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Full Length Research Paper

Development of efficient recirculation system for Tilapia (*Oreochromis niloticus*) culture using low cost materials

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In the current experiment, a recirculation system was built using low cost materials that are available locally and its performance was tested. The performance evaluation procedure was carried out in an aquaculture system in greenhouse with sex-reversed male Nile tilapia (*Oreochromis niloticus*) production in Querétaro State, Mexico. The recirculation system had four sections (sediment collector, gravel and sand filters, biofilter and clarification) in order to eliminate the organic matter produced by the fish excretion material and uneaten food, as well as, the nitrogenous compounds undesirable in the water tanks, such as, total ammonia nitrogen (TAN). The monitored variables include: temperature, dissolved oxygen, pH, visibility, TAN, nitrites and nitrates. The obtained data were compared with previous studies to evaluate the achieved state of the system. This research clearly demonstrated that it is feasible to use the proposed configuration in aquaculture systems in areas where water source is limited. Consequently, the obtained results represent an environmental standpoint for the conservation of water use in the aquaculture industry and also constitute an important contribution to the aquaculture and farmers who receive minimal economic support.

Key words: Water recirculation, aquaculture, sustainability, low cost, water use efficiency.

INTRODUCTION

Worldwide, aquaculture plays a very important economic role in the food production industry because of the high protein content found in fish meal as a food for human. This industry is a key factor for increasing the economic income in developing countries, most notably in the rural areas while providing new employment opportunities to improve the economic situation for the people in these regions. Also, it allows these individuals to produce their own food (Maigualema and Gernat, 2003; Hafeez-Ur-Rehman et al., 2008). However, aquaculture operation demands high quantities of water. Therefore, aquaculture has been a topic of ongoing research in order to improve the production techniques and to optimize the use of water (Quazi, 2001). Some recent research dealt with fish environment (Cnaani et al., 2000; Cao et al., 2007; Roy et al., 2009), fish feeders (Chang et al., 2005; Soto-Zarazúa et al., 2010) and water quality (Michaud et al., 2006; Johnson and Chen, 2006; Colt, 2006). However, the scarcity of water in regions where there is not an abundant supply produces negative ecological impact when the water is not re-used. One way to address this problem is to re-use water through the treatment procedure in recirculation systems. Although, sometimes farmers lack economic support and integration can be compli-cated due to the high costs in implementing new systems. For these reasons, a recirculation aquaculture system built using low cost locally accessible materials is presented in this study. The system evaluation was accomplished in an aquaculture system in Querétaro State, Mexico.

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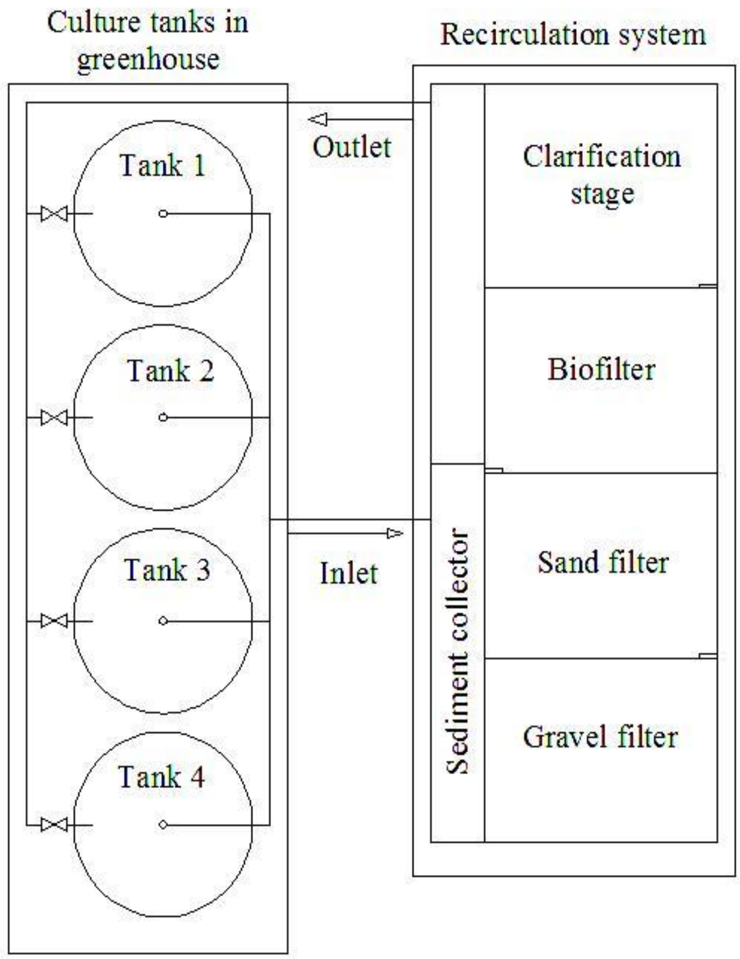

Figure 1. Aquaculture system schematic diagram integrated by the culture tanks in greenhouse and the recirculation aquaculture system.

MATERIALS AND METHODS

The evaluation of the recirculation aquaculture system in this research was carried out in an aquaculture system inside a polyethylene greenhouse measuring 672 m^2 which is located at longitude 100º 16'W; latitude, 20º 42'N and altitude 1920 m. Four circular tanks of 20 m^3 with conical bottoms were used. The tanks were stocked with sex-reversed male Nile tilapia (*O. niloticus*) at a density of 60 fish/m^3. Fish were fed daily at rates of 1.8 - 5% of total biomass with commercial diet floating food pellets as recommended by Morales-Diaz (2003) in the feeding scheme for fish under intensive conditions. The production tanks were equipped with an aeration system (blower, diffuser stones and polyvinylchloride (PVC) pipe of 5.8 cm) to maintain the dissolved oxygen level up to 70% of saturation (Buentello et al., 2000) in the culture tanks. During the experimental period, the water loss due to evaporation and through sediment extraction in the aquaculture system was restored with freshly supplied water.

Throughout the experiment, monthly a sample of 100 fish was taken from each tank to measure the weight gain (Soto-Zarazúa, 2008) using a digital balance OHAUS MODEL EC6, USA. Feed intake was based on cumulative tank data by computing the total rations and collective weight gains of each tank (Aderolu et al., 2010). Feed conversion rate was determined taking into account the total feed intake (kg)/Total biomass produced (kg).

Recirculation aquaculture system configuration

The recirculation aquaculture system developed was integrated by four concrete compartments of 1 × 5 × 1.2 m dimensions that correspond to sediment collector; sand and gravel filters; biofilter and clarification stages (Figure 1), each compartment have a valve in order to drain the sludge.

The recirculation system was installed outside the greenhouse but this was covered with polyethylene using a tunnel type structure of steel. The water flows between the culture tanks and the recirculation system was 10 l/min. This is sufficient to obtain daily average 14.4 m^3 of water which corresponds to approximately 18% of water treated as has been recommended by van Rijn et al. (2006) in order to maintain acceptable water quality in fish production (Table 1). The characteristics and activities of each recirculation system phase are described in the following list:

1. Sediment collector: In this stage the water that comes from the culture tanks is received and the biggest suspended solids are concentrated in the bottom by sedimentation.
2. Sand and gravel filters: This stage is divided in two sections. The first one contains gravel of approximately 2 cm in size which is used

Table 1. Acceptable ranges of quality water for fish production (Buentello et al. 2000, Shnel et al. 2002, Azaza et al. 2008, El-Sherif and El-Feky 2009, Soto-Zarazúa et al., 2010).

Parameter	Acceptable range
Visibility (cm)	> 30 cm of visibility
Temperature (ºC)	26–28
Dissolve oxygen (%)	> 70%
pH	7 – 9
TAN (mg/l)	< 4
Nitrite (mg/l)	0.10
Nitrate (mg/l)	0.50 – 7

TAN = Total ammonia nitrogen.

to trap the solids not caught in the sediment collector. The second one contains river sand that is approximately 1.5 mm in order to filter smaller particles after to the biofiltration process and to avoid clogging in the biofilter with excess organic matter.

3. Biofiltration phase: The nitrification process was carried out using a colony of *Nitrosomona* sp. and *Nitrobacter* sp. bacteria fixed in PVC pipe media as recommended by Al-Hafedh et al. (2003) in recirculation systems because these systems superior performance in waste removal, and the reduction of the production cost because they are readily available and cheaper.

4. Clarification: The clarification phase is the final phase in the water treatment in recirculation systems for aquaculture. Activated carbon was used to eliminate the color and smell in the water, as well as, an ultraviolet module for sterilize water.

Measurements of water quality parameters

The recirculation aquaculture system performance was evaluated by measuring the physio-chemical parameters that determines the water quality in aquaculture to offers a healthy environment , promoting fish growth and survival (Pfeiffer and Malone, 2006) . The major variables considered important in fish production were temperature (°C), dissolved oxygen (%), pH, visibility (cm), TAN (mg/l), nitrites (mg/l) and nitrates (mg/l) (Grommen et al., 2002; Milstein et al., 2001). Measurements of these parameters were recorded weekly throughout the production cycle. The temperature and dissolved oxygen were measured with HQ40D multi dual-input meter, BRAND HACH, USA with LDO101-03 probe sensor; and the pH was monitored using the water proof pH tester 10, BRAND EUTECH, USA Instruments. The visibility was measured using a common Secchi disk; and the nitrites, nitrates and TAN were measured with a DR/2400 portable spectrophotometer (HACH, USA) utilizing the 10019, 8171 and 8038 Hach Methods.

RESULTS AND DISCUSSION

The minimum, mean and maximum values of the physio-chemical evaluated parameters are presented in the Table 2.

Temperature

The trend of the mean temperature values are presented in Figure 2. During the production cycle in the four tanks, the temperature ranged between 23.98 and 29.34°C which corresponds with the recommended ranges in various previous investigations for Tilapia production and in general for poikilothermic fish species in order to obtain good growth and survival rates (Cnaani et al., 2000; Buentello et al., 2000; Shnel et al., 2002; El-Sherif and El-Feky, 2009a). The temperatures in the tanks can be attributed to the internal greenhouse environment which allows operators to maintain these while saving energy because of the hot air surrounding the tanks. If the tanks were located in an open field or any other outdoor location it would be virtually impossible to obtain such temperature conditions. This reinforces the feasibility to produce species in a greenhouse in other regions were the climate conditions are different, for example Queretaro State, Mexico.

Dissolved oxygen

In aquaculture the dissolved oxygen is a chemical factor that affects the fish growth and survival rates of fish. In the last decade various research projects have been considered in order to demonstrate the acceptable levels of dissolved oxygen necessary in water to obtain high growth and survival rates (Buentello et al., 2000; Xu et al., 2006). In Tilapia production, a concentration of 70% or greater has been as acceptable. In Figure 3, the dissolved oxygen during the production cycle is presented. This data shows that the dissolved oxygen concentration was higher than 70% of saturation, having a mean measurement of 114.77%.

pH

The pH levels during the production cycle are presented in Figure 4. The pH measurements ranged between 7.23 and 8.91, having an average value of 8.17. This value is considered acceptable for fish production to obtain favorable growth and survival rates (El-Sherif and El-Feky, 2009b) as well as ensuring food consumption.

Visibility

The visibility was used as an indicator of the suspended solid concentrations in the water. For fish production visibility it is recommended to keep concentrations of suspended solids, sediments and wastes that are generated by the fish excretion and uneaten feed low. In this study the visibility was found to be between 74.6 and 82.6 cm of visibility with an average measurement of 78.23 cm. This visibility distance is widely acceptable for fish production tanks (Soto-Zarazúa et al., 2010). The visibility is

Table 2. Physio- chemical environmental parameters in the water tanks during the production cycle July, 2008 – January, 2009.

Parameter	Minimum	Mean	Maximum
Temperature (°C)	23.98	26.55	29.34
Dissolved oxygen (%)	60.60	114.77	168.10
pH	7.23	8.17	8.91
Visibility (cm of visibility)	74.60	78.23	82.60
TAN (mg/l)	1.67	2.93	3.67
Nitrites (mg/l)	0.01	0.11	0.21
Nitrates (mg/l)	0.10	1.47	5.80

TAN = Total ammonia nitrogen.

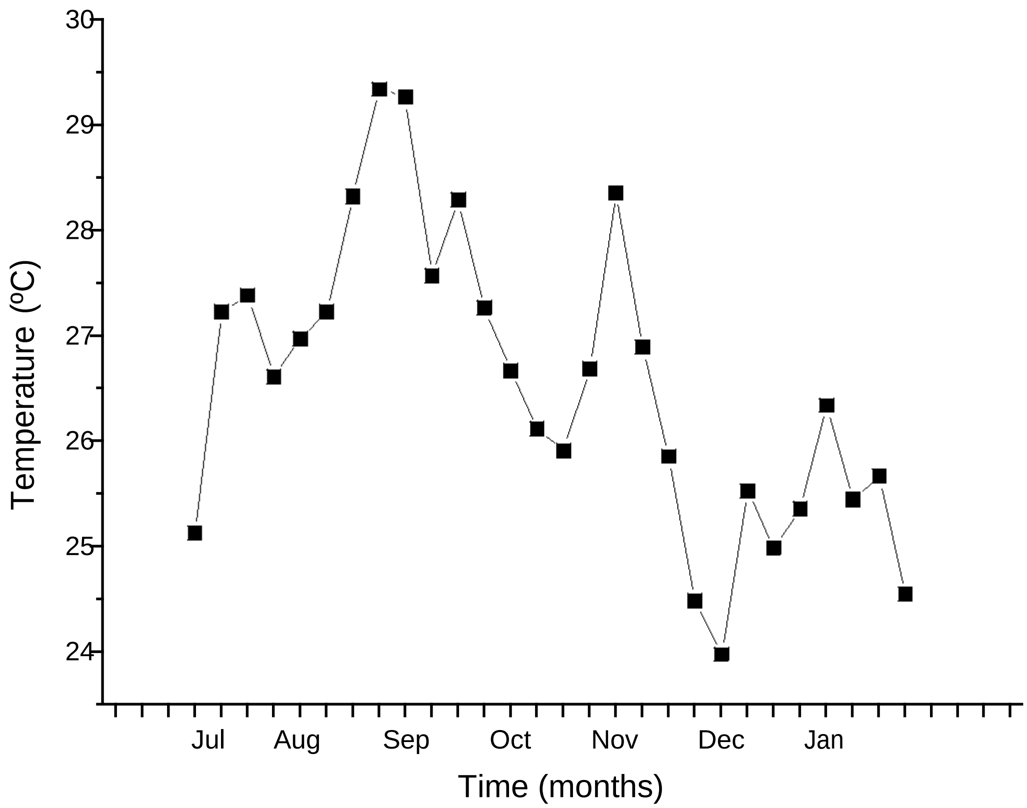

Figure 2. Water temperature recorded during the production cycle, July, 2008 – January, 2009.

presented in Figure 5. These results show the high performance of the sediment collector involved in the recirculation system prior to the sand and gravel filters and the biofiltration stage. All of which guarantee a lack of solid matter that generate dissolved oxygen consump-tion (Tafangenyasha and Dube, 2008) in the tanks.

Total ammonia nitrogen

The TAN concentrations are often a factor that reduces water quality in intensive aquaculture systems (Grommen et al., 2002). Therefore, high concentrations must be avoided. In this investigation, the TAN concentration was found to be between 1.67 and 3.67 mg/l which corres-pond with the results obtained by Shnel et al. (2002) in similar conditions (Figure 6). This TAN concentration is widely accepted in order to obtain high fish growth and survival rates. These results show the biofilter high effi-ciency in the removal of TAN from the water. Conse-quently, this recirculation aquaculture system can be used in production systems to decrease the water wastage and

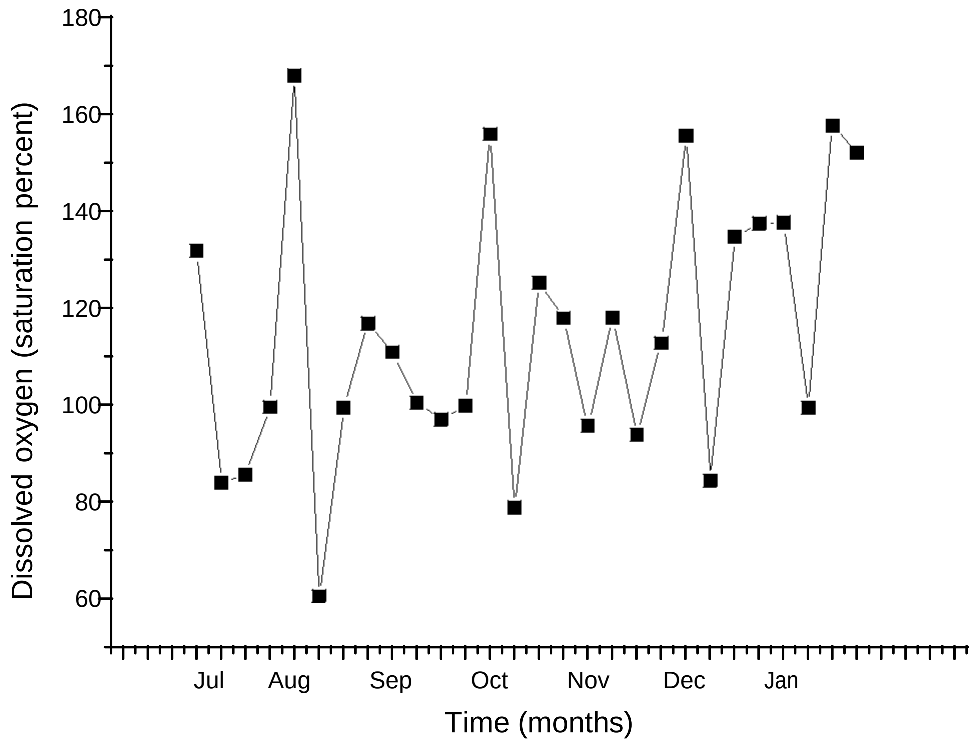

Figure 3. Recordings of water dissolved oxygen during the production cycle, July, 2008 – January, 2009.

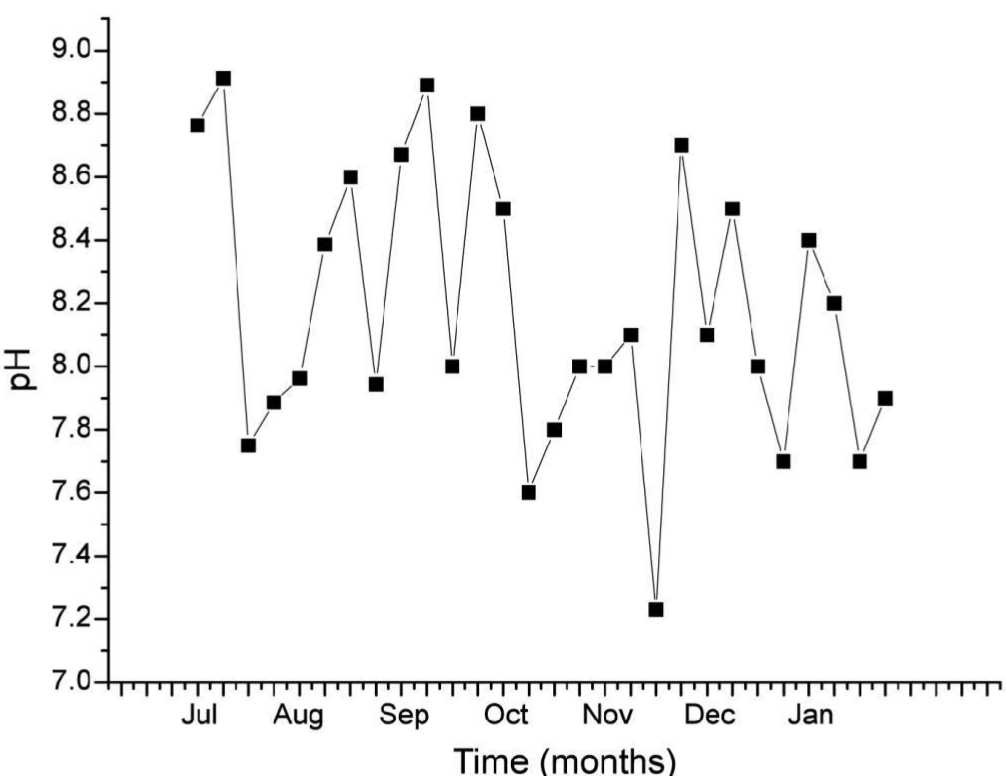

Figure 4. Water pH readings fluctuation during the production cycle, July, 2008 – January, 2009.

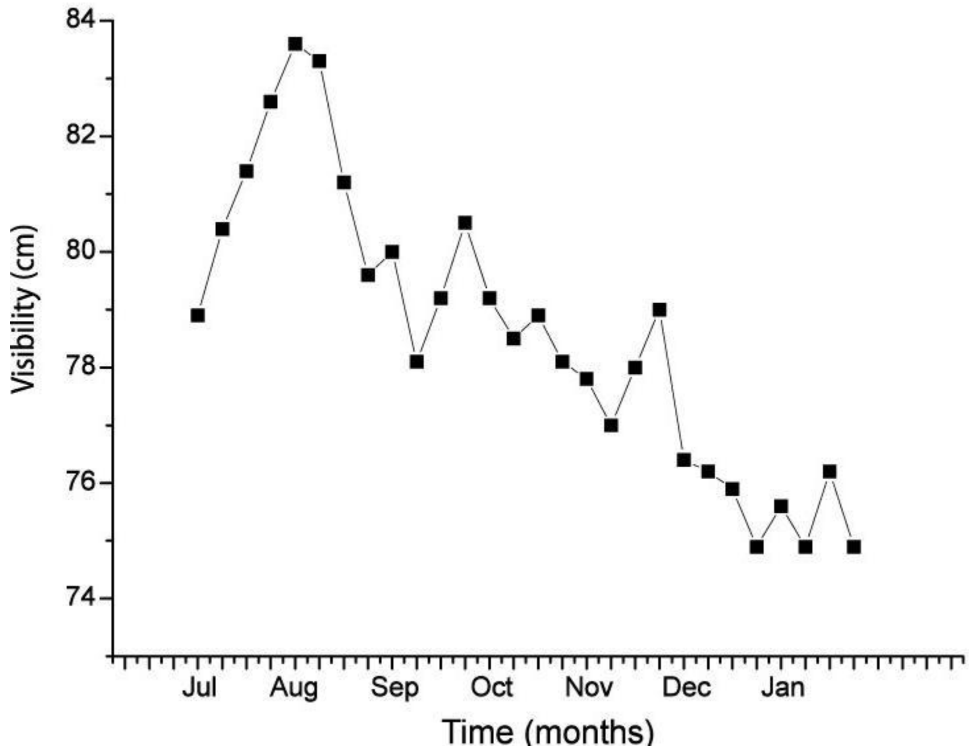

Figure 5. Water visibility recorded during the production cycle, July, 2008 – January, 2009.

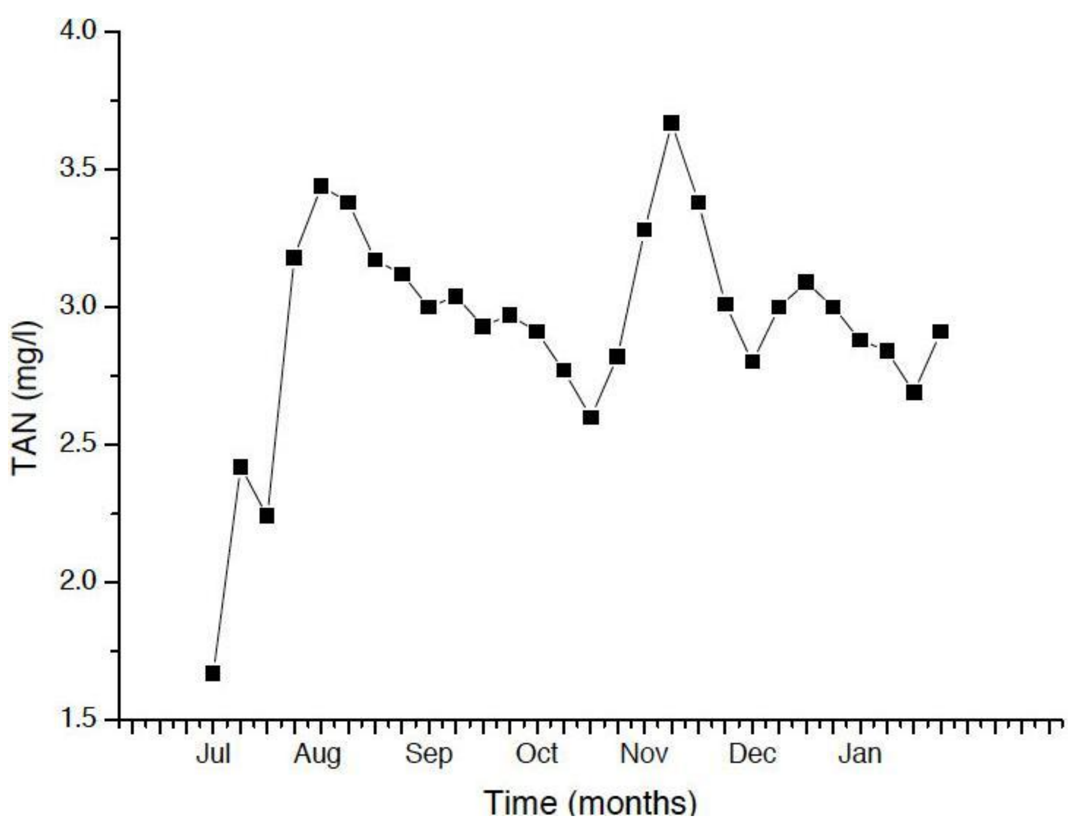

Figure 6. Water TAN recordings during the production cycle, July, 2008 - January, 2009.

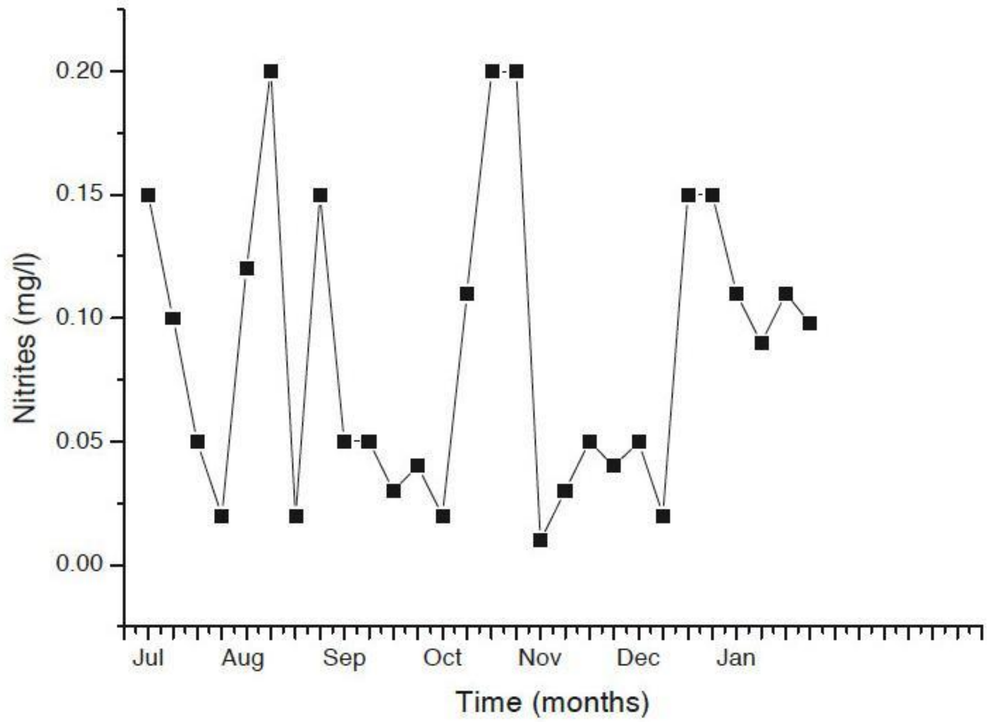

Figure 7. Water nitrites recordings during the production cycle, July, 2008 – January, 2009.

achieve high yields optimizing the use water, most notable in areas were water is scarce.

Nitrites

The nitrites recorded during the production cycle are presented in Figure 7. The measurements ranged between 0.01 and 0.21 mg/l with an average measurement of 0.11 mg/l. This is considered to be an acceptable nitrite concentration for fish production in order to avoid lethal and sub-lethal levels that can in turn cause massive death which translates to huge economic losses for the fish farmer, as has been reported by Blancheton, (2000). These results also show the high performance and capability of the proposed recirculation aquaculture system in the removal of the undesired nitrogen compounds with higher toxic levels for the fish. All of this guarantees that the fish water is kept at acceptable conditions without water wastage through the use of the flow holders within the production system.

Nitrates

Nitrates are one component with minor toxicity levels for the fish. These levels are obtained by use of the second step of the nitrification process. However, not all nitrogen components are desirable in the fish water. The task of the operator of any recirculation system for the purpose of aquaculture is to remove the nitrogenous components or reduce them to form other compounds with less toxic levels, such as nitrate. In this investigation the nitrate level was found to be between 0.1 and 5.8 mg/l with an average of 1.47 mg/l which is considered acceptable for fish production. The nitrates dynamic during the production cycle is presented in Figure 8.

Fish growth

At the beginning of the experiment, July of 2008, the average weight of fish in the tanks was 20.23 g. At the end of the experiment, January of 2009, the average fish weight was 484.25 g. The fish biomass produced in the four tanks at the end of the experiment was of 2312.78 kg. The feed intake was of 3786.74 kg and the feed conversion rate achieved was of 1.64. The average survival in the four tanks was 99.5%. Details of final production in each tank are presented in Table 3.

Water used during the experiment

The objective of water treatment plants in aquaculture is to maintain the variables within the acceptable ranges for

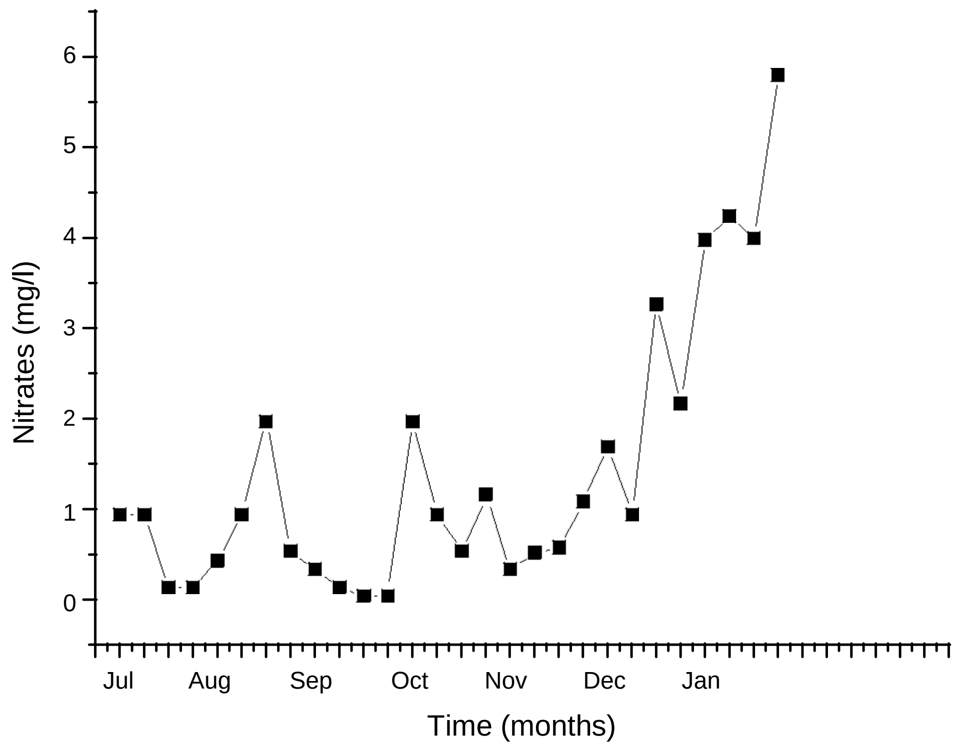

Figure 8. Water nitrates recordings during the production cycle, July, 2008 – January, 2009.

Table 3. Results about the fish growth at the end of the experiment using the recirculation system.

Production results	Tank 1	Tank 2	Tank 3	Tank 4
Initial average tilapia weight (kg)	0.02	0.02	0.02	0.02
Final average tilapia weight (kg)	0.49	0.50	0.47	0.49
Initial fish quantity	1200	1200	1200	1200
Total tilapia biomass produced (kg)	580.33	591.62	559.99	580.84
Feed intake (kg)	940.13	970.26	929.58	946.76
Feed conversion rate	1.62	1.64	1.66	1.63
Survival (%)	99.10	99.60	99.50	99.80

fish growth and survival, as well as, to reduce the waste water. At the beginning of the experiment, 80 m^3 of water were used to fill the four tanks. During the experiment, the total water evaporation inside the greenhouse was approximately 7 m^3. The water quantity used to compensate the sludge extraction was of 21 m^3.

Conclusions

Recirculation aquaculture systems built with low cost local materials easily accessible showed high performance. The system discussed in the present study allows viable solutions which also reduce water wastage in aquaculture in order to achieve maximum production which will therefore result in greater economic gains for aquaculture farmers or simply for self-consumption. Considering that traditional aquaculture systems in general use continuous water flows without proper treatment and that these systems represent potentially negative ecological impacts, it is very important to create an ecological conscience in the farmers. The proposed recirculation system is a very feasible approach to use in aquaculture production and allow increase the water use efficiency.

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