Evaluation of the efficiency of a low-cost aerator and water quality in intensive production systems of tilapia with bioflakes at different stocking densities

Avaliação da eficiência de um aerador de baixo custo e da qualidade da água em sistemas intensivos de produção de tilápias com bioflocos em diferentes densidades de estocagem

Evaluación de la eficiencia de un aireador de bajo costo y la calidad del agua en sistemas de producción intensiva de tilapia con bioflakes a diferentes densidades de población

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Abstract

Among the types of production systems applied in aquaculture, the biofloc culture system (BTF) has been gaining space due to its sustainable techniques. Noteworthy is the low or zero renewal of water, the formation of the microorganism population predominantly autotrophic and heterotrophic, resulting in microbial flakes. Taking into consideration the effectiveness of the system in tilapia farming, this work aimed at the fabrication, implementation, and analysis of the efficiency of a low-cost aerator. To evaluate and control the physical and chemical parameters of the water, 3,780 Nile tilapia fry were used with an initial average biomass of 3±0.5g, distributed in 24 rectangular tanks with a useful volume of 125 liters. The experiment included 6 treatments (T1: 360 fish m^{-3}, T2: 1800 fish m^{-3}, T3: 1080 fish m^{-3}, T4: 1440 fish m^{-3}, T5: 720 fish m^{-3} and T6: 2160 fish m^{-3}) and four repetitions. The efficiency of the Venturi effect aerator and the water quality parameters were analyzed. Comparisons of the averages were performed using Tukey's test at 5% significance. From the dissolved oxygen analysis, it was possible to conclude that the aerator Venturi effect was efficient during the experiment, meeting the desired levels, also taking into consideration the ease of applicability and low cost for its development. Through the analysis of the physical-chemical parameters of the

water and the mortality rates during the experiment, it can also be concluded that the safest density to operate using the bioflocci is up to 720 fish m^{-3}.
Keywords: Bioflakes; Aeration; Water quality; Density.

Resumo
Dentre os tipos de sistemas de produção aplicados na aqüicultura, o sistema de bioflocos vem ganhando espaço devido às suas técnicas sustentáveis. Destaca-se a baixa ou nula renovação de água, a formação da população de microrganismos predominantemente autotrófica e heterotrófica, resultando em flocos microbianos. Levando em consideração a eficácia do sistema na criação de tilápias, este trabalho teve como objetivo a construção, implantação e análise da eficiência de um aerador de baixo custo. Para avaliação e controle dos parâmetros físicos e químicos da água, foram utilizados 3.780 alevinos de tilápia do Nilo, com biomassa média inicial de 3±0,5 g, distribuídos em 24 tanques retangulares com volume útil de 125 litros. O experimento incluiu 6 tratamentos (T1: 360 peixes m^{-3}, T2: 1800 peixes m^{-3}, T3: 1080 peixes m^{-3}, T4: 1440 peixes m^{-3}, T5: 720 peixes m^{-3} e T6: 2160 peixes m^{-3}) e quatro repetições. A eficiência do aerador de efeito Venturi e os parâmetros de qualidade da água foram analisados. As comparações das médias foram realizadas pelo teste de Tukey a 5% de significância. A partir da análise do oxigênio dissolvido, foi possível concluir que o efeito aerador Venturi foi eficiente durante o experimento, atendendo aos níveis desejados, considerando também a facilidade de aplicabilidade e o baixo custo para seu desenvolvimento. Por meio da análise dos parâmetros físico-químicos da água e das taxas de mortalidade durante o experimento, também pode-se concluir que a densidade mais segura para operar com os bioflocos é de até 720 peixes m^{-3}.
Palavras-chave: Bioflocos; Aeração; Qualidade da água; Densidade.

Resumen
Entre los tipos de sistemas de producción aplicados en la acuicultura, el sistema biofloc ha ido ganando espacio debido a sus técnicas sostenibles. Destaca la escasa o nula renovación de agua, la formación de una población de microorganismos predominantemente autótrofos y heterótrofos, dando lugar a escamas microbianas. Teniendo en cuenta la efectividad del sistema en la creación de tilapia, este trabajo tuvo como objetivo construir, implementar y analizar la eficiencia de un aireador de bajo costo. Para evaluar y controlar los parámetros físicos y químicos del agua se utilizaron 3.780 alevines de tilapia del Nilo, con una biomasa promedio inicial de 3±0.5 g, distribuidos en 24 tanques rectangulares con un volumen útil de 125 litros. El experimento incluyó 6 tratamientos (T1: 360 peces m^{-3}, T2: 1800 peces m^{-3}, T3: 1080 peces m^{-3}, T4: 1440 peces m^{-3}, T5: 720 peces m^{-3} y T6: 2160 peces m^{-3}) y cuatro repeticiones. Se analizaron la eficiencia del aireador de efecto venturi y los parámetros de calidad del agua. Las comparaciones de medias se realizaron mediante la prueba de Tukey al 5% de significancia. Del análisis de oxígeno disuelto se pudo concluir que el efecto aireador Venturi fue eficiente durante el experimento, cumpliendo con los niveles deseados, considerando también la facilidad de aplicabilidad y el bajo costo para su desarrollo. Mediante el análisis de los parámetros físico-químicos del agua y las tasas de mortalidad durante el experimento, también se puede concluir que la densidad más segura para operar con los bioflocs es hasta 720 peces m^{-3}.
Palabras clave: Bioflakes; Aireación; Calidad del agua; Densidad.

1. Introduction

The contribution of aquaculture production in the world has been growing steadily in recent years, reaching 46.8% in 2016. The annual growth rate is 5.8% during the period from 2001 to 2016 (FAO, 2016). Aquaculture is a practice that has stood out with its increase in relation to the other most consumed foods worldwide (FAO, 2018). In Brazil, it is estimated that growth until 2025 should exceed 104 % (FAO, 2016).

FAO (2018) indicates that the increase in consumption was not only triggered by the increase in production but also due to the practices of reducing waste, better use of it in employment, logistics applied in distribution and increased demand, factors connected with the increase in population and income sources.

Increasing productivity is one of the priorities in the development of aquaculture, especially tilapia farming. The intensification of productive systems is considered the easiest way to achieve this objective (Avnimelech et al., 2008).

Interest in closed tilapia farming systems is increasing, as they include biosafety and environmental issues. At the moment that water is used, some threats, such as the proliferation of pathogens and the discharge of wastewater, are contained or even eliminated (Ray, 2012).

The system called BFT (Biofloc Technology System) is based on the development and maintenance of predominantly heterotrophic and aerobic microorganisms in suspension on water (Avnimelech, 2007). The formation of these microorganisms is driven by the addition of organic carbon (sugars) to water, in quantities that maintain the Carbon: Nitrogen (C:N) ratio expected (within 15-20:1) for the generation of bioflocci (Avnimelech, 1999). This system is evaluated as an efficient alternative system, provided that there is continuous use of its nutrients. The sustainable approach of such a system is based on the growth of microorganisms in a culture medium, with minimal or no water replacement. The application of these microorganisms in the system is based on the maintenance of water quality, converting nitrogen into microbial protein-based compounds, increasing the viability of the culture by reducing feed protein levels by up to 50% (Ray, 2012).

In aquaculture, several models of mechanical aerators are used for oxygen distribution in culture tanks, such as propeller aerators, blade or fan aerators, air blowers, among others (Boyd, 1998).

For good performance in closed systems with bioflocci, the aeration operates important functions, which will lead to great results for the production (Burford et al., 2003). One of aeration system's purposes, besides demanding oxygen to the animals, is the availability of the mixture of the upper layer of the culture water, abundant in dissolved oxygen, with the lower layer commonly lacking, distributing it in a more homogeneous way to the tanks (Avnimelech & Ritvo, 2003).

Brandão (2015) describes the production of an aerator built with low-cost materials, with materials usually used in the civil construction sector, and that does not require typical equipment such as blowers, diffusers, or compressors. It is different from those seen in the market, and the aerator does not use electric energy.

The methodology of self-cleaning air systems is based on the design of the Venturi tube. It is used to supply water oxygen where the ejector is used as a mechanism to mix the oxygen from the air with the water. These ejectors allow the transformation of the fluid pressure energy into velocity energy that will drive the generation of vacuum in the Venturi contraction section, allowing the suction of atmospheric air through a vessel parallel to the flow. Therefore, in this type of aeration, water oxygenation is created by the processes of dissolved air and dispersed air, with no limitations on the amount of air that has a chance of being added without the use of air compressors. Thus, there is an excellent efficiency with low investment, as well as low energy consumption (Peccin et al., 2010).

Through the approach of the proposed theme, this paper had as a general objective the implementation and evaluation of a low-cost aerator in systems of cultures with bioflocs and evaluation of water parameters during the cultivation with bioflocs at different densities, to verify the best cultivation density.

2. Materials and Methods

2.1 Study location

The experiment was conducted in the aquaculture laboratory of the Western Paraná State University (UNIOESTE), Campus Toledo, geographically located and defined by coordinates 24º73' South latitude (S) and 53º75' West latitude (W) and altitude of 577 meters above sea level. It is worth noting that it was performed in the 60-day period between October and December 2018.

The study was based on the methodology proposed by Santos et al. (2017).

2.2 Experimental design

We acquired 3378 male Nile tilapia (*Oreochromis niloticus*) fry (initial phase of the fish), with initial average biomass of 3 ± 0.5g, from a commercial producer located in the city of Toledo - PR, Brazil. After arrival at the Aquaculture Laboratory, the animals were separated according to treatment and maintained in rectangular polypropylene tanks with a useful volume of 125 liters.

The experiment was a completely randomized design. The structure was formed by 6 lines (treatments), arranged vertically. Each line has 4 tanks, totaling 24 tanks in the heterotrophic environment (Figure 1). Each line had a different distribution of tilapia; that is, the number of animals stored varies according to the treatment.

Each box received a heater thermostat of 200 power watts, intending to reduce the abrupt temperature variations throughout the experiment, maintaining a range of 26-28ºC.

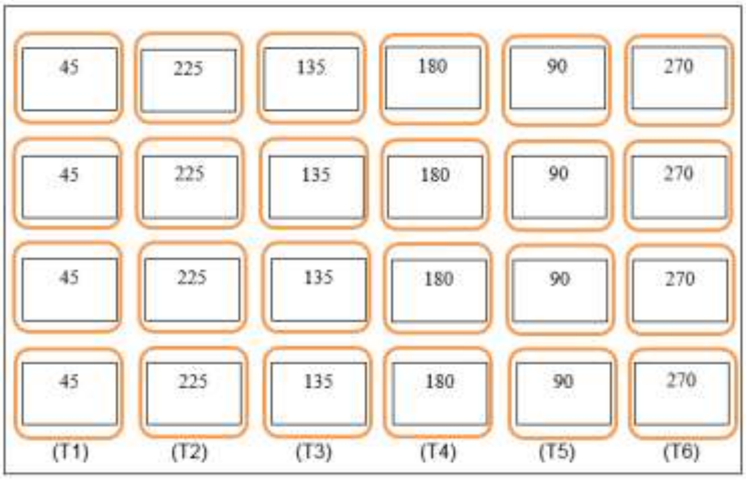
Figure 1. Experimental prototype of bioflocs in aquaculture laboratory.

Source: Authors.

2.2.1 Treatments

The treatments consisted of T1 (45 fry per box and an initial density of 360 fish m^{-3}), T2 (225 fry, totaling a density of 1800 fish m^{-3}), T3 (135 fry, totaling 1080 fish m^{-3}), T4 (180 fry), totaling 1440 fish m^{-3}), T5 (90 fry, totaling 720 fish m^{-3}) and T6 (270 fry, totaling 2160 fish m^{-3}) The distribution of the animals was performed according to (Figure 2).

Figure 2. Distribution of Tilapia in the tanks: T1 (360); T2 (1800); T3 (1080); T5 (720); T6 (2160) in fish m^{-3}.



Source: Authors.

The animals were fed twice a day (8h and 17h) with commercial extruded feed containing 45% crude protein. Initially, to perform the experiment, rice by-products (residue) were added as a carbon source for the development of nitrifying microorganisms. To maintain the C:N ratio at 20:1, crystal sugar was added daily. The daily sugar dosage was defined according to the results of the nitrogen level analysis.

2.2.2 Water recirculation

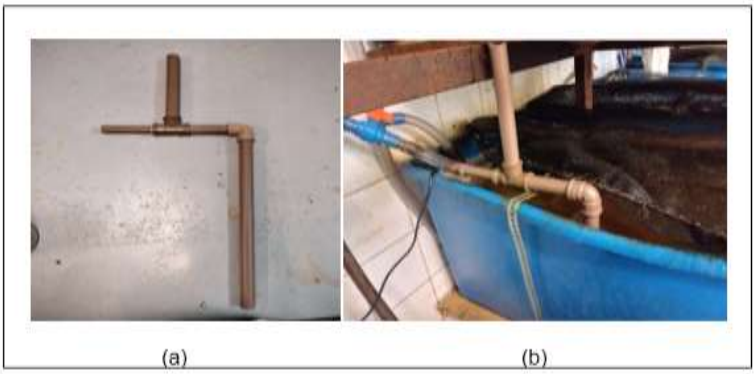
To promote water recirculation, each line had a peripheral motor pump ¼cv IDB-35 bivolt installed next to the first lower box. Using crystalline hoses installed in the pumps, the water was sent from the lower box to the top box. Upon reaching the specified level of the upper tank, the water flowed (by gravity) through the PVC pipes (white), distributing the other tanks until reaching the first lower tank again and thus becoming a cyclic process, only replacing the volume lost by evaporation.

2.2.3 System oxygenation

To perform oxygenation in the system, we used a low-cost aerator (venturi effect) in each box, 24 prototypes. The aerator was installed directly at the end of the hose that recirculates the water through the motor pump. The water flows through the pipe, comes into contact with the atmospheric air, and the oxygen is incorporated into the water (Figure 3).

In order to achieve a better recirculation performance and, consequently, boost oxygenation without altering the structure of the bioflocci by the pressure that water causes in the system, we worked with flows of 0.027 m³ min^{-1}, following the recommendations described by Santos et al. (2017), performed in his work.

Figure 3. (a) aerator mounted (b) aerator deployed and operating.



Source: Authors.

2.2.4 Materials for fabricating the aerator

For Santos et al. (2017), the materials required to fabricate the aerator are as follows:

- 10 cm PVC tube 3/4 inch;
- PVC glue tube;
- 1/2 inch plug with a 5mm hole in the center;
- 1 Connection "T" PVC 3/4 inch;
- 10 cm PVC tube 1/2 inch;
- 20 cm PVC tube 3/4 inch;

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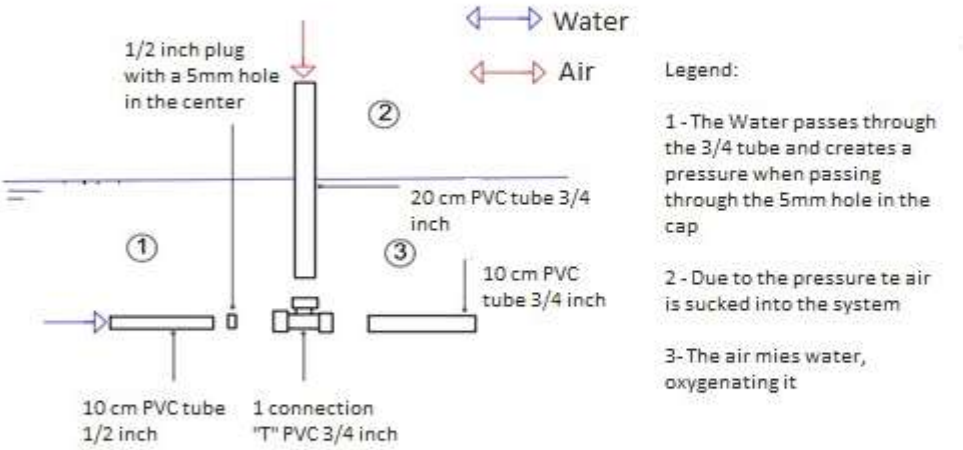
Figure 4. Mounting steps of the aerator used.



Source: Authors.

2.3 Monitoring program

For the characterization of the culture water quality, the following physical-chemical variables were analyzed:

Daily, in the afternoon, the following variables were monitored: pH from the sensor programmed by Arduino; temperature (ºC) using a commercial thermometer; dissolved oxygen (OD) using the multiparameter probe YSI professional plus®; total ammonia (AT) and nitrite (NO_2^-).

Once a week we analyzed the chemical oxygen demand (COD); biochemical oxygen demand (BOD); phosphate (PO_4^{-3}); nitrate (NO_3^-); sedimentary solids (SS) and total alkalinity (AlcT), performed in the laboratory of aquaculture and microbiology at the UNIOESTE Toledo campus.

2.4 Statistical analysis

The water quality parameters were compared through statistical analysis, using the Sisvar® software (Ferreira, 2011). The data, submitted to unidirectional analysis of variances (ANOVA), with measurements containing 3 repetitions applied in the analysis of the water physical and chemical variables, as well as verified using the F test ($p < 0.05$) (Gomez & Gomez, 1984). The comparisons of the averages were performed by the Tukey test with 5% significance (Zar, 2010).

3. Results and Discussion

3.1 Aeration system approach

Table 1 shows the total costs for the implementation of the aeration system in the experiment. The total value for the aerator's fabrication was R$ 112.28.

Table 1. Total cost for the deployment of the aeration system for the 16 boxes.

Materials	Total amount used	Unitary value	Amount
PVC tube ¾'	4.80 meters	R$ 3.00/meter	R$ 14.40
PVC tube ½'	1.60 meters	R$ 3.00/meter	R$ 4.80
PVC plug ½'	16 units	R$ 1.19/un.	R$ 19.04
PVC connection 'T' ½	16 units	R$ 0.89/un.	R$ 14.24
PVC glue tube	2 units	R$ 29.80/un.	R$ 59.80
Total			R$ 112.28

Source: Authors.

The cost for the implementation of this system is low, compared to other conventional systems that are manufactured from materials with higher costs, such as steel.

The conventional systems need electric energy to develop their operations, as opposed to the low-cost aerator that does not need electric energy, but only the support of peripheral pumps ¼cv IDB-35 bivolt water pump, operating at minimum flows that, by recirculating the water, provide its transport to the aerator, incorporating oxygen to it and powering the aeration.

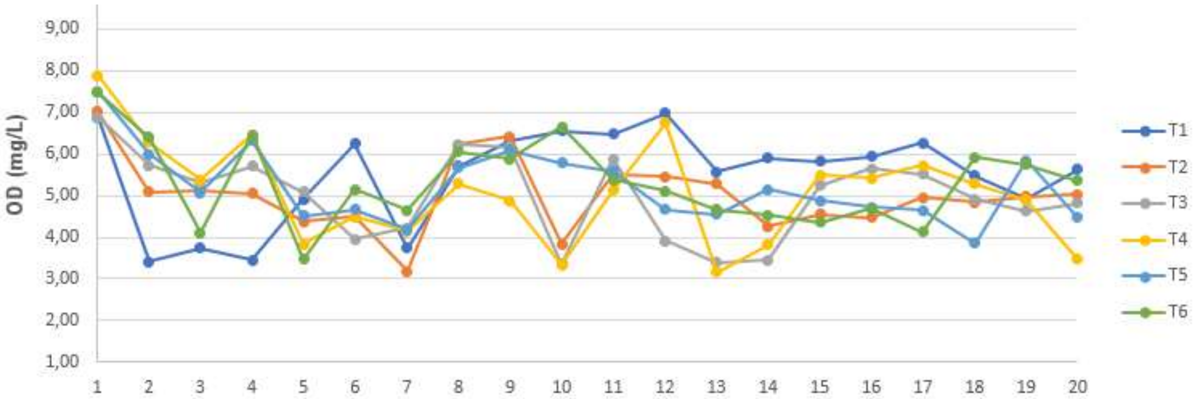
3.2 Physical-chemical parameters

3.2.1 DO, t water, ph and alct parameters

The averages related to the parameters DO, T water, pH, and AlcT during cultivation are shown in Table 2.

It was possible to observe that the Dissolved Oxygen (DO) was not significantly different between treatments, because, with the density increase, the oxygen solubility in the water does not decrease throughout the experiment. It is clear that, in both treatments, the DO concentration was within the levels considered ideal for tilapia, that is, above 3 mg L^{-1} (Figure 5) (Boyd, 1998). Near-saturation DO levels result in optimal productivity, and saturation levels below 50% should be avoided (Mcgraw et al. 2001).

Figure 5. Variations of dissolved oxygen during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

From the results presented in Figure 5, it is shown the efficiency of the Venturi effect aerator applied to the BTF system, contributing to oxygenation, reaching the desired levels for a good operation during the experiment.

The results of the analyzed parameters prove that there were significant differences in water temperature (Cº) and alkalinity, as indicated in Table 2.

Table 2. Means and standard deviations of physical and chemical parameters OD/Twater/pH/Alct during tilapia cultivation in the BTF system at different stocking densities in fish/m³

	Parameters			
Treatments	OD (mg L^{-1})	T water (ºC)	pH	Alct (mg $aCo_{3}.L^{-1}$)
T1 (360)	5.50±1.12^{a}	26.76±0.62^{a}	7.20±0.54^{a}	68.75±18.49^{a}
T2 (1800)	4.88± 0.87^{a}	27.67±1.15^{c}	7.23±0.53^{a}	98.50±28.48^{c}
T3 (1080)	4.87±1.02^{a}	27.19±1.03^{b}	7.13±0.60^{a}	71.75±21.83^{a}
T4 (1400)	5.03±1.22^{a}	27.20±0.60^{b}	7.22±0.69^{a}	95.50±30.29^{c}
T5 (720)	5.22±0.88^{a}	27.43±0.87^{b}	7.24±0.45^{a}	68.08±20.81^{a}
T6 (2160)	5.31±1.01^{a}	27.42±0.92^{c}	7.16±0.39^{a}	77.50±22.79^{b}
CV (%)	20.46	3.22	7.64	29.44

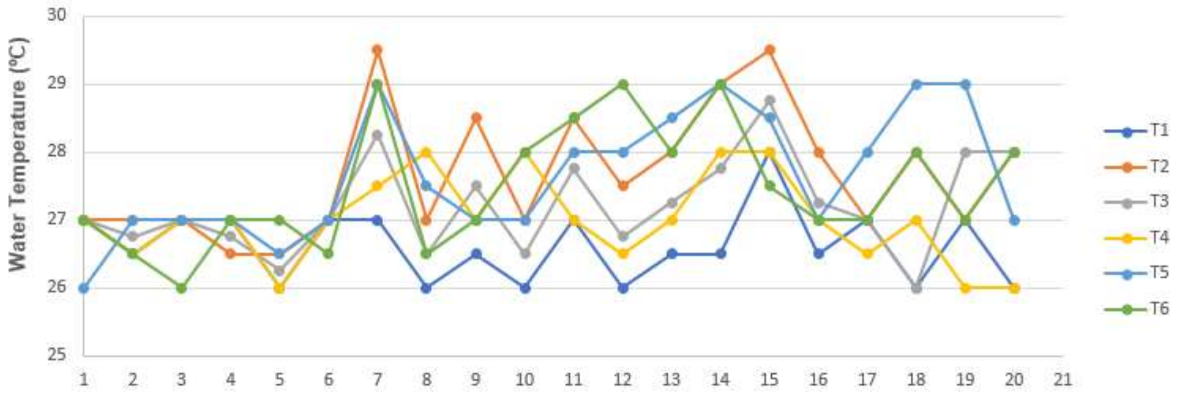
Source: Authors.

The pH did not present significant differences between the treatments. However, all of them remained within the ideal pH values for tilapia, between 6.0-8.0 (Chien, 1992).

We noticed that the use of heaters during the experiment was necessary. In Figures 6 and 7, the temperature and pH variations during the experiment are presented, respectively.

On the 38th day, the pH values decreased in all treatments but were soon stabilized again.

Figure 6. Variations of water temperature during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

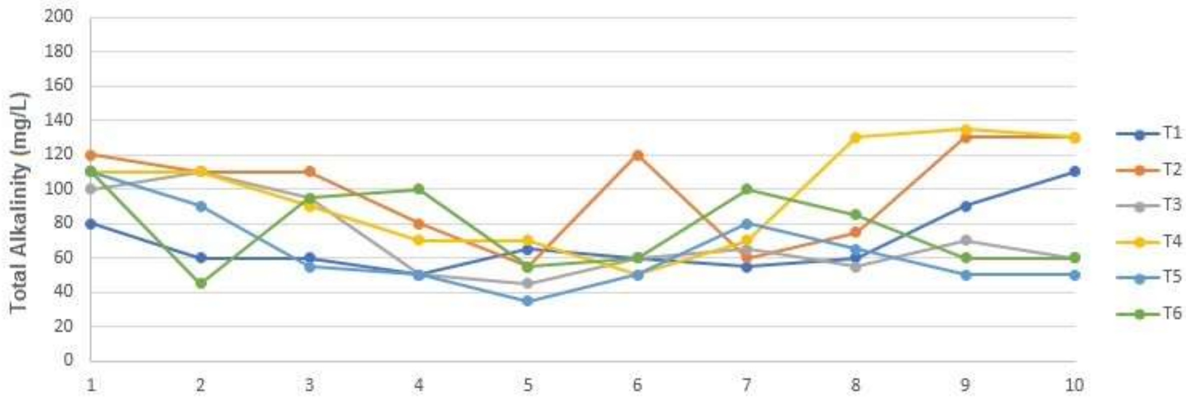
Figure 7. Variations of pH during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.

Source: Authors.

Regarding alkalinity, there is a difference between the treatments. The T2 and T4 treatments had the highest concentrations, being the average of 98.50 ± 28.48 mg L^{-1} of $CaCO_3$ for T2 and 95.50 ± 30.29 mg L^{-1} of $CaCO_3$ for T4. The alkalinity values for almost all treatments in the proposed study did not negatively affect tilapia, except for T5, which was below the minimum value described by Furtado et al. (2014), because it reports that the concentration should be above 40 mg L^{-1} and optimal values close to 100 mg L^{-1}.

It was decided not to perform alkalinity corrections to verify how the system would behave, allowing it to be adjusted naturally. However, it was possible to prove that the system needs these corrections to perform well. The values of the alkalinity distributions can be seen in Figure 8.

Figure 8. Variations of Total Alkalinity during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

3.2.2 Parameters of nitrogen and phosphate compounds

Table 3 displays the average concentrations of total ammonia, nitrate, nitrite, and phosphate during the experiment. No significant differences were identified between the treatments for nitrate, total ammonia, and phosphate. On the other hand, nitrite concentration was different in T6, which presented higher values, on average 3.06±2.62 mg L^{-1}.

Table 3. Means and standard deviations of physical and chemical parameters nitrite/total ammonia/nitrate/phosphate during tilapia cultivation in the BTF system at different stocking densities in fish/m³

Treatments	Parameters			
	Nitrite (mg L^{-1})	Total ammonia (mg L^{-1})	Nitrate (mg L^{-1})	Phosphate (mg L^{-1})
T1 (360)	1.57±1.97[a]	0.99±1.23[a]	2.71±1.79[a]	23.62±16.11[a]
T2 (1800)	1.47± 1.42[a]	0.97±1.08[a]	2.94±2.70[a]	25.10±15.02[a]
T3 (1080)	1.42±1.40[a]	1.58±1.24[a]	2.78±2.42[a]	23.81±13.45[a]
T4 (1400)	1.20±1.34[a]	1.27±1.04[a]	2.56±1.89[a]	26.54±16.09[a]
T5 (720)	0.98±1.41[a]	1.10±1.43[a]	2.80±2.21[a]	24.83±14.51[a]
T6 (2160)	3.06±2.62[b]	1.02±0.64[a]	3.02±2.95[a]	26.89±15.19[a]
CV (%)	107.27	118.02	82.26	58.48

Source: Authors.

Figures 9, 10, 11, and 12 show variations in nitrite, ammonia, nitrate, phosphate, and total ammonia concentrations, respectively, during the experimental period.

Figure 9. Variations of nitrite during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.

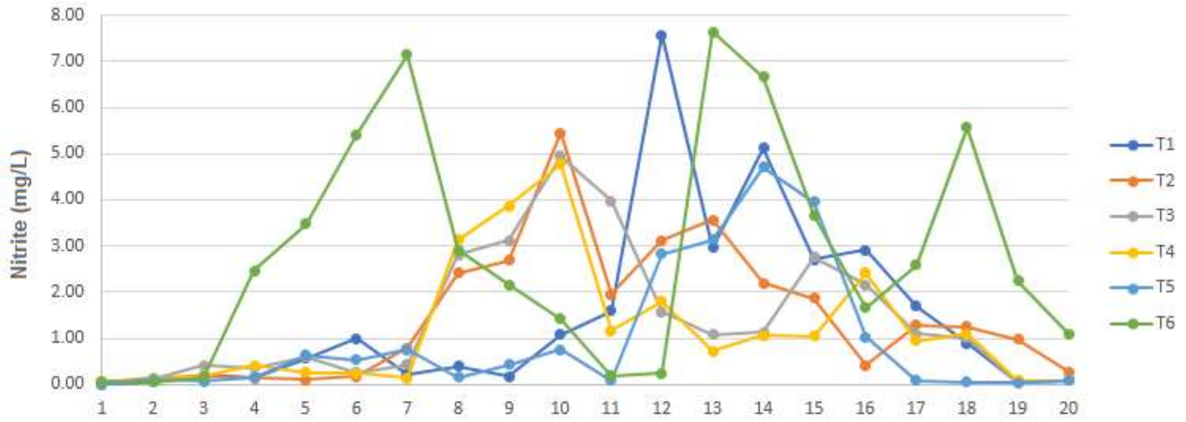


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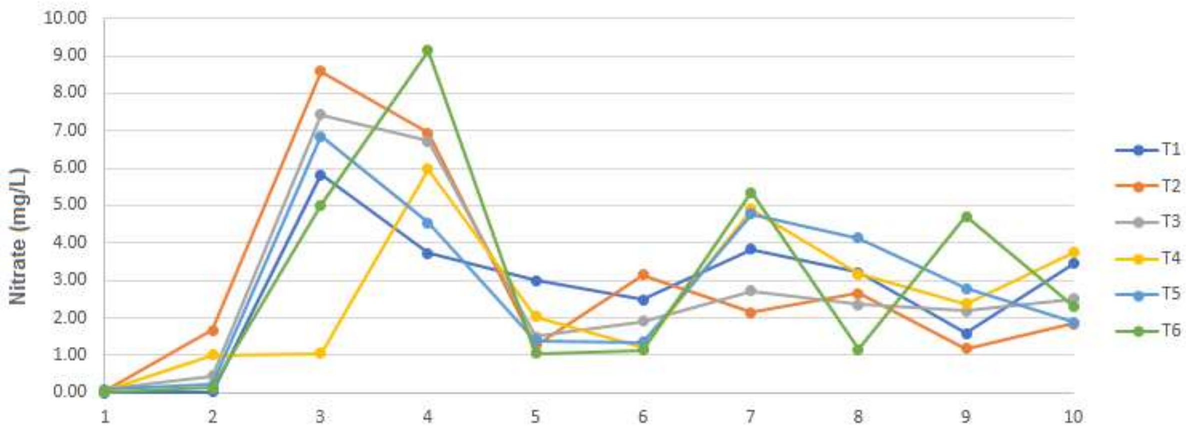
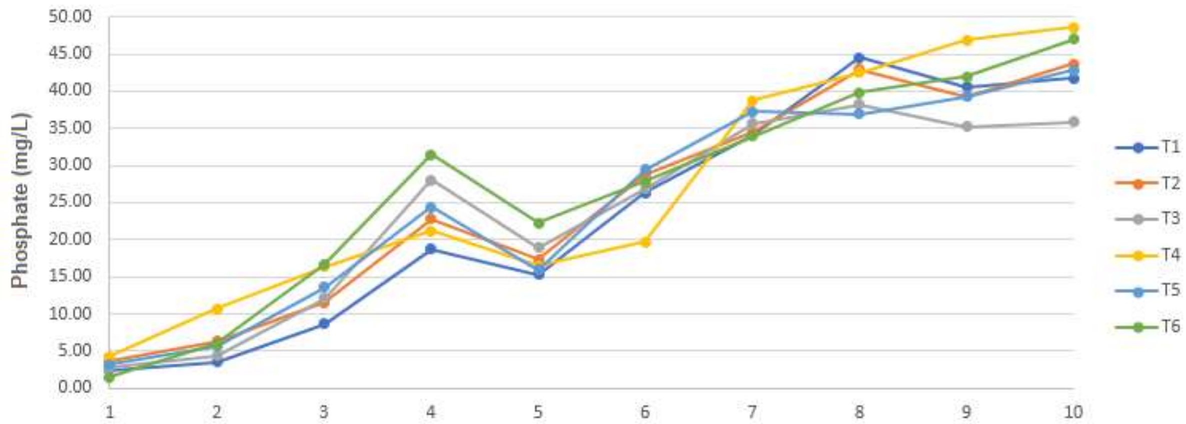
Figure 10. Variations of nitrate during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

Figure 11. Variations of phophate during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

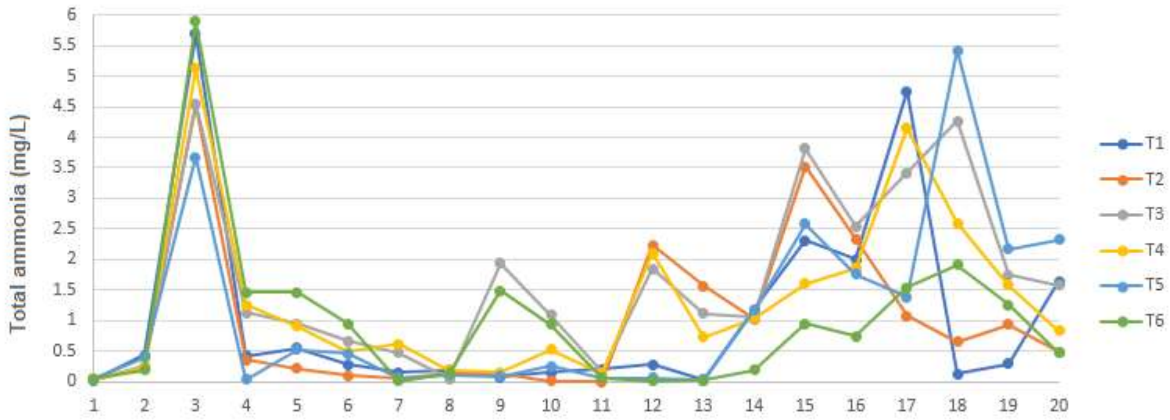
From the nitrate and nitrite graphics, it was possible to certify that, during cultivation, nitrification was not the decisive factor in the contribution to ammonia removal. After all, the concentrations of nitrification reaction by-products have not been constant throughout the culture, with large variations, especially nitrite values. In addition to the decelerated growth of nitrifying bacteria, there is competition between microorganisms with another profile for the environment and oxygen with heterotrophic microorganisms, as cited by Hargreaves (2006).

High nitrite concentrations in water affect gas exchange in fish by converting hemoglobin to methaemoglobin. Chloride molecules use the same entry mechanism into the gills used by nitrite; salinization of system water is a preventive method, averting intoxication of farmed fish (Avnilemech, 2009).

However, adding organic matter to the environment has inhibited the growth of autotrophic microorganisms. Silva et al. (2013) observed when evaluating the interaction between nitrogen and phosphorus in tilapia culture with bioflocci, an increase in nitrate concentrations from the first week of culture, reaching maximum values between 6 mg L^{-1} and 9 mg L^{-1} between treatments. In this research, clarification did not occur. Thus, the nitrifying bacteria were not removed from the system.

Total ammonia increased during the first week of cultivation but was soon reduced to acceptable levels until the 42nd day. Again, the peaks in ammonia concentrations between the 33rd and 54th days were observed from Figure 12, reducing in the last week of the experiment.

Figure 12. Variations of total ammonia during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

As for phosphate, there is an increase in its concentration during cultivation since it is a feed element (Figure 11). This increasing growth may be attributed to the compounds present in the feed. In this situation, Xu et al. (2012) certified the increase in phosphorus with the extension of the C:N ratio.

Saturation by the assimilation of phosphorus by microalgae was described as a possible cause of the difference, but assuming that crystallized sugar was used as a source of carbon and high C:N ratios lead to greater supplementation of the carbon source. However, only about 30% of the phosphorus in the food is normally incorporated into the tilapia biomass, with the rest being excreted (Avnimelech, 2006).

Table 4 presents the values for biochemical oxygen demand (BOD), chemical oxygen demand (COD) in all treatments. It was verified that there was a significant difference between the treatments. For COD and BOD, probably because of the amount of sugar added during the experiment maintaining the C:N ratio at 20:1. Based on COD and BOD values, it was possible to characterize the biodegradability of the culture water. In this case, the COD/BOD ratio between all treatments was higher than 4, presenting high concentrations of inert or non-biodegradable material in the medium (Von Sperling, 1996).

In this regard, only a small amount of organic material is available for micro-organisms in the medium. According to Von Sperling (1996), this inert organic material is produced by decreasing the microbial biomass by death, endogenous metabolism, predation, and so on. Salinity levels can cause divergent effects on microbial flora, causing plasmolysis and a decrease in cellular activities (Medeiros et al., 2005), possibly explaining the high concentration of inert material in all treatments.

The T2 and T6 treatments, with the highest densities, presented high values, both for COD and BOD, this is due to high concentrations of inert materials (added sugar). For COD, the values for T2 and T6 were 679.99±280.45 mg L^{-1} and 1386.17±584.61 mg L^{-1}, respectively. For BOD, T2 and T6 were 61.37 ± 30.28 mg L^{-1} and 90.09 ± 40.37 mg L^{-1}, respectively.

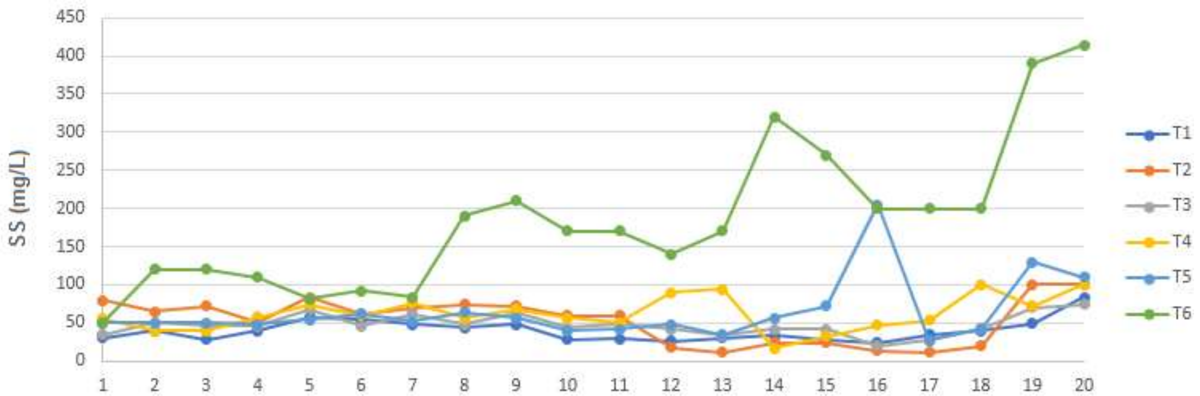
Table 4. Means and standard deviations of physical and chemical parameters DBO/DQO/SS during tilapia cultivation in the BTF system at different stocking densities in fish/m³

Treatments	Parameters		
	DBO (mg L^{-1})	DQO (mg L^{-1})	SS (mL L^{-1})
T1 (360)	42.19±17.38^a	580.05±470.39^a	41.62±15.73^a
T2 (1800)	61.37±30.28^b	679.99±280.45^b	56.33±32.22^a
T3 (1080)	46.92±27.93^a	422.88±170.26^a	50.71±21.06^a
T4 (1400)	44.21±23.81^a	643.54±157.95^a	65.86±28.64^a
T5 (720)	49.93±31.83^a	601.34±153.93^a	67.48±39.91^a
T6 (2160)	90.09±40.37^b	1386.17±584.61^b	197.71±105.81^b

Source: Authors.

From the data detailed in Table 4, the concentrations of sedimentary solids had significant differences between treatments. The treatments T1, T2, T3, T4, and T5, had the same behavior, maintaining much of the experiment. On the other hand, the T6 treatment showed the highest levels of SS, reaching average values of 197.71±105.81 mL L^{-1}. Therefore, it is likely that the decantation process was not sufficient to reduce the solids for this treatment, due to the high density stored in the line. The levels of each treatment are presented in Figure 13.

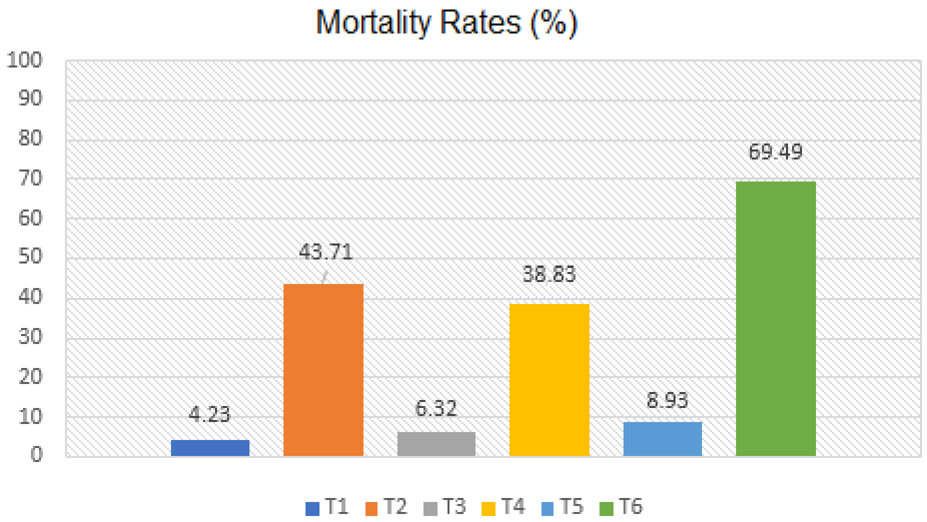
Figure 13. Variations of total ammonia during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160), analyzed every 3 days.



Source: Authors.

It was observed in Figure 14 the mortality rates during the experimental period, i.e., the highest levels of mortality were recorded in T2 (1800) with 43.71%, T4 (1440) with 38.83% and T6 (2160) with 69.49%.

Figure 14. Mortality rates during tilapia cultivation in BFT system at different stocking densities: T1 (360); T2 (360); T3 (1080); T4 (1440); T5 (720); T6 (2160).



Source: Authors.

From the data in Figure 14, it can be concluded that T2, T4, and T6 treatments are not adequate densities to work with bioflocci since they are densities that caused high concentrations of solids due to the large volume of fish present in the culture.

The negative relationship between stocking density, growth and survival during the tilapia farming period has already been noted by several authors (Moss & Moss, 2004) and is probably associated with competition by space (Arnold et al., 2006) and by food (Lemos et al., 2004).

4. Conclusion

Therefore, from the aeration tests performed using the multiparameter probe, we can conclude that the aerator produced with low-cost material showed excellent results for the aeration levels in the water, reaching dissolved oxygen concentration values within the acceptable ranges for good performance. Thus, the aerator proved to be efficient in the transportation of oxygen to water.

One of the advantages of using the BFT system is the saving in the total amount of water used and added only to the replacement of water lost due to evaporation or management needs. Nonetheless, fish farming can be installed even in regions where there is no abundant water.

Regarding the analyzed parameters, we conclude that the nitrogen compounds had a higher concentration in the higher densities studied, due to the amount of generated excreta and waste remains to be lower than the number of nitrifying microorganisms, responsible for conversion and maintenance of quality in water.

Another relevant point is the mortality rate caused by densities higher than 720 fish m^{-3}, as a result of space competitiveness and the accumulation of inert materials.

From the results obtained, it is inferred that the stocking density of up to 720 fish m^{-3} is a safe density to be used in the tilapia farming in biofloc culture systems, without water renewal and correction of nitrogen compounds during the culture.

The suggestion for future work is that this study methodology be evaluated for other fish species.

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