



Latin American Journal of Aquatic Research

E-ISSN: 0718-560X

lajar@ucv.cl

Pontificia Universidad Católica de Valparaíso  
Chile

Gullian-Klanian, M.; Arámburu-Adame, C.  
Performance of Nile tilapia *Oreochromis niloticus* fingerlings in a hyper-intensive recirculating  
aquaculture system with low water exchange  
Latin American Journal of Aquatic Research, vol. 41, núm. 1, 2013, pp. 150-162  
Pontificia Universidad Católica de Valparaíso  
Valparaiso, Chile

Available in: <http://www.redalyc.org/articulo.oa?id=175025740011>

- How to cite
- Complete issue
- More information about this article
- Journal's homepage in redalyc.org

redalyc.org

Scientific Information System  
Network of Scientific Journals from Latin America, the Caribbean, Spain and Portugal  
Non-profit academic project, developed under the open access initiative

## Research Article

# Performance of Nile tilapia *Oreochromis niloticus* fingerlings in a hyper-intensive recirculating aquaculture system with low water exchange

M. Gullian-Klanian<sup>1</sup> & C. Arámburu-Adame<sup>1</sup>

<sup>1</sup>Universidad Marista de Mérida, Periférico Norte Tablaje Catastral 13941, Carr. Mérida-Progreso  
P.O. Box 97300, Mérida, Yucatán, México

**ABSTRACT.** The aim of this paper was evaluate the performance of Nile tilapia fingerlings (*Oreochromis niloticus*) raised at hyper intensive stocking density in a recirculating aquaculture system (RAS) with minimum water replacing. The experimental system was performed in a single-batch nursery system to obtain 50 g fish size in 60 days. Fish ( $2.07 \pm 0.04$  g) were stocked in triplicate at 400 (T1), 500 (T2) and 600 (T3) fish  $m^{-3}$  (0.84, 1.05, 1.22  $kg\ m^{-3}$ ). RAS functioned with 12,000 L of recirculating water and 252 L  $day^{-1}$  of water replacing (2.1% daily). The efficiency of the biofilter for removing the total ammonia nitrogen (TAN) was  $48 \pm 12.5\ mg\ L^{-1}$ . Stocking density did not affect significantly the survival (89.5 to 93.6%). The growth rate of T1 ( $0.96\ g\ day^{-1}$ ;  $5.01\%\ day^{-1}$ ) and T2 ( $0.92\ g\ day^{-1}$ ;  $4.95\%\ day^{-1}$ ) was significantly higher than T3 ( $0.83\ g\ day^{-1}$ ;  $4.80\%\ day^{-1}$ ). The specific growth rate (SGR) of T1 was 41% influenced by temperature. For T2 and T3 the SGR were influenced by the variation of dissolved oxygen (DO) that explained 47 and 44% of the fish weight variation, respectively. The SGR from T3 was also affected by the concentration of ammonia nitrogen (31%). The high stocking density affected the overall size of fish and the size homogeneity, but had no negative effect on the length–weight relationship (L-W). Data support the conclusion that fingerling stocked at 400 and 500 fish  $m^{-3}$  shows high performance during 9-weeks when the biomass not exceed  $37\ kg\ m^{-3}$ . At this time fish have reached the desired final nursery weight (50 g) for transfer to grow-out facilities.

**Keywords:** Nile tilapia, recirculating aquaculture system, low water exchange, intensification.

## Rendimiento de juveniles de tilapia del Nilo *Oreochromis niloticus* en un sistema híperintensivo de recirculación acuícola con mínimo recambio de agua

**RESUMEN.** El objetivo de este trabajo fue evaluar el rendimiento de juveniles de tilapia del Nilo *Oreochromis niloticus* sembrados en densidades hiperintensivas en un sistema de recirculación acuícola (SRA) con mínimo remplazo de agua. El sistema experimental consistió en un sistema de precría de cosecha única para obtener peces de 50 g en 60 días. Los peces ( $2.07 \pm 0.14$  g) se sembraron por triplicado a densidades de 400 (T1), 500 (T2) y 600 (T3) peces  $m^{-3}$  (0.84; 1.05; 1.22  $kg\ m^{-3}$ ). El SRA funcionó con 12,000 L de agua recirculante y un remplazo diario de 252 L (2.1% por día). La densidad de siembra no afectó significativamente la supervivencia (89.5-93.6%). El biofiltro removió el amonio nitrogenado total con una eficiencia del  $46.9 \pm 7.0\%$ . La tasa de crecimiento de T1 ( $0.96\ g\ día^{-1}$ ;  $5.01\%\ día^{-1}$ ) y T2 ( $0.92\ g\ día^{-1}$ ;  $4.95\%\ día^{-1}$ ) fue significativamente mayor que T3 ( $0.83\ g\ día^{-1}$ ;  $4.80\%\ día^{-1}$ ). La temperatura influyó 41% en la tasa de crecimiento específico (TCE) de T1. La concentración de oxígeno disuelto (DO) influyó en la variación de peso en T2 (47%) y T3 (44%). La TCE de T3 también se vio afectada por la concentración de nitrógeno amoniacal (31%). El aumento de la densidad de siembra afectó el tamaño y la homogeneidad de tallas de los peces, pero no afectó la relación longitud-peso (L-P). Los datos respaldan la conclusión que los juveniles sembrados a densidades de 400 y 500 peces  $m^{-3}$  tienen alto rendimiento durante nueve semanas consecutivas, siempre y cuando la biomasa no se exceda de  $37\ kg\ m^{-3}$ . En este tiempo los peces alcanzan el peso final esperado de precría (50 g) y pueden ser transferidos hacia las instalaciones de engorde.

**Palabras clave:** tilapia del Nilo, sistema de recirculación acuícola, bajo recambio de agua, intensificación.

## INTRODUCTION

Tilapia culture has traditionally relied on extensive and semi-intensive systems in earthen ponds or cages. The expansion of tilapia culture across the world, together with the shortage of freshwater and competition for it with agriculture and with urban activities has gradually shifted tilapia culture from traditional semi-intensive systems to more intensive production systems (El-Sayed, 2006).

Tilapia culture in Mexico is widely diversified in terms of geography and methods of production. Semi-intensive culture is practiced in small water bodies and ponds, with stocking density range of 4 to 6 fish  $\text{m}^{-3}$  and yields of 1 to 4 ton  $\text{ha}^{-1}$  per production cycle (Hernández-Mogica *et al.*, 2002; Ponce-Marbán, 2006). Intensive culture is practiced in cages, raceways, ponds, and secondary or tertiary irrigation channels (Arredondo & Lozano, 2003). The stocking densities vary from 80 to 100 fish  $\text{m}^{-3}$  and the annual production ranges from 1.5 ton  $\text{ha}^{-1}$  in rustic ponds to 25 ton  $\text{ha}^{-1}$  in raceways (Camacho-Berthely *et al.*, 2000). In 2006, the production of tilapia reached a maximum of 81,250 ton, of which the 98% came from nine states of Mexico. Although the favourable mean annual temperature (28.5°C), the Yucatan state located at the southeast Gulf of Mexico occupied the place number 28 in the national production ranking (CONAPESCA, 2010). Its particular geological and hydrographical characteristics, such as the lack of rivers and surface water, and the karst and impermeable soils, have prevented producers to adopt tilapia farming technologies from other regions of Mexico. In this sense, the development of the commercial-scale aquaculture in the Yucatan state requires the construction of tanks and pumping of groundwater, which would bring an increase in investments and production costs, making this activity not always profitable. At present, 82% of farmers are growing tilapia at intensive levels (80 fish  $\text{m}^{-3}$ ) and 100% use circular tanks (Vivanco-Aranda *et al.*, 2011). However, the intensification should be increased over 150 fish  $\text{m}^{-3}$  to meet financial outcomes (Arámburu-Adame, 2011).

Recirculating aquaculture systems (RAS) are characterized by the ability to support extremely high stocking densities and high net production compared with open aquaculture systems (Timmons *et al.*, 2002). For example, using a RAS, it is possible to produce over 45,000 kg of fish in a 464  $\text{m}^2$  building, whereas an 8 ha of outdoor ponds would be necessary to produce an equal amount of fish, with the traditional open pond culture (Helfrich & Libey, 1990). Similarly, since water is reused, the water

volume requirements in RAS are only about 20% of what conventional open pond culture demands. RAS offers a promising solution to water use conflicts, water quality, and waste disposal. Raceways, for example require, on the average, 2.9 to 3.6  $\text{L min}^{-1}$  of flow available for each kg of biomass (Parker, 2011). Nevertheless, RAS consume approximately 250-1000  $\text{L kg}^{-1}$  of fish, and discharge less effluent compared with open systems, reducing the volume and cost of wastewater treatment (Shnel *et al.*, 2002). In RAS the water is reconditioned by clarification, biological filtration and re-aeration, so that most of the water is reused, and only 10% of the total daily flow is replaced by new water, to compensate water evaporation and for diluting the nitrate concentration (Timmons *et al.*, 2002). The productive capacity of RAS depends on the ability of the biological, chemical and physical treatment units to remove waste, as well as on the volume of replacement water used to improve water quality.

Performance data on tilapia in RAS are scarce, particularly at intensive stocking densities. Two production modalities have been reported for recirculating tilapia systems with different performance; nursery (1 to 50 g), and grow-out phase (50 g to market-size). Most authors report performance data from the grow-out stage. Suresh & Lin (1992), reported a relatively low growth (0.77, 0.65 and 0.64  $\text{g day}^{-1}$ ) of red tilapia *Oreochromis aureus* (75 g) stocked in RAS, at 50, 100 and 200 fish  $\text{m}^{-3}$  (3.6, 7.5, 15.3  $\text{kg m}^{-3}$ ) for 70 days. Ridha & Cruz (2001), reported high growth rate (1.17  $\text{g day}^{-1}$ ) and 97.6% of survival in Nile tilapia *Oreochromis niloticus* (62 g) reared in RAS at 166 fish  $\text{m}^{-3}$  (10.3  $\text{kg m}^{-3}$ ). Initially, 20-30% of the system water was changed with new water, to dilute the high levels of ammonia and nitrites; however, as the experiment progressed, the daily water exchange rate was reduced to 10-15%. Performance data about the intensification of Nile tilapia at nursery phase is even scarcer. Bailey *et al.* (2000) performed an experiment to study the intensive production of Nile tilapia fingerlings (4.3 g) in RAS. Fish stocked at 200 fish  $\text{m}^{-3}$  grew slightly faster (0.78  $\text{g day}^{-1}$ ) than those stocked at 450 fish  $\text{m}^{-3}$  (0.60  $\text{g day}^{-1}$ ). The total ammonia nitrogen (TAN) ranged from 0.82 to 1.33  $\text{mg L}^{-1}$  and nitrate from 1.3 to 83.8  $\text{mg L}^{-1}$ . The heterogeneity of size was pronounced in both treatments, where over 50% of the population in each treatment was greater than the desired 50 g-size.

Good aquaculture practices should minimize the increase of size heterogeneity over time, in order to minimize food wastage that may result from the establishment of dominance hierarchies as size heterogeneity soars (Jobling & Baardvik, 1994).

Partial harvesting is useful in some types of systems, where only large individuals are caught and the smallest are left in the system to grow larger. However, besides the increase in labour and facilities, partial harvest in RAS increases the water losses associated for harvesting procedures and also makes difficult the correct supply of food with appropriate pellet sizes. The aim of the present study is to evaluate the performance of Nile tilapia fingerlings, raised at hyper intensive stocking density, in a RAS with minimum water replacing. The experimental system is performed for a nursery with a single-batch, for obtaining a desired 50 g-fish size in 60 days harvest. The study recorded grow-out and survival data of fish and monitored water quality parameters as indicators of the system performance.

## MATERIALS AND METHODS

### Experimental fish

Sex-reversed Nile tilapia *Oreochromis niloticus* fingerlings ( $2.07 \pm 0.04$  g), were acquired from a commercial farm (Tabasco, México) and transported in oxygenated plastic bags to the experimental unit of the Universidad Marista de Mérida (México).

### Experimental facilities and design

The experiment was performed in a RAS, which consisted of nine circular indoor tanks ( $1.2 \text{ m}^3$  each), containing 12,000 L of total recirculating water. The system included a  $2.7 \text{ m}^2$  concrete settling basin, two  $5 \text{ }\mu\text{m}$ -capacity filter cartridges (10 inch Big Blue<sup>TM</sup>), and a wet/dry trickle filter with  $405 \text{ m}^2 \text{ m}^{-3}$  of substrate area (Ultra Fibra, México). Water was continuously recirculated from the rearing tanks through the sedimentation area and pumped (Venus, 1 HP) through the filter cartridges to the biological filter. A protein skimmer (200 x 800 mm) was installed between the biofilter and the aeration system. The water flow rate was adjusted to  $80 \text{ L min}^{-1}$ . The dissolved oxygen (DO) concentration was increased using a 1 HP blower (Sweetwater) with air diffusers. Ion profile of groundwater using in the RAS was:  $86.1 \text{ mg L}^{-1} \text{Ca}^{2+}$ ,  $27.6 \text{ mg L}^{-1} \text{Mg}^{2+}$ ,  $126 \text{ mg L}^{-1} \text{Cl}$ ,  $376.2 \text{ mg L}^{-1} \text{CaCO}_3$  of hardness,  $325.5 \text{ mg L}^{-1} \text{CaCO}_3$  of alkalinity and  $\text{pH} = 7.0$ . The biofilter was inoculated with  $45 \text{ mg L}^{-1}$  of ammonium chloride ( $\text{NH}_4\text{Cl}$ ) and  $70 \text{ mg L}^{-1}$  of sodium nitrite ( $\text{NaNO}_2$ ) twice during the first week prior to stocking with fish. The water level indicator placed into each tank was used to estimate daily water loss in the RAS. Accordingly, an equal volume of water was replaced three times a week.

Nile tilapia fingerlings ( $2.07 \pm 0.14$  g) were stocked at  $T_1 = 400$ ,  $T_2 = 500$  and  $T_3 = 600 \text{ fish m}^{-3}$  (0.84, 1.05,  $1.22 \text{ kg m}^{-3}$  respectively) with three replicates of each density, and fed three times a day for 70 days. Commercial floating pellet containing 40% crude protein and  $3400 \text{ kcal kg}^{-1}$  metabolizable energy (Nutripec, Purina) was used until the fish reached 35 g of body weight (BW). After that, fish were fed with 32% protein and  $3,152 \text{ kcal kg}^{-1}$  ME until harvest. The weekly feeding rate was adjusted according to a 1:5 feed conversion ratio (FCR), declining from 4.5 to 3.8% BW at the 5 week, and continuing at 3.1% BW until harvest.

### Fish growth

Each week, 45 fish from each tank were individually weighed and their total length measured. Fish were removed from each tank using a minnow seine, and returned to the tank following measurement. The sample size ( $n$ ) required for estimating growth was calculated with a 15% relative error and 0.05% confidence level (Zar, 1999). A digital scale (Ohaus, 0.01 g) was used to record fish weight and a vernier caliper (Westward, 0.01 mm) was used to estimate length. At the end of the 11<sup>th</sup> week all fish were harvested, weighed and counted. The absolute growth rate (AGR,  $\text{g day}^{-1}$ ) was estimated for each treatment as a function of  $W_t - W_i$  over time ( $t$ ) where:  $W_t$  and  $W_i$  is the final and initial weight, respectively, and  $t$  is the number of days in the experimental period. The specific growth rate (SGR,  $\% \text{ day}^{-1}$ ) was estimated as  $(\ln W_t - \ln W_i) 100 t^{-1}$ . Mortality was recorded every day, and calculated according to the difference between the number of fish stocked and harvested. Gross yield ( $\text{kg m}^{-3}$ ) was calculated as the sum of individual weights of harvested fish. The ratio of feed fed (kg) to wet fish weight gain during the feeding period was expressed as FCR.

### Water quality parameters

Water temperature and dissolved oxygen (DO), in each tank, were measured three times a day using an oxymeter (YSI 200). Weekly measurements were taken of ammonium ( $\text{NH}_4^+$ ), nitrite ( $\text{NO}_2^-$ ), nitrate ( $\text{NO}_3^-$ ), pH and total organic carbon (TOC). All water samples were collected in triplicate and analyzed in the laboratory. Total ammonia nitrogen (TAN) was determined using the salicylate hypochlorite method (Solorzano & Sharp, 1980). The concentration of unionized ammonia nitrogen ( $\text{NH}_3\text{-N}$ ) was calculated according to Thurston *et al.* (1979). Nitrite nitrogen was determined using sulphanilamide in an acid solution.  $\text{NO}_3\text{-N}$  was measured as  $\text{NO}_2\text{-N}$  after its reduction in a Cd-Cu column (Strickland & Parsons,

1972). TOC was determined using the heated-persulfate oxidation method (Clescerl *et al.*, 2000). The pH was measured with a pH meter (Oakton 510). At harvest, three effluent samples were collected in quadruplicate at the beginning, middle, and end of the discharge. Samples were pooled to analyze total phosphorus and total nitrogen concentrations, using Kjeldahl and ammonium molybdate methods (APHA, 1999).

### Removal efficiency of solid and soluble waste

Weekly water samples were also collected in triplicate from the pre- and post-settling basin and from the pre- and post-biofilter, to estimate the TOC, TAN and the C/N ratio (TOC/TAN). The loading rate and the removal efficiency of solids and TAN was determined using the formula proposed by Suresh & Lin (1992); loading rate =  $C_i \times Q$ ; and removal efficiency (%) =  $[(C_i - C_e) \times Q / (C_i \times Q)] \times 100$ , where  $C_i$ : affluent concentration,  $C_e$ : effluent concentration,  $Q$ : flow rate.

The abundance of total heterotrophic bacteria (HB) was determined in the laboratory by the standard plate count method (Norrell & Messley, 1997). Samples were blended at 16,000 rpm for 1 min to achieve the greatest recovery of HB attached to suspended solids. Serial 10-fold dilutions were made transferring 1 mL of sample into 0.9% NaCl sterile solution. For each sample, five dilutions were plated over Nutrient Agar (Difco, 213000), in triplicate. Incubation was performed at  $28 \pm 1^\circ\text{C}$  for 48 h (Isotemp 625D, Fisher Scientific). The number of surviving HB was evaluated as the mean number of colony-forming unit (CFU) per dilution, multiplied by the dilution factor. Results were expressed as CFU  $\text{mL}^{-1}$  of water and correlated with TOC concentration.

### Data analysis

Survival percentage data were converted to arcsine x square root, before statistical analysis. Analysis of variance (one-way ANOVA) was used to test the effect of stocking density on fish growth rate and survival. Final weight, was tested via analysis of covariance (ANCOVA) using the initial body weight as the covariate. Significance of water quality parameters, between treatments and over weeks, was evaluated at the 0.05-probability level using ANOVA and Tukey test. Before performing the ANOVA and ANCOVA, the data were checked for normality and homogeneity of variance using a Shapiro-Wilks test and F distribution, respectively.

The statistical significance of the effect of each water quality variable (predictors) on SGR (response variable), was evaluated by forward stepwise regression. The quality of the regression model was

judged by the SGR variability described by the systematic predictor in order to present only the significant water quality variables. The Monte Carlo permutation, with 5000 permutations, was used to assess the quality of each potential predictor to extend the subset of the response variable used in the regression model (Braak & Smilauer, 2002). Significant water parameters were added to the Gompertz model

$$w(t) = ae^{be^{ct}}$$

to obtain the predicted trend line of growth, where  $a$  represents the initial weight,  $b$  is the weekly growth rate, and  $c$  is the fitting parameter number (Ricker, 1975). Curve fitting parameters were estimated using the Rosenbrock and quasi-Newton method ( $P < 0.05$ ). The predicted curve reliability was examined for likelihood and accuracy, using Theil's inequality coefficient (Pindyck & Rubinfeld, 1991). Thiel's inequality coefficient ( $U$ ) can be interpreted as follows:  $U = 0$ , means that the estimated data has the same trend line as the observed data;  $U = 1$ , means the worst fit. Therefore, a Thiel's  $U$  close to zero corresponds to the best data-fitting curve.

The relationship between total length and weight (L-W), in each treatment, was analyzed using the statistical significance of the isometric exponent  $b$  and adjusted using the potential model:  $W_i = a TL_i^b$ , where  $TL$  is the total length,  $a$  is the proportionality constant and  $b$  the isometric exponent (Pauly, 1984). In order to define the isometric or allometric L-W relationship, the  $b$  value was tested by the expression  $t_b = |b-3|/S_b$  and checked on a one-tailed test. Statistical analysis was conducted using Statistics 5 and CANOCO software.

## RESULTS

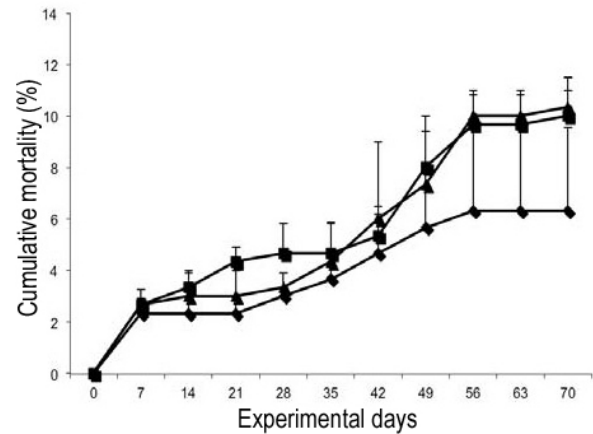
### Effect of density on fish growth and survival

Stocking density had a significant effect on the absolute growth rate (AGR) ( $F_{(2,6)} = 13.3$ ,  $P < 0.05$ ), specific growth rate (SGR) ( $F_{(2,6)} = 10.6$ ,  $P < 0.05$ ) and the final weight ( $F_{(2,6)} = 12.7$ ,  $P < 0.05$ ). The growth and final weight were higher at the lower densities ( $T1 = 400 \text{ fish m}^{-3}$ ,  $T2 = 500 \text{ fish m}^{-3}$ ) than at the highest density ( $T3 = 600 \text{ fish m}^{-3}$ ). Total gross yield increased with increasing stocking density but fish from  $T3$  were significantly smaller than those in  $T1$  and  $T2$  (Table 1). Fish survival decreased with increasing stocking density but no significant differences were found between treatments (Table 1). Cumulative mortality was less than 5% during the first month, after which the rate increased, particularly with medium and high densities (Fig. 1). According to the slope

**Table 1.** Performance of Nile tilapia fingerlings (*Oreochromis niloticus*) cultured in a recirculating system for 70 days.

Stocking density (Fish m <sup>-3</sup> )	Stock data		Growth data				Harvest data							
	Initial weight (g)		AGR (g day <sup>-1</sup> ) <sup>a</sup>		SGR (% day <sup>-1</sup> ) <sup>b</sup>		Final weight (g)		Survival (%)		FCR <sup>c</sup>		Gross yield (kg m <sup>-3</sup> )	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
400 (T1)	2.10 <sup>a</sup>	0.05	0.96 <sup>a</sup>	0.01	5.01 <sup>a</sup>	0.02	68.8 <sup>a</sup>	1.04	93.6 <sup>a</sup>	1.81	1.27	0.03	37.1 <sup>a</sup>	1.27
500 (T2)	2.09 <sup>a</sup>	0.10	0.92 <sup>a</sup>	0.02	4.95 <sup>a</sup>	0.09	66.3 <sup>a</sup>	1.20	91.8 <sup>a</sup>	1.43	1.39	0.04	43.8 <sup>b</sup>	1.48
600 (T3)	2.03 <sup>a</sup>	0.04	0.83 <sup>b</sup>	0.02	4.80 <sup>b</sup>	0.03	59.8 <sup>b</sup>	1.19	89.5 <sup>a</sup>	0.67	1.78	0.02	46.4 <sup>b</sup>	1.14

Different letters indicate significant difference ( $P < 0.05$ ) between data in the same column. <sup>a</sup> Absolute growth rate, <sup>b</sup> Specific growth rate, <sup>c</sup> Food conversion ratio.



**Figure 1.** Cumulative mortality of Nile tilapia *Oreochromis niloticus* at three stocking densities in a recirculating system. ♦ 400 fish m<sup>-3</sup>, ■ 500 fish m<sup>-3</sup>, ▲ 600 fish m<sup>-3</sup>.

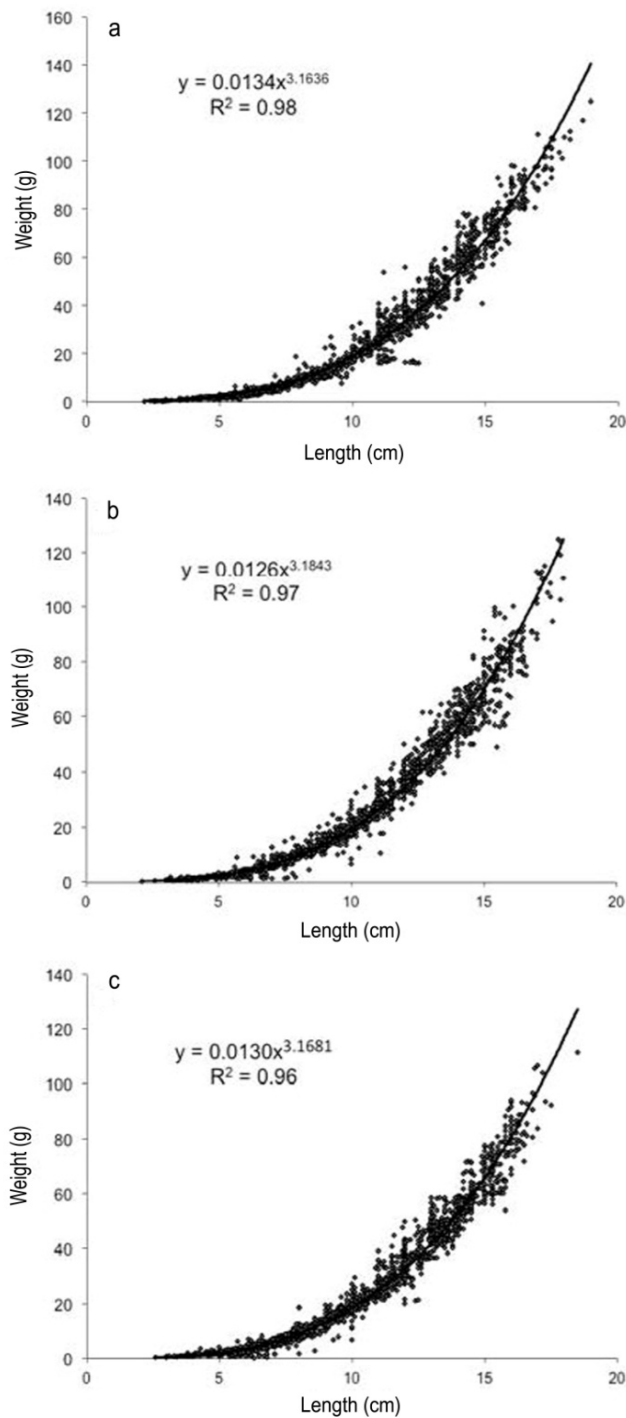
value (b), the fish length-weight (L-W) relationship of all treatments showed allometric growth [ $H_0 = b = 3$ ,  $H_a = b > 3$ ]; t-value = 43.8 (T2) and 34.3 (T1, T3),  $P < 0.05$ ), indicating a higher rate of growth in weight than in length (Tesch, 1968) (Fig. 2).

## Effects of water quality on fish weight and heterogeneity of population

Weekly variations in water quality parameters are presented in Table 2. The mean values were  $25.6 \pm 1.9^{\circ}\text{C}$ ;  $5.1 \pm 0.6 \text{ mg L}^{-1} \text{ DO}$ ;  $0.20 \pm 0.16 \text{ mg L}^{-1} \text{ NH}_3\text{-N}$ ;  $0.61 \pm 0.55 \text{ mg L}^{-1} \text{ NO}_2\text{-N}$ ,  $22.3 \pm 9.9 \text{ mg L}^{-1} \text{ NO}_3\text{-N}$  and  $7.79 \pm 0.33 \text{ pH}$ . Water parameters explained 71, 77 and 83% of the SGR variability for T1, T2 and T3, respectively (Table 3). The SGR of T1 was mainly influenced by temperature ( $P < 0.05$ ), which explained 41% of the variance in the fish growth. Fish growth from T2 was influenced by DO variation that explained 47% of the variance. The SGR from T3 was significantly affected by both DO (44%) and ammonia nitrogen (31%). Each significant water variable was added in the Gompertz model to plot the weekly increase of fish BW (Fig. 3). Thiel's inequality coefficient (U) was 0.174, 0.195 and 0.181 for T1, T2 and T3, respectively. Data clearly show a high standard deviation of fish weight that increased during the experiment (Fig. 4). The estimated growth rate, taking into account the heterogeneity in size, was 6.52, 4.68 and 4.44  $\text{g week}^{-1}$  for T1, T2 and T3 respectively.

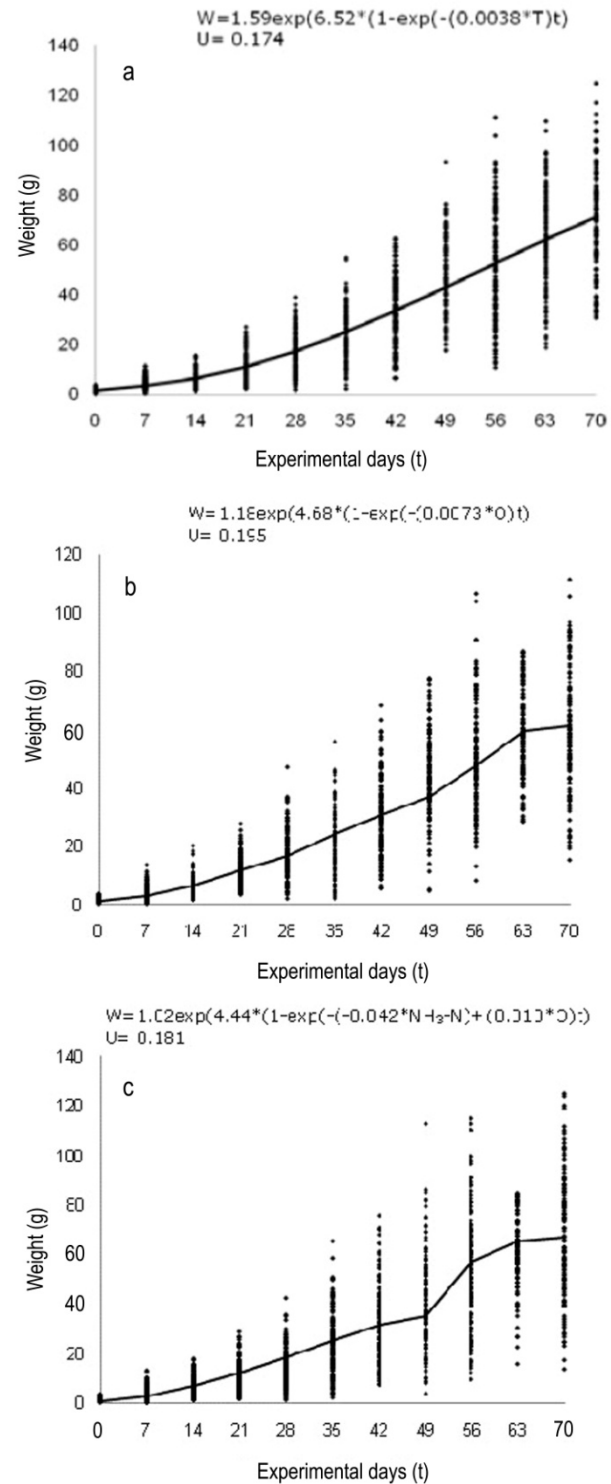
### Performance of waste treatment system

RAS functioned during 70 days with 12,000 L of recirculating water and replacing an average of 252 L day<sup>-1</sup>. Daily water loss was 2.1% on the average. The



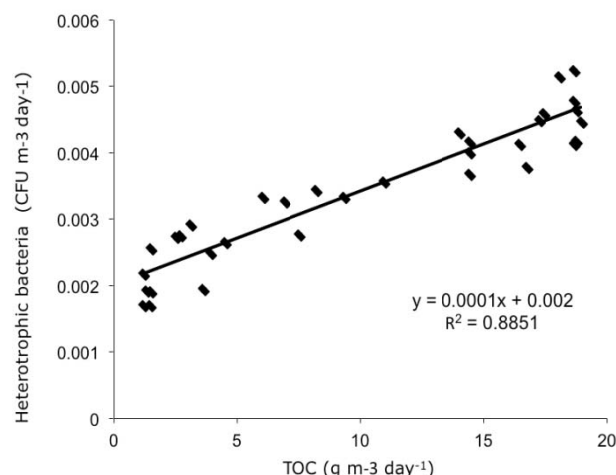
**Figure 2.** Length-weight (L-W) relationship of Nile tilapia *Oreochromis niloticus* at three stocking densities in a recirculating system. a) 400 fish  $m^{-3}$ ; b) 500 fish  $m^{-3}$ ; c) 600 fish  $m^{-3}$ . Point: mean data; Line: trend line.

specific water consumption was  $108.7 \text{ L kg}^{-1}$ . The efficiency of the settling basin and the bio-filter for suspended solids removal and TAN varied during the



**Figure 3.** Growth of Nile tilapia *Oreochromis niloticus* at three stocking densities in a recirculating system. a) 400 fish  $m^{-3}$ , b) 500 fish  $m^{-3}$ , c) 600 fish  $m^{-3}$ . Point: observed data, Line: predicted data.

experimental period. Increasing TOC indicated a decrease in the ability of the settling basin to remove



**Figure 4.** Relationship between total number of heterotrophic bacteria and total organic carbon (TOC) from the biofilter outlet of the recirculating tilapia system.

suspended solids. After the 6<sup>th</sup> week, rates of TOC removal were low (Table 4). The concentration of heterotrophic bacteria increased by 40% from the beginning (0.0019 CFU m<sup>3</sup> day<sup>-1</sup>) up to the end of the trial (0.0047 CFU m<sup>3</sup> day<sup>-1</sup>), and it was directly related to the increase of TOC (Fig. 4). The removal efficiency of TAN was relatively constant throughout the experiment (Table 4). The weekly loading of TAN was  $48 \pm 12.5$  mg L<sup>-1</sup> and the removal efficiency of the biofilter was  $46.9 \pm 7.0\%$ . The level of TAN in the water of different treatments was  $0.36 \pm 0.33$ ,  $0.52 \pm 0.56$  and  $0.62 \pm 0.41$  mg L<sup>-1</sup> for T1, T2 and T3, respectively. At harvest, the concentration of total nitrogen and total phosphorus from the effluent was  $25.6 \pm 5.1$  mg L<sup>-1</sup> and  $1.75 \pm 0.13$  mg L<sup>-1</sup>, respectively.

## DISCUSSION

Results showed the biological feasibility of culturing tilapia fingerlings at hyper intensive densities in RAS. The simple design-RAS used was successful in maintaining water quality within acceptable limits, requiring only 2.1% of daily water replacement. Mean temperature ( $25.6 \pm 1.9^\circ\text{C}$ ), ammonia nitrogen ( $0.20 \pm 0.16$  mg L<sup>-1</sup> NH<sub>3</sub>-N), and nitrite nitrogen ( $0.61 \pm 0.55$  mg L<sup>-1</sup> NO<sub>2</sub><sup>-</sup>-N), remained within the optimal range for the growth of Nile tilapia (Popma & Masser, 1999; Ross 2000). Stocking density did not affect significantly the survival (89.5 to 93.6%). Consequently T3 had the highest feed conversion ratio (FCR), given its high biomass. In general, the RAS supported  $37.1\text{--}46.4$  kg m<sup>-3</sup>, with a specific water consumption of  $108.7$  L kg<sup>-1</sup>.

Data of this study demonstrated that growth rate differences between stocking densities is due to the effect of weekly variation of the water parameters, in particular DO, NH<sub>3</sub>-N and temperature. The SGR of T2 and T3 was influenced by the DO variation, 47 and 44% respectively (Table 3). The influence of DO over the growth rate has been well established for tilapia species. Historical report of Tsadik & Kutty (1987), indicates a positive correlation between DO demand and AGR ( $r = 0.99$ ), and assimilation efficiency ( $r = 0.98$ ) of Nile tilapia. These authors reported a higher AGR ( $0.58$  g day<sup>-1</sup>) at  $7.3 \pm 2.6$  mg L<sup>-1</sup> of DO than at  $3.4 \pm 1.4$  mg L<sup>-1</sup> ( $0.15$  g day<sup>-1</sup>). Sofronios & Tziha (1996), reared Nile tilapia in RAS for 7 months obtaining an AGR of 1.6, 1.8 and 1.9 g day<sup>-1</sup> for DO levels of 2.62, 3.75 and 6.51 mg L<sup>-1</sup>, respectively. The growth rate was higher than our study; however, the stocking biomass is significantly less ( $0.0079$  kg m<sup>-3</sup>). The decline in individual growth rate with increasing stocking densities is a common occurrence that has been previously documented. This effect has been related to a social stress or chronic stress response, which may impair fish growth due to the mobilization of dietary energy by the physiological alterations provoked by the stress response (Kebus *et al.*, 1992). Thus, in the present study stocking density had a significant effect on the AGR and SGR. The growth rate of T1 ( $0.96$  g day<sup>-1</sup>;  $5.01\%$  day<sup>-1</sup>) and T2 ( $0.92$  g day<sup>-1</sup>;  $4.95\%$  day<sup>-1</sup>) was higher than T3 ( $0.83$  g day<sup>-1</sup>;  $4.80\%$  day<sup>-1</sup>); therefore the final weight of T1 and T2 ( $68.9$  and  $66.3$  g) was higher than T3 ( $59.8$  g).

Results of the present experiment showed that the SGR of T3 was also affected by the NH<sub>3</sub>-N concentration ( $0.25$  mg L<sup>-1</sup>) that was 58.6% higher than T1 ( $0.15$  mg L<sup>-1</sup>) and 1.19% higher than T2 ( $0.21$  mg L<sup>-1</sup>) (Tables 1, 3). Changes in water pH from present RAS indicated that the pH of T3 was higher than others treatments ( $7.97 \pm 0.31$ ), with a range of 7.12 to 8.40. Although that range is within the optimum values of pH recorded for Nile tilapia, there is more concentration of NH<sub>3</sub>-N toxic form at pH > 7.0 (Popma & Masser, 1999). The mean value of NH<sub>3</sub>-N ( $0.25$  mg L<sup>-1</sup>) would have no adverse effect on survival of T3, but possibly affected the growth rate. This data are in disagree with report done by Hargreaves & Kucuk (2001), which mentioned that continuous exposure to  $0.27$  mg L<sup>-1</sup> NH<sub>3</sub>-N (pH 8.0) did not affect SGR of blue tilapia reared at  $0.023$  kg m<sup>-3</sup>. However, the SGR reported by those authors ( $1.84\%$  day<sup>-1</sup>), was significantly lower than our study ( $4.95\%$  day<sup>-1</sup>), even at low stocking density. Bailey *et al.* (2000) reared Nile tilapia ( $4.3$  g) in RAS at the hyper intensive stocking densities of  $0.86$  and  $1.72$  kg m<sup>-3</sup>. The survival rate (91.9%) and the FCR (1.25),



**Table 2.** Mean water quality parameters in the recirculating tilapia system (*Oreochromis niloticus*) at three stocking densities.

Week	Oxygen (mg L <sup>-1</sup> )		Temperature (°C)		NH <sub>3</sub> -N (mg L <sup>-1</sup> )		NO <sub>2</sub> <sup>-</sup> -N (mg L <sup>-1</sup> )		NO <sub>3</sub> <sup>-</sup> -N (mg L <sup>-1</sup> )		pH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<b>Stocking density 400 fish m<sup>-3</sup></b>												
1	5.73	0.54	28.1	0.0	0.34	0.07	0.88	0.23	6.0	2.10	7.70	0.30
2	5.48	0.06	27.8	0.2	0.44	0.10	1.66	0.68	27.2	9.16	7.40	0.27
3	5.80	0.04	27.2	0.3	0.08	0.05	1.80	0.40	25.5	5.19	7.40	0.24
4	5.80	0.23	27.2	0.4	0.07	0.03	0.10	0.05	14.6	4.88	7.17	0.23
5	5.18	0.14	26.1	0.1	0.07	0.02	0.07	0.06	10.6	9.04	7.52	0.44
6	5.11	0.12	26.5	0.0	0.07	0.06	0.09	0.01	23.3	5.41	7.55	0.44
7	4.91	0.05	25.5	0.0	0.11	0.05	0.16	0.09	33.3	6.98	7.39	0.31
8	5.20	0.23	25.1	0.1	0.14	0.06	0.37	0.21	28.8	2.73	7.63	0.31
9	5.51	0.08	22.2	0.0	0.14	0.07	0.45	0.17	36.0	2.69	7.68	0.31
10	4.63	0.15	23.0	0.4	0.07	0.01	0.34	0.11	29.0	3.73	7.22	0.33
11	3.82	0.16	24.9	0.1	0.07	0.05	0.32	0.22	27.0	5.83	7.76	0.33
<b>Stocking density 500 fish m<sup>-3</sup></b>												
1	5.66	0.03	27.8	0.0	0.74	0.05	0.02	0.01	2.1	1.40	7.80	0.42
2	5.60	0.13	27.7	0.0	0.41	0.40	0.09	0.01	2.2	1.43	7.84	0.36
3	5.76	1.56	27.6	0.1	0.18	0.12	0.95	0.61	17.0	3.54	7.88	0.21
4	5.34	1.34	26.5	0.4	0.18	0.03	1.11	0.65	22.2	7.63	7.93	0.22
5	5.08	1.34	26.2	0.1	0.14	0.02	1.16	0.24	28.4	2.00	7.97	0.32
6	4.91	0.16	26.5	0.0	0.14	0.05	0.09	0.03	12.8	9.02	8.01	0.34
7	4.67	0.19	25.5	0.2	0.12	0.10	0.03	0.03	19.7	5.27	8.05	0.17
8	4.29	0.23	25.1	0.0	0.09	0.02	0.05	0.02	23.5	1.18	8.09	0.06
9	5.37	0.07	22.1	0.2	0.08	0.04	0.15	0.08	34.6	8.21	8.13	0.09
10	5.42	0.34	22.2	0.4	0.12	0.08	0.44	0.08	27.1	8.00	7.76	0.09
11	3.74	0.56	24.5	0.1	0.09	0.04	0.96	0.50	36.2	6.81	7.80	0.03
<b>Stocking density 600 fish m<sup>-3</sup></b>												
1	5.60	0.23	28.0	0.3	0.47	0.24	0.83	0.11	5.5	1.20	7.84	0.88
2	5.39	1.76	27.4	0.4	0.42	0.23	1.06	0.23	21.7	8.54	7.89	0.76
3	5.70	0.04	27.1	0.0	0.25	0.15	1.72	1.11	16.1	7.65	7.70	0.67
4	5.50	1.34	26.4	0.8	0.24	0.14	1.17	0.34	13.1	8.45	7.70	0.16
5	5.02	0.07	26.0	0.5	0.32	0.12	0.10	0.01	16.8	3.54	8.40	0.18
6	4.79	0.10	26.5	0.1	0.33	0.12	0.10	0.01	20.3	2.65	7.12	0.18
7	4.55	1.50	25.5	0.6	0.23	0.02	0.20	0.02	23.8	6.12	8.18	0.15
8	4.19	1.20	25.0	0.4	0.12	0.01	0.45	0.34	27.3	5.11	8.22	0.12
9	5.42	1.23	22.2	0.0	0.14	0.03	1.07	0.25	30.8	3.21	8.26	0.12
10	5.58	0.98	22.4	0.1	0.14	0.04	1.09	0.64	34.3	7.45	8.00	0.11
11	3.80	0.20	24.0	0.2	0.07	0.02	1.10	0.74	37.8	12.40	8.34	0.08

**Table 3.** Significant effect of water quality parameters on the specific growth rate (SGR) of Nile tilapia (*Oreochromis niloticus*) according to forward stepwise regression.

Stocking density (fish m <sup>-3</sup> )	400 (T1)		500 (T2)		600 (T3)	
	Variance (%)	P-value	Variance (%)	P-value	Variance (%)	P-value
Temperature (°C)	0.41	0.024*	0.02	0.055	0.01	0.706
Oxygen (mg L <sup>-1</sup> )	0.12	0.164	0.47	0.022*	0.44	0.016*
NH <sub>3</sub> -N (mg L <sup>-1</sup> )	0.13	0.162	0.07	0.288	0.31	0.030*
NO <sub>3</sub> <sup>-</sup> -N (mg L <sup>-1</sup> )	0.01	0.708	0.13	0.116	0.00	0.930
NO <sub>2</sub> <sup>-</sup> -N (mg L <sup>-1</sup> )	0.00	0.786	0.06	0.312	0.07	0.610
pH	0.04	0.454	0.02	0.614	0.00	0.916
Cumulative % variance	0.71		0.77		0.83	

\* Water parameters with P-value less than 0.05 are considered significant.

**Table 4.** Rate of reduction of total organic carbon (TOC) and total ammonium nitrogen (TAN) from the settling basin and biofilter of the recirculating tilapia system (*Oreochromis niloticus*).

Week	Settling basin				Biofilter				C/N ratio
	TOC (g m <sup>-3</sup> ) Load- ing rate		TOC (%) Removal efficiency		TAN (mg L <sup>-1</sup> ) Loading rate		TAN (%) Removal efficiency		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1	95.2	3.4	32.2	6.7	56.7	3.3	42.2	6.7	1.7
2	119.5	0.9	52.1	1.5	47.5	2.9	51.1	1.5	2.5
3	162.7	68.2	62.7	26.6	42.0	18.2	32.6	16.6	3.9
4	218.7	34.7	39.8	6.7	61.3	14.7	39.6	6.7	3.6
5	608.3	45.2	42.9	11.2	69.3	21.2	40.9	11.1	8.8
6	866.6	87.6	29.2	11.1	56.7	12.3	52.8	11.1	15.3
7	1472.0	27.7	15.1	3.8	56.1	27.7	61.0	3.7	26.2
8	1146.6	43.3	21.7	12.3	39.3	12.4	49.6	12.3	29.2
9	1456.0	69.2	6.0	4.8	48.1	4.3	51.3	4.8	30.3
10	1333.3	21.0	7.4	1.4	30.4	12.3	49.7	1.4	43.9
11	1272.0	23.9	3.4	1.2	29.3	8.2	45.5	0.8	43.4

were similar to that obtained in the T1 in the present experiment, but the AGR was lower than here (0.14 g day<sup>-1</sup>). The DO from RAS of the cited studied was higher than here, even in the high density (6.79 mg L<sup>-1</sup>), however the NH<sub>3</sub>-N of our RAS (0.20 mg L<sup>-1</sup>) was significantly lower (0.98 mg L<sup>-1</sup>). In addition, at high stocking densities the effects of a limited amount of space per organism also increased metabolic rates, and therefore, the oxygen consumption (Kisia & Hughes, 1993). The oxygen consumed and the ammonia excretion rate depends on the fish biomass and the oxygen consumption rate which, in turn, is a function of the average weight and water temperature

(Timmons *et al.*, 2002). Even when the mean of DO was not different between treatments, the data suggests that the DO concentration supplied in our RAS was not enough for the high stocking densities (T2 and T3), in contrast with T1 that was only influenced by the weekly temperature variation (Fig. 3).

The high stocking density affected the overall size of fish and the size homogeneity, but had no negative effect on the length–weight relationship (L-W). Several authors have reported that crowding intensifies the heterogeneous fish growth, due to the competition for a sparse supply of adequate food or

social dominance, which often coincides with increasing fish densities (Sahoo *et al.*, 2004; Jha & Barat, 2005; Barbosa *et al.*, 2006). When growth is density dependent, partial harvest of the standing fish have been use to decrease competition, and thereby increasing individual growth rate. However this procedure increases the water consumption. Martins *et al.* (2009), report that juveniles (up to 150 g) can be raised in RAS at  $3.8 \text{ kg m}^{-3}$  with water exchange rates of  $30 \text{ L kg}^{-1} \text{ feed day}^{-1}$ , without a decrease in feeding motivation. On the contrary, large fish ( $288.7 \pm 34.2 \text{ g}$ ) stocking at  $7.2 \text{ kg m}^{-3}$  exhibit growth retardation. Based on those studies we believe that partial harvest does not improve the performance of the juvenile's tilapia in the present RAS.

Tilapia exhibited an expected positive allometric growth ( $b > 3$ ), at the three stocking densities. The classical ontogenetic interpretation of the allometric L-W is that fish increases in weight at a greater rate than required, maintaining constant body proportions (Tesch, 1968). Fish grows isometrically ( $b = 3$ ), during their final growth stanza, while values of  $b < 3$  are usually associated with a shortage of suitable food or overcrowding (Ricker, 1979; Murphy *et al.*, 1991). The L-W model is sensitive to and reflects small changes in condition, and can alert producers to the onset of disease, stress due to overcrowding, bad water quality, or other physiological effects, before high mortality rates are suffered (Jones *et al.*, 1999). Although body weight is commonly recorded for culture management purposes (*e.g.*, estimations of growth rate, feed conversion ratio, harvest weight, and productivity), the application of L-W relationship could be use as a simple alternative to estimate body weight from length measurements that are less variable and more easily measured in the field. Rutten *et al.* (2005), clearly demonstrated the very strong relationship (0.90) between length and fillet weight from raised Nile tilapia. In this context, the L-W relationship was assessed for several commercial aquaculture species (Sofronios & Tziha, 1996; Peixoto *et al.*, 2004; Araneda *et al.*, 2008; Gullian *et al.*, 2010). Results of the present study represent the first report of L-W relationship for *O. niloticus* at hyper intensive nursery conditions.

Gradual build-up of nitrate ( $\text{NO}_3^-$ -N) was seen along the experimental weeks, indicating nitrification (Table 2). In the final week,  $\text{NO}_3^-$ -N concentration reached  $33.7 \pm 5.8 \text{ mg L}^{-1}$  and the total ammonia nitrogen (TAN) decreased up to  $0.06 \pm 0.01 \text{ mg L}^{-1}$ . Nitrate is relatively non-toxic to tilapia (Segalas *et al.*, 2003). In the classic autotrophic RAS, ammonia peaks in the first week, followed by a nitrite peak and the accumulation of nitrate (Timmons *et al.*, 2002). Thus,

many recirculating tilapia systems reach  $\text{NO}_3^-$ -N concentrations over  $50 \text{ mg L}^{-1}$  (Bailey *et al.*, 2000; Shnel *et al.*, 2002). Although data shows that TAN removal efficiency was less than 50%, the  $\text{NH}_3$ -N level denotes an acceptable function of the biofilter. Twarowska *et al.* (1997) achieved 65% of TAN removal using a high-rate linear-path trickling biofilter in a recirculating tilapia system at  $246 \text{ min L}^{-1}$ . The biofilter keep the TAN concentration at  $0.62 \pm 0.37 \text{ mg L}^{-1}$  and nitrite nitrogen concentration at  $1.62 \pm 1.10 \text{ mg L}^{-1}$ . Those values are according with the results from the present study at least for T1 and T2, where the biofilter at lower flow rate ( $80 \text{ L min}^{-1}$ ) held the TAN at  $0.36 \pm 0.33$  and  $0.52 \pm 0.56 \text{ mg L}^{-1}$ , respectively. The TAN level was slightly higher in T3 ( $0.62 \text{ mg L}^{-1} \pm 0.41 \text{ mg L}^{-1}$ ) than the cited study, and even the nitrite nitrogen concentration was relatively higher ( $1.71 \text{ mg L}^{-1} \pm 2.34 \text{ mg L}^{-1}$ ).

The data suggest that the accumulation of organic matter increased the oxygen-consumer heterotrophic bacteria population (HB) (Fig. 4). The reduction of nitrification rate, with increasing organic matter, has been previously reported. Zhu & Chen (2002), reported 70% reduction in the nitrification rate when the carbon-nitrogen ratio (C/N) increased up to 2.7. Ling & Chen (2005), also reported that the reduction of nitrification rate in the biofilter is about 60-70% when the concentration of TAN inside de biofilter rises to  $10 \text{ mg L}^{-1}$ , and also the C/N ratio increases up to 8.4. In this study, the C/N ratio overcame 2.7 from the 3<sup>th</sup> week to the 11<sup>th</sup> week. However, the TAN removal was  $57 \pm 7\%$  (Table 4). It is noteworthy that increased C/N ratio, through the consecutive experimental weeks, was not inversely proportional to the reduction nitrification process, possibly due to the available DO in the RAS. Jechalke *et al.* (2011), reported that nitrification is inhibited when the DO is less than  $1.2 \text{ mg L}^{-1}$ . Data of the present study showed that the minimum value of DO registered in the last week was  $3.78 \pm 0.03 \text{ mg L}^{-1}$ , higher than the inhibition nitrification value. If the experiment would be extended more than 11 weeks, it is likely that the nitrification efficiency will decrease due to increasing fast-growing heterotrophic bacteria competing with nitrifying bacteria for the limited oxygen available. This would have required increasing the oxygen supply or exchanging the water.

In summary, stocking densities and harvest yields are finite and are determined by the carrying capacity of the system. Results showed that Nile tilapia fingerlings grow in low water exchange RAS, at high stocking density, reaching between 60 to 69 g-fish size in 70 days. Data from growth curves suggest the 9<sup>th</sup> and 8<sup>th</sup> weeks as optimum harvest time for T2 and T3,

respectively. At this time, the biomass reached by these treatments was  $34.4 \text{ kg m}^{-3}$  for T2 and  $36.1 \text{ kg m}^{-3}$  for T3. Considering that T1 reached  $37.1 \text{ kg m}^{-3}$  and it had the highest SGR ( $5.01 \text{ g day}^{-1}$ ), we believe that biomass of the present RAS should not exceed  $37 \text{ kg m}^{-3}$  with a stocking density exceeding  $400 \text{ fish m}^{-3}$ . The average total nitrogen ( $25.6 \pm 5.1 \text{ mg L}^{-1}$ ) and total phosphorus ( $1.75 \pm 0.13 \text{ mg L}^{-1}$ ) concentration from the final effluent were lower than the long-term trigger values for irrigation concentrations of the nutrients recommended by the Official Mexican Standards (NOM-001-SEMARNAT-1996) ( $40 \text{ mg L}^{-1}$  of total nitrogen,  $20 \text{ mg L}^{-1}$  of total phosphorus). Based on the data, the nitrogen and phosphorus levels from the wastewater of the RAS can be used for irrigation and it is unlikely to cause a significant impact on the environment.

### ACKNOWLEDGEMENTS

The authors are grateful with the Universidad Marista de Merida (UMM) and Dr. J.C. Seijo for the support given to this research. We would like to acknowledge H. López-López, R. Villanueva-Poot, A. Romero-Yam, G. Arámburu-Gullian, N. López-Barahona, A. Alarcón-Sánchez, M. Vela-Magaña and P. Ceballos Gomez Luna for their field and lab assistance.

### REFERENCES

- American Public Health Association (APHA). 1999. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, 219 pp.
- Arámburu-Adame, C.R. 2011. Evaluación económica de la pre cría intensiva de *Oreochromis niloticus* en un sistema de recirculación. Tesis de Maestría. Universidad Marista de Mérida, México (UMA, HD 9450.5), 70 pp.
- Araneda, M., E.P. Pérez & E. Gasca-Leyva. 2008. White shrimp *Penaeus vannamei* culture in freshwater at three densities: condition state based on length and weight. *Aquaculture*, 283: 13-18.
- Arredondo, J.L. & S.L. Lozano. 2003. La acuicultura en México. Universidad Autónoma Metropolitana, Iztapalapa, 266 pp.
- Bailey, D.S., J.E. Rakocy, J.M. Martin & R.C. Schultz. 2000. Intensive production of tilapia fingerlings in a recirculating system. In: K. Fitzsimmons & J.C. Filho (eds.). Proceedings of the Fifth International Symposium on Tilapia in Aquaculture, Rio de Janeiro, Brazil, Rio de Janeiro: Panorama da Aquicultura, pp. 328-333.
- Barbosa, J.M., S.S. Brugiolo, J. Carolsfeld & S.S. Leita. 2006. Heterogeneous growth in fingerlings of the Nile tilapia *Oreochromis niloticus*: effects of density and initial size variability. *Braz. J. Biol.*, 66: 537-541.
- Braak, C.J.F. & P. Šmilauer. 2002. CANOCO, Reference manual and cano draw for windows user's guide: software for canonical community ordination (version 4.5). Section on permutation methods. Microcomputer Power, Ithaca, New York, 500 pp.
- Camacho-Berthely, E., C. Luna-Romo & M.A. Moreno-Rodríguez. 2000. Guía para el cultivo de tilapia *Oreochromis* spp. (Gunter, 1984). SEMARNAP, México, 136 pp.
- Clescerl, S.L., A.E. Greenberg & A.D. Eaton. 2000. Standard methods for the examination of water and wastewater. APHA/AWWA/Water Environment Federation, Washington DC, 787 pp.
- Comisión Nacional de Acuicultura y Pesca (CONA-PESCA) 2010. Anuario estadístico de acuicultura y pesca. Comisión Nacional de Acuicultura y Pesca, México, 132 pp.
- El-Sayed, A.F.M. 2006. Tilapia culture. CABI Publishing, Cambridge, 277 pp.
- Gullian, M., C. Arámburu, B. Sanders & R. Lope. 2010. Viability of culturing pink shrimp *Farfantepenaeus duorarum* in low-salinity groundwater from the Yucatán Peninsula (SE, México). *Aquaculture*, 302: 202-207.
- Helfrich, L.A. & G. Libey. 1990. Fish farming in recirculating aquaculture systems (RAS). Department of Fisheries and Wildlife. Sciences, Virginia Tech, New York, 19 pp.
- Hargreaves, J.A. & S. Kucuk. 2001. Effects of diel unionized ammonia fluctuation on juvenile hybrid striped bass, channel catfish, and blue tilapia. *Aquaculture*, 195: 163-181.
- Hernández-Mogica, M., J.L. Reta-Mendiola, F. Gallardo-Lopez & M.E. Nava-Tablada. 2002. Tipología de los productores de mojarra tilapia (*Oreochromis* spp.); base para la formación de grupos de crecimiento productivo simultáneo (GCPS) en el Estado de Veracruz, México. *Tropical & Subtropical Agroecosystems*, 1: 13-19.
- Jechalke, S., M. Rosell, C. Vogt & H. Richnow. 2011. Inhibition of nitrification by low oxygen concentrations in an aerated treatment pond system with biofilm. *Water Environ. Res.*, 83: 622-626.
- Jha, P. & S. Barat. 2005. The effect of stocking density on growth, survival rate and number of marketable fish produced of Koi carp, *Cyprinus carpio* vr. Koi in concrete tanks. *J. Appl. Aquacult.*, 17: 84-102.

- Jobling, M. & B.M. Baardvik. 1994. The influence of environmental manipulations on inter-and intra-individual variation in food acquisition and growth performance of arctic charr, *Salvelinus alpinus*. J. Fish Biol., 44: 1069-1087.
- Jones, R.E., R.J. Petrell & D. Pauly. 1999. Using modified length-weight relationships to assess the condition of fish. Aquacult. Eng., 20: 261-276.
- Kebus, N.J., M.T. Coltins, M.S. Brownfield, C.H. Amundson, T.B. Kayes & J.A. Malison. 1992. Effects of rearing density on stress response and growth of rainbow trout. J. Aquat. Anim. Health, 4: 1-6.
- Kisia, S.M. & G.M. Hughes. 1993. Routine oxygen consumption in different sizes of a tilapia, *Oreochromis niloticus* (Trewavas) using the closed chamber respiratory method. Acta Biol. Hung., 44: 367-374.
- Ling, J. & S. Chen. 2005. Impact of organic carbon on nitrification performance of different biofilters. Aquacult. Eng., 33: 150-162.
- Martins, I.M.C., D. Ochola, S.W. Ende, H.E. Eding & J.A. Verreth. 2009. Is growth retardation present in Nile tilapia *Oreochromis niloticus* cultured in low water exchange recirculating aquaculture systems? Aquaculture, 298: 43-50.
- Murphy, B.R., D.W. Willis & T.A. Springer. 1991. The relative weight index in fisheries management: status and needs. Fisheries, 16: 30-38.
- Norrell, S. & K. Messley. 1997. Microbiology, Laboratory Manual. Principles and applications. Prentice Hall, Upper Saddle River, New Jersey, 302 pp.
- Parker, R. 2011. Aquaculture Science. Delmar Cengage Learning, New York, 672 pp.
- Pauly, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM, Stud. Rev. 8, 325 pp.
- Peixoto, S., R.O. Cavalli, W. Wasielesky W.F. D'Incao, D. Krummenauer & A.M. Milach. 2004. Effects of age and size on reproductive performance of captive *Farfantepenaeus paulensis* brood stock. Aquaculture, 238: 173-182.
- Pindyck, R.S. & D.L. Rubinfeld. 1991. Econometric models and economic forecasts. McGraw Hill, Singapore, 630 pp.
- Ponce-Marbán, D., J.M. Hernández & E. Gasca-Leyva. 2006. Simulating the economic viability of Nile tilapia and Australian redclaw crayfish polyculture in Yucatán, Mexico. Aquaculture, 261: 151-159.
- Popma, T. & M. Masser. 1999. Tilapia life history and biology. Southern Regional Aquaculture Center (SRAC), Publication 283, USA, pp. 1-4.
- Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. J. Fish. Res. Bd. Can., 191: 209-210.
- Ricker, W.E. 1979. Growth rates and models. In: W.S. Hoar, D.J. Randall & J.R. Brett (eds.). Fish physiology. Academic Press, London, 3: 677-743.
- Ridha, M.T. & E.M. Cruz. 2001. Effect of biofilter media on water quality and biological performance of the Nile tilapia *Oreochromis niloticus* L. reared in a simple recirculating System. Aquacult. Res., 30: 203-210.
- Ross, L.G. 2000. Environmental physiology and energetics. In: M.C.M. Beveridge & B.J. McAndrew (eds.). Tilapias: biology and exploitation, fish and fisheries. Series 25, Kluwer Academic Publishers, Dordrecht, pp. 89-128.
- Rutten, M.J.M., H. Komen & H. Bovenhuis. 2005. Longitudinal genetic analysis of Nile tilapia (*Oreochromis niloticus* L.) body weight using a random regression model. Aquaculture, 246: 101-113.
- Sahoo, S.K., S.S. Giri & A.K. Sahu. 2004. Effect of stocking density on growth and survival of *Clarias batrachus* (Linn.) larvae and fry during hatchery rearing. J. App. Ichthyol., 20: 302-305.
- Segalas, C., C. Maxwell & M. Meade. 2003. The effects of acute exposure to nitrate and nitrite on the metabolic physiology of Nile Tilapia. J. Ala. Acad. Sci., Brief article, Apr 1.
- Shnel, N., Y. Barak, T. Ezer, Z. Dafni & J. Van Rijn. 2002. Design and performance of a zero-discharge tilapia recirculating system. Aquacult. Eng., 26: 191-202.
- Sofronios, E.P. & G. Tziha. 1996. Blue tilapia (*Oreochromis aureus*) growth rate in relation to dissolved oxygen concentration under recirculated water conditions. Aquacult. Eng., 15: 181-192.
- Solorzano, L. & J.H. Sharp. 1980. Determination of total dissolved phosphorus and particulate phosphorus in natural waters. Limnol. Oceanogr., 25: 754-758.
- Strickland, J.D. & T.R. Parsons. 1972. A practical handbook of seawater analysis. J. Fish Res. Bd. Can., 167: 107-112.
- Suresh, V.A & C.K. Lin. 1992. Effect of stocking density on water quality and production of red tilapia in a recirculated water system. Aquacult. Eng., 11: 1-22.
- Tesch, F.W. 1968. Age and growth. In: W.E. Ricker (ed.). Methods for assessment of fish production in fresh waters. IBP, Handbook Blackwell, London, pp. 93-123.
- Thurston, R.V., C.R. Russo & K. Emerson. 1979. Aqueous ammonia equilibrium - tabulation of percent

- of un-ionized ammonia. Montana State University & The United States Environmental Protection Agency, 440 pp.
- Timmons, M.B., J.M. Ebeling, F.W. Wheaton, S.T. Summerfelt & B.J. Vinci. 2002. Recirculating aquaculture systems. Northeastern Regional Aquaculture Center, USDA, New York, 769 pp.
- Tsadik, G.G. & M.N. Kutty. 1987. Influence of ambient oxygen on feeding and growth of the tilapia *Oreochromis niloticus* (Linnaeus). UNDP/FAO/NIOMR, Port Harcourt, Nigeria, 16 pp.
- Twarowska, J.G., P.W. Westerman & T.M. Losordo. 1997. Water treatment and waste characterization evaluation of an intensive recirculating fish production system. Aquacult. Eng., 16: 133-147.
- Vivanco-Aranda, M., F.J. Mojica & F.J. Martínez-Cordero. 2011. Foresight analysis of tilapia supply chains (Sistema Producto) in four states in Mexico: scenarios and strategies for 2018. Technol. Forecast Soc. Change, 78: 481-497.
- Zar, J. 1999. Biostatistical analysis. Prentice-Hall, New Jersey, 662 pp.
- Zhu, S. & S. Chen. 2002. The impact of temperature on nitrification rate in fixed film biofilters. Aquacult. Eng., 26: 221-237.

*Received: 14 May 2012; Accepted: 28 February 2013*