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Effects of $CaCO_3$ liming on water quality and growth performance of fingerlings of Nile tilapia, *Oreochromis niloticus*

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ABSTRACT. The present study was carried out for 6 week with Nile tilapia, *Oreochomis niloticus*, fingerlings (0.77 ± 0.04 g) to assess the effects of moderate $CaCO_3$ liming on water pH, total alkalinity, calcium hardness, free CO_2 and total ammonia, as well as on fish final body weight, final body length, survival and FCR. Eighteen 25-L polyethylene aquaria were used to hold the experimental fish (15 fish per aquarium). Nine aquaria were set in the lab's indoor room and nine aquaria in its outdoor area. Two types of water (clear or green) and three different water quality managements (none, HCl acidification and $CaCO_3$ liming) were evaluated simultaneously in a 3 x 2 factorial design. The application of analytical calcium carbonate at 1 g 10 L^{-1} in the clear or green waters has produced superior Nile tilapia fingerlings' final body weight and length. The best set of limnological conditions that improved Nile tilapia fingerlings growth was the following: pH: 7.4-8.2; total alkalinity > 50 mg L^{-1}; calcium hardness > 140 mg L^{-1}; free CO_2 < 7 mg L^{-1}. The total ammonia concentration in fish aquaria was not affected by $CaCO_3$ liming ($p > 0.05$).

Key words: fish culture, limnology, water alkalinity, water hardness.

RESUMO. Efeitos da calagem com $CaCO_3$ na qualidade da água e desempenho produtivo de alevinos de tilápia do Nilo, *Oreochromis niloticus*. O presente estudo foi realizado por seis semanas, com alevinos de tilápia do Nilo, *Oreochromis niloticus* (0,77 ± 0,04 g), para se avaliar os efeitos da calagem moderada da água com $CaCO_3$ no pH, alcalinidade total, dureza cálcica, concentrações de CO_2 livre e amônia total da água, assim como peso final, comprimento total final, sobrevivência e FCA dos peixes cultivados. Dezoito aquários de polietileno de 25 L foram utilizados para se manter os peixes experimentais (15 peixes por aquário). Nove aquários foram instalados na sala interna do laboratório e nove, na sua área externa. Dois tipos de águas (claras ou verdes) e três diferentes manejos de qualidade de água (nenhum, acidificação com HCl ou calagem com $CaCO_3$) foram avaliados simultaneamente em delineamento fatorial 3 x 2. A aplicação de $CaCO_3$ p.a. em 1 g 10 L^{-1} em águas claras ou verdes resultou em peso final e comprimento total significativamente maiores. As condições limnológicas que propiciaram os melhores resultados zootécnicos foram as seguintes: pH = 7,4-8,2; alcalinidade total > 50 mg L^{-1}; dureza cálcica > 140 mg L^{-1}; CO_2 livre < 7,0 mg L^{-1}. A concentração de amônia total nos aquários não foi afetada pela calagem com $CaCO_3$.

Palavras-chave: piscicultura, limnologia, alcalinidade, dureza.

Introduction

The limnology of fish ponds strongly affects fish survival, growth, reproduction and health. The success of aquaculture enterprises depends on greatly of the water quality in fish tanks and ponds. Fish culturists aware that pond productivity relies heavily on their limnology seek for improvements in the water quality conditions of their fish farms. Among the important aspects concerning the water quality of fish ponds, it is highlighted the acid-basic equilibrium of water which is related to its pH, alkalinity and free CO_2 concentration. The relationships between these variables need to be understood to efficiently manage fish ponds (KUBITZA, 1999).

In low water exchange units, liming can be successfully carried out to increase water pH and alkalinity. Besides, when liming is performed using limestone (calcium carbonate) it also increases the calcium concentration of water (water hardness). Calcium is an essential element for fish growth and health and a minimum concentration in water is desirable to get good growth performance indices. In general, culture waters with pH below 6.5 and total alkalinity less than 20 mg L^{-1} require liming (BOYD et al., 2007).

Rojas and Rocha (2004) have found that Nile tilapia, *Oreochromis niloticus*, post larvae (0.03 ± 0.007 g) grew significantly more when the total alkalinity of culture water was 30 mg L^{-1}. Fish maintained in waters with total alkalinity of 15 or 60 mg L^{-1} exhibited growth impairment. While the results for the water with total alkalinity of 15 mg L^{-1} were already expected, the poor growth for the water with total alkalinity of 60 mg L^{-1} was unexpected and even surprising. According to these authors, the culture water with total alkalinity, soluble calcium, total hardness and pH of 60 mg L^{-1}, 25 mg L^{-1}, 70 mg L^{-1} and 7.9, respectively, compromised significantly post-larvae growth. These values, however, are inside de adequate ranges for tropical fish culture (BOYD; TUCKER, 1998).

In order to clarify that question, the present study was carried out with Nile tilapia, *O. niloticus*, fingerlings to assess the effects of moderate $CaCO_3$ liming on water pH, total alkalinity, calcium hardness, free CO_2 and total ammonia, as well as on fish final body weight, final body length, survival and FCR.

Material and methods

Fish and experimental systems

One thousand male sex reversed Nile tilapia, *Oreochromis niloticus*, fingelings (0.47 ± 0.02 g) were obtained at the Centro de Pesquisas em Aqüicultura of the Departamento Nacional de Obras Contras as Secas (DNOCS) in Pentecoste, Ceará State, Brazil (3°47'40.49"S; 39°16'36.07"W). Fish were transported in a plastic bag with water (1/3) and pure oxygen (2/3) to the Laboratório de Ciência e Tecnologia Aqüícola – LCTA (Departamento de Engenharia de Pesca, Centro de Ciências Agrárias Universidade Federal do Ceará, Fortaleza, Ceará State, Brazil), where the fish were transferred to a 1000-L fiberglass tank (reception tank) which was served by 24-h forced air through small air pumps, silicon pipes and air diffusers.

Fish stayed in the reception tank for one week to acclimatize themselves to the laboratory conditions. Forty-eight hours after stocking, fish were treated with analytical grade potassium permanganate at 4 mg L^{-1} for 48 hours to prevent bacterial infestation. After this period, analytical grade sodium thiosulfate was used at 4 mg L^{-1} to neutralize the residual effect of potassium permanganate. Over the acclimatization period, fish were fed a high-protein commercial diet (Fri-Acqua 56) in four daily meals at 8 a.m., 11 a.m., 2 p.m. and 5 p.m. The commercial diet used had an average particle size of 0.8 mm. The daily feeding rate was equal to 10% of the stocked biomass.

Eighteen 25-L polyethylene aquaria were used in the present work to hold experimental fish. Nine aquaria were set in the lab's indoor room and nine aquaria in the outdoor area. Whereas in the indoor room top-roofed artificial lights are used and very little sunlight is allowed to it, the outdoor area exposes the aquaria directly to the sun. The aquaria were served by non-stop aeration and had a cotton mesh cover to prevent fish escape. At the onset of the experiment, fifteen fingerlings (0.77 ± 0.04 g) were stocked in each 25-L polyethylene aquarium. Pooled fish body weight was recorded for each aquarium as well as the total body length of ten individuals. During the first week, dead fish found in aquaria were replaced by others from the reception tanks with similar body weight and length. Fish were maintained in the experimental systems for 6 weeks.

Experimental design and husbandry

In the present work, two experimental factors were evaluated simultaneously in a 3 x 2 factorial design. There were two types of culture water and three different water quality managements. Tap water was used to fill in the aquaria after its residual chlorine had been removed by aeration and resting. The water was maintained clear in the indoor aquaria (no phytoplankton) and became green in the outdoor aquaria (plenty of phytoplankton). Aquaria with clear or green water were submitted to one of the followings water managements: none (positive control), acidification with concentrated HCl (negative control) or liming with analytical grade $CaCO_3$ (experimental group). Therefore, six different experimental conditions were set up: (1) clear water and no water management, (2) clear water and water acidification with HCl, (3) clear water and water liming with $CaCO_3$, (4) green water and no water management, (5) green water and water acidification with HCl and (6) green water and water liming with $CaCO_3$.

No fertilization was carried out in the outdoor tanks. Only the fish feed allowance in the outdoor aquaria produced a good phytoplankton growth. The physical-chemical characteristics of the tap water were the followings: total alkalinity = 50.7 ± 2.52 mg L^{-1}, calcium hardness = 64.7 ± 4.16 mg L^{-1}, pH = 7.7 ± 0.12, free CO_2 = 10.0 ± 2.00 mg L^{-1}, optical transmittance at 670 nm = 98.7 ± 0.58% and total ammonia = 0.0 ± 0.00 (mean ± s.d; n = 3). Three aquaria were designed randomly to each control or treatment group.

Initially, all aquaria were filled with tap water. In the second, third and fourth days, the water of the aquaria designed to acidified or limed treatments was replaced by acidified or limed water at 1/3, 2/3 and 3/3, respectively. From the fourth day till the end, weekly exchanges of water were carried out at 2/3 in order to maintain the designed physic-chemical characteristics of the experimental waters. One phytoplankton inoculation was performed in all aquaria. For this purpose, 50 mL of dark green water get from fish tanks of a nearby fish culture station was poured into the aquaria water at the 5^{th} experimental day. It was noted that the outdoor waters got a strong green color just four days after inoculation. No phytoplankton developed in the indoor aquaria.

All stocked fish were fed with the same artificial diet used during the acclimatization period. The feeding rates employed were 10, 8 or 6% of the stocked biomass in the weeks 1-2, 3-4 and 5-6, respectively. The amount of feed allowed to each aquarium was adjusted fortnightly after fish body weightings.

Experimental variables and analytical procedures

Water quality and growth performance variables were observed in the present work. The water pH, total alkalinity, calcium hardness, free CO_2 and total ammonia were monitored weekly in all aquaria. Besides, water temperature and pH from 6 a.m to 6 p.m. were recorded hour-to-hour in two different days. The water pH was measured by using a portable pH meter. The water temperature was observed by the use of a digital handy thermometer. The analytical determinations of total alkalinity, calcium hardness, free CO_2 and total ammonia were carried out according to the guidelines presented by APHA (1999). The culture water's light absorbance at 670 nm was recorded to measure the phytoplankton abundance in the aquaria (SILVA-NETO et al., 2008). Weekly, a water sample of one liter was withdrawn from each aquarium to perform the limnological analyses. The fish final body weight and length, survival and feed conversion rate were observed in all repetitions.

Statistical analyses

The water quality and growth performance results were submit to the two-way Anova to detect if there were significant differences between the experimental groups. When the differences were significant, the means were compared two-by-two using the Tukey test. The statistical analyses were performed with the aid of the Sigma Stat 2.0 software (Jandel Statistics). The 5% significance level was adopted in all statistical analyses.

Results and discussion

Water quality

No significant differences were found for light absorbance at 670 nm between the aquaria non-managed, acidified or $CaCO_3$ limed, both in clear and green waters. On the other hand, the light absorbance of pooled green water (36.87 ± 0.50%) was significantly higher than pooled clear water (5.24 ± 0.01%; $p < 0.05$).

In aquaculture systems, the main suspended particle in water that actively absorbs light radiation at 670 nm is green algae (DRAPCHO; BRUNE, 2000). As previously said, the clear water aquaria were almost devoid of phytoplankton. Thus, very low light absorbance was already expected for them. Moreover, it is suggested that the intentional acidification carried out in the outdoor aquaria (1.0 mL concentrated HCl 20 L^{-1} tap water) was not strong enough to hinder phytoplankton development in these aquaria. Besides, the $CaCO_3$ liming (1.0 g 10 L^{-1}) of the weakly acidified water had no significant effect on the micro algal growth.

During the day, from 6 a.m. to 6 p.m., the outdoor water temperature rose fast and reached values as high as 36.3°C. On the other hand, the indoor water temperature was almost stable, remaining circa of 28°C in the same period. Hence, the water temperature range in the outdoor aquaria is much wider than in the indoor aquaria. Whereas in the outdoor aquaria there was a water temperature variation of 10.9°C from 6 a.m. to 6 p.m., in the indoor aquaria the water temperature varied only 1.6°C in the same period (Figure 1).

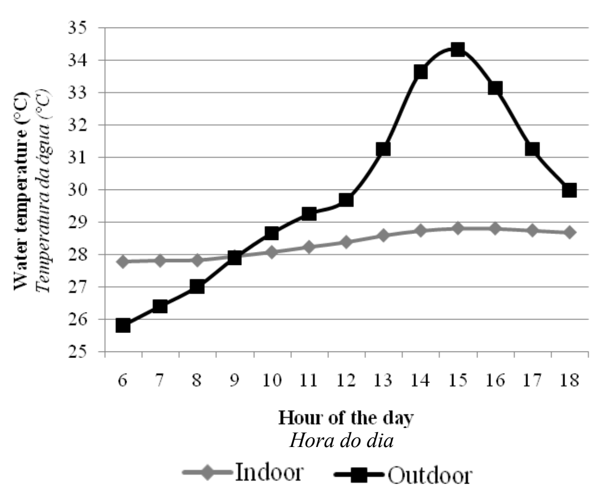

Figure 1. Water temperature in indoor (clear water) and outdoor (green water) 25-L polyethylene aquaria from 6 a.m. to 6 p.m.
Figura 1. *Temperatura da água em aquários de polietileno de 25 L instalados em ambiente interno (águas claras) ou externo (águas verdes) das 6 da manhã às 6 da tarde.*

The LCTA's indoor culture system has more stable limnological conditions than those in the outdoor system. While the indoor system simulates an oligotrophic, sheltered fish pond, the outdoor system simulates a eutrophic, opened pond. The broader ranges of water quality indicators in the outdoor aquaria can cause more stress to fish and impair its growth. Therefore, we believe it is interesting to compare the water quality and fish growth performance between these two conditions.

During the day, from 6 a.m. to 6 p.m., water pH was relatively constant in indoor aquaria, regardless of the water management carried out. On the other hand, diel water pH variations were wider in the outdoor aquaria. In the latter, water pH increased from 6 a.m. to 3 p.m. after which it began to go down. Therefore, fish suffered alkaline stress from high pH in the outdoor aquaria. Between 1 to 6 p.m., the water pH in the outdoor aquaria remained above 9 (Figure 2).

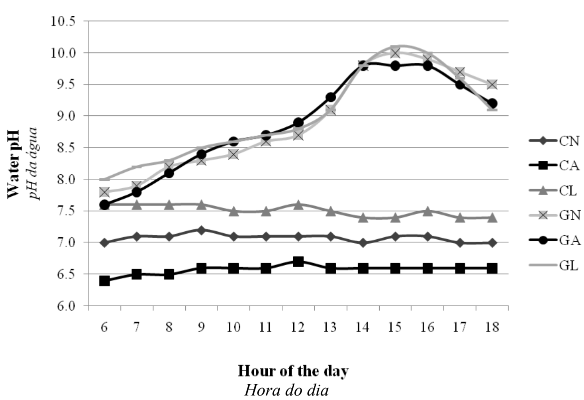

Figure 2. Water pH in indoor (clear water) and outdoor (green water) 25-L polyethylene aquaria. C: clear water, G: green water, N: no water management; A: water acidification with concentrated HCl (1.0 mL 20 L^{-1}) and L: acidified water liming with analytical $CaCO_3$ (1 g 10 L^{-1}).

Figura 2. *pH da água interna (águas claras) e externa (águas verdes) em aquários de polietileno de 25 L. C: água clara. G: água verde. N: nenhum manejo; A: acidificação de água com HCl (1,0 mL 20 L^{-1}) e L: calagem da água acidificada com $CaCO_3$ (1 g 10 L^{-1}).*

The results of water pH suggest that there was excessive phytoplankton in the outdoor aquaria, especially in the limed ones. This is thought due to the high value of water pH at 3 p.m. (< 10). Therefore, the total alkalinity of water in outdoor limed aquaria (59.2 mg L^{-1}), although inside the proper range for aquaculture (20-120 mg L^{-1}), was not capable to satisfactorily buffer the water pH because there was excessive phytoplankton in the aquaria. In future works, it will be installed a cover mesh over the outdoor aquaria to restrict sunlight incidence.

Table 1 presents the effects of the water type (clear or green) and water quality management (none, acidification with HCl or $CaCO_3$ liming) on the water pH, total alkalinity, calcium hardness, free CO_2 and total ammonia.

Table 1. Clear and green water quality variables monitored weekly in 25-L polyethylene aquaria stocked with fifteen Nile tilapia, *Oreochromis niloticus*, fingerlings (0.77 ± 0.04 g) and submitted to different managements (mean ± s.d.; n = 3). The results for total alkalinity and calcium hardness are in mg L^{-1} $CaCO_3$ equivalent; the results for free CO_2 and total ammonia are in mg L^{-1}.

Tabela 1. *Variáveis de qualidade de água das águas claras e verdes monitoradas semanalmente em aquários de polietileno de 25 L que foram estocados com juvenis de tilápia do Nilo, Oreochromis niloticus (0,77 ± 0,04 g), submetidos a diferentes manejos (média ± d.p.; n = 3). Os resultados para alcalinidade total e dureza cálcica estão em mg L^{-1} de $CaCO_3$ equivalente; os resultados para CO_2 livre e amônia total estão em mg L^{-1}.*

Water *Água*	Management *Manejo*		
	None *Nenhum*	HCl acidification[1] *Acidificação com HCl*	$CaCO_3$ liming[2] *Calagem com $CaCO_3$*
	pH		
Clear *Clara*	7.10 ± 0.03 Bb[3]	6.76 ± 0.03 Bc	7.41 ± 0.08 Ba
Green *Verde*	7.78 ± 0.02 Ab	7.51 ± 0.14 Ac	8.21 ± 0.05 Aa
	Total alkalinity *Alcalinidade total*		
Clear *Clara*	31.2 ± 3.46 Bb	21.3 ± 0.76 Bc	53.7 ± 0.83 Ba
Green *Verde*	56.7 ± 2.30 Aa	39.7 ± 2.14 Ab	59.2 ± 1.80 Aa
	Calcium hardness *Dureza cálcica*		
Clear *Clara*	81.9 ± 0.2 Bb	81.7 ± 1.3 Bb	145.9 ± 2.8 Ba
Green *Verde*	98.9 ± 10.4 Ab	90.5 ± 14.0 Ab	154.4 ± 20.7 Aa
	Free CO_2 *CO_2 livre*		
Clear *Clara*	13.9 ± 1.47 b	18.1 ± 0.64 a	6.9 ± 0.76 c
Green *Verde*	14.1 ± 1.79 b	17.5 ± 1.67 a	3.3 ± 1.10 c
	Total ammonia *Amônia total*		
Clear *Clara*	0.47 ± 0.07 B	0.45 ± 0.04 B	0.47 ± 0.06 B
Green *Verde*	0.79 ± 0.04 A	0.82 ± 0.05 A	0.70 ± 0.10 A

Two-way Anova *Anova bifatorial*

	pH	Total alkalinity *Alcalinidade total*	Calcium hadness *Dureza cálcica*	Free CO_2 *CO_2 livre*	Total ammonia *Amônia total*
Water type *Tipo de água*	< 0.001	< 0.001	0.047	ns[4]	< 0.001
Management *Manejo*	< 0.001	< 0.001	< 0.001	< 0.001	ns
Interaction *Interação*	ns	< 0.001	ns	ns	ns

[1]Acidification of the supply water with concentrated analytical grade HCl at 1.0 mL 20 L^{-1}; [2]Liming of the acidified water with analytical grade $CaCO_3$ at 1 g 10 L^{-1}; [3]For each variable, means with different capital letters in column or small letters in row are significantly different between themselves by the Tukey's test (p < 0.05). No letters means lack of significance; [4]Not significant (p > 0.05).

[1]Acidificação da água de abastecimento com HCl p.a. concentrado em 1,0 mL 20 L^{-1}; [2]Calagem da água acidificada com $CaCO_3$ p.a. em 1 g 10 L^{-1}; [3]Para cada variável, médias com diferentes letras maiúsculas na coluna ou minúsculas na linha são significativamente diferentes entre si pelo teste de Tukey (< 0,05). Ausência de letras representa falta de significância estatística; [4]Não-significante (p > 0,05).

The main rationality to carry out liming in fish tanks or ponds is to increase their water and soil pH. In the present work, the application of analytical $CaCO_3$ at 1 g 10 L^{-1} in the aquarium water was effective to accomplish that aim. The increase of the aquarium water's pH by the application of calcium carbonate can be explained by the following reaction: $CO_3^{-2} + H_2O \leftrightarrow HCO_3^- + OH^-$. Thus, when carbonate enters into the water, the previous chemical equilibrium is dislocated to the right with the production of bicarbonate and hydroxyl ions. The latter ion increases the water pH (QUEIROZ et al., 2004).

The liming application rate employed in the present work, i.e., 1 g analytical $CaCO_3$ 10 L^{-1} weakly acidified water was effective to increase water's total alkalinity, especially in the clear, oligotrophic waters. In these waters, liming not only off-set the reduction of alkalinity but also increased significantly the water's total alkalinity to 53.7 mg L^{-1}. The same was not observed in green waters. In these waters, liming of the acidified water just bring water alkalinity back to the previous, non-managed values. This difference between the clear and green waters can be explained by the photosynthetic activity which increases water's alkalinity when it removes free CO_2 from water (SCHIPPERS et al., 2004).

A statistical trend was detected for the effect of the water type (clear or green) upon the concentration of free CO_2 in water (Anova $p = 0.052$). Besides, there was also a trend for a significant interaction between water type and management ($p = 0.062$). These trends suggest that the concentrations of free CO_2 in clear limed waters are higher than in green limed waters. Moreover, the concentrations of free CO_2 in clear and green waters are not significantly different between the acidified or non-managed aquaria. The concentrations of free CO_2 in clear limed and green limed waters (6.9 ± 0.76 and 3.3 ± 1.10 mg L^{-1}, respectively) were significantly lower than for clear acidified and green acidified (18.1 ± 0.64 and 17.5 ± 1.67 mg L^{-1}, respectively) or clear non-managed and green non-managed (13.9 ± 1.47 and 14.1 ± 1.79 mg L^{-1}, respectively; Table 2). The concentrations of free CO_2 in the HCl acidified aquaria were significantly higher than in the non-managed ones.

The results of free CO_2 of the present work suggest that the reduction of CO_2 by $CaCO_3$ liming in eutrophic, green waters is stronger than in oligotrophic, clear waters. It is expected a lower concentration of free CO_2 in green waters than in the clear ones because phytoplankton actively absorbs CO_2 from water to undertake photosynthesis during the day. The reduction and increase of free CO_2 concentration in water as an effect of carbonate liming and HCl application, respectively, can be explained by the following reaction: $CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-$. When the input of carbonates in the water increases water pH, the reducing H^+ ions cause CO_2 consumption. On the other hand, the input of H^+ caused by HCl produces more CO_2 (HARGREAVES et al., 2000).

The different water quality management carried out in the aquaria, i.e., none, acidification with concentrated HCl or liming with analytical $CaCO_3$, did not affect significantly the total ammonia concentration in water. This was valid both for the clear and green waters. However, the total ammonia concentrations in green waters, regardless of the water management performed, were significantly higher than in clear waters ($p < 0.05$; Table 1). The main source of ammonia in aquaculture systems is the bacterial decomposition of fish feces and non-ingested diet. Beside those, when phytoplankton decay its decomposition also produces ammonia. Thus, heavily fed fish ponds and eutrophic waters are expected to contain more ammonia than moderately fed fish ponds and oligotrophic waters. There are risk of mortalities by low dissolved oxygen and high ammonia concentrations in the culture water when excessive phytoplankton occurs (TEW et al., 2006).

Growth performance

The final survival was not significantly different between the experimental treatments ($p > 0.05$). The survival rates ranged from 93.3 ± 6.65% up to 100.0 ± 0.00% (Table 2). On average, final survival for all treatments was 95.95 ± 0.49%. The high survival indicates that the critical values of pH, total ammonia and free CO_2 which cause fish mortality were not reached in the present work. Perhaps fish mortalities could be seen in some aquaria if the applied dosage of acid was greater than the one really done (1.0 mL 20 L^{-1}).

No significant differences were observed for final fish body weight between the clear and green waters in spite of the water quality management performed. The final fish body weights were 3.08 ± 0.15 and 2.98 ± 0.13 g for the clear and green waters, respectively. Final fish body weight in the $CaCO_3$ limed aquaria was significantly higher than in the non-managed or acidified aquaria ($p < 0.05$; Table 2). This was valid both for the clear (3.25 ± 0.09 g) and green (3.12 ± 0.05 g) waters. On the other hand, no significant differences were seen for the final fish body weight between the acidified and non-managed aquaria.

Table 2. Growth performance of Nile tilapia, *Oreochromis niloticus*, fingerlings (0.77 ± 0.04 g) stocked for 6 weeks in 25-L polyethylene aquaria submitted to different water quality managements. The results of final body weight, final total body length and survival are in g fish^{-1}, cm fish^{-1} and %, respectively (mean ± s.d.; n = 3).

***Tabela 2**. Desempenho produtivo de alevinos de tilápia do Nilo, Oreochromis niloticus (0,77 ± 0,04 g), estocados por seis semanas em aquários de polietileno de 25 L, submetidos a diferentes manejos de qualidade de água. Os resultados de peso corporal final, comprimento corporal final e sobrevivência estão em g peixe^{-1}, cm peixe^{-1} e %, respectivamente (média ± d.p.; n = 3).*

Water *Água*	Management *Manejo*		
	None *Nenhum*	HCl acidification[1] *Acidificação com HCl*	$CaCO_3$ liming[2] *Calagem com $CaCO_3$*
	Final body weight *Peso corporal final*		
Clear *Clara*	2.97 ± 0.25 b[3]	3.02 ± 0.15 b	3.25 ± 0.09 a
Green *Verde*	2.86 ± 0.09 b	2.97 ± 0.20 b	3.12 ± 0.05 a
	Final body length *Peso corporal final*		
Clear *Clara*	5.99 ± 0.15 b	6.17 ± 0.22 ab	6.34 ± 0.44 a
Green *Verde*	6.06 ± 0.16 b	6.17 ± 0.01 ab	6.35 ± 0.38 a
	Survival *Sobrevivência*		
Clear *Clara*	95.5 ± 3.87	95.6 ± 7.68	95.6 ± 7.68
Green *Verde*	100.0 ± 0.00	93.3 ± 6.65	95.5 ± 3.87
	FCR *FCA*		
Clear *Clara*	2.17 ± 0.32 A	2.11 ± 0.13 A	1.99 ± 0.09 A
Green *Verde*	2.23 ± 0.19 B	2.26 ± 0.27 B	2.35 ± 0.33 B

Two-way Anova *Anova bifatorial*	Body weight *Peso corporal*	Body length *Comp. corporal*	Survival *Sobrevivência*	FCR *FCA*
Water *Água*	ns	ns	ns	0.021
Management *Manejo*	0.032	0.028	ns	ns
Interaction *Interação*	ns	ns	ns	ns

[1]Acidification of the supply water with concentrated analytical grade HCl at 1.0 mL 20 L^{-1}; [2]Liming of the acidified water with analytical grade $CaCO_3$ at 1 g 10 L^{-1}; [3]For each variable, means with different capital letters in column or small letters in row are significantly different between themselves by the Tukey's test ($p < 0.05$). No letters means lack of significance; [4]Not significant ($p > 0.05$).

[1]Acidificação da água de abastecimento com HCl p.a. concentrado em 1,0 mL 20 L^{-1}; [2]Calagem da água acidificada com $CaCO_3$ p.a. em 1 g 10 L^{-1}; [3]Para cada variável, médias com diferentes letras maiúsculas na coluna ou letras minúsculas na linha são significativamente diferentes entre si pelo teste de Tukey ($p < 0.05$). Ausência de letras representa falta de significância estatística; [4]Não-significativo ($p > 0,05$).

In the present work, the presence of phytoplankton in green waters did not improve fish growth. Phyto and zooplankters may serve as food for some species of fish, especially over its early development. Tilapias are known as good phytoplankton feeders (MILSTEIN et al., 2008). Our results suggest that the nutritional input to the aquaria from the artificial diet has already satisfied the fingerlings requirements in this life stage (0.8-3.2 g fish^{-1}) and no plankton as food was needed. The daily stress suffered by the outdoor fish due to the wider temperature variations may also have counteracted the expected benefits of planktons in the green culture water (Figure 1).

The results of final body weight indicate that liming of acid waters with calcium carbonate increase significantly fish growth. The positive effect of liming on fish growth may be due to the higher water alkalinity and calcium hardness; and/or to the lower free CO_2 concentration in limed waters. The best results of fish growth were observed to the following set of limnological conditions: total alkalinity > 50 mg L^{-1}, calcium hardness > 140 mg L^{-1} and free CO_2 concentration < 7 mg L^{-1}. Among these conditions, we highlight calcium hardness and free CO_2 concentration which were markedly different between the experimental treatments, both for the clear and green waters.

The results of fish growth for the non-managed and acidified waters show that the HCl application was not strong enough to impair fish development. Hence, in spite of its significant effects on water alkalinity, pH and free CO_2, the dosage application of HCl in aquaria water (1 mL 20 L^{-1}) was not capable to affect negatively fish growth. It is suggested to try higher acid dosages in future works. The reductions in the clear water pH to 6.8 and total alkalinity to 21 mg L^{-1} remained inside the desirable ranges for fish culture, i.e., pH > 6.5 and total alkalinity > 20 mg L^{-1} (BOYD; TUCKER, 1998).

Rojas and Rocha (2004) found that the culture water of Nile tilapia post-larvae (0.03 g) with total alkalinity, total hardness and pH of 57 mg L^{-1}, 70 mg L^{-1} and 7.9, respectively, impaired post-larvae growth. On contrary, values as high as 60 mg L^{-1}, 154 mg L^{-1} and 8.2 for total alkalinity, calcium hardness, and pH, respectively, produced the best fish growth in the present work. The explanation for this difference could be the distinct fish life stage in the two works. Rojas and Rocha (2004) worked with 0.03 g Nile tilapia post-larvae. It was used 0.77 g Nile tilapia fingerlings in the present work. It seems that younger *O. niloticus* individuals thrive better when cultured in more acid waters. This is a question that warrants further investigation.

The final total body length of fish was not significantly different between the clear and green waters, regardless of the water quality management carried out. On the other hand, the final total body length of fish cultured in limed waters was significantly higher than that observed for fish cultured in non-managed water, both for clear and green waters ($p < 0.05$; Table 2). However, no statistical differences were seen for final total body length between acidified and non-managed aquaria; and between acidified and limed aquaria, both for the clear and green waters.

The feed conversion ratio (FCR) of fish reared in clear waters was significantly better than the observed in green waters, in spite of the water quality management performed. Both for the clear and green waters, there were not significant differences in the FCR's results between the water quality managements, i.e., none, acidification or $CaCO_3$ liming (Table 2). These results indicate that the currently rearing conditions of the LCTA's indoor system allow the achievement of better growth performance results than those set in the laboratory's outdoor system. Water temperature is probably the critical factor that hampers fish growth in the outdoor aquaria. As previously cited, water temperatures higher than 36°C may occur in some outdoor aquaria at the afternoon's end. The FCR's results strengthen fish growth data and suggest that the best water quality which attained sound fish performance were total alkalinity > 50 mg L^{-1}, calcium hardness > 140 mg L^{-1} and free CO_2 concentration < 7 mg L^{-1}.

Conclusion

The results obtained in the present work enable us to conclude the following: the application of analytical calcium carbonate at 1 g 10 L^{-1} in clear, oligotrophic or green, eutrophic waters, that were weakly acidified with chloridric acid, produced superior Nile tilapia fingerlings' final body weight and length. Both for the clear, oligotrophic and green, eutrophic waters, the best set of limnological conditions that improved Nile tilapia fingerlings growth was the following: pH: 7.4-8.2; total alkalinity > 50 mg L^{-1}; calcium hardness > 140 mg L^{-1} (soluble calcium > 56 mg L^{-1}); free CO_2 < 7 mg L^{-1}. Total ammonia concentration in fish aquaria was not affected by $CaCO_3$ liming.

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