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Artificial floating islands as a tool for the water quality improvement of fishponds

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ABSTRACT

In this study, the ecotechnology artificial floating islands (AFIs), colonized by *Eichhornia crassipes*, have been tested as a tool for water quality improvement of fishponds. The experiment was carried out in semi-intensive production during the grow-out period of Nile tilapia, comprising one production cycle. It was completely randomized with two treatments (with and without AFIs) and three replications. Temperature, dissolved oxygen, conductivity, pH, turbidity, total dissolved solids (TDS), transparency (Secchi) and concentrations of chlorophyll *a* (CL *a*), total nitrogen (TN), total ammonia nitrogen (TAN), total phosphorus (TP) and orthophosphate (PO_4^{3-}-P) were analyzed fortnightly in the fishponds. Two groups ordered based on environmental characteristics were formed by applying the Principal Component Analysis (70.68% of explicability). The fishponds with AFIs were assigned to higher values of Secchi and lower values of pH, turbidity, TDS and concentrations of nutrients. On the other hand, the fishponds without AFIs were assigned to the highest values of these variables, except for Secchi. In 30 days, the AFIs showed the lowest concentrations of TP and PO_4^{3-}-P, and for CL *a*, TN and TAN, the differences were recorded after 90 days. The use of AFIs has demonstrated potential to conserve water quality in fishponds, notably for biologically assimilable elements (PO_4^{3-}-P and TAN) and for those directly related to eutrophication (P and N). Artificial floating islands should be encouraged for small and medium-sized farmers as tool to improve water quality in fishponds. However, new AFIs coverage rates must be evaluated, as well as the control of hydraulic retention rates.

Keywords: aquaculture, ecotechnology, free-floating aquatic macrophytes.

Ilhas flutuantes artificiais como ferramenta para melhorar a qualidade da água de viveiros de piscicultura

RESUMO

No presente estudo, a ecotecnologia de ilhas flutuantes artificiais (IFAs) colonizadas por *Eichhornia crassipes* foi testada como uma ferramenta para a melhoria da qualidade da água de viveiros de peixes. O experimento foi realizado em sistemas de produção semi-intensivos durante o período de crescimento de tilápia, compreendendo um ciclo de produção. Foi completamente randomizado com dois tratamentos (com e sem IFAs) e três repetições. A temperatura da água, oxigênio dissolvido (OD), condutividade elétrica, pH, turbidez, sólidos totais dissolvidos (STD), transparência da água (Secchi) e concentrações de clorofila *a* (CL *a*), nitrogênio total (NT), nitrogênio amoniacal total (NAT), fósforo total (PT), ortofosfato ($P\text{-}PO_4^{3}$) foram analisados quinzenalmente nos viveiros. Dois grupos ordenados com base nas características ambientais foram formados por meio da aplicação da análise de componentes principais (70,68% de explicabilidade). Aos viveiros com IFAs foram atribuídos maiores valores de Secchi e menores valores de pH, turbidez e STD e das concentrações de CL *a*, NT, NAT, PT, $P\text{-}PO_4^{3-}$. Aos viveiros sem IFAs foram atribuídos os maiores valores dessas variáveis, exceto Secchi. Em 30 dias, viveiros com essas variáveis apresentaram as menores concentrações de PT e $P\text{-}PO_4^{3-}$, e para CL *a*, NT e NAT, as diferenças foram registradas após 90 dias. O uso de IFAs tem demonstrado alto potencial para manutenção da qualidade da água adequada para a produção de peixes, notadamente para elementos biologicamente assimiláveis (ortofosfato e nitrogênio amoniacal) e para aqueles diretamente relacionados à eutrofização (fósforo total, nitrogênio e Secchi). A tecnologia de IFAs deve ser encorajada para pequenos e médios produtores rurais como ferramenta para melhorar a qualidade da água de viveiros de piscicultura. Contudo, novas taxas de cobertura de IFAs devem ser avaliadas, com cuidado, bem como o controle das taxas de retenção hidráulica, para promover melhorias mais significativas na qualidade da água, sem prejudicar a produção de peixes.

Palavras-chave: aquicultura, ecotecnologia, macrófitas aquáticas livre-flutuante.

1. INTRODUCTION

Brazilian aquaculture has developed rapidly, attaining, in 2016, 13th place among the largest producers in the world (FAO, 2018). In 2019, fish production increased 4.9% in relation to the previous year, reaching a yield of 758,006 tons, even in a scenario of low national economic growth. This increase represents the importance of the sector for the country, which is the 4th largest producer of tilapia in the world (PeixeBr, 2020).

The quality of water in suitable conditions for the production of aquatic organisms is an essential requirement for the success of aquaculture activities. In excavated fishponds, detailed knowledge of ecological and biological aspects and constant monitoring of environmental variables contribute to the management and maintenance of desirable water quality in aquaculture, improving the development of organisms and optimizing productivity by area (Mercante *et al.*, 2007; Sipaúba-Tavares *et al.*, 2015).

The feeding practices necessary to sustain semi-intensive and intensive fish farming systems contribute to the input of large amounts of nutrients into the water. No more than 25% of N and 30% of P added to fishponds as feed are converted into fish biomass (Moraes *et al.*, 2016; Chatvijitkul *et al.*, 2017; David *et al.*, 2017a; 2017b; Osti *et al.*, 2018a). Additionally, overfeeding or the use of unbalanced feed reduces the absorption of nutrients by fish, which can result in excess of organic matter and nutrients in production systems, with direct consequences on water quality, favoring their assimilation by phytoplankton and aquatic macrophytes. The increase in phytoplankton abundance may lead to the reduction in water transparency and depletion of dissolved oxygen, which can compromise the productivity performance and increase fish mortality (Cyrino *et al.,* 2010; Boyd, 2016; Mercante *et al.*, 2020).

The adoption of Best Management Practices (BMPs) and the development of technologies that combine the necessary speed for an economically viable production, without compromising the water quality of fishponds, must be adopted to ensure a suitable environment for the fish, as well as the conservation of aquatic environments, promoting the sustainability of the activity. The technology of artificial floating islands (AFIs) is an innovative variant of the built wetland system and consists of the elaboration of floating rafts that are colonized by emerging and floating aquatic macrophytes, with the roots of plants submerged below the water surface (Afzal *et al.*, 2019; Spangler *et al.*, 2019; Osti *et al.*, 2020). In these systems, the improvement of water quality is due to the direct assimilation of nutrients by the root system of plants, but also by the biofilm formed by algae, bacteria and other microbes that adhere to the entire surface area of the AFIs (roots of the plants).

Plants and island (structure) aid in the assimilation of nutrients, by attenuating light, inhibiting phytoplankton growth, zooplankton herbivory and allelopathic chemical compounds produced by macrophytes (Sipaúba-Tavares *et al.*, 2015; Park *et al.*, 2018; Spangler *et al.*, 2019; Kurashov *et al.*, 2021). The technology of AFIs has been tested in the control of pollution from different activities, such as swine waste (Hubbard *et al.*, 2004); in rainwater drainage systems (Headley *et al.*, 2008; Lynch *et al.*, 2015); and at acid mine drainage sites (Gupta *et al.*, 2020). Furthermore, the adequacy of this technology was also tested to control the release of nutrients by fishponds' effluents (Osti *et al.*, 2020). These authors concluded that AFIs technology implemented in fishponds can reduce the load of total nitrogen and total phosphorus exported by 66% and 27%, respectively, showing its efficiency. Likewise, the studies cited above have shown that AFIs technology has become an environmentally viable option for removing nutrients and metals from water and/or retaining particulate matter in suspension from different polluting sources. However, information on the influence of AFIs implementation aiming at the maintenance of water quality of fishponds, as well as the ideal development of fish in production systems, is still a challenge. Thus, in this study, the authors have evaluated the effect of AFIs implementation, colonized by *Eichhornia crassipes*, on the water quality of Nile tilapia fishponds and on the development of these animals during the grow-out period.

2. MATERIALS AND METHODS

2.1. Study area

This study was carried out for 133 days (November 2018 to April 2019) in six fishponds producing Nile tilapia located at the Experimental Station of the Regional Pole for Technological Development of the Paraíba Valley Agribusiness, Pindamonhangaba, São Paulo State, Brazil.

2.2. Description of production system and feed management

Six excavated earthen-bottom fishponds with 200 m^2 of surface area, approximately 1.2 m deep and a total volume of 240 m^3 were used. The water supply came from the water reservoir located inside the experimental station and the effluent was discharged into the receiving water body (Ribeirão do Borba), which is one of the sources of Ribeirão do Cortume, part of the Paraíba do Sul River Basin, SP, Brazil (Figure 1). Water renewal in the fishponds was constant, the average water residence time was 26 h during the experiment and there was no mechanical aeration.

The limnological characteristics of the water supply, such as water temperature (26.4ºC), pH (6.25), turbidity (25 NTU), conductivity (50 $\mu S\ cm^{-1}$), dissolved oxygen (6.88 mg L^{-1}) and

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total dissolved solids (0.034 mg L^{-1}), were regularly monitored during the study period and are detailed in Osti *et al.* (2020). The semi-intensive production system was used for the grow-out period of male Nile tilapia (*Oreochromis niloticus*), sexually reversed, with an initial average weight of 22.64 g, stocked at the density of three fish per m^2.

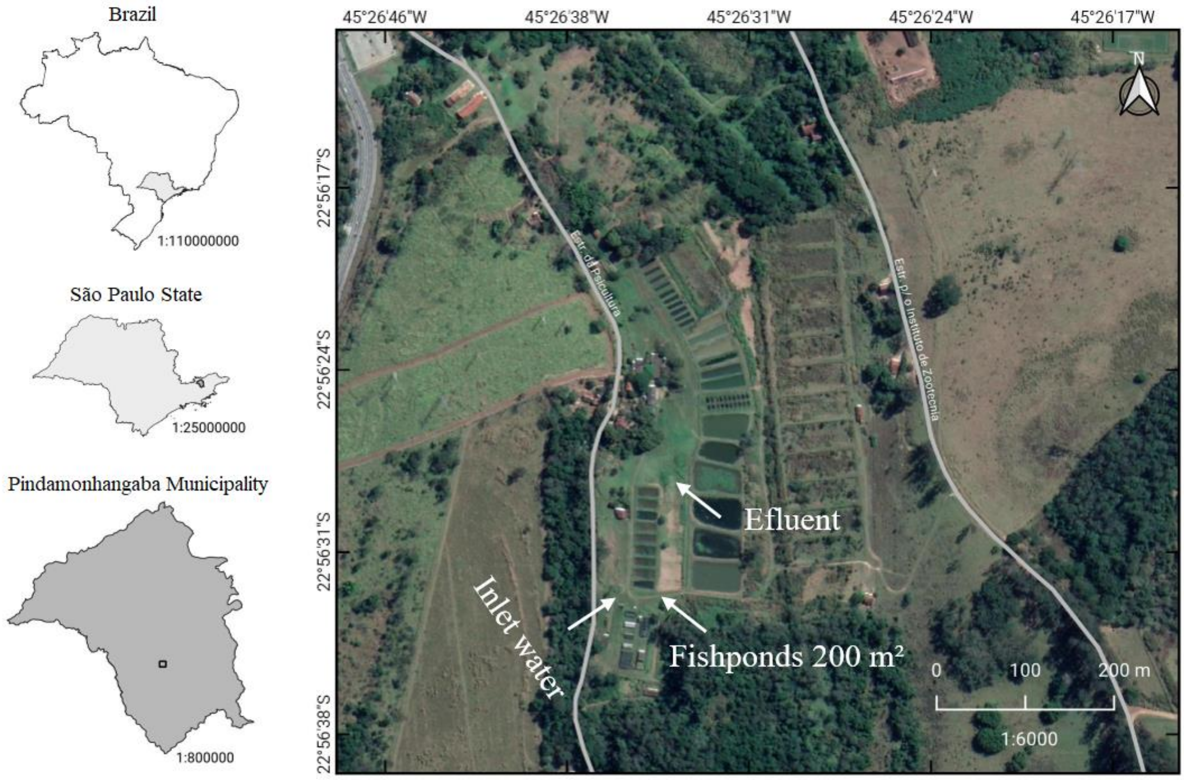

Figure 1. Study area location. The 200 m² excavated fishponds distributed in series, the source of water supply and the place where the effluent is discharged from the fishponds are highlighted. (Google Earth pro source - Image taken on July 23, 2019).

During the grow-out period, the extruded formulation of QUALY® fish feed containing 32–45% crude protein and 1.0–1.3% phosphorus was offered twice a day. The amount of feed offered was 1.5–3.0% of the total estimated biomass, taking into account the stage of population development (size/age) and the estimated biomass produced. To estimate the biomass produced, biometrics were performed monthly considering the analysis of a batch containing 10% of the total fish population of each pond.

2.3. Design of artificial floating islands

The experimental design was completely randomized with two treatments and three replications (Figure 2). The treatments were as follows: T1) Nile tilapia grow-out fishponds with artificial floating islands (AFIs) colonized by *Eichhornia crassipes* and T2) Nile tilapia grow-out fishponds without artificial floating islands (without AFIs).

The artificial floating islands installed in the fishponds were built with 2 m² each, using PVC pipes and fishing nets, easy-finding and low-cost materials, occupying 10% of the fishpond area. The details of the structure and dimensions of the AFIs are described in Osti *et al.* (2020). According to the aforementioned authors, the floating artificial islands model is easy to install and maintain, robust enough to withstand macrophyte management, and it is not necessary to remove it for fish measurements throughout the grow-out period. The fishing nets are suited to fix the root system of macrophytes, preventing their dispersion in the fishponds.

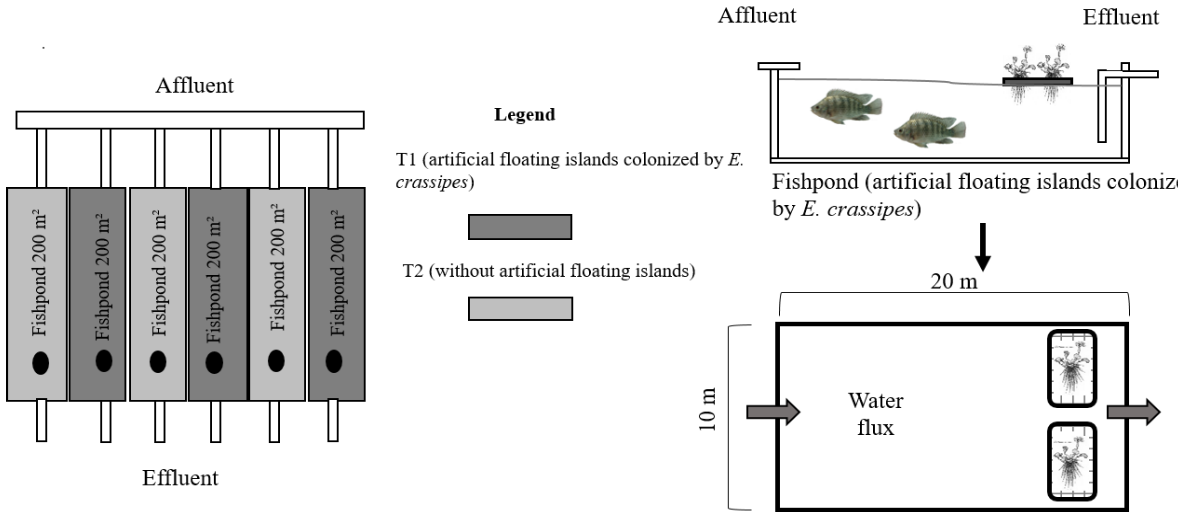

Figure 2. Schematic drawing of the Nile tilapia (*O. niloticus)* grow-out fishponds and the artificial floating islands colonized by *Eichhornia crassipes*. Adapted from Osti *et al.* (2020).

2.4. Limnological variables

Limnological variables were measured based on triplicates of water samples collected every two weeks during 133 days from December 2018 to April 2019. Sampling was carried out in the center of the fishponds between 9:00 am and 10:00 am (Figure 2).

Water temperature (°C), dissolved oxygen (mg L^{-1}), electrical conductivity (μS cm^{-1}), turbidity (NTU), total dissolved solids (mg L^{-1}) and pH were measured *in situ* using a Horiba U-50 multiparametric probe. The water transparency was determined through the visual disappearance of the Secchi disk (m). With the aid of sterilized bottles, water samples were collected for the analysis of total nitrogen (TN) (μg L^{-1}) and total phosphorus (TP) (μg L^{-1}) following the methodology described by Valderrama (1981); nitrite (NO_2^--N) (μg L^{-1}) and nitrate (NO_3^--N) (μg L^{-1}) were determined according to Giné *et al.* (1980). While the total ammonia nitrogen (TAN) (μg L^{-1}) followed the Nessler technique described in APHA *et al.* (2005), the ammonia (NH_3-N) and ammonium ion (NH_4^+-N) fractions were determined based on the chemical balance between nitrogen forms as a function of temperature and pH, according to the mathematical model described by Emerson *et al.* (1975) and Chapra (2008). Organic nitrogen (OrgN) was estimated by the difference between TN and the sum of NO_2^--N, NO_3^--N and TAN. Orthophosphate (PO_4^{3-}-P) (μg L^{-1}) was determined by the method described by Strickland (1960). The concentration of chlorophyll *a* (CL *a*) was estimated using the method and calculation described by Marker *et al.* (1980) and Sartory and Grobellar (1984). The analyses were performed at the water quality laboratory of the Fisheries Institute.

2.5. Statistical analyses

The means of the final weight, harvest mass and apparent feed conversion rate were compared between the fishponds with and without AFIs using the t-test (Semmar, 2013). A descriptive analysis was performed for the limnological variables between the fishponds with and without AFIs structure and for the tilapia production data. To assess possible differences in water quality between the fishponds with and without AFIs, we used the Kruskal-Wallis independent non-parametric test ($\alpha = 0.05$) (Corder and Foreman, 2014).

To assess the relationship of limnological variables between treatments, especially the influence of macrophytes in the fishponds with AFIs, we used the Principal Component Analysis (PCA) through the correlation matrix between the Nile tilapia grow-out fishponds with and without artificial floating islands and limnological variables (Vicini, 2005). The limnological variables that showed the highest Pearson correlation with axes 1 and 2 ($r > 0.5$) were retained, whereas the variables that could cause multicollinearity were excluded

(Legendre and Legendre, 2012). For the analysis, the PC-ORD 6.0 program for Windows (McCune and Mefford, 1997) was used, and the data was transformed by [log (x + 1)], except for pH.

3. RESULTS

The final average weight, survival rate and harvest mass in the fishponds with artificial floating islands technology were 232.78 g per animal^{-1}, 90% and 5,753 kg ha^{-1}, respectively. These results were similar to those observed in the fishponds without AFIs, which corresponded to 233.35 g per animal^{-1}, 90% and 5,788 kg ha^{-1}, respectively. The amount of feed offered throughout the grow-out period was the same for both fishponds and reached 9,743 kg ha^{-1} (Table 1).

Table 1. Zootechnical performance data of Nile tilapia during the grow-out period in a semi-intensive production system and excavated fishponds (n = 3) with artificial floating islands colonized by *Eichhornia crassipes* (AFIs) and without artificial floating islands (without AFIs). Data from Osti *et al.* (2020).

Zootechnical performance	AFIs	Without AFIs
Initial average weight (g)	23.97 (2.8)	21.3 (1.3)
Final average weight (g)	232.78 (14.2)	233.35 (44.35)
Harvest mass (kg ha^{-1})	5,753 (395)	5,788 (1.170)
Survival (%)	90	90
Apparent Feed Conversion Rate	1.7 (0.1)	1.73 (0.4)

In general, the results of limnological variables observed in the Nile tilapia fishponds with or without AFIs are within the ideal range for tropical fish production when compared to specialized literature (Table 2). The fishponds with AFIs had the lowest average concentrations of TN and TP (409.1 ± 68.3 µg L^{-1} and 66.2 ± 11.8 µg L^{-1}, respectively), when compared to the fishponds without AFIs (449.8 ± 77.3 µg L^{-1} of TN and 84.4 ± 14.2 µg L^{-1} of TP). The mean value of water transparency registered in the fishponds with AFIs (0.47 ± 0.1 m) was higher than the mean value observed in the fishponds without AFIs (0.44 ± 0.1 m). The mean values of conductivity, water temperature, pH and DO did not differ between the fishponds with AFIs (50 ± 10 µS cm^{-1}; 26.9 ± 0.9ºC; 5.9 ± 0.3 and 5.7 ± 0.9 mg L^{-1} and without AFIs (0.05 ± 0.01 µS cm^{-1}; 27.3 ± 1.2ºC; 6.1 ± 0.2 and 5.8 ± 1.2 mg L^{-1}), respectively (Table 2). We observed a decrease in nutrient concentrations between the fishponds with and without AFIs. Ammonia and ammonium ion concentrations were reduced by 44 and 10%, respectively, while total phosphorus and orthophosphate decreased by 21.6 and 16%, respectively.

The joint analysis of the data, through the Principal Component Analysis (PCA) (Table 3; Figure 3), evidenced in the first axis (PC1 = 50.63% of explicability) the formation of two groups ordered based on the presence or not of the AFIs technology and limnological characteristics. The first group was formed by the fishponds with AFIs and related to the highest values of water transparency (Secchi) and the lowest values of pH, turbidity, total dissolved solids and concentrations of chlorophyll *a* (CL *a*), total nitrogen (TN), total ammonia nitrogen (TAN), total phosphorus (TP) and orthophosphate (PO_4^{3-}-P). The second group was formed by the fishponds without AFIs and related to the highest values of the variables mentioned, except for water transparency, which was lower. The second axis (PC2 = 20.05% of explicability) showed the relationship between limnological variables compared to the production period. With approximately 30 days of production, the fishponds with AFIs had the lowest concentrations of TP and PO_4^{3-}-P, whereas for CL *a*, TN and TAN, the differences were registered more accentuated only after 90 days of production and coincided with the plant management period. Although reduced concentrations of dissolved oxygen were observed shortly after plant management, the fish development was not compromised, since DO concentrations remained above 4 mg L^{-1}, which is considered suitable for tropical fish production.

Table 2. Average concentrations, standard deviation (SD), minimum (Min) and maximum (Max) values of the limnological variables of the fishponds with and without artificial floating islands (AFIs), during the grow-out period of Nile tilapia. Average values followed by different letters (*a* and *b*) in the same row indicate differences of statistical significance by Kruskal-Wallis test ($p < 0.05$).

Limnological variables	**Without AFIs**		**AFIs**		**References**
	Average (SD)	Min-Max	Average (SD)	Min-Max	
T. (ºC)	27.32 (1.23) **a**	25.2-29.2	26.90 (0.98) **a**	25.4-28.8	26-30[€]
pH	6.14 (0.29) **b**	5.5-6.7	5.94 (0.33) **a**	5.1-6.4	6.0-8.5[§]
Cond. (µS cm^{-1})	55.97 (16.05) **a**	24.0-96.0	54.23 (13.58) **a**	37.0-86.0	---
Turbidity (NTU)	36.29 (17.2) **b**	11.1-76.7	27.86 (17.18) **a**	7.3-79.3	< 100 [β]
DO (mg O_2 L^{-1})	5.82 (1.53) **a**	4.2-9.7	5.72 (1.46) **a**	3.2-8.9	> 5.0[#]
DO (%)	73.97 (21.19) **a**	46.8-128.8	69.01(23.32) **a**	5.7-116.0	> 50%[§]
TDS (µg L^{-1})	36.80 (10.15) **a**	14.0-65.0	36,26 (10.01) **a**	25.0-60.0	---
TN (µg L^{-1})	449.76 (80.03) **b**	293.3-609.9	409.11 (69.42) **a**	303.1-546.8	---
TAN (µg L^{-1})	434.3 (74.92) **b**	300.0-506.7	389.0 (68.04) **a**	290.0-480.0	---
NH_4^+-N (µg L^{-1})	433.8 (77.70) **b**	279.5-577.8	388.7 (68.05) **a**	279.9-479.3	---
NH_3-N (µg L^{-1})	0.50 (0.34) **b**	0.078-1.355	0.28 (0.20) **a**	0.025-0.742	< 70[β]
NO_2^--N (µg L^{-1})	3.53 (0.59) **a**	2.3-4.6	3.21 (0.72) **a**	1.2-4.5	< 300[§]
NO_3-N (µg L^{-1})	0.015 (0.005) **a**	0.1-0.02	0.014 (0.005) **a**	0.01-0.02	---
PO_4^{3-}-P (µg L^{-1})	7.55 (0.55) **b**	6.4-8.9	6.34 (0.89) **a**	4.8-8.2	---
TP (µg L^{-1})	84.41 (16.64) **b**	44.6-129.0	66.19 (13.95) **a**	33.5-103.1	---
Secchi (m)	0.43 (0.11) **a**	0.22-0.62	0.47 (0.12) **a**	0.26-0.72	30-50[§]
CLa (µg L^{-1})	4.45 (1.67) **b**	2.5-7.7	3.01 (0.44) **a**	2.5-4.1	---

[β] El-Sayed (2019); [§] Kubitza (2003); [#] Boyd and Tucker (1998); [€] Ono and Kubitza (2003).

Table 3. Pearson correlation coefficient between physical and chemical variables in the fishponds with AFIs and Without AFIs, during the grow-out period of Nile tilapia.

Limnological variables	**Abbreviation**	**Axis 1**	**Axis 2**
Dissolved oxygen (mg L^{-1})	DO	-0.041	**-0.523**
Total dissolved solids (mg L^{-1})	TDS	-0.450	-0.408
Secchi (m)	Secchi	**-0.685**	**-0.577**
Chlorophyll *a* (µg L^{-1})	CL*a*	**0.830**	-0.119
Total nitrogen (µg L^{-1})	TN	**0.806**	0.278
Total ammonia nitrogen (µg L^{-1})	TAN	**0.822**	0.283
Total phosphorus (µg L^{-1})	TP	**0.677**	**-0.593**
Orthophosphate (µg L^{-1})	PO_4^{3-}-P	**0.635**	**-0.584**
	Explicability	**50.63%**	**20.05%**

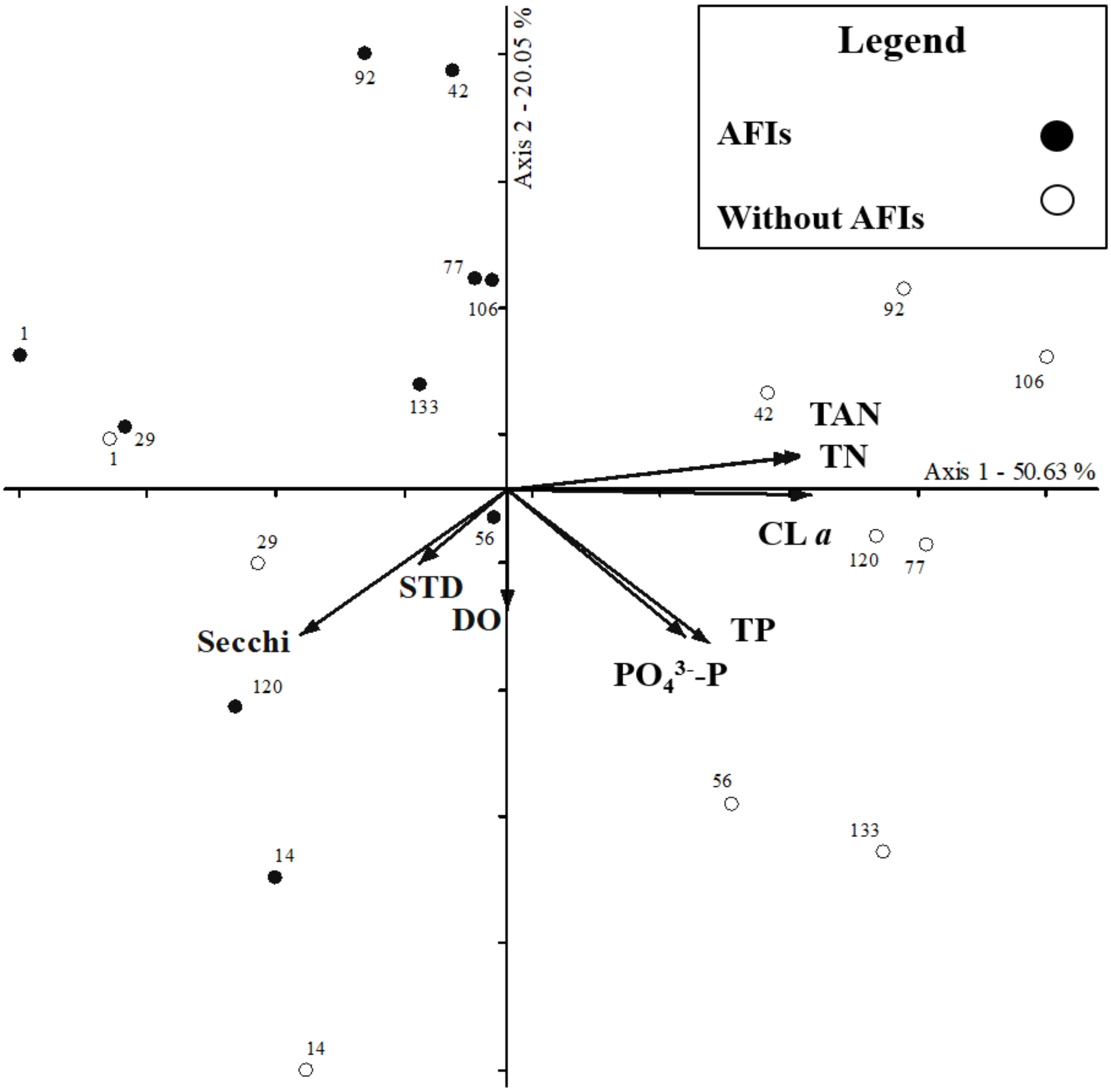

Figure 3. Principal component analysis biplot with ordination of the studied environments in relation to limnological variables in the fishponds with AFIs and Without AFIs, during the grow-out period of Nile tilapia.

4. DISCUSSION

The artificial floating island technology used in this study improved the water quality of the Nile tilapia fishponds, significantly reducing concentrations of TN, TAN, NH^{+}_{4}-N, NH_3-N, TP, PO_4^{3-}-P and chlorophyll *a*, without affecting zootechnical performance of fish that achieved a yield considered satisfactory for the species (Pezzato *et al.*, 2004; Luz and Portella, 2005).

The AFIs with macrophytes and their associated periphyton exert changes in the water quality of fishponds (Crispim *et al.*, 2009, Sipaúba-Tavares *et al.*, 2015; Chang *et al.*, 2017), as shown in Figure 3. These alterations occur directly and indirectly. The direct change is the assimilation of nutrients that are present in the water body, which are used in the growth metabolism of macrophytes and their associated periphyton. The assimilation of nutrients by autotrophic organisms, such as macrophytes and algae, in general, is associated with the activity of chloroplast through reactions that are activated by light, as well as the balance of CO_2/HCO_3^-/CO_3^{2-}, which influences the pH, associated with photosynthesis/respiration processes (Henry-Silva and Camargo, 2008; Rodrigues *et al.*, 2010). Aquatic macrophytes with large biomass and fast growth, such as *E. crassipes*, probably require more nutrients when compared to emerging and/or free-floating macrophytes with less biomass and, therefore, efficiently remove nutrients from the water column (Henares and Camargo 2014; Osti *et al.*, 2018b). Cumulatively, macrophytes and their periphyton remove nutrients and pollutants present in the water by various mechanisms, such as assimilation, development of biofilms, release of extracellular enzyme, sedimentation and trapping of contaminants, as well as increase flocculation of suspended matter (Sipaúba-Tavares *et al.*, 2015; Yeh *et al.*, 2015; Nafath-Ul-Arab *et al.*, 2021). Chang *et al.* (2017) suggests that the ability of macrophyte roots to secrete oxygen, forming anaerobic/anoxic/oxi micro-areas, promote mechanisms that are similar to the process of treating sanitary effluents by activated sludge with removal of nutrients, known as the Phoredox system or A^2/O (anaerobic/ anoxic/oxi). The indirect action of macrophytes in the water, on the other hand, occurs through competition between macrophytes and phytoplankton, either for nutrients or for photosynthetic radiation (Abdel-Tawwab, 2006). In fishponds, phytoplankton are of fundamental importance for maintaining water quality, since they can significantly alter the concentration of nutrients, gases and water pH during photosynthesis/respiration processes (Boyd and Tucker, 1998; Rodrigues *et al.*, 2010), and when in bloom formation, they can lead to a decrease in productivity performance and fish mortality with a consequent decrease in the profitability of the activity (Mercante *et al.*, 2007; Boyd, 2006).

The phosphate ion, an assimilable form by autotrophic organisms, represented less than 10% of the total phosphorus in the fishpond water. However, the ammonium ion represented more than 90% of the total nitrogen present in the water, followed by the organic fraction with less than 5%, as shown in Table 4. Despite the high concentration of nitrogen in the ammoniacal form, the concentration of ammonium gas remained at levels considered safe in both treatments due to the neutral/slightly acidic pH, which led to the predominance of the ammonium ion in the fishpond water (Mercante *et al.*, 2018).

Table 4. Nitrogen fractions present in the fishponds with and without artificial floating islands (AFIs), during the grow-out period of Nile tilapia.

	OrgN (%)	*NH_4^+-N (%)*	*NH_3-N (%)*	*NO_2^--N (%)*	*NO_3^--N (%)*
AFIs	4,16	94,96	0,07	0,81	0
Without AFIs	2,64	96,45	0,11	0,80	0

Reduced forms of nitrogen, that is, the organic and ammoniacal forms, consume oxygen through nitrification in the oxidation process of the ammonium ion (NH_4^+-N). The two main genera of bacteria that participate in this process are Nitrosomonas, that oxidize NH_4^+-N to nitrite (NO_2^--N), and Nitrobacter, that oxidize NO_2^--N to nitrate (NO_3^--N) (Vasconcelos *et al.*, 2020). During this process, each 1 g of nitrogen in ammoniacal form consumes 4.57 g of dissolved oxygen (Esteves, 2011). Thus, the average concentration of ammonium ion found in the fishponds without AFIs (433.8 µg L^{-1}) represents a theoretical oxygen demand of 1.98 mg L^{-1} for its oxidation to nitrate, 12% higher than what was registered in the fishponds with AFIs (1.77 mg L^{-1}). The dissolved oxygen concentration observed in both fishponds was close to the lower limit considered suitable for fish production (Boyd and Tucker, 1998). Thus, the concentrations of total ammonia nitrogen exerted an extra pressure on the DO concentration, which is an essential gas for the success of the production system.

In the fishponds with AFIs, the reduction in TP concentration was lower than that of TN (Table 2). This result can be explained by the fact that the preferred form of nutrient assimilation by macrophytes is the inorganic fraction (Chang *et al.*, 2017), and phosphorus limitation may have occurred for the full development of the macrophyte, given that only 10% of the total phosphorus was in the inorganic form. The high concentrations of TP observed in the fishponds with AFIs (103.1 µg L^{-1}) may have led to phosphorus saturation in the plant tissue. According to Henares and Camargo (2014), this is due to the species saturation point that is 0.26 mg L^{-1} of N and 77 µg L^{-1} of P. A similar result was recorded by Gaballah *et al.* (2021), who evaluated the efficiency in the removal of nutrients with AFIs colonized by *E. crassipes* in a pilot study, and verified a decline in the removal of P after 5 days of experiment and related these values to phosphorus saturation. The N:P ratio should also be considered when studying the removal of nutrients by *E. crassipes*, since this species accumulates N more quickly in its tissue than P, and phosphorus assimilation is affected by the N:P ratio (Jayaweera and Kasturiarachchi, 2004). Sato and Kondo (1981), in an experimental trial, found out that concentrations of 50 mg L^{-1} of nitrogen and 13.8 mg L^{-1} of inorganic phosphorus are needed for the ideal development of *E. crassipes*, which results in a DIN:DIP ratio of 8:1. Reddy and Tucker (1983) suggest that to achieve the maximum biomass yields of *E. crassipes*, the optimum N:P ratio in the water must be between 5:1 and 11:1 of DIN:DIP ratio. In the fishponds with AFIs, the average N:P ratio was 14:1, whereas the average DIN:DIP ratio was 134:1 (Figure 4).

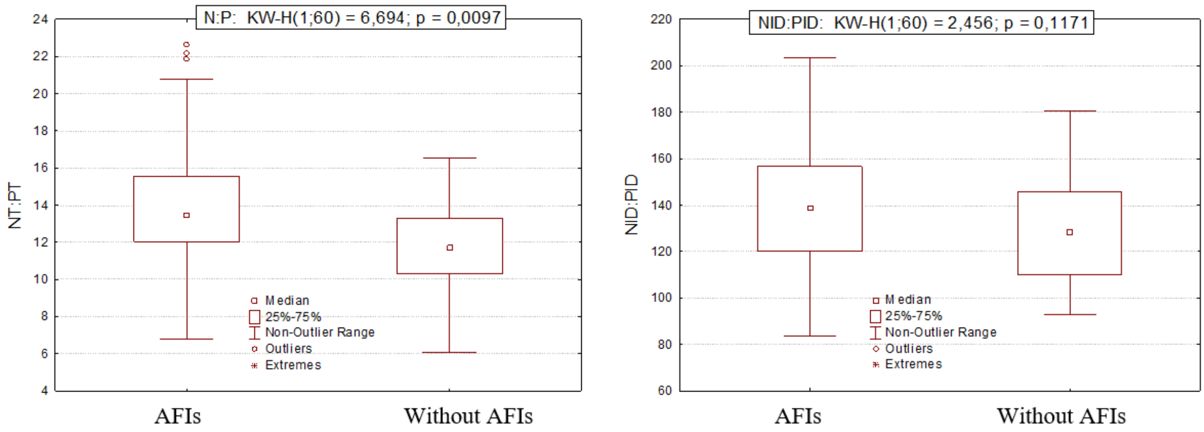

Figure 4. Box-plot of N:P and NID:PID ratios in the fishponds with and without artificial floating islands (AFIs), during the grow-out period of Nile tilapia. Box plot presents the median (squares), interquartile distance (box), minimum and maximum (whiskers), outlines (circles) and extremes (asterisks).

The residence time of water in fishponds is a parameter that must be controlled to improve the efficiency of the AFIs (Osti *et al.*, 2020). Sipaúba-Tavares *et al.* (2002) recommend hydraulic retention time between 1 and 4 days for a more efficient removal of nutrients and other pollutants by aquatic plants. However, Gentelini *et al.* (2008) and Osti *et al.* (2018b) observed phosphorus removal efficiency of 41 and 38% with hydraulic retention times of 12 and 13 hours, respectively. In this experiment, the total phosphorus removal efficiency by the AFIs was 21.6% with a hydraulic retention time of 26 hours, which may have limited the AFIs removal efficiency. The proper water quality, even in the fishponds without AFIs, may be explained by the low hydraulic retention time and the quality of the water that supplies the production system.

The coverage rate of the islands is an extremely important factor, since AFIs can restrict the diffusion of oxygen from air to water (Chang *et al.*, 2017). Boyd and Tucker (1998) suggest that macrophyte coverage between 10-20% in fishponds is generally harmful. Abdel-Tawwab (2006) observed that coverages above 50% of the surface area of fishponds, colonized by the macrophyte *Azolla pinatta*, significantly reduced the concentrations of oxygen, pH, conductivity, phosphate, nitrate, phytoplankton, zooplankton and fish productivity. The author recommends that macrophyte coverage should not exceed 25% of the surface area of fishponds to obtain a balanced ecosystem. Saeed and Al-Nagaawy (2013), when evaluating the effect of *E. crassipes* with a coverage of 10% in tilapia fishponds, observed a slight effect on water quality, a decrease in the nutrient load and phytoplankton biomass, which had no significant effect on fish production. Chang *et al.* (2017) point to an ideal coverage of approximately 20%, as long as the aerobic condition is maintained without artificial aeration. In this study, the presence of AFIs, at a coverage rate of 10% of the fishponds' surface, improved the water quality, reducing the values of pH and turbidity, as well as the concentrations of TN; TAN; TP; PO_4^{3-}-P and Cl *a* (Table 2), without affecting fish productivity.

5. CONCLUSIONS

The artificial floating islands (AFIs), colonized by *Eichhornia crassipes* and covering 10% of the fishponds area, reduced the concentrations of nutrients and chlorophyll *a* without affecting the zootechnical performance of Nile tilapia. After 30 days of colonization with *E. crassipes*, the reduction of inorganic and organic forms of nitrogen and phosphorus were evidenced. The decrease in pH, water transparency, chlorophyll *a* and turbidity occurred after 90 days of colonization. Artificial floating islands technology should be encouraged for small- and medium-sized farmers as a tool to improve water quality in fishponds. However, new AFIs coverage rates must be evaluated, as well as the control of hydraulic retention rates, to promote meaningful improvements in water quality without impairing fish production.

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7. ETHICS COMMITTEE

All procedures used during this study followed the ethical procedures in animal experimentation adopted by "Colégio Brasileiro de Experimentação Animal" (COBEA) and were approved by the Ethics Committee of Animal Experimentation of the Fisheries Institute (CEEAIP) (Protocol No. 08/2018).

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