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Treatment of Fishery Wastewater Using a Floating Treatment Wetland Planted with Umbrella Sedge

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Abstract

This study evaluates the effectiveness of floating treatment wetlands (FTWs) using umbrella sedge (*Cyperus* spp.) for removing organic and nitrogen from fishery wastewater in Thailand. Aquaculture in Thailand produces significant wastewater with high organic matter and nitrogen, necessitating effective treatment solutions. FTWs are designed to float in fishponds, providing a flexible and space-saving method for wastewater treatment compared to traditional wetlands. The study used four laboratory-scale FTW reactors with varying hydraulic loading rates (5, 10, 15, and 20 cm/d) to assess their impact on pollutant removal. The FTW with the lowest hydraulic loading rate, 5 cm/d (HRT 20 days) achieved the highest removal efficiencies of 45% 63% and 61% for COD TKN and NH_3-N, respectively, demonstrating the system's effectiveness. Umbrella sedge grew best in the 5 cm/d reactors, where improved aerobic conditions boosted biodegradation, nitrification, and pollutant decomposition. The study concludes that FTWs are a sustainable and efficient solution for treating aquaculture wastewater, particularly at lower hydraulic loading rates, thus supporting better aquaculture practices.

Keywords : floating treatment wetland; synthetic fishery wastewater; nitrogen removal; organic removal; umbrella sedge

Introduction

Aquaculture in Thailand is a significant source of wastewater from agricultural activities in the country. Leftover fish food and excrement results in high levels of organic matter and nitrogen in the water discharged from fishponds. Generally, tilapia farming involves transferring water from upstream ponds to downstream ponds without wastewater treatment. This leads to the accumulation of organic matter and nitrogen in the water of the downstream ponds, reducing oxygen levels and making the water unsuitable for fish growth. Additionally, it affects public water sources when wastewater is discharged from the farming area, causing pollution in the receiving water bodies. Aquaculture farmers need a simple and low-cost wastewater treatment system, and constructed wetlands suit this purpose. However, traditionally constructed wetlands require large areas, reducing the space available for aquaculture. Therefore, floating treatment wetlands (FTW) have been designed to float in fishponds, reducing the additional space needed for treatment. They are also flexible to changes in water levels in the ponds. Floating treatment wetlands (FTW) were created using floating rafts for growing wetland plants without soil, which is recognized as an effective mechanism of water treatment and is used in a wide range of applications. The raft will float on the surface of the water. The pollutant removal mechanism occurs in the root zone of plants under the water surface, which helps increase the amount of oxygen in the water to microorganisms living both around the roots and suspended in the water, causing a reaction to decompose organic matter and other pollutants. Newman [1] found that FTW systems provide design flexibility that can be built in small spaces. The system can be scaled to fit a pond or water source. It is a habitat for living creatures, enhancing their beauty and creating fascinating scenery. Water level fluctuations, as long as they are attached to the bottom or water source, thus the system is not damaged. Therefore, FTW systems are an interesting option used to treat wastewater from fish ponds. Floating treatment wetlands use a variety of plants to help improve water quality by absorbing excess nutrients and breaking down contaminants. Some commonly used plants in FTW such as cattail (*Typha* spp.) umbrella sedge (*Cyperus* spp.) and bulrushes (*Schoenoplectus* spp.). These plants absorb nutrients and contaminants and provide a habitat for beneficial microbes that further enhance the water purification process. The plants in floating constructed wetlands that provide good treatment efficiency include *Cyperus spp*. These plants are tolerant of pollutants in wastewater, grow quickly, and increase biomass, resulting in a high accumulation of organic matter and nitrogen. Additionally, their long roots help distribute oxygen in the water, enhancing the efficiency of pollutant treatment in wastewater. The FTWs planted with umbrella sedges show higher organic and nitrogen removal efficiency than other plants, which were 85% and 77% for organic in the form of COD and TKN, respectively [2]. This study compared the different hydraulic loading rates' organic and nitrogen removal efficiency. However, there is not much information on the use of floating treatment wetland systems to treat wastewater from fishery farming in Thailand. As a result, there is insufficient information on treatment efficacy, plant species, or design requirements to decide on the right treatment system for wastewater. Therefore, this study analyzed the treatment efficiency of a floating treatment wetland system using umbrella sedge (*Cyperus* spp.) to treat wastewater from fish farming by comparing the treatment efficiency with different hydrological load rates. The results of this study can be used to design this system more appropriately in the future.

Materials and Methods

This study used a lab-scale model with four wastewater flow rates to compare the efficiency of organic matter and nitrogen treatment. Four laboratory-scale floating treatment wetland reactors were used in this study, as shown in Figure 1. Each reactor is 0.5 meters wide, 1.0 meters long, and has a water depth of 0.6 meters, with a freeboard of 0.1 meters. The 40x80 cm floating raft was planted with an umbrella sedge (*Cyperus* spp.) 2-3 clumps per raft. The experiment was set in four different hydraulic loading rates (HLR) of 5, 10, 15, and 20 cm/d (C1, C2, C3 and C4, respectively).

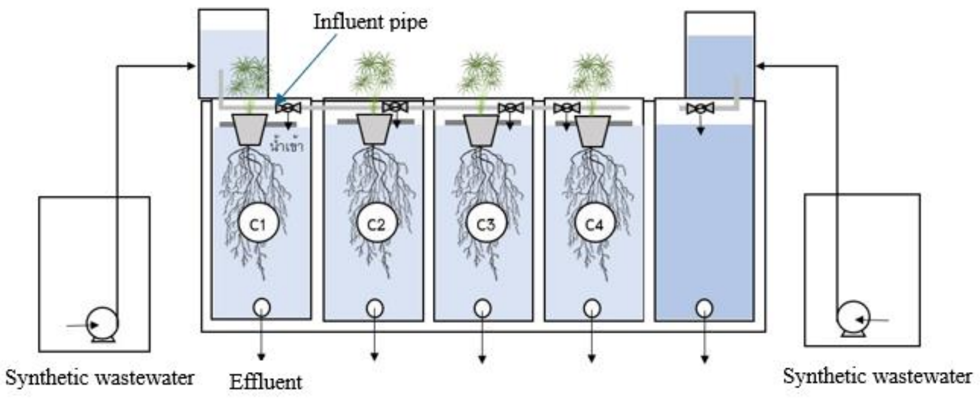

Figure 1 Schematics of the lab-scale reactor

The fishery wastewater was synthesized by mixing molasses and urea as an organic and nitrogen source to match the COD NH_3-N and TKN concentrations of 80-200 mg/L and 20-50 mg/L, respectively shown in Table 1. Synthetic wastewater with an average COD of 168 mg/L, NH_3-N, and TKN at 26 mg/L was pumped into the floating treatment wetland reactor continuously. The peristatic pump was set to feed at HLR 5, 10, 15 and 20 cm/d with the hydraulic retention time at 20, 10, 6.7 and 1.4 days, respectively. The removal efficiencies were determined by collecting the Influent and effluent samples every week and analyzed for COD TKN and ammonia nitrogen. The steady state of the experiment was determined primarily by the ammonia nitrogen concentration in the effluent was almost constant.

This experiment uses umbrella sedge as a plant in the FTW reactor because the previous study reports that the FTWs planted with umbrella sedge provide good efficiency in removing pollutants, specifically, nitrogen removal. This plant can be found in general and is also popular to grow as an ornamental plant. An umbrella sedge grows well in wastewater, can increase the height and number of plants quickly, and has a well-distributed root system. The square raft was made of PVC pipes with a 1-inch diameter a width of 40 cm and a length of 80 cm. In the middle of the raft were cut for planting pots. At the beginning of the experiment, plants were cut to the same initial height as 30 centimeters and an average initial root length of 30 cm and planted 1 clump per pot as shown in Figure 2. About 2 months before the beginning of the experiment, the wastewater was diluted to a concentration of about 25-30% so that the plants could grow easier. The 100% wastewater was fed when the average height of the plants increased from 20 cm to 30 cm, and new plant shoots had grown. Plant height and root length were measured at the beginning and the end of the experiment.

Results and Discussion

The reactors C1, C2, C3 and C4 were fed at 15, 30, 45 and 60 L/d (HRT 20, 10, 6.7 and 1.4 days, respectively). Influent and effluent samples were collected for the 3-month study period. The steady state of the experiment started 14 days of an experiment where nitrogen effluent was nearly constant.

The averages COD TKN and NH_3-N concentration in the influent and effluent is shown in Table 2. There was no significant difference of COD concentration in the effluent for all reactors at the 95% confidence level. The COD removal efficiency was in the range of 32-45%. The COD in the effluent tendency increased as the experimental period lengthened, as shown in Figure 3.

Table 1 Comparison of synthetic and fishery wastewater

Parameters	Averaged concentration,	
	Fishery wastewater	Synthetic wastewater
COD, mg/L	80-200	168
TKN, mg/L	20-50	26
NH_3-N, mg/L		26
SS, mg/L	2	1.5
pH	6-7.5	7.29

Figure 2 Umbrella sedge at the beginning of the experiment

Table 2 Average concentration of influent effluent plant height and plant root length

Parameter	Influent	Average Concentration			
		5 cm/d (C1)	**10 cm/d (C2)**	**15 cm/d (C3)**	**20 cm/d (C4)**
HRT, d		20	10	6.7	1.4
pH	6.6 (SD 0.16)	6.8 (SD 0.07)	7.2 (SD 0.23)	7.4 (SD 0.20)	7.3 (SD 0.18)
COD, mg/L	171 (SD 4.8)	94 (SD 20)	102 (SD 23)	108 (SD 24)	116 (SD 24)
TKN, mg/L	27 (SD 0.3)	10 (SD 1.1)	15 (SD 1.2)	16 (SD 0.7)	17 (SD 0.5)
NH_3-N, mg/L	26 (SD 0.3)	10 (SD 0.3)	13 (SD 0.4)	16 (SD 0.2)	18 (SD 0.7)
Root Length, cm		70.8	57.8	65.8	54.2
Plant Height, cm		50.3	60.3	50.8	58.9

A large number of algae was found to occur in the system because the vegetation on the raft was not dense enough. Therefore, light could penetrate the water, stimulate the growth of algae and fall off with the effluent. The TKN and ammonia nitrogen in the influent were similar because the synthesis of wastewater used urea fertilizer as a representative of nitrogen in the wastewater, which gave nitrogen in the form of ammonia rather than organic nitrogen. The nitrogen in the effluent both TKN and NH_3-N shows a steady state after 14 days of the experiment as shown in Fig 3. At the HLR 5 cm/d (C1) showed significantly high nitrogen removal efficiency for both TKN 63% and NH_3-N 61%, compare to the reactor C2, C3 and C4 at 95% confidence level. At this hydraulic loading rate the retention time was 20 days. There are not many reports related to the water retention period in the FTW system and wastewater treatment efficiency. However, Nuruzzaman [3] found that the FTW system planted with Carex *fascicularis* was able to remove up to 93.3% of TN in just 3 days, and it was found that nitrogen removal in FTW depends on the initial nutrient concentration and plant performance. Toet [4] used a surface-flow wetland treating sewage and found that increasing the HRT enhanced the removal efficiencies of fecal coliform and nitrogen, with a HRT of 4 days required to meet desired standards.

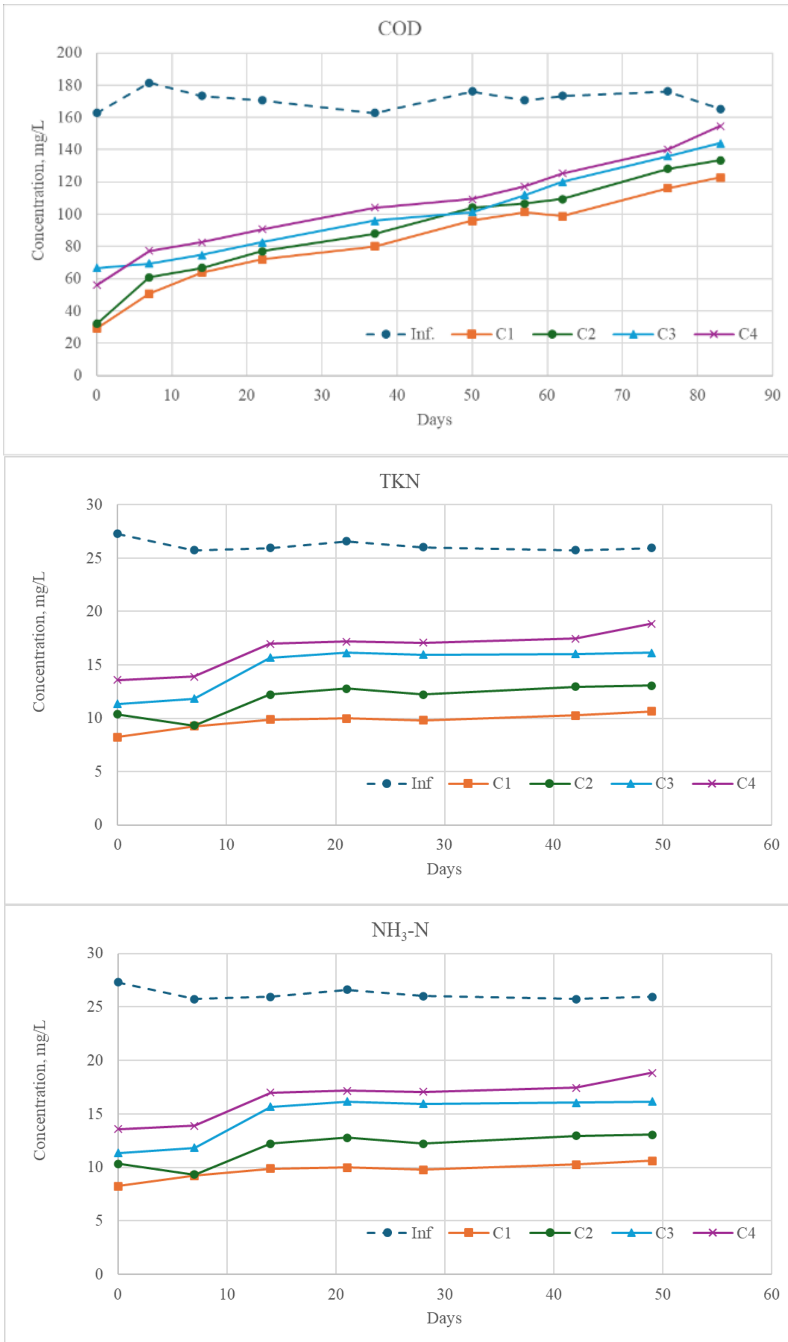

Figure 3 Changes in COD TNK and NH_3-N concentrations

It was found that as the hydraulic loading rate increased, the treatment efficiency decreased, as shown in Figure 4. The TKN removal efficiency was slightly lower than the NH3-N removal efficiency because the algae formed in the system were also mixed into the effluent. It was found that the C1 model provided similar TKN and NH_3-N removal efficiency because the plants in the system grew well above the water, thus blocking the light and reducing the growth of algae more compared to the C2, C3, and C4 models, which had less dense above-water plants (Fig 5). Plant uptake is a process that decreases nitrogen levels in wastewater by converting it into plant tissue. In the C1 reactor, which achieved the highest nitrogen removal, plant weight increased from about 0.02-0.03 kg initially to 2-3 kg by the end of the experiment, with moisture content at 70-80%.

The control system without plants showed slightly lower removal efficiency. Algae thrived due to increased sunlight exposure, resulting in higher organic matter levels in the effluent compared to systems with plants. In comparison, the nitrogen treatment of the control system is like the planted reactors, since the algae themselves contribute to nitrification and help to accumulate nitrogen. This makes the nitrogen value in the effluent similar to that of the system planted with an umbrella sedge.

Nitrogen balance analysis showed that nitrogen removal in this FTW system primarily occurs through nitrification and denitrification, which converted nitrogen to gas and releases to the atmosphere. Effluent nitrate levels were low (0.3–0.45 mg/l), confirming denitrification in the experiments. Nitrogen accumulation in plants during the experiment ranged from 0.06 to 0.8 gN/m^2, with the C1 model showing the highest accumulation (0.8 gN/m^2), representing 2.8% of input nitrogen. Compared to nitrogen accumulation in plants in Hanneke's experiment [5], nitrogen accumulation in cattail and iris was 1.2 and 18.6 g/m^2, respectively. About 60% of nitrogen accumulated in algae or was lost as gaseous nitrogen through nitrification and denitrification; however, algal nitrogen was not directly measured. In the control reactor (without plant), at HLR 5 cm/d, only 27% of nitrogen was removed by deposition in algae or as nitrogen gas in plant-free systems about half the removal seen in planted models. This indicated that plants significantly increase nitrogen transformation. With plants, 10.4 gN/m^2 (37%) remains in effluent, while without plants this rises to 20.6 gN/m^2 (73%), showing that plants significantly lower nitrogen levels. Plants improve total nitrogen removal through uptake and other biological processes, making them effective for reducing effluent nitrogen in wastewater treatment systems. A well-distributed root system allows for aerobic conditions in which microorganisms can decompose organic matter well. Zhang et al. [6] studied the causes of oxygen environments and the response characteristics of plant oxygen release (POR) in subsurface-flow constructed wetlands and reported that the root zone DO increased significantly to 2.05-4.37 mg/L, and was positively correlated with the TN and TP removal rates. *Cyperus* spp. showed a good tendency to release oxygen in the root zone. Yao et al. [7] showed that oxygen released by *Vetiveria zizanioides* L. roots through the biochemical process contributed to 77% and 74% of total root oxygen release under nutrient solution conditions and artificial wastewater conditions, respectively, and that was 72% and 71% of total root oxygen release for *Cyperus alternifolius* L. At experiment's end, plant height and root length in C2, C3, and C4 reactors matched C1, but shoot and root density was lower leading to reduced organic matter and nitrogen removal efficiency. Well-distributed plant roots cause aerobic conditions, which enhance biodegradation and nitrification, were mainly present where dense roots occurred (Fig 6).

In addition, as the hydraulic load rate rises, the flow becomes even more turbulent. This shortens the duration of the wastewater in the model and provides less treatment efficiency. Asaeda and Rashid [8] studied the effect of water turbulence motion and the growth of three types of aquatic plants. The study found that high turbulence velocity inhibits the normal metabolic activities of all three plants, while low to medium turbulence does not harm the floating-leaved plants. This study found that nitrogen reduction followed a first order plug-flow model (R^2=0.95) more closely than a completely mixed-flow model. This aligns with observed flow characteristics, which showed intermediate dispersion (D/L = 0.02–0.03). Plug flow facilitates continuous reactions, such as nitrogen treatment, by maintaining the movement of substances in one direction with minimal mixing.

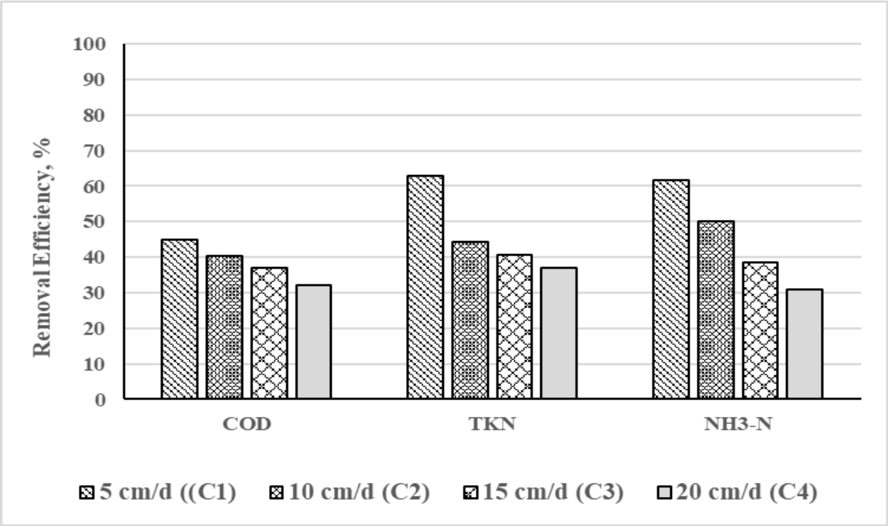

Figure 4 Removal efficiencies compared to HLRs

Figure 5 Plant shoot above the water surface in C1 C2 C3 and C4 at the end of the experiment

Figure 6 Plant root at the end of the experiment at 5 cm/d (C1)

This process makes it possible to establish aerobic zones for nitrification and subsequent anoxic zones for denitrification, which is necessary for effective nitrogen removal. It was found that intermediate dispersion in water flow pattern led to moderate nitrogen removal, influenced by substance dispersion and occasional recirculation.

The removal efficiency in this study was higher compared to the other studies. Barco and Borin [9] report that FTW in Northern Italy has significantly reduced COD and NH_4-N by 16.7% and 25.2%, respectively, whose effectiveness depends on the concentration in the inlet and the wastewater temperature. According to a study by Nichols et al. [10] which used FTW to treat stormwater runoff over 2 months, it was found that 53% of phosphorus and 17% of total nitrogen could be treated. In this study, long, dispersed plant roots throughout the width and length of the reactor provide aerobic conditions. Combined with a long hydraulic retention time (20 days) resulting in the complete degradation reaction for both organic and ammonia nitrogen. A full-scale FTW with Cyperus spp. treating Nile Tilapia aquaculture wastewater reduced COD by 20.3-33.96% and NH_4-N by 25.86-27.87% [11]. However, in real wastewater treatment, floating wetlands may be less efficient due to uncontrollable factors like wind or water flow direction, which influence microbial and plant performance.

Conclusions

This study concluded that FTW planted with an umbrella sedge was effective in removing organic and nitrogen from fishery wastewater, especially at lower hydraulic loading rates. The lowest HLR (5 cm/d) showed the highest removal efficiency for both organic and nitrogen 45% and nitrogen removal at 63% and 61% for TKN and NH_3-N, respectively. Even root distribution boosts organic matter and nitrogen treatment, improving biodegradation and nitrification. This approach offers a sustainable, space-saving way to treat aquaculture wastewater.

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