

## Implementation of an Integrated Floating Wetland and Biofilter for Water Treatment in Nile Tilapia Aquaculture

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### ABSTRACT

Due to the high nutrient and organic matter contents of fish pond water, the water must be treated before disposal to prevent the eutrophication and deterioration of natural receiving waters. Floating wetlands (FTWs) and biofilters are environmentally friendly ecological treatments that can be used for this water. Thus, this study aimed to investigate the performance of FTWs with biofilters (FTW/Bs) for nutrient and organic compound removal. Two FTW/Bs were applied in a pond with 5,000 Nile tilapia. The macrophyte species in the FTWs were *Cyperus* (*Cyperus* spp.) and *Heliconia* (*Heliconia* spp.). The buoyant mats of the FTWs were made from bamboo, and 200 bioballs were loaded below the mats. The water quality parameters in the pond were monitored for 5 weeks between the control test without the FTW/Bs and the experimental test with FTW/Bs at sites 1 (S1) to 8 (S8). The FTW/Bs were located at sites 2 (S2) and 3 (S3). The results showed reductions in all water quality parameters except orthophosphate (ortho-P) at S2 and S3. The COD, BOD, NH<sub>4</sub>-N, and SS at S2 and S3 parameters during the experimental test were significantly lower than those during the control test, in the ranges of 20.34–33.96, 25.47–29.41, 25.86–27.87, and 26.00–28.44%, respectively.

**Keywords:** aquaculture, biofilter, fish pond water, floating wetland.

### INTRODUCTION

Fishery farms are a source of wastewater with high nutrient and organic matter contents. Nile tilapia is an important species produced by aquaculture worldwide. The production of Nile tilapia was 70.3% higher in 2018 than in 2010 [FAO, 2020]. In Thailand, Nile tilapia fish farming has also been increasing due to the niche domestic and international markets for this fish. In practice, the water in fishponds must be withdrawn and discarded into natural receiving waters to control the concentrations of pollutants that are toxic to fish. The discarded wastewater can cause eutrophication and deterioration in the natural receiving waters. Constructed wetlands are an ecologically sound treatment technique for this wastewater because of their low cost and low maintenance requirements [Wu et al., 2015]. They contain the plant and bedding

materials that remove nutrients, organic matter, and suspended solids from water. However, constructing these systems requires a large area [Borne et al., 2013]. Floating treatment wetlands (FTWs) are one type of wetland in which macrophytes grow on buoyant mats and float on surface water [Tanner and Headley, 2011, Castro-Castellon et al., 2016]. The macrophyte roots are suspended in and directly contact the water, which increases the nutrient uptake rate [Tanner and Headley, 2011]. FTWs not only drive nutrients to the macrophyte biomass but also increase contaminant decomposition and the filtration of suspended solids by plant roots [Tanner and Headley, 2011, Castro-Castellon et al., 2016]. The roots of the FTW plants provide oxygen through their axial tissues and secrete exudates that surround the rhizosphere to enhance the activity of microorganisms as well as the physical and biochemical reactions

that damage pollutants [Bisseger et al., 2014, Pawlineri et al., 2017, Benvenuti et al., 2018]. FTWs do not require land for construction, have low investment and maintenance costs, and do not consume energy [Abed et al., 2017]. Moreover, they can be applied on fish farms due to their ability to move with the water level. Macrophytes are usually planted in FTWs, such as *Iris pseudacorus L.*, *Canna indica L.*, [Wu et al., 2016], *Cyperus alternifolius* [Zhang et al., 2014], *Canna flaccida*, and *Juncus effusus* [White and cousin, 2013]. The buoyant mats are made from various materials, such as PVC pipes, plastic mesh, foam, and bamboo [Pawlineri et al., 2017]. However, FTWs can be enhanced by adding substrates such as ceramsite and rice straw as well as biodegradable plastic [Cao et al., 2016, Lopardo et al., 2019] for use as carbon sources and for biofilm attachment. Biofilters are systems that contain bioballs to increase the surface area for biofilm attachment. Biofilms can support FTWs to increase the population of attached microorganisms and their efficiency at removing organic compounds from water. Wu et al. [2016] reported that plants coupled with fiber filters increased the COD removal by approximately 14.7% compared with the treatment with plants alone. The previous research has used this technique to treat nutrients and heavy metals in domestic sewage [Saeed et al., 2014, Benvenuti et al., 2018], stormwater [White and Cousins, 2013, Borne et al., 2013, Wang et al., 2014, Tharp et al., 2019], polluted rivers [Cao et al., 2016, Shahid et al., 2019], gray water [Abed et al., 2017], and agricultural runoff [Barco and Borin, 2020].

In Mungkung et al. [2017], FTWs were integrated with biofilters to treat the water from a Nile tilapia fish pond at the laboratory scale. The results showed that an FTW with a biofilter could reduce the TKN, TP, and BOD by approximately 81.64, 41.50, and 67.75%, respectively, with a hydraulic retention time (HRT) of 7 days. In addition, in a control test without FTW and biofilters, TKN, TP, and BOD decreased by only 46.23, 38.00, and 27.75%, respectively. Thus, this study aimed to investigate the performance of FTWs with biofilters (FTW/Bs) to remove nutrients and organic compounds from the fish pond water. The plants used in this study were a polyculture of *Cyperus* and *Heliconia*. The experiment was conducted at the pilot scale. The source of wastewater in this study was a Nile tilapia pond.

## METHODOLOGY

### Site description

The study site was an earthen Nile tilapia pond. The area of the pond was 1600 m<sup>2</sup> (20 m x 80 m width and length). Approximately 5,000 4-month-old Nile tilapia were cultured. The sampling points were located at 8 sites, from site 1 (S1) to site 8 (S8), as shown in Figure 1. Inside the fishpond, nine-blade turbines were installed at sites 6 (S6) and 7 (S7). This turbine was operated 6 hr/day in both the control test (C) and the experimental test (T). A water pump was installed at site 1 (S1), which was assumed to be in the inlet and outlet for the water in the fish pond. FTW/Bs were placed at sites 2 (S2) and 3 (S3).

### Experimental setup

The two buoyant mats were made from bamboo, with an area of 0.9 m<sup>2</sup>/mat (0.6 m x 1.5 m x 0.6 m width x length x depth), as shown in Figure 1. Seven *Cyperus* (*Cyperus spp.*) and *Heliconia* (*Heliconia spp.*) plants were placed on the top of each mat, and 200 bioballs were placed below. The surface area of the bioballs was 105 m<sup>2</sup>/m<sup>3</sup>. The plants and bioballs were acclimated to the fish pond water for two weeks before they were transferred to the buoyant mat to form the integrated floating wetlands and biofilters (FTW/Bs). The control test (C) was conducted without FTW/Bs, and the experimental tests (T) were carried out with FTW/Bs. The FTW/B reactors were acclimated for 4 weeks before gathering the water samples. The water quality was monitored for 5 weeks. Both the control test and experimental test were performed in the same fish pond, but the experiments were conducted at different times.

### Water sampling and chemical analysis

One liter water samples were collected in PE bottles. The pH, temperature, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH<sub>4</sub>-N), orthophosphate (ortho-P), and suspended solids (SS) were measured. The pH, temperature and DO were analyzed by a multimeter (PCD650, Eutech). The COD, BOD, TKN, NH<sub>4</sub>-N, ortho-P, and SS were measured according to the standard methods [APHA, 2005]. All samples were measured with two replicates.

### Statistical analysis

All statistical analyses were conducted with Stata version 14.2 software (StataCorp LLC., Texas, USA). The differences in water qualities between the control test and experimental test were analyzed by one-way ANOVA with Duncan’s post hoc test and were considered significant at the 0.05 level.

## RESULTS AND DISCUSSION

### Physiochemical properties of wastewater from fish farms

This study investigated the water quality in a fish pond with approximately 5,000 Nile tilapia per 1,600 m<sup>2</sup>. The results showed that the concentrations of COD, BOD, TKN, NH<sub>4</sub>-N, ortho-P, and SS were in the ranges of 39.20 – 94.08, 12.00 – 63.40, 5.60 – 24.64, 3.36 – 17.92, 0.04 – 0.13, and 60.00 – 212.00 mg/L, respectively. In practice, to maximize the growth of Nile tilapia, they are fed a diet containing 30% protein [Siddiqui et al., 1988]. The high nitrogen and organic pollutant levels in the pond water might be caused by uneaten fish feed and fish excretions. Brune et al. [2003] reported that fish excrete approximately 36% of their input feed as organic waste. Moreover, approximately 59–75 and 60–62% of the nitrogen (N) and

phosphorus (P), respectively, in the excretions are released into the pond water [Brune et al., 2003, Piedrahita, 2003]. Some pollutants are toxic to fish, especially total ammonia nitrogen (TAN), which is the sum of unionized ammonia (NH<sub>3</sub>-N), and ionized ammonia (NH<sub>4</sub>-N) present in the water. NH<sub>3</sub>-N is more toxic than NH<sub>4</sub>-N [Crab et al., 2007]. TAN has health impacts on Nile tilapia juveniles at a concentration of 5–10 mg/L [Hegazi et al., 2010]. The optimal NH<sub>3</sub>-N concentration for Nile tilapia is in the range of 0.01 – 0.004 mg/L [Sherif et al., 2008]. Thus, to control the concentrations of toxic compounds, the pond water should be withdrawn and replaced with fresh water. However, this withdrawn water is directly discarded to the receiving water, which causes eutrophication and quality deterioration in the receiving water. In a previous study, the integration of FTW and biofilters was shown to reduce TKN, TP, and BOD by approximately 82, 42, and 67%, respectively [Mungkung et al., 2017]. In this study, FTW and biofilters were set up and applied in a Nile tilapia pond.

### Performance of the integrated FTW and Biofilter (FTW/B)

In the control and experimental tests, the COD, BOD, TKN, NH<sub>4</sub>, ortho-P, and SS at S6 and S7 were lower than those in the other tests due to the aeration by the turbine. The concentrations of all parameters

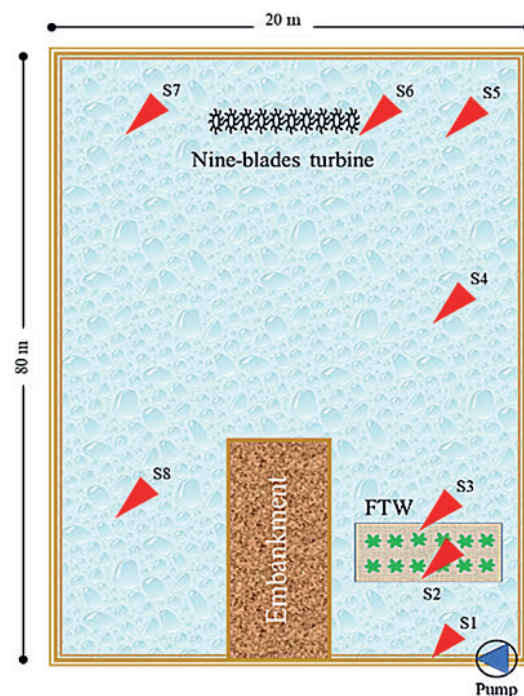


Figure 1. FTW/Bs system and water collection sites

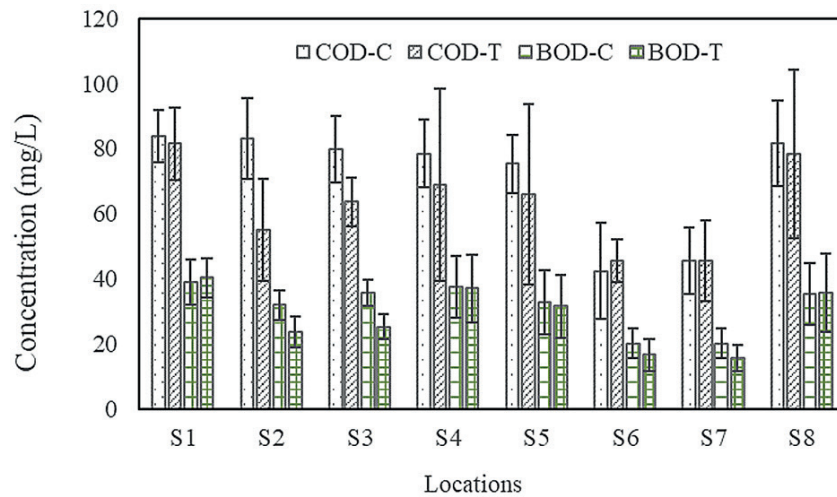


except ortho-P at S2 and S3 in the experimental test were lower than those in the control test.

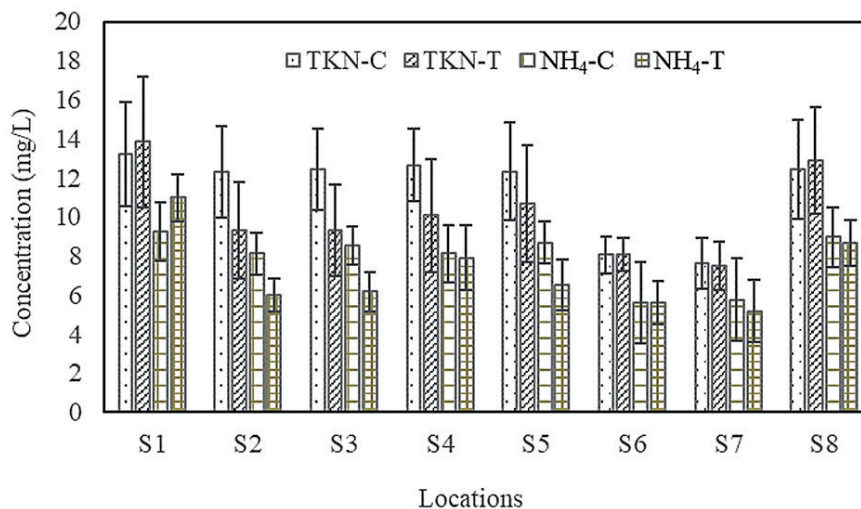
As shown in Figure 2, the COD at all sites in the control test except S6 and S7 was in the range of 75.26 – 83.89 mg/L. The COD at S6 and S7 was approximately 42.34 – 45.47 in both tests. In the experimental test, the COD at S2 and S3 was significantly lower ( $p < 0.05$ ) than that in the control test, by approximately 20.34 – 33.96%. Similarly, the range of BOD was 31.80 – 39.00 mg/L at S1 and S4-S8 and 15.60 – 20.01 mg/L at S2-S3 in the control. The BOD at S2 and S3 in the experimental test was significantly lower than that in the control test, by approximately 25.47 – 29.41%. The lowest COD and BOD achieved at S2 and S3 were due to the biodegradation of

pollutants by the microorganisms in the biofilms attached to the plant roots and biofilters [Barco and Borin, 2020]. Some organic matter was also filtered out by the plant roots [Barco and Borin, 2020]. Moreover, the activity of microorganisms was supported and accelerated by the release of oxygen passing through the aerenchyma tissue of plants into the rhizosphere area [Pavlineri et al., 2017]. This study found that the DO at S2 and S3 was in the range of 5.30 – 5.50 mg/L in the experimental test, whereas 4.88–4.98 mg/L DO was observed in the control test.

Figure 3 shows the variations in TKN and  $\text{NH}_4\text{-N}$  in each test. A significant change ( $P < 0.05$ ) in TKN was not observed between the control and experimental tests. However, TKN declined



**Figure 2.** The changes in COD and BOD in the control (C) and experimental test (T). (Error bars show the standard deviation)



**Figure 3.** The changes in TKN and  $\text{NH}_4$  in the control (C) and experimental test (T). (Error bars show the standard deviation)

at S2, S3, S4, and S5 in the experimental test. In addition, the  $\text{NH}_4\text{-N}$  in the experimental test was significantly lower than that in the control test at S2, S3, and S5, by approximately 25.86, 27.87, and 25.00%, respectively. TKN was reduced at the site near FTW/B because of the microorganismal activity and the sedimentation of organic nitrogen [Dunne et al., 2013, Zhang et al., 2014]. Ammonia nitrogen was also reduced by microbial nitrification, which was enhanced by the oxygen released from the plant roots. Wu et al. [2016] demonstrated the strong growth of aerobic heterotrophic bacteria in root zones. When a fiber filter is built under the plants in an FTW, twice as many bacteria can grow on the fiber filter as on the plant roots [Wu et al., 2016]. However, the plant nitrogen uptake was probably only a minor mechanism for  $\text{NH}_4\text{-N}$  reduction. Plant harvesting can remove approximately 2–8% of the nitrogen in water. Without harvesting, the nitrogen returns to the water due to the decomposition of the plant [Langergraber, 2005].

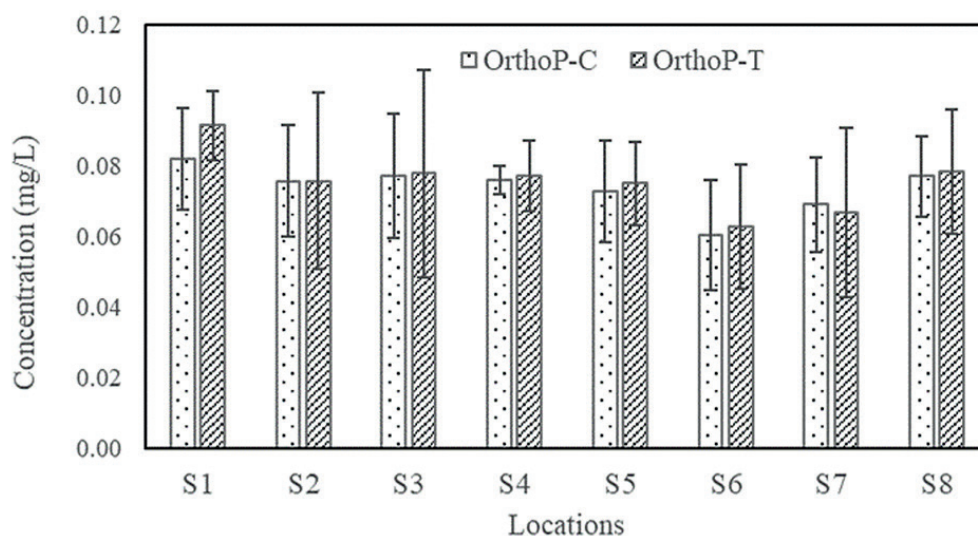
As shown in Figure 4, no significant differences in ortho-P were observed between treatments. The ortho-P values in all tests were in the range of 0.042–0.105 mg/L. FTW/B did not contribute to the reduction of phosphorus, as observed in the study of Barco and Borin [2020]. Normally, phosphorus is reduced by sorption, precipitation, and plant uptake processes [Maucieri et al., 2020]. However, the previous research has reported that approximately 79% of ortho-P is removed in FTWs by sedimentation and is further released from the sediments to the water in wetlands, with long hydraulic retention times [Chang et al., 2013,

Dunne et al., 2012]. In this study, the treatment system was placed in the fish pond for 5 weeks, and some phosphate redissolved into the water. Moreover, the previous research suggested that the phosphorus uptake by plants in FTWs did not result in a significant reduction in the phosphorus levels [Tanner and Headely, 2011, Borne, 2014].

The changes in SS in each test are shown in Figure 5. The SS at S2, S3 (near the buoyant mat), and S4 in the experimental test was significantly lower than that in the control test ( $P < 0.05$ ), by approximately 26.00, 28.44, and 21.61%, respectively. The *Cyperus* roots grew by approximately 10 cm within the 5 weeks of the FTW operation. The growth of macrophytes and the dense roots under the buoyant mat were particularly effective in filters and trapped SS, as observed in the study of Pappalardo et al. [2017]. Moreover, the biofilters under the macrophytes were another mechanism for SS trapping and sedimentation.

## CONCLUSIONS

The integrated FTW and biofilter significantly contributed to reducing COD, BOD,  $\text{NH}_4\text{-N}$ , and SS levels. FTW/Bs can be implemented for the treatment of aquaculture water. However, their removal efficiency depends on the macrophyte species, hydraulic retention time, and water quality. In practice, FTW/Bs should be separated from the fish culture compartment of the aquaculture pond. Moreover, the pollutant loading reduction per area by FTW/Bs remains to be determined.



**Figure 4.** The changes in ortho-P in the control (C) and experimental test (T). (Error bars show the standard deviation)

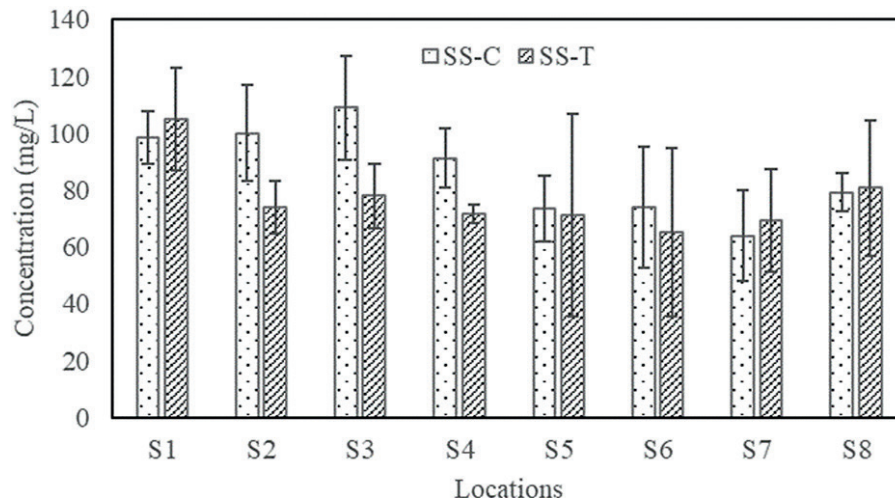


Figure 5. The changes in SS in the control (C) and experimental test (T). (Error bars show the standard deviation)

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