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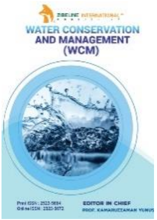

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RESEARCH ARTICLE

REMEDIATION OF NUTRIENTS FROM MUNICIPAL WASTEWATER USING GERMAN GRASS-AIDED FLOATING TREATMENT WETLAND

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ABSTRACT

The potential of using German grass (*Echinochloa polystachya*) in FTWs (Floating Treatment Wetlands) to treat municipal wastewater was investigated in this study. This mesocosm-based study was conducted over a 7-day Hydraulic Retention Period (HRT) with a total of 28 experimental days following a Randomized Complete Block Design (RCBD) with four treatments and three replicates. To evaluate system efficiency, mean temperature, P^H, total dissolved solids (TDS), and electrical conductivity (EC) were also measured along with nitrate and phosphate concentrations. On day 28, the nitrate removal rate obtained with Pickerel weed was 88.65 % while German grass showed 86.56 % of remediation. On the other hand, while Pickerelweed removed 9.5 % of phosphate, German grass removed 7.47 %. The study demonstrated that the use of German grass in FTWs can be highly effective in the removal of nitrate ions from wastewater, while the removal of phosphate ions was minimal.

KEYWORDS

German grass, Floating treatment wetlands, Municipal wastewater, Mesocosm.

1. INTRODUCTION

Like other developing countries, Bangladesh does not have proper wastewater management facilities. Hence, surface water bodies are often discharged with wastewater and its effluents, which are vessels for domestic and industrial wastes, resulting in pollution. With regards to municipal wastewater, mainly containing sewage water, stormwater, domestic water, and agricultural runoff is often discharged into surface water bodies like rivers, canals, and lakes without being treated properly. One common effect of this untreated discharge is the eutrophication of surface water bodies, which is caused due to the presence of nutrients, especially nitrate and phosphate. For the reclamation of water bodies subjected to eutrophication, it is important to apply a feasible and sustainable water treatment technology.

Hence, to fulfill this purpose, FTWs (Floating Treatment Wetlands) are a new tool, which can be employed in existing water bodies at a very cheap cost. Because of its innovative buoyant hydroponic design, which can move up and down with changing water levels in the stormwater pond and can treat highly variable flows, FTW is very capable of overcoming the technical and operational challenges that arise in stormwater treatment as a result of the erratic nature of hydrologic and input pollutant loads (Sharma et al., 2021). The key advantages of using FTWs are they do not require additional land area, they are environment-friendly, easy to construct as well as maintain, and can be used to enhance the visual appeal of the surface water bodies.

Floating treatment wetlands consist of a buoyant, porous platform on which plants are established to remediate water quality or habitat issues while mimicking the mechanism of natural wetlands (Uddin et al., 2016). For the attached biofilm growth and entrapment of suspended particulate matter, the plant roots beneath the floating mat provide an extensive surface area. Plants are forced to acquire their nutrition directly from the water column since they are not rooted in the soils like subsurface flow constructed wetlands. This phenomenon may enhance nutrient and element uptake rates into biomass (Tanner and Headley, 2011).

Several studies have investigated the effectiveness of floating treatment wetlands (Stewart et al., 2008); however little to no research has been carried out to evaluate the potential of using forage species (German grass) as wetland plants to remove nutrients from municipal wastewater. As farming is a common practice in many developing countries, the use of livestock feed grass as wetland plants can add more value to the existing FTWs technology. To magnify the system's efficiency, nutrients can be removed from the system by harvesting plants; this collected biomass could be used directly as a food source for animal or humans (Pavlineri et al., 2017).

Hence, the aim of this study was to investigate the possibility of using German grass in FTWs and to compare its performance with a well-studied wetland species (Pickerelweed) to evaluate its efficacy in the removal of nutrients from municipal wastewater.

2. MATERIALS AND METHODS

2.1 Study Site and Collection of Wastewater

The experiment was conducted in Amberkhana which is approximately 4.5 km away from Sylhet Agricultural University (SAU). The study was carried out in June and July 2019. The average temperature was 33°C during that period and the average rainfall was 815.5 mm (Hasan et al., 2021).

Wastewater used in this study was collected from a channel flowing through Sylhet city. The sewerage network of Sylhet city consists of many

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small drains connected with some natural hilly channels called ‘Chara’, which fall into the Surma River. The largest ‘Chara’ in Sylhet city is called the MalniChara, which originated from MalniChara Tea Garden (Figure 1). The branch of MalniChara selected for this study flows through the Sylhet stadium area. Like all the other branches of MalniChara, this branch is highly contaminated because of the nutrient overloading from the domestic and sewage water effluent of the surrounding locality. Among all the areas under Sylhet city, this area is containing the maximum amount of Total Solid (600 mg/l) and maximum nitrate (42 mg/ l) (Alam et al., 2006).

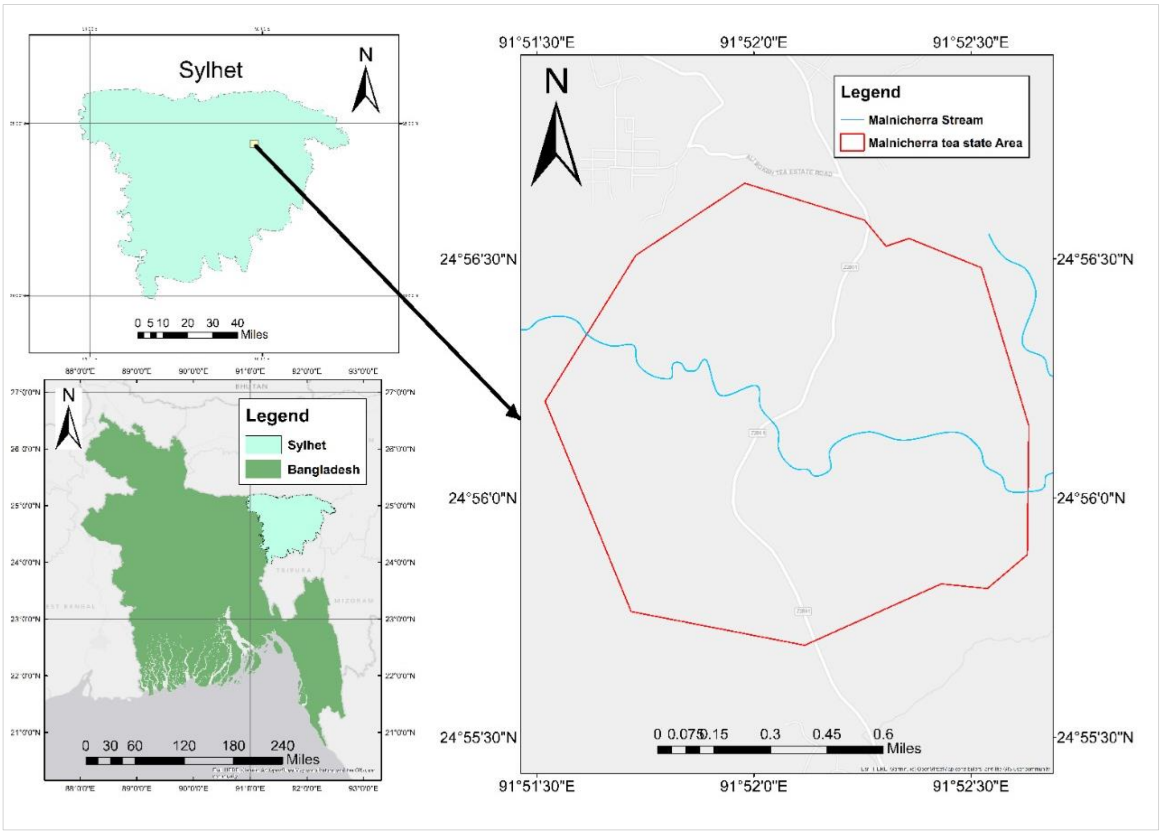

Figure 1: Study Area

2.2 Experimental Design

30L polyethylene buckets were used as mesocosms, all the buckets were black so that proliferation of planktonic and attached algae could be avoided. Each of the mesocosms was having a depth of 35 cm; however, the operational depth was 30 cm. To maintain the operational depth and compensate for evaporation and transpiration loss all the floating beds in the mesocosms were irrigated with de-ionized water daily.

The surface area of each mesocosm was 0.13 m with vegetation coverage of 0.07 m^2 and they were installed under a 2.9 m × 3.8 m transparent horticultural shed. The shed was made with bamboo and a clear polyethylene sheet to provide shelter from rainwater and debris.

The study was conducted in two phases, the initial phase of the study started on 1st June; on that day the seedlings of Pickerelweed and German grass were placed in the buoyant structure and allowed to grow in buckets filled with fresh water. After 30 days when the roots of the plants were visible under the aerator cups, then the vegetated mats were shifted to the buckets filled with wastewater mix.

The second phase of the study was the experimental phase. This phase started on 1st July 2019 and continued till 28th July 2019. For this phase, a completely randomized design was followed which included four treatments (Table 1) with three replicates (T1R1, T1R2, T1R3) including control to determine the influence of the floating wetlands (Figure 2). Controls were provided with a black polyethylene sheet to provide the same amount of shading as that of the floating structure.

Table 1: Treatment Combinations for the Experimental Design

Treatment	Identification code
Pickerelweed	T1
German grass	T2
Floating mat only	T3
Control (black polyethylene sheet only)	C

Figure 2: Mesocosms After Construction

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2.3 Plants and Their Preparation

Two plant species were selected to be used for this study; these were Pickerelweed (*Potenderia cordata)* and German grass (*Echinochloa polystachya*. Both of these plants were collected from a lake, which was located at SAU. During the period of plant collection, the grab sampling method was used. As per the requirements of the study, a total of 18 plants were selected randomly from the corner of the lake where more plants were available. The average shoot height of Pickerelweed was 20 cm in height while the root length was 8 cm, on the other hand, German grass of approximately 30 cm shoot height and 9 cm root length were chosen as the starter plants. After collecting the plants, they were rinsed thoroughly with deionized water to remove all kinds of planting substrates.

2.4 Configuration of Buoyant Structure

A floating mat was prepared using Styrofoam, a lightweight foam buoyant in water. The length of the structure was 27 cm while the width was 25 cm. To carry the plants two holes of 9 cm diameter were made in each floating mat, moreover to hold the growth media (coco coir); plastic aerator cups were installed in each hole of the floating mat **(Figure 3)**. The coco coir pith was collected fresh from local shops. The diameter of each aerator cup was 10.5 with a depth of 8 cm.

2.5 Nutrients

A commercially available hydroponic fertilizer (Maxel super, Marshal Agrovet Chemical Industries Limited) mix was introduced into buckets, filled with wastewater. It contained several micronutrients along with nitrogen and phosphorus. Prior to the experimental stage, 12.5 mg L^{-1} fertilizer was used in each bucket and stirred properly with a bamboo stick to make a wastewater mix.

2.6 Sample Collection and Analysis

At the start of the experimental days, a 100 ml grab sample was collected from a mesocosm with a Pyrex 250 ml beaker, to represent the initial water quality of all the mesocosms on day 0. For all of the treatments, samples were collected on day 0, day 7, day 14, day 21, and day 28 keeping a hydraulic retention time of 7 days. Samples were collected at 11:00 am on each respective day by removing plants from the floating beds without interrupting the system. After collecting the samples, they were kept in the freezer until tested.

The physicochemical parameters P^H, temperature, electrical conductivity (EC), and total dissolved solids (TDS) were measured immediately using a multiprobe water quality tester (EZ DO, Model 7200).

To measure nitrate and phosphate concentration present in water, samples were delivered to the water treatment laboratory, department of Civil and Environmental Engineering, Shahjalal University of Science and Technology (SUST). To analyze NO3-N and $PO4^{3-}$, the cadmium reduction method and USEPA1 PhosVer 3 (Ascorbic Acid) Method2 were followed respectively.

2.7 Statistical Analysis

All values are reported as mean ± the standard deviation of the mean unless otherwise noted. All the statistical analysis was performed in Excel, 2019. Analysis of Variance (ANOVA) was performed to understand the statistical significance of the treatments, at a 5% level of significance. Where significant differences were identified, Tukey's post hoc analysis ($P<0.05$) was performed to determine, between which treatments the differences existed. To find out the relationship between parameters, a correlation (R^2) value was also obtained

Figure 3: Representation of Buoyant Structure

3. RESULTS AND DISCUSSION

The water quality parameters that were tested during this study depict the efficacy of floating treatment wetlands under different treatment conditions. In this study, the evaluation was done for both vegetations and without vegetation conditions with a mesocosm used as control. Hence, the results would help understand the remediation capacity of both the emergent plant species, while showing the overall impact of vegetation in floating treatment wetlands to remove nutrients from municipal wastewater.

The nitrate and phosphate removal and physiochemical responses (Temperature, P^H, EC, and TDS) of the four treatments (Pickerel weed, German grass, Floating mat only, and Control containing black polyethylene sheet only) were compared and are illustrated in the following sections. To determine the remediation efficiency precisely nutrients were added prior to the experiment, thus the initial nutrient concentration recorded was significantly high. The initial concentration for different parameters obtained in this study is shown in Table 2.

Table 4 shows the cumulative removal of nutrient concentrations after 28 days with an HRT of 7 days. The Results show that the treatments with vegetation were more efficient in the removal of nitrate than treatments without plants. In addition to that, it also shows that all the treatments are significantly different from each other.

Mean nitrate concentration was (11.0033 ± 0.038) lowest in the case of FTWs treated with Pickerel weed (Figure 10), and significant variation ($F=310.51$, $P<0.05$) among all the treatments was observed for nitrate concentration.

Table 2: Quality of Wastewater Used in This Study as Influent for Mesocosms

Sl. No	Parameters	Unit	Concentration in untreated water
1	EC	mS/cm	1.48
2	TDS	ppm	950
3	pH	-	7.54
4	Nitrate	mg/l	97
5	Phosphate	mg/l	116.33

Lin et al., (2002) found that denitrification occurring in anaerobic micro-environments at ambient conditions is the most significant pathway of NO3–-N removal from a wetland system. The macrophyte root and rhizomes in the rhizosphere leak oxygen into microzones (Juwarker et al., 1995) and Radial Oxygen Loss (ROL) creates aerobic conditions in the rhizosphere. The rhizosphere of plants of wetlands is believed to play a significant role in treatment processes (especially for nitrogen) within FTW systems.

The phosphate removal efficiencies were 9.5, 7.47, 1.07, and 0.22 % for T1, T2, T3, and C respectively and all the treatments showed a significant difference between each other (F= 94.38, P<0.05). Moreover, the mean phosphate concentration was (105.21 ± 0.18) the lowest in mesocosms treated with Pickerel weed (Figure 11).

On the other hand, a strong correlation was observed between treatments and time while removing nitrate, and phosphate from mesocosms water (Table 5). Spangler et al., (2019) observed a similar correlation when conducting two trials of study with different nutrient concentrations.

3.1 Physiochemical Responses

The physicochemical properties of the mesocosms were measured in situ on day 0, day 7, day 14, day 21, and day 28 maintaining a hydraulic retention period of seven days. All the parameters were measured at 11.00 am on a respective day. The physiochemical properties of mesocosms water are summarized in Table 3.

The maximum temperature recorded in the multiprobe water quality tester during the study was, 30.23°C while the minimum temperature was 26°C. The FTW treatments showed higher mean values than the control treatments with the highest mean value (28.93 ± 1.29) for pickerel weed (Table 3). The average temperature was lowest on day 0, while it reached a peak on day 7. Moreover, for these two observations temperatures recorded in different treatments were approximately the same. However, before reaching a plateau from day 21 to 28, the temperature varies significantly on day 14 for pickerel weed (Figure 4). Overall, there was no substantial difference in temperature between the treatments and the controls as the controls were provided with equivalent shading.

Table 3: Overall Statistics of Effluent Concentration in Each Unit

Overall statistics of effluent concentration in each unit

	Effluent Concentration (mg/L)			
	T1 (Pickerel weed)	**T2 (German grass)**	**T3 (Coco Coir)**	**C (Control)**
Temperature				
Mean	28.93	28.71	28.77	28.76
S.D	±1.29	±1.32	±1.27	±1.31
Maximum	30.06	30.23	30.06	30.23
Minimum	26.7	26.7	26.7	26.7
pH				
Mean pH	6.86	6.46	6.36	8.39
S.D	±0.42	±0.65	±0.78	±0.48
Maximum	7.54	7.54	7.54	8.72
Minimum	6.43	5.97	5.55	7.54
Electrical Conductivity				
Mean	1.30	1.19	1.42	1.46
S.D	±0.12	±1.65	±0.04	±0.02
Maximum	1.48	1.48	1.48	1.48
Minimum	1.17	1.09	1.37	1.45
TDS				
Mean	836.53	761.93	914.86	938.99
S.D	±78.56	±105.83	±27.49	±10.17
Maximum	950	950	950	950
Minimum	752	699	877	928

Table 4: Mean Cumulative Removal of NO3-N and PO4 (G and %) by Different Treatments Used in Ftws, N=3 for Each Treatment

Treatment	cumulative removal after 28 days			
NO_3-N (mg) (%)			PO_4 (mg)	(%)
T1 (Pickerelweed)	85.92	88.65	11.05	9.5
T2 (German grass)	83.87	86.46	8.71	7.47
T3 (Floating mat)	26.38	27.2	1.24	1.07
C (Control)	16.26	16.77	0.25	0.22
ANOVA F ratio, *P* value	310.51 <0.0001		94.38, <0.05	

3.1.1 *Temperature*

The maximum temperature recorded in the multiprobe water quality tester during the study was, 30.23°C while the minimum temperature was 26°C. The FTW treatments showed higher mean values than the control treatments with the highest mean value (28.93 ± 1.29) for pickerel weed (Table 3). The average temperature was lowest on day 0, while it reached a peak on day 7. Moreover, for these two observations temperatures recorded in different treatments were approximately the same. However, before reaching a plateau from day 21 to 28, the temperature varies significantly on day 14 for pickerel weed (Figure 4). Overall, there was no substantial difference in temperature between the treatments and the controls as the controls were provided with equivalent shading.

3.1.2 *P^H*

A significant variation in P^H was observed between the treatments (T1, T2, and T3) and control. While the mean pH in control was 8.39 ± 0.48, for other treatments it varied from 6.36 ± 0.78 to 6.86 ± 0.42 (Table 3). Moreover, the P^H in the control treatment increased from 7.54 to 8.72, as opposed to other treatments for which it dropped steadily throughout the study (Figure 5), possibly due to respiration occurring through plant roots and microbial communities (Tanner and Headly, 2011). Wang and Sample, (2014) observed considerably lower P^H levels for FTWs planted with pickerel weed. Similar results were reported by Borne et al., (2014), in a pond scale study they observed lower P^H values for wetlands with vegetation than for control. Moreover, the mesocosms study conducted by Spangler et al., (2018), also reported lower P^H levels for planted treatments than the control.

3.1.3 *Electrical Conductivity (EC)*

Electrical conductivity is a handy and useful parameter as an indicator of total salt content in water (Morrison et al., 2001; Zhao et al., 2013). In the present study, the maximum electrical conductivity recorded, was 1.48mS/cm with the highest mean value of 1.46 ± 0.02 in the case of control treatment mesocosms and the lowest mean value of 1.19 ± 1.65 in mesocosms treated with treatment T2 (German grass) (Table 3). With regards to treatment T1(Pickerel weed), the value dropped steadily, as opposed to T2 for which, it dipped significantly on day 7 keeping a minimal reduction for the rest of the period. On the contrary, in the control treatment and treatment with a floating mat only; ion removal was minimal (Figure 6). Overall, EC reduced with the passage of time. This reduction occurred due to nutrient uptake by plants and the binding of dissolved elements with suspended particles (Zhao et al., 2013).

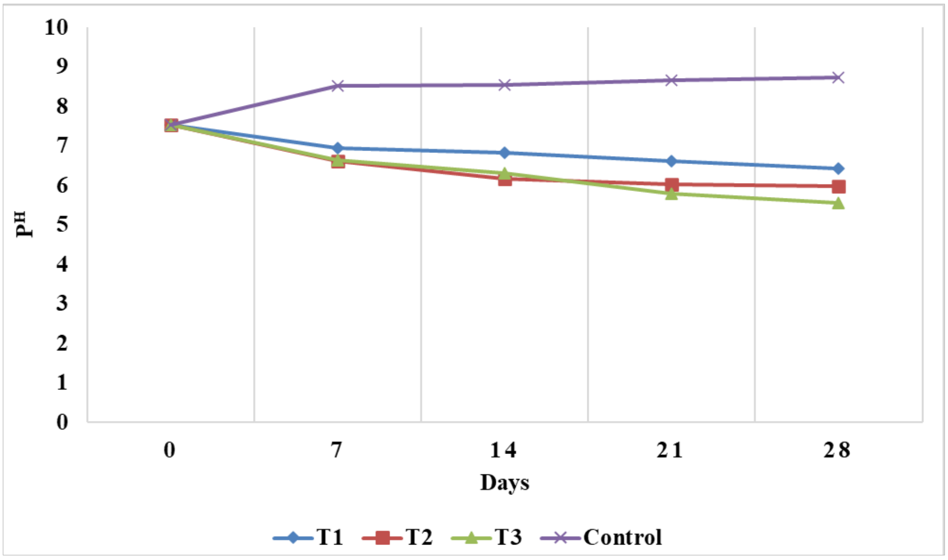

Figure 5: Average P^H in Mesocosms Water During the Experimental Period (N=3 for Each Treatment)

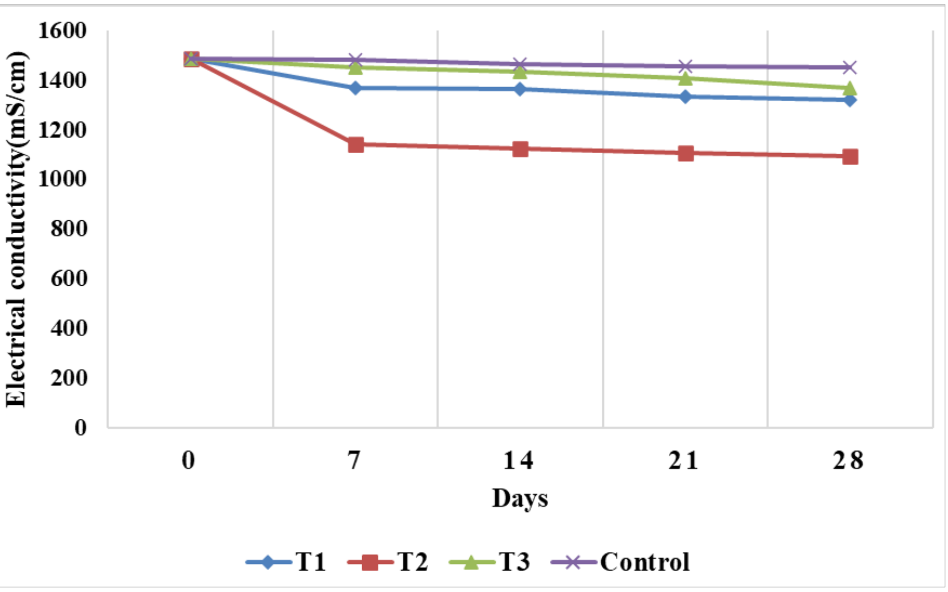

Figure 6: Average EC in Mesocosms Water During the Experimental Period (N=3 for Each Treatment)

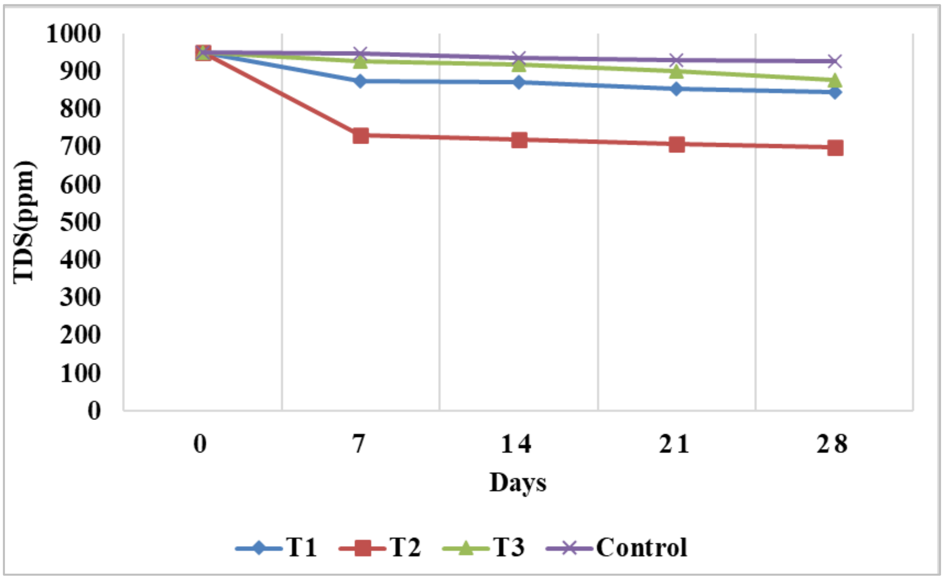

Figure 7: Average TDS in Mesocosms Water During the Experimental Period (N=3 for Each Treatment)

3.1.4 Total Dissolved Solids (TDS)

The minimum value for TDS was recorded in mesocosm treated with German grass with a mean value of 761.93 ± 105.83, while the highest mean value (938.99 ± 10.17) was obtained in controls (Table 3). A significant decrease was observed on day 7, for mesocosms treated with T2, the reason for this sudden reduction is unknown. Treatment T3 and control showed a minimal decrease in TDS concentration (Figure 7) may be due to the absence of plants.

3.2 Nutrient Responses

Nutrient removal recorded in this study, are Nitrate-N and Phosphate-P which are major components of total nitrogen and total phosphorus, respectively.

3.2.1 Nitrate-N Removal

Influent nitrate concentration was 97 mg/l while the lowest nitrate value recorded after the experimental days was 11mg/l. The highest cumulative removal rate (88.65 %) was obtained for mesocosms treated with treatment T1, while the lowest removal rate (16.77%) was measured in the control treatment (Table 4). Moreover, while nitrate removal efficiency was steadily increasing for T1, it was fluctuating for T2 with an overall increase during the study.

On the contrary, for the treatments T3 and control, the value showed a minimal increase compared to T1 and T2 (Figure 8). While conducting a similar study, under the same environmental condition, Uddin et al., 2016 observed only 22.22% of nitrate removal, he concluded that nitrate removal was not good enough because the plant was not strong enough to purify the heavily polluted water like Hatirjheel Lake. On the contrary, Shahid et al., (2018) observed greater performance with FTWs inoculated with bacteria. Van de Moortel et al., **(2010)** observed that the value of the redox potential measured in the control was lower than the value obtained in the root mat in their FTW with vegetation. The authors suggested that oxygen-consuming reactions could be stimulated by the oxygen released from the roots within the root mat and the root oxygen release was higher than oxygen diffusion from the air. Hence it can be explained why in the case of our study the nitrogen removal efficiencies were lower in T3 and control compared to FTWs with plants.

3.2.2 Phosphate-P Removal

On the first day of the experiment, the phosphate concentration present in mesocosms water was 116.3 mg/l. The highest cumulative removal was 11.05 mg for treatment T1, while T2 showed removal of 8.71 mg only. On the other hand, treatment T3 and control removed only 1.07% and 0.22% of phosphate respectively (Table 4), this removal happened due to the algal uptake. This result contrast with Lynch et al., (2014), who observed 31% TP (Total Phosphorus) removal in their study, this significant removal occurred may be because the duration of that study was much longer than this one. Furthermore, the phosphorus removal efficiency of 67 % to 76 % was obtained in a study conducted with inoculated bacterial consortium by Shahid et al. (2018). On the other hand, for T1 the removal efficiency increased rapidly on day 7 before a steady increase from day 7 to day 21 as opposed to T2, for which it increased significantly during the last two weeks (Figure 9).

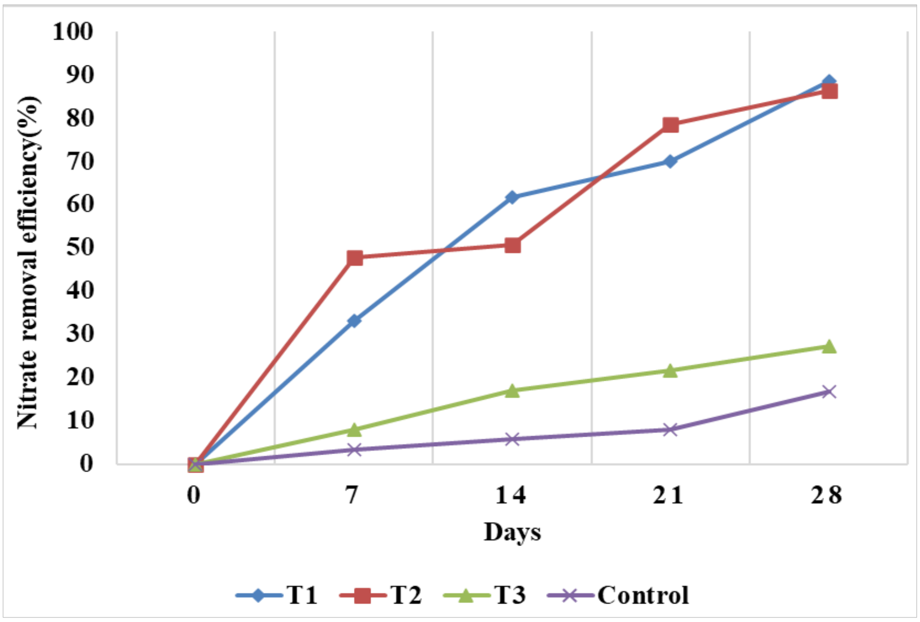

Figure 8: Nitrate Removal Efficiency in Mesocosms Water During the Experimental Period (N=3 for Each Treatment)

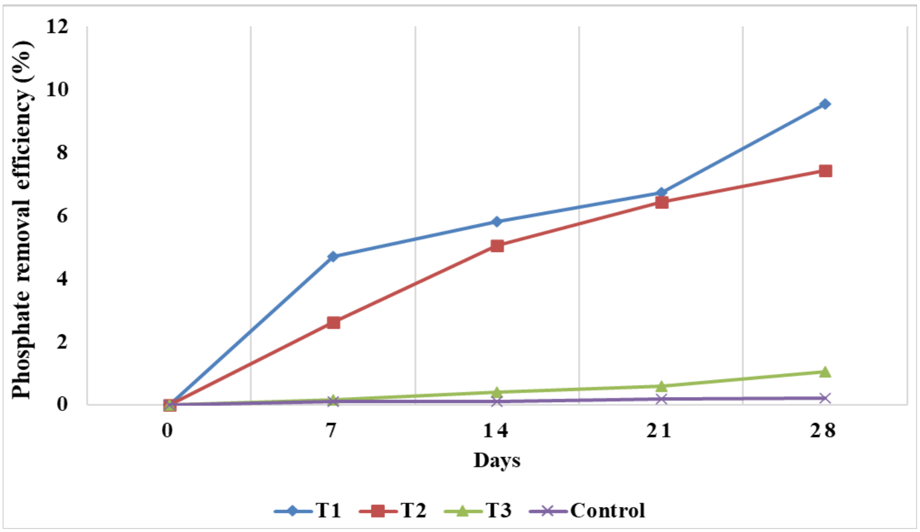

Figure 9: Phosphate Removal Efficiency in Mesocosms Water During the Experimental Period (N=3 for Each Treatment)

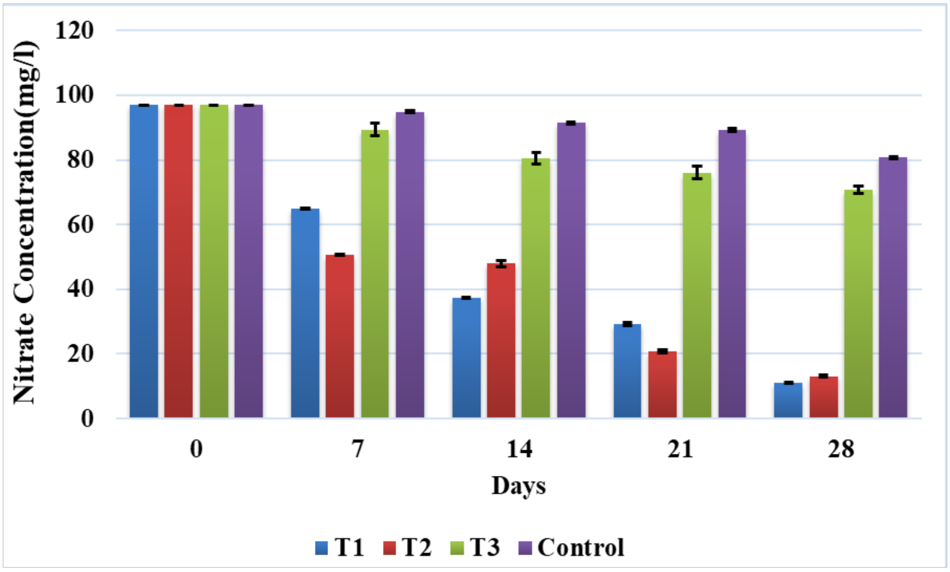

Figure 10: Mean (± standard error) Nitrate concentration for different treatments after 28 days of the experimental period.

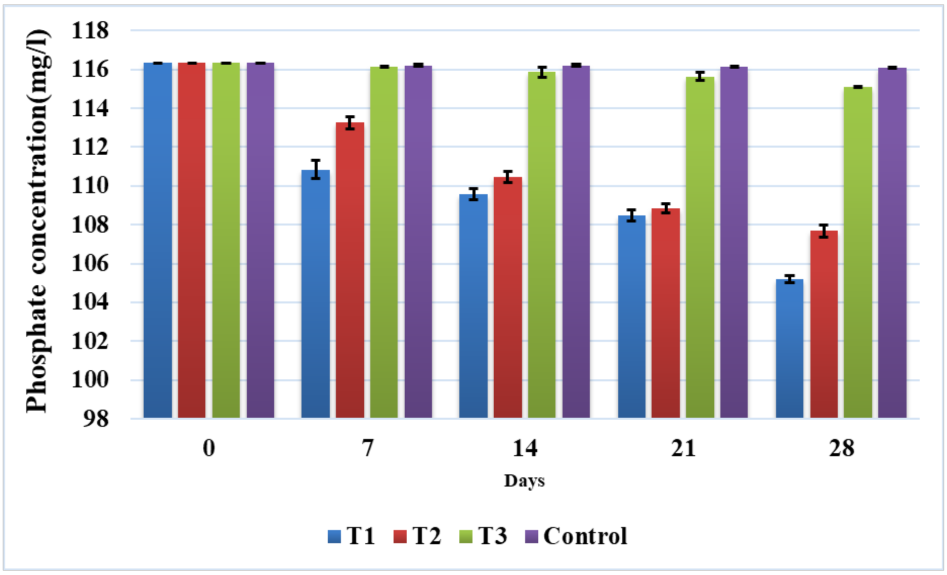

Figure 11: Mean (± standard error) Phosphate concentration for different treatments after 28 days of the experimental period.

CONCLUSION

The results have demonstrated that floating wetlands with vegetation can successfully remove nutrients from municipal wastewater. The nitrate remediation efficacy of Pickerelweed was higher (88.65 %) than FTWs treated with German grass (86.46 %) after 28 days of hydraulic retention period. However, Phosphate removal was comparatively minimal for both of the plants while used in FTWs. The cumulative removal rate for Pickerel weed was only 9.5 % while German grass removed only 7.47 %. Overall, the results of this study demonstrate the efficiency of German grass as a wetland plant in the removal of nutrients from municipal wastewater. However, to better understand the performance of German grass longer-duration research is needed. Future research should also investigate nutrient accumulation in plant roots and shoots and nutrient distribution patterns in the whole plant.

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