Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Nile tilapia (Oreochromis niloticus) and lettuce (Lactuca sativa) production integrating a floating-raft aquaponic system with biofloc technology

Lorena Cangussu de Melo

lorenacangussudemelo@gmail.com

Federal University of Mato Grosso do Sul

Ruy Alberto Caetano Corrêa-Filho

Federal University of Mato Grosso do Sul

Jayme Aparecido Povh

Federal University of Mato Grosso do Sul

Rebeca Maria Sousa

Federal University of Mato Grosso do Sul

Adryadine Almeida Costa

Federal University of Mato Grosso do Sul

Luis Felipe Arruda Cruz

Federal University of Mato Grosso do Sul

Lucas Brasileiro Oliveira

Federal University of Mato Grosso do Sul

Lais Santos Roque

Federal University of Mato Grosso do Sul

Susana Amaral Teixeira Manso

Federal University of Mato Grosso do Sul

Research Article

Keywords: Aquaculture, Aquaponics, BFT, Sustainability

Posted Date: May 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9117324/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

In contemporary aquaculture, aquaponic systems and biofloc technology offer sustainable alternatives for food production by reducing water loss and enhancing nutrient recycling. However, research integrating these systems remains limited, highlighting the need for further investigation. This study aimed to evaluate Nile tilapia (*Oreochromis niloticus*) production in floating raft aquaponic systems with and without biofloc technology over 42 days. A completely randomized design compared two treatments: a floating-raft aquaponic recirculating system (AQ) and a floating-raft aquaponic system incorporating biofloc technology (AQBFT). Each module contained twenty-eight male Nile tilapia (initial weight: 0.330 kg) and thirty-two leaf lettuce seedlings. Results indicated that the AQ system outperformed AQBFT in fish growth metrics, with a final tilapia weight of 0.528 kg, daily weight gain of 4.73 g/day, final biomass of 14.80 kg/m³, and biomass gain of 5.56 kg, all significantly higher ($P < 0.05$) than AQBFT's results (0.474 kg; 3.37 g/day; 13.2 kg/m³; 3.87 kg). Similar trends were observed in lettuce performance, where the AQ system achieved significantly greater leaf weight (186.84 g), root weight (25.13 g), and total biomass (3.13 kg/m²) compared to AQBFT (76.56 g; 10.87 g; 1.22 kg/m²). Overall, the floating-raft aquaponic system incorporating biofloc technology (AQBFT) resulted in lower growth performance for both fish and plants compared to the standard aquaponic system (AQ).

Introduction

Population growth combined with the progressive demand for water resources fosters the proposal of environmentally and economically sustainable alternatives for animal production, especially concerning the use of water resources. In aquaculture, aquaponics systems and biofloc technology (BFT) are presented as alternatives for achieving sustainability in the food production sector, as both systems offer low water loss and nutrient recycling.

Aquaponics is the combination of hydroponic and aquaculture systems, highlighting an efficient use of water and enabling the simultaneous production of plants (vegetables and greens) and aquatic organisms without increasing water consumption (Hundley & Navarro, 2013). In this system, plants improve water quality for aquatic organisms and, at the same time, the nitrogen generated by aquatic organisms in the culture tanks is absorbed by plant roots in the grow bed, contributing to water quality improvement before returning to the fish culture tank (Franco et al., 2024; Rocha, H. et al., 2025), reducing or eliminating the need for complete water exchanges in fish farming systems (EMBRAPA, 2024). Thus, the system maintains nitrogen compound toxicity levels within tolerable limits for the survival of aquatic organisms (Jordan, 2022).

Aquaponics has been gaining prominence in the national context, as evidenced by Emereniano et al. (2016), who assessed the current state of research, science, and innovation in aquaponic systems in Brazil, conducted between October 2015 and February 2016. However, studies addressing the integration of this modality with other technologies, such as biofloc technology (BFT), are still scarce.

The sustainability of biofloc technology is rooted in the reuse and growth of microorganisms that recycle nutrients, while also serving as a high-protein food source for various aquatic organisms. This dual function makes BFT a compelling area of study and application in aquaculture.

The microorganisms present in BFT, in addition to having nutritional and probiotic functions, are essential for maintaining water quality. Heterotrophic and chemoautotrophic bacteria compose the microbial flocs, which require carbon sources, such as molasses, and high concentrations of dissolved oxygen in the water (Avnimelech, 2011). Heterotrophic bacteria use organic matter as an energy source, and the availability of organic carbon sources such as molasses, along with nitrogen in the form of ammonium (NH_4^+) in the system, favors these bacteria. In contrast, chemoautotrophic bacteria use inorganic compounds as an energy source, consuming inorganic carbon sources (carbon dioxide, CO_2), nitrogen in the form of NH_4^+, and nitrite (NO_2^-) (Jiménez-Ojeda et al., 2018).

The use of different associated technologies aims to reduce the impacts generated by excessive effluent discharge, which still contains nutrients that, instead of being discarded, can be reused by other organisms. In this context, the objective of this study was to evaluate the production of Nile tilapia in a raft aquaponic system associated with biofloc technology (BFT).

Materials & methods

Study site, animals, and plants

The experiment was conducted at the Experimental Fish Farming Station of the Federal University of Mato Grosso do Sul (UFMS), situated in Campo Grande, Mato Grosso do Sul, Brazil. The protocol was approved by the Institutional Ethics Committee (Protocol No. 1.357/2025).

Experimental Animals and Stocking

A total of 280 adult male Nile tilapia (Oreochromis niloticus) with an initial mean weight of 0.33 kg were obtained from a commercial fish farm in Campo Grande, Brazil. Fish were stocked at a density of 9 kg m^{-3} (28 individuals per unit). No significant differences in initial mean weight or biomass were observed among treatments.

Plant Material

A total of 320 hydroponic seedlings of loose-leaf lettuce (Lactuca sativa) were used. Seedlings of uniform size, each with 3–4 leaves, were transplanted approximately 30 days after germination and distributed equally among the experimental units.

Experimental Design

A completely randomized design was adopted, consisting of two treatments with five replicates each: (i) raft aquaponic system with water recirculation (AQ), and (ii) raft aquaponic system integrated with biofloc technology (AQBFT). The trial lasted 42 days.

Experimental Units

Each experimental unit (Fig. 1) consisted of an aquaponic module composed of three components: (i) a plant grow bed (500 L; 200 × 100 × 40 cm) equipped with a floating raft made of high-density T5 Styrofoam; (ii) a fish culture tank (1,000 L polyethylene container); and (iii) a pump/filter tank (100 L polyethylene container) housing a 24 W submersible water pump.

All tanks and grow beds were continuously aerated using a 1.5 hp blower connected to porous hoses. Dissolved oxygen levels were maintained at ~ 5.5 mg L^{-1}, as recommended by Tran-Duy et al. (2012). In each 1,000 L fish tank, a 1.2 m arc of porous tubing was installed, while grow beds contained four 30 cm aeration points.

In AQ modules, the reservoir tank (100 L) also functioned as a biological filter filled with gravel and expanded clay to promote nitrifying bacterial colonization. Grow beds were shaded with a PVC arc structure covered by a 35% shade cloth to reduce excessive solar radiation and pest incidence. Water circulation followed a flood-and-drain design using an inverted “U” siphon (32 mm PVC). Fish tank water flowed into the reservoir via two communicating siphons (32 mm PVC and 40 mm hose), then was pumped (22 W; 2,000 L h^{-1}) to the grow bed, from which water returned by gravity through a 32 mm PVC drain.

Aquaponic systems

Water cycling was initiated by daily addition of agricultural urea (5 g $module^{-1}$) for five consecutive days until nitrite and nitrate formation confirmed biofilter maturation (adapted from Pereira & Mercante, 2005). Once stabilized, water was homogenized across modules. Four partial water exchanges were performed during the 42-day trial when total ammonia nitrogen (TAN) and nitrite exceeded safe levels (El-Sayed, 2020).

Evaporation losses were replenished weekly. Replacement water was dechlorinated with sodium thiosulfate, adjusted with NaCl (2–3 g L^{-1}) to mitigate nitrite toxicity, sodium bicarbonate (30 g m^{-3} d^{-1}) to maintain alkalinity (80–100 mg L^{-1}), and 85% phosphoric acid when necessary to stabilize pH near 7.0. Fertilizer (Forth Hortaliças®) and neem-based insecticide (Original Nim®) were applied when nutrient deficiencies or pest outbreaks occurred. Shade cloths were occasionally irrigated to mitigate high (> 30°C) temperatures.

Biofloc Technology Integration

In AQBFT treatments, 1,000 L of mature biofloc water was inoculated to seed microbial communities. Floc density was adjusted weekly to 8–10 mL L^{-1} by adding molasses when needed (Ebeling et al., 2006), measured using 1 L Imhoff cones after 30 min sedimentation (Avnimelech, 2007). Excessive biofloc sedimentation in grow beds required daily manual suspension by briefly lifting rafts, which resulted in visible floc accumulation on lettuce roots.

Water Quality Monitoring

Physicochemical parameters were routinely monitored. Nitrite, nitrate, and alkalinity were measured weekly using commercial kits, while colorimetric assays determined TAN. Salinity was measured with a conductivity meter (Hanna Hi98319). Daily measurements of temperature (°C), pH, and dissolved oxygen (mg/L) were taken using a multiparameter probe (YSI ProPlus).

Feeding Regimen

Fish were fed twice daily (morning and late afternoon) with 36% CP extruded tilapia feed (93.8% DM; 10.3% ash; 35.6% CP; 3.4% EE). The feeding rate was 3% of the initial biomass, increasing by 10% weekly based on the offered feed. The feed was weighed using a precision digital balance.

Performance Evaluation

Two samplings were conducted: at baseline and at 42 days. Fish were fasted for 24 h, anesthetized with clove oil (50 mg L^{-1}), and weighed. Growth parameters included final weight (kg), daily weight gain (g d^{-1}), final biomass (kg m^{-3}), biomass gain (kg), feed conversion ratio (FCR), and survival (%). Lettuce plants were harvested at day 41, and leaf weight (g), root weight (g), and total biomass (kg m^{-2}) were recorded.

Statistical Analysis

Fish performance, water quality, and proximate composition data were analyzed using Student's t-test for independent samples after normality verification by the Shapiro–Wilk test. When normality was not met, the Mann–Whitney test was applied (lettuce performance variables). A significance level of 0.05 was adopted. All analyses were performed using SAS (2002), following the guidelines outlined by Zar (2010).

Results

Significant differences were observed in Nile tilapia performance between systems for all variables, except survival. Contrary to expectations, mean final weight (kg), daily weight gain (g day^{-1}), final biomass (kg m^{-3}), and biomass gain (kg) were higher in AQ (0.52 kg; 4.73 g day^{-1}; 14.80 kg m^{-3}; 5.56 kg) compared to AQBFT (0.47 kg; 3.37 g day^{-1}; 13.20 kg m^{-3}; 3.87 kg), respectively. Also, the FCR mean was higher (less efficient) in AQBFT (2.18) and lower (more efficient) in AQ (1.55) (Table 1).

For lettuce performance, significant differences ($P < 0.05$) were detected for all median variables, except for the final number of plants. Leaf weight (g), root weight (g), and total biomass (kg m^{-2}) were higher in AQ than in AQBFT (Table 1).

Table 1
Mean values (± standard deviation) of the productive performance variables of Nile tilapia (Oreochromis niloticus) and median values of the productive performance variables of curly lettuce (Lactuca sativa) in raft aquaponic systems with recirculating water system (AQ) and raft aquaponic systems with biofloc technology (AQBFT) during a 42-day experimental period

	AQ	**AQBFT**	**[1]CV(%)**	**[2]P-value**
Productive performance of Nile tilapia				
Final weight (kg)	0.52 ± 0.01 a	0.47 ± 0.03 b	4.47	0.005
Feed conversion ratio (FCR)	1.55 ± 0.14 b	2.18 ± 0.38 a	12.93	0.003
Daily weight gain (g/day)	4.73 ± 0.35 a	3.37 ± 0.62 b	13.05	0.003
Survival (%)	90 ± 0	87.71 ± 4.87	4.08	0.346
Final biomass (kg/m^3)	14.80 ± 0.36 a	13.20 ± 0.85 b	4.71	0.004
Biomass gain (kg)	5.56 ± 0.41 a	3.87 ± 0.75 b	13.34	0.002
Productive performance of curly lettuce				
Leaf weight (g)	192.47 ± 0.08 a	186.84 ± 0.01 b	-	0.048
Root weight (g)	25.13 ± 0.01 a	10.87 ± 0.001 b	-	0.048
Total biomass (Kg/m^2)	3.13 ± 2.65 a	1.29 ± 0.29 b	-	0.048
Final number of plants (u)	29.5 ± 6.76	29 ± 3.85	-	0.408

(1) CV (%): coefficient of variation.

(2) P-value from Student's t-test (independent samples) for Nile tilapia performance variables and from the Mann–Whitney test for lettuce production variables, considered significant when $P < 0.05$.

No significant differences were detected for water temperature (°C) and dissolved oxygen (mg L^{-1}) across treatments during the 42-day trial. However, mean pH values were lower in AQ (6.96) compared with AQBFT (7.3) ($P < 0.05$; Table 2). Regarding nitrogenous compounds, nitrite (NO_2^-, mg L^{-1}) concentrations did not differ significantly between treatments. Nevertheless, the mean of the total ammonium nitrogen (TAN) was higher in AQBFT (1.47 mg L^{-1}) than in AQ (0.17 mg L^{-1}) ($P < 0.05$). Conversely, nitrate (NO_3^-, mg L^{-1}) concentration was lower in AQBFT (39.18 mg L^{-1}) than in AQ (63.19

mg L^{-1}) ($P < 0.05$). Mean alkalinity was also lower in AQ (80 mg L^{-1}) compared with AQBFT (115 mg L^{-1}) ($P < 0.05$) (Table 2).

Table 2
Mean values (± standard deviation) of water quality parameters in the raft aquaponic system with recirculating water system (AQ) and in the raft aquaponic system with biofloc technology (AQBFT) during a 42-day experimental period

	AQ	AQBFT	[1]CV(%)	[2]P-value
Temperature (°C)	**26.6 ± 0.43**	**26.58 ± 0.41**	**1.58**	**0.896**
pH	6.96 ± 0.08 a	7.30 ± 0.05 b	0.99	< 0.001
Dissolved oxygen (mg/L)	6.51 ± 0.09	6.3 ± 0.23	2.71	0.093
Total ammonium nitrogen (mg/L)	0.17 ± 0.18 b	1.47 ± 0.55 a	79.7	0.001
Nitrite (mg/L)	1.07 ± 0.16	0.98 ± 0.59	42.55	0.755
Nitrate (mg/L)	63.19 ± 8.20 a	39.18 ± 10.08 b	20.37	0.005
Alkalinity (mg/L)	80.00 ± 0 b	115.00 ± 7.16 a	4.51	< 0.001

(1) CV (%): coefficient of variation (2) P-value from Student's t-test for independent samples, considered significant when $P < 0.05$. Although survival was high in both treatments, water quality occasionally deviated from the optimal range. Monitoring of water quality dynamics (Fig. 2) revealed sharp increases in TAN, nitrite, and nitrate concentrations in AQBFT units. Temperature and nitrite levels showed wide variation in both systems. Fluctuations in pH were also observed, with AQBFT units consistently showing higher values (> 8.0) compared to AQ units (6.5–7.5).

Proximate composition of tilapia fillets (skin-on) did not differ significantly between AQ and AQBFT treatments for moisture (%), crude protein (%), ash (%), or ether extract (%) (Table 3). In lettuce, however, significant differences were found. Crude fiber (%) was lower in AQBFT while moisture (%) and ether extract (%) were higher in AQBFT (91.68; 0.46%) compared with AQ (90.02; 0.39%) ($P < 0.05$).

Table 3
Mean values (± standard deviation) of the proximate composition analyses of Nile tilapia (Oreochromis niloticus) fillets (with skin) and curly lettuce (Lactuca sativa) in raft aquaponic systems with recirculating water system (AQ) and raft aquaponic systems with biofloc technology (AQBFT) during a 42-day experimental period

Nile tilapia fillet	**AQ**	**AQBFT**	**[1]CV(%)**	**[2]P-value**
Moisture (%)	73.21 ± 1.34	72.84 ± 0.93	1.57	0.622
Crude protein (%)	20.91 ± 0.88	20.58 ± 0.99	4.57	0.607
Ash (%)	0.88 ± 0.04	0.9 ± 0	3.73	0.346
Ether extract (%)	0.83 ± 0.11	0.87 ± 0.07	11.64	0.557
Curly lettuce				
Moisture (%)	90.02 ± 0.31 b	91.68 ± 0.59 a	0.66	0.002
Crude protein (%)	1.22 ± 0.07	1.14 ± 0.04	4.77	0.062
Ash (%)	2.12 ± 0.04	2.06 ± 0.04	10.87	0.696
Fibra bruta (%)	1.99 ± 0.03 a	1.88 ± 0.10 b	3.75	0.040
Ether extract (%)	0.39 ± 0.01 b	0.46 ± 0.05 a	8.74	0.015
(1) CV (%): coefficient of variation				

(2) P-value from Student's t-test for independent samples, considered significant when $P < 0.05$.

The proximate composition of microbial flocs consisted of 23.65% crude protein, 0.08% lipids, 94.12% moisture, and 2.75% ash. Average settleable solids concentration was 8 mL L^{-1}, with fluctuations recorded throughout the experimental period in BFT units (Fig. 3).

Discussion

The association of different technologies for food production in a more sustainable way has gained space for promoting sustainability and reducing the use of water resources, as well as reducing the emission of effluents. The present study evaluated the association between the use of aquaponics and biofloc technology, two systems that prioritize sustainable practices.

High densities in aquaponic systems can pose challenges for both fish and plants. Barbosa et al. (2022), comparing the performance of Nile tilapia in aquaponic gravel systems with and without BFT, used an initial density of 4 kg/m³ for a period of 30 days and did not observe differences between treatments. In our study, the challenge for the aquaponic system was greater, as we used an initial density of 9 kg/m³ and an experimental period of 42 days. The aquaponic system with BFT showed inferior results. In both

studies, it was possible to observe that the accumulation of flocs in areas of the systems hinders the good performance of the fish, since a large part of the microbial flocs accumulated in the grow bed and in the roots of the plants, and could not be accessed by the fish all the time.

The accumulation of flocs in the grow beds and roots may have led to the mortality of microbial organisms, which would generate an increase in the concentration of nitrogen compounds in the system and consequently cause a deterioration in water quality. According to Kubitza (2022), toxic ammonia (NH3) at high concentrations reduces appetite and weight gain in fish. In this sense, with the increase of this compound in the BFT, it may have negatively influenced the productive performance of these fish.

A better performance was observed for the FCR of the fish in AQ, which was significantly lower than the FCR of the fish in AQBFT. The values obtained in AQ remained within the expected range for tilapia culture in aquaponic systems similar to research carried out by Shaheen et al. (2022) (FCR: 1.54) and by Félix-Cuencas et al. (2025) (FCR: 1.62), and were higher than the values found by Barbosa et al. (2022) (FCR: 1.23). Still in other studies with aquaponic systems, the authors Guimarães et al. (2017), Hassan et al. (2024), Yang and Kim (2020) and Pinho et al. (2017) found feed conversion values higher than the present study (1.68; 1.88; 1.76; 4.02; respectively) at different biomass densities (7.69 kg/m³; 9 kg/m³; 20 kg/m³; 3.2 kg/m³; respectively).

In the AQBFT system, FCR was above the expected value for tilapia farming, which ranges from 1.2 to 1.8 kg (Kubitza, 2022; Carneiro et al., 2015). In the studies by Barbosa et al. (2022) and Pinho et al. (2017), the productive performance of Nile tilapia in aquaponic gravel and raft systems, respectively, with the use of biofloc technology, was evaluated. The FCR values recorded by the authors (1.06; 1.87, respectively) were much lower than those of the present study (2.18). In other studies related only to tilapia production in the adult stage (Oreochromis spp.) in systems with biofloc technology, Widanarni et al. (2012), Pérez-Fuentes et al. (2016), and Lima et al. (2018) also found lower values (with better feed conversion) than the present study at different initial biomasses (FCR 1.76 at 3.8 kg/m³; FCR 1.74 at 9.0 kg/m³; FCR 1.74 at 2.5 kg/m³, respectively).

These facts demonstrate that the fish may not have efficiently used the microbial flocs as a protein source, and/or the protein in the flocs was of low value. At the end of the experiment, the flocs were collected, and after bromatological analysis, only 23.65% crude protein was found in their composition. Still, according to Lyu et al. (2024), in farming with biofloc technology, flocs formed by smaller particles lead to better productive performance in tilapia farming; thus, the presence of flocs with larger particles may have negatively influenced the use of BFT as a food source. Another issue is the variation in the concentration of settleable solids during the experiment; although the average concentrations were close to 8 ml/L, there were many variations over the weeks in the modules, recording values from 2 to 14 ml/L.

In this work, despite the aeration system being distributed at four points, the assembly of a drainage system and daily stirring of the water in the grow beds were insufficient to maintain efficient circulation of microbial flocs. It is important to emphasize that the recommendation of the concentration of

settleable solids (SS/L) for adult tilapia farming should be between 20 and 50 SS/mL, so that there is better utilization as a food supplement (Emerenciano et al., 2017). In the present work, the concentration obtained was maintained below 5 to 10 ml, which is in line with this recommendation. This concentration was maintained to avoid the accumulation of excess microbial flocs in the grow beds and in the plant roots.

We also highlight that the excess of settleable solids can further decrease the productive performance of the plants, potentially rendering production impossible. Thus, it is essential to explore alternative system setups to enhance circulation and drainage in the grow bed, preventing floc accumulation and the formation of stagnant areas without water flow.

Barbosa et al. (2022) evaluated the polyculture of Nile tilapia and freshwater shrimp in a gravel aquaponic system with biofloc technology and clear water. After 30 days, the association did not show differences between treatments for the same vegetable performance variables. Another study conducted by Rocha, H. et al. (2025), evaluating the growth of lettuce and Nile tilapia in an aquaponic system over a period of 33 days, showed that although the lettuce showed good development, there were many variations in plant performance characteristics. The authors concluded that water quality had a direct influence on lettuce growth. Therefore, the excessive accumulation of microbial flocs in the grow bed may have led to a deterioration of water quality due to excess nitrogen in the system and, consequently, the underdevelopment and weakening of the lettuces grown in the AQBFT treatment. The roots of the plants in the AQBFT system showed considerable underdevelopment compared to those in the AQ system, where the former were smaller, atrophied, and had flocs accumulated on their surface.

Rocha, A. et al. (2025) evaluated the comparison of lettuce production in a floating-raft aquaponic system with biofloc technology (Aquafloc), in clear water with a floating-raft aquaponic system (Aqua), and production in a hydroponic system (Hidro) over a period of 45 days at low fish stocking densities. The authors reported that lettuces in the hydroponic system reached the desired size in 30 days. In contrast, lettuces in the Aquafloco system required an additional 15 days to meet the minimum performance parameters. On the other hand, the Aqua system did not meet the nutritional requirements of the lettuce, making production impossible. In the present study, even with high densities, the systems were able to meet the dietary needs of the lettuce in clear water. Still, weekly foliar fertilization of the lettuces was applied, unlike the study by Rocha et al. (2025), which did not report the use of any fertilization for the plants in their system.

It is essential to highlight that the lettuce heads, in both treatments, reached the final average weight similar to the work of Barbosa et al. (2022). And total biomass similar to the work of Dediu et al. (2012) (3.3 Kg/m²; period of 21 days) for the AQ system and to the work of Pinho et al. (2017) (in the AQBFT system (1.36 Kg/m²; period of 21 days). Authors who obtained a high final biomass worked with more extended experimental periods, such as Yang and Kim, 2020 (10.5 Kg/m²; period of 90 days) and Johnson et al., 2017 (4.7 Kg/m²; period of 70 days). However, this wide variation can be influenced by several environmental factors according to Lenz et al. (2017). During the experimental period of the

present work, there were several power outages, sudden temperature changes, pest outbreaks (caterpillars), and many days of intense sunlight and heat, which may have hindered the development and size of the plants, generating high variation in the productive results of the vegetables.

The evaluation of the performance of the association of the two systems can be obtained through the productive performance of the fish and the vegetables. In this case, it was observed that both organisms showed differences in the different systems. When kept in AQ, the lettuce showed higher values in bromatological composition within the range described by Barbosa et al. (2021). Still, according to these authors, the adherence of flocs to the roots can prevent the efficient absorption of nutrients by them, which possibly delays growth and may have influenced the excess TAN in the system. The water quality variables of the aquaponic systems were similar between the two treatments (AQ and AQBFT). The average temperature and dissolved oxygen obtained in aquaponics and in aquaponics integrated with BFT were adequate for Nile tilapia (> 5 mg/L; between 25 and 29ºC), both for BFT (Emerenciano et al., 2017) and for other production systems (El-Sayed, 2020). However, there was significant variation in temperature in the experimental units, and values above 29ºC and below 25ºC were recorded at specific times during the experimental period. Likewise, although pH was higher in aquaponics integrated with BFT, the values recorded in both systems were adequate (between 6.5 and 8.5; Emerenciano et al., 2017; El-Sayed, 2020); however, in the experimental units of the floating-raft aquaponic system with biofloc technology (AQBFT), pH values far from neutrality (> 8) were recorded. This issue, associated with the presence of ammoniacal nitrogen in the system, with peaks of high concentrations of total ammoniacal nitrogen and toxic ammonia in the experimental units with the AQBFT system, may have contributed to a deterioration in water quality of this system and harmed the development of fish at certain times.

Alkalinity and salinity were adjusted in both systems, with a better concentration obtained for the AQBFT system, including a concentration of alkalinity within the range considered adequate for production in BFT for Nile tilapia (> 100 mg/L; Emerenciano et al., 2017). However, the lower alkalinity concentration in aquaponics did not result in a deterioration in the development of the bacteria that carry out the nitritation process, which is the first stage of the nitrification process, which consists of the oxidation of ammonia (NH_3/NH_4^+) to nitrite (NO_2^-); and in the nitration process, which is the final stage of nitrification and consists of the oxidation of nitrite to nitrate (NO_3^-). In addition, alkalinity for clear-water conditions for Nile tilapia above 20 mg/L can be considered adequate (El-Sayed, 2020).

Regarding nitrogen compounds, it was observed that there was a greater accumulation of total ammonium nitrogen in the AQBFT system, including values higher than recommended for Nile tilapia in BFT (< 1 mg/L; Emerenciano et al., 2017), a situation that was controlled by the addition of a carbon source. Total ammonium nitrogen was present in the water mainly in the form of NH_4, given the pH close to neutrality, which is not toxic to fish; however, there were fluctuations in pH values throughout the experiment, reaching values above 8 in the AQBFT system, which may have harmed the development of fish at certain times. However, its conversion to nitrite, through the nitrification process by nitrifying bacteria, was similar in both systems, with the concentration close to the acceptable range for Nile tilapia (< 1 mg/L; Emerenciano et al., 2017, El-Sayed, 2020), but even with possible oscillations

throughout the experiment, maintaining system salinity (> 2 g/L) prevented possible methemoglobin formation. Finally, the higher nitrate concentration in the AQ system indicated better efficiency of this system in converting nitrogen compounds to a less toxic form for fish, given that nitrate is harmful to fish only at extremely high concentrations (> 100 mg/L; Kubitza, 2022).

In general, it is possible to infer that for efficient Nile tilapia production in a floating-raft aquaponic system with biofloc technology (AQBFT) and with good productive performance, a better system for circulation and agitation of microbial flocs in the plant grow beds would be necessary. A system that caused a more intense tide effect might solve this. One possibility would be the use of deeper grow tables, so the flocs would not accumulate on the roots and would not harm the lettuce seedlings. Another alternative would be to use a device for shredding the flocs in the system, using a methodology similar to Lyu et al. (2024), since flocs formed by smaller particle sizes and consequently with reduced density would generate less accumulation in the grow beds and plant roots, and better productive performance for the fish. In addition, the use of root protectors, which are commonly employed in aquaponic and hydroponic systems, can be adapted to limit the passage of flocs, thus improving seedling development. In this sense, further research is still needed on the integration of biofloc technology and floating-raft aquaponic systems.

Conclusion

The floating-raft aquaponic system incorporating biofloc technology (AQBFT) resulted in lower growth performance for both fish and plants compared to the standard aquaponic system (AQ).

Declarations

Funding Declarations

The research described in this manuscript did not receive funding.

Author Contribution

L.C., J.A., S.A., and R.C. worked on conceptualization, investigation, and writing—review & editing. L.C., R.M., A.A., L.F., L.B., and L.S. worked on methodology and formal analysis. L.C. worked on supervision and project administration. All authors reviewed the manuscript.

Acknowledgement

This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES); the National Council for Scientific and Technological Development (CNPq);

the Foundation for the Support of the Development of Education, Science and Technology of the State of Mato Grosso do Sul (FUNDECT); and the Federal University of Mato Grosso do Sul (UFMS).

References

1. Avnimelech Y (2007) Feeding with microbial flocs by tilapia in minimal discharge biofloc technology ponds. *Aquaculture* 264:140–147. https://doi.org/10.1016/j.aquaculture.2006.11.025
2. Avnimelech Y (2011) Tilapia production using biofloc technology: saving water, waste recycling improves economics. *Glob Aquac Advocate* 14(3):66–68
3. Barbosa PTL, Rodrigues RV, Henriques MB, Luz RK, Martins ML, Tavares-Dias M (2022) Nile tilapia production in polyculture with freshwater shrimp using an aquaponic system and biofloc technology. *Aquaculture* 551:737916. https://doi.org/10.1016/j.aquaculture.2022.737916
4. Barbosa PTL (2021) Nile tilapia production in an aquaponic system: different volumes and integration with biofloc technology (BFT) in polyculture with shrimp. PhD dissertation, Federal University of Mato Grosso do Sul, Campo Grande, Brazil
5. Carneiro PCF, Garcia F, Silva TS, Santos CL, Mattos BO (2015) Integrated production of fish and vegetables in aquaponics. Embrapa Coastal Tablelands, Aracaju, Brazil, 27 p
6. Dediu L, Cristea V, Zhang X (2012) Waste production and valorization in an integrated aquaponic system with bester and lettuce. *Afr J Biotechnol* 11(9):2349–2358
7. Ebeling JM, Timmons MB, Bisogni JJ (2006) Engineering analysis of the stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia–nitrogen in aquaculture systems. *Aquaculture* 257(1–4):346–358. https://doi.org/10.1016/j.aquaculture.2006.03.019
8. El-Sayed AFM (2020) Environmental requirements. In: El-Sayed AFM (ed) *Tilapia Culture*, 1st edn. Academic Press, Cambridge, MA, pp 47–61. https://doi.org/10.1016/B978-0-12-816541-6.00004-0
9. EMBRAPA (2024) Residential aquaponics. Embrapa, Brasília, DF, Brazil. https://www.embrapa.br/busca-de-solucoes-tecnologicas/produtoservico/6298/aquaponiaresidencial. Accessed 12 Jan 2025
10. Emerenciano MGC, Pinho SM, Carneiro PCF (2016) Aquaponics in Brazil: what does the future hold? *Aquac Bras*
11. Eano MGC, Peixoto SR, Schveitzer R, Ballerini C, Valladão GMR (2017) Biofloc technology (BFT): a tool for water quality management in aquaculture. In: Tutu H (ed) *Water Quality*. InTech, Rijeka, pp 91–109
12. Félix-Cuencas L, García-Trejo JF, López-Tejeida S, De León-Ramírez JJ (2025) Nitrogen and phosphorus flow under three productive stages of tilapia (*Oreochromis niloticus*) in a hyperintensive aquaponic system with tomato (*Solanum lycopersicum*). *Aquaculture* 606:742594. https://doi.org/10.1016/j.aquaculture.2025.742594
13. Franco JR, Oliveira MT, Rezende AC, Moura RG (2024) Implementation of an aquaponic system for small producers. *Rev Eletr Compet Digit Agric Fam* 10(2):1002187

14. Guimarães D, Sousa CF, Moreira AC, Vasconcelos HP (2017) Evaluation of a semi-intensive aquaponics system, with and without bacterial biofilter in a tropical location. *Sustainability* 9(4):592. https://doi.org/10.3390/su9040592
15. Hassan AR, Mohamed HA, Saad AM, Mahmoud AA (2024) Sustainability of growth performance, water quality, and productivity of Nile tilapia-spinach affected by feeding and fasting regimes in nutrient film technique-based aquaponics. *Sustainability* 16(3):1305. https://doi.org/10.3390/su16031305
16. Hundley GC, Navarro RD (2013) Aquaponics: the integration between fish farming and hydroponics. *Rev Bras Agropecuária Sustentável* 3(2):52–61
17. Jiménez-Ojeda YK, Collazos-Lasso LF, Arias-Castellanos JA (2018) Dynamics and use of nitrogen in biofloc technology (BFT). *Aquac Aquarium Conserv Legislation* 11(4):1107–1129
18. Johnson GE, Collins BH, Hopkins KD, Manning B, Taylor EM (2017) Evaluation of lettuce between spring water, hydroponic, and flow-through aquaponic systems. *Int J Veg Sci* 23(5):456–470. https://doi.org/10.1080/19315260.2017.1313839
19. Jordan RA (2022) *UFGD Aquaponics Manual*. UFGD, Dourados, Brazil. https://www.researchgate.net/publication/362835773_Manual_de_Aquaponia_da_UFGD. Accessed 28 Jan 2025
20. Kubitza F (2022) *Fundamentals of fish farming in recirculating systems*. F. Kubitza, Campinas, Brazil, 108 p. ISBN 978-85-98541-07-2
21. Lenz GL, Durigon EG, Lapa KR, Emerenciano MGC (2017) Lettuce (*Lactuca sativa*) production in effluents from tilapia cultures maintained in low-salinity BFT systems. *Bol Inst Pesca* 43(4):614–630
22. Lima ECR, Souza RL, Girão PJM, Braga IFM, Correia ED Souza (2018) Culture of Nile tilapia in a biofloc system with different carbon sources. *Rev Ciênc Agronômica* 49(3):458–466. https://doi.org/10.5935/1806-6690.20180052
23. Lyu, X., Guo, Y., Liu, W., Tan, H., Luo, G., Zhang, H., & Hu, X. (2024). Evaluation of long-term operational and production performance of biofloc technology (BFT) system within various particle size. Aquaculture, 578, 740090.
24. Pereira LPF, Mercante CTJ (2005) Ammonia in fish culture systems and its effects on water quality: a review. *Bol Inst Pesca* 31(1):81–88
25. Pinho SM, Molinari D, De Mello GL, Fitzsimmons KM, Emerenciano MGC (2017) Effluent from a biofloc technology (BFT) tilapia culture on the aquaponics production of different lettuce varieties. *Ecol Eng* 103:146–153. https://doi.org/10.1016/j.ecoleng.2017.03.009
26. Pérez-Fuentes JA, Domínguez LS, López-López E, Sánchez ÓR (2016) C:N ratios affect nitrogen removal and production of Nile tilapia (*Oreochromis niloticus*) raised in a biofloc system under high density cultivation. *Aquaculture* 452:247–251. https://doi.org/10.1016/j.aquaculture.2015.11.028
27. Rocha AF, Cardoso AP, Favreto R, Rotta MA (2025) Lettuce production in a DWC aquaponic system with and without bioflocs compared to a hydroponic system in southern Brazil. *All Life* 18(1):2410927. https://doi.org/10.1080/26895293.2024.2410927

28. p HDC, Nascimento BLM, Gomes BRA, Rodrigues AB, Sousa LBS, Silva JMV, De Sousa ILP (2025) Aquaponics as an organic lettuce production system for urban areas. *Caderno Pedagógico* 22(6):1–20
29. SAS Institute (2002) *Statistical Analysis System User's Guide*, Version 9.0. SAS Institute, Cary, NC, 525 p
30. Shaheen MR, Al-Marzouqi AH, Hussain A, Al-Sharhan AA, Eltayeb EE (2022) Growth and yield of cucumber and tilapia fish in aquaponics under UAE climatic condition. *Innov Agric* 2:45–52. https://doi.org/10.3897/ia.2.e32842
31. Tran-Duy A, Van Dam AA, Schrama JW (2012) Feed intake, growth and metabolism of Nile tilapia (*Oreochromis niloticus*) in relation to dissolved oxygen concentration. *Aquac Res* 43:730–744. https://doi.org/10.1111/j.1365-2109.2011.02880.x
32. Widanarni W, Ekasari J, Maryam S (2012) Evaluation of biofloc technology application on water quality and production performance of red tilapia (*Oreochromis* sp.) cultured at different stocking densities. *HAYATI J Biosci* 19(2):73–80. https://doi.org/10.4308/hjb.19.2.73
33. Yang T, Kim H (2020) Comparisons of nitrogen and phosphorus mass balance for tomato-, basil-, and lettuce-based aquaponic and hydroponic systems. *J Clean Prod* 274:122619. https://doi.org/10.1016/j.jclepro.2020.122619
34. Zar JH (2010) *Biostatistical Analysis*. Pearson Prentice-Hall, Upper Saddle River, NJ

Figures

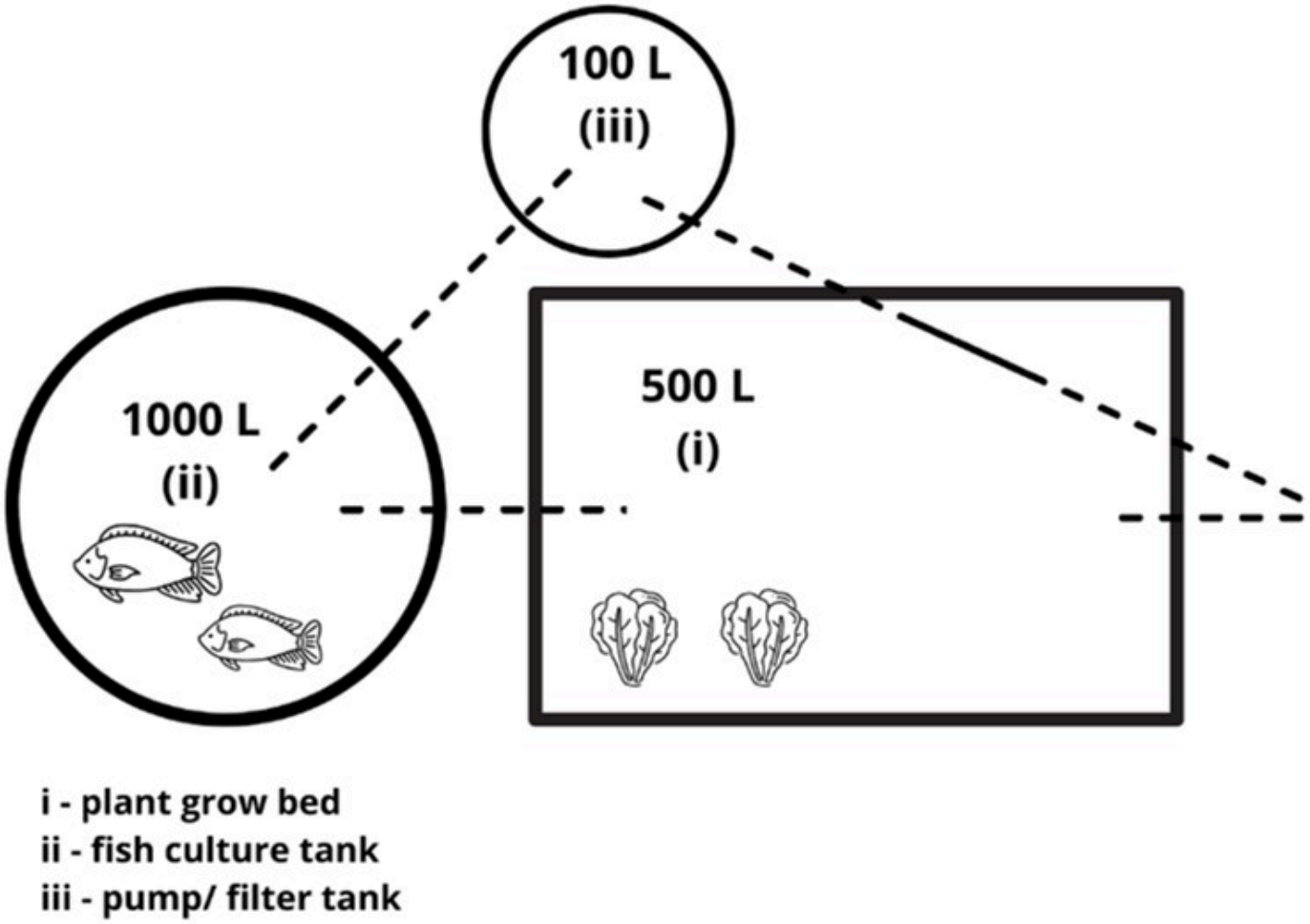


Figure 1

Experimental unit representation (author's figure)



Figure 2

Water quality parameters graphs of the experimental units during the 42-day trial (author's figure)

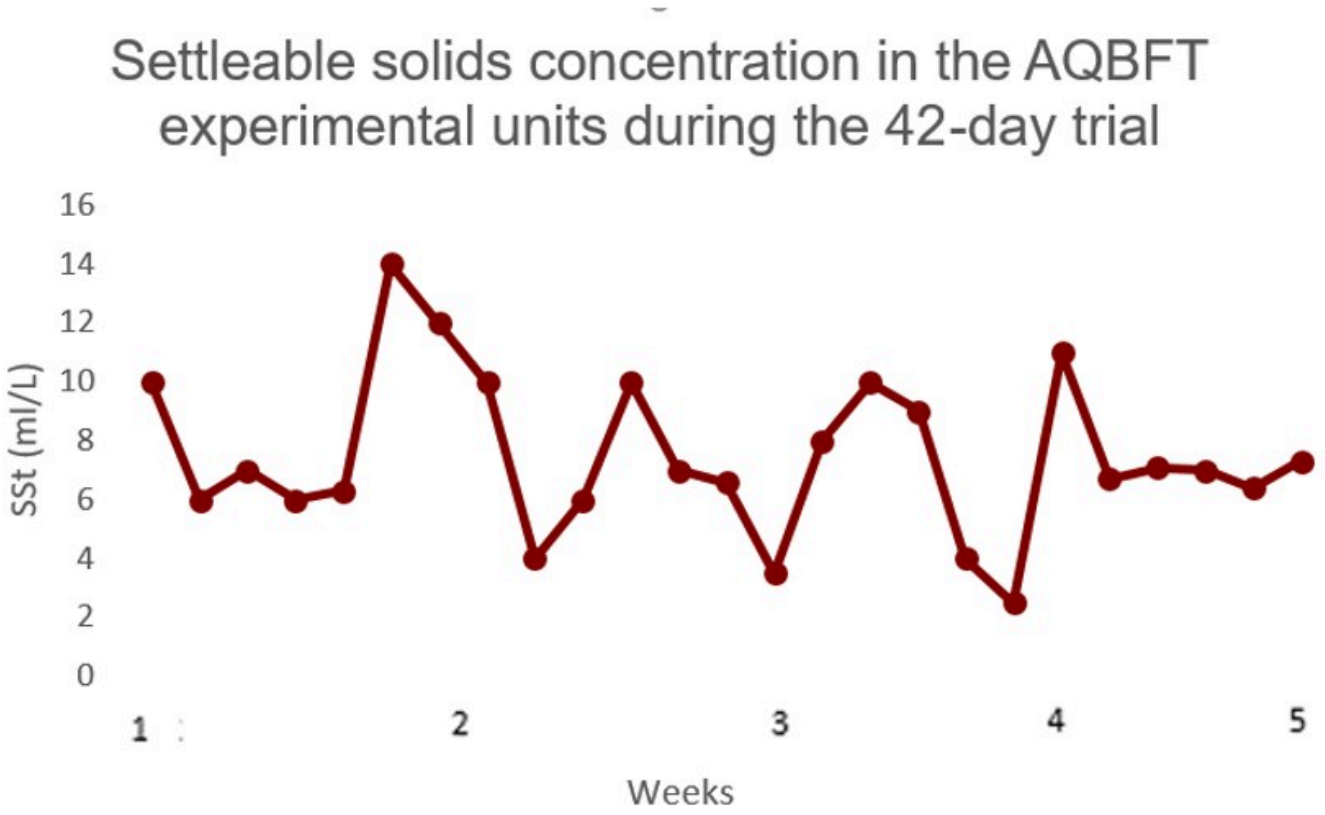


Figure 3

Settleable solids concentration graph measured in the AQBFT experimental units during the 42-day trial (author's figure)