter of produced sludge was between 5.00–10.00%, which are comparable to the results of other experimenters. At the present study, the recovery of input feed nutrients by sludge ranged from 0.30–4.00% for Fe, 4.00–16.00% for Mn, 0.035–0.08% for Zn, 0.64–0.56% for Cu, 2.82–4.90% for Ca, 0.0008–0.0075% for Mg, 2.11–2.87% for N, 2.95–3.89% for P, and 0.024–0.50% for K. Input feed nutrients recovery of between 99–160% for Fe, 43–60% for Mn, 48–90% for Zn, 143–226% for Cu, 71–169%for Ca, 14–24% for Mg, 8–15% for N, 33–59% for P, and 3–6% for K have been reported in a integrated fish and plant culture, using supplemental nutrients (Seawright et al., 1998). Total phosphorous content of fresh sludge usually ranges from 0.5% to 3.5%, and potassium ranges from 0.05% to 0.70%; comparison of these findings shows some differences in the results reported by the different experimenters and a controversial conclusion which can be related to supplemental nutrient and effect of plant on recovery of nutrient in the integrated fish and plant culture system; however, high level of nutrient recovery occurs in the older sludge. It was calculated that 13.69–19.37% of the dry mater of feed settled in the hydroponic troughs at the end of experimental period as sludge. Total dry solid in fish tank ranged from 5.30% to 10.12% of dry feed input. Low concentrations of nitrogen in the dry sludge that settled in the hydroponic troughs after a 3-week period illustrated the absorption or releasing the N from the faecal material by microorganisms through the culture system. Feed N recovery by 3-week old sludge (in the hydroponic area) was 5.55% compared to the rate of 28% for fresh faecal solid pointing to nitrogen recovery by bacteria. The concentration of micronutrients (Zn, Mn, Cu, and Fe) decreased in water with the rate of lower than 0.0001 mg L^{-1}, while their concentration in the dry sludge was reasonable. This pointed to the ability of solids in the absorption of micronutrients from the water, which is comparable to the operation of sediment in the absorption of micronutrients in fish and shrimp ponds (Avnimelech and Lacher, 1979) and absorption of supplemental nutrient by feacal solid or sludge in an integrated fish and plant culture system (Seawright et al., 1998). The load of nutrients to the system due to feeding the fish was at the highest rate for N followed by P, Ca, Mg, and K, considering quantities of 3.20 g for Ca and 1.60 g for Mg required by the water supply (640 L) at the start of experiment. These pointed to Ca accumulated in water at the highest rate followed by P, N, K, and Mg at the end of experimental period. Macronutrient accumulation was related to feed input with one exception for N. There was no significant relationship between feed input and N. Similar results have been reported by Seawright (1993). Sum of percentage of feed nutrients recovery by water, sludge, and fish averaged 57.63% for Zn, 115.54% for Fe, 62.02% for Cu, 22.16% for Mn, 31.90% for Ca, 16.03% for Mg, 51.97% for N, 13.77% for P, and 12.69% for K. The rate of dissolved nutrients as percent of input feed nutrients was 6.4% for Fe, Mn, Zn, and Cu and was between 4.10–6.23% for Ca, 23.09–80.90% for Mg, 2.90–10.19% for N, 18.93–30.94% for P, and 23.68–38.17% for K; considering these rates in the water source at the initiation of study, it means 0.09–0.14% for Fe, 14.78–26.04% for Mn, 0.13–0.26% for Zn, 30–55% for Cu and 5.15–9.08% for Ca, 10.47–18.45% for Mg, 0.81–2.40% for N, 0.0016–0.00245 for P and 0.005–0.007% for K, concluding that a large amount of nutrient was recovered by suspended solid and bacteria in the water. However, some minerals can precipitate due to changes in the physicochemical condition of water such as pH and temperature. High concentration of Ca and P in water could be related to low pH and higher solubility of these elements under low pH; these two elements precipitate in the form of calcium phosphate $Ca_3(PO_4)_2$ (Rakocy et al., 2000). The EC of water increased among the experimental fish groups. It was between 0.40–0.50 mmohs/cm at the end of experimental period. These findings pointed to rapid build up of TDS due to lack of water exchange and mineralization of organic matters occurred by microorganisms. During the experimental period, pH of water decreased in all treatments, which could be related to acid production due to operation of bacteria in degradation of organic matters and reactions of denitrification and build up of nitrite and nitrate from ammonia (Naegel, 1977; Rakocy, 1989, 1995; Mackay and Tover, 1981). In commercial recirculating systems, KOH and Ca $(OH)_2$ are added to the culture system in equal amounts alternatively several times weekly to maintain pH between 7.0–7.5 for fine performance of nitrifying bacteria (Austin and Austin, 1989; Rakocy et al., 1993).

Nutrient accumulation occurs in a recirculating system due to high feeding rates, low water exchange, and rapid build up of TDS to potentially toxic levels, more than 2,000 mg L^{-1}. An increase in TDS at toxic levels happens, while 10 kg of feed is added to 1 m^3 of water in the culture system (Rakocy et al., 1993). Aquaponics are generally designed to meet the minimum size required for the TDS removal and biofilteration compounds as a separate biofilters. In this respect, the portion of hydroponic area to fish rearing component would be the main concern in an aquaponic system. Scientists have had some studies to find this ratios, however, they faced some restrictions (MacMurtry et al., 1997; Rakocy, 1989, 1994; Gloger et al., 1995). In another study (Rafiee, unpublished data), effluents produced by different fish groups (each period of red tilapia culture in the system) were applied as nutrient solutions for culture of 42 seedlings of 1 week old for a 5-week culture period to evaluate recovery of input nutrient by plant. The yield of lettuce was not significantly different and exceeded mean of 2 kg/m^2, and nutrients recovery by lettuce was also determined (Rafiee et al., unpublished data).

5. Conclusion

In this study, the operation of red tilapia in assimilation of nutrients during different stages of its growth in relation to an increase in the fish biomass, changes in environmental factors (changes in water quality parameters), and operation of natural flora of bacteria on TDS and TSS production were investigated. The sludge accumulated over hydroponic areas qualified and quantified during different stages of red tilapia growth. The findings of this study showed the directions for water quality management in recirculating and pond fish culture systems as well as management of wastewater in land use treatment and its application in crop production. These findings would be useful in the build up of an artificial equilibrium aquaponics ecosystem, in balancing the specific ratios for plant/fish/feed, and in integrating the raft hydroponics.

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