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Water quality in an aquaponics system interconnected with a biofilter

Adriano-Anaya, María, L.[1]; **García-López, Kenia, Y.**[1]; **Reyes-Flores, Maciel**[1]; **Salvador-Adriano, Miguel**[1]; **Salvador-Figueroa Miguel**[1*]

[1] Instituto de Biociencias, Universidad Autónoma de Chiapas, Campus IV. Boulevard Príncipe Akishino s/n, Col. Solidaridad 2000, C.P. 30798. Tapachula, Chiapas, México.

* Correspondence: miguel.salvador@unach.mx

ABSTRACT

Objective: To determine the water quality of an aquaponics system interconnected by a biofilter, using sponge gourd (*Luffa cylindrica*) as an inert support.

Design/Methodology/Approach: The organisms used in the aquaponics system were juvenile tilapia (*Oreochromis niloticus*) and wormseed (*Chenopodium ambrosioides*). The following physicochemical parameters of the water were analyzed: temperature, pH, dissolved oxygen, electrical conductivity, NH_4^+, NO_2^-, and NO_3^-. Data generated in this work were subjected to an analysis of variance (ANOVA) and to the comparison of means (Tukey's test, $p<0.05$).

Results: Recirculating tank water through the biofilter and plants reduced NH_4^+ and NO_3^- by 31.6% and 18.5%, respectively. The total ammonia nitrogen in the tank did not exceed 0.022 mg L^{-1}. The fish survival rate was 100% and 725.8 g of wormseed were harvested. The wormseed did not show symptoms of mineral deficiency.

Study Limitations/Implications: Aquaponics production is still limited to small surfaces, as a consequence of the costs involved in its handling.

Findings/Conclusions: Water quality parameters of the tilapia (*Oreochromis niloticus*)-wormseed (*Chenopodium ambrosioides*) aquaponics system —interconnected through a biofilter with *Luffa cylindrica*— fulfilled the recommendations for such system.

Keywords: biofilter, aquaculture, mineralization, ammonia.

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INTRODUCTION

Aquaculture is an activity that depends on water availability. However, as a result of such activity, water becomes saturated with fish excreta and food waste (Martins *et al.*, 2009). Therefore, the exchange of water is essential; otherwise, fish population can die. Aquaponics has been developed as an alternative for water purification and conservation (Dediu *et al.*, 2011). This technology does not impact water bodies and does not deteriorate soil (Ramírez *et al.*, 2008).

Image by Paul at Pixabay

In the aquaponics system, the organic waste dissolved and suspended in the tank water is used as a source of nutrients for the development of edible and/or commercial plants (García-Ulloa *et al*., 2005). In the first stage, water passes through a clarification tank where the suspended solids are precipitated; the water is subsequently filtered (using sand, gravel, plastic or other materials) to capture fine solids. After that, water passes through the mineralization station where (aerobic) bacteria transform the dissolved material. As the penultimate stage, dissolved gases (carbon dioxide, methane and hydrogen sulfide) are released. Finally, water flows into the system (where the plants, floating raft or inert bed are located) and returns to the fish tank (Van Gorder, 2003; Ramírez *et al*., 2008; Dediu *et al*., 2012).

A biofilter is a place where bacteria are provided with large areas to colonize and perform NH_3 a NO_3^- transformation, which is essential for water quality parameters in aquaponics systems. *Oreochromis niloticus* and *Lactuca sativa* have been produced in spaces where solids were previously removed; the plants work as an additional biofilter (Al-Hafedh *et al*., 2008) for the removal of nitrogenous species. Moreover, Ramírez *et al*. (2009) used a sand and gravel filter in a *Carassius auratus* - *Lactuca sativa* system, obtaining NH_3, NO_2^-, and NO_3^- concentrations that ranged from 0.1 to 6.7 mg L^{-1}, from 0.1 to 6.0 mg L^{-1}, and from 0 to 80 mg L^{-1}, respectively. Danaher *et al*. (2013) compared water quality parameters, using a cylinder-conical clarifier and a vortex separator for the primary treatment of solid waste in a *O. niloticus* - *Ipomoea aquatica* culture. However, they did no find significant differences in TAN (total ammonia nitrogen), NO_2^- and NO_3^- concentrations.

In aquaponics, all the filtration components are important (clarifier, mineralizer, and degasser), but their operation requires equipment and space. An alternative to the situation is to replace the three above-mentioned elements with a single biofilter. Therefore, the objective of this study was to determine the water quality of an aquaponics system through the integration of a biofilter in the process.

MATERIALS AND METHODS

Aquaponics system

The structure of the aquaponics system consisted of a fish tank, a biofilter, a NFT (Nutrient Film Technique) system as a grow media for plants, and a water pump to recirculate the water. A Frame Pool™ semi-rigid pool (399 cm long × 211 cm wide × 66 cm high) was used as an aquaculture tank. It operated at 90% of its total capacity (3,300 L). The upward flow biofilter (100.00 cm long × 15.24 cm diameter) was built with polyvinyl chloride (PVC) tubing. Sponge gourd (*Luffa cylindrica*) cubes with 3.0 cm edges, previously washed, were used as the inert substrate of the biofilter. The filter was connected in series to the NFT system with five pre-drilled PVC tubes (300 cm long × 15.24 cm diameter). Nineteen holes for plant growth were drilled in each tube. The resulting total holes (95) were filled with tezontle and were used to hold 300-ml containers. Wormseed (*Chenopodium ambrosioides*) seedlings were then planted in the perforations. Water recirculation was performed with a 3,500 L d^{-1} water pump that connected the fish tank and the biofilter.

Hydraulic conditions and fish and plant culture

In two 90-day trials, 140 L h^{-1} of water were recirculated in the aquaponics system. Once the recirculation system was structured, an initial sampling of the water, fish and plants was performed. Subsequently, the physicochemical water parameters and biometry of fish and plants were determined every 15 days. In the aquaculture component, 148 tilapia (*Oreochromis niloticus*) fingerlings —weighing 14.31 g and measuring an average of 7.26 cm long— were placed. Fish were fed with a 32% protein commercial diet (Silver Cup "El Pedregal"). The daily ration was estimated at 5% of live weight day^{-1}. Food was administered in two portions, at 8:00 a.m. and 4:00 p.m. Wormseeds (*Chenopodium ambrosioides*) were germinated in an Andosol and, 15 days after germination, seedlings were transplanted to the containers (after the roots were washed with running water) and randomly placed in the NFT system. Fish and plants culture was performed for 91 days with two replicates.

Fish length, weight, and survival

The length and weight of each individual fish were determined every 15 days. Length was determined from the head to the caudal peduncle with an ichthyometer and the weight was measured with a Rhino® precision analytical balance. Fish survival was recorded daily by visual inspection of the tank. The weight and length values were used to calculate the weight gain and length of the tilapia The feed conversion was obtained by dividing the total food supplied by the total biomass produced.

Height, weight, chlorophyll content, and survival of plants

The height of the plants was determined using a metric rule (cm) at the time of pruning and harvesting. The plants were pruned 45 days after sowing (dds) and the harvest was carried out at 90 dds. An effort was made to leave 5-cm high stolons after the pruning. During the harvest stage, plant height was measured from the base to the apex. The fresh weight of plants was established with a Rhino® precision analytical balance. Before the plants were pruned and harvested, their nutritional status was determined by reading the SPAD units with a Konica Minolta® SPAD 502 portable meter.

Physicochemical parameters of water

A Hanna® HI 9829 multiparameter meter was used to determine the physicochemical parameters of water: temperature (°C), pH, dissolved oxygen (mg L^{-1}), and electrical conductivity (μS m^{-1}). Ammonium $\left(NH_4^+\right)$, nitrite $\left(NH_2^-\right)$ and nitrate $\left(NH_3^-\right)$ were determined with a Hach® DR/890 portable colorimeter. Every 7 days, all the parameters were determined in the tank, in the biofilter outlet, and in the outlet of every plant growth device.

Statistical analysis of the data

The data generated in this work were subjected to an analysis of variance (ANOVA) and a comparison of means (Tukey's test, $p<0.05$) with the professional version of the InfoStat software (2011).

RESULTS AND DISCUSSION

Physicochemical parameters of water

Table 1 shows the mean values of the water physicochemical parameters used in the aquaponics system —taken from seven sampling points, during 13 weeks of processing and two productive cycles. The variations in the mean temperature (T), pH, and electrical conductivity (EC) values were not significant. However, variations of DO (1.8-2.9), N-NH_4^+ (0.2-2.0), N-NO_2^- (0.7-1.4) y N-NO_3^- (10.4-17.2) values (measures in mg L^{-1}) showed a significant difference.

From the perspective of the sampling points, the interior of the tank, the biofilter outlet, and the point of return to the tank (outlet of the plant growth system), only the DO, NH_4^+ and NO_3^- variables showed significant changes (Table 2). Accordingly, DO increased 21%, while NH_4^+ and NO_3^- decreased 35% and 24%, respectively.

Table 1. Mean temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), NH_4^+, NO_2^- and NO_3^- values of aquaculture water. The value of each of the variables is the mean of the seven sampling points and two crop cycles.

Week	T (°C)	pH	DO (mg L^{-1})	EC (μS cm^{-1})	N-NH_4^+ (mg L^{-1})	N-NO_2^- (mg L^{-1})	N-NO_3^- (mg L^{-1})
1	28.5	7.6	2.6 bc	655.6	1.0 cd	1.1 b	14.1 b
2	28.4	7.4	1.9 ef	629.6	0.9 de	0.8 c	17.2 a
3	28.2	6.9	2.4 c	698.5	0.2 f	1.1 b	12.1 cd
4	28.1	7.6	2.8 ab	686.3	1.7 ab	0.7 c	14.5 b
5	27.9	7.3	1.8 f	526.7	0.9 de	1.4 a	10.7 d
6	27.7	7.2	2.6 bc	644.6	1.3 bc	1.2 ab	14.3 b
7	27.6	7.6	2.7 ab	672.0	1.5bc	1.2 ab	13.0 bc
8	27.4	7.3	2.2 cd	644.6	1.0 cd	1.1 b	10.4 d
9	27.3	7.1	2.3 cd	640.2	1.3 bc	1.2 ab	10.7 d
10	27.1	7.6	2.1 cde	627.2	2.0 a	1.1 b	10.8 d
11	27.0	7.4	2.9 a	599.2	1.1 cd	1.2 ab	12.9 bc
12	28.7	7.5	2.6 bc	571.0	1.7 ab	1.1 b	11.5 cd
13	28.8	7.6	2.4 c	596.3	1.0 cd	1.1 b	11.0 d

Values with dissimilar letters were statistically different (Tukey's test, α<0.05).

Table 2. Mean temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), NH_4^+, NO_2^- and NO_3^- value of water within the tank, at the biofilter outlet, and in the point of return of the tank of the aquaponics system. The value of each of the variables is the mean of 13 weeks of processing and two crop cycles.

Site	T (°C)	pH	DO (mg L^{-1})	EC (μS cm^{-1})	N-NH_4^+ (mg L^{-1})	N-NO_2^- (mg L^{-1})	N-NO_3^- (mg L^{-1})
Bosom of the pond	27.8	7.2	2.4 b	625.6	2.0 a	1.2	14.5 a
Biofilter outlet	27.8	7.1	2.6 ab	629.9	1.9 a	1.2	13.5 b
Retum of tank	27.7	7.3	2.9 a	687.3	1.3 b	1.1	11 c

Values with dissimilar letters were statistically different (Tukey's test, α<0.05).

In the aquaponics system studied, water quality parameters fall within the values required by the biological components of the system; these results match the findings of Somerville *et al.* (2014). In this respect, DO concentration within the tank seems limited; however, it has been reported that tilapia can develop between 2 and 3 mg L^{-1} (Somerville *et al.*, 2014). pH was maintained within the 6.9-7.6 range, which is suitable for the development of fish and plants (Tyson *et al.*, 2004). Likewise, water temperature was within the appropriate range for the fish species, as well as for plants and nitrifying bacteria (Somerville *et al.*, 2014); meanwhile, the EC fluctuated between 0.53 and 0.70 dS m^{-1} (*i.e.*, a low ion concentration in water).

Using the data reported by Emerson *et al.* (1975) for the $NH_3 \Leftrightarrow NH_4^+$ equilibrium in an aqueous solution, the average ammonia concentration (NH_3, a gas which is toxic to fish) was <0.022 mg L^{-1}, under the pH and temperature conditions of the tank. This concentration is 91 times lower than the level required to detect symptoms of fish poisoning (Somerville *et al.*, 2014); therefore, TAN did not exceed the 3 mg L^{-1} recommended by Timmons *et al.* (2002).

The passage through the biofilter reduced the NH_4^+ and NO_3^- content of the tank water by 5.0% and 6.9%, respectively; meanwhile, the passage of the same water through the culture system decreased their content by 31.6% and 18.5%, respectively. The efficiency with which the biofilter-plant system in culture removed NH_4^+ and NO_3 was 35.0% and 24.1%, respectively. The equivalent amount of TAN removed by the system under study was similar to that reported by Mulay and Reddy (2021) for a system with basil. However, the NH_4^+ and NO_3 removal was 2.5 and 3.6 times lower and 2.3 and 3.3 times lower for the water spinach (*Ipomoea aquatica*) system and for the mustard (*Brassica juncea*) system, respectively (Enduta *et al.*, 2011).

Growth of *Oreochromis niloticus* and *Chenopodium ambrosioides*

The fish growth (length- and weight-wise) was quantified at the end of the cycles. In this period, fish grew, on average, 0.05 cm day^{-1} and gained 0.73 g day^{-1} (Figure 1). The average production of fish biomass was 9.67 kg. The amount of food supplied during the cycle was 23.16 kg. Therefore, the feed conversion ratio (FCR) was 2.38 —although the

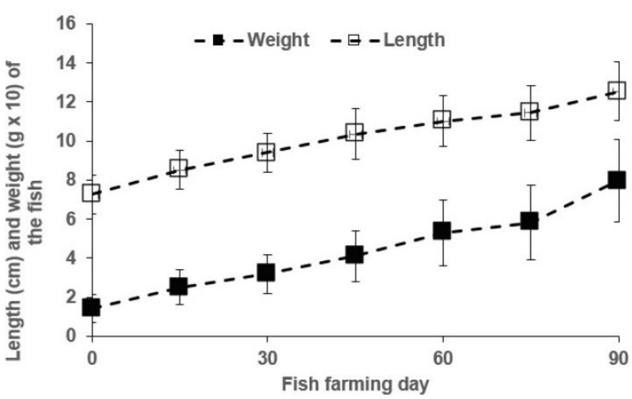

Figure 1. Weight and length gain dynamics of *Oreochromis niloticus*, cultivated for 91 days in an aquaponics system.

FCR is considered acceptable below 2 (Craig and Helfrich, 2009)— and the fish survival was 100%.

The rate of growth and weight gain of wormseed (*Chenopodium ambrosioides*) plants during the 90-day cycle was 0.68 cm day^{-1} and 0.085 g day^{-1}, respectively. A total production of fresh matter of 725.8 g was obtained. The SPAD readings remained unchanged throughout the cycle (33.9 units), which means that the nitrogen concentration in the system is enough for the *C. ambrosoides* production.

CONCLUSIONS

After 91 days of work, the water quality parameters of the tilapia (*Oreochromis niloticus*)-wormseed (*Chenopodium ambrosioides*) aquaponics system —interconnected through a biofilter with a sponge gourd (*Luffa cylindrica*)— were within the recommendations for the said system.

During the time that the work lasted, no symptoms of toxicity or dead fish were recorded. Consequently, the aquaponics system under study had the capacity to maintain ammonia nitrogen below the toxicity concentration.

No mineral deficiency symptoms were observed in wormseed (*Chenopodium ambrosioides*). This result was confirmed by the SPAD level.

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